Report Outline

I. GREAT PLAINS: SCOPE, HISTORY, AND RECENT TRENDS

1.1 SOCIAL-ECOLOGICAL SETTING (CLIMATE-ENVIRONMENT-SOCIETY)

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1.1 GREAT PLAINS: Social-Ecological Setting

The U.S. Great Plains covers an area of 1.3 million km^2 (over 500,000 sq mi) in the Central U.S. and was historically predominantly grasslands. The Great Plains include portions of 10 states in the Central portion of the United States, including Montana, North Dakota, Wyoming, South Dakota, Colorado, Nebraska, Kansas, New Mexico, Oklahoma, and Texas. The Plains are characterized by a temperature gradient that gets warmer from north to south and a precipitation gradient that gets wetter from west to east. Annual average precipitation ranges from 200 mm in the west to approximately 1100 mm in the east and southeastern portion of the range and can be highly variable from year to year (Fig.XXX). There is strong seasonality, high variability, and frequent extreme weather events in the Great Plains including droughts, floods, tornadoes, hail, ice storms, heat waves, and blizzards. 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.

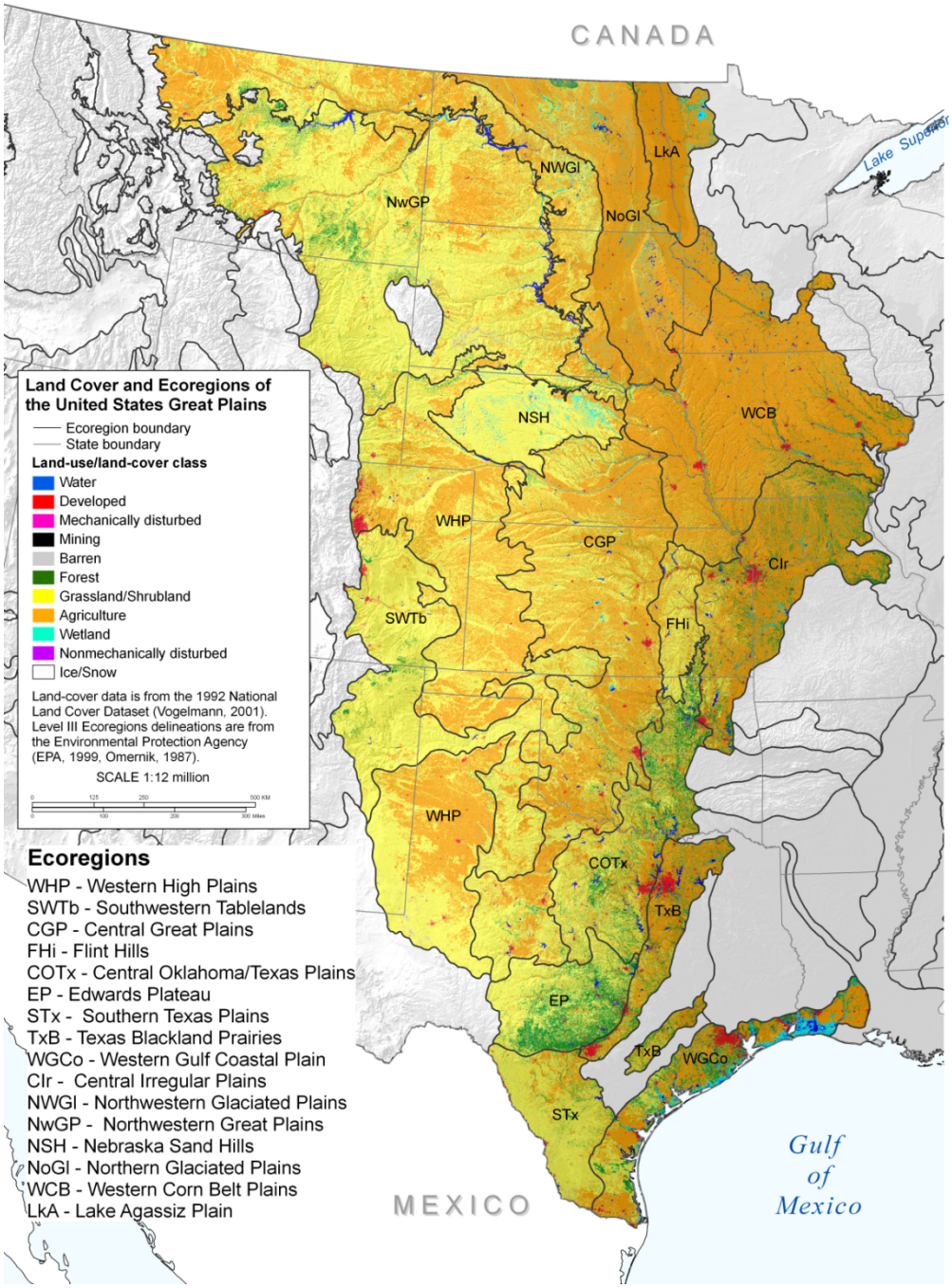


Figure 1. Land Use/Cover Change in the US Great Plains, 1973-2000

Nomadic and semi-nomadic Native American populations occupied these grasslands for thousands of years. Although they altered ecosystem dynamics in their own way, the hunting-gathering societies characterizing Native American cultures did not extensively alter the flow of water and nutrients in the ecosystems of the Great Plains. The lands occupied by most tribes in current times are

located in relatively marginal areas. Many tribes thus lack access to fertile soils. They often also lack access to appropriate housing, electricity and energy sources, and food and water resources, all of which make living in tribal areas more challenging. However, tribal governments have started the process of developing and sustaining viable economies on their lands and providing a set of strategies to cope with climate change.

The socio-economic system is characterized by extensive rural livelihoods with a recent concentration of populations into urban areas. The population density average over the region is about 66 people per square mile, with a median of 10 people per square mile (US Census Bureau, 2010a).However, urban population numbers of the past 20 years have grown to about 41 million persons representing about 80% of the population of the Great Plains in 2010 (US Census Bureau, 2010a). 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. The population in the Great Plains grew steadily 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 (Lackett and Galvin 2008). Expansion of farms in the Great Plains may be explained by the uncertainty in precipitation, leading to increased acreages in order to increase incomes.

In 2010, there are over 40 million people (approximately 13% of the total U.S. population) living in the 9 US Great Plains states, including Colorado (USDA ERS, 2012). 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 2010 (US Census, 2010), with rural counties much more likely to lose population than those with some urban developments .

Native American Legacy

Native Americans in the Great Plains have a rich and varied history extending back many generations. Prior to European incursion, many Plains tribes such as they were fully nomadic, following the seasonal migrations of vast herds of buffalo. Other Plains' tribes were semi-sedentary, not only hunting buffalo but living in villages and raising crops. The tribes were very successful at adapting to natural cycles and weather extremes (**24**). Plains tribes were also adept at adapting to technology

brought by the Europeans, quickly adopting both horsemanship and guns to their economic and oftentimes military advantage (**16**,**49**).

Today the Great Plains are home to 65 Native American tribes (**1**). According to the 2000 Census (US Census 2000), about 20% of all American Indians call the Great Plains home, and as of 2000, close to 450,000 of them live on Great Plains reservations/Oklahoma Tribal Statistical Area (OTSAs). In Oklahoma and South Dakota, 11.5% and 9.0% of the state population, respectively, claim at least part American Indian or Alaska Native (AIAN) ancestry.

The policies towards Native peoples adopted by the U.S. at various points throughout its history are sometimes grouped into distinct periods. One of these periods is the relocation and reservation era of the 1800s. During this time in order to reduce conflicts between Indians and non-Indians, the U.S. moved dozens of eastern tribes to west of the Mississippi to a region that is now Oklahoma (**33**). Tribes already living in the Plains were confined to much smaller portions of their traditional homelands. During the assimilation and allotment period, tribal lands were further fragmented under the Allotment Act of 1887 that divided reservations into parcels of land, which were than distributed to individual Indians with the ultimate goal of creating thousands of independent Indian farmers who would be assimilated into society. Instead, because many Indians were unable to farm their arid parcels, they ended up selling their land or losing it due to delinquent taxes (**33**).

The years of relocation, reservation, acculturation, and assimilation, however, has left many legacies. As of the 2000 census, in the Great Plains, on-reservation/OTSA Native unemployment rates were almost two times the national average, and in certain states including Nebraska, South Dakota, and Wyoming the rates were roughly four times the national average. The median on-reservation/OTSA Native household income was about $26,700, which was roughly 36% below the national average of $42,000. In North Dakota, South Dakota, Wyoming, and Texas, the median household income was closer to 90% or more below the national average. Poverty levels for Natives living in Great Plains reservations/OTSA's as a whole were over twice the national average. In North Dakota, Montana, Nebraska, Wyoming, and Texas, they were over three times national average, and in South Dakota, roughly 50% of Natives on reservations had incomes below the poverty line.

These economic hardships and the lack of well-paying, long-term livelihoods cause Native populations to be more vulnerable to climate change impacts than wealthier sectors of society. The resources of many tribal governments are already extremely taxed without any additional climate stress (**24**).

Land Use and Ecosystem Considerations

The composition and productivity of native rangelands of the Great Plains are highly dependent upon rainfall and temperature and range from shortgrass steppe in the west to tallgrass pastures in the east. Large numbers of ungulates co-evolved in what once were the extensive grasslands of the Great Plains with large herds of bison, elk, and pronghorn observed across the landscapes of the Great Plains in the 1800's. The network of rivers, playas, and wetlands intersecting the Great Plains also provided critical habitats for migratory and wetland bird species. Short grass steppe occupies about 280,000 km^2 in the Great Plains from western Texas to the Colorado-Wyoming border (Lauenroth and Milchunas, 1991). Most native pastures/rangelands are inappropriate for cropland agriculture because of factors such as uneven terrain, poor soil quality, high erosion potential, and/or low rainfall, and many are inaccessible for mechanical harvesting of forage.

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 dry conditions. Narrowing profit margins and technology changes have also been driving forces behind the recent trend in farm consolidation in the Great Plains (Lackett and Galvin 2008). The total market value of agricultural products sold in the region is over $92 Billion, with 43 percent of this is from crops and 46 from livestock (USDA ERS 2012a). 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. XXX).

Currently in the US Great Plains, the grazing industry is commercially-oriented and not based on subsistence. The size of ranches is often quite large, and when cattle are pulled off of the range they are often finished at feedlots where they are corn-fed. Many ranchers also grow crops, some for sale and some for feed, so separating livestock operations from cropping operations is often difficult in the Great Plains.

In the Great Plains land managers are worried about a variety of factors related to climate variability and change, though often climate change is not the most important concern. More likely, other factors such as market or commodity prices, incentives, conservation policy, and social factors are considered in the decision making. In fact, many operators in this region are vulnerable due to the declining reward scale for farming and ranching. Many land use managers and households are operating on the economic margin, and small shifts in climate or markets may drive them out of business. A number of operations have diversified their income streams to provide an economic and household buffer to maintain their ranching or farming enterprise (ERS 2010). Foreclosures in the region

have led to increased consolidation of agricultural operations into larger enterprises. This leads to population declines in the region, and the aging of the farm population, as new 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.

In the Great Plains environment, variability in weather and economic dynamics results in enhanced uncertainty in land use decisions. The rangeland ecosystems have proven highly vulnerable to changes in precipitation patterns during the past decade. The changes 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 in the rangeland systems and the social well-being of the region. Associated changes in vegetation structure due to droughts in the semi-arid ecosystems affect the grassland production and the extent of shrub cover affecting the forage availability in these rangelands.

Reduced summer precipitation and greater proportion of winter precipitation favors deep rooted woody vegetation relative to grass species. These changes in vegetation communities in the foothills and the plains in the region will affect forage availability for domestic and wild grazers. In addition, these conditions also favor certain cool season invasive species, such as cheatgrass (CCSP 2008). Climate change is being experienced in various ways, such as increased night-time temperature, increased intensity of rainfall events, extended growing season, extended drought periods, and elevated atmospheric CO_2 concentration (Field et al 2007, CCSP 2008). The potential impacts of climate change include: the modified vulnerability of farm and ranch families to climate and market stresses, the modification of crop and livestock production systems, impacted water use competition, changed water quality, expansion of weeds, pests, and diseases, a change in plant-animal communities, altered fire and storm patterns, changes in grassland ecosystems, species composition, disruption of pollinator relationships, tree mortality, enhanced vulnerability to drought conditions, and insect or disease outbreaks in a number of ecosystems (Parmesan and Yohe 2003; Parmesan 2006; Field et al. 2007, CCSP 2008a, b).

1.2 AGRICULTURAL CHARACTERISTICS.

1.1 AGRICULTURAL SYSTEM

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). While wheat and beef production are important across most or all of the Great Plains States, one or more of the states also contribute significantly to production of other animal (hogs, dairy, broilers and sheep) and crop (corn, soybean, cotton, sorghum, canola and other) commodities (Table __) 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 wellbeing and ecosystem integrity of the region.

The states of the Great Plains, as well as bordering states, are a major food production area of the U.S. and world. In the 9 states (Colorado, Kansas, Montana, Nebraska, North Dakota, Oklahoma, South Dakota, Texas, and Wyoming) that comprise the Great Plains there are approximately 510,405 farms and 340,653,196 total acres in farms (NASS, 2009). Approximately 42 % (143 million acres) is in cropland and approximately 52 % (178 million acres) is in permanent / native pastures. Of the 143 million acres of cropland, in 2007 over 22 million acres were planted to corn, over 4.8 million were planted to cotton, over 5.6 million were planted to sorghum, over 14.2 million acres were planted to soybeans and over 29.5 million acres were planted to wheat (NASS, 2009). An additional 14.8 million acres of cropland was in improved pastures and 15 million acres of Great Plains farmland was in the CRP program.

Within the region, animal and crop production are both important. Beef cattle production ranks within the top three for all ten Great Plains states, but hog, broiler, and dairy production are also important in the region. Of the annual crops, wheat, corn, and soybean dominate across the north to central portions of the region. Other important crops in one or more states include cotton, sorghum, canola, barley, lentils, and sugar beets. Hay is an important crop in the northwestern portion of the Great Plains.

Table 1 – Value of Top 5 Agricultural Commodities by State (USDA ERS, 2012)

		Value of receipts thousand $	Percent of state total farm receipts	Percent of US value
Colorado	1. Cattle and calves	2,852,521	47.4	5.5
	2. Corn	604,082	10	1.3
	3. Wheat	500,407	8.3	4.6

	4. Dairy products	456,740	7.6	1.5
	5. Hay	287,127	4.8	5.3
Kansas	1. Cattle and calves	6,533,521	46.8	12.7
	2. Corn	2,118,661	15.2	4.7
	3. Wheat	1,724,662	12.4	15.9
	4. Soybeans	1,470,992	10.5	4.4
	5. Sorghum grain	673,287	4.8	50.4
Montana	1. Cattle and calves	1,084,644	35.6	2.1
	2. Wheat	1,032,557	33.9	9.5
	3. Hay	267,970	8.8	5
	4. Barley	157,348	5.2	21.2
	5. Lentils	77,593	2.5	37
Nebraska	1. Cattle and calves	7,193,865	41.6	14
	2. Corn	5,347,448	30.9	11.9
	3. Soybeans	2,647,762	15.3	8
	4. Hogs	815,836	4.7	4.6
	5. Wheat	326,594	1.9	3
North Dakota	1. Wheat	1,901,364	28.7	17.5
	2. Soybeans	1,247,264	18.9	3.8
	3. Cattle and calves	731,092	11.1	1.4
	4. Corn	665,142	10.1	1.5
	5. Canola	356,746	5.4	90.3
Oklahoma	1. Cattle and calves	2,984,670	48.5	5.8
	2. Broilers	724,446	11.8	3.1
	3. Hogs	696,411	11.3	3.9
	4. Wheat	533,510	8.7	4.9
	5. Dairy products	171,000	2.8	0.5
South Dakota	1. Corn	2,065,603	26.9	4.6
	2. Cattle and calves	2,002,387	26	3.9
	3. Soybeans	1,588,307	20.7	4.8
	4. Wheat	657,325	8.6	6

	5. Hogs	455,370	5.9	2.5
Texas	1. Cattle and calves	7,564,446	38	14.7
	2. Cotton	2,589,126	13	41.3
	3. Broilers	1,757,613	8.8	7.4
	4. Dairy products	1,505,313	7.6	4.8
	5. Greenhouse/nursery	1,311,139	6.6	8.4
Wyoming	1. Cattle and calves	732,883	62.5	1.4
	2. Hay	122,520	10.5	2.3
	3. Hogs	71,070	6.1	0.4
	4. Sugar beets	44,252	3.8	2.7
	5. Sheep and lambs	34,604	3	6.5

1.1.1 Livestock Production and Greenhouse Gas Emissions

1.1.1.1 Beef Cattle Production

Because of the vast quantities of native rangelands, livestock production; mostly beef cattle, is one of the most important sectors in U.S., Great Plains agriculture, both economically and socially. On average, 30% (North Plains) to 68% (South Plains) of total farm production value in the Great Plains comes from beef cattle (McBride and MacDonald, 2011).

The total number of ungulates grazing the Great Plains today is estimated to be similar to the numbers before European settlement (Table). Essentially wild ungulates have been replaced with domesticated ungulates. In contrast to pre-settlement, animals on native pastures are frequently supplemented with mineral, energy and/or protein supplements to improve reproduction and animal growth.

Table 2. Estimated populations of wild and domestic ruminants in the Great Plains today and in the 15th century (Hristov, 2012)

Species	Pre-settlement	Current
Bison	30,000,000 to 75,000,000	500,000

Elk (wapiti)	10,000,000	1,000,000
White tailed deer	30,000,000	25,000,000
Mule deer	13,000,000	4,000,000
Beef cattle	0	64,800,000
Dairy cattle	0	13,800,000
Sheep	0	5,700,000
Goats	0	3,100,000
Total	83,000,000 – 128,000,000	117,900,000

Grazing animals, both domesticated and wild, play a vital role in the ecology of grasslands by providing an efficient means of recycling plant and soil nutrients. Ruminants such as beef cattle can consume fibrous feeds and byproducts of other industries such as grain-ethanol, soybean oil and cottonseed oil that are unfit for human consumption and turn them into high quality foods. Livestock can potentially affect climate change via their impacts on grasslands and other segments of agriculture and via enteric and manure based GHG emissions. However, they may also be affected by climate change. Livestock production (especially grazing) systems in different parts of the U.S. and world have evolved over long periods of time to fit local environmental conditions such as water and forage availability (Reynolds, et al 2010).

The U.S. and Great Plains beef cattle industry is comprised of 4 major sectors: 1) cow-calf, 2) stocker, 3) feedlot, and 4) packer. Approximately 40% of U.S. beef cows, 75% of all U.S. feedlot cattle, and 50% of U.S. domesticated bison are in the Great Plains. The cow-calf, stocker, feedlot, and packer segments of the US cattle industry are inexorably linked and changes in one sector can have major impacts on the other sectors (Galyean et al., 2011).

In the Great Plains approximately 18.4% of cow-calf operations have fewer than 50 cows, compared to 24.9% in the bordering states and 28.7% nationally. Over 60% of the operations have of over 100 beef cows (Table : NASS, 2007). These cow-calf operations occur primarily on native

rangelands because they are an efficient means of harvesting the available forage. The cow-calf herds are a year-round system that must live within nutritional constraints of the ecoregion in order to be economically and ecologically sustainable (McBride and Mathews, 2011; Phillips et al., 2011). Supplemental feed is often necessary during seasons where forage is lacking and these protein/energy supplements are normally comprised of byproducts of the corn milling (distiller's grains) or vegetable oil (i.e., soybean meal and cottonseed meal) industries, respectively.

Table 3. Typical size of beef cow operations: % of operations (NASS, 2007)

Number of cows	Great Plains	Bordering States	US Average
< 50 cows	18.4	24.9	28.7
50-99 cows	16.7	16.6	17.2
100-199 cows	22.0	17.2	17.5
200-499 cows	27.6	21.8	20.5
500 cows or more	15.3	19.4	16.1

Changes in forage availability or quality caused by climate change can alter the supplementation strategies needed to maintain animal production. Over 70% of beef calves in the U.S. are born between January and April (USDA, 2009; Phillips et al., 2011) - typically termed "spring calving". In most of the Great Plains this is when pastures are beginning their spring growth and are highest in nutritional value. This provides the lactating cow with adequate nutrition to replenish body stores that are lost during the winter and at calving. The spring forage also provides sufficient energy and protein for milk production. Only about 80% of U.S. beef cows wean a calf each year (McBride and MacDonald, (2011). On average, in the Great Plains it requires 11 to 13 acres to support each cow-calf unit: these values may range from 30 or more acres in the arid west to 3 to 5 acres in the east. This compares to 3 acres per cow-calf unit in the North Central and Southeast regions of the U.S. and over 19 acres in the far west.

A small percentage of cattle are finished on pastures, rather than in feedlots. The biggest challenge grass-fed beef producer's face is having a high quality chain of forage available for 12 consecutive months. On average, cattle in feedlots are fed for approximately 150 days before going to slaughter. Typically they consume about 20 lb of feed dry matter each day, they gain 3 to 4 lbs of body weight each day and require approximately 5.0 to 6.5 lb of feed dry matter for each lb of weight gain.

Typical feedlot diets today will contain from 20 to 80% corn grain and up to 60% byproducts such as distillers grains or gluten feed (Vasconcelos and Galyean, 2007). Approximately 3,969,400 acres (or about 5% of U.S. corn acreage) are required to produce the corn used annually by the U.S. cattle feeding industry to feed 22.3 million head (USDA, 2011). In 1961, it required approximately 0.6 acres of farmland per person to produce enough feed for the meat, dairy and poultry consumption; in 2005 that had declined to approximately 0.27 acres (Elam, 2007). In 1960, approximately 80% of U.S. grain and soybean acres were used for livestock feed production. In 2005 than had declined to 50%. Today, approximately 2 acres of cropland produce the feed to produce one ton of meat and poultry production.

1.1.1.1.2 Beef Cattle Greenhouse Gas Emissions:

++++++++++++++++ Start Box on Ruminant Animals and Enteric Methane Emissions +++++++++++++++

Ruminant animals, such as cattle, bison, sheep, and deer; have a multi-compartment stomach that allows them to utilize roughages more efficiently than monogastrics animals, such as swine, poultry, and humans. The multi-compartment stomach allows for fermentation of feeds in the upper stomach compartments producing more nutritious compounds to be absorbed in the intestine. A natural byproduct of the fermentation of carbohydrates and proteins in the digestive tract is methane. In general, the more efficient the gut fermentation is, the lower the methane production. For example, feeding highly digestible starch (i.e., grains) in place of poorly digested cellulose in forages (i.e. low quality grass) decreases enteric methane (and probably fecal) methane production as a percentage of energy intake. Methane emissions as a proportion of energy intake are greater in cows on forage diets than for cattle on high concentrate finishing diets. Thus, the cow calf and stocker sectors may be the most amenable to improvements and mitigation strategies.

DeRamus et al (2003) noted that grazing management and season could affect enteric methane emission from growing heifers and mature cows. Emissions were generally less with high quality growing forage than with aged, mature forage. Cows tended to produce more enteric methane than heifers – due in part to body weight and probably forage consumption. Providing protein supplements to growing heifers on low-medium quality pastures can decrease enteric methane emissions (Johnson et al 1996).

++++++++++++++++++++++++++++++ End of Box +++++++++++++++++++++++++++++++++++

Although cattle are frequently implicated as a major source of atmospheric methane, in the U.S., enteric methane production from all domesticated ruminants (beef, dairy sheep, goats, horses, etc.) accounts for only about 1.8% (140.8 Tg CO2e/yr: 99.6 Tg for the 2011 US beef cattle herd and 33.2 Tg for the 2011 U.S. dairy herd) of all U.S. greenhouse gas emissions (7,054.2 Tg CO2e/yr)(U.S. EPA, 2008; Hristov, 2012). These compare to estimated enteric methane emissions of 62 to 154 Tg CO2e/yr (estimates based on 30 vs. 75 million bison) for the 15th century U.S. bison herd (Hristov, 2012). Emissions of CH4 and N2O from all livestock manures (62.1 Tg CO2e/yr) make up an additional 0.8 % of U.S. GHG emissions (US EPA, 2008). Capper (2011) estimated the carbon footprint of the U.S. bison herd in 1860 to be 228 billion kg CO2e: this compared to 112 billion kg CO2e for the U.S. dairy herd in 2007. Kelliher and Clark (2010) estimated enteric methane emissions by the ancient bison herd (assumed 30 million head) to be equivalent to 55 Tg CO2e.

Typical enteric methane emissions of cattle estimated by the most recent EPA (2011) report ranged from 3.9% of gross energy (GE) intake for feedlot cattle to 6.5% of GE intake in beef cows and stocker calves on pasture. In contrast, the International Panel on Climate Change (IPCC, 2006) values ranged from 3% to 6.5% of GE intake. In more recent studies with “modern” beef cattle finishing diets, enteric methane emissions ranged from 2.4 to 3.8% of GE intake (Hales et al., 2012).

Liebig et al (2010) noted that moderately- or heavily-grazed native grasslands in the Northern Great Plains were net C sinks; whereas, because of N fertilizer application and increased N2O emissions, a fertilized crested wheat grass pasture was a net CO2e source. Approximately 19 Tg CO2e were emitted from energy used in agriculture in the Great Plains in 2008 – about 26% of all (72 Tg) U.S. agricultural energy use (USDA, 2011 estimated from figure 5.1).

1.1.1.2 Other Livestock Production and Greenhouse Gas Emissions

Other animal production systems contribute to Great Plains agricultural economies, including dairy, hogs, poultry and sheep. Dairy, hogs and poultry production is dominated by large confined operations. For dairy and hog production, a large percentage of the animals are managed in large confined operations throughout the live cycle, concentrating the inputs and wastes in relatively small areas. These systems operate under Confined Animal Feeding Operations (CAFO) standards of the Environmental Protection Agency. Poultry production houses are located on thousands of small to large farms in the southeastern US, extending into eastern Oklahoma and Texas. The production houses are operated under contract to the integrator corporations. While the integrators retain ownership of the

live birds throughout the life cycle, individual farmers have responsibility to manage dead birds and animal waste on individual farms, and therefore the waste management for most poultry production does not operate under CAFO rules. Poultry litter, the animal waste mixed into bedding material, is a widely used fertilizer source, particularly for pasture production in the southeastern regions. Sheep are a minor commodity in the US but can be regionally important in western ranches or in small farms in the southern portion of the Great Plains.

Animal production under confinement systems provides opportunities to control the extreme cold and hot temperatures the animals are exposed to minimize temperature-related stress. However, energy costs associated with high and low temperatures constitute a major production expense and the energy utilized has an environment footprint. For confinement systems that utilize lagoons for waste management, methane capture from the lagoons can provide energy for on-farm use. Land application of manures provides nutrients for forage and crop production, but appropriate timing, rate, and application methods are needed to minimize nitrous oxide emissions from the soil. While additional improvement is needed, animal producers are adopting improved nutrient management practices and technologies. In 2009, 55% of U.S. hog farms followed a nutrient management plan, up from 30% in 2004. (Key et al., 2011). Additionally, dairies and beef feedlots often utilize distiller grains from biofuels and other by-products from numerous agricultural enterprises, improving the economic return to those enterprises and reducing the need for grains, with the associated environmental footprint, in the cattle feeding operations.

1.1.2 Crop Production and Greenhouse Emissions

Historical data show that there was no crop yield trend before 1945, but due to technological improvements, productivity of most agricultural enterprises has increased in decades since. The U.S. Climate Change Science Program reported (2009) that the yield response to recent technological changes has overwhelmed responses to global changes that are also present but are statistically undetectable when compared to improvements in technology (Hatfield *et al*., 2008). These improvements include greater irrigation often using fossil water supplies, increased application of inorganic fertilizer, access to inexpensive energy supplies, increased herbicide and insecticide use, improvements in crop varieties (including genetically modified crops), and improvements in tillage practices and summer fallow (Parton *et al.,* 2007).

Figure 2 – Total Great Plains plant production for corn, wheat, hay, and cotton (Parton et al. 2007)

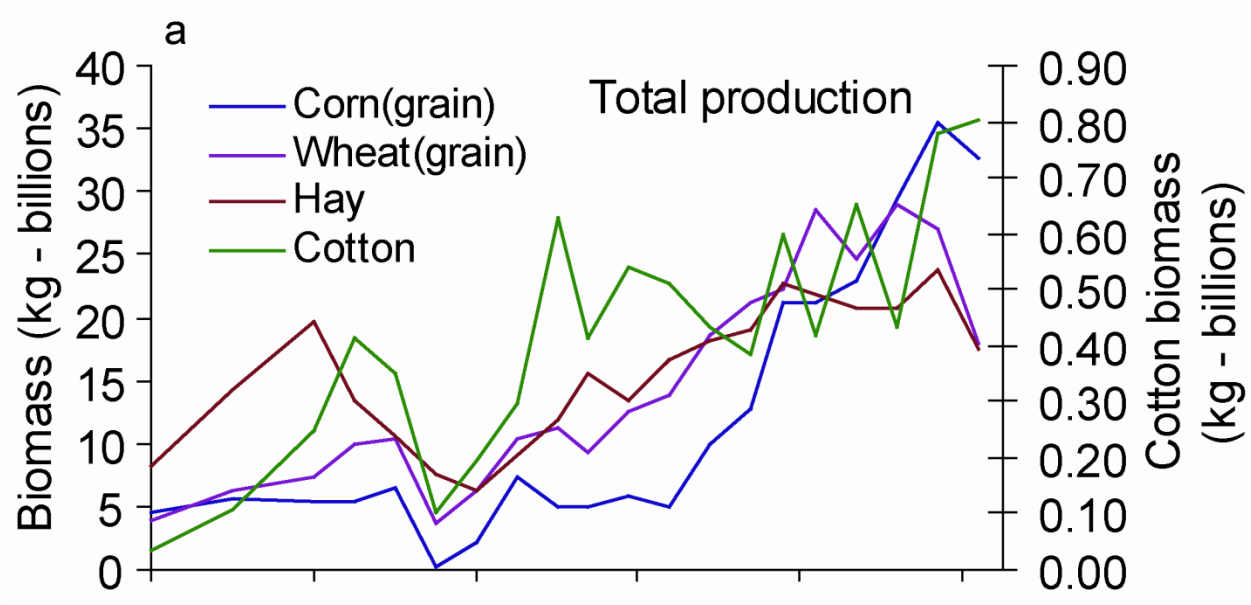


Figure 3 – Average Great Plains crop yields for corn, wheat, hay, and cotton (Parton et al. 2007)

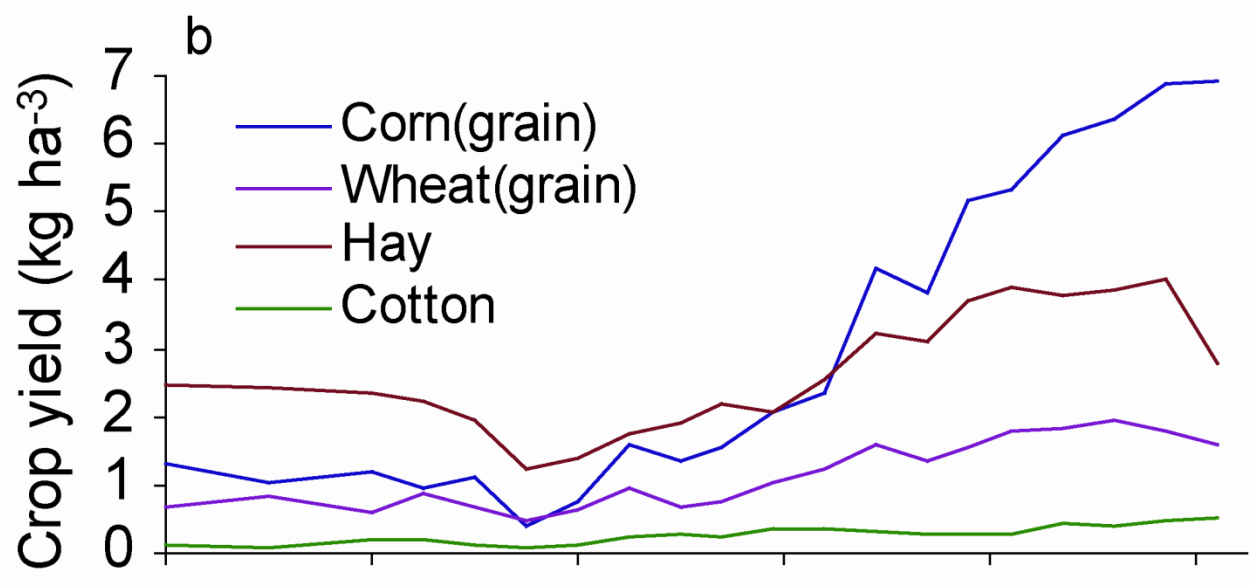
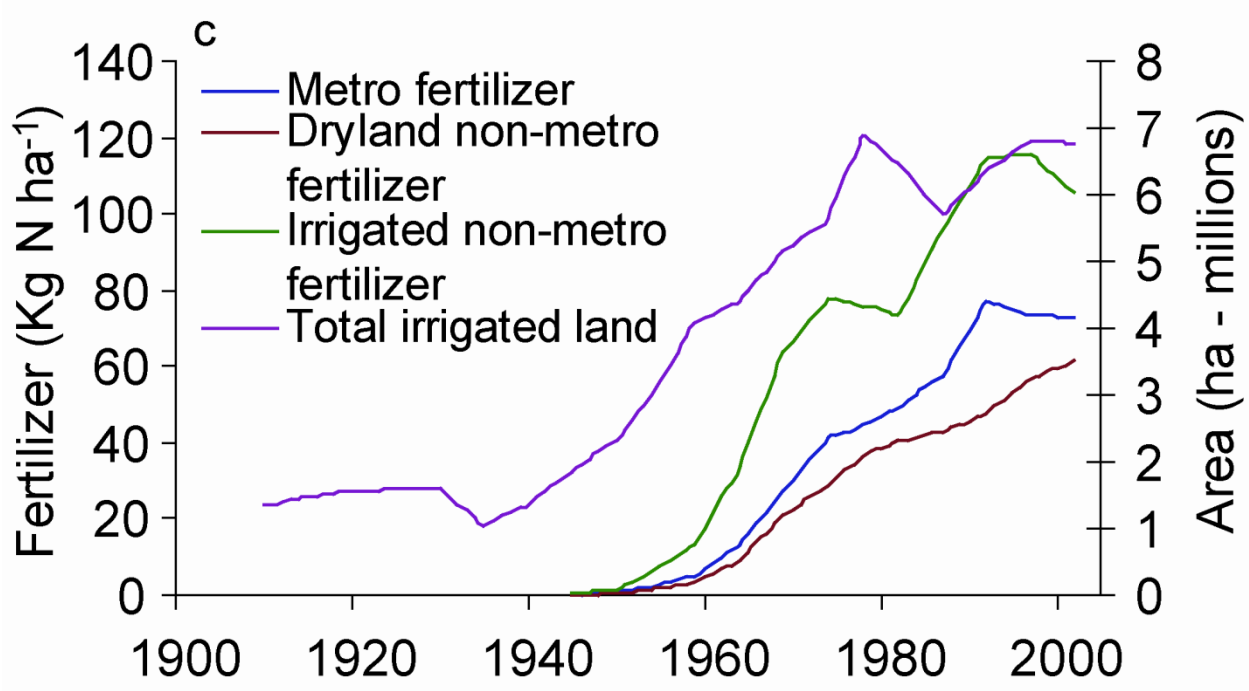


Figure 4 – Total area of Great Plains irrigated nonmetro land and average nitrogen inputs from fertilizer for metro, dryland nonmetro, and irrigated nonmetro land.



Technological improvements and yield increases do come at a cost. The proportion of farm income spent on agricultural inputs (fertilizer, herbicides, insecticides and energy use) has steadily increased since the 1950s (Parton *et al*. 2007). Inputs accounted for 30% of gross farm income in 1949 and more than 60 percent during the 1990s. This rise in cost has reduced the potential for profit, despite exponential yield increases.

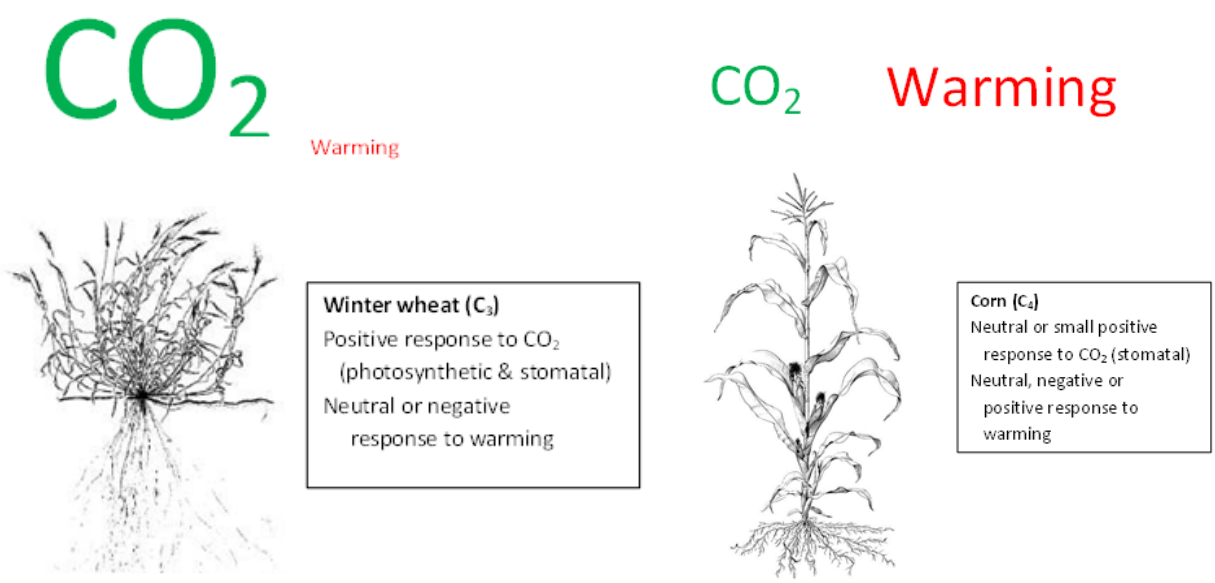
Although input costs have increased, profit predictability is stable and risk has been lowered due to better technology, increased irrigation and government payments to farmers (which has increased more than 60% since the 1980s) (Parton *et al.,* 2007).

A number of crops are produced throughout the region and vary according to climatic gradients. C3 plants tend to grow better in the cooler, wetter northern and eastern region and C4 plants thrive in the southern and western region, although irrigation has allowed the growth of corn and wheat in the west and south. (Tieszen *et al*., 1996) The major harvested crops are wheat (accounting for 50% of harvested land), hay (20%) corn (15%) and cotton (4%) (Parton *et al*., 2007). Production of wheat in the Great Plains accounts for 51% of the nation's wheat and is the most productive in the world. Forty

---------- **C_3 & C_4 Plants BOX** ----------

C_3 & C_4 Differential Responses to CO_2 & Temperature

The vast majority of plant species in agronomic and grassland ecosystems in the Great Plains belong to two photosynthetic classes of plants, C_3 and C_4. Plants with the C_3 photosynthetic metabolism account for over 95% of Earth's plant species, including most crop species (e.g. rice, beans and wheat). They are found under diverse environmental conditions, but often perform best under moderate temperature and light conditions and when water is relatively abundant. In contrast, C_4 plants comprise less than 5% of Earth's plant species, have characteristically high water use efficiency, and thrive under high light and temperature (e.g., corn and sorghum). C_4 grasses are an important component of grasslands and savannas, and C_4 crops produce 40% of the world's grain. Due to differences in photosynthetic pathway, rising CO_2 is expected to directly enhance photosynthesis and therefore growth of C_3 plants, but have little direct effect on C_4 photosynthesis (Ainsworth and Long 2005). Rising CO_2 also closes the stomatal pores in most plant species, C_3 and C_4 alike (Wand et al. 2009), which reduces water loss and improves plant water use efficiency (WUE) (Morgan et al. 2004; Leakey 2009). Thus, CO_2 has the potential to enhance photosynthesis and growth of C_3 plants, but will likely only affect C_4 plants under water-limited conditions when high WUE is adaptive. Warming increases plant water loss and stress, but may favor warm-season C_4 plants. The combined effects of rising CO_2 and climate change on plant production and species responses are complex and likely to effect C_3 and C_4 plants differently, depending on present-day conditions (warm, cool, wet, dry) and the degree and pace of global changes. percent of the country's sorghum, 36 percent of its barley, 22 percent of its cotton, 14 percent of its oats and 13 percent of its corn are produced in the region (Ojima *et al*., 1999).



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The north-south temperature gradients and east-west precipitation gradients result in gradients in dominant agricultural products and production practices across the region. Annual cropping is more dominant in the north and eastern portions of the region and rangeland and cattle production, while important across the region is more dominant in the drier western and southern parts of the region. However, climate and topography of the Great Plains reduce possibilities for diversification in agricultural practices and land management at any given part of the region. Particularly in the northern part of the region, there is little flexibility in planting dates and a limited number of suitable crops due to short frost-free period. The southern and western parts of the state cropping season are constrained by precipitation patterns. Rainfed cropping across the region must have stored soil water at planting because at least some portion of the growing season will experience precipitation deficits lasting weeks to years in most growing seasons.

As stated above, increases in yields are largely attributed to technological improvements and shifts in practices. The most important among these are increased being increased irrigation, pest management and fertilizer application, improved tillage practices, and improved plant varieties (Parton *et al*., 2007).

Tillage, utilized for all crops in the region, is the physical loosening of soil to optimize conditions for germination, seedling establishment and growth of crops (Lal, 1979). The benefits of tilling include: seedbed preparation, weed control, evaporation suppression, water infiltration enhancement, and erosion control (IBSRAM, 1990). Increases in irrigation and herbicide use have caused a shift in practices from traditional tillage. Tillage reduction increases water and energy efficiency, carbon sequestration and other nutrient retention.

Fertilizer application is commonly used across the region, however over application of fertilizer (particularly nitrogen) causes leaching of nutrients and eventually eutrophication of waterways (Rabalais, Turner & Wiseman, 2002). N20 emissions and NO3 leaching follow a general pattern of increased cultivation and nitrogen fertilizer usage, low in the western part of the region and increase rapidly eastward. They follow a similar pattern because both increase with greater crop intensity. (Parton *et al*., 2007).

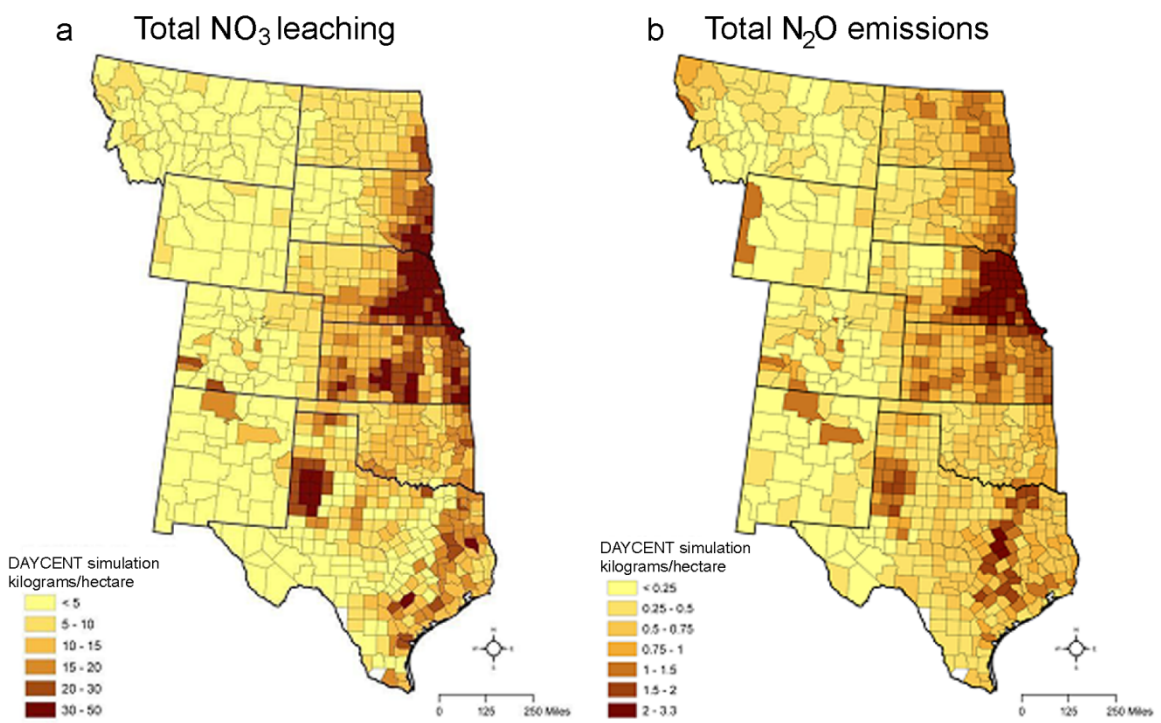


Figure 5 – Average DAYCENT model-simulated (a) nitrate (NO_3) leaching below the rooting depth and (b) nitrous oxide (N_2O) gas fluxes for counties with the Great Plains (Parton et al, 2007)

In the semiarid portion of the Great Plains, dryland wheat farming has been made possible mainly by fallow systems, where only half of an operator's land is planted each year and the other half is

left idle to accumulate water and nutrients (Ojima and Lackett, 2002). Wheat fallow is a common practice in the western Great Plains and provides farmers with a reliable income and stabilizes yields from year to year (Croissant et al., 2008). However, the system also have low water use efficiency and result in declining soil organic matter and increased soil nitrous oxide fluxes to the atmosphere Reduced tillage systems allow more diverse crop rotations with less frequent fallow, which leads to increased precipitation-use efficiency and enhances soil function (Westfall et al., 2010) In long-term cropping studies in eastern Colorado, annualized grain production from no-till systems with less frequent fallow increased by 75%, and economic return by 13% to 36% compared with the traditional wheat-fallow cropping system.

Irrigated cropping is important in all of the Great Plains states, based either on pumping of groundwater, dominated by irrigation from the Ogallala Aquifer which spans from the Texas High Plains through the Oklahoma Panhandle, western Kansas, eastern Colorado, Nebraska, into southern South Dakota. In addition, there is a significant amount of irrigation from surface water supplies, primarily from major water projects managed by the Bureau of Land Management.

Table 4. Freshwater Withdrawals in Great Plains States

	ND	SD	NE	KS	OK	TX	MT	WY	CO	NM
Irrigation, MGD	151	292	8460	2740	495	7800	9670	3990	12300	2810
Livestock, MGD	23	48	108	108	162	258	39	16	33	51
Public Supply, MGD	67	100	330	403	646	4270	142	96	864	286
Domestic, MGD	9	8	52	15	25	257	24	6	29	32
Surface for irrigation, MGD	73	143	1150	114	134	1680	9530	3570	10000	1550
Groundwater for irrigation, MGD	78	149	7310	2620	361	6120	140	422	2320	1270

Source: Kenny, J.F., Barber, N.L., Hutson, S.S., Linsey, K.S., Lovelace, J.K., and Maupin, M.A., 2009, Estimated use of water in the United States in 2005: U.S. Geological Survey Circular 1344, 52

Most Great Plains cropland has undergone loss of soil carbon compared to uncultivated prairie soils (Hartman et al., 2003). Adoption of no-tillage systems and intensification of crop intensity may have the potential to enhance soil carbon sequestration. Many studies have shown that soil carbon is

increased in surface soil layers in no-tillage compared to conventionally tilled system across the Great Plains (Peterson et al., 1998; Sainju et al., 2006, 2011; Potter et al., 1997; Blanco-Canqui et al., 2011). However, Blanco-Canqui et al. (2011) found for three long term studies (>21 years) in Kansas, profile soil carbon to a 1 m depth was not significantly increased by no-till compared to conventional tillage management. Few additional studies have compared full-profile soil carbon content for Great Plains cropping systems. While the potential for carbon mitigation is uncertain, the benefits of increased soil carbon and improved aggregation in the surface soil layers on infiltration and increased surface crop residue on reduced evaporation and temperature can allow cropping system diversification and intensification (Peter son and Westfall, 2004; Westfall et al., 2010) which improve productivity and economic returns.

For cropland, a primary greenhouse gas emission of concern is nitrous oxide, associated with fertilizer and manure application. Ribaudo et al. (2011) found that in the Northern Great Plains, nitrogen management failed to meet conservation criteria due to rate (28%), timing (15%) or method of application (45%). In the Southern Great Plains failure to meet conservation criteria for rate, timing, or method were 32%, 38%, and 18%, respectively.

1.1.2 Multi-functional rangelands and prairies, land use change

The large amount of native grazinglands and introduced pastures in the Great Plains landscape provide a multitude of ecosystem services in addition to agricultural production. They provide critical habitat for a number of species. However, fragmentation and degradation of the native vegetation through overgrazing, drought, and encroaching species, such as junipers, reduce the effectiveness of these lands for many species of concern such as lesser prairie chicken, prairie dog, burrowing owls, and a wide variety of songbirds. Additionally, fragmentation and degradation of these grazinglands impede the hydrologic function and nutrient cycling in the landscape.

Land use changes have slowed during the past 30 years (Parton et al 2007, in press). Recent analyses of land use changes indicate the strong influence of conservation policies (Parton et al 2007, Loveland et al. 1995). The Conservation Reserve Program in the 1980 to 2000 accounted for croplands to be taken out of production. Recent conversion of the lands back to cropland is a combination of increased demand for maize and the termination of conservation contracts across the region. Other agricultural policy programs, including crop insurance, commodity, and disaster programs also influence land use change from grasslands to croplands (Classen et al., 2011)

In addition, recent land use conversions have taken place. During the late 20th century, the Conservation Reserve Program (CRP) set aside less productive cropland into grasslands, thereby helping to reduce soil erosion and enhance biodiversity in agricultural landscapes. However, grasslands and CRP lands are being looked at as production areas for potential bioenergy feedstock. Cultivation of CRP lands for crop production is now occurring in the Great Plains due to higher grain prices in response to the need for bioenergy feedstock. Future considerations for additional feedstock production with 2nd generation cellulosic bioenergy production technology may affect even larger areas of grassland environments. These climate and land use changes present challenges and opportunities to grassland managers.

1.3 NATURAL RESOURCES AND WILDLIFE ASPECTS

Water, land and soils, energy, wildlife

Water Resources

Drought has always been a factor in the region, 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. Water users 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 water users in this region are vulnerable due to the declining reward scale for farming and ranching.

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. In the Great Plains as a whole agricultural land contributes 49% (57.3 Bm^3/year) of the water supply (compared to a national average of 26%), followed by rangeland (25.8Bm^3/year), forest (19.9Bm^3/year), and wetlands (8.9Bm^3) (Brown, Hobbins and Ramirez 2008). Seasonality is an important factor affecting land systems in the Great Plains. 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 (McMahon et al 2007, McGuire et al 2011)).

In addition, 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. Considerable water pollution results from extraction processes; farm management practices associated with fertilizer usage, pesticide applications, manure and sediment run-off; industrial run-off, and inflow from built environment and waste runoff. 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. Alteration of vegetation, introduction of nonnative plant and animal species, and over-harvesting of native species has also damaged these aquatic ecosystems.

Major River Basins

The Great Plains are intersected by 4 major river basins, the Souris-Red-Rainy Basin in the northeast, the Missouri River in the north, the Arkansas-White-Red Basin draining the central region and the Texas Gulf Basin, including the Rio Grande River, in the south. These river systems have served as passage ways into and across the Great Plains. They continue to serve as critical resources for energy, irrigation, and conservation efforts throughout the Great Plains. An overview of these major river systems are provided here.

Souris-Red-Rainy

The Red River of the North originates in North Dakota. The river flows in a northward direction for 545 miles through the Red River Valley containing cities such as Fargo-Moorhead and Greater Grand Forks, eventually entering Manitoba where it discharges into Lake Winnipeg (Benke and Cushing 2005). The Red River's 48,490 square mile drainage area, which includes the Devils Lake sub-basin, is near the geographic center of North America and includes portions of North Dakota, South Dakota, and Minnesota as well as parts of Manitoba and Saskatchewan (Benke and Cushing 2005), USACE website).

The Red River Valley is part of what used to be the extremely flat floor of ancient glacial Lake Agassiz, and the river has a remarkably low gradient that can be as little as 1.5 inches per mile in some reaches.

The flat topography of the Red River Valley combined with the synchrony of a northward flowing river and a northward moving spring thaw makes this region one of the most flood-prone areas in the U.S. Runoff from the warmer southern portion of the Valley progressively joins with fresh, melted waters from more northerly reaches. These flows may then get dammed by natural ice jams downstream. River water then overflows, spreading across and flooding the flat former lakebed. Based on more than 100-year old river stage data collected in Fargo, the Red River exceeded the major flood stage, the point at which extensive inundation of structures and roads is expected to occur, 16 times.

Missouri River Basin

In the northern and central Great Plains, the dominant river system is that of the Missouri. Originating in the northern Rocky Mountains of southwestern Montana near the city of Three Forks, the river flows over 2,300 miles in a southeasterly direction through Montana, North Dakota, South Dakota, Nebraska, Iowa, Kansas, and Missouri, finally discharging into the Mississippi River near St. Louis. The Missouri is typically identified as the longest river in the U.S. and the longest named river in North America (Benke and Cushing 2005). Thirty-seven tributaries flow into the Missouri including the Yellowstone, White, Platte, and Gasconade rivers. In addition to part of two Canadian provinces, the river drains over 500,000 square miles consisting of all or part of ten states and 25 Native tribal reservations or lands, roughly one sixth of the land area of the Lower 48 states (Benke and Cushing 2005, Reclamation 2011).

The drainage area of the river consists mainly of two physiographic divisions that vary greatly in terms of climate. One is the Rocky Mountain system where total annual precipitation in the mountains averages over 80 cm (31 inches) and often falls as snow (Benke and Cushing 2005). The largest portion of the Missouri River watershed, though, falls within the semiarid Great Plains where total annual precipitation averages just 36 cm (14 inches) (Benke and Cushing 2005). Thus despite its length and large watershed, the average discharge of the Missouri at its mouth is 76,200 cubic feet per second and is less than the discharges of other rivers such as the Ohio and Columbia (USGS, 1990). In addition to water sources rising within the basin, water is also transferred from the Colorado River to Northern Colorado via the Colorado-Big Thompson and Windy Gap projects. The water transfer is for agricultural,

industrial, municipal, and hydroelectric power purposes. (1996 BOR report; CWRRI, 1994; BOR and Northern Water websites).

Discharge patterns in the Missouri main-stem reflect the influence of both the Rocky Mountains and the Great Plains physiographic divisions. Flow in the main-stem starts to rise in March with the melting of prairie snow and then peaks in June due to a combination of Rocky Mountain snowmelt and late spring precipitation on the Plains (Benke and Cushing 2005, USACE 2006). Discharge then declines in July. Although system regulation helps reduce flooding, if floods do occur, they typically happen between March and (USACE 2006). Portions of the Missouri Basin has experienced massive flooding events associated with unusual weather patterns contributing to heavy rainfall concurrent with rapid snow melt during the Spring of 2011. (National Climate Data Center list of billion dollar U.S. Weather/Climate disasters http://www.ncdc.noaa.gov/oa/reports/billionz.html#chron)

Arkansas-White-Red Basin. The Arkansas-White-Red Basin consists of the Arkansas River and the Red River of the South, which are the two main rivers draining the Central and Southern Great Plains region, and the White River, which is outside of the Great Plains and drains parts of the states of Arkansas and Missouri, discharges into the Mississippi, and is connected to the Arkansas River through a manmade navigation canal (USACE website; USGS Water Supply paper). The Arkansas River arises in the Rocky Mountains of central Colorado near the city of Leadville and, and some of the tallest peaks in Lower 48 states (Benke and Cushing 2005). Also, the Arkansas River may receive snowmelt runoff imported from Colorado's west slope across the continental divide to its semi-arid east slope via the conduits, tunnels, and reservoirs of the Bureau of Reclamation's Fryingpan-Arkansas Project, completed in 1990, as well as through several other non-federal diversion projects (Arkansas River Water Needs Assessment – BLM – 2000, BOR Annual Operating Plan for the Fryingpan-Arkansas Project Water Year 2010). It flows approximately 1,460 miles in a generally east/southeasterly direction through the Royal Gorge, the states of Kansas and Oklahoma and into Arkansas where it discharges into the Mississippi River near the town of Napoleon (Benke and Cushing 2005); SWQMP, 2011). It drains an area of roughly 161,000 square miles (Benke and Cushing 2005), and the average discharge at its mouth is 41,000 cfs (USGS 1990).

The source waters of the Red River of the South arise among streams flowing through the Texas Panhandle (Benke and Cushing 2005). As the river travels east towards Wichita Falls, Texas, it drains some of the driest regions in the Southern Plains that receive less than 20 inches of rainfall per year, as a

result, the river here may experience extended "no flow" periods and pooling up (Benke and Cushing 2005). However, the river becomes more substantial as it continues its eastward trajectory past Wichita Falls and enters Lake Texoma, a reservoir shared by Oklahoma and Texas and formed by the Denison Dam (Benke and Cushing 2005). The Red River forms the long-debated boundary between these two states. The Army Corps of Engineers has undertaken a Red River Basin Chloride Control Project to reduce naturally occurring brine emissions into several Texas and Oklahoma sub-basins, the goal being to improve water quality for municipal, industrial, and agricultural uses (**USACE website http://www.swt.usace.army.mil/projects/civil/civil_projects.cfm?number=86 downloaded January 30, 2012**). Although there would be benefits from the water supply viewpoint, water withdrawals from the river would increase possibly resulting in an increase in no flow days in the upper basin (Benke and Cushing 2005). In addition, changes in the river's natural salinity regime could affect river ecology (Benke and Cushing 2005).

Texas Gulf Basin. In the Texas Gulf Hydrologic Unit, 11 major rivers traverse through Texas and discharge into the western Gulf of Mexico (RONA). They include from southwest to northeast – the Rio Grande, Nueces, Guadalupe/San Antonio, Lavaca, Colorado, Brazos, San Jacinto, Trinity, Neches, and Sabine. The two major rivers are the Rio Grande and Trinity Rivers (RONA). The Rio Grande rises in the San Juan Mountains of Colorado (part of the Rocky Mountains) and flows south through New Mexico passing Albuquerque on its way towards El Paso/Ciudad Juarez (RONA). From there, it flows generally southeast forming the international boundary between Texas and Mexico as it travels towards the Gulf of Mexico where it discharges near Brownsville, Texas (BOR 2011). Along the way, it passes through several reservoirs including the Cochiti, Elephant Butte, Caballo, Amistad, and Falcon. Two stretches of the river have been declared part of the National Wild and Scenic Rivers system, including one reach running through Big Bend National Park (RONA). The total length and drainage of the basin are approximately 1,900 miles and an area of approximately 336,000, respectively.

The mountain headwater region of the Rio Grande may receive 40 inches of precipitation per year, much of this as snow (BOR 2011). Snowmelt is the main source of water for the river and dominates the hydrograph for the upper portion of the Rio Grande, with peak flows typically occurring in spring and early summer (RONA, BOR 2011). However, further downstream, as the Rio Grande passes through multiple reservoirs, reservoirs become the controlling factor in the river's hydrograph (BOR 2011). In recent years, increased human consumption of Rio Grande water by both the U.S. and Mexico has resulted in intermittent or lower flows reaching the lower reaches, and, in 2002 and 2003, Rio

Grande waters did not reach the Gulf of Mexico for multiple months (BOR 2011, RONA). Irrigation of croplands are major water demand on the water supply. Important issues in the Rio Grande basin include endangered species and water quality issues such as salinity (BOR 2011). The Rio Grande Compact Commission is undertaking a multi-state salinity control program modeled after the Colorado River Salinity Control Forum (Southwest Hydrology, 2008).

The 715 mile-long Trinity River starts in the Four Forks region in the north-central/northeastern part of the Texas. The Clear Fork and West Fork of the river join near Fort Worth, the Elm Fork near Dallas, and the East Fork just south of Dallas (RONA, TMP 2010). The river then flows generally southeast where it discharges into the Gulf of Mexico. The Trinity River provides water for two of the most populous metropolitan areas in the U.S. (Houston and Dallas/Fort Worth) and the river empties into Galveston Bay, one of the nation's most productive ecosystems and commercial fisheries (TMP 2010; find census reference). The Trinity River drains 18,000 square miles and is the largest river basin in Texas that lies entirely within the state. Most of the flow in the river comes from rainfall runoff. Precipitation varies within the basin ranging from 29 inches per year further west to 53 inches per year closer to the coast (TMP, 2010). Flow in basin streams is quite variable, and during the summer can be very low. In order to provide for a more stable water supply, a total of 31 reservoirs have been built on the river and its tributaries (TMP 2010). In addition, seven reservoirs outside the watershed either provide water to Trinity basin users or are under contract to do so in the future (TMP 2010). Because of the scarcity of groundwater availability, Trinity basin users must rely on surface water (TMP 2010).

Land and Soils

The primary land use on roughly 95% of the watershed in the U.S. is agricultural (USACE 2006). About 180 million acres (281,250 square miles) are pasture and range grassland for grazing, 28 million acres (43,750 square miles) are forest and woodland areas, most of which are grazed as well, and 104 million acres are cropland. Other uses in include urban development, transportation, and water surface areas.

In the southern portion of the Great Plains, especially along the Rio Grande River, land use in the Rio Grande basin consists of shrubland (43%), grassland (31%), forest (14%), urban (7%), and cropland (5%) (RONA). The main use of Rio Grande water is for irrigated agriculture (RONA). Important irrigated agricultural areas along the Rio Grande river corridor include the San Luis Valley in Colorado where alfalfa and potatoes are major crops, the Middle Rio Grande and Mesilla Valleys in New Mexico where

crops include alfalfa, cotton, pecans and irrigated pasture, and the lower Rio Grande Valley of southern Texas where citrus fruits, cotton, and vegetables are grown (RONA; BOR 2011).

Great Plains Land Cover Change

The pace and characteristics of land cover change are highly variable across the Great Plains region (Figure 6) (Drummond et al. 2012). This is due in large part to the spatial heterogeneity of natural resources and climate that underpin land use decisions. Land quality (e.g. soil type, topography, erosion), water availability, precipitation and temperature regimes, and other biophysical factors play a substantial role in shaping the broad-scale geographic patterns of crop production, livestock grazing, and other uses. Areas with good soil and favorable climate have a long history of persistent cultivation, while areas that are unsuited for crops are primarily used as rangeland or may fluctuate between dryland crops and grazing. However the spatial and temporal dynamics of land use and land cover change are ultimately decided by a combination of landowner decisions, government policies, economic opportunities, population and demographic trends, technological advances, energy and input costs, and evolving agricultural practices.

Much of the overall extent of Great Plains land cover change results from the episodic expansion and contraction of cropland (Figure 7). Between 1973 and 2000, agriculture to grassland conversions outpaced all other land cover changes combined, though the pace and direction of these conversions varied over time. Urbanization in the more populated sections of the Plains, cyclic brush clearance in the southern plains, wetland inundation in the northern plains, and other smaller conversions also contribute to the overall net trends.

Recent trends show that agricultural land cover had a net expansion during the 1970s, which was later reversed by the policies of the 1985 Farm Bill's Conservation Reserve Program (CRP). The CRP provides an economic incentive to convert marginal and environmentally-sensitive cropland to grassland cover or other natural cover types. Historically, government policy is among the important drivers of expansion and decline. However, land cover changes result from interactions among a mix of drivers. For example, the increase of agricultural land cover in the early 1970s was in response to higher grain prices, policies and price supports that favored cropland expansion, and reasonable land prices and interest rates. Technological changes, including the spread of center pivot irrigation, also allowed cropland to expand in areas of water availability such as the extension of feed corn production and

associated industries to the High Plains (Ogallala) Aquifer area. Conversely, local-scale declines in agriculture occurred as urban areas expanded in response to population growth and migration to cities.

Net agricultural expansion was followed by a period of slow rates of land cover change driven by the contraction of export markets, increased costs associated with farm inputs, and high interest rates (Stam and Dixon 2004). By 1985, policy again had a significant effect on land cover as the CRP enabled millions of acres of cropland conversion to grassland cover, including in areas of declining groundwater that overlay the High Plains Aquifer. The initial CRP period (1986-1992) had the largest effect on land cover between 1973 and 2000 (Figure 8). Currently, farmers are responding to new economic realities, energy policy designed to promote biofuel production, and other drivers that will continue to change the land cover composition of many areas of the Plains including some key areas of CRP decline in the north central plains and the southern high plains and irrigation decline in parts of the high plains (USDA, various dates).

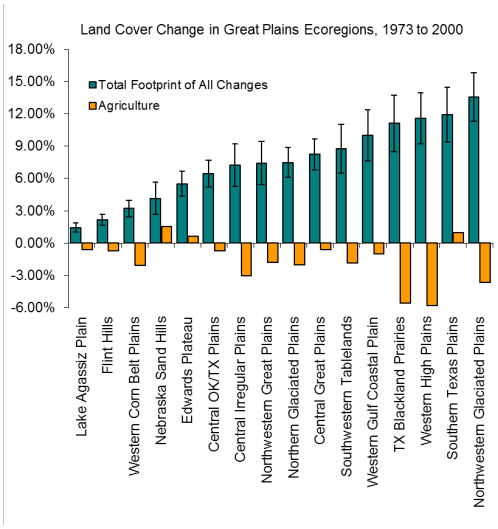


Figure 6. The variable extent of land cover change in Great Plains ecoregions between 1973 and 2000.

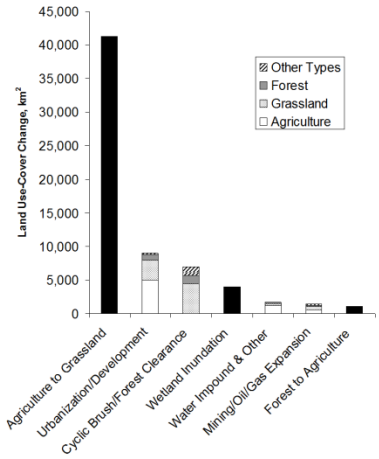


Figure 7. The seven most extensive processes of land cover change between 1973 and 2000. "Other Types" of cyclic brush/forest clearance refers to land that remained in a state of clearance during two consecutive time intervals. (Drummond et al. 2012, Land Use Policy)

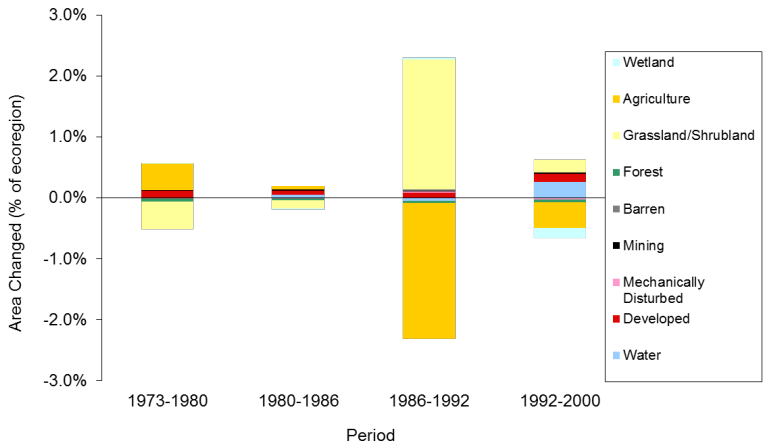


Figure 8. Area of net land-cover change during four time intervals

Figure 9. Land Cover Transitioned from Ag dominant to Grass dominant

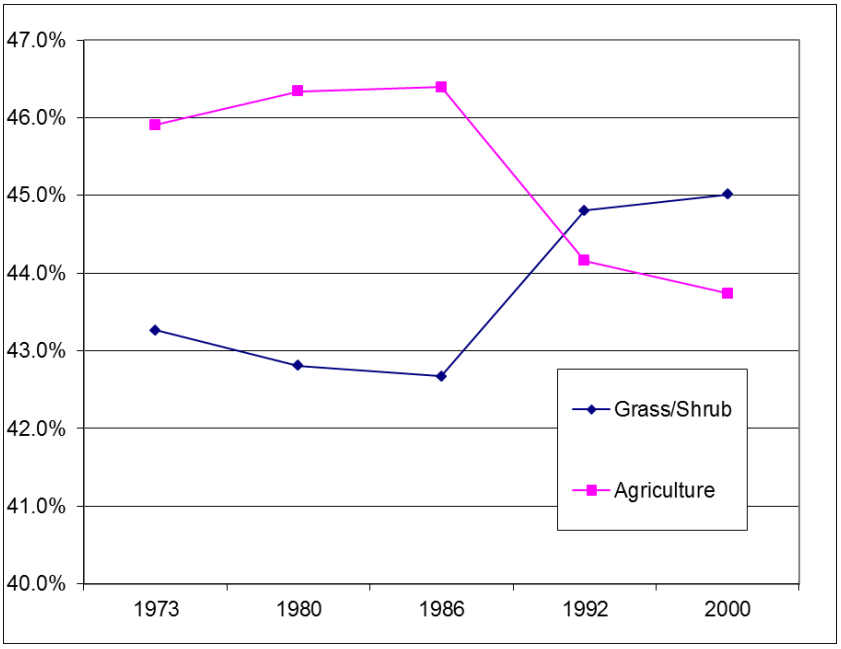
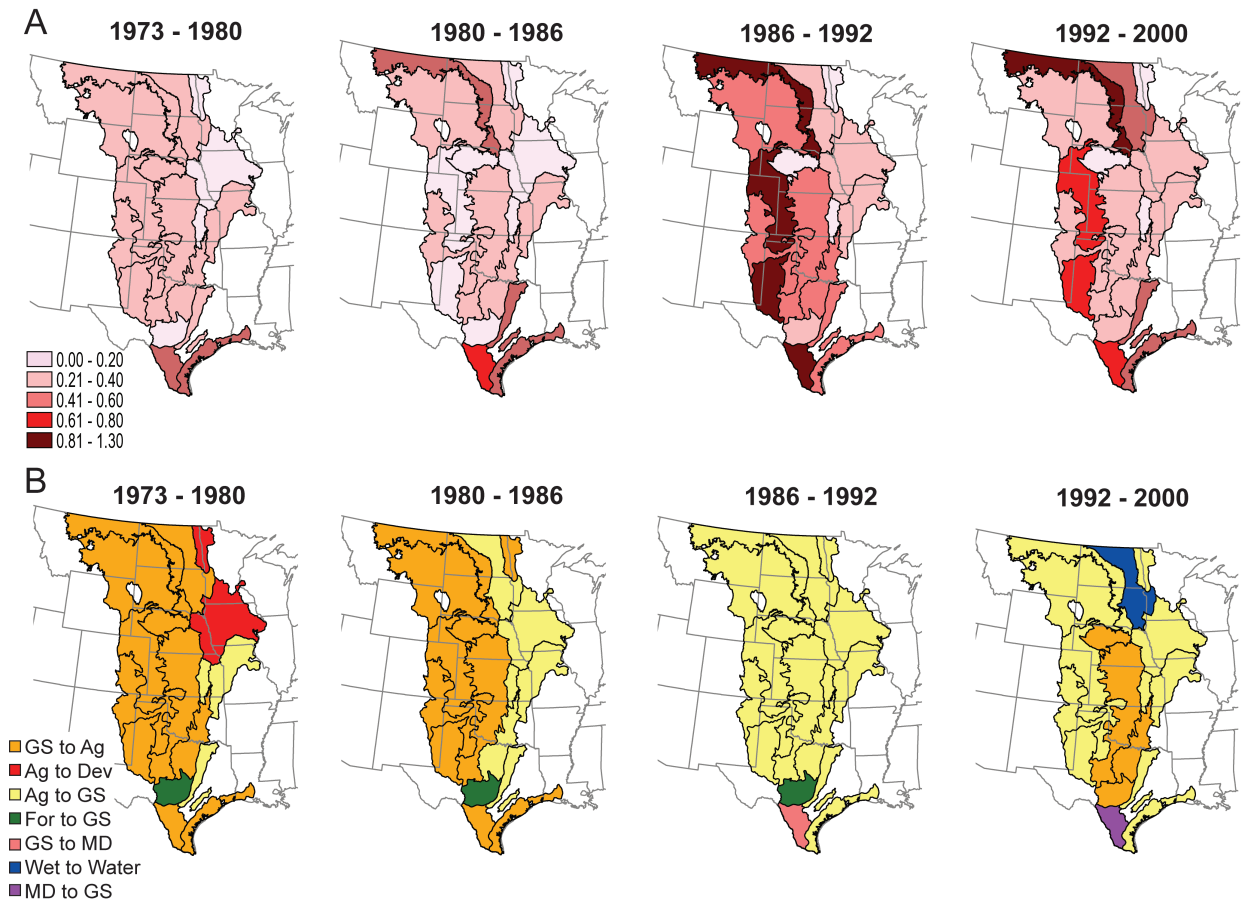


Figure 10. Regional Variability of Rates & Types of Conversion

- **Individual ecoregions generally at or near highest rate of change during 1986-92, indicates influence of government policy**
- **Regionally cohesive patterns as agricultural expansion transitions to grassland expansion**



Soil in the region

The Great Plains lie west of the Mississippi River and east of the Rocky Mountains, rising gradually from about 30 m above sea level to over 5,500 m at the foot of the mountains. Before their widespread conversion to intensive agriculture, the Great Plains were noted for their extensive grasslands, from tall-grass prairie in the east to short-grass prairie in the western High Plains. The generally low relief of the plains is broken in several places, notably by the Ozark and the Ouachita Mountains, which form the Interior Highlands, the only major mountainous region between the Rocky Mountains and the Appalachian Mountains (see Havstad et al 2009).

Soils of the Great Plains region are predominantly Mollisols, characterized by a thick, dark surface (A) horizon, and a high base saturation. The dark surface horizon results from the process of melanization -- darkening via the addition of organic matter. Mollisols form as a result of long-term accumulations of plant material and are high in organic matter content. Biological activity is important in Mollisols, where soil fauna such as earthworms and rodents help break

down and incorporate organic matter. These soils characteristically form under grassland or prairie vegetation in climates that have ~~a~~ moderate to pronounced seasonal moisture deficits-but under a wide range of temperature regimes. The typical topography associated with Mollisols is flat or gently rolling to undulating. The parent material is associated with unconsolidated material resulting from glaciation, aeolian deposits (loess) high in calcium, and/or sedimentary rocks. Mollisols are characteristic not only of North America, but also of the steppes of Europe, Asia and South America.

The high organic matter soils of the Great Plains are derived from a wide variety of parent materials: limestone, sandstone, shale, metamorphic and igneous outwash (soil deposited by flowing water), and loess (Pieper 2005). Mollisols are typically deep soils with dark A horizons and high (>50 percent) base saturation, especially Ca (Fig. x); the clay content is evenly distributed throughout the A and B horizons. The translocation of clays from the B to the A horizons occurs by a variety of processes, including a common prairie ant (*Formica cinerea)*. The development of these dark, relatively fertile soils occurs via the process of "melanization" involving (1) penetration of plant roots into the soil profile and their subsequent death, (2) decay of organic material, (3) mixing by soil microorganisms, (4) movement of organic and some inorganic colloids within the soil by water (eluviation and illuviation), and (5) formation of resistant "ligno-protein" residues producing the dark color in the soil. These soils generally support prairie vegetation. In the eastern, more humid portion of the Great Plains, grassland soils are dominated by Alfisols. These soils have developed in higher rainfall environments and have undergone moderate leaching and have subsurface accumulation of clay and ≥35% base saturation. These soils are generally occupied by forests, savannas and open prairies.

At the time of European settlement of the Southern Great Plains, woody plants, including eastern red cedar (*Juniperus virginiana*), Ashe juniper (*J. ashei*), Pinchot or redberry juniper (*J. pinchotii*), Rocky Mountain juniper (*J. scopulorum*), and honey mesquite (*Prosopis glandulosa*), were restricted primarily to riparian or deeply dissected areas that seldom experienced fire. However, beginning early in the 20th century, woody plant encroachment became a substantial land management issue that continues to occur at a rapid rate.

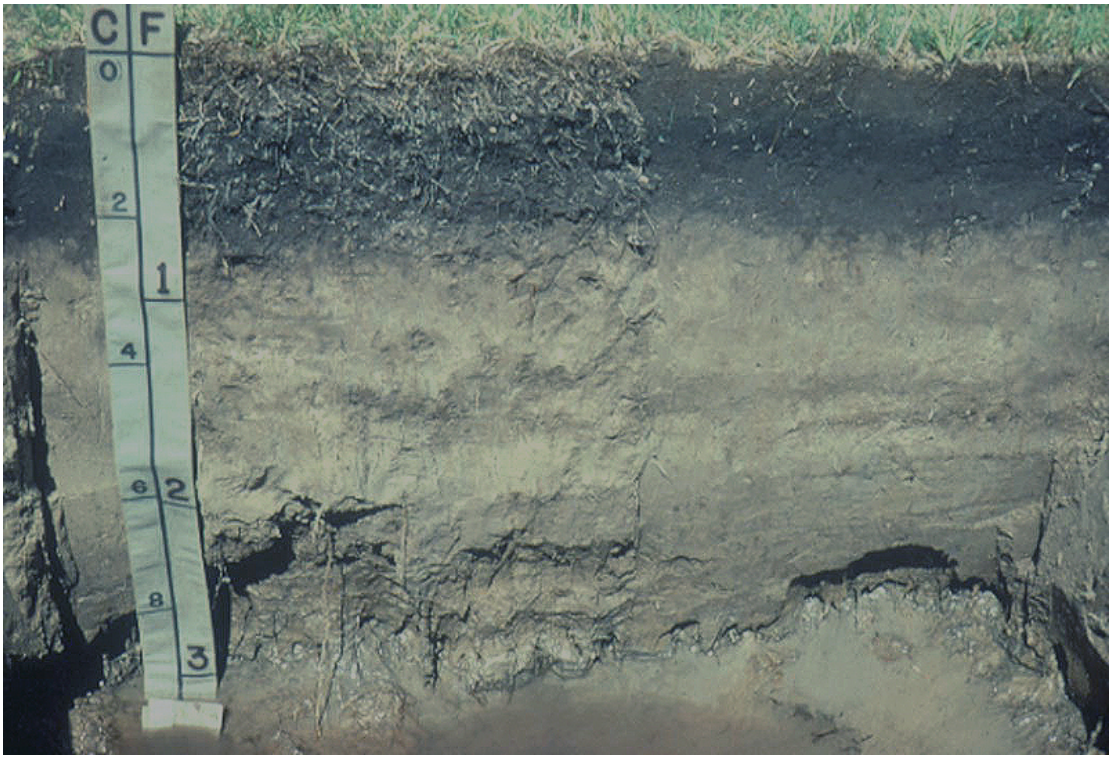


Figure 11. Mollisols are the soils of grassland ecosystems. They are characterized by a thick, dark surface horizon. This fertile surface horizon, known as a mollic epipedon, results from the long-term addition of organic materials derived from plant roots. Image is a Typic Endoaquoll. http://soils.cals.uidaho.edu/soilorders/mollisols.htm.

Energy resources

The Great Plains are rich with energy sources, from coal, oil, natural gas and nuclear, to wind, solar, biomass, biofuels, and geothermal. This provides economic opportunitiesthrough the extraction, transportation, processing, and sale of raw materials, fuels, and electricity that provide sources of jobs and incomes for communities throughout the region. However, there are challenges associated with these processes that will be exacerbated by the impacts of a changing climate. For example, large amounts of water are needed to produce things like natural gas and biofuels, and to run our power plants (see Section 4 for more on this topic). Higher average temperatures and drought will threaten water supplies and the operation of these facilities. Additionally, the increased flooding seen in recent years in the Great Plains also threatens power plants located in flood-prone areas.

Per capita energy Consumption in the Great Plains region is very high. It is the highest energy consuming region in the United States with Wymoing as the highest per capita energy consumption state consuming 956 million BTUs per person compared to the national average of 308 million (http://energy.gov/maps/2009-energy-consumption-person). Not surprisingly, Texas and Wyoming are the biggest energy producers in the United States, producing 16.4% (primarily natural gas) and 14.23% (primarily coal) of total U.S. energy produced, respectively (http://energy.gov/maps/2009-total-energy-production-state). At the same time, Texas has also been the fastest growing state for new wind energy facilities.

Wildlife and Conservation Issues

The Great Plains contain a number of natural areas and conservation areas hosting a diversity of wildlife, grassland and wetland ecosystems, riparian corridors and environmental gradients which support a unique set of birds, fauna, vegetation and insects of interest to the region. The climate gradient and the variability of weather patterns provides a diversity of habitat conditions in support of iconic species such, the American bison, Greater Sage Grouse, sandhill cranes, ferrets, coyotes, golden eagles, ducks of many kinds, warm water fish populations, pronghorn, horned lizards, amphibians, and others across the Great Plains. Climate change and land use patterns across the Great Plains have affected a number of environmental factors and ecosystem services. State wildlife plans and federal wildlife and conservation planners have been developing modified management plans to better incorporate climate issues into their management strategies (Mawdsley et al xxx, NWF xxx, etc).

Native vegetation communities 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 in turn transition 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 a greater number of tree species. Though dominated by grasslands, the Great Plains is also home to a diversity of plants and animals in shrubland, wetland, and forest communities.

Many plant and animal species have coped with changing climates throughout their evolutionary histories (Axelrod 1985, Elias 1991, Lovette 2005). Grassland birds, which have persisted through millennia of both climate stasis and extreme variability, date to the early Pliocene, 4.3-4.8 mya

(Emslie 2007) when extensive prairie and steppe habitat dominated the Great Plains and climate was relatively stable. With the advent of the glacial-interglacial cycles of the Pleistocene beginning ca 2.5 mya, the prairie-steppe habitat periodically appeared and disappeared (Emslie 2007). During moister glacial times such as the late Wisconsinian (15,000-12,000 bp), areas now covered with grassland were mostly covered by glacial ice or open forests and woodlands with scattered grasslands, as indicated by high levels of tree pollen immediately below the surface (Axelrod 1985). Through the combined impacts of a drier climate, fire, and grazing by large herbivores, the area reverted to extensive grassland interrupted by narrow riparian woodlands along many lakes, creeks, and rivers. During the past 10,000 years, the Holocene, relatively moist conditions across grassland landscapes were repeatedly interrupted with droughts intense enough to impact vegetation composition and mobilize sand dunes (Forman et al. 2001).

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 native ungulates and other mammals, as well as a diversity of arthropods, reptiles, amphibians, and birds. Although more than 1,100 species of vertebrates have been recorded on the Great Plains, 97 are considered endemic (unique to the Great Plains) or as having a strong affinity to the plains (Knopf and Sampson 1997). Predominant mammals include 16 endemic species, such as the bison (*Bison bison*), pronghorn (*Antilocapra americana*), swift fox (*Vulpes velox*), black-footed ferret (*Mustela nigripes*) black-tailed prairie dog (*Cynomys ludovicianus*) and many other rodent species, and white-tailed jackrabbit (*Lepus townsendii*). Many groups of birds breed across the Great Plains (primarily hawks, grouse, waterfowl, shorebirds, and songbirds) and in addition, hundreds of migrant species cross the interior during migration from northern breeding areas and southern wintering grounds. Breeding birds endemic to the grasslands include ferruginous hawks (*Buteo regalis*), mountain plovers (*Charadrius montanus*), long-billed curlews (*Numenius americanus*), lark buntings (*Calamospiza melanocorys*), and others.

The wetland basins in the Prairie Pothole region of the Northern Great Plains and the playa lakes region of the Central and Southern Great Plains provide important breeding and migratory habitats for a diversity of wetland dependent species. Several species of waterfowl nest in grasslands associated with the prairie potholes, notably mallards (*Anas platyrhynchos*), gadwalls (*A. strepera*), and pintails (*A. acuta*), and many species of breeding and migrating shorebirds and other wetland-dependent birds range across the entire plains region. Prairie wetlands host a multitude of northbound shorebird

migrants in spring, the most numerous being the calidridine species such as semipalmated sandpipers (*Calidris pusilla*) and white-rumped sandpipers (*C. fuscicollis*) (Skagen et al. 2008).

Amphibians such as plains spadefoot toads (*Spea bombifrons*) and plains leopard frog (*Rana blairi*) are endemic to the Great Plains, as are six reptilian species. The amphibians and reptiles of the Great Plains comprise about 20% of the species native to the United States and Canada and feature a mixture of species with primarily southeastern or southwestern distributions and only 10–15 endemic species (Corn and Peterson 1996). Reptiles and amphibians rely on their ambient environment to maintain optimal operating temperatures and are sensitive to changes in climate. This is evidenced by a gradient of decreasing species diversity running from South to North and East to West in the Great Plains. Thus, they are thought to be particularly susceptible to changes in climate (Gibbons *et al.* 2000), and there is some evidence for climatological impacts to lizards elsewhere (Sinervo *et al.* 2010). Most of the species diversity is associated with non-grassland habitats, such as permanent water or riparian woodland. However, species of western spadefoots (genus *Spea*) and the Great Plains toad (*Anaxyrus cognatus*) require ephemeral rainwater-filled wetlands for breeding habitat.

Fish habitats include large streams with erratically variable flow, prairie ponds, marshes and small streams, and residual pools of highly intermittent streams. Seven families and 34 species of fish are endemic to the plains, including pallid sturgeon (*Scaphirhynchus albus*), several species of minnow and shiners (family Cyprinidae), madtoms (family Ictaluridae), and darters (family Percidae).

The largest and most diverse class of animals in the Great Plains is insects, including 92 species of dragonflies and damselflies, 220 species of butterflies, and 82 species of grasshoppers that occur in the ecoregion (Ostlie et al. 1997). The many taxonomic groups of aquatic invertebrates and zooplankton include amphipods, copepods, and cladocerans (Wissel et al. 2011).

Many taxa of biota, including plants, insects, and birds, have evolved the capacity to adapt to gradual environmental changes associated with climate, primarily through movement to more favorable areas. An exception to this is the mass extinction of large terrestrial mammals (North American megafauna, including mammoths, mastodons, ground sloths, horses, camels, and others) during the late Pleistocene (ca 11,500-10,500 bp). Although heavily debated, a primary hypothesis for the cause of these abrupt extinctions is the combination of human predation (the arrival of Clovis hunters to North America) coincident with major climatic and environmental changes that had already reduced population sizes (Benedict et al. 1996, Stuart 2008).

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II. SOCIAL ECOLOGICAL OPPORTUNITIES AND CHALLENGES FACED BY THE GREAT PLAINS

2.1 AGRICULTURE:

While the Great Plains agriculture is highly productive, rising input costs associated with high energy costs, changing demographics, and extreme climate events decrease the resilience. Until the recent increase in commodity prices, associated with increased export demands, increased demand for bioenergy, farm-gate prices were often below the full cost of production. The long history of payments to US farmers has become increasingly controversial with many outside the agricultural sector advocating for a change in long-term US policy to shift federal expenditures toward payments for environmental services, new farmers, alternative production practices, such as organic and healthy food programs. With US agriculture operating in a global environment, many macroeconomic factors affect the stability and resilience of agriculture, including variability in currency exchange rates, changes in international trade, foreign and domestic income, rural employment, interest rates, and energy costs (ERS). Franzluebbers et al. (2011) discuss many of the forces acting on the US rainfed agriculture, including the Great Plains region, and identified ongoing challenges to enhance water use efficiency, protect the soil against the considerable forces of wind and water erosion, and to increase integration of crop-livestock systems to reduce need for expensive purchased inputs to enhance profitability in these low-margin commodity production systems.

2.1.1 Changing environmental factors

A. Long term impacts of climate change (temperature / CO2) on crop production (rather than go into exhaustive detail, give brief synopsis, insert table from Pg 8 and highlight some of the key changes. Refer to 2009 Climate Assessment Report for more detail.)

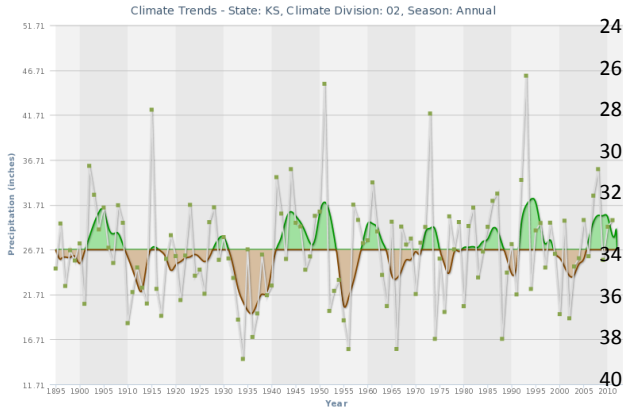

Fig. 1 Long-term precipitation (1989-2011) for North Central Kansas showing annual precipitation (thin line) and five-year running average precipitation (heavy line highlighted by brown, drier periods and green, wetter periods. Prepared using Southern Climate Impacts Planning Program data tools.

Climate variation and extremes have always been a defining characteristic of the Great Plains and no sector is

more vulnerable to climate than agriculture. One aspect that is often under-appreciated is the extent to which multi-year patterns characterize the climate record (Fig. 2). For agriculture, as for so many other sectors, multi-year droughts present a more difficult challenge than shorter term droughts, as soil and water reserves as well as financial resources are depleted. Similarly, multi-year wet periods may offer opportunities to intensify production, but also may pose increased challenges due to water-logged soils and flooding.

Similar multi-year patterns are seen with temperature as with precipitation. To some extent, there is correspondence between wet and cool periods, and dry and hot periods, though the patterns, but additional factors influence these patterns. Heat waves can cause severe costs and yield reduction to livestock and crop production, over and above the losses often associated with drought.

Extended growing season associated with warming mean climate may present an opportunity to diversify cropping. Crops across the diverse landscape of the region will be impacted differently by climate change. Production in some areas will increase, due to more rainfall and longer growing seasons, but drought and higher temperatures will cause production to decrease in other areas. Additionally, shifts in precipitation and temperature will influence pests and weeds (USGCRP, 2009).

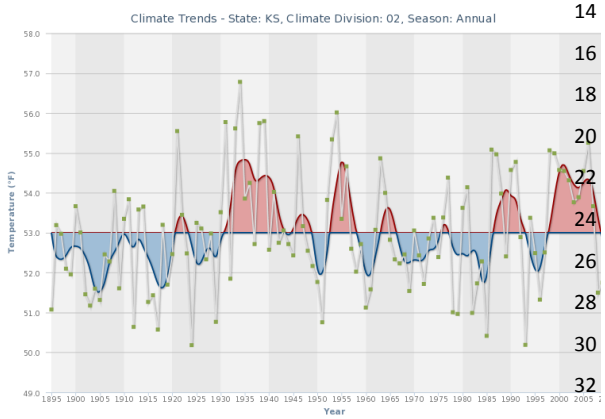

Fig. 2 Long-term temperature (1989-2011) for North Central Kansas, showing annual average temperature (thin line) and five-year running average temperature (heavy line highlighted by blue, cooler periods and red, warmer periods. Prepared using Southern Climate Impacts Planning Program data tools.

1) Critical temperature ranges for life cycle development differ for crop species. As stated in Section 3, mean air temperatures are predicted to increase across the Great Plains, with variable changes in precipitation. Table XX illustrates the percent grain yield and evapotranspiration response to increased temperature and increased CO2. [Extract Plains and relevant crops into new table]. (Karl, Melillo & Peterson, 2009)

Table XX – Percent grain yield and evapotranspiration responses to increased temperature (1.2°C), increased CO_2 (380 to 440 ppm), and the net effects of temperature plus increased CO_2 assuming activity. Current mean air temperature during reproductive growth is shown in parenthesis for each crop/region to give starting references, although yield of all the cereal crops declines with a temperature slope that originates below current mean air temperatures during grain filling (Extracted from USCCSP, 2009).

Table 1.

	Grain Yield			Evapotranspiration	
Crop	**Temp (1.2°C)**	**CO_2 (380-440 ppm)**	**Temp/CO2 Combined Irrigated**	**Temp (1.2°C)**	**CO_2 (380-440 ppm)**
% change					
Corn[1]	-4.0	+1.0	-3.0	+1.8	--
Soybean[1]	+2.5	+7.4	+9.9	+1.8	-2.1
Wheat	-6.7	+6.8	+0.1	+1.8	-1.4
Sorghum	-9.4	+1.0	-8.4	+1.8	-3.9
Cotton[2]	-5.7	+9.2	+3.5	+1.8	-1.4

2) [1] Yield and evapotranspiration estimates for the Midwest. [2] Yield and evapotranspiration estimates for the South.

In a meta-analysis of the literature, Kimball (1983) reported that in laboratory and free-air CO_2 enrichment (FACE) studies crop yield is increased by CO_2 fertilization, but may not be adequate to offset negative effects associated with high temperature and decreased water availability. Increased temperatures and decreased rainfall generally negatively affect crops. The degree of harm varies by crop and the point in its life cycle, but temperature increases have the greatest impact when occurring during or just prior to critical pollination phases. A crop's sensitivity and ability to compensate during later, improved conditions, depends on the synchrony of anthesis in each crop (Karl, Melillo & Peterson, 2009).

++++++++++++++++++PHACE BOX MORGAN+++++++++++++++++++++++++++++++++++++

Prairie **H**eating **a**nd **C**O_2 **E**nrichment (PHACE) Experiment. As climate change increasingly takes us into new environmental space, our knowledge and experience from research conducted in present-day and past environments are of limited use for predicting the future. For instance, with ambient CO_2 concentrations now higher than they have been for more than several hundred thousand years, and concentrations predicted to continue increasing, information is needed to understand not only how plants and agro-ecosystems will respond to a warmer atmosphere, but also how rising CO_2 concentrations will affect plants. The PHACE Experiment is one such endeavor to evaluate agro-ecosystem responses to future environments, employing technology to increase ambient CO_2 to 600 ppm and day/night temperatures by 1.5/3 °C to observe how plants and soils of the northern mixed grass prairie respond to conditions expected in the second half of this century.

Early results from this experiment suggest that the desiccating effects from warming may be offset by considerable improvements in plant water use efficiency which occurs as CO_2 concentrations increase (Morgan et al. 2011). As a result, average productivity of many native grasslands of the Central and Northern Great Plains may be sustained or even enhanced slightly in the next few decades. However, the possible water saving benefits are not expected to overcome the severe droughts predicted for regions in more southern latitudes where both warmer temperatures and declining precipitation are predicted to result in more severe and protracted droughts (Seager and Vecchi, 2010). Thus, the southern Great Plains may experience increased frequency and severity of droughts, curtailing productivity. Further, such CO_2-induced increases in water use efficiency may eventually be overwhelmed by some of the substantive warming predicted for the end of this century. The PHACE experiment also suggests that rising CO_2 concentrations will not necessarily enhance the ability of such native, semi-arid grasslands to sequester more C, in part because the resistant soil C may become susceptible to decomposition under future conditions (Carrillo et al. 2011). These and other results from manipulative type experiments provide important insights of how rangelands will respond to the

novel environments we are facing.

Photo caption: Photo by Sam Cox shows one of 30 experimental plots of the Prairie Heating and CO_2 Enrichment (PHACE) experiment. This is a collaborative experiment by the USDA-Agricultural Research Service, the University of Wyoming and Colorado State University.

++++++++++++++++++++++END of BOX +++++++++++++++++++++++++++++++++++

The northern and eastern regions of the Great Plains are projected to have an increase in high-precipitation events (Reference to SECTION 3). An economic consequence of excessive precipitation is water-logged soils and delayed spring planting, which particularly jeopardizes crops that require long growing seasons. Increased rainfall over concentrated time periods may amplify the likelihood of water shortages at other times due to changes in frequency of rainfalls. (Karl, Melillo & Peterson, 2009). Field flooding associated with intense rainfall events can cause crop losses or reduction in yields associated with increased susceptibility to root diseases, anoxia, soil compaction, and could cause more leaching of nutrients and agricultural chemicals into groundwater and surface water (Karl, Melillo & Peterson, 2009). Heavy winds, which often accompany storms with heavy rain, also have potential to uproot crops and can have a reduction in yield.

Increased temperatures are anticipated to result in shifting of the cropping patterns across the Great Plains. Beach et al. (2010) evaluated implications of climate change scenarios on the potential range, acreage, and yield of US crops and found that substantial changes in the distributions and yields can be anticipated for rainfed small grains, hay, corn, cotton, sorghum, and soybean in the Great Plains states. In particular, for a range of GCM scenarios, the projection was for decreased barley and increased oats and rye in the northern Great Plains; a shift of corn toward the south, decreased soybean in northern portions of the region, expansion of cotton to the north and east, a decrease of wheat in the southern Great Plains, and an increase across the region of hay.

Global climate models do not produce reliable information about extreme events and impacts of extreme events on crop yields are difficult to simulate. However, the losses to extreme events are catastrophic so that the projections of intensification of the climate cycles with increase frequency of extreme events is of concern (See SECTION 3). Rosenweig et al. (2000) estimated that US crop losses from the 1988 drought totaled $56 billion and from the 1993 floods along the Mississippi River were $23 billion. The 2011 drought resulted in over $5.2 billion is agricultural losses in Texas alone (http://agrilife.org), and resulted in massive residential, wildlife, tourism, and agricultural losses to wildfires.

Some weeds have more positive responses to CO_2 fertilization than most cash crops, particularly C_3 weeds (Ziska and George 2004; Ziska 2003) competing in major C_4 crops (C_3, C_4 BOX) such as corn and sorghum. The C_4 weed species show smaller response to atmospheric CO_2 relative to C3 crops, but most crops must compete with both C_3 and C_4 weeds and as weed pressures shift the industry may not have registered pesticides for new crop-weed combinations. Additionally, the most competitive weeds for a particular crop are those with similar growth habits and photosynthetic pathways and weed / crop competition studies show weed growth is favored as CO_2 increases over crops of similar photosynthesis (Ziska and Runion, 2006). Recent research also suggests that glyphosate herbicide (most commonly used herbicide in the U.S.) becomes less effective as CO_2 levels increase.

Change in CO_2 and climate also impacts beneficial and harmful insects, microbes and other organisms in agroecosystems. Studies show temperature to be the single most important factor affecting insect ecology, epidemiology, and distribution (Coakley et al. 1999). Populations of insect species that are currently marginally over-wintering in high latitude and high altitude regions will increase with warmer winters. Organisms that do not tolerate freezing temperature will move northward. These shifts will lead to an increase in pesticide use, which has ecological effects for other insects and microbes in the area (Karl, Melillo & Peterson, 2009). An overall increase in humidity and

frequency of heavy rainfall events projected for many parts of the United States will tend to favor some leaf and root pathogens (Coakley et al. 1999). However, an increase in short- to medium-term drought will tend to decrease the duration of leaf wetness and reduce some forms of pathogen attack on leaves (Karl, Melillo & Peterson, 2009). Increased atmospheric concentrations of CO_2 cause higher carbon-to-nitrogen ratios of leaves in plants, which can increase insect feeding to meet higher nitrogen requirements (Coviella and Trumble 1999). However, a diet of high CO_2 plants can slow insect development and lengthen insect life stages where they are more vulnerable to attack by parasitoids (Coviella and Trumble 1999).

2.1.2 Opportunities and challenges and changing farm trends as a result [Insert sections on Precision nutrient management, herbicide resistant crops, water availability, irrigation use]

Given the great importance of food production derived from the Great Plains region, research, extension, and policy efforts have been undertaken at federal, state, and private sector levels to improve production levels, efficiencies, and environmental protection. Many of these modifications have been taken in response to regulatory demands related to conservation practices and good stewardship standards. The improved technologies also contributed to reduced diversity in agricultural systems (Sylvester and Cunfer, 2009) However, a number of practices also have been developed to improve the efficiency of the agricultural practices related to water use, soil tillage, and nitrogen usage. In addition, market changes related to energy and commodity prices have also influenced the crop production systems, as evidenced by the expansion of corn production to accommodate corn-ethanol productions.

Water conservation

Great Plains agriculture is extremely vulnerable to groundwater depletion associated with over allocation of water from an aquifer with extremely limited recharge. In the southern portions of the Great Plains, the Ogallala Aquifer has already depleted by 274 million acre feet since predevelopment (before 1950) (McGuire 2011). With all sectors reliant on the groundwater resource, and with agriculture being by far the greatest user of water, improved irrigation efficiency to reduce groundwater extraction or adapted to lower levels of groundwater production has been a long term focus of research and technology development. SECTION 4 describes improved efficiencies associated with new irrigation technologies, new approaches to irrigation control and scheduling, and introduction of economically viable crops and crop varieties with lower water requirements. In addition, as land is taken out of

production because of failure of wells or sale of water rights to non-agricultural users, then effective conversion of irrigated land to rainfed cropping or perennial vegetation is essential to protect the soils from erosive forces of wind and water and to provide on-going economic benefit to the landowner.

More water-efficient dryland production is needed to minimize the economic disruption caused by groundwater depletion and decrease in irrigated agriculture in the Great Plains. While no-tillage systems provide enhances water conservation and allow diversification and intensification of rainfed agriculture, compared to the very low productivity wheat-fallow systems, no-tillage adoption has been highest in crop species that have herbicide-tolerant crops which do not involve residual herbicides in soil that limit crop sequencing. To date, the industry has not been able to ensure good integrated pest management practices with pesticide and herbicide-tolerant crops with many pest species now exhibiting tolerance to the chemicals that are applied for control. This remains a challenge that limits the resilience of future crop production systems when the need for reduced tillage for water conservation will be increased.

Precision nutrient management

To control nutrient variability between and with fields and prevent over-fertilization, the practice 'precision nutrient management' is being utilized. A complete nutrient map of the field site is taken by collecting aerial imagery or site map(s) and a soil survey map of the site; results of soil, water, manure, and/or organic by-product sample analysis; results of plant tissue analyses, when used for nutrient management; a complete nutrient budget design for nitrogen (N), phosphorus (P), and potassium (K) for the crop rotation or sequence; adaptive nutrient management application rates, timing, form and method of application and incorporation, and guidance for implementation, operation, maintenance, and recordkeeping (USDA, 2010).

While using precision nutrient management increases yields, it is also more costly than traditional, whole-farm alternatives. A comparison of site-specific management zones of continuous corn cropping systems in Northeastern Colorado to conventional uniform application, Koch et al. (2003) determined it to be more economically feasible due to a decrease of total fertilizer inputs but an increase in yield. This shifts land management from whole farm to an acre-by-acre basis.

Herbacide resistant crops

Glyphosate-resistant (GR) crop varieties of soybeans, cotton and maize were introduced in the mid-1990s, resulting in extraordinary change in agriculture. Weed control tactics were simplified by

allowing producers to apply a single herbicide (glyphosate) over an entire farm without concern of harming the crop (Carpenter & Gianessi, 1999), which has transformed the way farming is conducted. Adoption of GR cultivars has increased rapidly with an estimated 89 percent of soybeans planted in 2006, 79 percent of cotton in 2005, and 36 percent of maize in 2006 (Owen, 2007).

The new technology comes with ecological and economic implications on agroecosystems. A reduction of biodiversity of arable land, weed population shifts in weed communities and evolution of GR weeds are all concerns that require further research (Owen, 2007). Additionally, GR seeds are expensive and cannot be collected and replanted, which significantly increases production costs.

2.1.3 Changing socio-economic factors influencing agriculture

Through decades, US agricultural producers have faced shrinking profit margins and received a reduced portion of agricultural profits at the farm-gate. These trends have been related to a wide range of economic, energy, and agricultural policies that have led to globalized markets, aggressive competition in international trade, and rapidly evolving high-capital agricultural technologies. Other economic policies have led to a higher portion of production to come from larger farms with a decline in mid-sized farms. While the larger farms may have capacity to adopt more efficient production practices and systems, small farms continue to be important, making up 88% of U.S. farms in 2007, holding 63% of agricultural land, and marketing 16% of farm product. Small farms accounted for 76% of land enrolled in USDA land-retirement programs, indicating their significant role in natural resource and environmental outcomes of agriculture within landscapes (Hoppe and Banker, 2010). Urban agriculture provides potential for higher income from small, fragmented landscapes in rural-urban fringe and helps maintain an abundance of environmental services including hydrologic function which may have increasing importance in an era of urban heat islands and climate change.

Increased farm size, reduced farm number, and reduced population have greatly reduced the capacity of many Great Plains rural communities to support agricultural, economic, and social infrastructure. However, most Great Plains residents reside in urban areas or in metropolitan-influenced counties (Parton et al,2007). Emerging local foods marketing opportunities provide potential or young farmers and more diverse farmers to get a start in agriculture. The U.S. local food market was $4.8 billion in 2008 and small farmers were utilized local markets at a higher rate than larger farms (Low and Vogel, 2011). Small and midsized farms with local food sales were more likely to list farming as the principal operator's primary occupation than small farms that did not utilize local sales. While the

potential for small farms and local food markets is obvious for the more urban portions of the Great Plains, many of the US most food-insecure counties are in the rural Great Plains, resulting from large distances to grocery stores and households without access to cars, due to health or poverty (Ver Ploeg et al., 2009). The need is great for farmers markets, community supported agriculture, community gardens and other local food enterprises in the rural Great Plains.

Great Plains agriculture has been dramatically shaped by increasing energy costs, including the influence of energy prices on fertilizer, equipment, and on-farm fuel use. Intensive production systems that were developed in an era of relatively inexpensive energy, such as irrigated agriculture and large confined animal feeding operations, face many challenges to maintaining profitability under the new economic conditions. New bioenergy markets provide great opportunity for agriculture, but also present societal challenges associated with the potential for competition between food, energy, soil and water conservation, and greenhouse gas mitigation needs. Adler et al. (2007) evaluated several bioenergy crops proposed for expansion and found that switchgrass (one of the species most often proposed for Great Plains cellulosic energy production) would reduce GHG emissions by about 115% compared with the life cycle of gasoline and diesel, ethanol and biodiesel from corn rotations.

Due in large part to government mandates, over the past 12 years production of ethanol from feed grains has increased exponentially from approximately 54 plants producing 1.7 billion gallons of ethanol to over 200 plants producing 13.5 billion gallons of ethanol. In the Great Plains states there are approximately 63 bioethanol plants with capacity to produce about 4.2 billion gallons of ethanol annually – they use approximately 1.5 billion bushels of feed grains annually (Table 2). The "border states" have an additional 73 bioethanol plant that can use 1.8 billion bushels of corn and have the capacity to produce 5.1 billion gallons of ethanol annually. In the U.S. there are about 200 ethanol plants using about 4.6 billion bushels of grain annually; or about 30% of the U.S. corn crop. In comparison, about 5.5 billion bushels are used directly as livestock feed. However, recent policy changes which eliminated some of the subsidies related to corn ethanol production may alter the usage of corn products in the production of ethanol in the region.

Table 2. Bioethanol plants in the Great Plains and border states (RFA, 2011)

State	No. of plants	Total capacity (million gallons of ethanol)	Bushels of feed grains used, million
Great Plains States			

Texas	4	355	125,442
Oklahoma	0	0	0
Kansas	12	520	183,922
Nebraska	26	1,693	598,233
South Dakota	15	1,066	376,678
North Dakota	6	594	209,893
Border States			
New Mexico	1	54	10,081
Arkansas	0	0	0
Colorado	4	125	44,169
Missouri	5	251	88,692
Wyoming	2	12	4,063
Iowa	39	3,370	1,190,813
Montana	0	0	0
Minnesota	22	1,331	470,353

Distiller's grains are a byproduct of the grain ethanol industry. Each bushel of corn (56 lb) produces about 18.7 lb of ethanol (2.83 gallons), 18.7 lbs of CO2 and 18.7 lbs of dried distiller's grains. Corn gluten feed is a byproduct of the corn starch/sweetner industry. Over 32 million metric tons of distiller's grains and 5 million metric tons of corn gluten feed were produced in 2010. The beef cattle industry consumes approximately 41% and the dairy industry consumes approximately 39% of all U.S. distillers grain produced (RFA, 2011). Approximately 61% was fed in the dry form and 39% in the wet form. Feeding these byproducts to cattle in the wet form has several advantages over feeding the dry product: most notably it saves the high cost of drying a 70% moisture product to a 10% moisture product for transporting and to avoid spoilage.

Today at least 30% of all U.S. corn production is used in the bioethanol and corn sweetener industries. Government ethanol policies and other factors will determine if this trend continues. The primary use of these byproducts will probably continue to be as livestock feed. However, changes in production procedures (for example removing the fat from distiller's grain for use as biodiesel) may alter the feeding quality and demand for these byproducts.

With increased grain and energy costs, there is a need to reduce duration and/or reliance on feedlot-finishing of US beef. This will require changes in the livestock and forage genomics and improved management practices to provide efficient beef cattle finishing with increased reliance on forages. Many consumers are attracted to forage-finished beef because of fatty-acid profiles that may have human health benefits in grass-finished, compared to grain-finished beef.

Various efforts have been developed to better evaluate the impact of agricultural practices on greenhouse gas emissions and life cycle assessments have been applied to various cattle production systems to evaluate the range-fed and feedlot beef production. Methane production from cattle is a major concern. A recent life cycle assessment of beef production in Australia (Peter et al., 2010) reported that dry lot feeding of beef cattle generated fewer greenhouse gases than grass-based systems because the additional effort of producing and transporting concentrate feeds was offset by the increased efficiency of meat production in feedlots. Similar results were found by Capper and Caddy (2010, Capper (2011), and Pelletier et al (2010). Their results indicated that overall GHG reduction and greater production efficiency was due to differences in the performance of animals on grass relative to animals in feedlots and to differences in enteric methane production of grass-fed animals compared to concentrate-fed cattle (Table 3), Peters et al (2010) review estimated the C footprint of beef production based on 16 studies in .t least nine countries. U.S. feedlot production was near the low end of the measures at 10 kg of CO2e / kg of hot carcass weight.

Table 3. Comparison of resource inputs and waste outputs generated by finishing beef steers in corn-fed or grass-fed systems (Capper and Cady, 2010)

Item	Corn-fed	Grass-fed
Starting weight, kg	254	254
Ending weight, kg	635	522
Dressing percent	64.0	57.5
Carcass weight , kg	406	300
Daily weight gain, kg	1.96	0.76
Days to finish	187	337
Methane emissions, g/d	310	370
Methane, kg/carcass	57	125
Methane, g/kg of carcass	140	417

Total water, liters/head	161,159	928,811
Total land, ha/head	0.31	0.94

Capper (2010) compared the environmental impact of U.S. beef production (cow calf to slaughter) from 1977 to 2007 using the Deterministic Environmental Impact Model and a modified life cycle assessment approach. During the 30-year period, total beef production increased from 10.6 to 11.9 billion kg but with 5 million fewer cattle (33.7 vs. 38.7 million head). Total feedstuff inputs decreased by 20%, total land area required to support beef production was reduce 30%, water use per kg of beef produced was decreased by 14%, and fossil fuel use per unit of beef produced was decreased 9% over the 30-year period. Methane and nitrous oxide emissions per kg of beef produced were reduced 21 and 13%, respectively over the same timeframe. The total carbon footprint (as CO2e) per kg of beef produced was reduced 18%. These effects were produced primarily by increases in average slaughter weight and growth rate, and by improvements in nutrition, and management.

Pellitier et al (2010) reported that a beef production system that included feedlot finishing had a lower C footprint than a grass-only system; however even the most optimal system had a lower efficiency than swine or poultry system (Table 4). The total energy and protein efficiencies of beef production (total energy or protein input per unit of food energy or protein produced) tend to be less than other livestock systems (Table 4; Gill et al., 2009). This low overall production efficiency is largely due to the low reproduction rate of beef cattle compared to the high fecundity of swine and poultry (Pellitier et al., 2010). In general, less than 80% of U.S. beef cows wean a calf each year. In addition, 30% or more of the heifers produced must be retained as replacements that will not reproduce until at least 2 years of age. Thus, for each beef animal finished in feedlots each year there are approximately 1.66 cows. In contrast, sows can produce 20 or more offspring each year and hens can produce hundreds of offspring that can reproduce within a few months. Thus increasing the number of weaned calves will greatly decrease the carbon footprint of the cow herd. However, because of the extensive use of forages and by products in the beef production systems, when energy or protein production efficiency is based on human edible energy and protein inputs vs. human edible energy and protein outputs, beef production has efficiencies similar to or greater than swine or poultry production systems.

Table 4. Comparative efficiencies of different livestock production systems in the US (Gill et al., 2009)

Product	**Energy**	**Protein**

	Total efficiency	Human-edible efficiency	Total efficiency	Human-edible efficiency
Milk	0.25	1.07	0.21	2.08
Beef	0.07	0.65	0.08	1.19
Swine	0.21	0.31	0.19	0.29
Poultry meat	0.19	0.28	0.31	0.62

Total efficiency calculated as outputs of human edible energy and protein divided by total energy and protein inputs. Human edible efficiency calculated as outputs of human edible energy and protein divided by human edible inputs.

2.2 WATER AND LAND MANAGEMENT

Water in the Great Plains is a critical natural resource that determines the social-ecological dynamics of critical processes related to conservation, agriculture, energy, and urban development, among others. Climate regimes across the Great Plains vary tremendously and affect in seasonal distribution of water inputs and availability. Changes in the precipitation patterns, such as the variability and intensity of rain or snowfall, seasonality of precipitation, and alterations of large scale circulation patterns associated with sea surface temperatures, have major impacts on water resources in the region. This is complicated by a legal allocation system that determines when, where, and how much water can be diverted and used, which has evolved under past precipitation and climate conditions. In addition, the river systems dissecting the Great Plains, such as the Red River of the North, Missouri, Platte, Arkansas, and Rio Grande Basins, emerge from the Rocky Mountains and the hydrologic flow is connected to the snow deposition in this region. Water usage across the Great Plains is dominated by agriculture demands, though increased concentrations of urban development across the region has affected water rights and usage, and changes in water ownership during the past few decades have seen increased transfer of water rights to various municipalities. This has resulted in conflict and legal battles between states and between various uses and users.

Local water development has been augmented greatly over the decades through development of diversions and reservoirs and the drilling of wells into aquifers. These water infrastructure developments have altered hydrological flows in numerous ways including stream and river flows, wetland extent and hydrological dynamics, and sedimentation rates affecting river and stream morphology and reservoir depths. Climate scientists predict that water cycles will be altered so that the range of expected precipitation patterns no longer provide a guide for the future (i.e., the concept of "nonstationarity") (Milly et al. 2008). This will require new ways to manage and govern water resources in the context of all the multiple climatic and non-climatic stressors involved (Huntjens et al. 2012, van de Meene, Brown and Farrelly 2011, Farrelly and Brown 2011, Birkmann et al. 2010, Steyaert and Jiggins 2007, Ison, Roling and Watson 2007, Norgaard, Kallis and Kiparsky 2009, Pahl-Wostl et al. 2007, Lebel, Grothmann and Siebenhuner 2010).

Water use and management

Multiple and diverse users compete for water in the Great Plains region, however, agriculture is by far this biggest user of water accounting for 65% of combined fresh water withdrawals (Kenny et al. 2009). Other uses include urban and rural domestic and municipal entities, energy extraction and power production, industry, recreation, and wetlands and riparian ecosystems as well as esthetic and spiritual uses. Thermoelectric power and public supply accounting for 21% and 10% of Great Plains water withdrawals, respectively; in two states North Dakota and Texas, thermoelectric power accounts for the majority of withdrawals, 79% and 41%, respectively (Kenny et al. 2009). In Oklahoma, it is public water supply (42%) that is the largest user (Kenny et al. 2009). Maintaining ecosystems services that water provides and the well-being of all life that depends on clean and available water requires careful management and policies to sustain adequate water quality and quantity in a variable and changing climate (Rosenzweig et al. 2004).

When considering fresh surface and groundwater sources separately, surface water supplies 68% of Great Plains water needs and groundwater provides 32% (Table Xb). In particular, for irrigated agriculture, surface water provides for 57% and groundwater for 43% of total withdrawals. However, at a state level, the distribution in some cases is more skewed. In Colorado, Montana, and Wyoming, surface water provides for over 80% of irrigation needs. In Kansas, Nebraska, and Texas, it is groundwater that provides for over 75% of irrigation needs.

Table 5. 2005 fresh water withdrawals by water-use category in thousand acre-feet per year separated by surface and groundwater sources

State	Public Supply		Domestic		Irrigation		Livestock		Aquaculture		Industrial		Mining		Thermoelectric		Total	
	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW
Colorado	855	114	0	39	11,200	2,600	12	25	80	19	156	4	1	6	131	7	12,400	2,810
Kansas	272	180	0	17	128	2,940	27	95	4	2	7	40	5	11	499	15	942	3,300
Montana	84	75	1	25	10,700	157	31	13	44	3	33	42	38	1	100	0	11,000	317
Nebraska	106	264	0	58	1,290	8,190	23	99	83	10	0	13	11	0	3,970	9	5,480	8,650
North Dakota	39	36	0	10	82	87	10	15	7	0	11	6	0	6	1,190	0	1,340	160
Oklahoma	597	127	0	28	150	405	120	61	21	0	18	9	2	1	183	1	1,090	634
South Dakota	39	74	0	9	160	167	32	22	16	21	0	5	7	5	4	1	258	303
Texas	3,440	1,350	0	288	1,890	6,860	108	182	10	6	1,190	210	72	30	10,800	63	17,500	8,990
Wyoming	52	56	0	7	4,000	474	11	7	24	3	2	5	15	43	248	1	4,350	595
GP Totals	5,484	2,276	1	481	29,600	21,880	374	518	289	64	1,417	333	152	104	17,125	98	54,360	25,759

Table 5 Total Water Withdrawals in Great Plains Region by State 2005: Total water withdrawals by water-use category 2005, in thousand acre-feet per year (values may not sum to totals because of independent rounding)Source: (Kenny et al. 2009)

a. Drought

Drought is a familiar part of the history and climate variability of the region. Over the last decade many drought emergencies have been declared resulting in water restrictions in cities and counties. The early 2000's drought was a severe to exceptional drought throughout much of the region, and 2002 was the worst drought year on record since 1895 for much of the western Great Plains and the United States (Tronstad and Fuez 2002, Pielke Sr. et al. 2005). During the drought of 2002 a good portion of the central and northern Plains suffered significant agricultural losses – Colorado, Kansas, Montana, Nebraska and South Dakota combined reported an approximate $7.5 billion loss (Knutson 2008a). The drought of the early 2000s showed that ranchers among others throughout the region were dealing with multiple stresses (Nagler et al. 2007) and were largely unprepared for the impacts of prolonged drought (Miller 2005). Drought adaptation strategies will be discussed in Section 5.

The longest recorded drought occurred in the 1950s, and the most disastrous was the during the 1930s "Dust Bowl" (CROSS-REF w/ section 3). However, most recently, in 2011 the most severe drought in the observational record occurred in the Southern Plains. Texas was the hardest hit state overall with record heat, drought, and fires wreaking havoc on the region and the economy approaching around $10 billion in losses to crops, livestock and timber alone (NOAA 2011a). In July and August of 2011 most of the state was in "extreme" to "exceptional" drought (Figure 3). Using tree ring records to put this drought into long-term historical perspective (back to 1550), 2011 was only matched in extremity by the year 1789 (NOAA 2011b). However, several prolonged droughts occurred that were similar to the

drought of the 1950s, so while prolonged droughts are less rare, 2011 is a relatively rare event (NOAA 2011b) (see Fig 3 below).

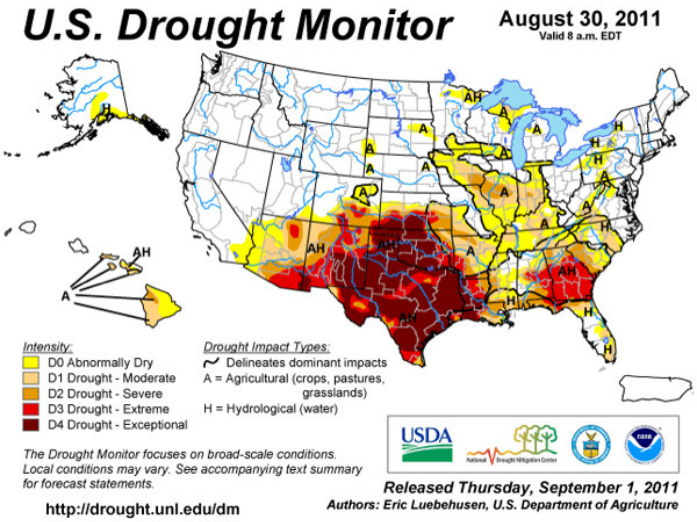

Figure 3. The 2011 Drought extreme level experienced in the Southern Great Plains indicated a severe and exceptional condition. Some relief in 2012 has occurred due to rainfall into the region.

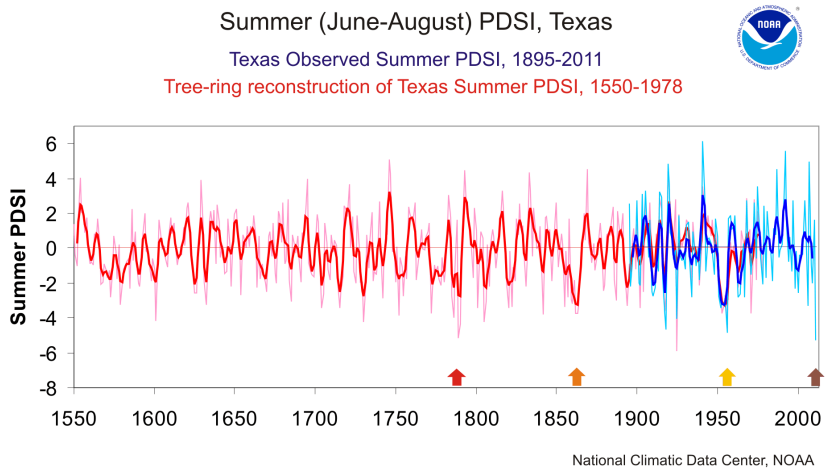

Fig.4. *29-year tree-ring reconstruction (1550-1978) of Texas summer (June-August) PDSI. Annual values are in light red, with a 5-year weighted average in dark red. This time-series was composited from the 13 gridpoint reconstructions within the state of Texas from the gridded network of reconstructions developed by Cook et al. (1999, 2004) covering most of North America. The composite Texas reconstruction is based on tree-ring data from over 100 sites in Texas and surrounding states. The correlation between the reconstructed statewide PDSI and the statewide instrumental PDSI record over their common period (1896-1978) is 0.826, indicating a very high degree of shared variance. (compiled by Jeff Lukas, Western Water Assessment).*

While the 2011 drought is consistent with projections for more intense drought events with climate change (IPCC 2012), it still has yet to be confidently determined if it can be attributed to anthropogenic climate change. Experts say that the drought appears to be more strongly associated with natural variability, and specifically La Niña phase of the El Nino-Southern Oscillation (ENSO) conditions in the Pacific Ocean, as well as the Pacific Decadal Oscillation (PDO) and the Atlantic Multi-decadal Oscillation (AMO). However, it is extremely difficult to definitively understand the role of natural variability versus climate change specific to any one event (pers. comm. Klaus Wolter).

It is not just drought that results in less moisture that causes major impacts, but the combination of both lack of water along with changes in land use and land cover from agriculture and development practices that lead to deleterious effects (Cook, Miller and Seager 2009) in addition to various household and policy mechanism that both structure drought vulnerability as well as coping

mechanisms to reduce vulnerability (Kallis 2008). Groundwater depth also plays an important role in the regional effects of drought as precipitation minus evaporation (P-E) anomalies show a strong dependence on convergent flows and water-table depth (Maxwell and Kollet 2008).

In Nebraska research shows that the most vulnerable areas to agricultural drought were non-irrigated cropland and rangeland on sandy soils, located in areas with a very high probability of seasonal crop moisture deficiency (Wilhelmi and Wilhite 2002). The identification of drought vulnerability is necessary for addressing the issue of drought vulnerability in the state and can lead to preparedness and mitigation-oriented drought management (Wilhite, Svoboda and Hayes 2007, Wilhite and Pulwarty 2005). Research with farmers involved in sustainable agriculture organizations in Nebraska reported implementing a range of practices to reduce their drought vulnerability (e.g., organic soil building techniques, reduced tillage, targeted crop selection, and diversification of crop and livestock production systems) (Knutson et al. 2011). Those same farmers reported a number of barriers to adapting to drought risk such as a lack of capital and market variability and responses (Knutson et al. 2011). Incorporating these non-climatic variables into science and policy response to potential increased drought from climate change will be vital to farmers' viability in the Great Plains region and throughout the United States (See Section 5).

b. Flooding

The Northern Great Plains are projected to increase in precipitation from climate change, leading to more flooding events in some areas (Reclamation 2011). Heavy precipitation could increase as high as 30% in South Dakota, which has already seen considerable flood damage in the past decade with 9 flood disaster declarations since(FEMA 2012). One study used a SWAT model (Soil and Water Assessment Tool) to assess historical and projected hydrological changes in the Upper Mississippi River Basin (UMRB) with increased atmospheric CO2 and found that approximately 1–4% of the streamflow in the UMRB during 1986 through 2008 could be attributed to the elevated CO 2 concentration (Wu, Liu and Abdul-Aziz 2012). The same study also projects (to 2071-2100) increased spring water yield and soil moisture and a substantial decreased summer water yield and soil moisture, which could lead to both increased flooding and droughts (Wu et al. 2012). However, it is important to note that even without climate change scenarios more persistent flooding and drought periods were common in the Great Plains before the 1800s AD as determined by studies of paleo records from tree ring and lake sediment data (Shapley et al. 2005). Decadal climate variability in the Missouri River Basin is also known to have

strong teleconnections to oscillation patterns that affect water yield in some locations (Mehta, Rosenberg and Mendoza 2011). In other words, it will be important to understand both climate variability and climate change for the development of early warning systems for variable streamflows and both floods and droughts as well as planning efforts for water projects into the future (Knutson 2008b).

Groundwater issues as these related to climate variability

Water level changes in the High Plains (Oglalla) Aquifer from the time prior to extensive ground water irrigation (before about 1950) to 2009 ranged between a rise of 41 feet and a decline of 178 feet with an average water-level decline of 14 feet since predevelopment -(McGuire 2011). Total storage of the Oglalla Aquifer has declined by 274 million acre feet since predevelopment (McGuire 2011). Observed water-level declines since the 1950s, indicate a range from 9.8 feet to 164 feet depending on the relative magnitudes of discharge and recharge in the aquifer (McMahon et al. 2007). Groundwater withdrawals from the High Plains Aquifer in 2000 accounted for 20% of the total U.S. groundwater withdrawn, 97% of which is used for irrigation (Maupin and Barber 2005). Ground water extraction for drinking water support about 82% of the people in the High Plains aquifer region (Gurdak, McMahon and Bruce 2011). Groundwater from the vast Ogallala Aquifer, one of the largest aquifers in the world, in the Central Plains is predicted to continue to decline as long as irrigation remains viable considering escalating energy costs and farm production costs (seed, fertilizer, equipment, etc.) (Howell 2009). Water right transfers from agriculture to urban and industrial requirements will further exacerbate this inevitable resource strain. Weather directly affects the water requirements of crops and thus their irrigation requirement (Howell 2009). An indirect effect of climate change is increased groundwater pumping, which could affect hydraulic heads in many aquifers, allowing upward leakage of groundwater with poorer-water quality, such as in the High Plains aquifer (McMahon et al. 2007). The combined effects of groundwater development and climate change may lead to less dilution of contaminants in streams during low flow than was assumed in setting stream discharge permits (Alley 2001, (Green et al. 2011) .

Groundwater depth determines the relative susceptibility of regions to changes in precipitation and temperature, and groundwater storage acts as a moderator of watershed response and climate feedbacks (Maxwell and Kollet 2008). There is a “critical zone” of groundwater depth – between 2 to 5 meters deep – where there is a very strong correlation between water-table depth and land-surface energy response (Maxwell and Kollet 2008). Playa lakes are unique hydrological formations to the High

Plains area and an essential mechanism for the recharging of the Ogallala Aquifer, which means they play an important role in ground water management and sustainability of the aquifer (Gurdak and Roe 2010). There are approximately 61,000 playas in the region with the highest concentration in the southern region in Texas and part of the central and northern High Plains aquifer region in Kansas and Nebraska (see Figure 5) (Gurdak and Roe 2009, Gurdak and Roe 2010). New techniques to monitor surface and sub-surface groundwater levels using the GRACE (Gravity Recovery and Climate Experiment) satellite that uses gravity to measure groundwater, soil moisture, surface water, snow and ice, and biomass will become increasingly important for understanding how to manage for irrigation and sustainable agroecosystems and the relative influences of climate change versus agricultural practices (Strassberg, Scanlon and Chambers 2009, Scanlon, Reedy and Gates 2010).

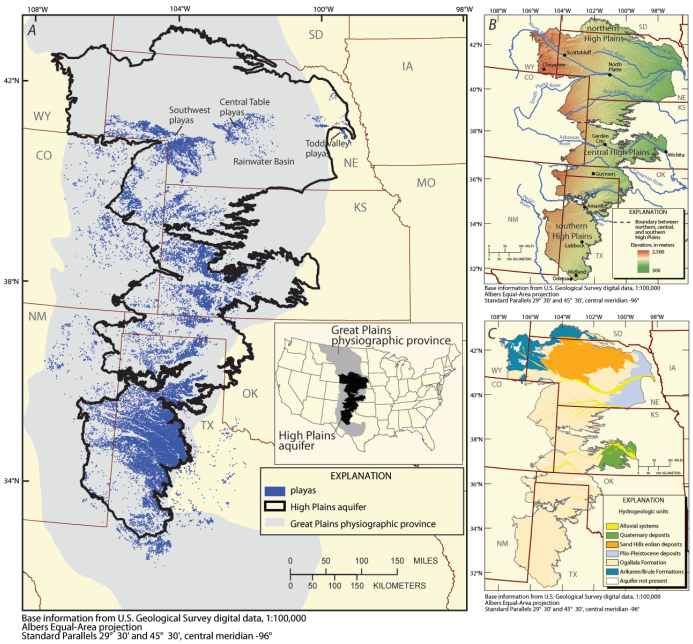

Fig. 5 Modified from Gurdak and Roe (2010) and playa coverage from McLachlan (2008) and B and C McMahon et al., 2007 http://pubs.usgs.gov/pp/1749/

Water quality of the High Plains Aquifers will be impacted by decreased precipitation or drought due to increased groundwater pumping from high-capacity wells, thereby increasing upward flow of

saline groundwater from underlying geologic units and further reducing groundwater quality (Gurdak et al. 2011). Also, under certain precipitation or irrigation situations on sandy or coarse textured soils may result in agricultural chemical products to move downward in the soil profile and affecting ground water quality (Gurdak et al. 2011). Climate forcings and teleconnections on decadal timescales such as those associate with the Pacific Decadal Oscillation (PDO), Atlantic Multi-decadal Oscillation (AMO), and El Niño-Southern Oscillation (ENSO), have been identified as having substantial control on the recharge and water-table fluctuations on the High Plains Aquifer (Green et al. 2011, Gurdak et al. 2007, McMahon et al. 2007).

Across regions of the High Plains aquifer in Kansas, streamflow declines are historically caused by high rates of groundwater pumping, but also correlate with climate variability since the mid- 1980s (Brikowski 2008). Brikowski (2008) showed that projected climate change for the region will likely continue streamflow declines, resulting in severe consequences for surface-water supply and the strong possibility of unsustainable surface storage of water resources in the region. The result may lead to greater pressure on the groundwater resources of the already- stressed High Plains aquifer (Brikowski 2008).

In southeastern Colorado salinization and degradation of both ground and surface water through excessive irrigation and seepage has occurred, which can lead to diminishing crop yields (Gates, Garcia and Labadie 2006). All of these changes to groundwater and surface water quantity and quality are increasingly critical by removing risk buffers of climate change impacts on water availability.

Evapotranspiration (ET) influences the amount of water ultimately reaching rivers, and, in agricultural areas, it affects the amount of water needed for irrigation. Changes in temperature magnitudes, precipitation amounts, CO2 concentrations, and precipitation timing associated with climate change will all influence ET, sometimes in conflicting ways. Precipitation and temperature changes could act in combination either to enhance plant growth, which could increase total amounts of ET occurring, or they could act to decrease plant growth, for instance if a species' optimal temperature range was exceeded, which could decrease plant growth and ET (Thomson et al, 2005; Brekee et al., 2010). Increased CO2 concentrations also affect plants and ET. Some studies have shown that higher CO2 concentrations may lead to increases in leaf area and plant growth and vigor, which could lead to increase ET and water consumption overall (Brekke et al., BOR, 2010; Baldocchi and Wong, 2006; Wu et al., 2012). On the other hand, under higher CO2 conditions, plants have been observed to partially close the stomatal openings on their leaves, which results in decreased transpiration and water loss (Field et al., 1995; Gedney et al., 2006) possibly because higher concentrations mean that less stomatal opening

is required for plants to absorb the amount of CO2 they need for photosynthesis (Sellers et al., 1996; Wu et al., 2012). One study provides evidence suggesting that the rise in continental runoff observed during the 20th century is consistent with CO2 induced suppression of transpiration (Gedney et al., 2006, Nature Letters). In snowmelt-dominated regions such as the Rocky Mountains that are the headwaters for many of the Great Plains' rivers, snowmelt earlier in the season would result in increased soil moisture at a time when potential evaporation is lower than would normally be the case (Barnett et al, 2005, Nature).

In contrast to evapotranspiration, which includes vegetative water losses, evaporation may also take place directly from water surfaces of streams as well as of reservoirs. Reservoir evaporation in the Great Plains is currently considerable. For instance, annual evaporation from the six largest reservoirs on the Missouri River's main stem has been estimated to be about 5% of the average annual river discharge (Benke and Cushing 2005). In the Rio Grande, evaporation from the major reservoirs has been estimated to exceed municipal water usage in the basin . Such reservoir losses could increase if warmer temperatures dominate other factors.

**********BOX**********

Box: Changes in demand for irrigation water under changed climate

Two main models have been used to estimate long-term climate change on crop water requirements and irrigation requirement. The earlier and simpler ones used were sensitivity analyses of regular ET equations and/or crop simulation models to estimated climate scenarios based on projections of weather scenarios (Rosenberg, 1981) as exhibited by Warrick (1984) used 1930s weather data wh a statistical yield model that showed a 50% wheat yield decline in the Great Plains; Terjung et al. (1984) used a yield model with four climate scenarios for air temperature, solar irradiance, and precipitation to find that ET and total applied irrigation were sensitive to the climatic scenarios and locations used; Liverman et al. (1986) reported lower dryland yields under cloudy, hot, and dry climates; and Rosenzweig (1985) suggested that in the Southern Great Plains spring wheat varieties might be required to replace winter wheat cultivars due to colder winter temperatures with a doubling of CO_2. Most recent efforts have used general circulation models (GCMs) from various global climate research efforts (Rosenzweig, 1990). Many GCM models have been developed (see Hansen et al., 1983; Smith and Tripak, 1989; and Manabe and Wetherald, 1987 for explanations and examples). The Intergovernmental Panel on Climate Change (IPCC; see http://www.ipcc.ch/) that was established in 1988 has attempted to serve as the 'clearing house' and 'repository' to provide reports at regular intervals that can become

standard works of reference to be widely used by policymakers, experts and students. Houghton et al. (2001) is an example. The 4th Climate Change 2007 Synthesis Report was released in 2008

Climate change (changes in temperature and/or precipitation regimes) would likely lead growers to change crops, cultivars, and management practices, including irrigation, to mitigate any adverse effects or to take advantage of more favorable conditions. Peterson and Keller (1990) suggested that higher temperatures and reduced precipitation could increase crop water demand in some areas and prompt the development of irrigation in regions previously devoted to dryland or rainfed cropping. They reported that the percentage of cropland irrigated in the western U.S. increased when global mean temperature (GMT) exceeded 3°C and a decline in production resulted from inadequate water for irrigation. Tung and Douglas (1998) found in a study of crop response to GCM projected climate change with double atmospheric CO_2 concentrations that the higher ET effects outweighed the effects of CO_2 fertilization in some areas of the U.S., and they suggested that irrigation could mitigate effects of climate change.

Accurately predicting global climatic change impacts on the Great Plains remains largely uncertain. Nevertheless, future environments in the Central Great Plains will have elevated CO_2 and GHGs in the atmosphere that will impact the surface energy balance, photosynthesis, water use efficiency, cloudiness, and precipitation, and likely extreme weather phenomena. These all have some degree of uncertainty and probably more variability than past climatic patterns. Most reports indicate few impacts immediately; however, in the out-years (~>2050), potential for significant shifts in weather in the Great Plains maybe expected. Some will be 'positive' (growers need to be prepared to utilize) while others might be more 'adverse' (growers will need to make strategic decisions to minimize impacts). Undoubtedly, some changes in Great Plains agriculture will be necessitated, e.g., crop hybrid changes, crop species adjustments, crop management, and irrigation will continue to be a significant factor, especially in the Central Great Plains, as crop calendars change and water availability decreases.

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Physical infrastructure

In the Great Plains an extensive system of water-related infrastructure has arisen to provide for a more stable water supply in a semi-arid region with widespread agriculture and with precipitation regimes that are dependent on snowmelt in the western plains and variable rainfall in the eastern

plains. Water-related infrastructure also provides for flood control, hydroelectric power, navigation, recreation, stormwater management, and wastewater treatment. Components include dams, reservoirs, pipelines, irrigation canals, wells, pumps, water treatment systems, dikes, levees, floodgates, hydroelectric plants, storm sewers, wastewater treatment systems, and more (WSWC, 2011).

Some of the important water infrastructure components for the major Great Plains river basins are discussed below. This is followed by a discussion of the American Society of Civil Engineers (ASCE) national report card on infrastructure and the current status of dam and drinking water infrastructure in the Great Plains. The section ends with some notes on infrastructure recommendations made by the Western States Water Council, which is comprised of representatives appointed by the governors of 18 Western states including all of the states in the Great Plains region.

In the Missouri River basin, human infrastructure modifications started to increase after 1902 with the passage of the Reclamation Act that established support of irrigation in the western U.S. In 1937, the first of the main-stem dams was constructed at Fort Peck, MT as part of a Works Progress Administration project to provide minimum flows for downstream navigation. (RONA; NRC 2002, recovery) In 1944, U.S. Army Corps of Engineers and Bureau of Reclamation Missouri River basin management plans were merged in an agreement that has become known as the Pick-Sloan Missouri Basin Program (BOR 2011; NRC 2002 – recovery). The stated program goals included providing for flood control, irrigation, navigation, power, water supply, wildlife, and recreation (NRC 2002 – recovery; BOR 2011). Pick-Sloan resulted in the construction of five main stem dams downstream of Fort Peck and over 40 dams on basin tributaries.

Today, owing to a variety of projects, the Missouri River drainage basin contains over 17,200 reservoirs providing a storage capacity of about 141 million acre-feet, 73.4 million acre-feet of which are provided by reservoirs behind six U.S. Army Corps of Engineers-built main-stem dams, making the reservoir system the largest in the country (USACE, revised 2006). Three of the main-stem reservoir lakes (Fort Peck in Montana, Sakakawea in North Dakota, and Oahe in South Dakota) are among the largest human-made lakes in the country behind only Lakes Mead and Powell (NRC, 2002, recovery). The combined surface area of the six USACE main-stem reservoirs at normal pool levels is about 1 million acres and provides fish and wildlife habitat as well as recreational opportunities. However, the large surface area also leads to considerable evaporation losses, which vary from year to year but are estimated to average about two million-acre-feet per year (USACE, 1998).

In addition, to providing water for irrigation, domestic, municipal, and industrial uses, Missouri River water plays a key role in electricity generation for the region. Twenty-five thermal electric power plants along the main-stem use either reservoir or river water for cooling and together have a gross generation capacity of about 15,000 MW (RONA; Army Corps, 2001). Hydropower from six of the main-stem dams (Fort Peck and those further downstream) contributes an additional 2435 MW of capacity (RONA).

In the Arkansas River basin, one of the main human infrastructure modifications is the McClellan-Kerr Arkansas River Navigation System, which is an extensive series of locks and dams on the White, Arkansas, and Verdigris Rivers that ensure that barge traffic can move year-round between the Tulsa, Oklahoma Port of Catoosa and the Mississippi River (USACE website). The 445-mile long system includes a 377-mile stretch of the Arkansas River and a 9-mile, manmade Arkansas Post Canal that connects the White and Arkansas Rivers (USACE website). Resources shipped through the McClellan-Kerr include agricultural products, petroleum, and coal (Enc. Brit). In addition to providing for navigation, the system, dedicated in 1971, provides for flood control and hydroelectric power (Enc Brit).

In the Red River of the South basin, an important reservoir is Lake Texoma, located at the junction of the Red and Washita rivers. Lake Texoma is the twelfth largest lake in the U.S. in terms of capacity and serves a variety of purposes. Since the opening of Denison Dam in 1944, the project has prevented cumulative flood damages of over $852 million in average 2008 dollars (USACE, 2010, Reallocation). Hydropower facilities currently have a generating capacity of 70 MW. In terms of water supply, the lake currently has only one full-time user, the Greater Texoma Utility Authority acting for the City of Sherman, Texas. Others make use of Lake Texoma water during low flow periods. However, future anticipated population growth in the region has caused both Texas and Oklahoma to start securing rights to the lake water for future water supplies. Potential future customers include the Dallas-Fort Worth area (RONA). Lake Texoma is also a popular recreational facility with over six million people visiting annually. In addition, the lake provides two state parks, two national wildlife refuges, and is one of the few reservoirs in the U.S. in which striped bass reproduce naturally. (USACE, 2010, Reallocation).

In the Texas Gulf hydrologic unit, important reservoirs include Lake Livingston in the Trinity River basin and Lakes Conroe and Houston in the San Jacinto River basin, all of which supply surface water for Houston (http://www.publicworks.houstontx.gov/utilities/

drinkingwater.html). Lake Livingston accounts for 75% of Houston's surface water supplies (TMP 2010). Lakes Lewisville, Grapevine, Ray Roberts, and Ray Hubbard in the Trinity River basin all supply water for Dallas as does Lake Tawakoni in the Sabine River basin (http://www.dallascityhall.com/dwu/water_utilities_faqs3.html ; TMP 2010). Lake Fork in the Sabine River basin and Lake Palestine in the Neches River basin are on reserve for future Dallas water supply (http://www.dallascityhall.com/dwu/water_utilities_faqs3.html). In the Rio Grande River basin, some of the main reservoirs are the Cochiti, Elephant Butte, and Caballo in New Mexico, and the Amistad and Falcon, both of which are international, shared by Texas and Mexico.

Infrastructure status

A 2009 American Society of Civil Engineers (ASCE) Report Card gives the nation's dam infrastructure a grade of "D" and the nation's drinking water, wastewater, levees, and inland waterways infrastructure grades of "D-" (ASCE, 2009; WSWC). The status of dam and drinking water infrastructure in the Great Plains is discussed in more detail below.

As can be inferred from the river basin infrastructure descriptions, dams abound throughout the Great Plains and thus dam safety is a concern. Dams may be considered deficient because of aging and deterioration, lack of maintenance, or because of increased engineering knowledge about the ability of a dam to withstand large flood events or earthquakes. According to a 2009 American Society of Civil Engineers (ASCE) report card on the nation's infrastructure, the two states in the Great Plains region that had the highest number of dams in need of rehabilitation to meet applicable dam safety standards were Oklahoma and South Dakota with 150 and 67 dams, respectively. Dams in the high hazard category are those that if they fail are anticipated to result in loss of life. According to the 2009 ASCE report, as of 2008, over 85, 40, 25, and 20 high hazard dams in Texas, Wyoming, Oklahoma, and South Dakota, respectively, had no Emergency Action Plan (EAPs). ASCE recommended that all high hazard dams throughout the U.S. develop EAPs by 2011.

In the context of climate change, planners will need to factor in new levels of safety that take changing peak flows and precipitation regimes into account in dam design, operation, and regulation (California Department of Water Resoures, 2008). In addition, more extreme rainfall events may increase soil erosion, which could increase sedimentation behind dams.

In 2007, EPA conducted its fourth survey and assessment of the nation's drinking water infrastructure needs, in particular the twenty-year (2007-2026) capital improvement need for water

systems to continue to provide safe drinking water to the public. The results of the survey noted that much of the nation's drinking water infrastructure is approaching or has reached the end of its design life and is now in a "rehabilitation and replacement" stage (EPA, 2009). This is reflected in the over $320 billion estimate of infrastructure investments needed by the nation's drinking water utilities over the next 20 years (in average January 2007 dollars).

The 2007 survey identified an emerging need related to new source water infrastructure required to address existing or anticipated drought conditions, and in their 2011 survey the EPA included supplemental questions related to climate readiness (EPA 2011 questionnaire). The results of this survey are not yet available.

Some Western States Water Council Recommendations

The Western States Water Council (WSWC) is an advisory group that reports to the western governors and is tasked with helping ensure that western states have an adequate, sustainable water supply now and in the future. A 2011 report documents recommendations made by individual participants attending a workshop on Western Water Resources Infrastructure Strategies: Identifying, Prioritizing, and Financing Needs. Among the many recommendations were ones related to emphasizing water conservation as a crucial water supply strategy that can delay or reduce the need for developing new water supplies and related infrastructure. Tools noted that promote water conservation included full cost pricing strategies that account for water scarcity, approaches that reduce per capita demand, and programs to monitor and address leakage. Another group of recommendations revolved around the diversification of local water supply sources for instance through water reuse (Section 4.X), the use of brackish groundwater, and through desalination. Lower quality waters (e.g. brackish groundwater, reclaimed wastewater) could be used for nonpotable purposes while higher quality waters could be reserved for potable needs. Investment in green infrastructure was also proposed as a cost effective approach to managing stormwater and conserving water (Section 4.Y). In terms of financing, the WSWC notes that Public Private Partnerships (PPPs) are one option that could make it easier to finance water infrastructure projects. PPPs are contractual agreements between public entities and private sector companies to provide a public service or project, and the WSWC notes are not equivalent to privatization. The WSWC also recommends that state and federal agencies examine their ability to provide assistance to small communities, many of which are located in rural areas and many of which lack the resources to finance projects on their own. The report notes that although local water supplies

should be developed first, interbasin water transfers and markets are an option that may be necessary. Some interbasin transfers are already occurring as noted in Section 1.

Managing Water in the Great Plains

The availability of water is critical to the viability and prosperity of the Great Plains region. Water scarcity through both the legal over allocation of existing water resources combined with a relative decrease in physical availability from climate change is quickly becoming one of the greatest challenges in the Western United States. In the Great Plains, the trend is for people and water to move from rural areas to cities (as stated in Section 1). To accommodate increasing populations in certain areas, development and growth, and increasing energy needs, water is increasingly going to be reallocated to “higher valued uses” (Western Governors' Association 2006). The risks and uncertainties for creating policy and management frameworks that are flexible and responsive while addressing vulnerabilities of local communities and ecosystems is a major challenge for the Great Plains region.

There are many complex legal and policy issues when it comes to water allocation and this sometimes can lead to conflict (Bell and Taylor 2008). One example is in the Pumpkin Creek watershed in Nebraska where surface water irrigators have taken ground water irrigators to court claiming that their excessive use prevents the surface irrigators from being able to withdraw their appropriations (Knutson 2008a). As climate change impacts water availability, this could further complicate these types of legal battles where streamflows and water availability is decreased.

In snowmelt dominated river basin systems (i.e., the western Great Plains), the possibility of climate change shifting seasons to result in earlier timing of runoff has implications for water use and management in states where there are timing regulations built into water rights. Where state laws specify when certain users can divert and use water, and earlier snowmelt and runoff could lead to impacts on users, management problems, and legal conflict where runoff timing is mis-matched with irrigation season, for example (Kenney et al. 2008). To date, this has not resulted in litigation, but water managers and irrigators are increasingly concerned about the implications of this issue. States in the Great Plains vary in terms of how much their water rights systems have explicit timing requirements, however, multiple inter-state compacts in the Great Plains have timing requirements, which could result in additional legal conflicts between states over water rights and allocations (Kenney et al. 2008).

Groundwater rights and management are also unique in each state. In the High Plains Aquifer region the three states that overlay most of the aquifer and withdrawal significant amounts of water for irrigation of agriculture are Kansas, Nebraska, and Texas. All three states use different doctrines for

groundwater allocation (Peck 2007). What this means is that they have very different laws and institutions for managing and regulating water, and with the implications of diminishing shared aquifer and changes in hydrological cycles, water availability, and recharge rates, collective efforts for managing impacts and adaptations will require considerable interstate cooperation beyond anything already experienced to date. This will require increased cooperation and mechanisms for conflict resolution between states, local users, and the federal government (Peck 2007), and ones that include incorporating the understanding of climate variability and change into institutional knowledge and decision- and policymaking.

The process of quantifying water rights is time-consuming, costly, and complex(Colby, Thorson and Britton 2005). It can sometimes take decades to complete and, involve a number of specialists to determine water allocation, water rights, which crops are sustainable, and how much water is needed to grow them, as well as other issues. For instance, on tribal lands the settling of priority dates and quantification of water rights can be accomplished by tribes or non-tribal entities either through litigation or negotiation, with litigation sometimes providing the impetus for negotiations (Colby et al. 2005). Negotiations can cover issues more than just the settlement of priority dates and the quantification of water rights, however. They can provide additional flexibility for addressing deficiencies in state and federal policies, for instance with respect to hydrologic connections between groundwater pumping and streamflows, and allow for more integrated water resource management from both stakeholder and environmental points of view (Colby et al. 2005). Water can be re-allocated or new development projects agreed upon. Many tribes may not have the financial capacity to convert paper water rights entitlements to actual wet water infrastructure, and sometimes provisions in negotiated settlements can include financial backing. Given the increase in climate variability expected, one particularly important aspect of negotiations, could be the agreement among users as to water allocation and management during wet versus dry years. Another important aspect could be agreement on the selling or leasing of water and on subsequent profit-sharing.

Although all of the physical engineering in the Great Plains region has provided benefits, there have also been some costs, in particular for riverside Native American communities that were relocated when their fertile floodplain homelands were inundated as reservoirs were created. In addition, the engineering has greatly reduced the amount of sediment transported by the Missouri, which has altered riverine habitat important to some native biota. This has contributed to the listing of two bird species, the least tern and the piping plover, and one fish species, the pallid sturgeon, under the federal

Endangered Species Act (NRC 2011). The changes in the Missouri's sediment transport regime have also resulted in channel bed lowering, which is causing problems for infrastructure by eroding bridge foundation at many sites, foundations of flood protection structures in and near Kansas City, and lowering water levels at municipal intakes (NRC 2011).

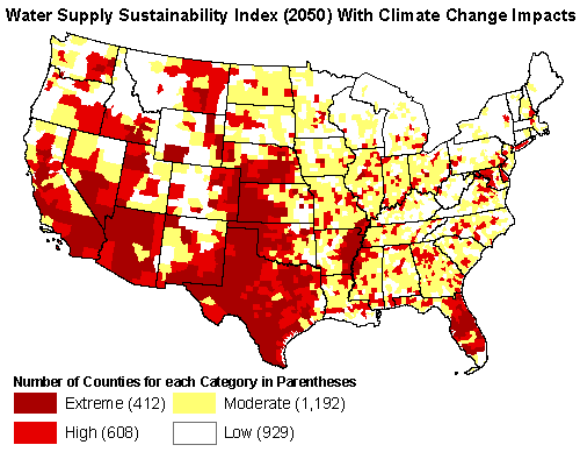

Fig. 6 Water Supply Sustainability Index in 2050, (a) with available precipitation computed using projected climate change. Source: Roy et al 2010

The socio-economic dynamics of the Great Plains region has increased vulnerability to water stress regardless of climate change, yet the projected climate change mentioned in this report makes the prospect of painful drought impacts and requires proactive planning to ameliorate future suffering (Knutson 2008a). Since the epic drought of the 1930s, many programs and adaptations have been put in place to buffer risk from drought. However, despite these measures, considerable vulnerability to water stress and drought still exists because of the continual expansion of and competition between water users, changing water availability, and various management strategies that have had unintended consequences or varying impacts on different stakeholders (Knutson 2008a).

Table 6. Great Plains Water Shortage Risk and Crop Value in At-Risk Counties, by State

State	Percent of	Total At-Risk	Extreme Risk	High Risk	Moderate	Value of All

	Counties At-Risk				Risk	Crops Produced in At-Risk Counties (in $1,000s)
Colorado	55%	35	12	15	8	$1 ,484,453
Kansas	86%	90	41	20	29	$4 ,197,856
Montana	46%	26	1	17	8	$7 37,187
Nebraska	97%	90	46	27	22	$6 ,423,909
New Mex	82%	27	10	9	8	$3 50,376
N Dakota	83%	44	0	4	40	$ 3,895,935
Oklahoma	91%	70	25	27	18	$ 8 91,167
S Dakota	56%	37	0	7	30	$ 1,863,979

Excerpted from: Roy et al 2010

Pumping of the Ogallala Aquifer has lowered the water table so much in certain areas, that in Nebraska, they have begun to issue moratoriums on new well drilling in several basins (Knutson 2008a). Conservation has been implemented in some areas throughout the region, however, a tradeoff is that this leads to reduced return flows for downstream users (Knutson 2008a). Interviews with agricultural producers in Nebraska found that they identified lack of capital and the need to respond to markets as barriers to adapt to drought risks (Knutson et al. 2011).

McLeman and colleagues (2008 and 2010) used analog studies to look at past responses to drought vulnerability, which can provide many lessons for current understanding of adaptation in terms of how climate change adaptation happens within the context of overall vulnerabilities and adaptive capacities to a broad range of socio-economic conditions. Important findings from these studies on the 1930s drought in Oklahoma were on how different demographics had different adaptive capacities and therefore adapted differently (land owners versus tenant farmers); the important role that social capital and social services played in sustaining livelihoods; and the critical role that federal programs played such as the AAA (Agricultural Adjustment Act), WPA (Works Progress Administration), and the FSA (Farm Security Administration) (McLeman and Smit 2006). While social and environmental conditions have changed in modern times, these lessons learned can provide valuable insights into understanding how communities and governments respond to drought.

While significant vulnerabilities exist of water resources from climate change, a new paradigm for water policy and management is emerging with new and innovative solutions for Top-down water planning of the past is being replaced by local stakeholder processes that incorporate the needs of communities into state planning processes (Western Governors' Association 2006). This will be discussed in more detail in Section 5.

2.3 RURAL-URBAN DYNAMICS

Although vast with the majority of the landscape consisting of remote areas, nearly 80% of the 41,000,000 residents of the Great Plains live in urban areas (U.S. Census Bureau, 2010a). As with almost all other facets of life in the region, there is great diversity in population density and socio-economics even within rural and urban areas (Table XX). Rural areas range from counties in Montana with less than 1 person per every 2 square miles to counties outlying major metro areas, that will likely transition to urban areas in coming years. The degree of urban residents varies from state to state ranging from South Dakota, which is almost evenly split between urban and rural residents to Colorado and Texas, each of which has over 80% of their residents living in urban areas (U.S. Census Bureau, 2010a). Texas contains two of the most populous and fastest growing metropolitan areas in the country, Dallas-Fort Worth-Arlington and Houston-Sugar Land-Baytown, which as of the 2010 Census rank fourth and sixth in the nation in terms of population magnitudes (U.S. Census Bureau 2010a; Census Brief, 2011).

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Rural Urban Continuum

There are multiple demarcations between rural and urban areas used by government agencies. One commonly applied for comparison is the Office of Management and Budget 2003 Rural-Urban Continuum Code. Counties are grouped as metro or non-metro according to a classification scheme, subdivided into nine categories, that accounts for population size of the county and adjacency to a metro area. Rural counties (non-metro) are classified as those containing less than 50,000 people (USDA ERS, 2012b).

Figure 7 – Rural-Urban Continuum Code, 2003.

Source: USDA ERS 2012c
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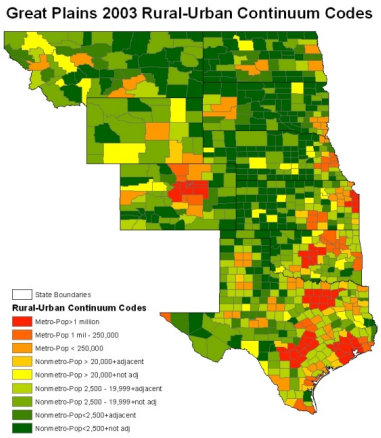

The Great Plains is primarily composed of rural counties, 638, with a population of 8,707,229 (21%) people and 155 urban counties with 32,938,150 people (US Census Bureau, 2010a). Yet, the majority of the population 32,938,150 (79%) of the Great Plains actually live in urban areas.

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ END BOX~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Defining Rurality in the Great Plains

The diversity of the landscape and population of the Great Plains makes it difficult to precisely determine what constitutes rural communities in the region. Few comparative studies have been conducted of rural versus urban areas, partly because of the expansive geography, and also because of the lack of homogeneity of communities. The gradient ranges from farming communities, near metro areas in the Southern Great Plains to communities centrally focused on livestock grazing in the North (Figure 8).

Figure 8– Great Plains Rural and Urban Counties

Source: USDA ERS 2012c
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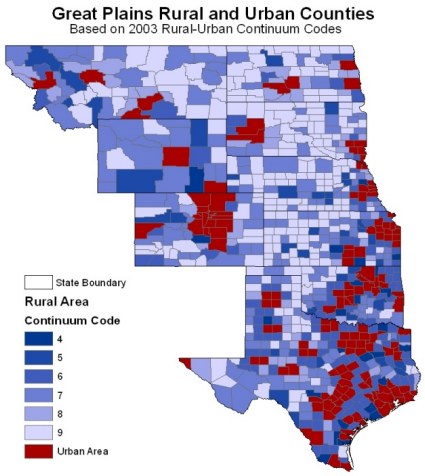
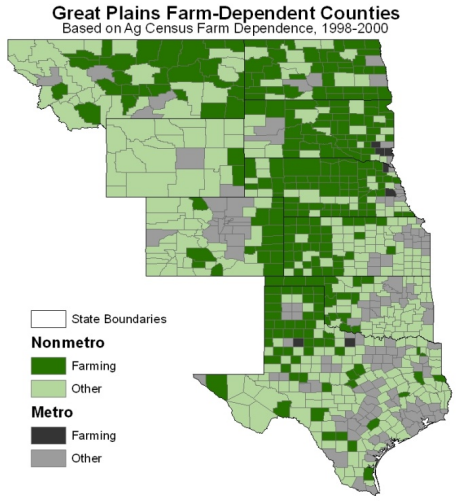


Characteristics of Great Plains Rural Areas

Although rural areas in the Great Plains are diverse, there are some defining characteristics of counties within rural areas. Potentially the most significant common feature of rural counties is the dependence of rural economies on agriculture. Forty-five percent of non-metro counties are farm dependent, compared to just four percent of metro counties (USDA ERS, 2012d). Farm dependence, as defined by USDA, is based on two thresholds. Farm earnings must account for an annual average of at least 15 percent of total county earnings or farm occupations must account for at least 15 percent of all occupations of employed county residents.

Figure 9: Great Plains Farm-Dependent Counties

Source: USDA ERS 2012d



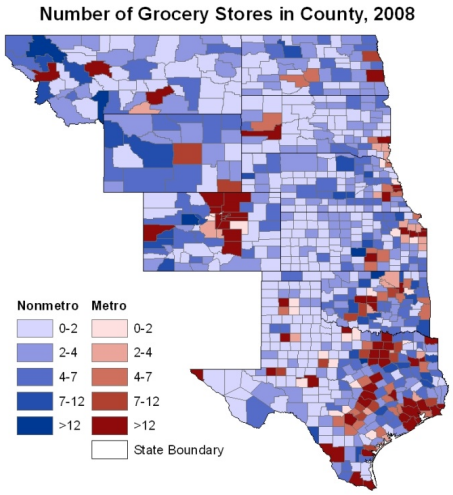
Due to the remoteness of rural areas, many residents are lacking easy access to resources and services. The scope varies as communities become more remote, and generally access to resources and services decreases. Analysis of water availability and sanitation services by the Rural Community Assistance Partnership determined that the percentage of households lacking proper water and sanitation is highest in places with populations of less than 1,000 and rural farm populations. This is largely attributed to rural areas lacking economies of scale to support such services without subsidization and a lack of financing or technical assistance (Vaswani and Gasteyer, 2004).

For the same reason, rural areas typically have less access to other public services; such as medical care (including ambulatory services), fire departments, and schools; that declines as populations reduce and counties become more remote from metro areas. Accessibility of health care tends to deteriorate as geographic isolation increases and population density declines. Accounting for transportation costs, this results in rural families traveling further distances for medical care and, therefore spending a greater proportion of income on medical care than urban residents (Lal, 2011). Emergency response systems are often less effective, due to the population dispersion and geographic isolation. Lal (2011) concludes that the combined effects of changing demographics and increasing health costs are more likely to make it difficult to supply rural areas with adequate public health services.

Access to goods is also marginal in rural, isolated areas. Throughout the Great Plains, grocery stores are many miles apart in most non-metro counties, causing residents to drive long distances for food. Similar to medical care, this results in families spending a larger proportion of income on food than urban residents (USDA ERS, 2012e).

Figure 10 – Number of Grocery Stores in County

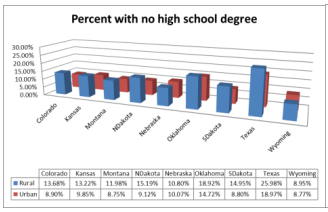
USDA ERS, 2012e

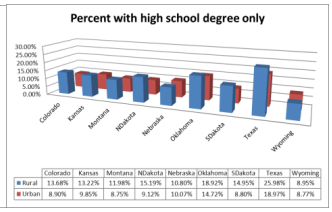


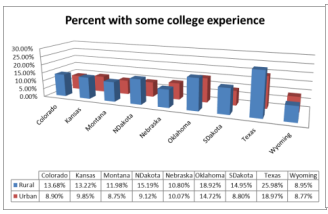
Overall, average income in rural counties in lower, indicating availability of fewer skilled jobs. As a result people who receive college degrees typically do not return and fewer people with degrees are employed in the rural labor market (Lal, 2011). A comparison by Lal (2011) of nation-wide rural-urban dynamics determined that the widening rural-urban income gap is associated with lower costs of living in rural areas, lower educational attainment, less competition for workers among employers and fewer highly skilled jobs. This trend can be seen across the Great Plains region as well, expressed in trends of lower educational attainment rural areas (Figure 11).

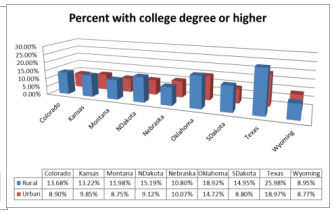
Figure 11. Education Tables

U.S. Census Bureau, 2010c





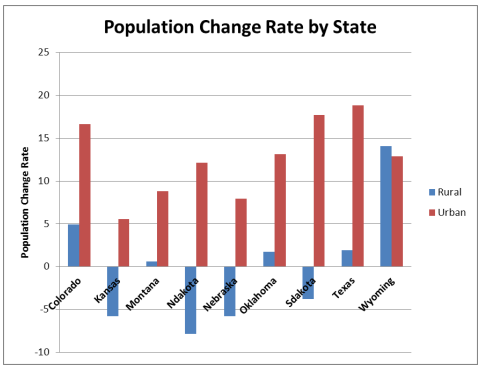




The lack of skilled jobs in rural communities has led to an out-migration of working-age population from agricultural communities (Figure 12). Parton et al (2007) concludes that this out-migration of youth has had the secondary consequence of reducing fertility and intensifying the downsizing of many aspects of community life, particularly activities and schools that focuse on children, leading to the acceleration of further out-migration. Counties with higher levels of irrigated agriculture tend to see lower rates of out-migration and have steadier and relatively younger populations. It has yet to be determined whether this trend will sustain over time or if it is just slower because of improved economic conditions (Parton et al, 2007).

Figure 12 – Rural-Urban population change rate

U.S. Census Bureau, 2010d



This chronic out-migration and lower fertility rates have led to an aging population in rural areas. The proportion of the population over 65 (Table 7) has increased more rapidly in rural areas than in urban areas. The shortage of access to public services (particularly health services), stated above, causes a real problem for these vulnerable populations.

Table 7 – Population Over 65

U.S. Census Bureau, 2010d

Percent Population Over 65			
	Rural	**Urban**	**Total**
Colorado	15.65%	10.94%	14.40%
Kansas	18.87%	14.07%	18.09
Montana	18.51%	14.98%	18.26%
NDakota	20.86%	12.02%	20.19%
Nebraska	19.99%	13.14%	19.33%
Oklahoma	16.77%	13.46%	16.04%
SDakota	18.05%	13.93%	17.61%
Texas	16.99%	12.81%	15.72%
Wyoming	14.60%	12.49%	14.42%

Climate Change Impacts on Rural Areas

The impacts of climate change on rural communities are determined by a set of complex interactions among the environment, different sectors, and population groups. There is a scarcity of information and literature on the interface of how socioeconomic and demographic factors will respond to the biophysical changes accompanying global change and almost no information on how the interconnected socio-economic / ecological systems will respond (Lal, 2011).

One certainty is that vulnerability to climate change is intensified in rural areas with highly climate-sensitive livelihoods where communities have fewer resources and alternatives than metro areas. Lal (2011) suggest that rural areas typically have higher poverty rates and lower household incomes, putting them at higher climate-related risk, historically, from weather-related shocks. The impacts of climate change and capacity to manage resulting challenges will vary across the region and even within communities as households have differentiated vulnerabilities and coping mechanisms. A range of impacts will be felt across different communities, with some benefiting from climate-induced changes, and other facing devastating losses. Further regional research that improves upon current understanding of socio-economic and biophysical impacts of global change on rural communities would be useful to develop appropriate policies and mitigate negative consequences (Lal, 2011).

As stated in Section 4.2, the response of agricultural systems to climate change will vary across the region. However, the disproportionate percentage of rural counties (versus metro counties) reliant on agriculture as a primary source of economic activity suggests rural communities will experience the brunt of climate impacts on agriculture (USDA ERS 2012d; Lal, 2011). If yields do decrease, not only will profits and income be lowered, but families reliant on agriculture for subsistence will be doubly impacted by both a loss of income and food source. Similarly, farming communities are expected to experience additional water stress from climate change, particularly in counties reliant on irrigation. [Section 2.2] details critical issues related to the effects climate change will have on water. Aquifers in the Great Plains continue to be tapped faster than the recharge rates causing unsustainable water-use in the region (Barnett et al, 2008). Although urban areas are using more total water, the greatest percentage is surface-water. On average, rural communities use more ground-water and almost eight times the total water of urban areas (USGS, 2005)

Effects of climate-related events on social systems are less known but can be expected to be negatively felt remote areas. As previously stated, the accessibility of health care resources tends to deteriorate as population density declines. With decreased access to health infrastructure and a higher

proportion of income spent on health services, rural communities are likely to become more vulnerable to the harmful climate change impacts on health discussed in [Section 2.6.2].

Climate Change Impacts on Urban Areas

Urban areas currently face a wide variety of environmental challenges. Many of these may be exacerbated by climate change. One such issue is ground-level ozone. Ground-level ozone is a known pulmonary irritant and is the primary constituent of smog (Ebi and McGregor, 2008). Some Great Plains cities such as Tulsa and Oklahoma City have had problems meeting ozone standards (EPA database), and the Houston area has been in non-attainment of the EPA ozone standard since it was set in 1977 (Raun, 2010). Higher temperatures may result in greater ozone formation because the chemical reactions resulting in ozone formation are temperature dependent (Bell et al., 2005). In addition, biogenic volatile organic compounds, which are ozone precursors, increase as temperatures rise (Bell et al., 2005).

Suspended particulate matter (PM) also presents a potential air quality issue in cities. Sources of PMs include construction sites, smokestacks, fires, emissions from power plants, and automobiles http://www.epa.gov/pm/basic.html. PMs can penetrate deep into the lungs and cause health problems. Prolonged or severe droughts may result in dusty conditions and wildfires that can cause an increase in suspended particulates including smoke, pollen, and fluorocarbons (CDC, 2010).

The urban heat island (UHI) effect occurs when cities have warmer air and surface temperatures than surrounding rural areas, in particular at night (Grimm et al., 2008(EPA 2008)). This is attributable to a variety of causes including decreased vegetation, increased low albedo impervious surfaces, and urban building morphology (Grimm et al., 2008)(EPA 2008). In urban areas with 1 million or more people, annual average air temperatures can be 2-5 °F higher than surrounding areas. On individual clear, calm nights the UHI can be as much as 22 °F warmer. Smaller cities and towns can create heat islands as well, although the urban-rural temperature differences often decrease as the city size decreases (EPA 2008). UHIs can act in conjunction with climate change to create more extreme temperatures.

An increase in high temperatures, particularly long stretches of days over 100 will damage the integrity of transportation systems. High temperatures, particularly those exceeding 90 ºF, can cause pavements to degrade faster, compromising its integrity (Bjune et al., 2009; Savonis et al., 2008). Increased temperatures can also cause some types of rail to develop “sun kinks” in which sections of the rail buckle (Savonis et al., 2008). Increased cooling and thus energy consumption may be required for freight operations as well as passengers (Savonis et al., 2008). Compounding the problem, crews responsible for construction and maintenance may not be able to work during times of extreme heat

(Bjune et al., 2009; Savonis et al., 2008).

Extreme rain events could result in increased flooding if flows start to exceed the design capacity of a city's culverts and storm sewer system. (Bjune et al., 2009; Savonis et al., 2008**)**. Bjune et al. (2009) assesses that this would present a particular problem for cities lying on flat terrain, as is the case with many metro-areas in the Great Plains. More intense storms will also reduce clearance under bridges and increase erosion of road bases and bridge supports Bjune et al., 2009; Savonis et al., 2008.

Climate change could also have a variety of impacts on municipal water supplies. The headwaters of many Great Plains' rivers are in the Rocky Mountains, and cities in the western part of the region, such as Denver, are often dependent on snowmelt. The snowpack acts as a natural and massive reservoir for water storage, holding water historically until late spring/early summer. Warming temperatures will not only result in a decreased amount of snow and reduced water storage in the snowpack, but it will also cause snow to melt earlier in the spring (Barnett et al., 2005). In the absence of precipitation changes, maximum runoff will shift to earlier in the season, further from the peak water demand months of July and August.

In addition to shifting times of peak runoff, warmer temperatures may also affect evaporation rates. Many cities in the Great Plains are dependent on reservoirs for their water supplies, and these reservoirs currently lose considerable amounts of water to evaporation. Annual evaporation from the six largest reservoirs on the Missouri River's main stem, for instance, has been estimated to be about 5% of the average annual river discharge (Benke and Cushing 2005). In the Rio Grande, evaporation from the major reservoirs has been estimated to exceed municipal water usage in the basin (Benke and Cushing 2005). Such reservoir losses could increase if warmer temperatures persist without an increase in precipitation.

Increases in precipitation intensity could adversely affect municipal water supplies by resulting in elevated levels of turbidity, organic matter, pathogens, and pesticides in source waters in some cases from rises in nonpoint source pollution loads and in some cases from increased infiltration influencing groundwater quality (Clark et al., 2011; Kundzewicz et al., 2008). For cities, such as Kansas City, in which storm and wastewater sewers are combined, high rainfall events could also overload the capacity of wastewater treatment plants leading to situations in which untreated or partially treated sewage may be discharged into streams (Kundzewicz et al., 2008; Delpa et al., 2009; Struck et al., 2009). Droughts can lead to water-quality problems for municipalities, as well as water-quantity issues. In some areas, droughts may result in elevated levels of toxic algae and organic matter in source waters, and lower streamflows may lead to the concentration of pollutants adversely all of which may affect the

ability of treatment plants to meet safe drinking water standards (CDC, 2010, refind second source). Excessive drying of soils can damage pipes leading to breaks in water mains such those experienced in Texas during the state's most severe one-year drought on record. In Houston alone, over 6000 water main breaks were reported during the summer of 2011. (Houston City Council District G Newsletter; Aug.-Sept. 2011; Houston City Save, Vol. 16, No. 3, Fall 2011; Texas State Climatology Office press release, Aug. 2011; Royal Academy of Engineering, 2011).

2.4 ENERGY CONSIDERATIONS

Climate and Energy Context for the Great Plains region

There is strong seasonally-dependent variability in both energy and water demand in this region. Water use peaks during the summer irrigation season, with the timing of greatest water consumption dependent on cropping patterns and constraints on water availability (Schneekloth, and Andales, 2009). There is considerable variability across the region in total energy use for irrigation water delivery as a result of differences in total cropped acreage, dependence on groundwater or surface water, depth to groundwater, type of crop grown and weather-dependent crop evapotranspiration (e.g. USDA, 2010). Overall, electric power use generally follows a U-shaped seasonal pattern with higher consumption in both winter and summer than in spring or fall (Fan et al., 2007; Colby and Tanimoto, 2011; Fisher and Ackerman. 2011). A statistical analysis of the role of weather variables in driving seasonal differences in electricity demand in Arizona, found that: "..the relationship between load and temperature follows a quadratic pattern… temperature levels that are far from a certain neutral point lead to more consumption of electricity for cooling or heating. … the insensitive level found in exploratory analysis was around 15 degrees C." (Colby and Tanimoto, 2011, p. 218).

A similar U shaped relationship between electricity use and temperature was found in the Midwest with the exact shape of the relationship varying somewhat between different areas as a result of differences in the sensitivity of demand to weather (Fisher and Ackerman 2011) Similarly, differences in the exact shape of the temperature, electricity demand relationship were found across states (Fisher and Ackerman. 2011) and across different climatic zones within a single state (Aroonruengsawat, A. and M. Auffhammer, 2009). In all of those studies winter heating and summer cooling demand were found to be important drivers of seasonal electric use variability. These findings suggest that summer cooling demand is likely to become an increasingly important driver of electric power use in the Great Plains region as the region's climate warms, as evidenced by record peak electric power use in Texas during the record heat wave in the summer of 2011 (ERCOT, 2012).

Climate change that will result in increased summer extreme heat days will require more of both energy and water in the Great Plains region. This will be discussed in more detail below.

Overview of energy-water-land nexus

Most forms of energy production require significant amounts of water for mining, fuel processing, and electric power generation (USDOE 2006, Averyt and Fisher 2011, Cooley, Fulton and Gleick 2011). In addition, moving and treating water consumes major amounts of energy, especially in areas where it has to be moved great distances from the source to the users. As a result of multiple, interacting stressors at the water-energy nexus, the Great Plains region is experiencing increasing problems with both water quality and quantity for maintaining critical ecosystem services such as drinking water, irrigation for crops, hydropower, healthy fish populations, aesthetic and spiritual values, among many others. These stresses are especially common in the semi-arid western areas of the region, which face even dryer conditions with climate change, and where many major rivers systems are already over-allocated to agricultural, municipal, industrial, recreational, and environmental uses (Barnett and Pierce 2009). Decisions made today about water and energy use, and climate adaptation and mitigation will have impacts for decades to come. The myriad uncertainties posed by alternative socio-economic pathways and different plausible climate change scenarios mean that decisions taken today need to take into account the risks of climate change and these multiple stressors in the future.

Land use and land-use changes are closely linked to the availability and use of water resources and energy. Energy demand as well as the resource and economic opportunities for developing renewable and non-renewable energy resources such as gas and oil, coal, biofuel, hydropower, solar, and wind power are high. Energy production, including alternative-energy options, have a wide range of effects on land cover and productivity, and other factors that affect carbon, water, and energy fluxes and, in turn, climate (Dale et al. 2011). Relative impacts of energy on land use are influenced by characteristics such as the extent, duration, intensity, and reversibility of change. Energy infrastructure for storage, transportation, and processing will likely alter the landscape for long periods of time. Likewise, conversion native prairie grasslands to croplands are almost irretrievable; as their ecological integrity has evolved over thousands of years.

At the heart of the cross-cutting issues bridging, energy, water, and land is the nexus between climate mitigation and adaptation. Mitigating emissions of greenhouse gases has implications for both water and land resources. Be it evolving fuel portfolios, carbon capture and storage technologies, land sequestration of carbon, these practices have the potential to compromise our ability to adapt to

climate driven impacts to water and land resources. Similarly, in an effort to adapt to changing water and land regimes, moving water and altering land can be energy intensive—creating a feedback that may compromise efforts to minimize greenhouse gas emissions.

The energy-water-land nexus is a multi-stressor problem with drivers that extend beyond the climate. Population growth and concomitant demands for energy, municipal water supplies, and land are as much a problem. Texas and Wyoming were among the states seeing the largest percentage of population growth since 2000 according to the latest US Census. Austin, TX was among top ten fastest growing metropolitan centers in the nation (37.3%), and Lincoln County, SD was one the most rapidly growing counties (85.8%, US Census Bureau http://www.census.gov/prod/cen2010/briefs/c2010br-01.pdf , Table 8). Translating population or population growth into water demands and land use, however, is not straightforward. Water and energy demand are not directly related to population or population increases, largely as a consequence of conservation efforts, and land use is similarly difficult to correlate. For example, in 2008, Texas, Nebraska, and Kansas came in second, third and fourth, respectively behind California for total on-farm energy use for irrigation pumping, accounting for 40% of total energy use (by expenditure) of the nation's use of power (of all types) for irrigation -- just over a billion $ out of a national total of~ $2.68 billion (USDA, 2010).

Table 8. Population Growth 2000–10 in Great Plains Region

Kansas	6.1%	Oklahoma	8.7%
Montana	9.7%	South Dakota	7.9%
Nebraska	6.7%	Texas	20.6%
North Dakota	4.7%	Wyoming	14.1%

Source: http://www.census.gov/prod/cen2010/briefs/c2010br-01.pdf

Navigating the nexus is expected to become more difficult as the regional climate continues to change

Water for Energy

Water is required for the development of most energy resources: from extraction, to building infrastructure, to generation of electricity. The thermoelectric cooling process (where water is used to

spin a turbine to generate electricity, and is then cooled) accounts for a greater proportion of national freshwater withdrawals than agriculture (USGS, 2009; http://water.usgs.gov/wsi/). But different combinations of fuels and cooling processes use different quantities of water (Fig 13 below; Macknick et al. 2011). For each kWh of electricity generated, nuclear technologies withdraw and consume the most water. Water use associated with concentrated solar plants is also relatively high, on par with coal-fired power plants. An important point here is that low carbon does not always equal low water use.

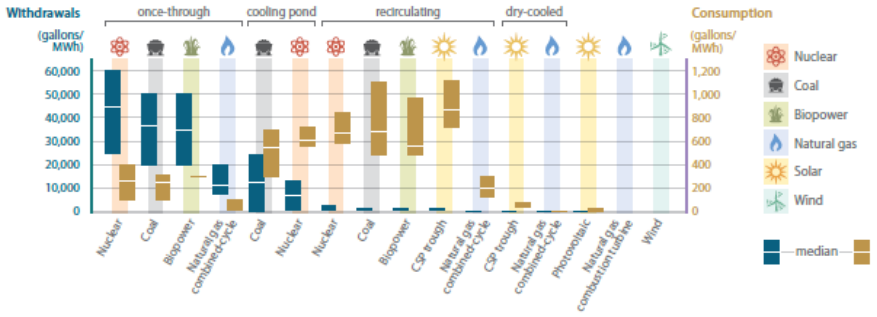


Fig. 13 Source: Averyt et al 2011, adapted from Macknick et al 2011

Caption from report: Water *withdrawals* per megawatt-hour (MWh) can range from almost zero for a solar photovoltaic, wind, or dry-cooled natural gas plant, to hundreds of gallons for an efficient plant using recirculating cooling, to tens of thousands of gallons for a nuclear or coal plant using once-through cooling. Water *consumption* per MWh can similarly range from almost zero for solar, wind, or gas plants using dry cooling to around 1,000 gallons for coal, oil, or concentrating solar power (CS P) with recirculating cooling. How much water a specific plant uses reflects its efficiency and age, and how much the plant is used, along with local humidity, air temperature, and water temperature.

There are approximately 1,750 power plants in the Great Plains. In 2008, these plants generated 674,000 10^3 GWh of electricity primarily using coal (50% of total generation) and natural gas (34%). The dominant cooling technology was once-through cooling—meaning that heat is dissipated through evaporation and hot water is not discharged back into rivers, streams, and lakes. The combination of power plants in the Great Plains yields a water intensity of 6.4 gallons of water withdrawn per kWh generated, and 0.4 gallons consumed per kWh. However, there are variations from state to state (Figure X).

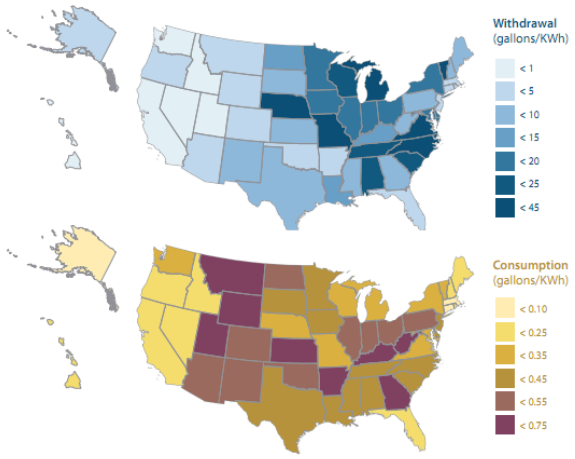


Figure 14. Freshwater intensity by state. (from Averyt 2011) (I am going to get the original file and generate the graphic with only the Great Plains states; pending receipt of the original from UCS so I can manipulate it; will send it once I get it)

smcneeley 2/28/12 1:46 PM
Comment: From Kristen Averyt

In contrast with the national portfolio, agriculture is the primary water user in the Great Plains region. Although much agricultural water is drawn from groundwater resources, 96% of water for thermoelectric cooling comes from known surface water sources, less than 1% from groundwater.

Aside from water for power plants, water use for development of energy resources, and implications for water quality are both issues in the Great Plains. Water requirements for most extraction practices are ill constrained and highly variable.

Energy for water

Energy is required to pump, treat, distribute, and use potable water, and to treat and discharge wastewater. The *energy intensity* of water, or the energy used to provide a unit of water (e.g., a gallon, acre-foot), depends on the source and quality of the raw water, and the type of use. For example, pumping raw water over long distances or over mountain ranges can use a large amount of electricity; California's State Water Project and Arizona's Central Arizona Project are well-known examples. Many cities in the West rely on high quality water that flows to city treatment plants by gravity, requiring very

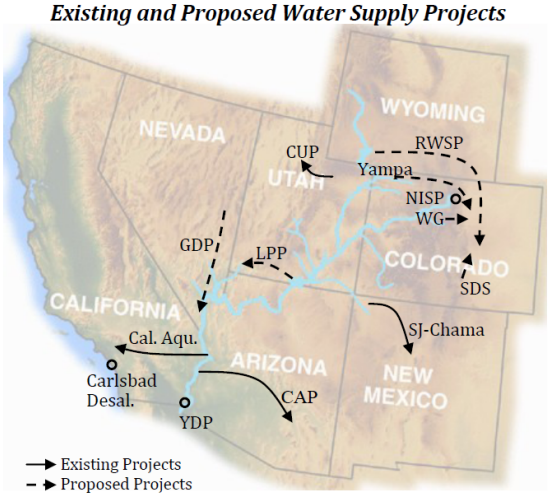
little energy to pump, treat, and distribute the water to customers; increasing urban water supplies will, in many cases, require cities to pump water over greater distances or from deeper aquifers.

The energy intensity of water will vary depending on the source (i.e. surface or groundwater) and the quality of the water. Cities that rely on surface water fed from snowmelt in the Rocky Mountains (e.g. Denver, CO) generally require only moderate amounts of energy to treat and distribute water. For example, the energy intensity of treating and distributing water in Denver, CO, in 2007 was 232 kWh/AF.[1] Colorado Springs, CO has also relied primarily on gravity-fed water supplies from the Rocky Mountains. To expand its supplies, Colorado Springs recently began construction on the Southern Delivery System, a project that will pump water from Pueblo Reservoir to Colorado Springs, requiring an estimated 4,631 kWh/AF (not including treatment or distribution).[2]

In many parts of the West, where water demands already exceed supplies, creating a need to import water between watersheds and across state lines, and tap additional groundwater resources. (Figure 1).

[1] Personal communication between Stacy Tellinghuisen, Western Resource Advocates, and Bob Peters, Denver Water. July 28, 2008.
[2] U.S. Bureau of Reclamation. 2008. Southern Delivery System Final Environmental Impact Statement. December 2008.

Existing and Proposed Water Supply Projects



Abbreviation	Project Name
Cal. Aqu.	California Aqueduct
CAP	Central Arizona Project
Carlsbad Desal.	Carlsbad Desalination Plant
CUP	Central Utah Project
GDP	Groundwater Development Project
LPP	Lake Powell Pipeline
NISP	Northern Integrated Supply Project
RWSP	Regional Watershed Supply Project
SDS	Southern Delivery System
SJ-Chama	San Juan-Chama Project
WG	Windy Gap Firming Project
Yampa	Yampa Pumpback Project
YDP	Yuma Desalting Project

Energy Intensity of the West's Water Supplies

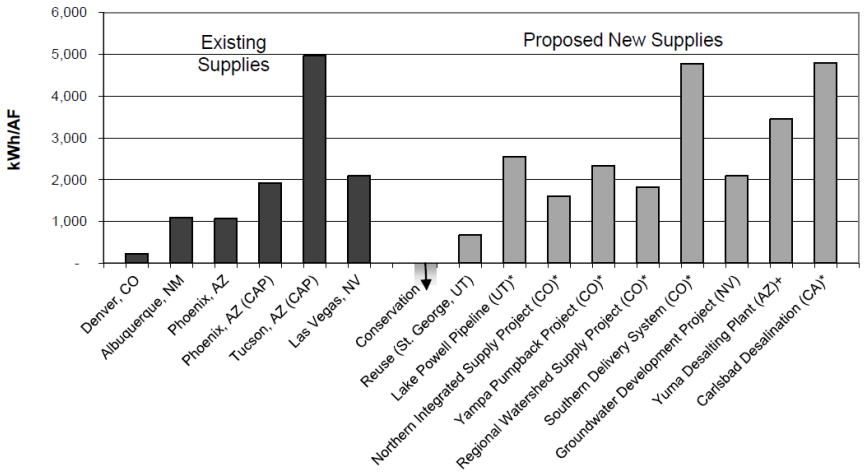


Figure 15. The energy intensity of many proposed projects exceeds the energy intensity of existing supplies. Notes: *Figures include an estimated 150 kWh/AF for treatment and/or distribution. +The Yuma Desalting Plant includes the energy used on site and the energy used to pump water to participating utilities in Arizona, Nevada, and California, as its operation is designed to increase water supplied to cities in those states. Colorado Springs' Southern Delivery System and the Carlsbad

Desalination Plant are now under construction. The upper map only includes the Colorado River system. These different projects require varied quantities of energy. (Table 8).

Table 8

Project (State)	Water Delivery (AF/yr)	Net Energy Use (MWh/yr)	Sources
Northern Integrated Supply Project (CO)	40,000	33,980 - 57,980	U.S. Army Corps of Engineers. 2008. Northern Integrated Supply Project Draft Environmental Impact Statement, table 4-15. April 2008.
Yampa Pumpback Project (CO)	300,000	595,680	Northern Water Conservancy District. 2006. Multi-basin Water Supply Investigation.
Regional Watershed Supply Project (CO)	250,000	199,000 - 496,000	Volume data: Wyco Power and Water, Inc. 2011. Application for Preliminary Permit, Regional Watershed Supply Project. Filed with the Federal Energy Regulatory Commission August 31, 2011. Energy Intensity data: Derived from Preliminary Permit Application; analysis summarized in Western Resource Advocates. 2011. Motion to Intervene in Opposition and Comments on the Preliminary Permit Application for the Regional Watershed Supply Project, Project No. P-14263-000. Filed with FERC on December 15, 2011.
Southern Delivery System (CO)	52,900	246,038	U.S. Bureau of Reclamation. 2008. Southern Delivery System Final Environmental Impact Statement. December 2008.

Water providers develop even more water supplies that require pumping from greater depths (groundwater) or conveyance over longer distances. Also in the future water providers may need to increasingly rely on lower quality supplies that require more extensive treatment, such as tapping more saline supplies that require reverse osmosis (RO). The energy intensity of RO depends on the salinity of the water treated; for example, in its demonstration run in 2007, the Yuma Desalting Plant used approximately 1,451 kWh/AF to treat brackish water (salinity of 2,539 mg/L, reduced to 252 mg/L).[3]

In addition to changing water availability, climate change may affect the timing and magnitude of runoff. For many water utilities, existing storage facilities may adequately accommodate variable

[3] Data: 3,819 MWh of electricity were used during the operation of the plant, and 2,632 AF were treated. Source: U.S. Bureau of Reclamation, 2008. Yuma Desalting Plant, Demonstration Run Report.

runoff regimes. Some utilities, however, may require additional storage. If “new” storage includes aquifer recharge (and subsequent recovery), it may lead to additional energy demands. Finally, wastewater treatment plants often discharge treated wastewater into streams; this depends on adequate stream flows to ensure that discharges do not exceed stream temperature or water quality standards. Reduced stream flows or elevated stream temperatures may drive wastewater treatment plants to increase treatment standards, increasing the energy intensity of treatment.

Managing the impacts of diminished and changing water supplies can be informed by current adaptation strategies. New water supply projects such as the Southern Delivery System may increase and diversify a water utility’s water supply portfolio, but also increase total energy demands. Alternative options include water conservation, increasing use of recycled water, and developing flexible leasing arrangements between cities and farmers. Each of these options has different benefits. Water conservation can both reduce total water demands and save energy, particularly if conservation efforts focus on reducing the use of hot water and/or energy-intensive water conveyance or pumping systems. Recycled wastewater is typically drought resistant; depending on the level of treatment required to provide recycled water, it may have additional energy demands. UV disinfection, for example, is energy intensive. However, the energy used to treat and distribute recycled water may be less than the energy required for new water supply projects. Under traditional agricultural-urban leasing agreements, cities pay farmers to temporarily fallow a portion of irrigated agricultural land and transfer water to cities; these agreements may enable cities to mitigate the impacts of more extreme droughts without increasing the need for energy intensive new infrastructure projects.

The energy impacts of adapting to changing water supplies are an important consideration; some of the strategies described above may help cities both adapt to and mitigate climate change, while others help cities adapt, but increase greenhouse gas emissions. The energy requirements necessary for adapting to climate-driven changes in water supply is an example of how decision making about climate adaptation can come into conflict with efforts to mitigation greenhouse gas emissions.

2.5 Ecosystem and Biodiversity Conservation Issues

Effects of Climate Change on Current

Climate change projections for the region presents a diversity of responses across the region which would exacerbate the current environmental stresses faced by many wildlife and conservation management efforts in the Great Plains. Changes in extreme events associate with droughts, floods, winter storms, have resulted in alterations of plant community phenology, hydrological dynamics of stream flow and wetland temporal dynamics, and availability fo ecosystem services (SAP 4.3), resulting in threshold changes of critical ecosystem level functions across the region (SAP 4.2).

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. Recent extreme events (i.e., droughts, heat waves, floods, etc.) have the potential to affect a number of key habitat and ecosystem functions and to trigger thresholds of physiological and life-cycle patterns of various species. These thresholds changes have a likely impact on species mortality, and the persistence of natural systems, including plant and animal populations (Allen et al 201).

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 CCSP 2009; Covich et al, 1997). Impoundments and diversions have a major impact on the hydrological flow and climate change have the potential of exacerbating the timing of water related to critical breeding or migratory timing of key species across the region that are responding to physical changes in climate where as flow dynamics have been regulated due to past policy decisions.

Hydrological regime changes and water temperatures can affect various species differently across the region. Perennial streams are now observed to flow intermittently resulting in changing plant and animal populations residing in these streams, ponds, and wetlands. 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.

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 (www.cgpregion.com/pg65.htm) 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.

Climate change and fragmentation

The highly productive Great Plains ecosystem originally constituted about 2 million km2 of intact grasslands that supported huge herds of bison and other ungulates. Major evolutionary grassland drivers were climatic variation, herbivory by nomadic ungulates, fire, and in the central and western grasslands, prairie dogs (Axelrod 1985, Anderson 2006). Populations of all native grassland ungulates and prairie dogs have been hugely reduced, and fire regimes no longer mimic natural processes. Furthermore, both terrestrial and aquatic habitats are extensively fragmented due to agriculture, roads, and water impoundments, with consequent effects on biota and ecological processes (Figures XX – map of roads, map of land cover)(Sabo et al. 2010; Heinz Center 2008).

The combined effects of climate change and land use change are key threats to ecosystem processes and biodiversity in the Great Plains. Many species are responding to increasing temperatures by shifting distributions, apparently at increasingly greater rates (Parmesan 2006; Chen et al. 2011). The simultaneous loss and fragmentation of habitats impedes the ability of species to move into new areas in response to rapid climate changes. In the Great Plains, the extensive network of roads (Figure roadless patches) and agriculture has resulted in highly fragmented grasslands – more than 85% of all intact grassland patches are now less than 100 mi2 (Heinz Center 2008). Connected landscapes are considered a foundation for preserving biodiversity in the face of climate change (e.g. Kostyack et al. 2011), and the degree of habitat loss and fragmentation of grasslands poses a clear threat to biota.

The loss of biodiversity in the Great Plains has been driven by habitat loss, degradation, and increasing fragmentation, with future biodiversity also subject to changes as a result of climate change (Becker et al. 2007). In the southern Great Plains, habitat loss, degradation, and fragmentation are due overwhelmingly to land conversion for agriculture, with over 70% of the land surface altered, and over 90% in some areas (Gray et al. 2004). Over 70% of playas >4 ha in basin area in the southern Great Plains have been modified for agriculture (either tilled or with pits dug to gather irrigation return water)

(Guthery and Bryant 1982). In 1965, only about ~0.6% of playas in TX were modified; by 1981, ~43% were (Nelson et al. 1983), so these changes are recent and severe. Land conversion alters wetlands and their biota by changing water chemistry, hydroperiod, and sheer presence of wetlands themselves. Land conversion to agriculture has been shown to greatly increase sedimentation within playas surrounded by cropland relative to indigenous grassland (Luo et al. 1997, Tsai et al. 2007), and sedimentation is considered the primary threat to playas (Smith et al. 2011). Playas within a tilled watershed typically experience a shorter hydroperiod relative to playas in untilled watersheds, although the mechanism is unclear, possibly resulting from reduction in basin volume as sediment depth increases, thereby inducing volume overflow and increased evaporative loss (Luo et al. 1997, Tsai et al. 2010), or from sediments keeping hydric soil cracks open and thereby facilitating infiltration (Ganesan 2010). Playas surrounded by cropland contain 8.5x the amount of sediment (Luo et al. 1997), which buries seed and insect egg banks (Gleason et al. 2003). Landscape fragmentation in the southern Great Plains has also been shown to impede the overland dispersal of amphibians (Gray et al. 2004), effectively isolating wetlands. Generally speaking (not just Great Plains), richness is lower in isolated wetlands for various insects (e.g. notonectids and dytiscids: Wilcox 2001; odonates: McCauley 2006).

Phenology

Changes in the timing of phenological events—such as flowering, migrations, and breeding—have been called a 'globally coherent fingerprint of climate change impacts' on plants and animals [Parmesan 2007]. Phenological shifts can result in perverse ecological effects, as there is a desynchronization of e.g. migratory birds and their prey, or pollinators and flowers. Simple shifts in phenology, as described below, can serve as sensitive and integrative indicators of climate change. More complex interactions between species and ecological processes are more difficult to detect, in part because little baseline data exists.

Climate-induced changes in phenology have been linked to shifts in the timing of allergy seasons and cultural festivals, increases in wildfire activity and pest outbreaks, shifts in species distributions, declines in the abundance of native species, the spread of invasive species, and changes in carbon cycling in forests. These fingerprints of climate change have been documented by scientists across the US using a variety of data sources. From Texas to Saskatchewan, length of pollen season for ragweed (Ambrosia spp.), a common human allergen, has increased from 1995-2009 by as much as 16 days certain areas (e.g., Fargo, ND). This increase was correlated with an increase in frost-free days as well as later onset of first frost in the fall, but not with annual precipitation Ziska et al. 2011). The mean laying

date of American Pipits (Anthus rubescens) has become approximately 5 days earlier, and mean clutch size has increased by 0.2 eggs in the mountains of Wyoming from 1961-2002. These changes were significantly related to earlier snowmelt, which occurred around 7 days earlier (Hendricks 2003). Using data from six locations throughout the Great Plains, it was observed that winter wheat is blooming 6 – 10 days earlier now than it was 70 years ago. Warming spring temperatures have also been observed over this same period [Hu et al. 2005].

Case Study: Shifts in Flowering Phenology in the Northern Great Plains Over 100 years [Dunnell and Travers 2011**]** [Make this a separate box]

Missouri Botanic Garden

First flowering dates (FFD) were compared for 178 species of plants from 1910-1961 and 2007-2010 in North Dakota. During this time period, temperatures increased 3°F from the first 9 years of the study to the last 9 years, and growing season duration increased from 132 days to 154 days. Between 24% and 41% of plants showed a change in flowering time when compared to flowering data for 2007-2010. More species showed a difference in FFD from the beginning of the century in the two warmer years of this study (2007, 2010) indicating that these species are sensitive to changes in temperature. It would be expected that these species that showed a strong response to climatic variables will show a continued response with increasing temperatures. More than 50% of the species did not show a change from earlier in the century. The reasons for this are unclear, but it is possible that the phenology of these species is not as tied to temperature or precipitation.

Predicting future community composition and timing

Based on how closely Konza community flowering tracks environmental conditions (Craine et al. in press) and its predictable differences from other floras, informed predictions about how future climate change may alter plant communities are possible. In Konza, where regional climate models consistently predict warmer future temperatures along with a more variable precipitation regime (Christensen, et al. 2007), a series of growing-season shifts may alter flowering. First, as found with many floras globally, early-season species may shift earlier as thermal sums required to trigger flowering

are met earlier. Alongside this, species invasions from donor floras may increase (Wolkovich and Cleland 2010) as the Konza season expands to increase overlap in phenological climatic space with floras such as those of Europe like Chinnor. Additionally, as the mid-growing season drought may become more pronounced--possibly reducing the number of species flowering mid-season—evidence of a such a shift towards a novel mid-season gap (or decrease) in flowering has already been suggested in other floras observationally (Aldridge, et al. 2011) and via experiments (Sherry, et al. 2007). Comparing the responses of flowering phenology to experimental warming and the differences in flowering between Konza and Fargo suggest a common inflection point around which flowering changes with changes in temperature. In an Oklahoma grassland experiment, warming caused early-flowering species to flower earlier and late-flowering species to flower later with an inflection point near mid- to late-July. This date range is similar to the July 14 inflection point for changes in flowering dates between Konza and Fargo. The universality of this mid-July date remains to be seen, but it appears to serve as a consistent benchmark for predicting the responses of flowering phenology to warming (Sherry, et al. 2007).

Phenological Indicators – Extended Spring Index

Schwartz et al. (2006) provided a set of modeled and derived phenoclimatological measures that reflect increasing temperature in the northern hemisphere. Schwartz et al. (2006) developed their spring index from station-level weather observation and confirmed the efficacy of the index from observations of cloned lilac and honeysuckle. The spring index has now been extended to areas outside the range of lilacs and honeysuckle (McCabe et al. 2011) and it reveals that first leafing and blooming dates have increased by as much as 8 days since the 1950's (Figure first leaf) in the northern Great Plains. The extended spring index and geographically sensitive, and unchanged or even later dates are reported for southern Great Plains regions.

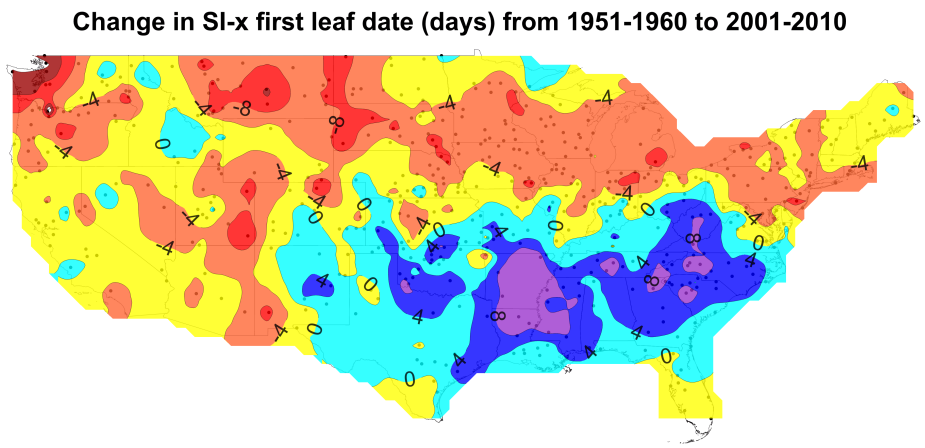


Figure 16 Changes in first leafing date as determined from the enhanced spring index (McCabe et al. 2011; Figure from M. D. Schwartz, U. Wisc.)

Effects of Climate Change on Vegetation and Ecosystems of the Great Plains

In general, patterns and dynamics of grassland ecosystems in the Great Plains are driven by climate and soil patterns with additional influences on species composition, biomass production and nutrient cycling induced by herbivory (livestock, wildlife, and insects) and biological responses, differences in plant nutrient use efficiency, water use efficiency, wildfire, plant disease, nutrient cycling and biomass decomposition. All of these are potentially affected, directly and/or indirectly by climate change (e.g. King et al., 2004; Morgan et al. 2008).

Strong gradients of temperature and precipitation help define the composition and structure of vegetation across the Great Plains (Lauenroth & Burke 1995; Peterson and Cole 1995). Mean temperatures increase from 4°C in Montana to 20°C in central Texas. Generally, the optimum temperature for photosynthetic rate in C4 plants is higher than for C3 plants (Black 1973, Ehleringer 1978, Epstein et al. 1998), however experimental trials at Long-Term Ecological Research sites indicate that increased concentrations of CO2 decrease actual evapotranspiration (AET) and increase efficiency of gas exchange disproportionately favoring C4 species.

Temperatures are projected to continue to increase across the Great Plains over this century, with summer changes projected to be larger than those in winter especially in the south-central plains (Christensen, et al. 2007). The average temperature in the Great Plains already has increased roughly

1.5°F relative to a 1960s and 1970s baseline. By the end of the century, temperatures are projected to continue to increase by 2.5°F to more than 13°F compared with the 1960 to 1979 baseline, depending on future anthropogenic emissions. Specific ecosystem effects of warming are unclear, given the complexities of interactions with soils, nutrients, CO_2, grazing and fire. Warming experiments in tallgrass prairie suggested increasing soil temperatures 2°C extended the growing season and yielded greater aboveground productivity, but did not affect belowground productivity (Wan et al. 2005). Whereas, in a mixed grass ecosystem, warming the canopy 3°C increased Nitrogen use (Dijkstra et al. 2010) without clear, overall effects on above or belowground productivity (Morgan et al. 2011). Projected increases in temperature, evaporation, and drought frequency add to concerns about the region's declining water resources. Water is the most important factor affecting activities on the Great Plains. Most of the water used in the Great Plains comes from precipitation and the High Plains aquifer (also known as, the Ogallala aquifer), which stretches from South Dakota to Texas and receives recharge from precipitation.

Precipitation gradients are also very strong across the region with mean annual deposition ranging from 30cm in the short-grass steppe along the foothills of the Rocky Mountains, to more than 100cm per year approaching the Mississippi River. Precipitation is projected to increase in the north and decrease in the southern high plains, including potential shifts in snowpack, spring rainfall and extreme events. Water availability and droughts here can critically affect threatened regional water resources, including the Ogalalla (High Plains) Aquifer, which are essential for agriculture, natural systems, protected species, and the health and prosperity of its citizens. The aquifer receives recharge from precipitation which mixes with "ancient" water which has been stored in subterranean basins since it washed down from the Rocky Mountains during the last ice age. As population increased in the Great Plains and irrigation became widespread, annual water withdrawals began to outpace natural recharge (McGuire 2007). Approximately 19 billion gallons of groundwater are pumped from the aquifer daily to irrigate 13 million acres of land and provide drinking water to more than 80 percent of the region's population (Dennehy 2000). Since 1950, aquifer water levels have dropped an average of 13 feet, equivalent to a 9 percent decrease in aquifer storage. In heavily irrigated parts of Texas, Oklahoma, and Kansas, reductions are much larger, from 100 feet to over 250 feet. Projections of increasing temperatures, faster evaporation rates, and more sustained droughts brought on by climate change will only add more stress to overtaxed water sources. (Lettenmaier et al. 2008; Backlund et al. 2008; Gurdak et al. 2007; Green et al 2007). Current water use on the Great Plains remains unsustainable, as the High Plains aquifer continues to be tapped faster than the rate of recharge. Without the irrigation buffer of the aquifer, agriculture on the high plains may become tenuous, and land-use changes including

abandonment of formerly productive croplands may be induced by water availability factors. It is unclear, at this time, what role these lands could have in the adaptive response of Great Plains ecosystems to climate changes.

By itself, changes in temperature affect both the rates of chemical reactions and also affect exchanges of energy between the land and the atmosphere. Kinetic responses have the potential to increase plant growth (Luo et al. 2009), speed up plant development (Cleland et al. 2006; Sherry et al. 2007; Hovenden et al. 2008), and increase the decomposition of soil organic matter (Rice et al. 1998). These same potentials can also be limited by soil moisture, and as a result, warming may increase the plant growth in rangeland systems in years with adequate moisture, but have little effect, or even negative effects, when soil moisture is inadequate and warming leads to increased evapotranspiration rates and desiccation (Fay et al. 2011; Morgan et al. 2011; Pendall et al. 2010; Xia et al. 2009).

Vegetation responses to rising atmospheric CO_2 concentration, warming, and other climate changes are regulated by interactions with independent variables including soil type which strongly influences plant and soil water relations, the regional species pool from which new species may enter an ecosystem, the disturbance regime, and synoptic climate. The disturbance regime and available species pool at any given location may be decisive in dictating vegetation responses to climate change. In general, however, each of the primary climate change drivers, including CO2 enrichment, warming, and an anticipated increase in precipitation variability and extreme weather events, influence vegetation by affecting soil water availability to plants. Given the strong imprint of the east to west gradient of declining precipitation on the composition and structure of semi-natural vegetation in the Great Plains, we anticipate that the collective effect of climate change drivers on vegetation will be manifest mainly through changes in soil water availability. These effects are evident in manipulative experiments with each of the individual aspects of climate change. For example, CO2 effects on vegetation composition usually are linked to the water-savings effects of CO2 enrichment on grasslands (Morgan *et al.* 2004*b*).

CO2 enrichment has modified species abundances in ecosystems as diverse as Swiss grassland and semi-arid shortgrass steppe by slowing soil water depletion and preferentially increasing seedling recruitment of certain species (Niklaus *et al.* 2001; Morgan *et al.* 2004*a*). In contrast, CO_2 had little effect on species abundances in C_4-dominated tallgrass prairie in Kansas, USA (Owensby *et al.* 1999), presumably because the growth of the shorter C_3 species was limited by low light or N availability, or C_3 plants were incapable of exploiting the mid- to late-season improvement in soil water that occurred at elevated CO_2.

Additional stressors

The removal of grazing and the suppression of fire from the Great Plains cause a decline in species diversity (Leach and Givnish 1996, Collins et al. 1998) and negatively impact ecosystem function. Fire suppression has caused an increase in woody plant encroachment (Bragg & Hulbert 1986; Schmidt and Leatherberry 1995) in the Great Plains. *Juniperus virginiana* and *Cornus drumundii* are two woody plant species of conservation concern in tallgrass prairie because of encroachment into native prairies modifying productivity patterns (Norris et al. 2001b; Lett et al. 2004; Lett and Knapp 2005) and decomposition dynamics (Norris et al. 2001a) which has consequences for regional carbon storage. In addition to woody encroachment, non-native plant species are invading the Great Plains, many of which are C3, cool season annual grasses (Cully et al. 2003). Extreme climatic events may increase plant invasions since disturbance is positively associated with plant invasion (Hobbs and Huenneke 1992). In addition both native and non-native species have the potential to become invasive as grazing and fire regimes are altered (Simberloff 2008), as climate, and humans, expand the potential habitat of species (Barney & DiTomaso 2010), and as monocultures of crops increase in land cover (Hartman et al. 2011). Complicating matters, woody plants have the potential to survive, and even thrive, with altered precipitation patterns as they access water from deeper soils than the dominant prairie plant species do (Ratajczak et al. 2011).

Significant amounts of atmospheric deposition of nitrogen, primarily from burning of fossil fuels, continue to be deposited across regions that are typically nitrogen limited. Increased nitrogen inputs due to both atmospheric deposition and runoff from agricultural areas (Vitousek et al. 1997) will likely continue to have large effects on the plant communities of the Great Plains. Nitrogen has a stronger effect on plant communities where water is not the primarily limiting factor, such as in mixed and tallgrass prairies. Increased nitrogen availability tends to result in decreased plant diversity, while increasing plant production (Wedin and Tilman 1993; Gough et al. 2000; Clark et al. 2007). Forbs and woody plants have been shown to increase in abundance with nitrogen, with the dominant C4 grasses decreasing in abundance (Seastedt et al. 1991; Briggs et al. 2005; Bond 2008).

The turnover in plant community composition as a result of global change factors may have strong functional consequences for the way prairie systems respond to altered precipitation and temperature patterns. The current prairie community, dominated by perennial C_4 grasses, is well adapted to deal with high variability in rainfall and temperature (Knapp and Smith 2001; Weltzin et al. 2003; Huxman et al. 2004). However, the decline of these dominant grasses due to one or several of the potential mechanisms would have unknown, but likely detrimental consequences. For example, due to

efficiencies of the C4 pathway (versus C3 pathway) the newly formed communities may be poorly adapted to variations in precipitation and temperature. Considering the phenology and functional traits of species dominating these altered communities will prove important for estimating local effects of climate change on the prairie systems of the Great Plains into the future.

Ecosystem Services and Human Uses

Land cover and land-use across this region is dominated by livestock based agriculture, especially cattle (see Section 3) and irrigated crops. However, within this matrix, untilled remnants of natural prairie retain ecosystems and habitats of the high plains region as a interspersed network of managed rangelands and natural areas. Agriculture has typically reduced the nutrient capacity of Great Plains soils through tillage and biomass extraction (Peterson and Cole 1995); however ungulates and grazing animals typically develop a somewhat symbiotic relationship with productivity patterns and nutrient cycling (Augustine et al. 1998) suggesting that natural patterns may be retained with some agro-economic systems.

All life on the Great Plains, including agriculture, depends on water, but human systems continue to deplete stored water (aquifers), alter (damage) recharge-wetlands (e.g. playas and prairie potholes), and degrade soil stability in watersheds through tillage and fertilization. Sedimentation from plowed fields surrounding wetlands is the greatest threat to conservation of these wetlands and the habitat, biodiversity and ecosystem services associated with them. Large rainfall events, especially after periods of prolonged drought, interact with exposed and tilled soils generating significant quantities of sedimentation and topsoil degradation (LaGrange et al. 2011).

Tallgrass prairie has been reduced to 1% of its historic land cover in North America (Samson and Knopf 1994), and unfortunately what remains of the Great Plains is being threatened by more global change factors than climate alone. Continued land use change, woody vegetation encroachment, plant invasions, and anthropogenic increases in nitrogen are of high conservation concern in the Great Plains Region. Individually these global change factors have serious consequences for community composition and ecosystem function, and each of these drivers has the potential to interact both directly and indirectly with climate change. Land use change though conversion of native grasslands into cultivated cropland results in decreased soil carbon storage, decreased biodiversity, and increased soil erosion (Davidson and Ackerman 1993; Parton et al 2005), and changes in grassland management through grazing and fire regimes has strong impacts on ecosystem health. Typical domestic grazing practices and

the suppression of fire from Great Plains grasslands cause declines in species diversity (Leach and Givnish 1996, Collins et al. 1998) and negatively impact ecosystem function.

Therefore, untilled rangelands offer the most promising reserve of native species and functioning Great Plains ecosystems, and the fragmented distribution of these lands represents the spatial framework for a spatial distribution of native plant and animals across the region in the future, but restoration of landscape-scale processes, especially in the context of climate change, presents a critical challenge for managers, planners and society.

Native ecosystems of the Great Plains supply important connections to history and heritage as well as critical ecosystem services to the people of the region. Indigenous Americans have a long relationship with the plants, animals and landscape, including plants used for traditional medicines and ceremonies. The plasticity, mobility and resilience of these species is largely unknown, but may be supported though supporting the ecosystems that supply these resources. Millions of bison (Bison bison) once ranged this landscape, and while the massive herds of history are lost, economic and ecological visions for restoration of these herds exist today. Forage for domestic livestock and wildlife from native rangelands, clean water from wetlands and the associated aquifer and critical habitats for millions of migratory water fowl in the spring and fall of each year are modern examples of services provided to humans on this landscape. The ecosystems of the Great Plains represent a critical resource base for indigenous peoples, ranchers, wildlife and urbanites via productive grasslands and wetlands. Changes in precipitation patterns and evapotranspiration budgets, accompanied by other human influences including land-use patterns, nutrient depletion, nutrient supplementation and CO2 enrichment will present challenges to all of these populations as the future unfolds.

Freshwater Ecosystems

Depressional wetlands

Two main types of wetlands in the Great Plains form a collective network of aquatic habitat in an otherwise semi-arid region. In the northern Great Plains, prairie pothole wetlands are glacially formed and heterogeneous in structure and hydrology. In the central and southern Great Plains, playa wetlands are aeolian equivalents of prairie potholes, but are far more uniform in shape and structure. Both types of wetlands are runoff-fed with variable hydroperiods that may be temporary to effectively permanent.

Pothole wetlands of the PPR range from freshwater ponds and marshes with ephemeral and temporary water regimes to more permanent, fresh and saline lake, as well as riverine wetlands They

range in size from <0.5 ha to >5,000 ha, although the vast majority are <1 ha with average water depths of <1 m. By some estimates, the number of wetlands throughout the entire PPR is upwards of 9 million (M. Goldhaber, pers. communication).

Playa wetlands have discrete clay basins, are typically <1 m in depth, and range in size from <1 to >300 ha in surface area (Smith 2003). The average size (surface area) is 6.3 ha and most are less than 12 ha in size. There are an estimated 60,000-80,000 such wetlands in the Great Plains of the U.S. (encompassing portions of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, and Texas), with approximately one-third of these in Texas alone. Playas are the primary source of aboveground freshwater for wildlife in this region and are the primary source of recharge for the Ogallala Aquifer (Bolen et al. 1989). But, playa also represent critical sources of biodiversity, accounting for approximately 350 different plant species (Haukos and Smith 1997) and providing critical migration and wintering habitats for nearly 200 species of birds.

Importantly, hydrologic functions, including timing and duration of water inundation of playas is a function of interactions between climate, topography, soil and vegetation cover, and land-use patterns (Haukos and Smith 1994, Smith 2003, Tsai et al. 2007, 2010).

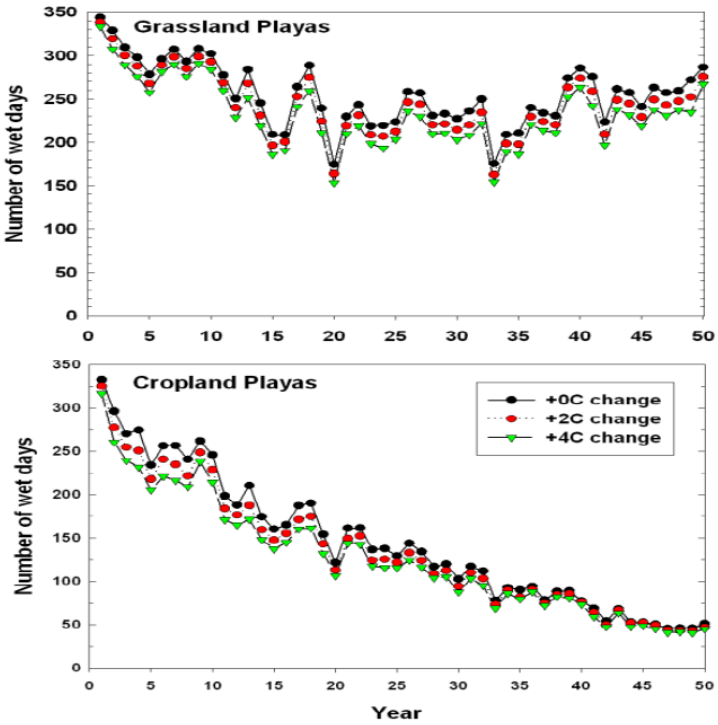


Figure 17 Duration of inundation of playa lakes wetlands within untilled grasslands and croplands, from Tsai, et al 2007.

In the conterminous U.S., an estimated 50% of wetlands have been lost in past 200 years (Dahl 1990), mostly in the Great Plains. Most of the remaining wetlands in the Great Plains are intermittent, so any organisms present must have withstood a selective filter for adaptation to ephemeral habitat resources. These wetlands form a naturally spatially heterogeneous and temporally dynamic system under intense anthropogenic demands (from agriculture) as well as one expected to be acutely impacted by climate change. Under current climate conditions, Great Plains wetlands go through frequent, naturally occurring but unpredictable, wet-dry fluctuations (Haukos and Smith 1994). The timing and duration of these fluctuations is critical to their ecology and delivery of ecosystem services.

Streams and Rivers

Great Plains streams and rivers are among the most fragmented freshwater systems in the United States (Sabo et al. 2010), and this fragmentation is associated with extirpation and reduced population level of some fish (Perkin and Gabo 2011). The combined effects of water diversions, impoundments, and increasing water temperatures are likely to threaten many of the remaining species in the Great Plains region.

Habitat fragmentation and flow regulation which reduce the amount of water in streams (often leading to zero flow in both large and small rivers in this region) for agricultural and domestic uses contributed to declines in the abundance and distribution of native stream-dwelling fauna (Fahrig 2003, Helfman 2007). Within the contiguous United States, 85% of rivers are fragmented by impoundments that disrupt organism movement and alter streamflow (Hughes *et al*., 2005) and these disturbances are associated with the declining and imperiled status of approximately 40% of North American freshwater and diadromous fishes (Jelks et al. 2008). Habitat degradation and population effects associated with fragmentation of river habitats include altered geomorphic processes and flow regimes, alteration of dispersal dynamics and isolation of sub-populations, altered phenology and reproductive cues, and overall reduction in amount of contiguous habitat (Gido et al. 2010). Among the principal factors, alteration to flow regime is most commonly implicated in the decline of stream-dwelling fish populations, and a growing body of literature suggests flow regime is a major component required for maintaining integrity within stream fish communities (e.g. Baxter 1977, Poff et al. 1997, Marchetti and Moyle 2001, Lytle and Poff 2004, Propst and Gido 2004, Taylor et al. 2008, Gido et al. 2010). For example, magnitude of floods and high flow pulses that maintain in-stream habitat are reduced following impoundment (Richter et al. 1996, Perkin and Bonner 2010) and depending upon reservoir management, downstream reaches of impounded streams may experience reductions in mean annual flow and an increase in number of days with zero flow (Bonner and Wilde 2000). As water availability fluctuates, due to weather and climate, and human demands increase, water reserved for in-stream habitats and species will be more heavily contested and restricted making flow regimes a critical concern for conservation of Great Plains fish under future climate scenarios.

These patterns of decline transcend spatial scales (i.e., the entire Great Plains), include multiple levels of phylogeny (i.e., 4 genera, 16 species, 2 subspecies; Platania and Altenbach 1998, Durham and Wilde 2009a, Gido 2010). The relative abundance of extirpated populations among eight species of suspected or confirmed pelagic-spawning cyprinids is positively correlated with minimum fragment

length, indicating that stream fragmentation has played a role in observed declines in abundance and distribution.

Human Uses & Impacts

Water is the most important factor affecting activities on the Great Plains. Most of the water used in the Great Plains comes from the High Plains aquifer (sometimes referred to by the name of its largest formation, the Ogallala aquifer), which stretches from South Dakota to Texas. The aquifer holds both current recharge from precipitation and ancient water trapped in sediment layers washed down from the Rocky Mountains during the last ice age. As population increased in the Great Plains and irrigation became widespread, annual water withdrawals outpaced natural recharge (McGuire 2007). Approximately 19 billion gallons of groundwater are pumped from the Ogallala aquifer each day. This water irrigates 13 million acres of land and provides drinking water to over 80 percent of the region's population (Dennehy 2000), the rest of the water comes from rivers, and reservoirs constructed to restrain the flow of surface water for later use.

Scarcity of water resources on the western prairies, as well as the western water law philosophy of "prior appropriation", often pits human needs in conflict with each other and with environmental conservation. Sustaining river flows is a fundamental requirement for the persistence of Great Plains fishes and other aquatic species but this water is also coveted for agricultural and domestic uses. As the global climate changes, many models have indicated the propensity and duration of drought on the Great Plains could increase. Increased droughts will increase the probability of conflict between anthropogenic demands and aquatic species requirements just as the need to maintain healthy habitats increases to support adaption to uncontrollable changes, i.e. climate. Connections between land-use practices, wetlands, surface water and groundwater extend the importance and relevance of water availability and water use beyond aquatic environments; the condition and distribution of upland habitats and native grasslands has implications for biodiversity, wildlife conservation and water quality/quantity across the entire Great Plains region. Collaborative, regional efforts have emerged to develop and support opportunities for cooperation and coordination, supporting financial efficiency and regional planning. Increased public knowledge of environmental issues is critical for the continuing success and expansion of these programs.

Responses of Wildlife

Birds

Grassland birds are the most consistently declining of all groups of North American avifauna, with 48% of species being of high conservation concern (North American Bird Conservation Initiative, U.S. Committee 2011). These declines have been attributed, in large part, to land conversion and the intensification of agriculture, yielding the critical bird habitat in the Great Plains among the most threatened landscapes in North America. The population declines likely will be exacerbated by climate change as vegetation and invertebrate food resources respond to altered precipitation, warmer temperatures, and higher rates of evapotranspiration that are expected across the nation's grasslands (North American Bird Conservation Initiative, U.S. Committee 2010, 2011). The differential responses among species to environmental change suggest that present day species assemblages will reconfigure as individual species respond uniquely to the same perturbations.

Wetland-dependent birds such as waterfowl, shorebirds, wading birds, and riparian associates are another important component of avian biodiversity in the Great Plains. Projected rises in temperature and evapotranspiration will undoubtedly strongly impact wetland ecosystems and the species dependent upon them, several of which are considered to have medium or high vulnerability to climate change, including Western Grebe's (Aechmophorus occidentalis), Clark's Grebes (A. clarkii), and Northern Pintails (Anas acuta) (North American Bird Conservation Initiative, U.S. Committee 2010). The shallow depressional wetlands in the playa and prairie pothole regions of the southcentral and northern Great Plains, respectively, are acutely threatened by climate change impacts on water levels and sedimentation from upland erosion (North American Bird Conservation Initiative, U.S. Committee 2010; Johnson et al. 2011, Burris and Skagen in review).

Amphibians and reptiles

Human activities have affected several species of amphibians and reptiles during the past century. At the eastern and northern margins of the Great Plains, wetland drainage and commercial harvesting have severely reduced populations of the northern leopard frog, *Lithobates pipiens* (Koonz 1992; Lannoo et al. 1994). Prairie streams, important habitats for leopard frogs (*L. pipiens* and *L. blairi*) in drier portions of the Great Plains (Lynch 1978), have been greatly altered by land-use practices (Dodds et al. 2004). In addition, large areas of terrestrial habitats have been degraded or lost, likely influencing the persistence of some native reptile species (Gibbons *et al.* 2000). Future climate change may affect distribution of amphibian and reptiles species indirectly by altering habitat availability, or directly by

affecting population demographic characters. There is some evidence for climate-related extinctions of lizards in Mexico (Sinervo *et al.* 2010), although the impact of climate change on reptiles will likely vary by species. Although effects of climate change on amphibians are also diverse (Corn 2005), populations in the Great Plains are less likely than reptiles to benefit from warming temperatures, yet the benefits and costs of climate change to lizards are also poorly understood.

Fish

Stream size is the most important environmental factor determining fish distributions (Schlosser 1982; Fisher and Paukert 2008), however stream habitat and fish assemblages throughout the Great Plains are not uniform (Matthews 1988) and substrate composition and in-stream cover also have important roles in structuring fish assemblages in the region. Large streams and rivers of the region are typically broad, shallow, and often braided with sandy substrates and elevated levels of dissolved solids (Matthews 1988). Riparian cover of narrower streams canopy is often higher, increasing thermal cover. These physical attributes are important determinants of the distribution of species across the region, for example the presence and abundance of the Arkansas darter is associated with narrower streams containing an abundance of in-stream cover (Haslouer et al. 2005), and the plains topminnow is strongly associated with small streams with abundant plant cover (Fisher and Paukert 2008). Furthermore, extensive and sometimes intensive agricultural operations in the watersheds that feed into the Great Plains Rivers (Missouri, Platte, Arkansas, Republican/Canadian and Red) provide measurable loading of sediments and contaminants, including nitrogen, phosphorus, pesticides and herbicides degrading water quality and habitat conditions (Huntzinger 1995). Extreme events are forecast to increase in magnitude and frequency in several climate models, and these events typically trigger increased rates of overland flow as precipitation rate exceeds infiltration rate. Case studies indicate a two to three-fold (2-3x) increase in contaminants due to runoff after storm events (Ellis et al. 1984, Staver et al. 1996).

Beyond the general class and characteristics of a stream reach, reproductive success of pelagic-spawning cyprinids is dependent on stream discharge to initiate spawning (Durham and Wilde 2006, 2009a), to retain eggs in suspension long enough for hatching (Bottrell et al. 1964) and larval fitness and survival, a critical population bottleneck (Wilde and Durham 2008, Durham and Wilde 2009b). Thus, the timing and volume of spring run-off as well as mid-season flows, which are the product of weather and land use, within the watershed, have important implications for the survival of these species. Extirpation of pelagic-spawning cyprinids has been greatest in the central and southern Great Plains regions, correlated with notable reductions in discharge since at least the 1970s (Cross et al. 1985, Pigg 1987,

1991, Gido et al. 2010). Further, these same regions include stream fragments created by desiccation whereby water does not flow for a majority of the year.

These impacts are chronic but not irreversible, however climate induced water limitations and drought will magnify the effects of increasing demand for water making conservation of species dependent on these habitats dependent upon securing in-stream flows during low-water years. Even when sufficiently long reaches are provided (i.e. >140 km) declining populations of the majority of pelagic-spawning cyprinids were extirpated (73%) of occurrences when stream discharges were reduced by at least half (Gido et al. 2010). Consequently, the possibility exists for reductions in discharge, both related to anthropogenic withdrawal and climate change, to contribute to declines and extirpations among Great Plains pelagic-spawning cyprinids (see Taylor 2010) and other fluvial organisms, notably fishes (Poff and Zimmerman 2010). In the U.S., 70 species of mussels and 32 species of snails are federally listed as endangered or threatened (USFWS 2005).

Invertebrates

Freshwater ecosystems are among the most imperiled ecosystems on Earth: globally, freshwater biodiversity is declining faster than in any terrestrial ecosystem (Revenga et al. 2005). Owing to their short generation times, macroinvertebrates such as insects should be particularly sensitive to changes being elicited by our changing climate. Of the invertebrates that have been used as indicators of climate change effects, odonates (Insecta: Odonata, dragonflies and damselflies) have figured prominently (Samways 2008). Odonates serve as umbrella species for overall wetland conservation (Oertli 2008), and are one of the chief taxa being used to test climate projections (Oertli 2010). Climate change may already be eliciting effects in odonate distributions and life history characteristics (Flenner and Sahlén 2008, Hassall and Thompson 2008). For example, range shifts attributed to climate change have been documented for odonates in the U.K., with distributions moving higher in latitude and altitude in recent years for several species (Hickling et al. 2005), and phenological shifts have been noted in the timing of emergence (Hassall et al. 2007). A recently developed North American data warehouse for odonata distributional data (over 300,000 vetted records from professional and citizen scientists; www.odonatacentral.org), however, will allow us to use a time-series of data that are necessary to distinguish natural variability from trends generated by climate change.

Although overall productivity can be quite high, invertebrate diversity in prairie wetlands is comparatively low because the abiotic conditions are highly variable and often harsh (e.g., Euliss et al., 1999; Tangen et al., 2003; Schultz, 2009). Invertebrate community composition is influenced to a large

degree by hydrology (e.g., hydroperiod), salinity, and vegetative structure. A majority of the invertebrate taxa are quite resilient to these harsh and variable conditions. For example, ephemeral wetlands that hold water for only a few weeks per year are inhabited by specialized invertebrates capable of completing their life cycles very rapidly, and highly saline wetlands are dominated by taxa with mechanisms for maintaining their osmotic balance. Under the more extreme conditions, however, diversity is often low (Swanson et al, 1988; Euliss et al., 1999; Gleason et al., 2009). Invertebrate taxa that inhabit prairie wetlands are generally hardy and thus may be somewhat resilient to direct impacts of climate change.

Because hydroperiod is a well-documented driver of the abundance and distribution of numerous aquatic species (Williams 1997, 2006) that is predicted to be radically altered by climate change, impacts should be particularly seen in the population dynamics and community structure of animals occupying lentic habitats. With predicted changes in the timing and amount of precipitation, the timing of snowmelt, and temperature, changes in wetland water budgets resulting in altered hydroperiods and salinity levels in turn may affect invertebrate community structure and productivity. For example, in the northern Great Plains, increased precipitation could extend hydroperiods and indirectly affect invertebrate productivity by moderating the nutrient cycling normally promoted during drying periods. Extended hydroperiods, elevated water depths, and increased wetland connectivity also could result in conditions that are more favorable for colonization by fish, which have been shown to impact ecosystem structure and aquatic invertebrate communities (Zimmer et al., 2000; Tangen et al., 2003; Hanson et al., 2005). Lastly, fluctuations in snowpack and temperature may affect the timing of the preliminary spring hatch of invertebrates associated with the smaller, seasonal wetlands.

Management Opportunities and Challenges

The dynamic nature of climate has long been an issue of duality, where land managers simultaneously recognize the inconsistencies in weather (rainfall, drought, etc.), but neglect moderate to long-term considerations of patterns in weather for guiding understanding of the systems and planning for management in the future. This is true, in part, because the planning horizon for most units is ten to twenty years. But long-term perspectives, along with forecasts and observations, indicate that rapid changes and extreme variations in weather are possible, even within these planning horizons, and certainly into the next. From a management perspective, whether the focus is commodities, or conservation of species, the dynamics of climate represent yet another uncontrollable variable affecting health and productivity of systems. This puts climate change in a dubious category, along with land use,

resource extraction, pollution and economic production, of factors and forces that contest/challenge sustainability of operations and conservation of species and wild habitats. The primary underlying drivers that challenge conservation of ecosystems and biodiversity in the face of climate change include alteration of freshwater systems, land use intensification (especially conversion of terrestrial and wetland systems to agriculture and domestic purposes), habitat fragmentation (division and isolation of remnant natural systems), and modification of natural processes such as fire and herbivory. The relatively low proportion of land protected for conservation clearly indicates that conservation will be effective only through broad-scale partnerships that will likely include public, private, and NGO parties.

Despite the relatively small area with protected status, National Parks in the some basins of the Great Plains host the majority of remaining native fish species (Lawrence et al. 2011). On one hand, these relict populations offer hope for conservation and expansion of native species to all or part of their former ranges; on the other hand, these fragmented relicts might represent the survivors of an anthropogenically induced bottleneck. If the latter case is reality, observing the subsequent extinction and/or fitness of species as these new populations are tested by climate variability will provide an informative, but potentially gruesome, evolutionary experiment. The interaction of natural and anthropocentric management of grasslands, and former grasslands (i.e. agriculture and urban), across the Great Plains promises to be challenging and contentious. Agriculture and other intensive land uses destabilize the soil profile and enable transport (loss) of critical nutrient and water retention capacities (Samson et al 2004). Therefore, opportunities for conservation of native grasslands, including species and processes, lie primarily and most immediately on a fragmented network of untilled prairie. Most of these lands continue to receive intensive use, especially domestic grazing, and while these systems developed with significant grazing pressure, the historic herds of the Great Plains adapted to climate, disturbance and associated habitat variability by migrating (Samson et al. 2004) but modern land-use patterns and structures preclude landscape-scale migrations. It will be difficult to restore these large-scale processes across the region, however restoration of processes, conservation of remnant species and habitats, and consolidation/connection of fragmented areas at landscape and local scales will be necessary to provide conservation of species and ecosystem services across the ecoregion. New adaptations and flexibility is needed at the interface between native habitats and ecosystems and agriculture. Recent history is characterized by sod-busting, wetland draining and open range fencing, but relatively little emphasis and effort have been placed on restoration of abandoned prairies. The realities of climate and groundwater supplies promise to force change on human structure and infrastructures that attempt to restrict and restrain natural variability. Renewed emphasis on soil and wetland

restoration, not simply dumping refined sewage on degraded soils or manufacturing retention ponds, but restoration of species and processes that provide critical ecosystem services, including soil stability and health, water conservation, aquifer recharge, forage for wildlife and domestic herbivores. In turn, these species and processes can support a sustainable socio-economic system where local products, tourism and culturally significant species accompany large-scale agriculture, industry, and international trade as fundamental components of society. Although industry and investment bankers prefer structure and stability (due to perception of strength and insurance), civilization in this region, and likely elsewhere, must embrace dynamics and adapt.

Managing for standardized vegetative goals precludes endemic species at the ends of the ecological continuum of grazing activity. Managing in the middle across broad landscape manages against species that require heavy grazing to create open areas and those that require lighter grazing that leaves more residual vegetation for the subsequent season's nesting cover. Managing for the middle across broad landscapes is managing to promote listings of species under the Endangered Species Act (1973) (Samson et al. 2004).

Successful adaptation of human systems and conservation of natural systems, with any semblance of healthy function will require (1) vision and regional scale planning and implementation, (2) renewed emphasis on restoration of ecological systems and processes, (3) recognition of the value, importance and "reality" of natural dynamics and diversity, and (4) considerable "luck" because changes such as extinctions can occur rapidly when populations are small and mobility is restricted and while ecological understanding has expanded tremendously in the past 100years, we know very little about many of these species and systems.

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CLIMATE OF THE U.S. Great Plains

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DRAFT

1. INTRODUCTION

This document describes the climate of the Great Plains in support of the upcoming 2013 National Climate Assessment report. It includes a discussion of the observed historical climate and of future projections of climate conditions based on simulations by global and regional climate models.

The description of the historical climate focuses on trends in key climate conditions and identifies climate factors that are important in the region. Many of the trend analyses are based on data from the National Weather Service's cooperative observer network, which has been in operation since the late 19th Century.

With regard to the future, the National Climate Assessment Development and Advisory Committee (NCADAC), at its May 20, 2011, meeting, directed the "use of simulations forced by the A2 emissions scenario as the primary basis for the high climate future and by the B1 emissions scenario as the primary basis for the low climate future for the 2013 report" for climate scenarios. Furthermore, they approved "the use of both statistically- and dynamically-downscaled data sets". This outlook responds to these directives by incorporating analyses from multiple sources. The core source is the set of model simulations performed for the IPCC Fourth Assessment Report (AR4), also referred to as the Climate Model Intercomparison Project 3 (CMIP3) suite. These have undergone extensive evaluation and analysis by many research groups. A second source is a set of statistically-downscaled data sets based on the CMIP3 simulations. A third source is a set of dynamically-downscaled simulations, driven by CMIP3 models. This outlook does not incorporate any CMIP5 simulations as relatively few were available at the time that the data analyses were initiated.

DRAFT

2. REGIONAL CLIMATE TRENDS AND IMPORTANT CLIMATE FACTORS

General Description of Great Plains Climate

The Great Plains region is characterized by a highly diverse climate with large spatial variations. The great latitudinal range of this region leads to a very wide range in temperatures; the region includes both some of the coldest and hottest regions of the coterminous U.S. as well as some of the wetter and drier regions. In addition to the latitudinal range, several geographic factors contribute to this variability. Because the mountains to the west of the region largely block moisture from the Pacific Ocean, the Gulf of Mexico is the major source of moisture for this region. Intrusions of moisture from the Gulf of Mexico become less reliable and infrequent the further north and west one goes. The lack of mountain ranges to the north means that the region is exposed to outbreaks of Arctic air that can bring bitter cold during the winter. The polar jet stream is often located near or over the region during the winter, with frequent storm systems bringing cloudy skies, windy conditions, and precipitation. Eastern and southern parts of the region are characteristically warm and humid due to a semi-permanent high pressure system in the subtropical Atlantic that draws warm, humid ocean air into the area. Summer also tends to be the rainiest season, with short-lived rainfall and thunderstorms. Precipitation tends to be erratic, and severe droughts occur from time to time. The Dust Bowl era of the 1930s brought extreme drought and heat, and is arguably the worst climate-related disaster in U.S. history. Potentially dangerous storms occur in every season. Winter can bring major snowstorms, damaging ice storms, or both. Warmer months, typically March-October, have heat waves and convective storms, including thunderstorms and lightning, flood-producing rainstorms, hail, and deadly tornadoes. This area has the highest incidence of tornadoes in the world due to the unique confluence of several geographical factors. Hurricanes are a major weather phenomenon for the coastal region of Texas.

The Great Plains has a very wide range of annual average temperature (Fig. 1). The coldest temperatures of less than 40°F occur in the higher mountain areas of Wyoming and Montana and along the northern border with Canada. By contrast, the average annual temperatures in south Texas are greater than 70°F.

Average annual precipitation (Fig. 2) also exhibits an extremely large range, illustrating the particular geographic features that determine the frequency of high moisture transport from oceanic sources. The far southeastern part of the region receives more than 60 inches per year, while some of the far western areas receive less than 10 inches per year.

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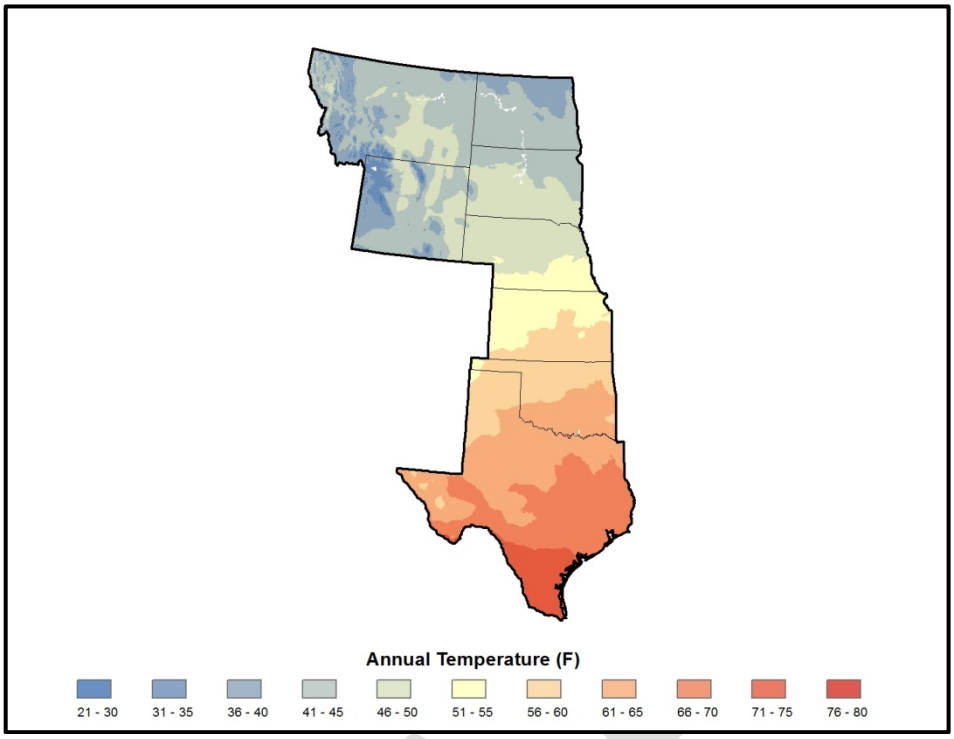


Figure 1. Average (1981-2010) annual temperature (°F) based on National Weather Service cooperative observer stations.

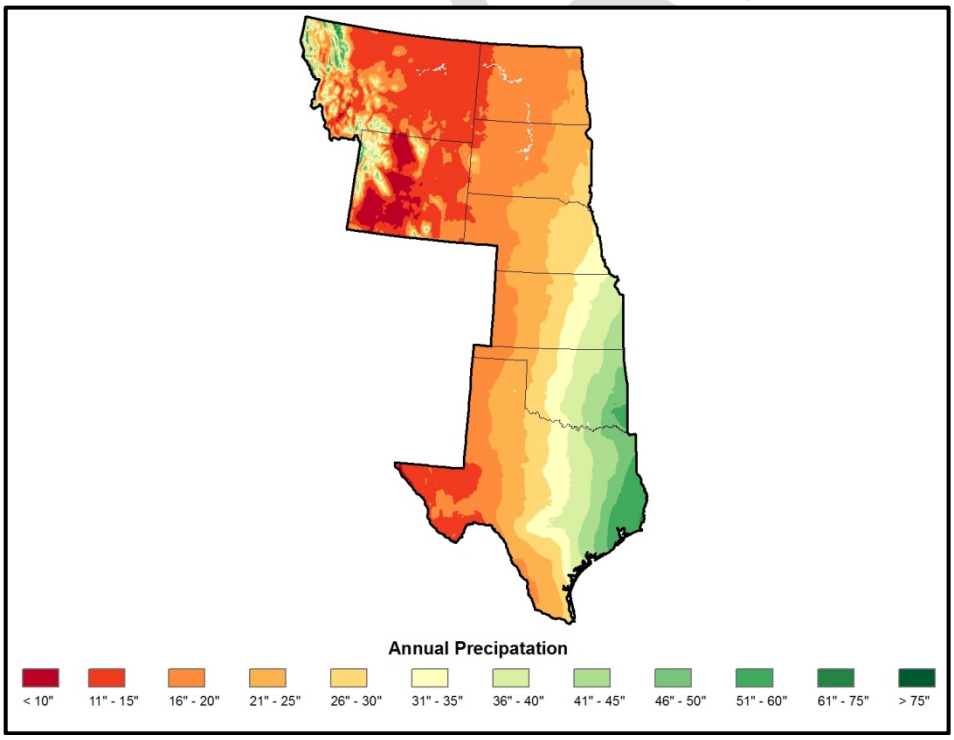


Figure 2. Average (1981-2010) annual precipitation (inches) based on National Weather Service cooperative observer stations.

The Great Plains has a few major urban areas, particularly in the south, notably Houston, Dallas-Fort Worth, and Austin. These urban centers experience the typical types of sensitivities that are unique to, or exacerbated by, the specific characteristics of the urban environment. Temperature extremes can have large impacts on human health, particularly in the urban core where the urban heat island effect raises summer temperatures. Severe storms, both winter and summer, result in major disruptions to surface and air transportation. Extreme rainfall causes a host of problems, including storm sewer overflow, flooding of homes and roadways, and contamination of municipal water supplies. Climate extremes combined with the urban pollution sources can create air quality conditions that are detrimental to human health. However, for the most part, this is not a highly urbanized region and large segments of the population live in small to moderately-sized communities.

Within the Great Plains region there are a number of Native American tribes and tribal lands. The majority of the tribal land, in terms of area, is located in the Dakotas, Montana, Wyoming, and Oklahoma. It has been shown that tribal populations are particularly vulnerable to climate extremes. Water availability is also a concern as most tribal land is located in areas with low annual average precipitation.

Agriculture is very important in this region and is highly diverse, a result of the diverse climate conditions. Unirrigated summer crop production occurs in the eastern parts of the region with significant output of soybeans and wheat. In western parts of the region, there are large areas of irrigated crop production, particularly corn, cotton, and alfalfa. Unirrigated agricultural production in particular is critically dependent on weather. Rainfall, heat stress, pests, ozone levels, and extreme events such as heavy precipitation, flooding, or drought can seriously affect production. The risks for such events are often higher for smaller farmers and different types of crops and other food production. The Ogallala aquifer is a major source of water for irrigation, but this resource is being depleted. The Great Plains is also a major producer of livestock, especially dairy and beef cattle, hogs, and others.

Major river basins in the Great Plains region include the Souris-Red-Rainy, Missouri, Arkansas-Red-White, and Texas-Gulf. The largest of these is the Missouri basin, encompassing more than 529,000 square miles. Periodically, these rivers reach and exceed flood stage due to high springtime snowmelt runoff from the Rocky Mountains and/or excessive rainfall.

Important Climate Factors

Some of the major climate issues that affect the Great Plains include:

Drought and Flood

Various types of drought can occur throughout the Great Plains. For example, *meteorological drought* (the severity and duration of a dry period) occurs in some portion of the Great Plains nearly every year. *Agricultural drought* largely refers to climate related problems in food production for farmers and cattlemen. Lush pastures can quickly wilt and dry up, leaving ranchers

with less hay and grazing resources than required for their cattle herds. Farmers may find their rain-fed crops undergoing severe stress due to water shortage, and as a result, yields will be reduced. Water supplies for cattle and irrigation may be adversely impacted when lakes, reservoirs, and ground water are affected by drought conditions. *Hydrological drought* occurs when water supply is reduced due to periods of precipitation shortages. The hydrologic storage systems are negatively impacted, as there is less water available for irrigation, navigation, hydropower and recreation.

Drought can occur in any area of the Great Plains and can vary in intensity and duration. The Dust Bowl is by far the most famous drought over the past 100 years, but prolonged drought has occurred recently as well. For instance, Wyoming, which is the 5th driest state, experienced moderate to severe drought conditions for nearly a decade beginning in 1999.

Drought episodes can impact the human population of the Plains in many ways. Crops that grow in drought stress conditions will have large losses of yield. Animals will experience heat stress and pastures will become non-productive. Cattlemen may be forced to reduce the size of their herds due to the lack of feed and grazing acres. Animals may die if the stress is severe or lasts for a long time.

Floods that occur in the Great Plains can be categorized into several types. One occurs when melting of a heavy snow pack in the mountains leads to flooding of rivers downstream and dangerously full reservoirs. For instance, floods in the Red River basin occur primarily during April and May and are caused by rapid spring snowmelt that may be accompanied by rain. In general, the later snowmelt begins in spring the more likely it will be accelerated by high temperatures and/or rainfall making flooding more likely. A second type is associated with short-duration heavy rainfall, usually from summer convective clouds. Convective energy is released in large cumulus or cumulonimbus cloud formations leading to strong updrafts and, in some cases, very high cloudtops. These strong storms occur on the plains when warm moist air from the south meets cooler air from the north. A third type occurs when heavy precipitation is persistent over many days to weeks, which can produce flooding on the largest river systems. Finally, along the gulf coast, heavy precipitation from hurricane rain band clouds can produce flooding over wide areas.

Geographical proximity to heavy rainfall is not necessary to experience flood effects. In the plains, many of the creek beds are usually dry due to lack of precipitation sufficient to maintain water flow. However, the dry creeks can suddenly fill with torrents of rapidly moving floodwaters. Loss of life may result from storms that occur miles upstream to unsuspecting individuals.

Topography and synchrony of spring melt makes the Red River of the North and the Red River Valley one of the most flood-prone areas in the U.S. The Red River flows north along the gently sloped Red River Valley. In the region of Fargo-Halstad, the gradient of the Red River averages 5 inches per mile of length. In the region of Drayton-Pembina, however, the gradient drops to 1.5 inches per mile. During floods, the Red River at Drayton tends to pool due to lack of slope - the region becoming essentially a massive, shallow lake. The Red River flows northward, but, at the same time, spring thaw proceeds steadily northward along the Valley. Thus, along the Red River, runoff from the southern portion of the Valley progressively joins with fresh, melted waters from

more northerly localities. Therefore the synchrony of melting creates natural ice jams in the downstream every year, making the Valley one of the most flood-prone areas in the US. Based on more than 100-year-old river stage data collected in Fargo, the Red River exceeded major flood stages (30 feet from a reference level and higher) 16 times. A time series of annual peak stream flow (Fig. 3) exhibits a strong upward trend over the 20th and early 21st Centuries.

The Devils Lake Basin is a 3,810-square-mile subbasin in the Red River of the North Basin. The elevation of the lake has fluctuated in time, and Figure 4 shows the elevation change since 1865 (USGS, 2011). However, continuous lake level measurements did not start until the early 1930s. The graphic shows that there has been a general rise in the lake levels since 1941 with a steady rise since 1993 from the 1992 elevation of 1423 feet to 1452.05 feet in 2010 (record elevation level during the instrumental era). In March 1993, Devils Lake had a surface area of 44,230 acres. At its June 2009 record elevation, it covered about 169,000 acres – an increase of 124,800 inundated acres, or about 195 square miles. Evidence shows that variation in the lake elevation is mostly part of the natural cycle of hydro-climate variability (Hoerling et al., 2010).

Winter Storms

This portion of the country is highly susceptible to the impacts of winter storm systems, which can produce heavy snows, high winds with blowing snow and reduced visibility, low wind chill temperatures and can result in snowmelt flooding. Major impacts primarily include a disruption of transportation and commerce, high removal costs, and loss of life and livestock due to exposure. For the southern Great Plains region, severe winter storms are less common, but ice storm events are generally more frequent than in the north (Changnon et al. 2006). Winter storms affecting the Plains region normally originate and strengthen on the leeward (east) side of the Rocky Mountains. There are two frequent locations for winter storm genesis; one in the north (sometimes termed an Alberta Low), and one in the south (the Colorado Low). These systems track in an eastward direction in association with the jet stream and prevailing winds at this latitude. Historically speaking, winter storms exhibit high variability in frequency of occurrence over time.

Blizzard conditions are not uncommon for the northern Great Plains and represent high impact events (Black 1971). These are defined by the National Weather Service as winds of 35 mph or greater with considerable snowfall and reduction in visibility to less than 0.25 miles prevailing for 3 hours or longer. The probability of a blizzard occurring in a given year is greater than 50% for the Dakotas and western Nebraska, the highest probability in the nation (Schwartz and Schmidlin 2002). The peak blizzard frequency for the northern Plains occurs in January and in March for the central Plains. Although blizzards were rare in the 1980s and most of the 1990s, during the winter of 1996 - 1997 there were nine blizzards and four winter storms that produced all-time record snowfalls of 60 to 120 inches over most of North Dakota. Work has been done to investigate winter season severity with large-scale atmospheric circulation processes, and there has been found a weak tendency for an increase in blizzards during La Niña winters. This can be amplified during conditions of a negative North Atlantic Oscillation pattern, such as during the extreme winter of 2009-2010.

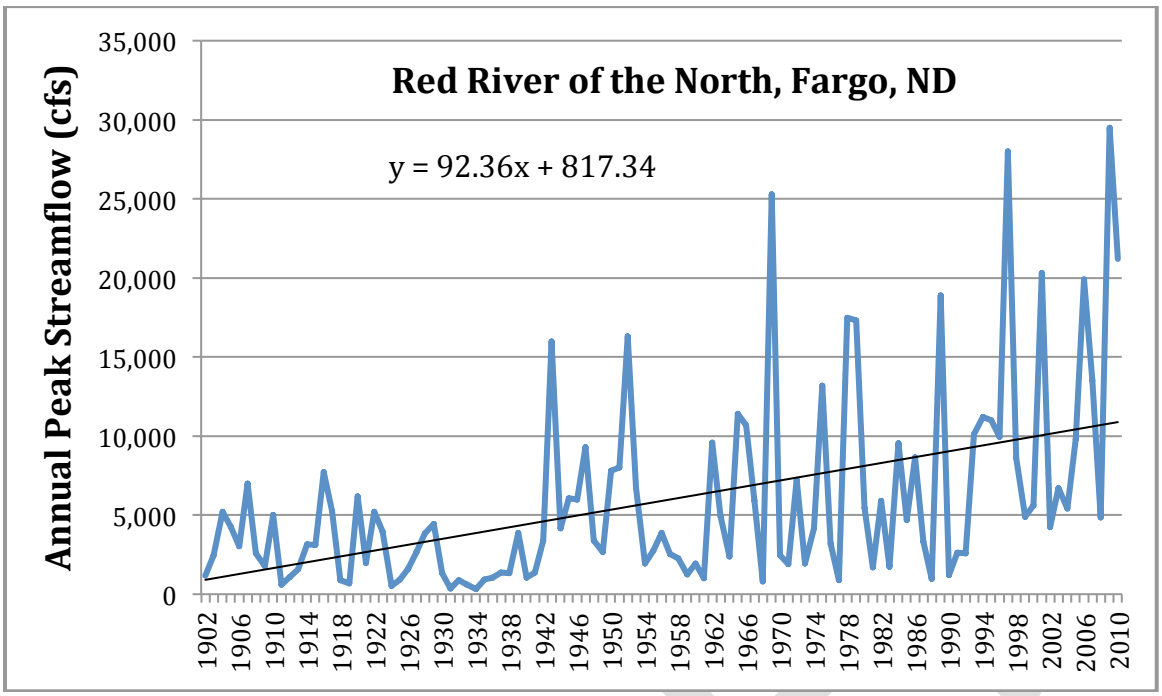


Figure 3. Annual Peak Streamflow Chart of Red River of the North, Fargo, ND

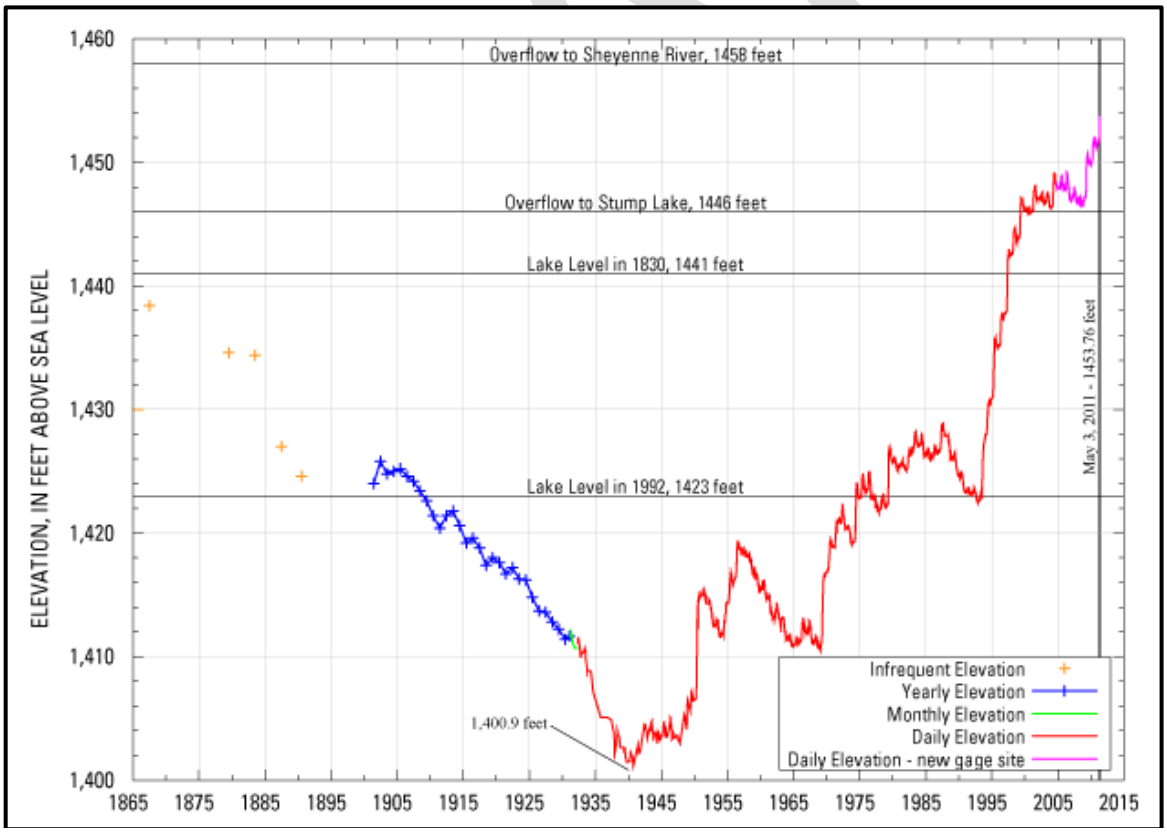


Figure 4. Devils Lake, North Dakota Elevation Change since 1865 (USGS, 2011)

Snow represents an important natural resource and is a significant component of the climate system with the ability to modify the surface energy budget. In the northern Plains, natural or structural fences are sometimes installed to capture windblown snow on the landscape for use in springtime recharge for water resources and/or to keep roadways clear during winter storm events. The period of time with snow on the ground in the Plains varies quite significantly across the region, with increasing duration in a northward progression. Snow cover is episodic and associated with winter storm events in the southern Plains, whereas the ground generally remains covered throughout the season for the northern Plains states. Snowfall represents one of the most difficult meteorological variables to accurately measure. However, high quality surface observing stations in the region show trends in seasonal snowfall amounts over time. These trends vary regionally with a general increase in the northern and western high Plains and a decrease in seasonal snowfall for the eastern southern Plains (Kunkel et al. 2009).

Convective Storms

This region of the country experiences a high frequency of convective storms during the spring and summer months. The area lies at the intersection of warm and moist air from the Gulf of Mexico colliding with warm and dry air from the west, resulting in local to regional-scale storms that impact the region. Hazards from these events range from downbursts, heavy downpours, and lightning, to hail, tornadic winds, and flash flooding. Severe storms peak in the spring for the southern Plains while the peak in storm activity is in summer for the northern Plains.

The occurrence of lightning strikes is at a maximum in the southeast portion of the region (particularly the Texas Gulf coast) and gradually decreases to the northwest with the fewest strikes in the mountains of Wyoming and Montana. The central and southern portion of the Great Plains is often referred to as 'tornado alley' due to the frequency of these events here compared to elsewhere in the U.S. (e.g. more than 100 per year on average in Texas and more than 50 per year in Kansas and Oklahoma). Most tornados (70%) are of weak intensity; however, violent tornadoes often result in significant damage and destruction. In May 2007, nearly 95% of Greensburg, KS, was completely destroyed in an EF5 tornado, and 11 lives were lost. The event was part of a tornado outbreak in a four-state region throughout the Plains.

Hail events associated with convective storm events peak in the central and southern Plains of the U.S. While most hail is smaller in size, some can be quite large and damaging to life and property. In fact, the largest circumference hailstone of 18.75 inches (1.34 lbs and 7.0 inch diameter) was reported in Aurora, NE, in June of 2003. A close second occurred in July 2010 near Vivian, SD, which was heavier (1.94 lbs) and greater in diameter (8.0 inches).

Heat Waves

The far reach of the Great Plains region lends itself to a wide range of temperatures. Statewide extreme temperatures of 115˚F and higher have been recorded for each of the states in the region; however, exposure to prolonged heat (i.e. a heat wave) varies widely. For instance, summer high temperatures of 95˚F and higher are quite common for areas of Texas and Oklahoma, but temperatures that high are quite uncommon in areas of the Dakotas. The east-west gradient of moisture that exists in the region has an impact on the magnitude of the effects of

heat waves. In the eastern portion of the Great Plains, moisture from the Gulf of Mexico can exacerbate the effects of heat waves as the combination of high temperatures and humidity can create dangerous conditions for humans and livestock, impact crops, and put stress on utilities. Alternatively, the dryness of the western portion of the Great Plains allows for an increased human tolerance for heat. Overall, the trend in average annual temperature for the Great Plains shows warming since 1895. As is the case for much of the globe, this annual warming trend is greater for nighttime low temperatures than for daytime high temperatures.

Some examples of historic heat waves in the Great Plains region include the Dust Bowl of the 1930s (Schubert et al. 2004) and the 1980 summer heat wave and drought (Karl and Quayle 1981). Most recently, the heat wave and drought of the summer of 2011 across the southern portions of the Great Plains region has had major impacts to human livelihood, crops, livestock, water supplies, and more. According to the National Oceanic and Atmospheric Administration's National Climatic Data Center, both Texas and Oklahoma recorded their warmest summer on record (records date back to 1895). In addition, the Dallas-Fort Worth area endured 40 consecutive days of 100˚F+ heat this summer, which was the second longest streak of 100˚F+ days on record (period of record 1898-2011). 1980 held on to the record of 42 days. Most areas of Texas and Oklahoma experienced at least 40 days of 100˚F+ heat (Fig. 5). Unfortunately, this heat wave was perpetuated partly because of the ongoing drought as the dry conditions allowed for higher temperatures. Although not as long lasting, the intense heat made its way to the northern portions of the region, impacting crops and cattle. In some areas, the heat came at a critical time for corn crops and there was concern for the quality of the yields in the fall. In South Dakota, unusually warm and humid conditions took their toll on livestock, and at least 1700 head of cattle perished. While these are preliminary reports, more finalized crop and cattle reports will show the true extent of the agricultural losses from the 2011 heat wave.

Cold Waves

Arctic air from Canada routinely plunges south into the Great Plains region during the winter months. As stated before, the large latitudinal extent of the region lends itself to a wide range of temperatures, and this is especially the case in the winter months. While statewide extreme maximum temperatures are similar across the region, the variation of statewide extreme minimum temperatures is large and ranges from -23˚F in Texas to -70˚F in Montana. A cold wave is determined by a prolonged (about 4 days or longer) departure from the average temperature at a given place. Many cold waves have affected the region over the years and two of the most widespread events occurred during the 1983-1984 winter season (Quiroz 1984) and 1989. When compared to past data, relatively few cold waves have occurred in the region since 2000.

Cold waves can have impacts on human health, utilities, and agriculture including both crops and livestock. Cold waves can be especially harmful when combined with wind. The measurement of the combination of cold and wind is better known as the wind chill. Results from a preliminary wind chill climatology indicate that wind chills below 0˚F are relatively common in the northern portion of the Great Plains where, on average, up to 30 days per winter have wind chills this low.

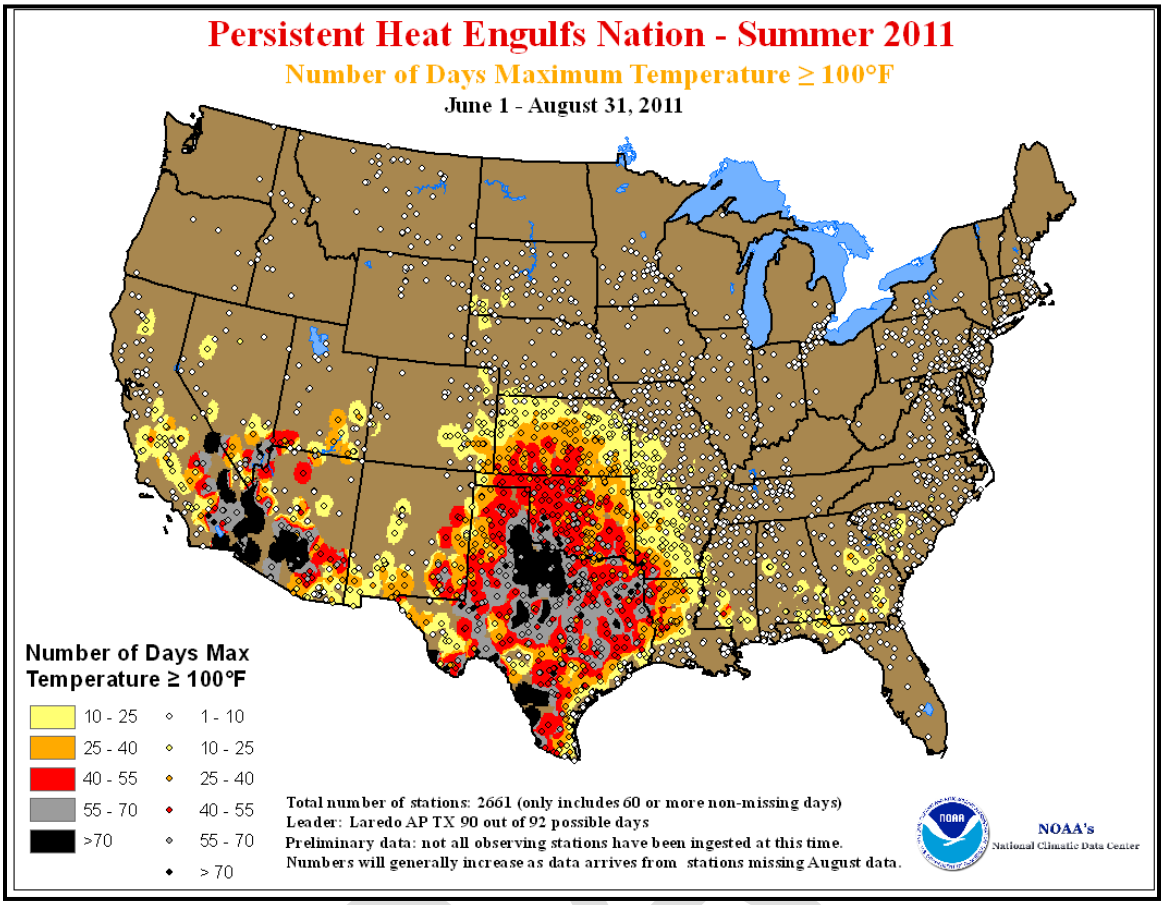


Figure 5. Number of 100˚F+ days in Summer 2011

Exposed skin can freeze in 30 minutes when wind chills are about -20˚F (National Weather Service 2011). Wind chills of this magnitude rarely, if ever, occur in the southern portions of the region, but do occur frequently in the north.

Cold waves can also have significant implications for agriculture. Cold waves that occur at the beginning of the growing season can impact planting dates or lead to replanting. Alternatively, cold waves that occur at the end of the growing season can negatively impact yields, depending upon the stage of the crop. In the southern portions of the region, where various crops can be grown year round, a cold wave can be devastating. One example is the cold wave of 1989, which resulted in $1 billion in agricultural losses in Texas (Nielsen-Gammon 2011).

Texas Hurricane Climatology

With a gulf coastline of roughly 367 miles, Texas receives its fair share of tropical storms and hurricanes. An extensive report on the climatology of Texas hurricanes and tropical storms is found in Roth (2000). According to this report, Texas averages approximately 0.8 named storms per year, or about three storms every four years. This generally equates to about 0.4 tropical storms per year and 0.4 hurricanes per year. Roth (2000) also indicates that any given fifty mile

coastal segment has an annual probability strike of approximately one storm per six years. Over the period of 1900 to 2010, Texas has endured over 85 known tropical storms and hurricanes, the latter of which make up approximately half the events. The busiest decade for the state occurred in the 1940s, when the state was hit by eight hurricanes and six tropical storms. The most recent decade has also seen above average storm counts with a total of 10 named storms making landfall, five of which were hurricanes. Perhaps the most memorable tropical storm event was the Galveston Category Four hurricane that made landfall in September, 1900. This storm resulted in approximately eight thousand fatalities.

As in other regions, the major impacts of tropical cyclones in Texas can be attributed to strong winds, flooding from heavy rainfall, and storm surge. According to Roth (2000), the tropical storm/hurricane rainfall record for Texas occurred in early August, 1978 at Bluff, Texas, with a storm total of 46 inches. Roth (2000) also lists eight other occurrences where storm rainfall totals were in excess of 30 inches. In addition to torrential rainfall, hurricanes have also resulted in devastating winds along the coast of Texas. In August 1970, wind speeds of 180 miles per hour were recorded at Aransas Pass (Roth 2000). There have also been nine instances where tropical cyclone wind speeds were recorded in excess of 131 miles per hour (lower limit wind speed for a Category Four Hurricane) (Roth 2000). Information on storm surges in Texas is not readily available; however, Roth (2000) notes that storm surges have reached heights of twenty feet, with several instances of measured surges at or above ten feet. A detailed description of gulf storm surges can also be found in Needham and Keim (2011).

Atlantic Tropical Storm Trends and Climate Change

As climate models keep trending toward a warmer planet, scientists are continually faced with many research problems. Among the most difficult of problems involves the issue of how climate change may impact the frequency and intensity of tropical cyclone activity. The forecasting of any given hurricane season is a daunting task, which involves a great deal of effort and modeling. This task becomes increasingly difficult when considering how the climatology of the hurricane season will be affected under a climate warming scenario.

A primary concern among scientists pertains to the quality of data. Many studies argue that the quality of the tropical cyclone data for the north Atlantic basin is insufficient for the determination of trends in storm counts (Landsea et al. 2006). Goldenberg et al. (2001) state that this data prior to 1944, which precedes aircraft reconnaissance, is not considered reliable and caution should be exercised with its usage in research analyses. The issue of data quality is also considered by Owens and Landsea (2003), citing 1944 as the start of complete and reliable data for the North Atlantic region. By contrast, other studies indicate that these issues of data quality are not substantial enough to preclude trend analyses (Emanuel 2005; Webster et al. 2005; Hoyos et al. 2006; Elsner et al. 2008; Holland and Webster 2007).

Data quality issues aside, many studies have addressed the issues of trends in tropical cyclone activity in the North Atlantic Basin, and how climate change may impact the frequency and intensity of tropical cyclones. Holland and Webster (2007) examine tropical storm and hurricane frequency for the North Atlantic Ocean over the past century. Their study identifies three distinct

regimes (1905-1930; 1931-1994; 1995-2005). Their findings illustrate a marked increase of approximately fifty percent in each regime over time. Their observed increase in tropical cyclone frequency is commensurate with observed increases in Atlantic sea surface temperatures. Holland and Webster (2007) conclude that observed increases are the combined result of both natural variability and anthropogenic-induced greenhouse warming. Emanuel (2005), Mann and Emanuel (2006), and Webster et al. (2005) also conclude that increases in Atlantic tropical cyclone activity are likely being driven by greenhouse-induced warming. Goldenberg et al. (2001), on the other hand, maintain that natural variability in the Atlantic Multidecadal Oscillation may be the primary driver behind the observed increasing trends. Landsea (2007) asserts that when data are adjusted for missing storms, a significant trend is not evident. These findings are also consistent with other studies which claim that observed increases in storm activity over the past century are not entirely obvious, despite the observed increases in Atlantic sea surface temperatures (e.g. Vecchi and Knutson 2008; Elsner et al. 2008; Knutson et al. 2010). In a study by Elsner et al. (2008), results indicate an increasing trend in the intensity of strong tropical cyclones. Their study examines trends in lifetime-maximum wind speeds and notes an upward trend over time for the North Atlantic, owing to increases in oceanic energy resulting from increases in Atlantic sea surface temperatures.

Many studies have examined the future of Atlantic tropical cyclone activity. Though a bulk of these studies conclude that global warming will more than likely result in an increase in both the frequency and intensity of events (e.g. IPCC, 2007a), a debate remains as to how the climatology of tropical storms will ultimately be affected. Knutson et al. (2010) caution that it is not entirely clear whether the variability of tropical cyclone activity has exceeded that which is expected by natural causes. The authors note that modeling studies suggest a shift toward stronger storms, with decreases in global-scale frequency on the order of six to thirty-four percent. Bengtsson *et al.* (2007) examine tropical cyclones in the northern hemisphere using the Max Planck Institute coupled ECHAM5/MPI-OM and atmosphere (ECHAM5) models. Their results indicate a reduction in storm numbers between the nineteenth and twentieth centuries, with no significant change in the number of intense storms. When focusing on the twenty-first century, Bengtsson et al. (2007) find that tropical cyclone counts decrease by approximately ten percent, whereas the frequency of intense storms increase by approximately one third. Reductions in storm count may be the result of the combined effect of a reduction in vertical circulation and an increase in static stability. A study by Vecchi and Soden (2007) examines eighteen of the models used for the 2007 IPCC climate report. Their findings demonstrate that for the twenty-first century, there is a modeled increase in vertical wind shear over the critical tropical storm season months of June to November. These findings are based on the typical A1B scenario (doubling of carbon dioxide to 720ppm by 2100). The authors note that modeled increases in vertical wind shear should be considered in projections of future cyclone activity. Increases in wind shear support a reduction in the number of tropical cyclone events. However, it is difficult how to assess how this may impact storm intensity.

Sea Level Rise

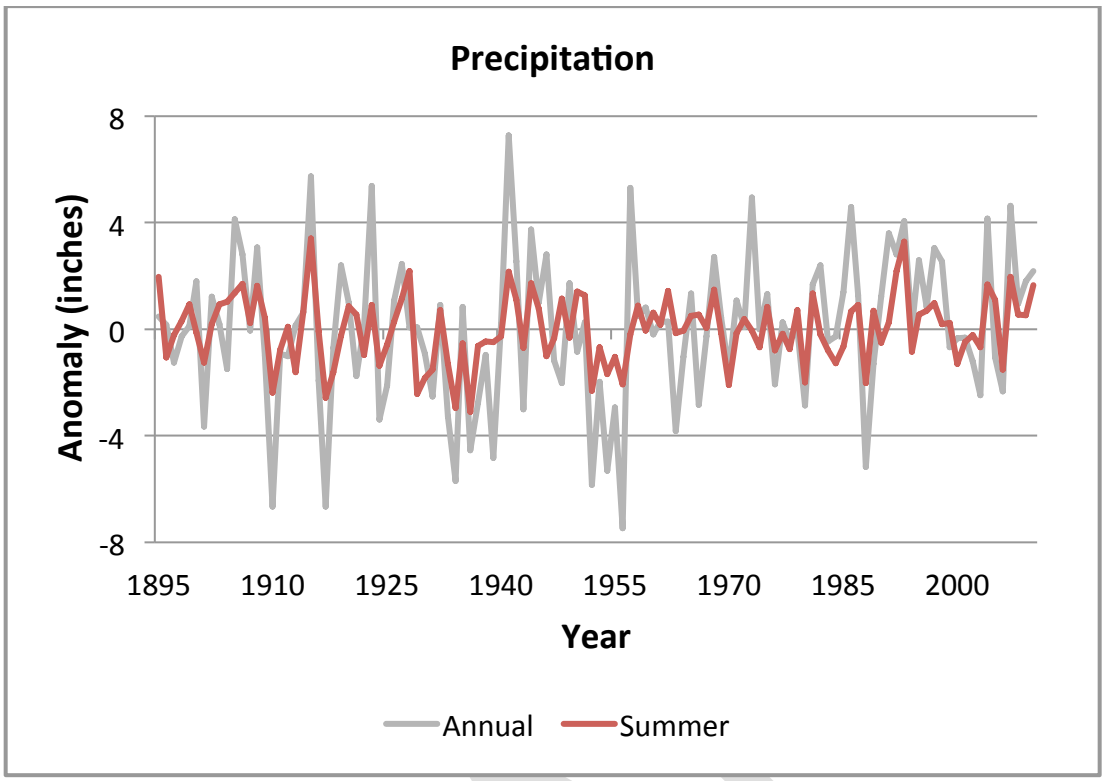
Changes in sea level can result from either a rise in oceanic water level, land subsidence, or a combined effect of these two variables. It is therefore a very difficult process to study and model. Kolker et al. (2011) note that the primary driver of subsidence in the Gulf of Mexico may be subsurface fluid withdrawal. Unfortunately, research which focuses on subsidence in Texas is not well documented. Additionally, fewer studies exist which examine the combined effect of subsidence and sea-level changes. One study by Penland and Ramsey (1990) examines sea-level rises in the Gulf of Mexico for the period of 1908 to 1988. Their results show that the highest observed sea level rises over their study period are observed along the Louisiana coastline. They note that Galveston, Texas, is experiencing an average sea-level rise of approximately 0.63 cm per year, which is slightly lower than the Louisiana rate of 1.04 cm per year. According to Church and White (2006), global sea-level rise has averaged approximately 1.7 mm per year over the past century. According to Donoghue (2011) and NOAA (2010), sea-level rises along the Texas coast have ranged from as low as 1.93 mm per year (1963-2010), to as high as 6.39 mm per year at Galveston Pier. Port Isabel, Texas, and Padre Island, Texas, have averaged approximately 3.64 and 3.84 mm per year of sea level rise, respectively (Donoghue 2011). The study of Donoghue (2011) notes that changes in sea level within the northern Gulf of Mexico have reflected that which has been observed globally. It is therefore reasonable to infer that global projections of sea level rise might suffice as an adequate estimate of how sea level may change in the Gulf of Mexico. The IPCC (2007b) indicates that models are predicting a global sea level rise of approximately 18 to 59 cm by the year 2100.

Climatic Trends

General

Annual precipitation (Fig. 6) was greater than normal during the 1990s, less than normal during the early 2000s, and greater than normal during the last few years. The early 1950s were the driest multi-year period, and included the single driest year on record, 1956. The 1930s were nearly as dry. The wettest single year on record was 1941. Summer precipitation anomalies are very similar to the annual behavior. The flood year of 1993 was the second wettest summer on record, after 1915.

Temperatures have been generally above the long-term average for the last 20 years (Fig. 6), both annually and for summer. Annually, all but 3 years have been above the long-term average. The warmest years on record were 1934 and 2006 (virtual tie). The heat that occurred during the Dust Bowl era is very evident in the summer time series. The warmest summer on record was 1936, with the second warmest being 1934. Eight of the last ten summers have been above average. Temperatures during the other seasons (not shown) have also generally been above average. States in the northern portion of the Great Plains region have experienced the most change in their long-term average temperatures. For instance, North Dakota's annual average temperature increased 0.26°F per decade during the last 130 years, the fastest increase in the nation. However, the maximum trend is observed during winter with a 0.44°F per decade increase on the average since 1881. February has the greatest monthly temperature trend with 0.75°F per decade.



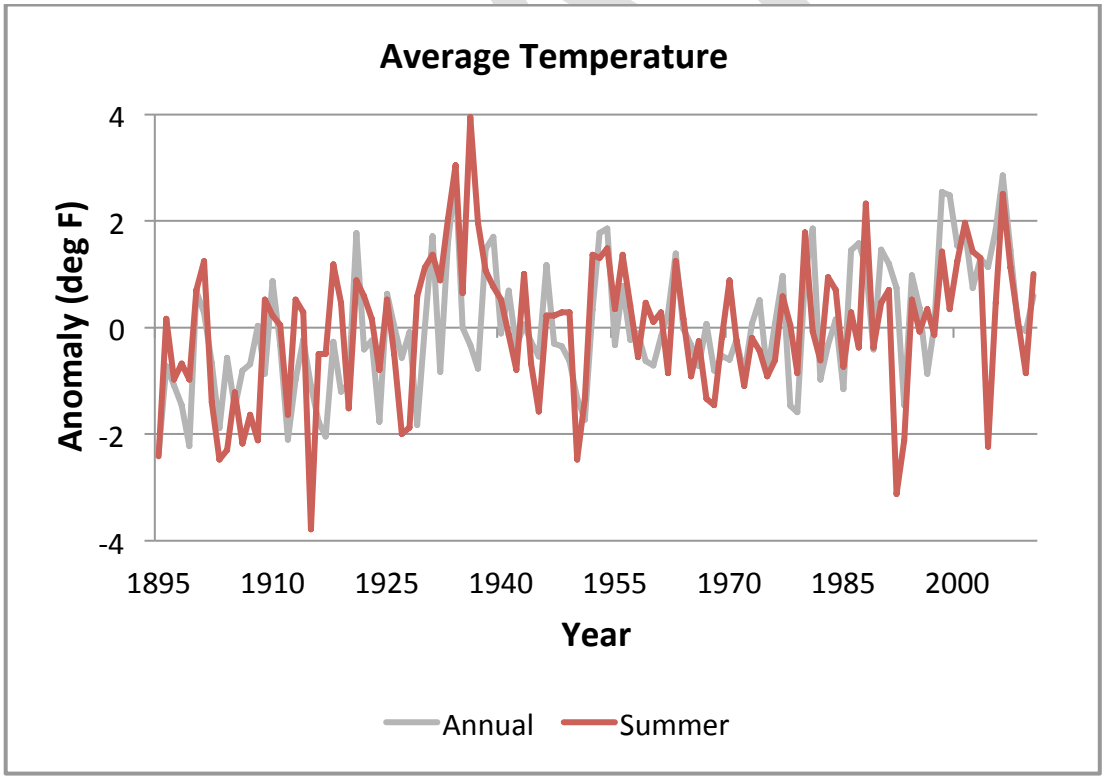


Figure 6. Precipitation and temperature anomalies in summer (red) and annual anomalies (gray) are shown for the states of MT, ND, WY, SD, NE, KS, OK, and TX. Based on data from the National Climatic Data Center for the cooperative observer network.

Extreme Precipitation

Figure 7 is a time series of an index of the number of extreme precipitation events exceeding a 1 in 5-yr recurrence interval. There is substantial interannual and decadal-scale variability in the number of extreme precipitation events. Since 1990, there have been a number of years with a high number of extreme events. The highest value overall for 1-day events occurred in 2007. The 1940s were characterized by a high number of extreme events that followed a period of low values in the 1930s. The high number of extreme events in the early part of the record is primarily a feature of the northern part of the region.

Extreme Temperature

Figures 8 and 9 are time series of an index of the number of cold wave and heat wave events, respectively, exceeding a 1 in 5-yr recurrence interval. There is a large amount of interannual variability in extreme cold periods and extreme hot periods, reflecting the fact that such events affect large areas when they occur and that there is a high degree of correlation among the climate stations. The frequency of extreme cold periods has been generally low since 1990, with the exception of 1996 when a severe cold wave in early February affected large areas. Other years with widespread severe cold included 1983 and 1989. The 1950s were a period of few severe cold waves. A separate analysis of the northern and southern parts of the region indicates that the tendency toward fewer cold waves recently is more prominent in the north than in the south.

The occurrence of heat waves, as illustrated by the heat wave index time series shown in Fig. 9, is dominated by the severe heat of the 1930s. The highest number of heat waves, by far, occurred in 1934 and 1936. Other years with a high number of heat waves include 1940, 1954, 1980, and 1988.

Growing Season

There has been a generally increasing trend since the early 20th Century in growing (freeze-free) season length (Fig. 10). The last occurrence of 32°F in the spring has been occurring earlier and the first occurrence of 32°F in the fall has been happening later. The longest growing season occurred in 1998. The average growing season length during 1991-2010 was about 6 days longer than during 1961-1990.

Shifts in planting dates have occurred as well. A preliminary study by Pathak et al. (2011) shows a one to three week shift in the dates when soil temperature reaches 55°F across Nebraska when the recent decade (2000-2009) is compared to the previous decade (1990-1999). Trends for when the soil temperature reaches 50°F, 60°F, 65°F, and 70°F are similar. These trends in the last two decades show a potential for shifting agricultural planting to earlier dates in Nebraska. If climatic conditions are closely monitored and farmers can plant earlier, the benefit would be that a longer season hybrid could be selected with a corresponding higher yield potential.

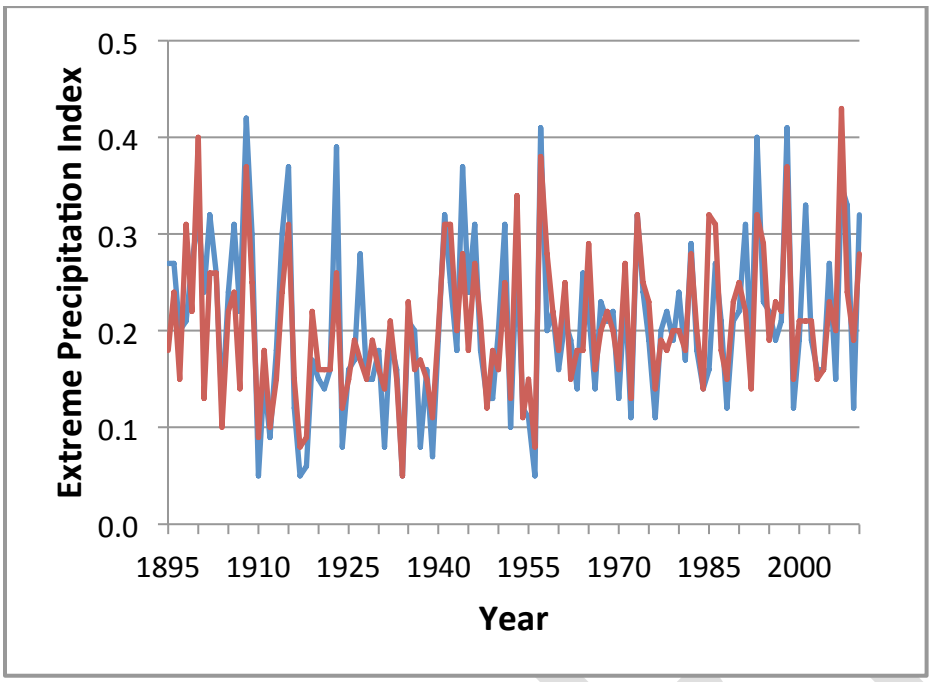


Figure 7. Time series of extreme precipitation index for the occurrence of 1-day, 1-in-5 year extreme precipitation events (red) and 5-day, 1-in-5 year events (blue). Analysis is average for the states of MT, ND, WY, SD, NE, KS, OK, and TX. Based on data from the National Climatic Data Center for the cooperative observer network and updated from Kunkel et al. (2003).

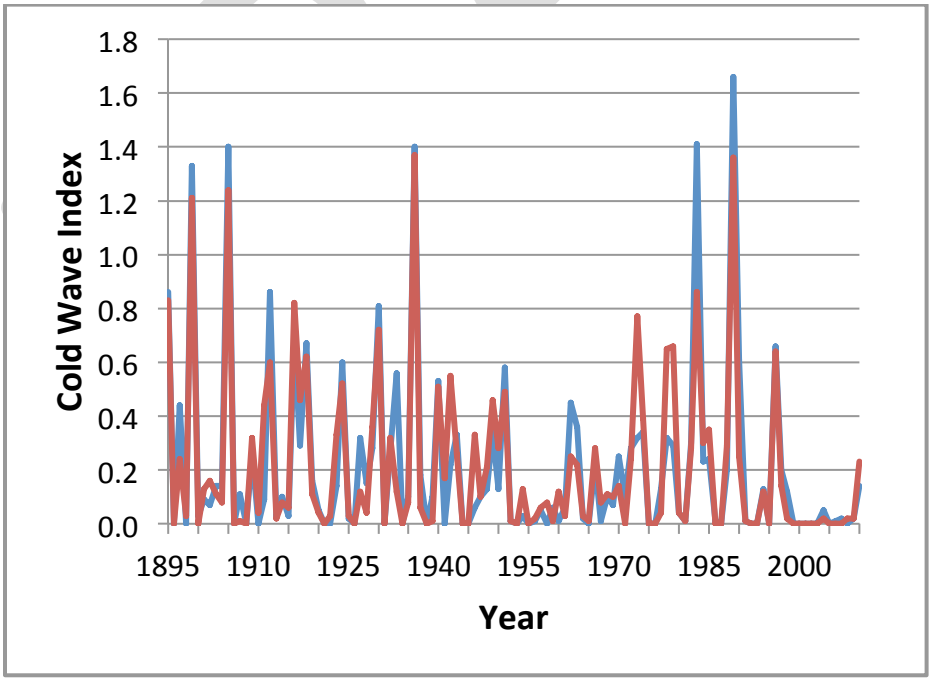


Figure 8. Time series of an index for the occurrence of cold waves defined as 4-day periods (blue) and 7-day periods (red) that are colder than the threshold for a 1-in-5 year recurrence. Based on data from the National Climatic Data Center for the cooperative observer network and updated from Kunkel et al. (1999).

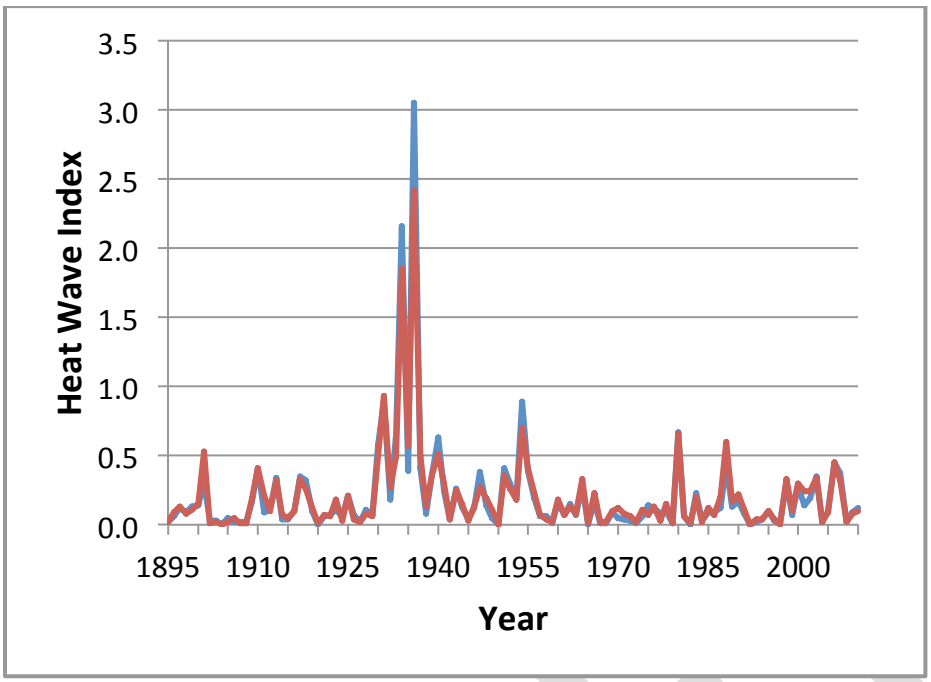


Figure 9. Time series of an index for the occurrence of heat waves defined as 4-day periods (blue) and 7-day periods (red) that are hotter than the threshold for a 1-in-5 year recurrence. Based on data from the National Climatic Data Center for the cooperative observer network and updated from Kunkel et al. (1999).

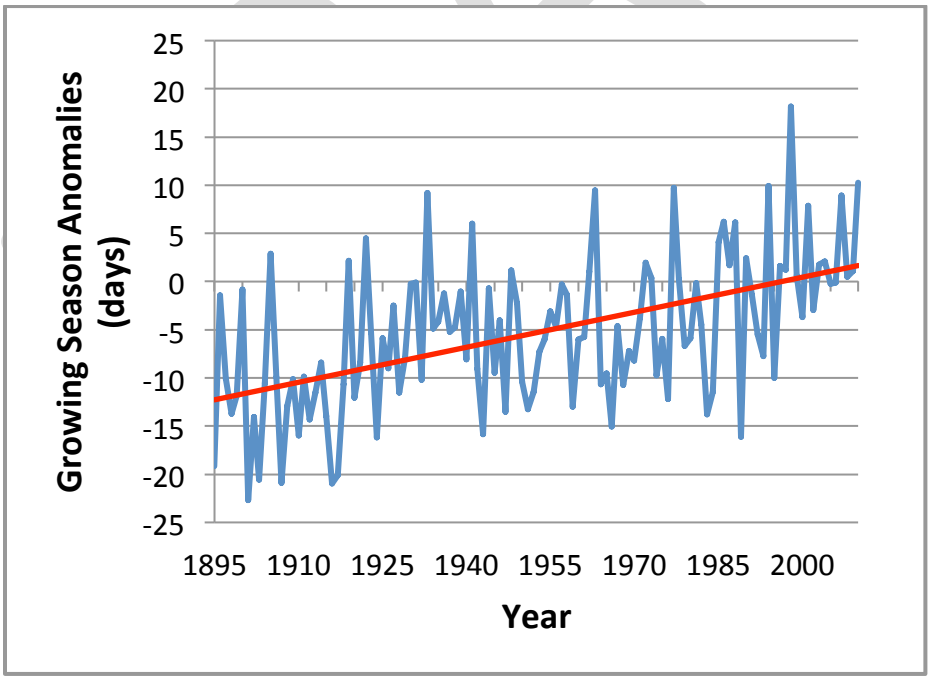


Figure 10. Growing season anomalies shown as number of days per year. Length of the growing season is defined as the period between the last occurrence of 32°F in the spring and first occurrence of 32°F in the fall. Red line is a linear fit. Based on data from the National Climatic Data Center for the cooperative observer network and updated from Kunkel et al. (2004).

3. REGIONAL OUTLOOK

The following outlook information provides statistics for the periods of 2021-2050, 2041-2070, and 2070-2099, with changes calculated with respect to the historical climate reference period of 1971-2000. These future periods will be denoted in the text by their mid-points of 2035, 2055, and 2085, respectively. Three different types of analyses are represented, as follows:

- **Multi-model mean maps** – To produce these, each model's data is first re-gridded to a common grid. Then, each grid point value is calculated as the mean of all the available models' values at that grid point. Finally, the mean grid point values are mapped. Although this type of analysis weights all models equally, a number of research studies have found that the multi-model mean is superior to any single model in reproducing the present-day climate. A multi-mean analysis of future spatial patterns may be the most robust estimate of future change.
- **Spatially-averaged products** – To produce these, all the grid point values within the Great Plains region boundaries are averaged and represented as a single value. This is useful for general comparisons of different models, periods, and data sources. Because of the spatial aggregation, this product may not be suitable for many types of impacts analyses.
- **Probability density functions (pdfs)** – These are used here to illustrate the differences among models. To produce these, spatially-averaged values are calculated for each model simulation. Then the distribution of these spatially-averaged values is displayed. This product provides an estimate of the uncertainty of future changes.

Description of Data Sources

This initial outlook for the National Climate Assessment (NCA) Great Plains region is based on the following model data sets:

- **CMIP3 GCM output** – Fifteen models identified in the 2009 NCA report were used. These also serve as the basis for the following downscaled data sets.
- Statistically-downscaled monthly temperature and precipitation – These data are at 1/8° (latitude and longitude) resolution. The data were downscaled using the bias-corrected spatial disaggregation (BCSD) method. Sixteen models were downscaled for the period of 1961-2100.
- **Statistically-downscaled daily temperature and precipitation** – These data are also at 1/8° (latitude and longitude) resolution. Daily data were created from the monthly data by randomly sampling historical months and adjusting the values using the "delta" method. Sixteen models were downscaled for the period of 1961-2100.
- **The North American Regional Climate Change Assessment Program (NARCCAP)** – This multi-institutional program is producing regional climate model (RCM) simulations in a coordinated experimental approach. At this time, there are 9 simulations available using different combinations of a RCM driven by a GCM. Each simulation includes the periods of 1971-2000 and 2041-2070 for the A2 scenario only, and is at a resolution of approximately 50 km.

Mean Temperature Outlook

Figure 11 shows the spatial distribution of the 15 CMIP3 multi-model mean annual temperatures for the future periods (2035, 2055, and 2085) and two emissions scenarios (A2, B1). Spatial variations are quite small, especially for the B1 scenario. As also seen in the climatology, the warming tends to be slightly larger in the north, especially in the Dakotas. On a temporal scale, the warming seen over the past 20 years is projected to continue, and also increases between B1 and A2 for each respective period. For 2035, B1 values range between 1 and 2°F and A2 values range slightly higher from about 1 to 3°F. For 2055, warming in B1 ranges between 2 and 4°F and for A2, ranges from 3 to 6°F. By 2085, the increases are in the 3-6°F range for B1 and 6-9°F range for A2.

Figure 12 shows the mean annual and seasonal temperature changes between 2041-2070 and 1971-2000 for the A2 scenario, for the 9 NARCCAP regional climate model simulations. The annual changes are quite uniform and generally in the range of 3-5°F, except for coastal Texas where the warming is smaller, less than 3°F. The seasonal changes show more spatial variability. Winter differences range from 3 to 7°F, and the greatest warming occurs near the Canadian border. Springtime warming is smaller than the winter season; however the warmest area is located in southwest Texas with an increase of 3-4°F. Summer also shows a large amount of warming, ranging from 3 to 7°F, with a localized maximum in southwest Kansas. Warming in the fall ranges between 3 and 6°F, with the greatest warming occurring in the central portion of the region.

Figure 13 shows the mean annual temperature changes for each future time period and both emissions scenarios, averaged over the entire Great Plains region for the 15 CMIP3 models. In addition, averages for the 9 NARCCAP simulations and the 4 GCMs used in the NARCCAP experiment are shown for 2055 (A2 scenario only). The small plus signs are values for each individual model, and the circles depict the overall means. For the A2 scenario, the CMIP3 models project average increases of 2.8°F by 2035, 4.4°F by 2055, and nearly 8°F by 2085. The increases for the low B1 scenario are nearly as large in 2035 at around 2.5°F, but by 2085 the increase of 4.6°F is over 3°F smaller than in the high A2 scenario. For 2055, the average temperature change simulated by the NARCCAP models is just less a little less than the mean of the CMIP3 GCMs for the A2 scenario.

A key overall feature is that early in the 21st Century, the multi-model mean temperature changes are relatively insensitive to the emissions path but late 21st Century changes are quite sensitive to the emissions path. However, the range of individual model changes is quite large. There is considerable overlap between the A2 and B1 results, even for 2085. The range of changes in 2055 for the NARCCAP GCMs is small relative to the range for all CMIP3 models and is probably largely responsible for the relatively small range for the NARCCAP models.

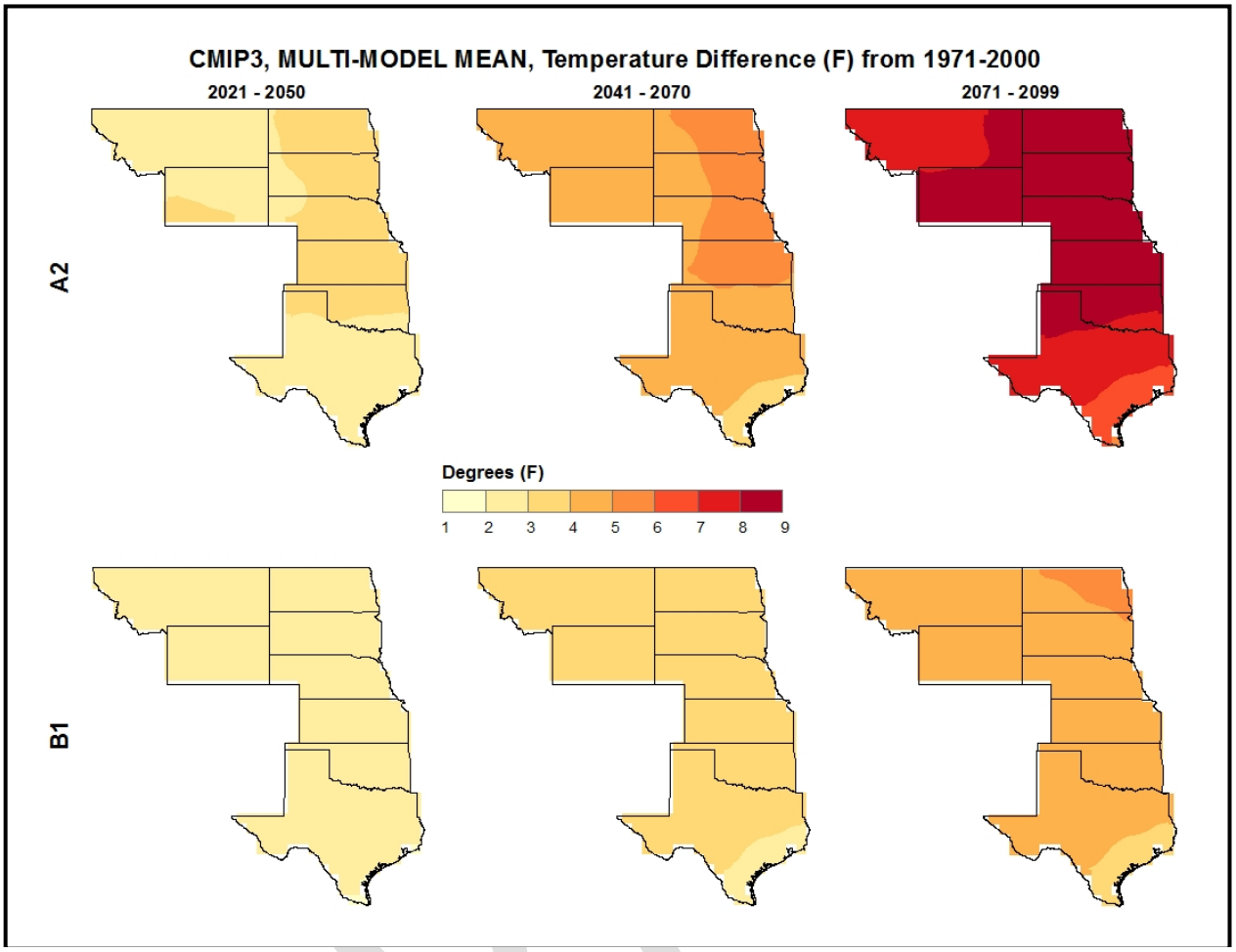


Figure 11. Multi-model mean annual differences in temperature (°F) between the 3 future periods and 1971-2000, from the 15 CMIP3 model simulations.

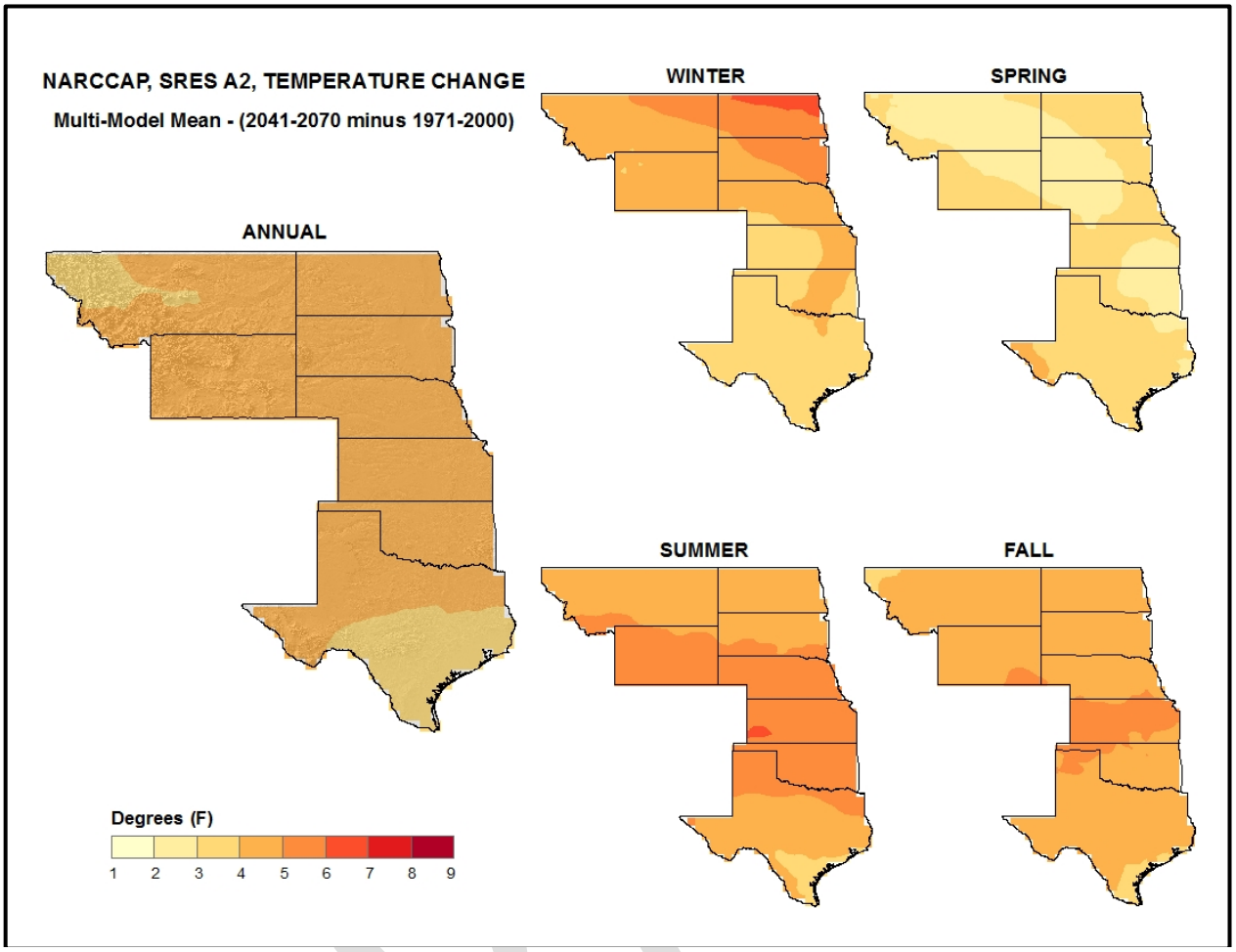


Figure 12. Multi-model mean annual and seasonal differences in temperature (°F) between 2041-2070 and 1971-2000, from the 9 NARCCAP regional climate model simulations.

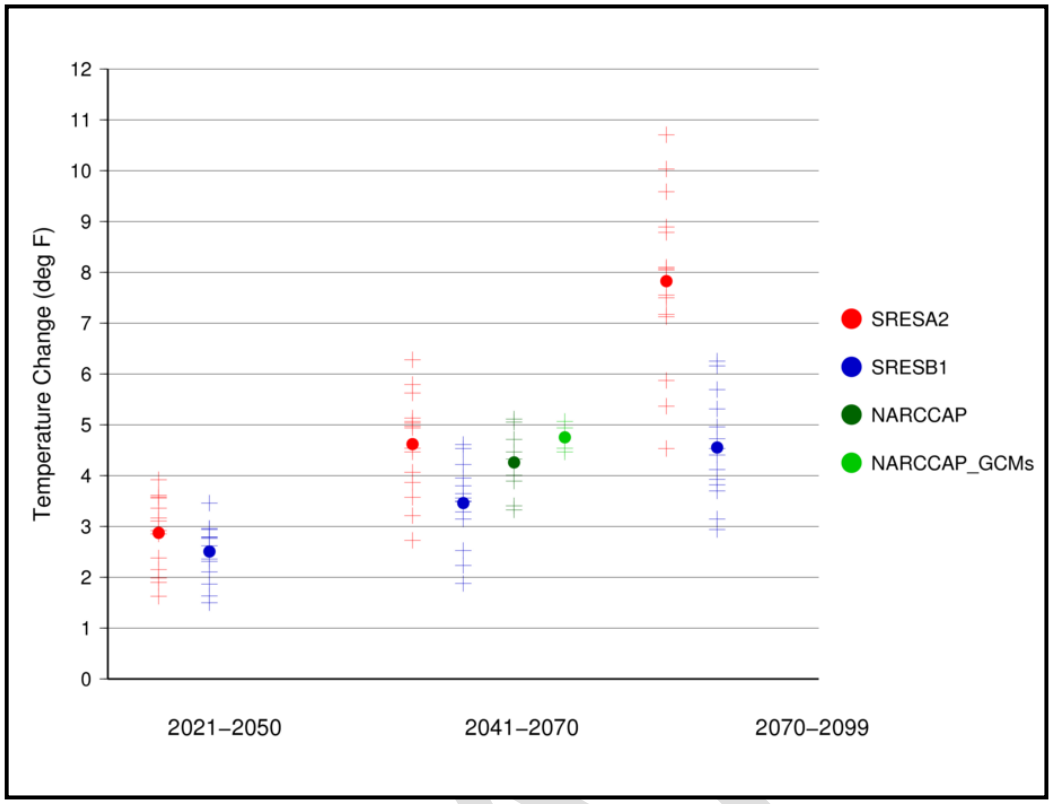


Figure 13. Mean annual temperature changes (°F) for each future time period with respect to the reference period of 1971-2000 for all 15 CMIP3 models, averaged over the entire Great Plains region for the high (A2) and low (B1) emissions scenarios. Also shown are results for the NARCCAP simulations for 2041-2070 and the 4 GCMs used in the NARCCAP experiment (A2 only). The small plus signs are values for each individual model and the circles depict the overall means.

Figure 14 shows the mean seasonal changes for each future time period for the A2 scenario, averaged over the entire Great Plains region for the 15 CMIP3 models. Temperature increases are largest in the summertime, with means around 3.3°F in 2035, 5.4°F in 2055, and 9°F in 2085. Wintertime experiences the lowest warming, starting at about 2.7°F in 2035 and ending at 7.1°F in 2085. The range of individual model temperature changes increases with each time period and is large relative to the differences between seasons and comparable to the differences between 2035 and 2085.

The distribution of changes in mean annual temperature for each future time period and both emissions scenarios across the 15 CMIP3 models is shown in Table 1. The range of changes from lowest to highest varies from 1.6°F in 2035 for the B1 scenario to 10.7°F in 2085 for the A2 scenario. The inter-quartile range of changes across all the GCMs is roughly between 1 and 2°F. Although the total range is seen to increase for each future time period, the inter-quartile range varies little.

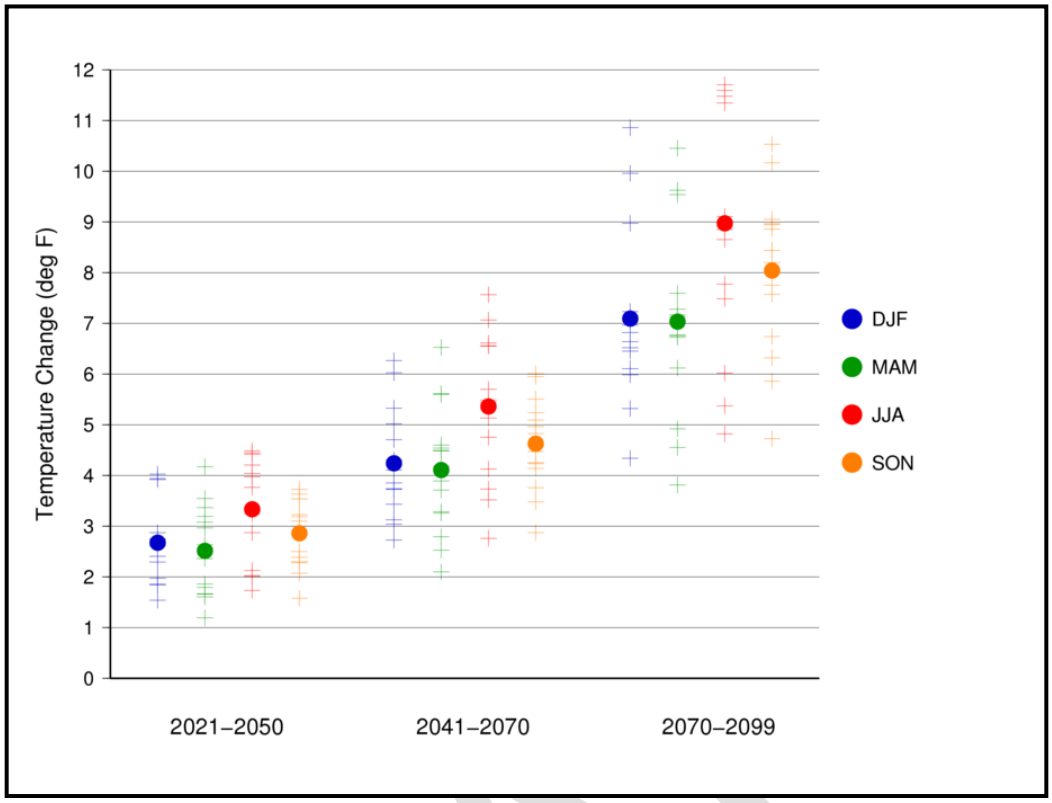


Figure 14. Mean seasonal temperature changes (°F) for each future time period with respect to the reference period of 1971-2000 for all 15 CMIP3 models, averaged over the entire Great Plains region for the high (A2) emissions scenario. The small plus signs are values for each individual model and the circles depict the overall means.

Table 1. Distribution of changes in mean annual temperature (°F) for the Great Plains region for the 15 CMIP3 models.

Scenario	Period	Low	25%ile	Median	75%ile	High
A2	2021-2050	1.6	2.3	3.0	3.5	3.9
	2041-2070	2.7	4.0	4.9	5.1	6.3
	2070-2099	4.5	7.2	8.0	8.8	10.7
B1	2021-2050	1.5	2.2	2.7	2.9	3.5
	2041-2070	1.9	3.2	3.5	3.9	4.6
	2070-2099	2.9	3.8	4.5	5.2	6.3

This table also illustrates the overall uncertainty arising from the combination of model differences and emission pathway. Following the A2 scenario, for 2035, the projected changes range from 1.6°F to 3.9°F and arise almost entirely from model differences. By 2085, the range of projected changes has increased to 4.5°F to 10.7°F, with roughly equal contributions to the range from model differences and emission pathway uncertainties.

Extreme Temperature Projections

A number of metrics of extreme temperatures were calculated from the daily NARCCAP and CMIP3 daily statistically-downscaled data sets. Maps of a few selected variables and a table summarizing all of the results follow. Each figure includes the difference between the 2055 period (2041-2070) and the model reference period (1971-2000), as well as a map of the reference period for comparison.

Figure 15 shows the spatial distribution of the NARCCAP multi-model mean change in the number of days with maximum temperatures exceeding 95°F between 2055 and the historical reference period. The largest absolute increases of more than 30 days occur in the extreme corners of Texas. The simulated changes for a large area from central Texas north to southwest Nebraska is more than 20. The smallest increases of less than 10 days are seen in the highest elevation areas of Montana and Wyoming where the present day climate also exhibits the fewest number of days greater than 95°F.

Figure 16 shows the spatial distribution of the NARCCAP multi-model mean change in the number of days with minimum temperatures below 10°F between 2055 and the historical reference period. The northern half of the region is projected to experience the largest decreases in the number of days compared to little or no change in southern areas. The largest decreases occur in higher elevation areas and near the Canadian border with some areas decreasing by 20 days or more. Local areas in Wyoming and Montana are projected to decrease by as much as 30 days. The smallest absolute decreases occur in Texas where the number of occurrences in the present-day climate is very small.

Consecutive warm days can have large impacts and are analyzed here as one metric of heat waves. Figure 17 shows the NARCCAP multi-model mean change in the average annual maximum run of days with maximum temperatures exceeding 95°F between 2055 and the historical reference period. The pattern is similar to that of the change in the total number of days exceeding 95°F. In Oklahoma and Texas, the average annual longest string of days with such high temperatures increases by 15 days or more. In the central portion of the region, the changes are smaller but still show an increase of 6-15 days. Across the northern tier of the region, the increase in the number of consecutive days exceeding 95°F is the smallest, at 0-6 days. The climatology indicates that such measures of extreme hot periods have a large amount of interannual variability.

The mean changes for selected temperature-based derived variables from the NARCCAP simulations between 2055 and the historical reference are summarized in Table 2. These were determined by first calculating the derived variable at each grid point. Then the spatially-averaged value of the variable was calculated for the present and each future period. Finally, the future-present difference or ratio was calculated from the spatially-averaged values. In addition, these same variables were calculated from the CMIP3 daily statistically-downscaled data set for comparison.

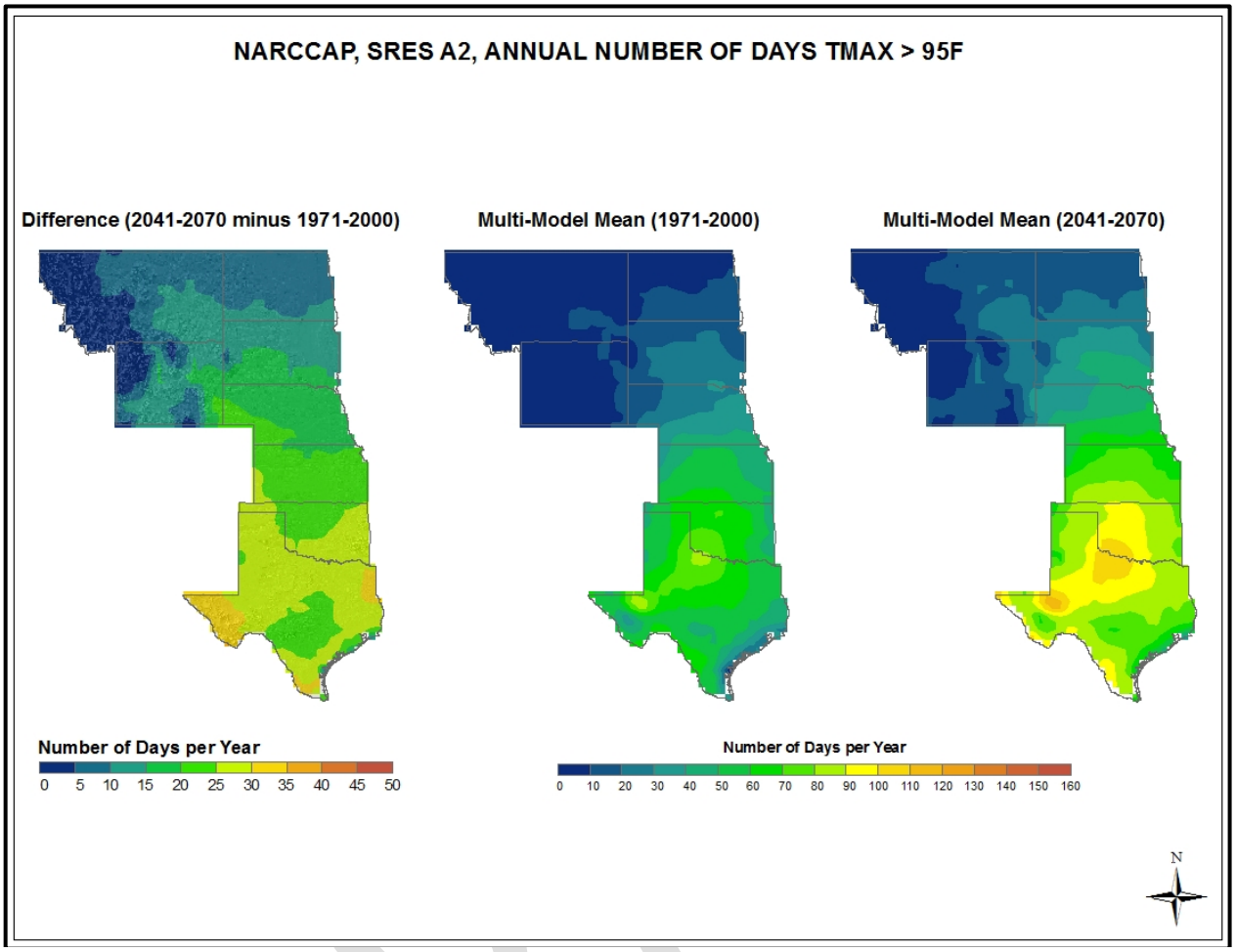


Figure 15. Spatial distribution of the NARCCAP multi-model mean change in the number of days with a maximum temperature greater than 95°F between 2041-2070 and 1971-2000 (top). Model reference periods of the number of days with a maximum temperature greater than 95°F (bottom).

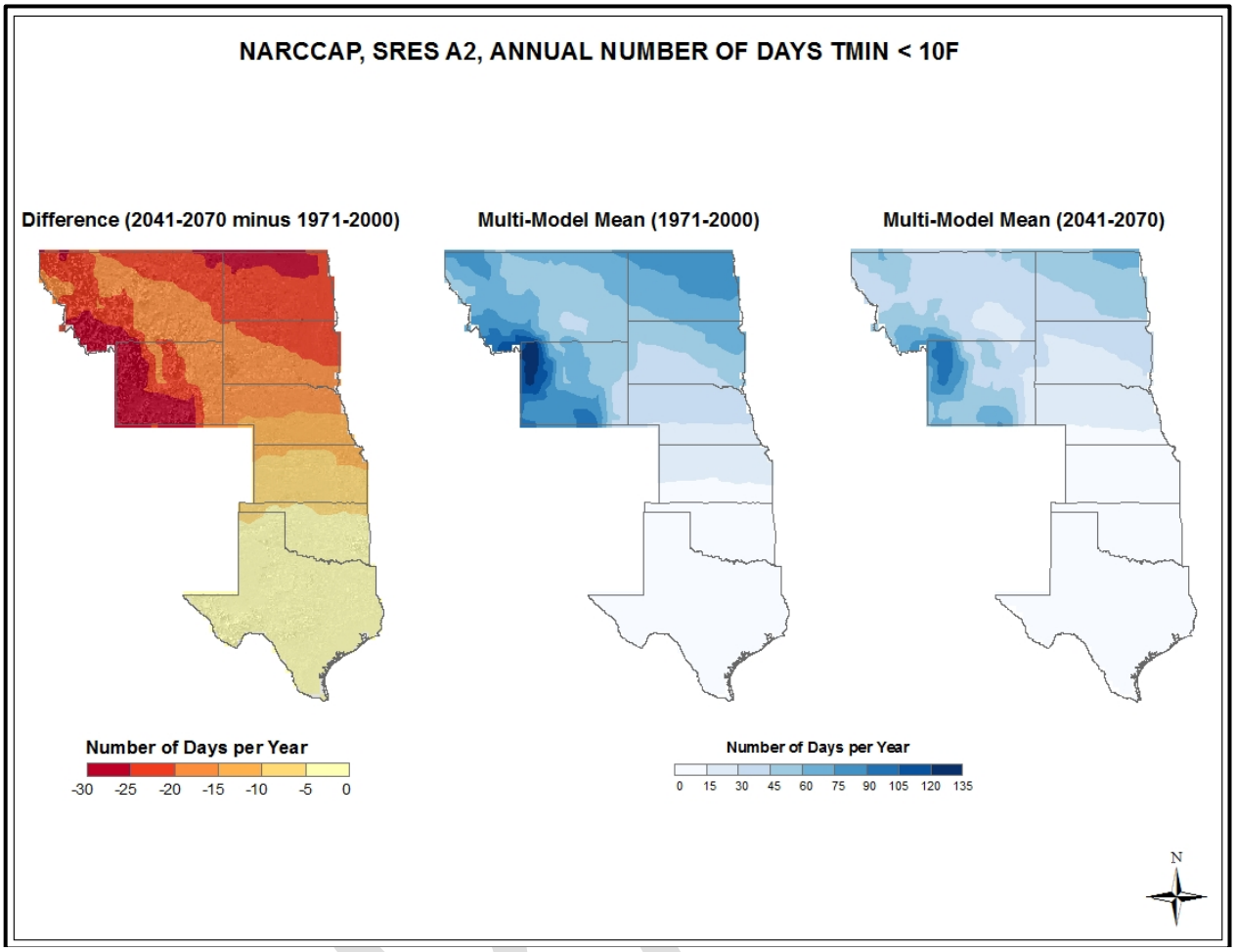


Figure 16. Spatial distribution of the NARCCAP multi-model mean change in the number of days with a minimum temperatures below 10°F between 2041-2070 and 1971-2000 (top). Model reference periods of the number of days with a minimum temperature less than 10°F (bottom).

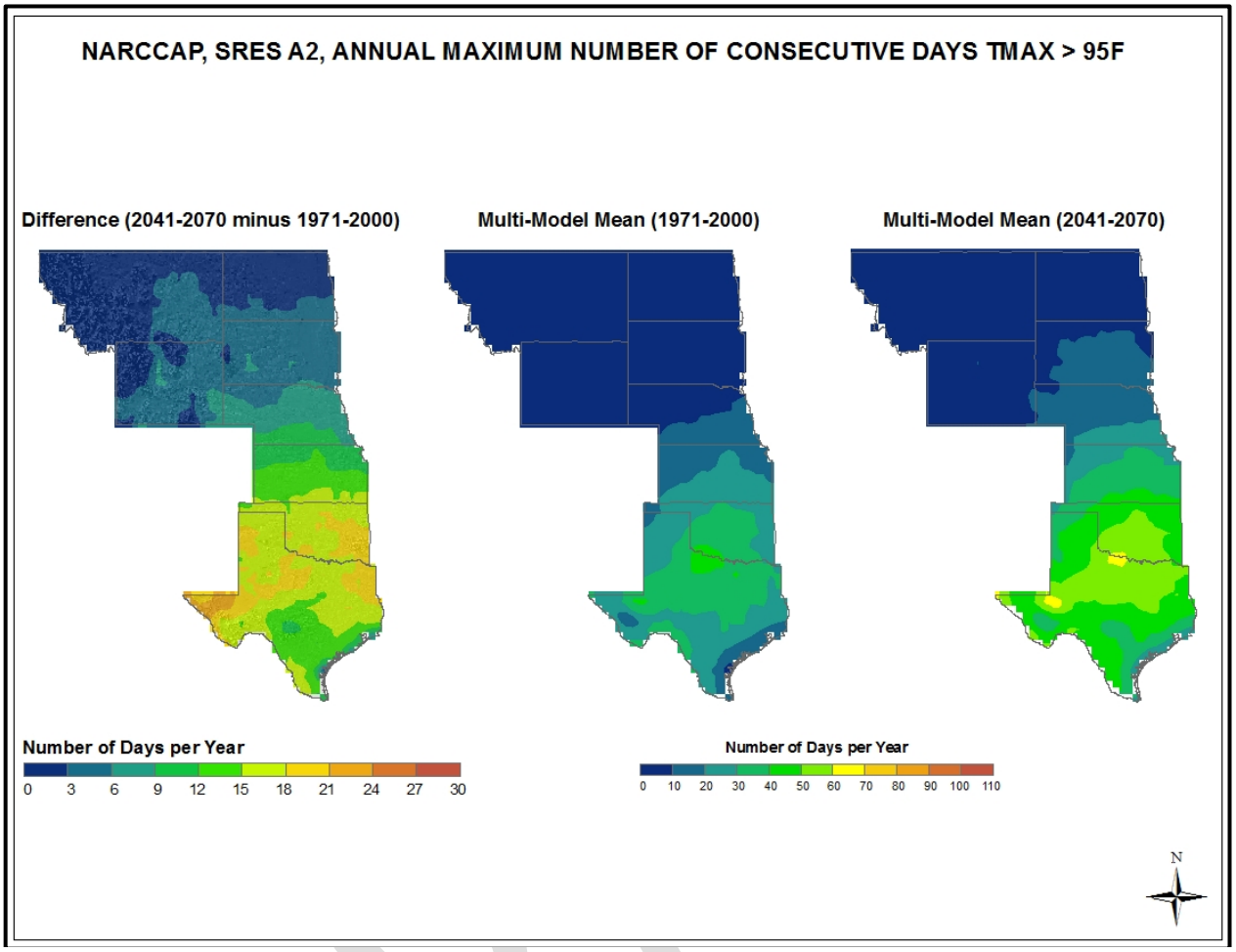


Figure 17. Spatial distribution of the NARCCAP multi-model mean change in the annual maximum number of consecutive days with a maximum temperature greater than 95°F between 2041-2070 and 1971-2000 (top). Model reference periods of the annual maximum number of consecutive days with a maximum temperature greater than 95°F (bottom).

Table 2. The mean and standard deviation of changes in selected temperature variables for the NARCCAP simulations. Mean changes from the CMIP3 statistically-downscaled analyses are also shown for comparison.

Variable Name	NARCCAP Mean Change	NARCCAP St. Dev. of Change	Statistically-Downscaled Mean
Frost-free period	+24 days	4 days	+22 days
#days Tmax > 90°F	+20 days	6 days	+30 days
#days Tmax > 95°F	+18 days	6 days	+26 days
#days Tmax > 100°F	+15 days	6 days	+17 days
#days Tmin < 32°F	-23 days	3 days	-24 days
#days Tmin < 10°F	-12 days	3 days	-10 days
#days Tmin < 0°F	-7 days	3 days	-6 days
Max run days > 95°F	+62%	29%	+134%
Max run days > 100°F	+77%	47%	+245%
Heating degree days	-16%	2%	-17%
Cooling degree days	+48%	14%	+55%
Growing degree days (base 50°F)	+27%	5%	+29%

For the NARCCAP changes, the frost-free period increases by 24 days. The number of days with daily maximum temperatures exceeding various thresholds increases by 20, 18, and 15 days for thresholds of 90°F, 95°F, and 100°F, respectively. The number of days with minimum temperatures falling below various thresholds decreases by 23, 12, and 7 days for thresholds of 32°F, 10°F, and 0°F, respectively. A measure of heat waves is the run of days exceeding thresholds. The average annual maximum run of days exceeding 95°F and 100°F increases by 62% and 77%, respectively, a near doubling of the length of such hot periods. Heating degree days (a climatic metric related to the energy required for heating in the cold season) decreases by 16% while cooling degree days (a climatic metric related to the energy required for cooling in the warm season) increases by 48%. The number of growing degree days increases by 27%.

For the variables calculated from the CMIP3 daily statistically-downscaled data set, the values are mostly comparable. The number of days with the maximum temperature greater than 90°F increases more in the statistically-downscaled data set (+30 days) than in NARCCAP (+21 days). There is also a larger increase in the run of days the maximum temperature exceeds 95°F and 100°F in the statistically-downscaled data set. However, the number of days with a minimum temperature of less than 32°F in the statistically-downscaled data set (-23 days) is comparable to that from the NARCCAP simulations (-24 days).

Projections for Other Temperature Variables

Changes in the variability of temperature can magnify or ameliorate the impacts of mean temperature changes. The monthly BCSD time series were used to calculate variability on the interannual and interseasonal time scales. The variability measure is the standard deviation of annual or seasonal mean values of temperature. Changes were calculated as the percent change in standard deviation between the future and present periods. The quantile mapping that constitutes the core of the BCSD methodology will have equal effects on the present and future simulated variability for all anomalies that are within the range of the control simulation. However, if future values fall outside of the control simulation range, an empirical procedure is used to extend the mapping function. There is no assurance that any such extensions will be physically realistic. Since this is likely to affect a small minority of the future simulated values, it is unlikely to affect the sign of any changes, but could add uncertainty to the quantitative value.

Figure 18 shows the CMIP3 multi-model mean changes in temperature variability between present and future periods for the A2 scenario, averaged for the entire Great Plains region. For annual temperature, there is an increase in variability at 2035 and 2085, but a small decrease at 2055. For individual seasons, variability increases for each time period. The largest increases occur in the summer, being more than 10% in 2055 and 2085. Winter variability increases by around 5% or slightly less in the three future periods.

The spatial distribution of the NARCCAP multi-model mean change in the frost-free season between 2055 and the historical reference period is shown in Fig. 19. The positive climatological trend of the last century is projected to continue, with at least 10 more days in the annual frost-free season across the region. The largest increases are found across the high terrain of Wyoming and Montana with values of greater than 30 days. The remainder of the region shows increases on the order of 3-4 weeks.

The spatial distribution of the NARCCAP multi-model mean change in cooling degree days between 2055 and the historical reference period is shown in Fig. 20. In general, the changes are quite closely related to mean temperature with the warmest (coolest) areas showing the largest (smallest) changes. The hottest areas, such as Texas and Oklahoma, are projected by the NARCCAP models to have the largest increase of cooling degree days per year (up to 1,000). Further north across Nebraska and the Dakotas, increases between 400-800 cooling degree days per year are projected. Areas across the Rockies are shown to have the smallest increases, around 200 days or less.

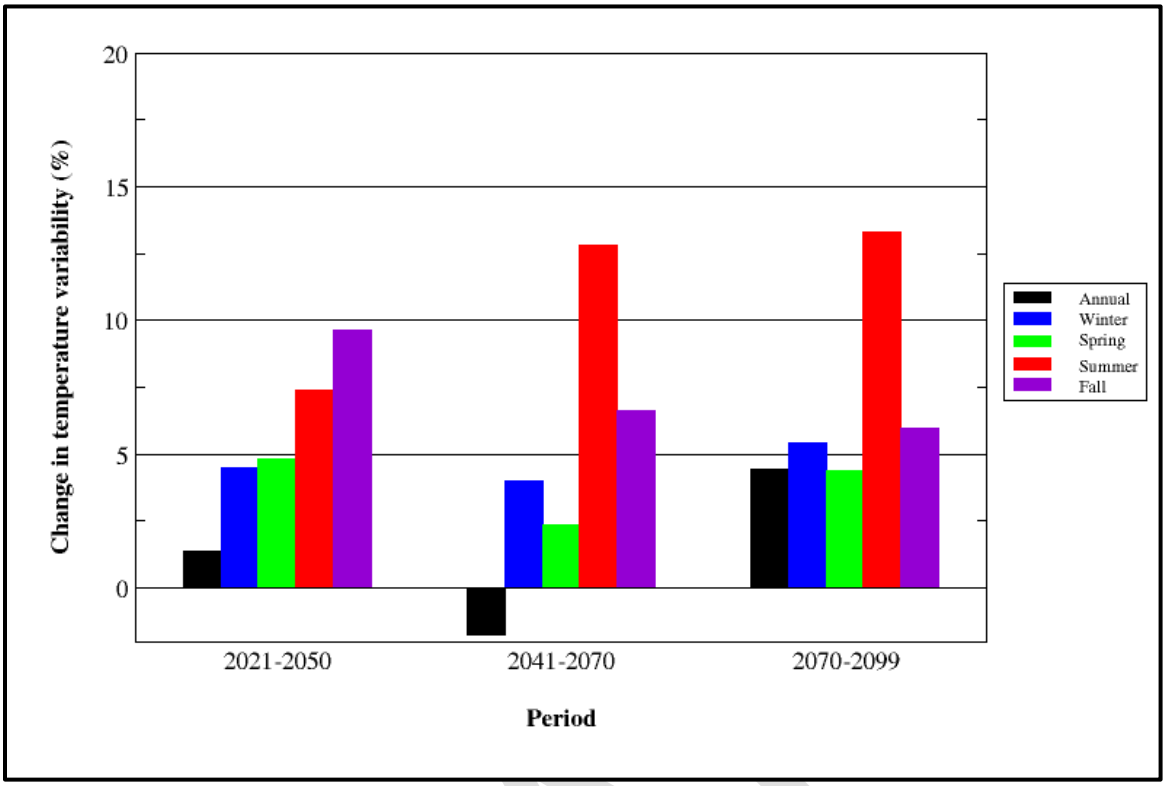


Figure 18. Multi-model mean annual and seasonal changes in temperature variability (%) for the 3 future periods with respect to the reference period of 1971-2000 for the high (A2) emissions scenario.

The spatial distribution of the NARCCAP multi-model mean change in heating degree days between 2055 and the historical reference period is shown in Fig. 21. The largest changes occur in higher elevation areas, where the projected decreases are up to 2,000 heating degree days. Areas further south are projected to experience the smallest decrease in heating degree days per year with a range of 400-1200 fewer days.

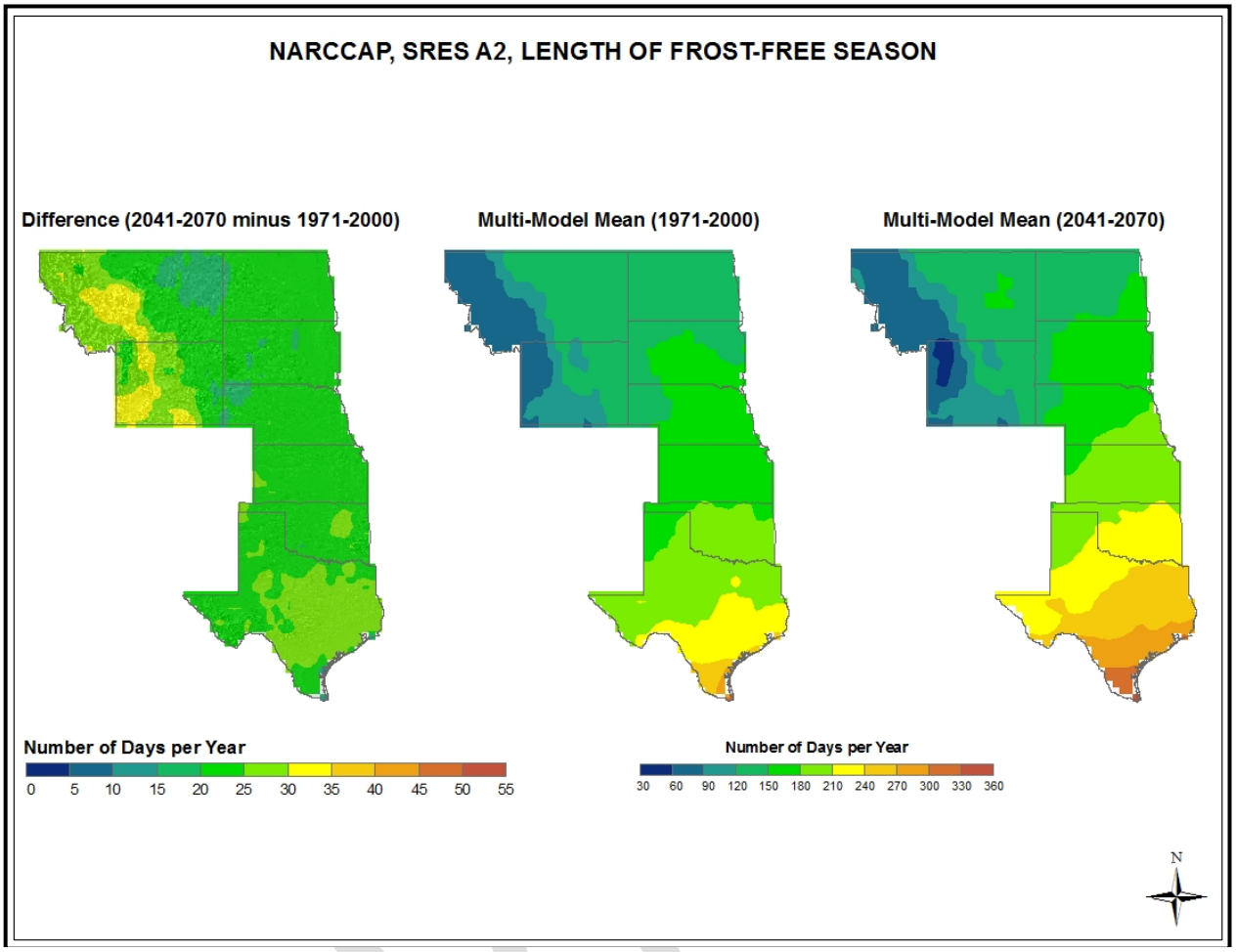


Figure 19. Spatial distribution of the NARCCAP multi-model mean change in the length of the frost-free season between 2041-2070 and 1971-2000 (top). Model reference periods of the length of the frost-free season (bottom).

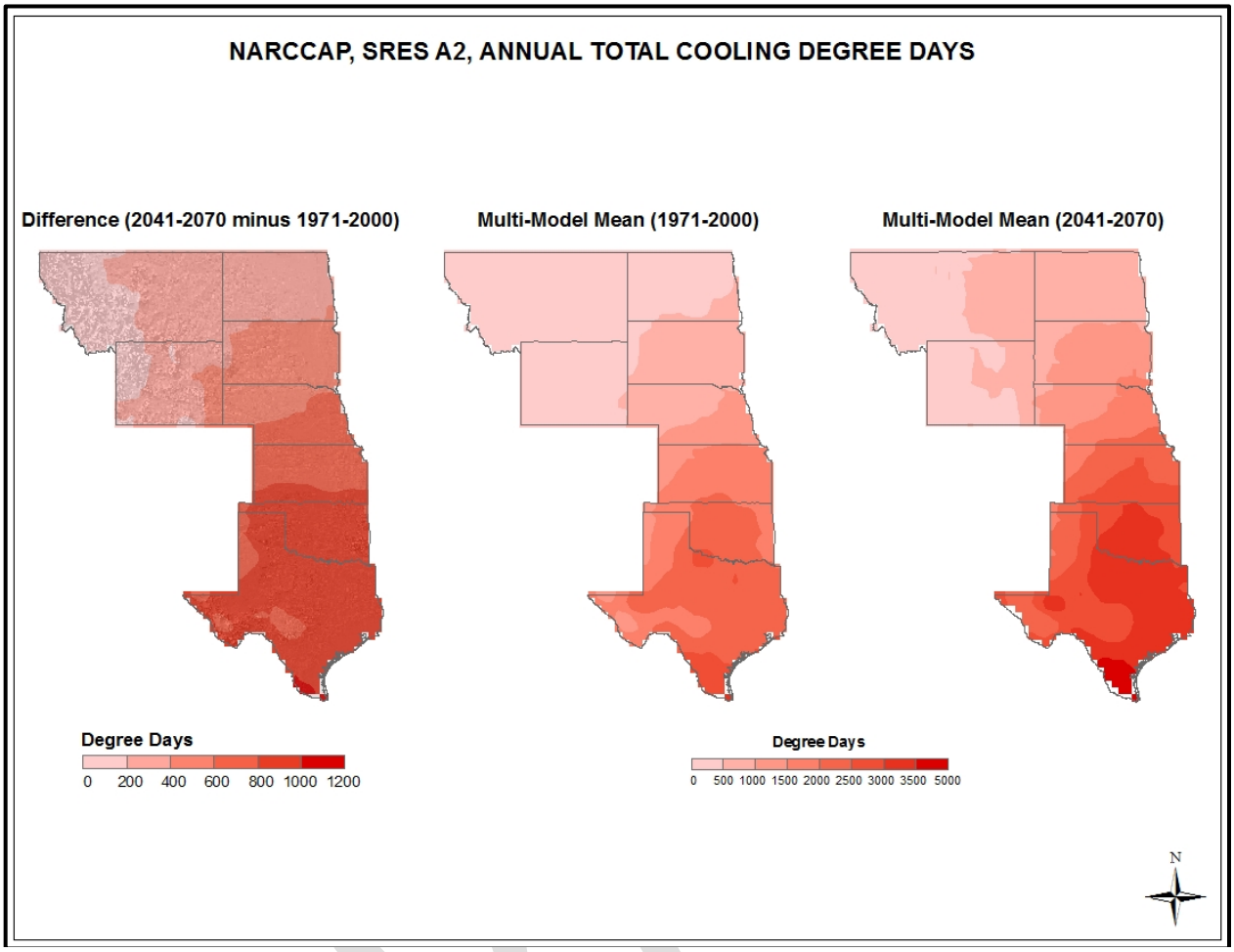


Figure 20. Spatial distribution of the NARCCAP multi-model mean change in the number of cooling degree days between 2041-2070 and 1971-2000 (top). Model reference periods of the number of cooling degree days (bottom).

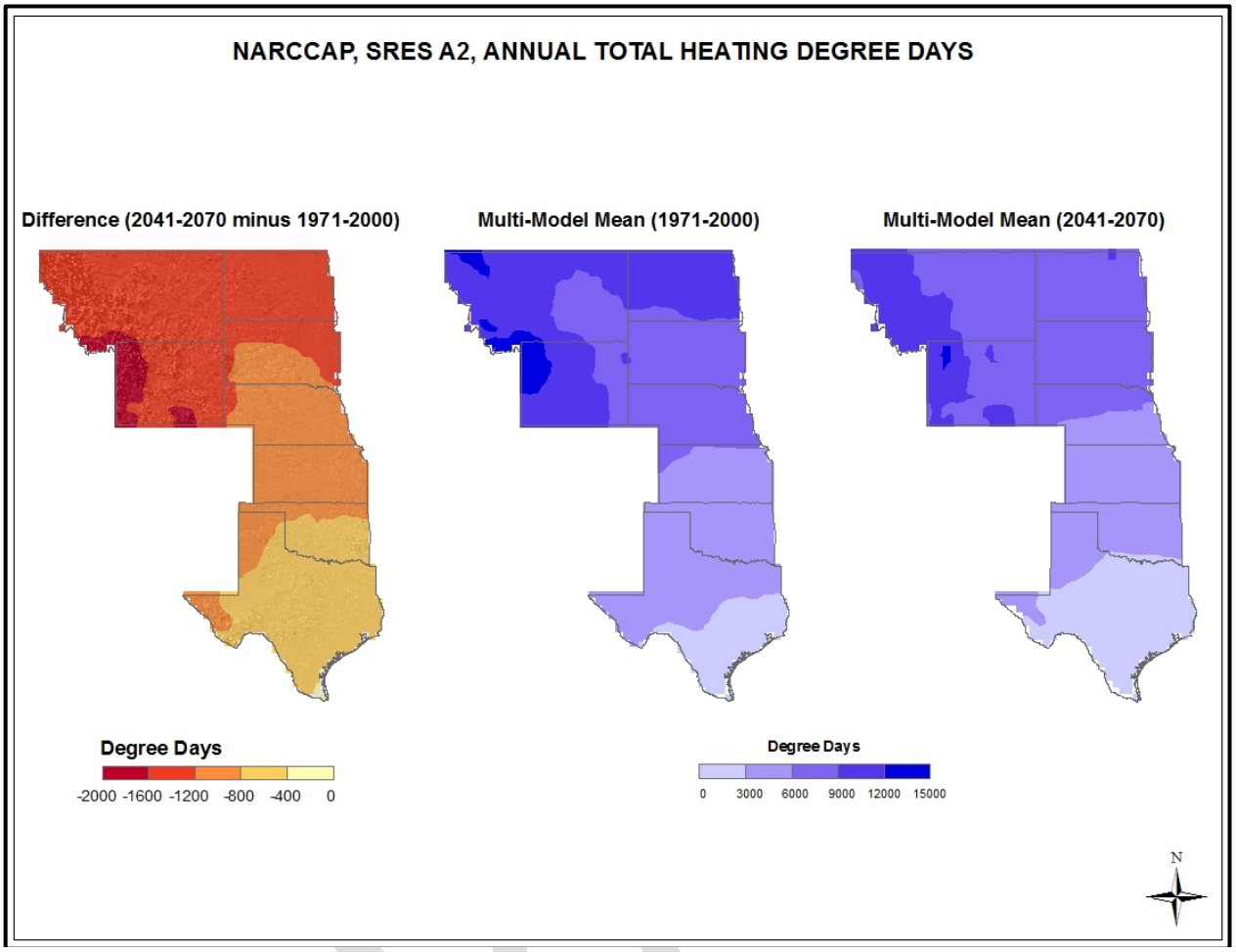


Figure 21. Spatial distribution of the NARCCAP multi-model mean change in the number of heating degree days between 2041-2070 and 1971-2000 (top). Model reference periods of the number of heating degree days (bottom).

Table 3. Distribution of changes in mean annual precipitation (%) for the Great Plains region for the 15 CMIP3 models.

Scenario	Period	Low	25%ile	Median	75%ile	High
A2	2021-2050	-6	-1	1	3	6
	2041-2070	-9	-3	0	5	6
	2070-2099	-15	-5	1	6	9
	NARCCAP	*-4*	*0*	*3*	*4*	*8*
B1	2021-2050	-5	0	1	2	4
	2041-2070	-3	-2	0	4	4
	2070-2099	-5	0	2	5	6

Mean Precipitation Projections

The distribution of the CMIP3 multi-model mean changes in annual precipitation is shown in Fig. 22, for the three future periods (2035, 2055, 2085) and two emissions scenarios (A2, B1). There is a pronounced north-south gradient in changes. The far southern regions show the largest decreases while the far northern areas show slight increases. This gradient increases in magnitude as the time progresses for the A2 scenario. The gradient in the B1 scenario is largely unchanged between the periods. The largest north-south differences are for the A2 scenario in 2085, varying from an increase of around 10% in the far north to a decrease of 12% in central Texas. Nominal differences occur for the A2 scenario in 2035, with increase of 2% in North and South Dakota, and a decrease of about 2-4% in areas such as Oklahoma and Texas.

The distribution of changes in mean annual precipitation for each future time period and both emissions scenarios across the 15 CMIP3 models is shown in Table 3. For all periods and both scenarios, the CMIP3 model simulations include both increases and decreases in precipitation. Nearly all the median values are positive, but small (less than 2%). The range of changes from lowest to highest is generally 10-15%. For example, in the A2 scenario the precipitation change for 2055 varies from a low of -9% to a high of +6%. The NARCCAP range of changes varies from -4% to +8%. The inter-quartile range of changes across all the GCMs is less than 15%.

Figure 23 shows the annual and seasonal precipitation change between 2041-2070 and 1971-2000 for the A2 scenario, the 9 NARCCAP regional climate model simulations. The annual changes are mostly positive, continuing the trend from the past few years, with the largest increases occurring in North Dakota. The exception is southwest Texas, which sees decreases of up to 14%. Winter changes are mostly positive, especially from Oklahoma north, ranging from near zero at the Oklahoma-Texas border to over 12% across Wyoming, Montana and the Dakotas. Spring changes are split between modest increases (4-12%) in the north-central portion of the Great Plains, and large negatives (8-20%) across the Rio Grande area of southwest Texas. The largest variability occurs in the summer time, ranging as high as +12% (North Dakota) and as low as -24% (east-central Oklahoma). Over the Rocky Mountains the projections vary from positive to negative (-16 to +10%). Fall changes are mostly positive, with the exception of south-central Wyoming and southwest Texas.

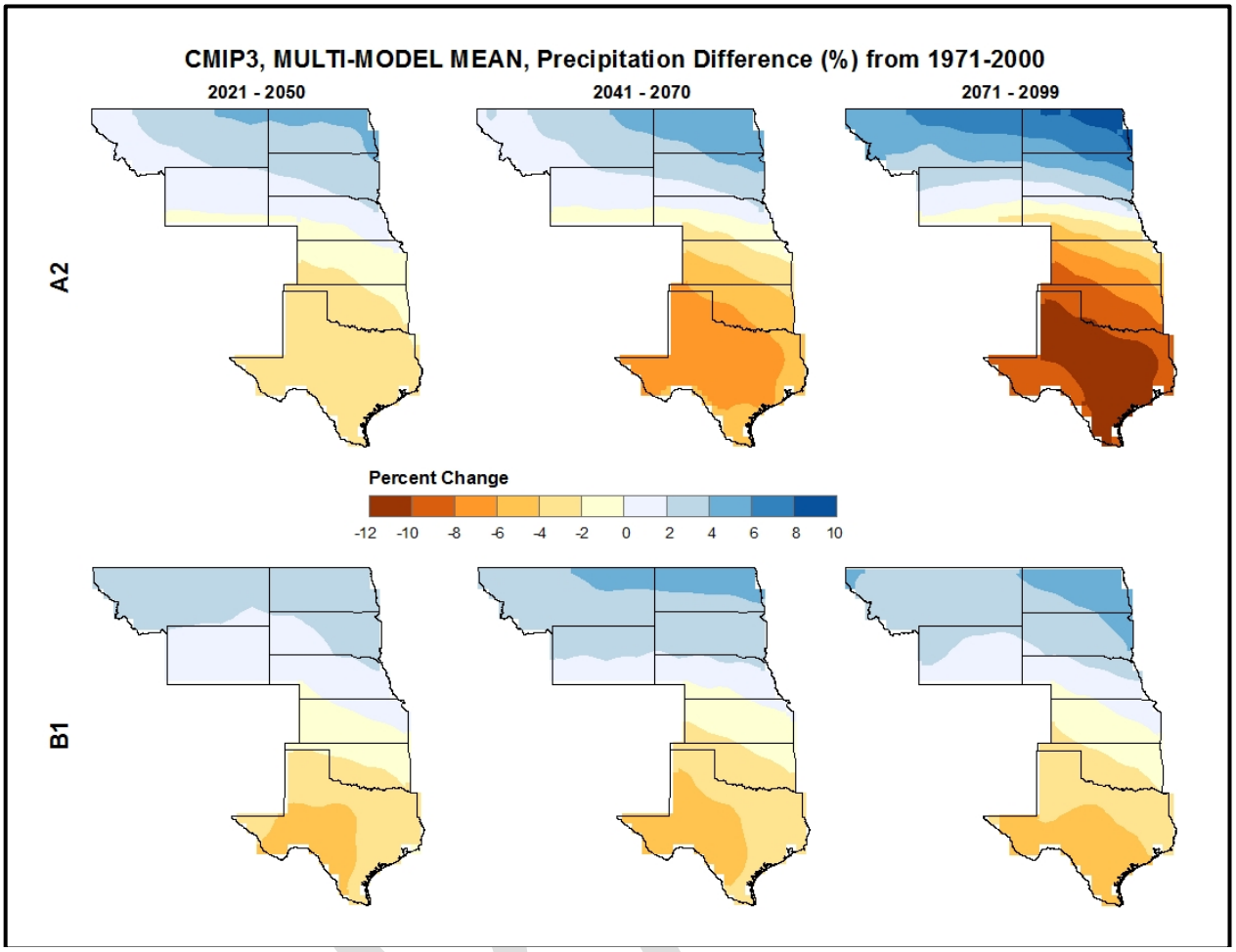


Figure 22. Multi-model mean annual differences in precipitation (%) between the 3 future periods and 1971-2000, from the 15 CMIP3 model simulations.

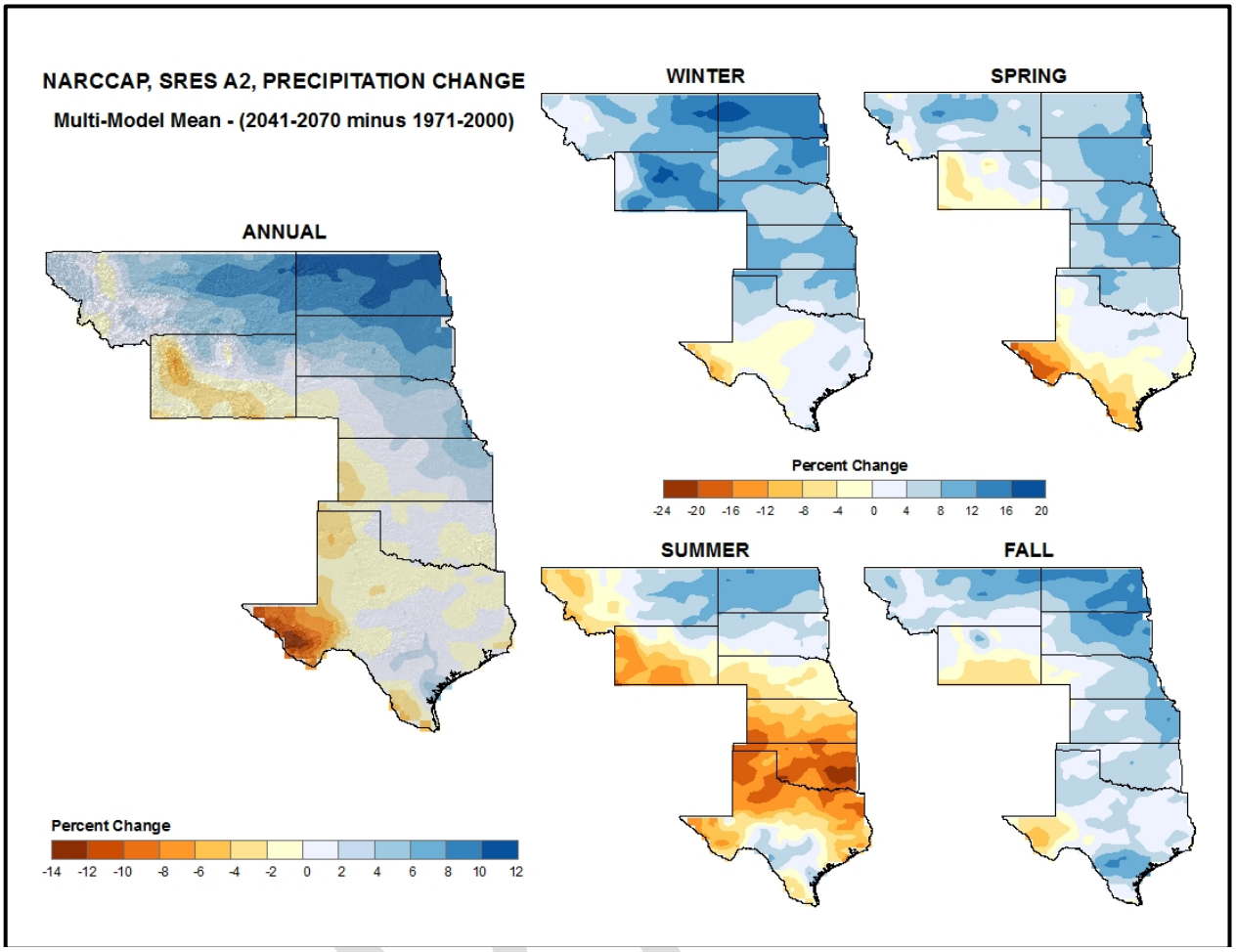


Figure 23. Multi-model mean annual and seasonal differences in precipitation (%) between 2041-2070 and 1971-2000, from the 9 NARCCAP regional climate model simulations.

Table 4. Distribution of changes in mean seasonal precipitation (%) for the Great Plains region for the 15 CMIP3 models.

Scenario	Period	Season	Low	25%ile	Median	75%ile	High
A2	2070-2099	DJF	-4	3	6	8	17
		MAM	-13	-3	3	7	9
		JJA	-34	-22	-8	6	15
		SON	-18	-3	4	7	14
B1	2070-2099	DJF	-2	1	2	6	9
		MAM	-10	2	4	5	9
		JJA	-15	-6	-2	5	14
		SON	-9	-1	2	4	10

Table 4 shows the seasonal distribution of precipitation changes across the 15 CMIP3 models, between 2070-2099 and 1970-2000 for both emissions scenarios. On a seasonal basis, the range of model-simulated changes is quite large, when expressed as percentages. For example, in the A2 scenario, the change in summer precipitation varies from a decrease of 34% to an increase of 15%. A majority of the models indicate increases in winter precipitation. In the other three seasons, there is a more even split between models showing increases and decreases. In the B1 scenario, the range of changes is generally smaller, but the distribution of changes in mean seasonal precipitation are comparable to that of the A2 scenario. The central feature of the results in Table 4 is the large uncertainty in seasonal precipitation changes.

Figure 24 shows the mean annual changes in precipitation for each future time period and both emissions scenarios, averaged over the entire Great Plains region for the individual 15 CMIP3 models. In addition, averages for the 9 NARCCAP simulations and the 4 GCMs used in the NARCCAP experiment are shown for 2055 (A2 scenario only). The small plus signs are values for each individual model, and the circles depict the overall means. The CMIP3 multi-model mean precipitation changes are near zero for both scenarios. The mean of the NARCCAP simulations is slightly higher than the mean of the CMIP3 GCMs and virtually the same as the 4 GCMs used in the NARCCAP experiment. The range of individual model changes in Fig. 24 is large compared to the differences in the multi-model means, as also illustrated in Table 3. In fact, for all three future periods and for the two scenarios, the individual model range is much larger than the differences in the CMIP3 multi-model means.

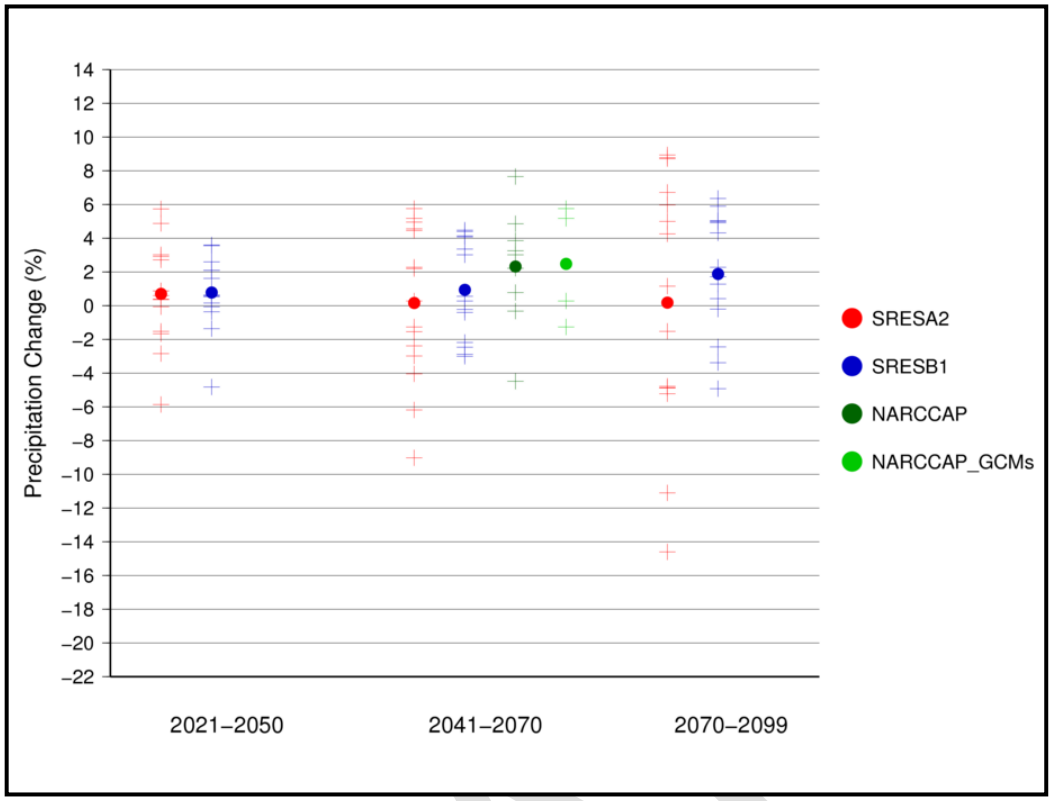


Figure 24. Mean annual precipitation changes (%) for each future time period with respect to the reference period of 1971-2000 for all 15 CMIP3 models, averaged over the entire Great Plains region for the high (A2) and low (B1) emissions scenarios. Also shown are results for the NARCCAP simulations for 2041-2070 and the 4 GCMs used in the NARCCAP experiment (A2 only). The small plus signs are values for each individual model and the circles depict the overall means.

Figure 25 shows the mean seasonal changes in precipitation for each future time period for the A2 scenario, averaged over the entire Great Plains region for the individual 15 CMIP3 models, as well as the NARCCAP models for 2055. There are differences seasonally with the CMIP3 models projecting increases during the winter of 1-2% and during the fall and spring of 0-2%. For the summer season, precipitation changes are near or below zero. The decreases are largest in the summer, ranging from around -2% in 2035 to around -8% in 2085. The NARCCAP models, which are displayed for 2055, are slightly higher than the CMIP3 mean in every season but by only a small amount. As was the case for the annual totals in Fig. 24, the model ranges in Fig. 25 are large compared to the multi-model mean differences. This illustrates the large uncertainty in the precipitation estimates using these simulations.

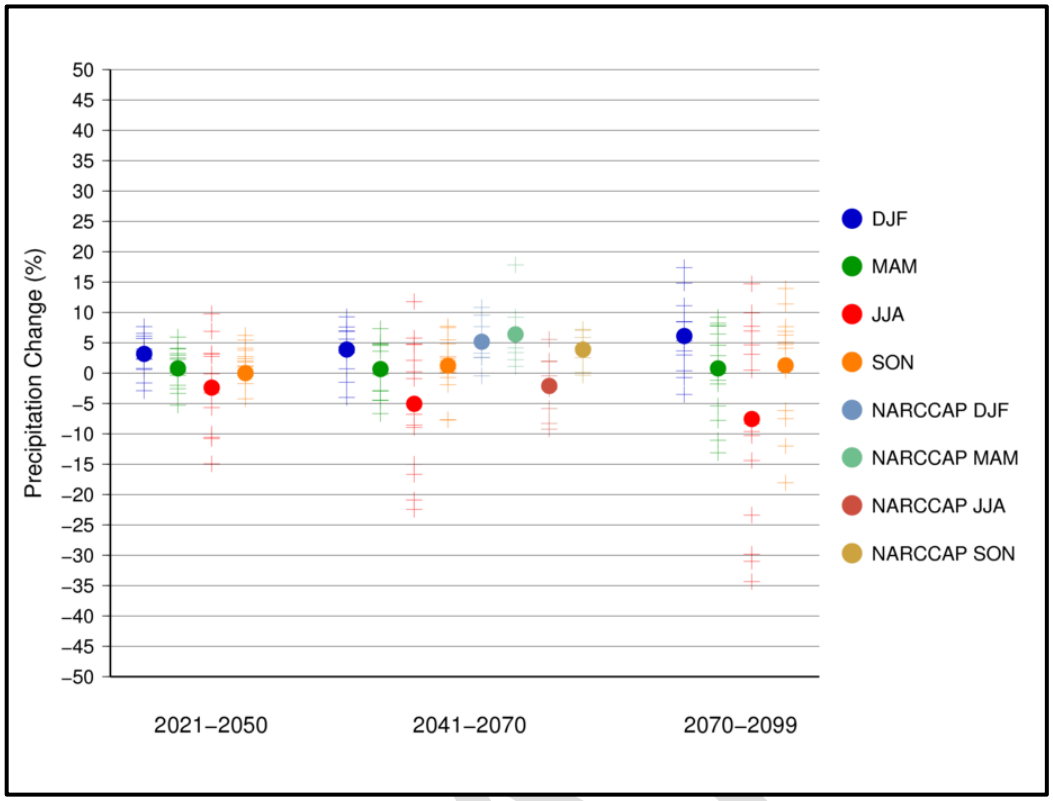


Figure 25. Mean seasonal precipitation changes (%) for each future time period with respect to the reference period of 1971-2000 for all 15 CMIP3 models, averaged over the entire Great Plains region for the high (A2) emissions scenario. Also shown are results for the NARCCAP simulations for 2041-2070 and the 4 GCMs used in the NARCCAP experiment. The small plus signs are values for each individual model and the circles depict the overall means.

Extreme Precipitation Projections

Changes in the variability of precipitation can magnify or ameliorate the impacts of mean precipitation changes. The monthly BCSD time series were used to calculate variability on the interannual and interseasonal time scales. The variability measure is the standard deviation of annual or seasonal totals of precipitation. Changes were calculated as the percent change in standard deviation between the future and present periods.

Figure 26 shows the CMIP3 multi-model mean changes in precipitation variability between present and future periods for the A2 scenario, averaged for the entire Great Plains region. Annually, there is an increase in precipitation variability for all future periods, from about 9% in 2035 to 14% in 2085. There is also an increase in each of the 4 seasons, with wintertime seeing the highest increase (approximately 9% in 2035, 13% in 2055 and 23% in 2085). Summer and fall show the smallest increases of around 5% or less in all periods.

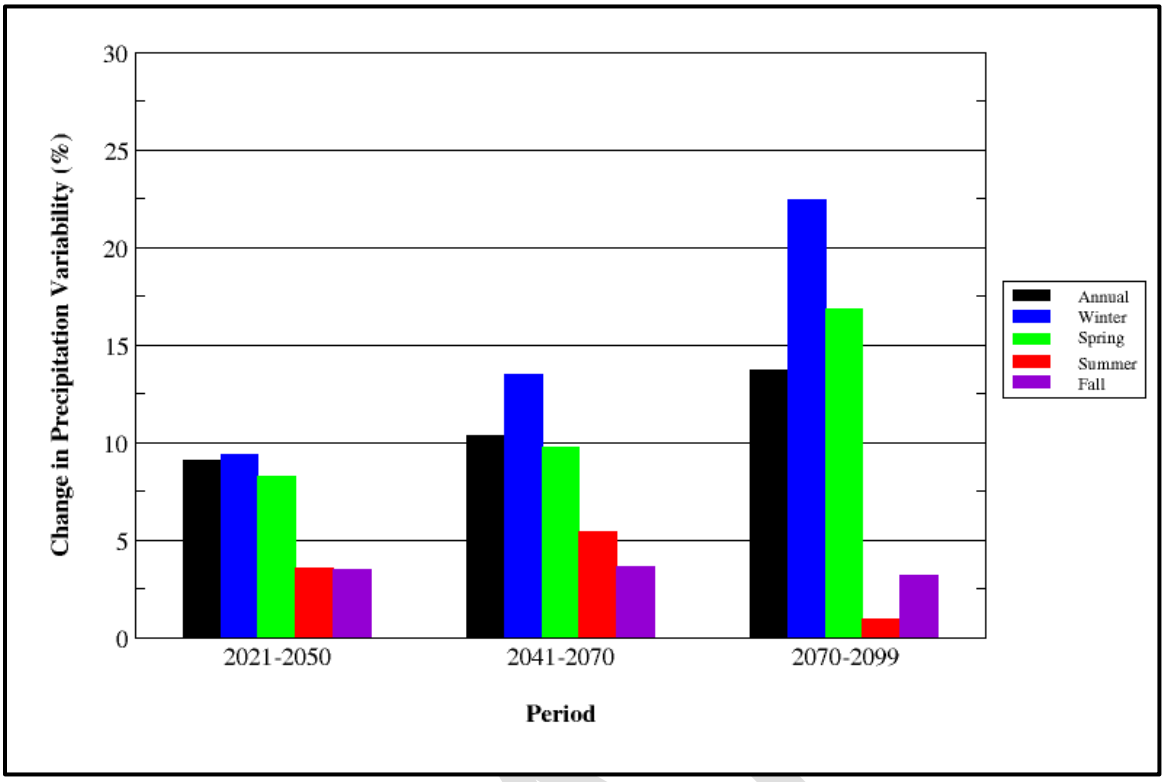


Figure 26. Multi-model mean annual and seasonal changes in precipitation variability (%) for the 3 future periods with respect to 1971-2000 for the high (A2) emissions scenario.

Table 5. Mean changes, along with the standard deviation of selected precipitation variables from the NARCCAP simulations. Mean changes from the CMIP3 statistically-downscaled analyses are also shown for comparison.

Variable Name	NARCCAP Mean Change	NARCCAP St. Dev. of Change	Statistically-Downscaled Mean
#days > 1 inch	+17%	6%	+9%
#days > 2 inches	+34%	22%	+29%
#days > 3 inches	+47%	39%	+57%
#days > 4 inches	+56%	58%	+96%
Max run days < 0.1 inches	+3 days	+1 day	+2 days

The spatial distribution of the NARCCAP multi-model mean change in number of days with precipitation exceeding 1 inch is shown in Fig. 27. Again this is the difference between the period of 2041-2070 and the 1971-2000 reference period. Maps of the model reference periods are also displayed. Nearly the entire region is projected to see increases, generally of up to 30%, although greater in some northern areas. Small areas in the far eastern portions of the region are projected to see slight decreases of up to 10%. Climatologically, such extreme precipitation metrics have shown substantial variability.

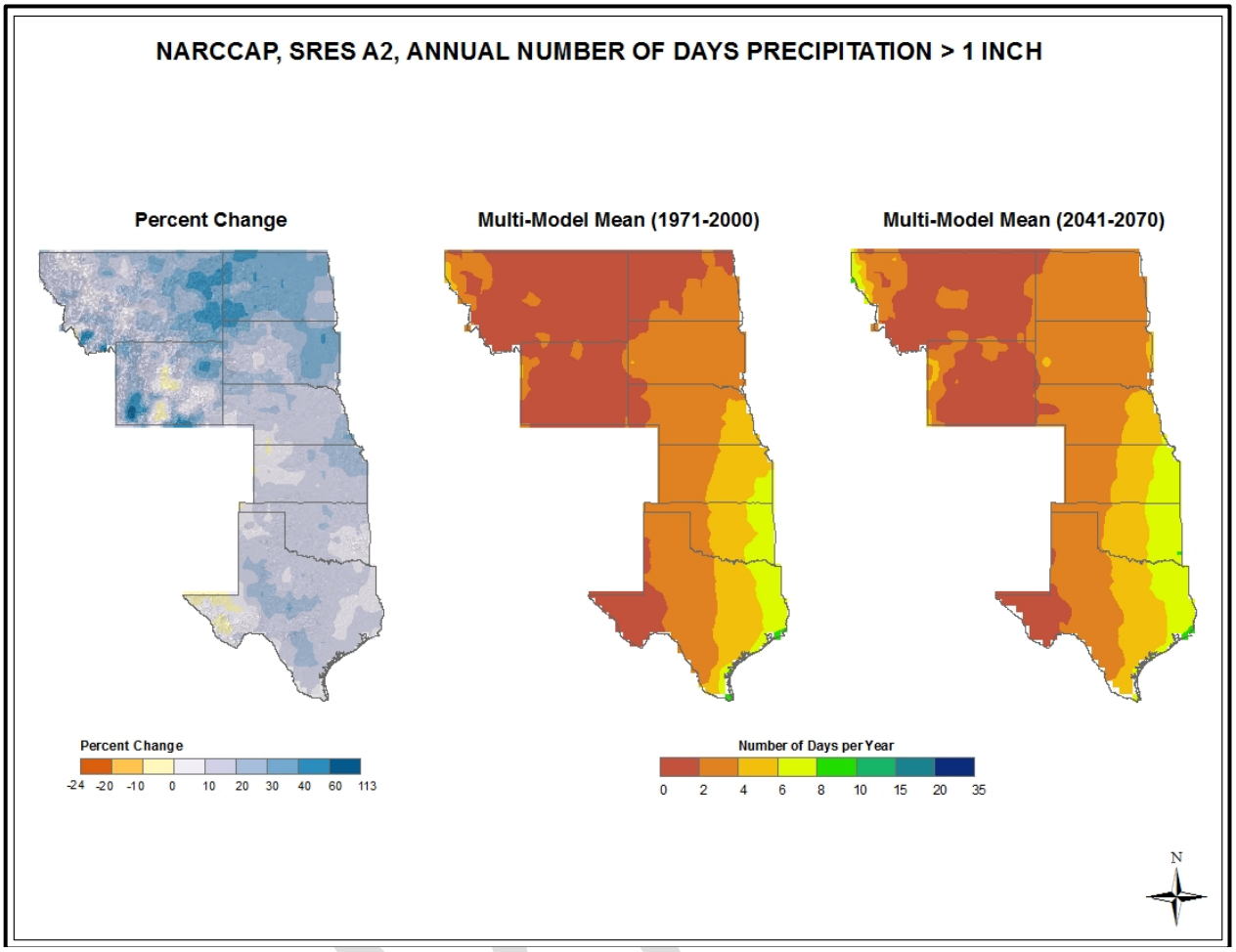


Figure 27. Spatial distribution of the NARCCAP multi-model mean percent change in the number of days with precipitation exceeding 1 inch between 2041-2070 and 1971-2000 (top). Model reference periods of the number of days with precipitation exceeding 1 inch (bottom).

Consecutive number of days with little or no precipitation can have large impacts. Figure 28 shows the NARCCAP multi-model mean change in the average annual maximum run of days with precipitation less than 0.1 inch. The areas projected to see the largest increases are in the south, with an increase of 5-15 days with little or no precipitation. By contrast, parts of the north, including the Dakotas, Wyoming and Montana, are projected to see decreases of up to 5 days per year, that is, the models project these areas to experience shorter dry periods.

The mean changes for selected precipitation-based derived variables from the NARCCAP simulations between 2055 and the historical reference period are summarized in Table 5. The same variables from the CMIP3 statistically-downscaled simulations are also shown for comparison. For the NARCCAP data, the number of days with precipitation exceeding high thresholds increases for all thresholds (+17% for 1 inch, +34% for 2 inches, +47% for 3 inches, and +56% for 4 inches). Interestingly, the increases are higher for the more extreme thresholds. The average annual maximum run of days with precipitation less than 0.1 inches increases by 3 days. Similar to the temperature changes, the means from statistically-downscaled simulations are higher than their NARCCAP counterparts, especially for the highest thresholds. The number of days with precipitation exceeding high thresholds increases for all 4 thresholds (9% for 1 inch, 29% for 2 inches, 57% for 3 inches, and 96% for 4 inches). The change in the average maximum run of days with precipitation less than 0.1 inches is +2 days.

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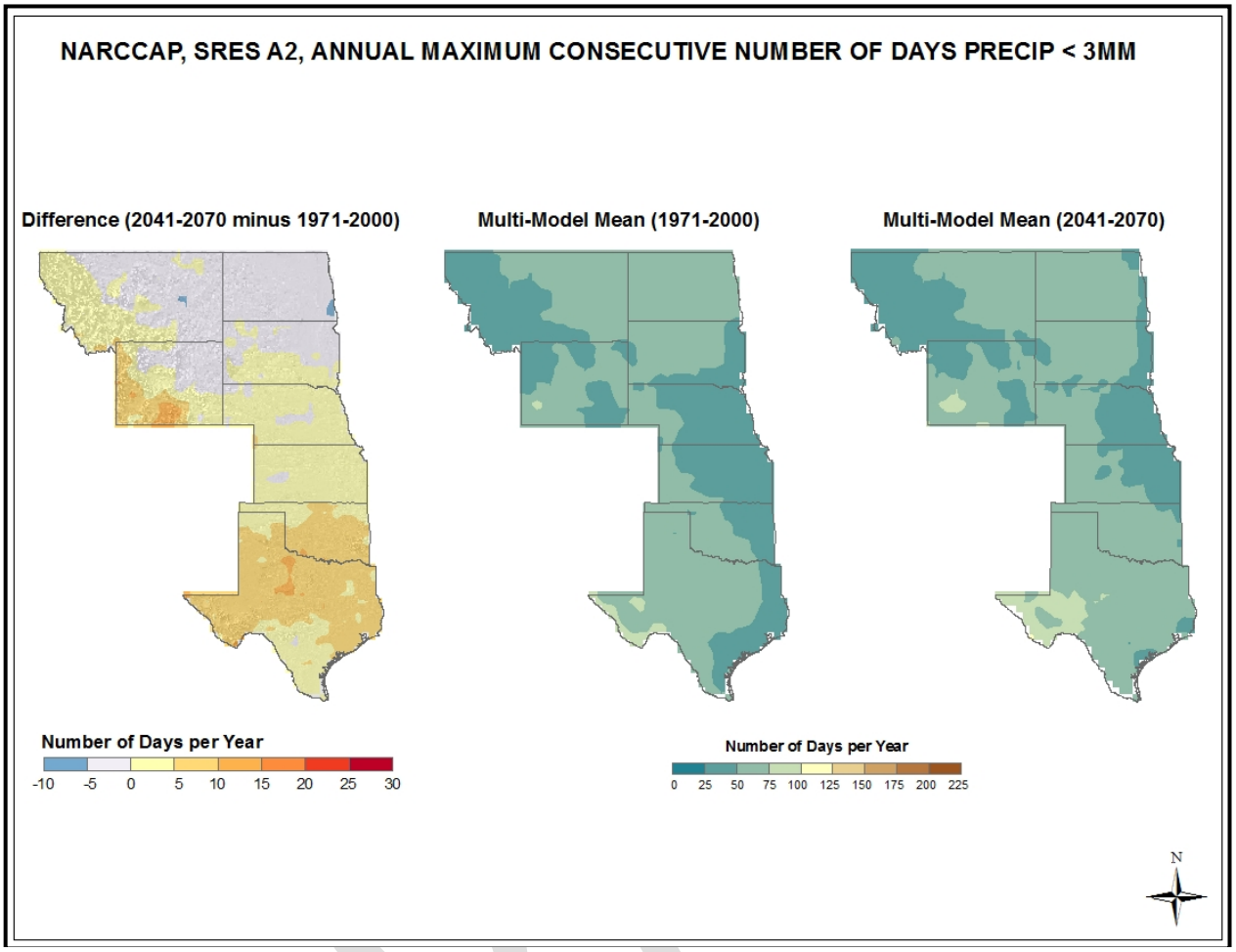

Figure 28. Spatial distribution of the NARCCAP multi-model mean change in the annual maximum number of consecutive days with precipitation less than 0.1 inches/3 mm between 2041-2070 and 1971-2000 (top). Model reference periods of the annual maximum number of consecutive days with precipitation less than 0.1 inches/3 mm (bottom).

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IV GREAT PLAINS CROSS-SECTORAL CONSIDERATIONS: IMPACTS AND CONSEQUENCES, VULNERABILITY AND RISK, ADAPTIVE CAPACITY, RESPONSE OPTIONS

=4.1 General Considerations of Vulnerability and Risk Management (S McNeeley/D Ojima)

CASE STUDIES

A) Energy-Water-Land

Increase demands, future constraints, regional solutions

B) Agricultural systems (land, water, biota)

Croplands, livestock, bioenergy, and conservation issues

C) Rural and Urban communities

- Tribal and rural landscapes: contrast and comparison vulnerability, opportunity, and adaptive capacity
- Rural Housing
- Urban Infrastructure

D) Human Health and Disease Vectors

E) Insurance Perspective: Vulnerability, Risk, and Economy

4.1 Responses strategies across a suite Social-ecological dimensions to multiple stresses in the Great Plains

The social ecological systems of the Great Plains are comprised of a suite of stakeholder communities and include a range of interests from ranchers, farmers, city dwellers, business entrepreneurs, energy developers, natural resource manages, recreationists, Native American tribes and many others. Each of the communities are affected by multiple stresses and interactions associated with climate change, environmental conditions, market forces, policy and regulatory statutes, cultural trends, and jurisdictional and institutional structures which affect decision responses that are oriented to their own specific needs.

The Great Plains region encompasses an area with great climate variability and multiple climate-sensitive livelihoods that are potentially vulnerable to climate change. Sustaining ecosystems and livelihoods in the region requires devising ways to incorporate understanding of climate change impacts into decision making and planning across a suite of enterprises, from agriculture, to energy needs, use, and sources, to water , land, and forest management, and building resilience of the many tribes, cities, and rural communities in the region. A sustainable livelihoods approach focuses on humans and their environments and the multiple factors that influence well-being, resilience, or vulnerability (Pasteur 2011, Hahn, Riederer and Foster 2009). It requires an understanding of the assets and resources that individuals, households, and societies have to maintain their livelihood and to respond to shocks and stresses of all types, increasingly exacerbated by climate change and projected to be even more so in the future. Livelihood assets can be thought of in terms of the "5 capital assets or resources" – i.e., natural capital (resource flows, including ecosystem services); financial capital; physical capital (such as infrastructure and means of transportation); human capital (such as knowledge, skills, and work capabilities); and social-political capital (e.g., relationships, networks, access to political processes and decision making, power and influence) (IISD, IUCN and SEI 2003).

In the Great Plains land managers are worried about a variety of factors related to climate variability and change, though often climate change is one of many concerns, and often not the most important (Ojima and Lackett 2002, Lackett and Galvin 2008). More likely, other factors such as market or commodity prices, incentives, conservation policy, laws and other social and cultural factors are

considered in the decision making. In fact, many agricultural operators in this region are vulnerable due to the declining reward scale for farming and ranching. Many land use managers and households are operating on the economic margin, and small shifts in climate or markets may drive them out of business.

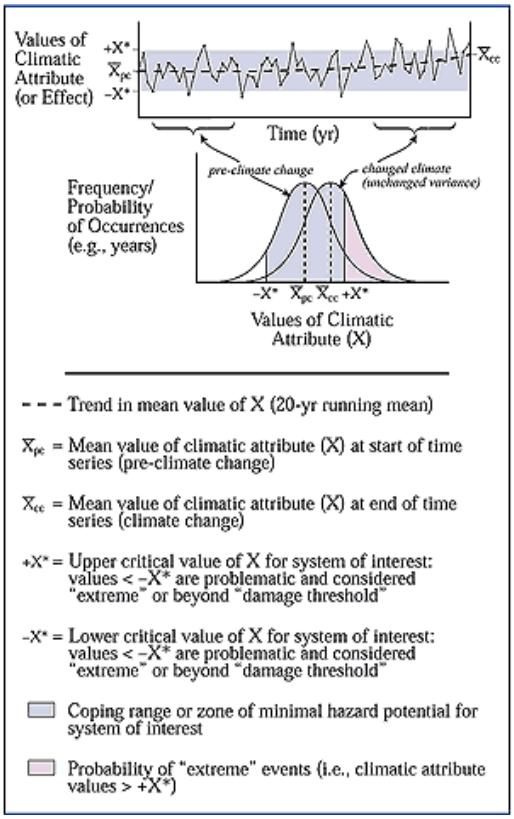
In the Great Plains environment, variability in weather and economic dynamics results in enhanced uncertainty in land use decisions. The rangeland ecosystems have proven highly vulnerable to changes in precipitation patterns during the past decade. The changes in climate patterns (extreme events, trends and variability in seasonal precipitation and temperatures) in the region due to on-going and projected climate changes adds to the uncertainty in the social-ecological well-being of the region. As discussed in more detail in chapter/section 3, climate change is being experienced in various ways, such as increased night-time temperature, increased intensity of rainfall events, extended growing season, extended drought periods, and elevated atmospheric CO_2 concentration (Field et al 2007, CCSP 2008). Associated changes in vegetation structure due to droughts in the semi-arid ecosystems affect the grassland production and the extent of shrub cover affecting the forage availability in these rangelands. The potential impacts of climate change include: the modified vulnerability of farm and ranch families to climate and market stresses, the modification of crop and livestock production systems, increased competition for scarce water resources, decreased water quality, expansion of weeds, pests, and diseases, a change in plant-animal communities, altered fire and storm patterns, changes in grassland ecosystems, species composition, disruption of pollinator relationships, tree mortality, enhanced vulnerability to drought and flooding conditions, and insect or disease outbreaks in a number of ecosystems (Field et al. 2007, CCSP 2008a, b) (See climate projections in Section 3).

Seasonality is an important factor affecting land systems in the Great Plains. A change in the statistical mean for temperature or precipitation is not as important to the stakeholders as a change in variability or seasonal patterns of change. For example, hotter temperatures and less moisture during the growing season may impact range or crop production dramatically. When looking strictly at range and livestock systems, there are a number of potential impacts identified (Morgan et al 2011, Ojima and Lackett 2002). First, forage production and quality will certainly be altered. Some of the changes may be beneficial, such as enhanced production under elevated CO2, while other changes may be deleterious, such as the fact that the forage may be less nutritious. Carrying capacity will be impacted and there will be vegetation shifts. Increased extreme events may lead to impaired genetics and performance of intensive livestock systems if livestock thermal thresholds are exceeded (Hahn et al 1998). There may be changes in the irrigation water supply, which has implications for the raising of

feed for livestock (Ojima and Lackett, 2002). Once again, patterns of pests, weeds, and diseases may be altered, and there may be changes in soil organic matter due to a warmer climate.

Strategies to cope with or adapt to climate change can take multiple forms. Mitigation of hazards and/or anticipatory adaptation are possible before a change occurs as proactive strategies Coping strategies that farmers, ranchers, and other residents of the Great Plains may use to deal with climate change include: better preparation for extreme events and multiple year events, diversification of land use practices in cropping and livestock systems in order to take advantage of opportunities and reduce vulnerabilities, researching new storage areas for water in case new storage locations are needed in the future under a changed hydrological regime, and increasing soil organic matter in order to increase water holding capacity and soil fertility. In some areas they are also expanding and/or consolidating operations as an adaptation strategy to deal with multiple economic and environmental stressors (Lackett and Galvin 2008).

The concept of a coping range provides a heuristic to conceptualize how a social-ecological system is vulnerable to conditions that fall outside some range of "normal" or expected climatic conditions range (though difficult to define concrete boundaries that reflect reality), Figure 1 below (Smit and Pilifosova 2001).



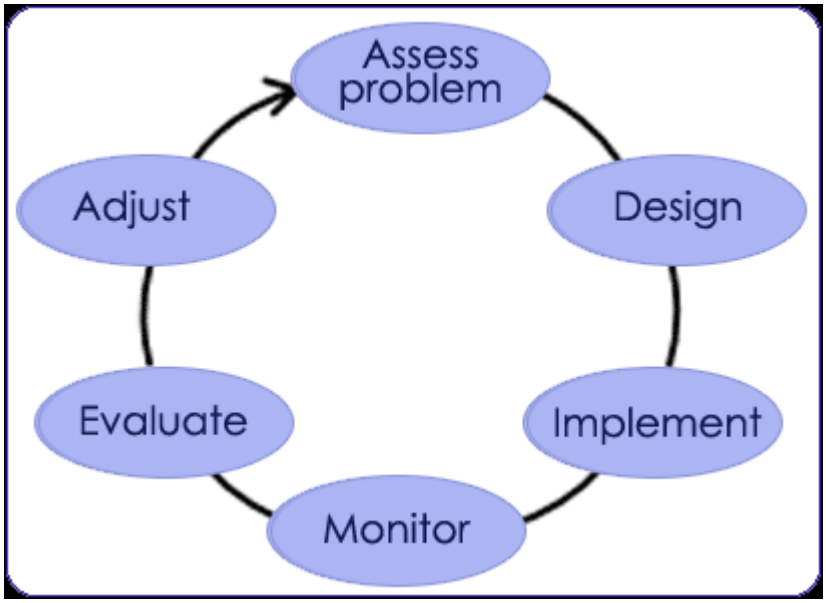
Climate changes that cause seasonal conditions or extreme events to fall outside of the coping range challenge a systems' resilience or adaptability or response capacity. Any system's coping range is spatially and temporally scale-specific, though a goal in vulnerability analysis is to understand where the thresholds might be exceeded to plan for serious consequences of future climate change. Thresholds are characterized by points at which there is a change in the system to cause either increasing vulnerability and/or limited response capacity to some climate disturbance. Events that breach a climatic threshold are thought of as extreme events, though there can be more subtle seasonal shifts that change the norm and make seasonal conditions that livelihoods are built around and regulations mis-aligned, which can have negative impacts on communities (McNeeley and Shulski 2011). The key to vulnerability assessment is identifying current and potential thresholds for coping with climate shifts in the norm, variability, and extremes. The challenge is capturing the dynamic nature of vulnerability across time and space, and incorporating understanding of future societal changes such as capacity built through adaptations or the damage of cumulative effects and/or multiple stressors.

Adaptive management is one approach that is increasingly attempted (though few successful examples exist to date) to try to cope with and anticipate the impacts of climate change. Adaptive management is potentially a useful approach when there is a high degree of uncertainty, risk, and lack of understanding. Especially under circumstances where decisions have to be made under these conditions with a goal of sustaining natural resources and ecosystem services and their underlying ecological processes (Lal 2001, Folke et al. 2005)**.** An adaptive management approach is one in which various tools are used to share and communicate understanding of resource issues between all the stakeholders involved, identify key uncertainties, explore and use alternatives, develop robust policies, and use the outcomes of this process to adapt future policies and actions (Gunderson et al. 1995). Adaptive management deals with uncertainty in a manner in which, from the outset, management is viewed as a tool to gain critical knowledge and cope with the uncertainty by incorporating flexibility to allow for various stakeholder interests under various management strategies toward the goal of "win-win" type situations where possible (Johnson 1999). Innovation in planning and implementing management schemes allows for new approaches and ideas to infiltrate thereby incorporating learning to guide ongoing management (Pahl-Wostl 2007).

The adaptive management approach requires that, first, the regional context of the change is understood. Second, "no-regrets" options, ones that make sense given current conditions and potential

future ones, should be identified and considered through the use of scenarios. Third, people need to be provided with practical and tractable alternatives for adaptation. Fourth, decision makers should "learn by doing" and evaluate results along the way, making the process of adaptation an iterative process. And last, the public must be kept informed of the implications of change. It also requires the creation or support of the appropriate institutions and collaborative learning mechanisms that include local stakeholders, managers, researchers, policy makers and other stakeholders that can help satisfy multiple goals such as achieving conservation goals while producing community benefits (Berkes 2004, Bosch, Ross and Beeton 2003). Berkes (2004) discusses how centralized management is poor fit for complex systems as it doesn't work at the level of the central government or at the community level, and it therefore creates mismatches in scale. This calls for the need for cross-scale interplay of institutions that involves horizontal and vertical linkages where communication, knowledge sharing, learning is occurring both within and between various stakeholder organizations (Berkes 2004).

The Department of Interior now has a website and technical guidance documents for land natural resource managers on implementing adaptive management approaches.



Source: Department of the Interior

http://www.doi.gov/initiatives/AdaptiveManagement/

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Vulnerability and Risk Conceptual Framing

There is a need now more than ever to develop an integrative approach to social-ecological studies of vulnerability and adaptation to decision making (Moser 2010). Vulnerability in general refers to social and/or ecological systems that are susceptible to harm from a changing climate, whether through seasonality changes or extreme weather events. Vulnerability to climate change is thought of as a function of a system's exposure, sensitivity and adaptive capacity (Figure 1).

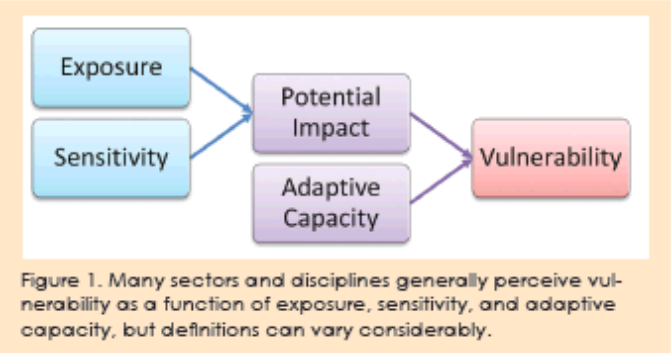

Figure 3. (USGCRP 2011)

The NCA defines these concepts as:

Exposure – in the context of vulnerability to climate change, the construct of exposure is used to describe the climate-related stressors that influence particular systems. This can include stressors such as drought (e.g., in the context of water resources, agriculture, forestry) or sea-level rise (e.g., coastal flooding, habitat loss);

Sensitivity – defined as "the degree to which a system is modified or affected by (climate) perturbations" (Adger 2006). Sensitivity is a measure of how responsive a particular sector or receptor is to climate variability and change;

Adaptive capacity – this is a measure of a sector's ability to reduce impacts through constructive change (USGCRP 2011).

Vulnerability assessments are important to identifying key vulnerabilities of a region or community in order to plan adaptation strategies that sustain livelihoods and ecosystems, and that build resilience to future climate-related shocks. Climate change impacts, vulnerabilities, and risks will differ across various sectors, places, populations, and time scales (Adger, Paavola and Huq 2006, Antle et al.

2004)It is important to identify “determinants” of vulnerability rather than relying solely on “indicators” or “indices” as not all aspects of vulnerability can or should be measured, except in certain cases where place and parameters can be well defined and usually on a local scale (Luers 2005, Hinkel 2011). Determinants of vulnerability are scale-dependent and sector-dependent – i.e., national scale determinants will not be the same as state or local or ecosystem scale (Posey 2009). For example, when looking at indicators for ecosystems at a landscape scale one might use indicators such as landscape diversity and connectivity (Czúcz et al. 2011). While the analysis of vulnerability and adaptive capacity of social systems in a water management context needs to account for variables such as social networks, knowledge of stakeholders, adaptive governance, among others (Huntjens et al. 2012, Downing et al. 2005, Pahl-Wostl 2009)

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IMPACTS AND CONSEQUENCES, VULNERABILITY AND RISK, ADAPTIVE CAPACITY, RESPONSE OPTIONS

Water resources and Climate change projections

Water demand across the Great Plains associated with the A1B and B2 climate projections indicate that the central portion will experience a slight decline in water yields ranging up to 3 cm/yr decline (Foti, Ramirez and Brown 2011). Western Montana and Wyoming will potentially be affected by lower water yield across a set of climate projections ranging from 2 to 8 cm/yr decreases in water yields (Foti et al. 2011). The eastern fringe of the Great Plains indicates a consistent decline in water yields (Foti et al. 2011). Southern Texas demonstrates the greatest variability in water yields for this portion of the Great Plains associate with model characteristics providing the specific rainfall pattern (Foti et al. 2011).

Evidence suggests that the Missouri River Basin as a whole may have experienced relatively wetter conditions during the 20th century compared to prior centuries as well as relatively less annual runoff variability (Reclamation 2011). Even omitting major flood events in 1996 and 1997, the 1990s were still the sixth wettest decade of the past 300 years (using data from the Yellowstone River) (Reclamation 2011, Graumlich et al. 2003). Climate reconstructions based on tree ring data have indicated that the 1930s were the driest extended period during the past 300 years with below average stream-flow and were virtually unprecedented during this record (Reclamation 2011). Observations

from 1957 to 2007 across 202 gauging stations in the Missouri River Basin indicate that streamflows are down in the western part of the Basin and upward in the eastern part (Anderson, Stamm and Norton 2008).

Elgaali et al (2010) found in the Colorado portion of the Arkansas River basin that there are already shortages in surface water supply, and a small amount (5% to 10%) of these shortages is met by groundwater pumping. Under two different climate scenarios based on the VEMAP climate data sets (Kittel et al 1995) which generated a statistical downscaled product using the Canadian Climate Center (CCC) and the Hadley Center (HAD) model results. The CCC suggest that the region could experience a shortage in water supply from the 2010s to the 2090s for the whole season and for each month in the season May through September with the summer greater than the spring. The HAD results also suggest a shortage in August with no shortages over the whole season, assuming that there is sufficient storage in the system to keep water in the system.

Climate projections for the Missouri River basin as a whole (i.e. at Omaha), indicate that the mean annual temperatures for the 2020s, 2050s, and 2070s decades will be 1.6 F, 3.5 F, and 4.8 F higher, respectively, than that for the 1990s (Reclamation 2011). The ensemble median shows a gradual increase in precipitation over the 21st century, for the Missouri River basin as a whole – up to an 8.5% increase by the 2070s decade as compared to the 1990s, however, individual projections are not in complete agreement as to the direction (Reclamation 2011). Many projections indicated decreasing precipitation, so less certainty is associated with these trends than is the case for temperature (Reclamation 2011).

Changes in temperature and precipitation will both affect snow accumulation during the late autumn through early spring, however, it is projected warming that seems to dominate projected snowpack changes (Reclamation 2011). Warming is expected to decrease snow accumulation with decreases being more substantial in areas, such as the eastern Plains, that have normal cool season temperatures closer to freezing thresholds (Reclamation 2011). The ensemble medians indicate decreases in snow water equivalent on April 1st for the basin as a whole of 76%, 81%, and 84%, respectively, for the 2020s, 2050s, and 2070s decades as compared to the 1990s (Reclamation 2011).

General Circulation Model projections of future climate through 2099 indicate a wide range of possible scenarios (Intergovernmental Panel on Climate Change, 2007). To determine the sensitivity and potential effect of long-term climate change on the freshwater resources of the United States,

Markstrom et al. (in press) selected fourteen basins from across the United States and modeled them with the Precipitation Runoff Modeling System (PRMS) surface water hydrology model (Markstrom et al., 2008). Two of these fourteen basins fall within the Great Plains Regional Assessment area. The Starkweather Coulee Basin, North Dakota (Vining, 2002) and the South Fork of the Flathead River Basin, Montana (Chase, 2011) were both the subject of previous PRMS modeling studies.

The Starkweather Coulee Basin exhibits little to no streamflow from September through February, mainly because of the sub-freezing temperature in the basin. This in not projected to change substantially. As projected temperatures increases, evapotranspiration increases, resulting in less streamflow available for runoff and storage. In the South Fork of the Flathead River Basin, by the end of the 21st century, seasonal streamflow is projected to increase from November through April and decrease in May, June, and July. These changes correspond to changes in mean monthly snowmelt (Markstrom et al., in press).

Numerous sources of uncertainty have been identified in the steps of this study. Large uncertainties are associated with the representation of the physical processes, model structure, and feedbacks within the climate system as projected by the GCMs. The scenarios chosen for this study represent different economic, social, political, and technological development for the future, none of which may be the actual path (Hay et al, 2011).

To date there have been multiple studies that have used climate models to try to predict future water availability in the Great Plains, yet these studies tend to have significant uncertainties on regional or watershed scales, and they often come up with varying results depending on the methodology, climate and hydrological models used, downscaling techniques, and the assumptions that go into the models (Thomson et al. 2005, Mehta, Rosenberg and Mendoza 2011). This calls for close and continued partnership between climate and related scientists and water and land managers, ideally using iterative, risk-based approaches that can be flexible and incorporate a range of scenarios into planning (Huntjens, Pahl-Wostl and Grin 2010, Kallis 2008, May and Plummer 2011, Vogel and O'Brien 2006, Pulwarty 2003, Brekke 2009).

These climate impacts on water resources will have consequences associate with energy generation and operations throughout the Great Plains. In addition, extraction of natural resources associated with energy development in the region will also be affected. The next section discussion the details of these interactions.

Energy Choice Options and Tradeoffs - Different Effects on Water and Land

The Great Plains region has an abundance of coal with high potential for development (USGS 2003). The most productive coal mines in the country are in the Powder River Basin of Wyoming (Averyt 2011). Coal-fired electric power plants are not only a major source of the greenhouse gas carbon dioxide and other air pollutants, but they are also heavy users of water (Averyt and Fisher 2011). Climate change will likely decrease water availability in already stressed areas and create increase competition among users. Rural communities often face sparse economic opportunities and many communities are highly dependent on jobs and tax revenues from fossil fuels – pre-dominantly coal in this region. This creates major challenges and trade-offs for their efforts to develop their economies and chart sustainable livelihoods, especially as the nation and global community transition to a cleaner energy future.

Choices about fuel portfolios will manifest differently for water and land resources. The nation has been moving away from coal-based electricity generation toward natural gas over recent years. However, coal is unlikely to be removed from the fuel portfolio in the Great Plains as the Wyoming Powder River Basin is the largest producer of coal and provides the cleanest coal in the United States. Coal extraction in the West has increased in recent years as it has declined or remained stagnant in the Eastern U.S. In addition, natural gas production in the West has increased and the Energy Information Administration (EIA) projects continued growth. Both surface and sub-surface coal mining can have deleterious effects on the landscape and on water quality (Turka and Gray 2005). Assessment of the impacts of coal-bed gas development in the Powder River Basin found that summer stream flows with high dissolved solids increased from untreated water discharge, increased sedimentation occurred from road and other construction, potential for chemical spills increased as well as access to sport fish harvest, all of which is harmful to the health of fish and the riparian ecosystem as a whole (Farag et al. 2010).

The United States production of oil and natural gas has increased dramatically, the key driver of which has been shale oil[1] and shale gas. This has resulted in job growth is areas like North Dakota where the Bakken Shale discovery has unearthed oil reserves that are said to be more than Prudhoe Bay, Alaska. And the production of natural gas has enabled natural gas prices to stay at record low in the U.S.

[1] Not to be confused with "oil shale," which is still largely speculative until a technology can be proven to cost-effectively convert hard kerogen into oil. "Shale oil" on the other hand is already exists in liquid form beneath the ground and just requires extraction as opposed to both extraction and heated conversion (requiring even more energy in the conversion process) that oil shale requires.

The tradeoff for these economic wins is increased carbon production, and impacts on water quality as the result of hydraulic fracturing ("fracking") in some areas. Major shale oil basins in the Great Plains include Bakken in North Dakota, Eagle Ford and Barnett in Texas, and Woodford in Oklahoma.

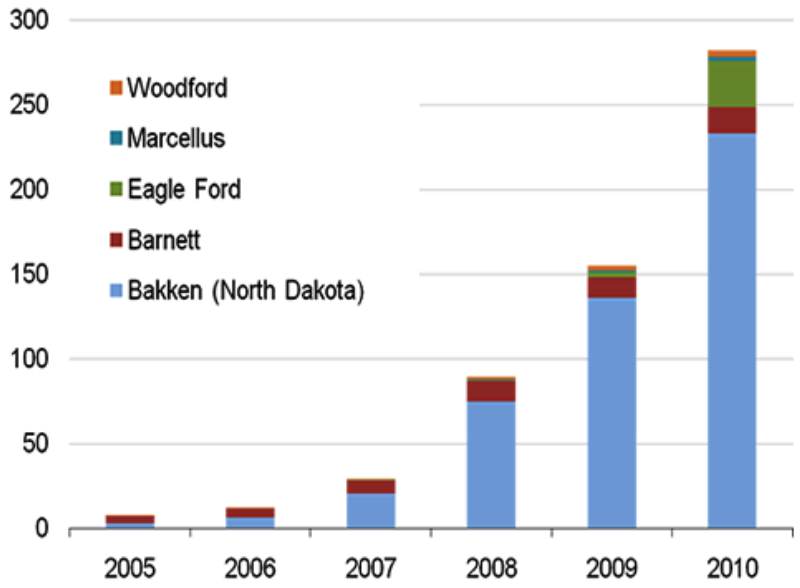


Fig.4 Crude Oil Production from Shale Oil Formations (million barrelsSource: U.S. Energy Information Administration

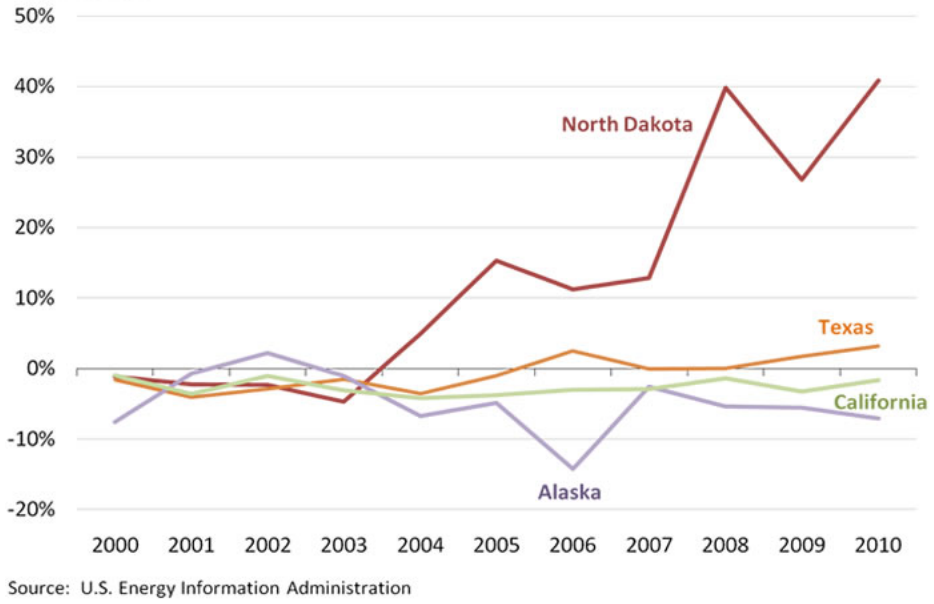


Fig. 5 Year-to-year Change in Oil Production

Fuel extraction & water quality

While data on the impacts of fuel extraction on water quality issue are only starting to emerge, this is an important area for future research as the risks of hydraulic-fracturing to water quality and community health are increasingly becoming a significant public risk perception issue, and conflict between local communities, the energy private sector, and government agencies is growing. One example of this is in the Williston Basin of North Dakota, Montana, and South Dakota. Information on this new research in this area can be found on the U.S. Geological Survey site here: http://steppe.cr.usgs.gov/.

Exploration and extraction of fossil fuels for energy production can have major impacts on land use, ranging from vast surface mining, to densely-located well pads that blanket a landscape. Much of the new oil and gas production in the region relies on the method of hydraulic fracturing. This method of production employs diagonal drilling which has limited some of the conversion on the land surface. However, well pads, storage infrastructure, and access roads can surmount to large changes in land use and land cover in certain regions. Figure 6 show the location of existing oil wells in the Williston Basin found in the northern portion of the Great Plains.

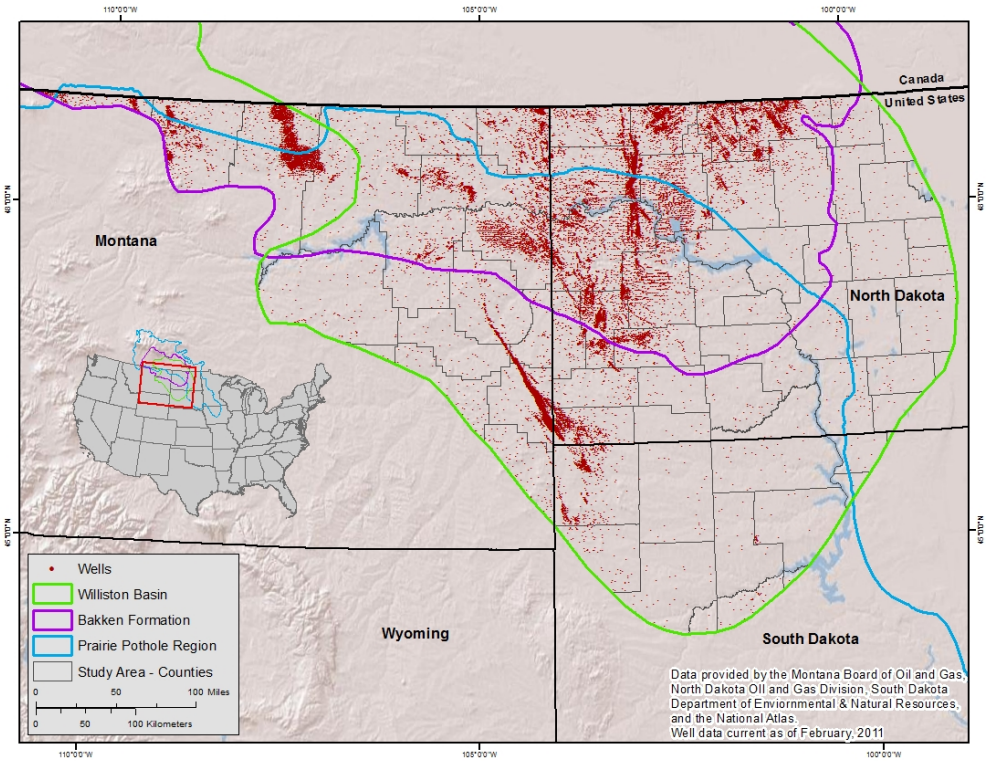


Figure 6. Map of the Williston Basin and Bakken Formation. Red points represent the spatial distribution of existing oil wells in the region. (Source: STEPPE, USGS, 2011)

Additionally, hydraulic fracturing is a water-intensive production method, requiring anywhere from 2-9 million gallons of water per site. The expansion of this industry has created new demands for water in a region that largely depends on groundwater from a diminishing aquifer. The financial offerings from oil and gas production are likely to out-compete farm commodity revenues. Land use stands to be impacted as water rights are negotiated and change hands. States and municipalities are discussing ways to keep up with this industry's thrust. The city of Gran Prairie in the Barnett Shale of North Texas became the first municipality to ban the use of the city water for fracking. Trucking water in from outside areas has started to take place, adding new energy demands to the production process.

There are multiple varying and uncertain factors that affect oil and gas well construction such as national and regional economic conditions, oil and gas prices, capital availability, corporate strategies, and technological innovations (COGCC 2012). In Colorado, the state agency the Colorado Oil and Gas Conservation Commission, projects a 35% increase in water needed for hydraulic fracturing between 2010 and 2015 (COGCC 2012). The amount of water used depends on the geology of the region and whether wells are drilled horizontally or vertically, according to the COGCC. Horizontal wells require

more than vertical wells, as well shale oil and gas formations located deep underground versus shallower coal bed methane sources.

a. Water for power plant thermoelectric cooling

The electricity generation system throughout the entire United States depends heavily on water for cooling. Wherever water scarcity is an issue, so is our reliable production of electricity also at risk. This is especially true in the western drier portion of the country and the Great Plains region. Power plants built since 1980 typically use evaporative-cooling technologies that withdraw less, but consume more water.[2] After the water is diverted from a local water body and used in the power plant, it is moved to a tower or pond for reuse. This shift to evaporative cooling technology is expected to continue, contributing to significant increases in energy sector water consumption. In fact, the Electric Power Research Institute (EPRI) projected that 446 counties nationwide, with the Southwest being hit especially hard, would face water constraints on thermoelectric cooling by 2025, even if climate change has no effect on water supply. Looming water shortages are not the only threat that climate change poses for electricity generation. Many thermoelectric plants become less efficient on extremely hot days, when more energy needs to be expended on cooling the boiler water. Every part of the country is expected to see significant increases in hot days; many areas in the Great Plains are projected to have more than 75 days each year when the temperature tops 100°F, if climate change continues unabated (refer to Section 3 for climate information). Such hot days are typically when power plants have their peak demand as customers turn up their air conditioning. At the same time, the extreme heat can stress power system components, causing them to fail more quickly. Many transformers are designed to cool off at night and may be unable to cool down sufficiently. This design choice could be especially problematic because night-time temperatures have been increasing faster than day-time temperatures (refer to Section 3 for climate information).

Choices about how we produce electricity in the coming decades could have a big impact on water consumption. For example, if the nation were to get 20 percent of its electricity from wind by 2030, water consumption could be reduced by about 10 percent, compared to 2005 consumption. On the other hand, if carbon capture and sequestration (CCS) technologies are widely adopted, water consumption could be increased further by 7.5 to 19 percent. CCS uses cooling water for the capture

[2] Meaning the water that is withdrawn is not then returned back to the source.

and compression processes, as well as to generate the extra electricity needed to perform CCS. Developing concentrated solar power plants also presents tradeoffs between water consumption and power generation efficiency, especially if dry-cooling approaches are used in hot climates. Because some of the electricity generated must be used to operate fans, electricity from a dry-cooled plant can cost about 10 percent more than that from a wet-cooled plant. These effects are especially acute when ambient temperatures exceed 100°F. Hybrid wet-dry cooling approaches are currently being developed as a promising alternative. These systems use dry cooling unless temperatures exceed a certain threshold, at which point they switch over to evaporative cooling. Such systems can use 90 percent less water than plants that rely only on evaporative cooling, and only see a 3 percent drop in energy performance.

In North Dakota and Texas, thermoelectric power accounts for the most water withdrawals 79% and 41%, respectively, of total withdrawals. In addition, if you look at the magnitudes of withdrawals by state and sector, the Texas thermoelectric power withdrawals are the second largest in magnitude (10,800 thousand acre-feet per year) - second only to Colorado's withdrawals for irrigated agriculture (11,200 thousand acre-feet per year) (Kenny et al 2009).

Potential for use of treated municipal wastewater for cooling plants in the Great Plains region can be seen below in Figures 7 and 8

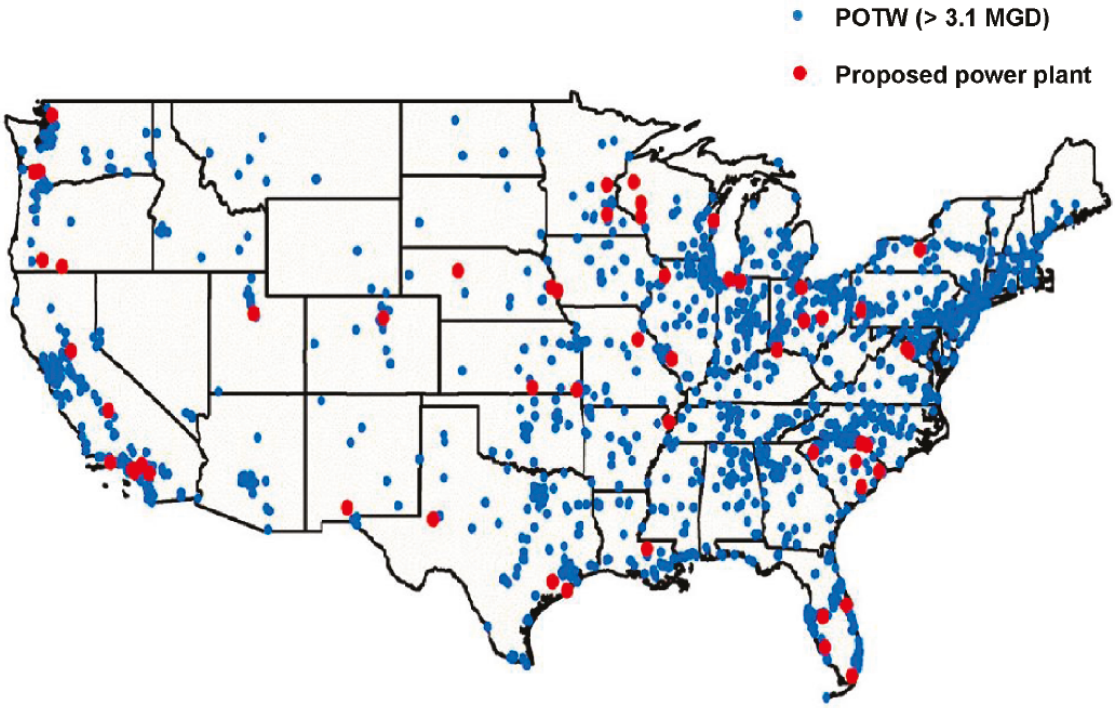


Figure 1. Locations of the proposed thermoelectric power plants (red dots) relative to the publicly owned treatment works (POTWs) that have flow rates greater than 3.1 MGD of treated MWW (blue dots) in the lower 48 states. A single red dot may represent multiple power plants if they are close to each other. The POTW locations were obtained from the U.S. EPA and the proposed power plant locations were obtained from the Energy Information Administration (2007).

Source: Li et al 2012

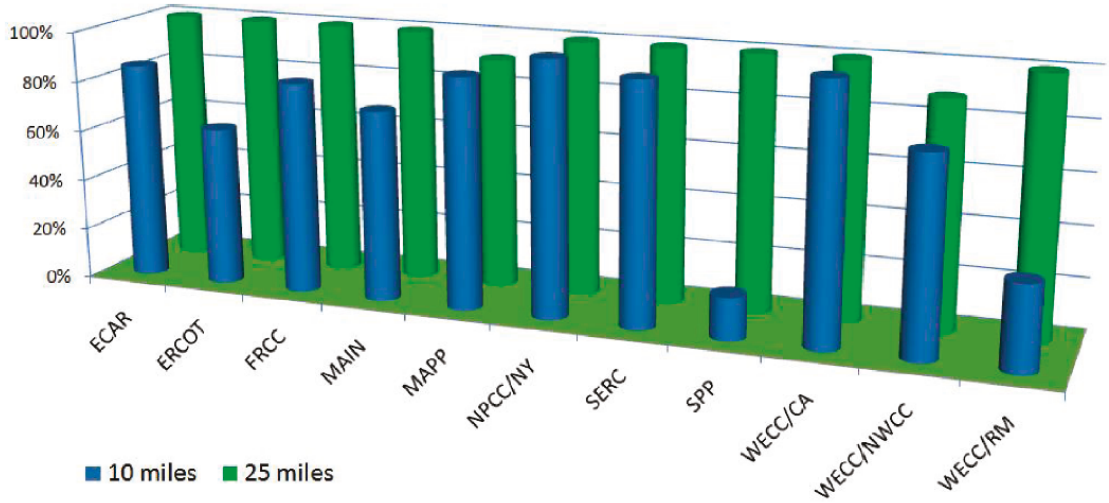


Figure 2. Fraction of the proposed thermoelectric power plants with sufficient amount of treated MWW available within the specified radii (10 miles and 25 miles). The power plants are categorized by NERC regions (NERC: North American Electric Reliability Council).

Source: Li et al 2012 (NERC regions in the Great Plains are SPP (Southwest Power Pool), MAPP (Mid-Continent Area Power Pool), ERCOT (Electric Reliability Council of Texas), and WSCC (Western Systems Coordinating Council) see map below in Figure XX for map with regions outlined.)

Water and land use for renewable & alternative energy sources

General issues, Land use and land use change

The Great Plains are an ideal place for renewable energy production. The Great Plains states have a medium to high solar energy potential3, and a fair to outstanding wind energy potential4, and many favorable sites for geothermal energy5. In Colorado, the DOE National Renewable Energy Laboratory reported that the state has considerable capacity for generating renewable energy through Photovoltaic (PV) installations on non-irrigated farmland, which could contribute significantly to Colorado's Renewable Portfolio Standards (RPS) goals (Roberts 2011).

States in the Great Plains are putting in place RPS and other mechanisms to build up the baseline of renewable energy sources. An RPS specifies that electric utilities generate a certain amount of electricity from renewable or alternative energy sources by a given date. Nearly all of the Great Plains states have enacted a RPS (two have not), with goals ranging from 10% to 25%. Most of these are mandatory, with the exception of two states where the RPS is voluntary[6].

States in the Great Plains region that have Renewable Portfolio Energy Standards (RPS) include: Montana, Texas, Colorado and New Mexico. North Dakota and South Dakota have nonbinding goals for renewable instead of an RPS. An RPS is a state requirement requiring electricity providers to obtain a minimum percentage of their power sources from renewable energy sources by a certain date.

Fig. 1 State in the Great Plains region with Renewable Portfolio Energy Standards (RPS) or Non-binding Goals (excerpted from source above)

State	Minimum Amount of Renewables	Year	Organization Administering RPS
Colorado	20%	2020	Colorado Public Utilities

[3] US Solar Resources Map. http://www.nrel.gov/gis/solar.html
[4] US Wind Resource Map. http://www.nrel.gov/gis/wind.html
[5] US Geothermal Resource Map. http://www.nrel.gov/gis/geothermal.html
[6] Pew Center on Global Climate Change – Map of US States with Renewable and Alternative Energy Portfolio Standards. http://www.pewclimate.org/what_s_being_done/in_the_states/rps.cfm

			Commission
Montana	15%	2015	Montana Public Service Commission
New Mexico	20%	2020	New Mexico Public Regulation Commission
North Dakota*	10%	2015	North Dakota Public Service Commission
South Dakota*	10%	2015	South Dakota Public Utility Commission
Texas	5,880 Megawatts (MW)	2015	Public Utility Commission of Texas

*States with non-binding goals instead of RPS

Source: Department of Energy, Energy Efficiency and Renewable Energy (EERE): http://apps1.eere.energy.gov/states/maps/renewable_portfolio_states.cfm

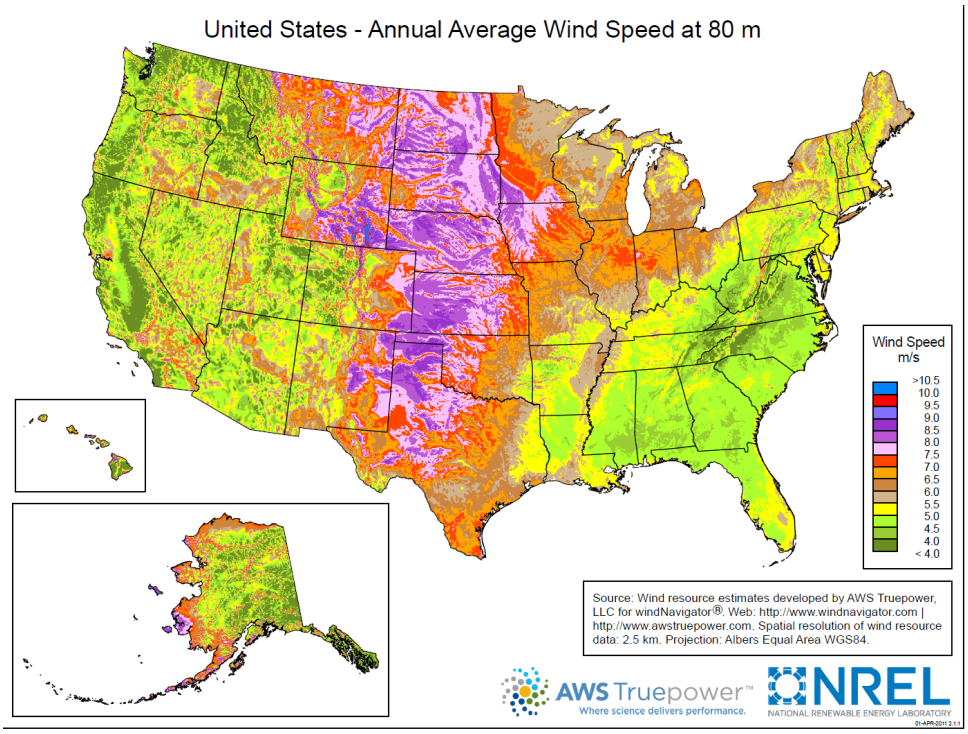
Useful resource: Database of state incentives for renewable and efficiency http://www.dsireusa.org/

Water availability for irrigation in the region will be off set to a certain degree by the exchange of current water usages with less consumptive processes (Foti et al. 2011). For instance, current power plants such as thermoelectric plants will be retired and replaced by more efficient or with renewable wind and solar sources which will require less water. However, the demand to meet RFS goals may off-set these apparent water gains (Foti et al. 2011). The added impact of climate change will also negate the potential increase in water availability in the Great Plains due to increased water consumption across sectors (Foti et al. 2011). These results indicate the strong interaction between water usage among sectors in the Great Plains and the potential increase in productivity to agriculture and other socio-economic enterprises in the region (Foti et al. 2011).

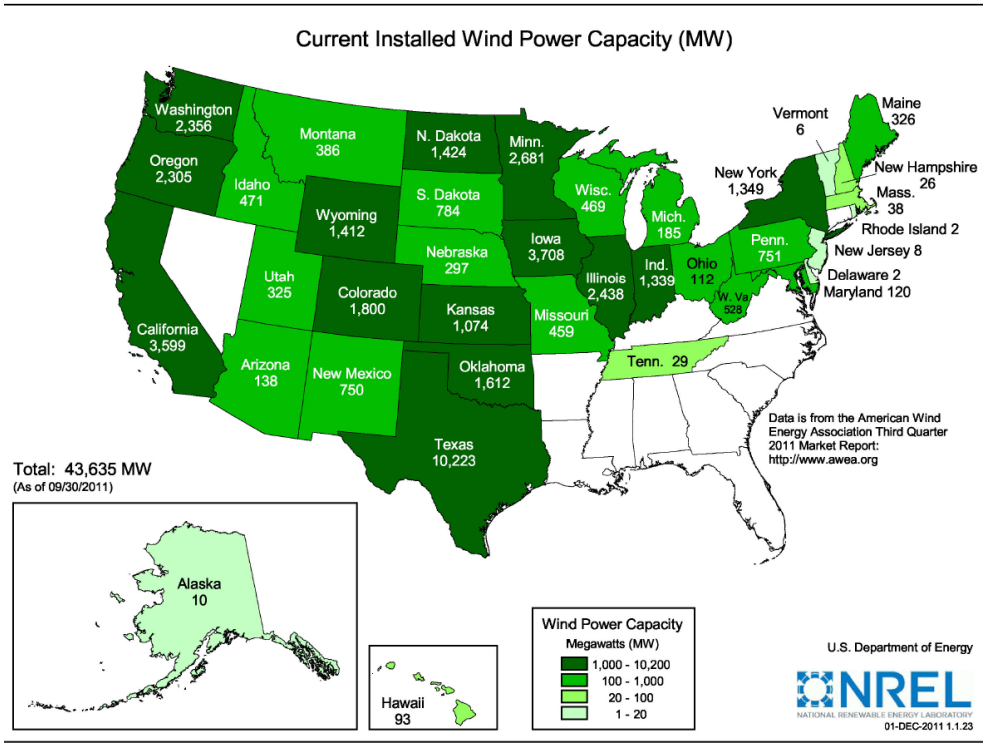
Ultimately each type of energy use has influence on the environment, land use, and landscape conditions. Impacts come via identification and extraction of requisite raw materials, transport from

source to the production center to the end user, and any by products or end wastes. The availability and economic viability of energy choices are influenced by past land-use decisions and prevailing climate conditions. Likewise, the energy choice made can, in turn, affect future land use and climate (Dale, 1997). Demands for inputs such as water go hand and hand with energy and land use decisions. Such requirements are likely to increase in the Great Plains as the region and its landscape attempt to keep up with growing food, fiber, and energy demands.

Other forms of alternative energy have expanded in the Great Plains and have implications on land use and land cover in the region, including wind power. While the resource inputs required for wind energy production are relatively small, and infrastructure constraints have resulted in lower deployment of these wind systems on farming and grazing lands. In addition, the concern over building new roads and transmission lines to maintain and transmit the wind farms and the energy generated further fragmenting lands in non-cropped areas which may further impact sensitive wildlife habitat. The Great Plains region has the highest wind power capacity in the country. Texas is the state with highest wind capacity built in 2011 (American Wind Energy Association 2011) and as of this writing, Texas has by far the highest installed wind capacity than any other state in the U.S. with 10,223 megawatts (see Fig 9 below).



http://www.windpoweringamerica.gov/wind_maps.asp



http://www.windpoweringamerica.gov/wind_installed_capacity.asp)

The highest capacity (class 5) wind resource regions in the Great Plains can be found in the highlands of North Dakota and the high plains in Montana, while the next highest (class 4) exist in North and South Dakota, the Sandhills of Nebraska, northwest Oklahoma, southcentral Kansas, northeastern New Mexico, and the Texas Panhandle[7]." Wind turbines could also be good for some crops and research is ongoing to determine this." (Source pers. comm. Eugene Takle)

http://news.nationalgeographic.com/news/energy/2011/12/111219-wind-turbines-help-crops-on-farms/

Resources for understanding the effects of wind energy development:

http://www.fort.usgs.gov/WindEnergy/

Bioenergy

Bioenergy is the use for fuels or power of various forms of biological material that is either grown and produced (e.g., corn for corn ethanol) or in the form of second generation biomass or waste

[7] Wind Energy Resource Atlas of the US. http://rredc.nrel.gov/wind/pubs/atlas/chp2.html#annual

(e.g., agricultural waste, forest industry waste, municipal paper and wood waste). Bioenergy is seen as an area of potential economic development in the United States, especially in rural areas, as well as a potential source to contribute to domestic energy independence and reduction of fossil fuel use and greenhouse gas emissions (Pate 2011).The Independence and Security Act of 2007 included significant funding and support for biofuels standards and research and development, which was then expanded through stimulus funding provided by The American Recovery and Reinvestment Act of 2009. The potential of bioenergy is entirely dependent on the form of biomass used and the variation of local and regional practices and conditions (Pate 2011). For example, much of the crop switching to produce ethanol is from soybeans to corn and some areas of the country the former requires more water for irrigation to grow than the latter, however, in the Great Plains region corn requires more water than soybeans to grow (Tidwell, Cha-tein Sun and Malczynski 2011).

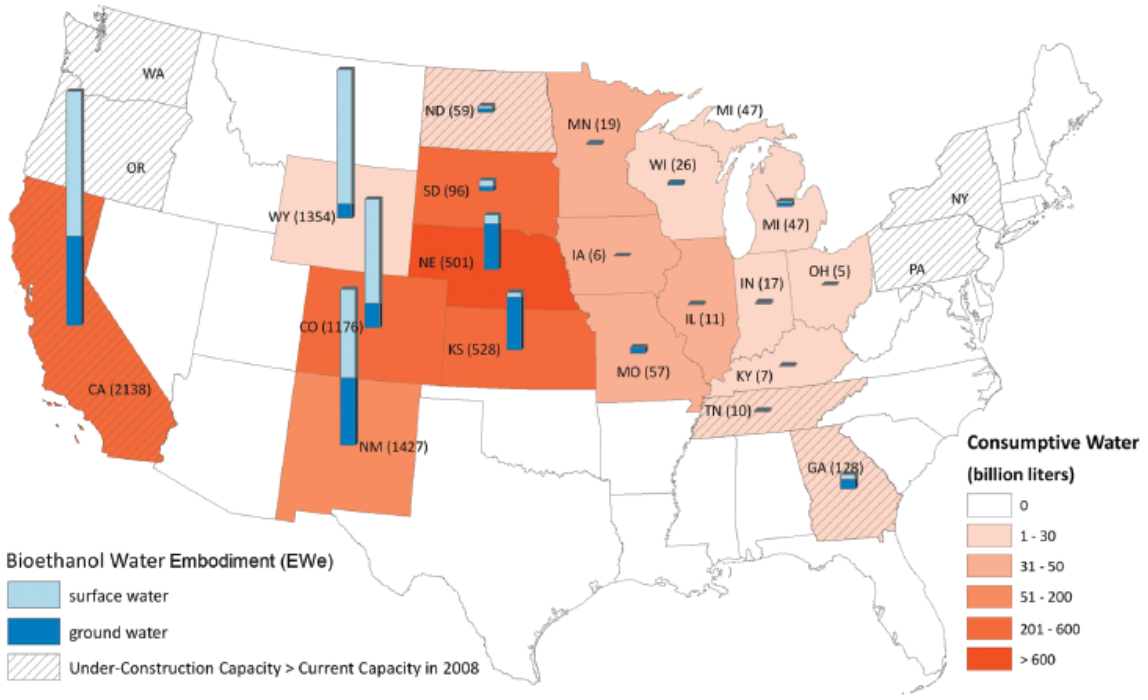


Fig 11. Embodied water for ethanol (EWe) and total consumptive water (TCW) use by state as of 2007. Source: (Chiu, Walseth and Suh 2009)

There will also be regional variation in terms of the water-energy nexus, as research to date shows that the amount of water needed for biomass production can vary significantly across the United States as a whole and within the Great Plains Region. For example, Figure X above and Figure XX below

shows the embodied water for corn ethanol (EWe) production and total consumptive water (TCW) in states across the Great Plains (Chiu et al. 2009). This study shows that across the United States estimates for water requirement from corn farm to fuel pump ranges from 5 to 2138 liters of water per liter of ethanol (EWe), and in the Great Plains it ranges from a low of 59 EWe in North Dakota to 1354 EWe in Wyoming (see Fig XX below). However, it is worth noting that a high EWe does not necessarily translate directly into a high TCW as in the case of Wyoming. This highlights the need to understand local and regional specifics in terms of conditions and practices when considering the potential and water-energy nexus of biofuels (Chiu et al. 2009).

Fig. 2 Embodied Water for Ethanol (EWe) and Total Consumptive Water (TCW) in ethanol producing states in 2007. All numbers listed are in million liters, and figures may not sum to totals due to rounding

			EWe					
State	Ethanol Production	EWe	Groundwater	Surface Water	Wir*	Wp*	TCW	Corn processed into ethanol
North Dakota	505	59	31	28	28,146	1824	29,970	18%
South Dakota	2203	96	38	58	203,762	7950	21,712	39%
Nebraska	2481	501	422	80	1,235,128	8954	1,244,082	16%
Kanasas	804	528	486	42	421,840	2903	424,743	15%
Colorado	322	1176	226	950	377,082	1161	378,243	20%
Wyoming	19	1354	125	1229	25,547	68	25,615	23%

Data excerpted from (Chiu et al. 2009)

*Wir = irrigated water; Wp =process water

The Great Plains region is dominated by land use devoted to agricultural production. Upwards of 70 percent of the region is classified as range and cropland, producing a variety of crops and livestock. While the total land cover devoted to agriculture has remained relatively unchanged over the last few decades, crop mix within the region has changed as economic, social, environmental, and technological variables have shifted. The mitigation of greenhouse gases and subsequent push for biofuels is one such development that has had large impacts on land use change in the region given its spatial extent, or what has been referred to as "energy sprawl" (McDonald et al., 2009). For instance, acres devoted to producing corn, a major bioenergy feedstock, have increased by roughly 32 percent between 1997 and 2007 or by over 5 million new acres. This change in crop mixture has and will continue to impact the demand for major inputs of production, especially water. However, biofuel-driven land use changes also have indirect effects on GHG emissions that may offset some of its benefits, such as changes to the surface energy and water balance from landscape modification, which need to be considered to ensure that emissions have a net decline (Georgescu, Lobell and Field 2011).

In the Missouri River Basin in the Great Plains, current assessments indicate that significant water demands will arise from requirements to meet the biomass production to support the Renewable Fuel Standard (RFS) goals in 2030 even without the inclusion of additional climate change effects (Foti, Ramirez and Brown 2011). The agricultural demand in 2030 in the Missouri River basin is projected to increase by about 30 million gallons per day (mgd) due to industrial and urban consumption, and agriculture would increase by around 158 mgd to meet the RFS goals (Foti et al. 2011).

One limitation on the expansion of corn ethanol production in the Great Plains is the use of ground water in already vulnerable and water-stressed areas. For example, the TCW for the Great Plains states in 2007 amounted to 2.4 trillion liters and 4.5 trillion liters in 2008 (Chiu et al. 2009). In 2007 68% of this water was supplied from ground water in the already vulnerable Ogallala Aquifer region and in 2008 the amount of water extracted accounted for approximately 18% of the entire annual rate of aquifer depletion (Chiu et al. 2009). One estimate found that in Nebraska and Kansas 15-19% of irrigation water went to growing corn for ethanol (Mishra and Yeh 2011). Careful consideration must be given to producing corn ethanol in areas that are not already at high risk for water stress. A 2003 GAO report named several states in the Great Plains region as being threatened by water shortages across local, state, and regional scales (USGAO 2003). Yet, there is an economic incentive, and pressure to grow corn for energy in the High Plains is strong where irrigation costs are only 20% of total production costs for corn, yet yield for energy crops can be increased significantly through irrigation (Tidwell et al. 2011) . Experts predict that competition between water for biofuels and other demands will be highest

in the nation in the High Plains region (Tidwell et al. 2011). This is one example of the tradeoffs that must be considered between fossil fuel energy, renewable energy to meet RPSs, and the water necessary to meet these economic and environmental goals. It is critical to take regional and local context into account for policy and planning across all scales of governance; and it requires careful planning at the watershed level within and between states at a regional level (Pate 2011). Some experts have suggested "next generation" biofeed stock such as perennial grasses and woody biomass will help meet the needs for bioenergy, however, the extent to which this potential exists or is limited by local and regional conditions in the Great Plains has yet to be determined (USGAO 2009).

b. – Vulnerabilities and mitigation/adaptation in the context of future energy-water demand and supply

Capital investments for long-term resource infrastructure such as reservoirs and power plants represent large scale and long-term resource commitments which are difficult to reverse once set in motion (Hegmon et al. 2008, Scheffer and Westley 2007). Iterative risk-based management and adaptive governance approaches are necessary for sustaining water and energy resources while maintaining sustainable livelihoods in the face of increasing demands for both. Evaluation of these tradeoffs between agriculture, energy, municipalities and the environment are needed to better assess the appropriate strategies to be considered.

Delivering water and wastewater services is an energy-intensive effort, as the water is treated, pumped to our homes and businesses, then pumped to wastewater facilities to be treated again. EPA estimates 3-4 percent of national electricity consumption, equivalent to approximately 56 billion kilowatts (kW), or $4 billion, is used in providing drinking water and wastewater services each year. Pursuing energy efficiency through these systems can significantly reduce operating costs, while mitigating the effects of climate change. Numerous resources exist to help water utilities pursue efficiency measures, including EPA's Energy Management Guidebook for Wastewater and Water Utilities[8], which is part of EPA's Sustainable Infrastructure effort[9]. Utilities in the Great Plains have been working with EPA to develop energy management programs based on the Guidebook, as well as case

[8] Ensuring a Sustainable Future: An Energy Management Guidebook for Wastewater and Water Utilities, January 2008. http://www.epa.gov/owm/waterinfrastructure/pdfs/guidebook_si_energymanagement.pdf

[9] Taken from EPA's Sustainable Infrastructure webpages on 01-25 12. http://water.epa.gov/infrastructure/sustain/waterefficiency.cfm and http://water.epa.gov/infrastructure/sustain/cut_energy.cfm

studies to demonstrate the benefits that they are seeing. One example in the Great Plains is the Missouri Water Utilities Partnership - Energy Management Initiative for Public Wastewater and Drinking Water[10]. The eight participating cities are in various stages of implementing projects that are collectively projected to reduce energy consumption by more than 8 million kWh, while cutting greenhouse gas emissions by 7.3 million kg (16 million lb).

Energy Transmission

The Great Plains sits at the physical intersection all three national grid systems, on the seam between the Eastern and Western Interconnects, which divides the Dakotas, Nebraska, Kansas and Oklahoma from Montana, Wyoming and Colorado, and astride the ERCOT system in Texas to the south. The Missouri River Basin straddles this electrical continental divide, with its headwaters in the Rockies of Montana and Wyoming and the bulk of its flowage and hydropower generation in the Eastern Interconnect.

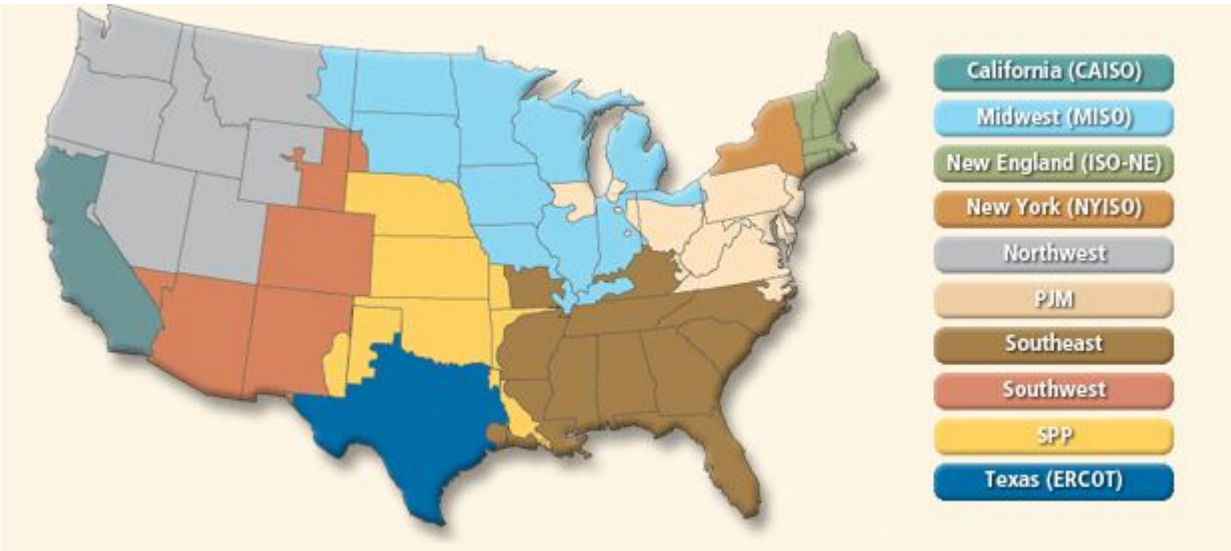


Figure 12: Electric Power Markets Map
source: http://www.ferc.gov/market-oversight/mkt-electric/overview.asp

These three systems are fully independent, with the east and west flow of power interchanges across the seam through the direct current (DC) interties in Montana, South Dakota Nebraska and New

[10] Taken from the EPA Region 7 webpage: Sustainable Infrastructure for Water Programs on 01-25-12. http://www.epa.gov/region7/water/si.htm

Mexico. This arrangement makes planning and operation of the electric system for the Great Plains more complex than if it was a single system (Kaplan 2009). The physical infrastructure of electrical system in the Great Plains is composed a variety of generation facilities including hydropower, coal, gas, nuclear, and renewables (primarily, wind), and of both the high voltage transmission and the stepped-down lower voltage distribution systems owned and operated by the Western Area Power Administration (WAPA), rural electric cooperatives, public power districts and municipal utilities. In the Upper Plains region, public power owns and operates almost half of the high voltage grid, as compared to the rest of the country where up to 80% may be operated by investor owned utilities (Kaplan 2009).

The federal transmission grid was originally built out by the U.S. Bureau of Reclamation beginning in the middle of the last century to collect and transmit electrical energy from Reclamation and Corps hydroelectric dams in the Missouri River watershed to preference customers throughout the upper Midwest and West. Today, the system is jointly operated by WAPA, in conjunction with regional generation and transmission organizations (G&Ts.) as an integrated system, through a complex set of federal authorities and federal and pubic agreements that have been developed over the past 50 years.

WAPA is one of four Federal power marketing administrations directed by law to market and transmit Federal power allocations at cost-based rates to preference customers, including Federal and state agencies, rural electric cooperatives, public power districts, Native American Tribes, and municipal utilities. This hydro power is delivered through nearly 100 substations, across nearly 7,800 miles of Federal transmission lines ranging from 69 KV to 500 KV in the Upper Great Plains Region. [REF WAPA: About the Upper Great Plains Regional Office, http://www.wapa.gov/ugp/aboutus/default.htm] These lines are connected with other regional transmission systems and groups. The physical transmission infrastructure, and especially the distribution system, consisting of tens of thousands of miles of wire on towers and poles, is significantly vulnerable to weather extremes and climate change. Winter weather conditions can combine to wreak havoc on the electric cooperative's power system, where Ice clings and builds on the power lines, causing them to sag under the tremendous weight. Blustery winds ripple the already-heavy lines, making them "gallop" and eventually cross. Transmission lines on the prairies where there are little to no physical features to block the wind power lines and poles are vulnerable to extreme wind or winter storm conditions.

The higher voltage is susceptible to short-circuiting during the summers due to stretching of the transmission wires during periods of over-heating caused by overloading and record high temperatures, as well as ice storms in winter. In November 2005, over 1,200 high-voltage transmission poles were

destroyed in East River South Dakota, with 725 miles of transmission lines put out of service and 35 substations serving local distribution cooperative systems were taken off line, at a repair cost of $6 million for the transmission system(East River Electric 2006). The lower-voltage distribution systems are even more susceptible to catastrophic ice storms, such as have occurred in the early winter of 2005 and in the late winter and the spring of 2010 and 2011 (Basin Electric Power Cooperative 2011).

In 2005, many local electric distribution systems were hard-hit by the combination of ice, snow and wind, with an estimated 10,000 distribution poles went down, leaving more than 20,000 electric cooperative members in eastern South Dakota without power as frigid Arctic air arrived. The most wide-spread and devastating ice storm in the state's history caused an estimated $20 million in damages to the rural electric cooperative systems (East River Electric 2006) In 2010, icing conditions destroyed nearly 20 percent of one electric cooperative's system, requiring the rebuilding of 500 miles of line in often very remote areas with rugged terrain, over a three week period (North Dakota Association of Rural Electric Cooperatives http://www.ndarec.com/mediagallery/galleryaprilstorm.html).

CASE STUDY: Development potential on Tribal lands [this seems like it might go better later, as it is a break in flow from the above to this section to the drought of 2011 case study section that follows]

Tribal residential concerns are often focused around the rising costs of fuel sources used for heating (24). This problem is compounded by the fact that housing on reservations is often poorly insulated and residents are often unable to afford to make repairs to their homes (12). Exterior doors and windows may have broken seals or glass, walls and floors may have gaps leading outside, and roofs may be partially collapsed. This combination leads to extremely energy inefficient residences and high energy bills.

Founded in 2006, Lakota Solar Enterprises (LSE), located on Pine Ridge, is one of the first 100% Native-owned renewable energy companies in the U.S. LSE has several initiatives that are helping Native residents to both reduce their heating costs and greenhouse gas emissions while simultaneously providing green jobs and training for tribal members. One initiative involves the manufacture and installation of solar air heaters on Pine Ridge. When installed in residential homes, these solar air heaters and their installation at dwellings to supplement and reduce the necessary amount of other fuel sources such as propane, wood, and primarily coal-powered electricity (29). LSE's solar air heaters have

also been put into place on several other reservations in the Northern Plains. Such small-scale renewable energy technologies may be particularly suitable throughout the Great Plains where an average of 33% of Native reservation housing units rely upon off-grid heating sources (2000 census). In North Dakota, Nebraska, and Texas, this figure is closer to 50%; in Kansas and South Dakota, it is closer to 70%.

LSE has also been collaborating with the nonprofit Trees, Water, and People (TWP) to plant wind breaks and shade trees around residences to further reduce energy costs . At the Red Cloud Renewable Energy Center on Pine Ridge, tribal members from all over the U.S. can receive hands-on training in renewable energy applications from Native LSE employees (29). Finally, LSE, again in collaboration with TWP, also oversaw the Little Thunder single home renewable energy demonstration project on the neighboring Rosebud Sioux Reservation, which includes photovoltaic solar panels, a small wind turbine, as well as a solar air heater and a windbreak. In addition to enterprises such as LSE, other potential adaptation and mitigation options include the development of tribal energy efficiency codes and weatherization programs, the latter of which could also provide local jobs.

At a larger scale, Great Plains tribal governments and communities as a whole may also be involved in and affected by energy production. Oil and gas operations on tribal lands provide income for the tribal governments in the form of leases and royalties. However, concerns about resulting water pollution and environmental contamination often compete with the desire to develop such resources for the benefit of tribal economic development (24). In some cases, large-scale renewable energy development also has serious impacts on Native communities. Hydroelectric power on the Missouri River has adversely affected Great Plains tribes through the historic relocation of riverside communities, the associated loss of their traditional environs, and the eventual erosion of culturally important gravesites (30).

As the United States as a whole starts to slowly transition away from a fossil-fuel based economy and begins to emphasize renewable energy development, Indian Country may be uniquely positioned, quite literally, to take advantage of development opportunities. Reservations are often located on the driest and windiest parcels of land, those that were historically the least desirable for agriculture or municipalities. Yet, these lands may be ideal for renewable energy production. The Great Plains are home to a phenomenal wind resource on millions of acres of unobstructed, undeveloped land (31, 29). On reservation lands in North and South Dakota alone, the wind power potential is over 250 giga-watts (30). This is at least one hundred times the hydroelectric power produced by the six large dams on the Missouri River (30). Moreover, development of tribal wind power in the Great Plains could

not only reduce greenhouse gas emission but also help alleviate some of the current and future management demands on the Missouri River (16). As the Great Plains population grows overall, demands for water supply, irrigation water, and electrical power will increase. Changes in water regimes associated with climate change will also complicate Missouri River management and hydropower generation.

The opportunities for large-scale wind development in the Great Plains are great. However, there are also challenges to developing wind energy that are unique to Indian Country. The Owl Feather War Bonnet (OFWB) wind energy project case study published in the South Dakota Law Review highlights some of these challenges (31). The OFWB project is being developed by the Rosebud Sioux Reservation, SD. The Rosebud Sioux are one of the first tribes in the country to create a commission to regulate reservation utilities (30). The tribe is also one of the first to pursue large, utility-scale energy generation (30). As proposed, the OFWB Wind Farm will be a 30 Megawatt facility large enough to power 7,500 individual homes with essentially no carbon dioxide emissions (31).

As illustrated in the OFWB case study, issues that are more particular to tribal wind energy production include locating and developing wind facilities in a way that protects sacred sites and cultural resources (30,31). In addition, given the history of misuse of tribal resources, tribal councils may be hesitant to work with private investors who can bring the necessary capital and expertise to implement a project (31). Indian Country is often far removed from the urban centers that need the electricity resulting in higher transmission costs (31). And because of tribes' domestic dependent nation status, legal questions may arise as to what laws apply or who has jurisdiction should a dispute arise. Fossil-fuel based electricity is still cheaper than its unsubsidized wind counterpart. By boosting profit margins, production tax credits (PTCs) often make the difference as to whether an operation will be economically viable. However, because tribes are not tax-paying entities, they are not eligible for PTCs (31).

CASE STUDY: Texas Drought and Energy-Water Impacts

In 2011 The Southern Plains drought was characterized as a "flash drought" because the onset was so rapid (where onset comes in weeks as opposed to months or seasons). While some portions of New Mexico, Oklahoma, Nebraska, and Louisiana experienced extreme to exceptional drought in 2011, Texas was at the epicenter of the event with the entire state experiencing some level of drought, which at the height in October experienced over 80% of the state in a D5 "exceptional drought" stage (NIDIS drought portal). Many weather stations in Texas showed they only had a mere 25% of their normal 12-month precipitation accumulation (Nielsen-Gammon 2011). Accompanying the drought was one of the

worst heat waves on record, which resulted in increased evaporation that further depleted already low stream-flow and reservoir levels (Nielsen-Gammon 2011). During the summer of 2011 Texas experienced both the hottest and driest conditions on record, temperatures were observed to be 2.5 °F hotter than previous record set in the summer of 1980 and rainfall was 2.5 inches lower than previous low rain amounts recorded in 1956. Other drought measures attest to the severity of the drought, "Texas' average PDSI this past summer (June through August) was -5.37 – the lowest, indicating the most severe drought conditions, since the start of the instrumental record in 1895" (Dawson, 2012). In the long-term paleo record using tree ring data, the 2011 drought was only matched in severity by the year 1789 (NOAA 2011). The severity of the drought appears to be the product of a La Nina event, exacerbated by climate change (John Nielsen-Gammon, 2011).

The drought threatens thermoelectric generation through limited availability of water while the heat wave induces increased demand for peak electricity. "More than 11,000 megawatts of Texas power generation — about 16 percent of the Electric Reliability Council of Texas' (ERCOT) total power resources — rely on cooling water from sources at historically low levels. If Texas does not receive "significant" rainfall by May, more than 3,000 megawatts of this capacity could be unavailable due to a lack of water for cooling" (ERCOT 2011). This potential impact is further intensified when considering that increased cooling demands caused by the heat wave drove peak electricity demands to all-time highs, exceeding the prior record on 8 of the first 12 days of August 2011. The peak demand rose to 68,294 MW closely approaching the state's capacity of 72,000 MW. While the state's growing utilization of wind power, currently 12.5% of the state's production, reduces challenges over limited water supplies it places the state at greater risk of meeting peaking demands due to the inherent variability of production.

Beyond thermoelectric generation, limited water is also threatening gas shale production. In 2010 the Texas Water Development Board estimated that 13.5 billion gallons of water were used in the drilling and stimulation of gas shale wells in Texas. In August of 2011 the town of Grand Prairie, in the northern part of the state, became the first in Texas to enact a ban on the use of water for fracking (Malewitz 2011). The Texas Water Development Board acknowledges concerns about the use of water for hydraulic fracturing in the energy industry, and says it will monitor this closely in its next regional water planning cycle (Texas Water Development Board 2011).

WATER AND CLIMATE CONSIDERATIONS FOR AGRICULTURAL PRODUCTION

IMPACTS OF CLIMATE CHANGE ON GREAT PLAINS ANIMAL AGRICULTURE

There are several potential impacts of climate change on livestock production systems. These are primarily determined by impacts on feed production (forage biomass production, forage quality), water availability, direct (thermal stress), and indirect (decreased immunity, increased disease and parasites, decreased reproduction or weight gain) effects on the animal, and other factors. For example, Dijk et al (2010) reported that climate change, especially elevated atmospheric temperatures, can change the abundance, seasonality, and spatial distribution of helminths (Nematoda / round worms and Trematoda / flatworms) that are parasitic to livestock. Changes in moisture and temperature conditions and growing season can potentially affect the growth of mycotoxins in grains; especially corn (Nardone et al., 2010). These myriad of factors may in turn affect GHG emissions from the livestock system.

In general, dynamics of grassland ecosystems such as those in the Great Plains can be altered by changes in plant nutrient use efficiency, water use efficiency, plant species present, biomass production, nutrient cycling, forage consumption by animals (livestock, wildlife, and insects), plant disease, and rate of biomass decomposition. Many of these can be potentially affected by climate change (King et al., 2004; Morgan et al. 2008).

By itself, changes in temperature affect both the rates of chemical reactions and also affect exchanges of energy between the land and the atmosphere. Kinetic responses have the potential to increase plant growth (Luo et al. 2009), speed up plant development (Cleland et al. 2006; Sherry et al. 2007; Hovenden et al. 2008), and increase the decomposition of soil organic matter, although those potentials can be limited or altered by soil moisture. As a result, warming may increase the plant growth in rangeland in mesic systems or years with adequate moisture, but have little effect (Fay et al. 2011; Morgan et al. 2011; Pendall et al. 2010; Xia et al. 2009), or even reduce plant growth when soil moisture is inadequate and where warming leads to significant desiccation through increased evapotranspiration (De Boeck et al. 2008).

Climate change may affect precipitation patterns that will subsequently affect rangeland productivity (Sala 1988, Lauenroth 2000), and ultimately, the carrying capacity of the range. Averaged over 9,500 sites in the Great Plains, Sala et al (1988) noted the following relationship between precipitation and above ground forage production:

Production (g/m2) = 0.6 (average annual precipitation, mm) -34. r2 = 0.90

However, more recent research suggests that responses of grazing lands to precipitation depend not only on the annual amount, but also on frequency and size of precipitation events (Fay et al. 2008, 2011). Furthermore, differences in evapotranspiration, plant community and soil type can affect how variation in precipitation affects soil water, plant utilization and species responses (Bates et al., 2006; Knapp et al., 2008; Craine et al., 2010; Debinski et al., 2010; Whitford and Steinberger, 2011). An interesting example of this complexity is illustrated in a recent report in which less frequent precipitation events decreased aboveground net primary productivity (NPP) in tallgrass prairie, but increased NPP in shortgrass steppe (Heisler-White et al. 2009). Thus, the specific effects of precipitation patterns can vary considerably across the region.

In addition to its effects on global warming, rising atmospheric levels of CO2 can affect plants directly as a substrate for photosynthesis and as an anti-transpirant. The former response is stronger in C3 plants, like cool-season grasses, as their photosynthetic metabolism is not CO2-saturated at present atmospheric levels ; increases in CO2 can potential increases photosynthesis and plant growth in C3 plants. That is not the case for C4 plants (mostly warm-season grasses in rangelands) whose photosynthetic apparatus is CO2-saturated or nearly so at present-day CO2 concentrations (Polley, 1997, Anderson et al., 2001, Reich et al., 2001, Poorter and Navas, 2003). However, the closure of stomates with rising CO2 and the resultant decreased leaf transpiration seem to be experienced by herbaceous C3 and C4 plants alike (Wand et al. 1999). As a result, rising CO2 can significantly increase water use efficiency in especially grasslands (Morgan et al. 2004; Polley et al. 2011), so much that it may off-set desiccation resulting from moderate levels of warming (Morgan et al. 2011).

Plant community composition governs in large part important ecosystem attributes like net primary production, water and nutrient cycling, and plant-animal interactions. While shifts in plant community species composition in response to global changes are likely already underway, predicting particular species or functional group responses remains challenging (Polley et al. 2010). Vegetation shifts are expected to occur gradually, although abrupt changes due to crossing critical environmental thresholds are likely to happen as well (Craine et al. 2010; Fay et al. 2011; Friedel, 1991; Polley et al. 2011). Vegetation changes will sometimes involve complex interactions of one or more global change factors influencing the susceptibility of vegetation to disturbances, like fire (Bond, 2008). For example, in the Great Plains, the expansion of tree islands in native grasslands is likely due to fire removal, but may be exacerbated by rising CO2 concentrations (Morgan et al. 2008).

The quality of grassland forage is an important determinant of livestock performance. While both rising CO2 and temperature can reduce forage quality (Henderson and Robinson, 1982; Akin et al., 1987; Newman et al., 2005; Morgan et al., 2008; Craine et al., 2010; Gentile et al., 2011), complex interactions of global change factors and the environment suggest that both increases and decreases in forage quality are possible. Similarly, plant species shifts may also result in either increased (Polley et al. 2011) or decreased (Morgan et al. 2007, 2008) forage quality. The combined effects of climate change on species composition and nutrient cycling are likely to affect forage quality differently in different rangeland ecosystems, so that rangeland managers will need to carefully monitor their resources.

A decrease in livestock carrying capacity will occur in areas that receive less rainfall as they change to shorter grasses and as biomass production decreases. In some cases, higher CO2 concentrations may increase forage production but may decrease protein (and possibly other nutrients) in the forages (King et al., 2004; Milchunas et al. 2005). Or severe droughts may remove forage. These changes in rangeland productivity may be partially mitigated by changes in supplementation strategies, grazing management, by moving to mixed grazing (sheep and/or goats with cattle for example), or even to increased use of wildlife as a part of the ranching operation. Changes in precipitation may not only affect production of monocultures of grasslands but may alter the predominate grasses and forbs present.

Changes in atmospheric CO2 concentration, N deposition in soils, rainfall (total and patterns), and/or temperature all may affect plant productivity and/or biodiversity. However, increases in temperature may also increase the rate of biomass breakdown in soils and the release of stored C as CO2 and CH4. Under drier conditions, the short grass steppe may migrate eastward where climate conditions in the future will be similar to eastern Colorado historically. With or without this migration, productivity of the mixed- and tall-grass prairies will be reduced due to the weather patterns less conducive to the species present under current climate conditions. The effect would a decrease the quantity of forage produced per acre: thus, a decline in the carrying capacity of these rangelands.

Climate change may also alter the suitability of land to grow crops or forage intended for livestock feed, particularly in drought prone areas. If the costs of moving feed, irrigation, or fertilizer usage increased substantially, it could result in a change in the location of intensive livestock production operations such as feedlots, or alternatively, decreases in the number or size of feeding operations.

Climate change may also change the length of the growing season and subsequently alter plant species, plant disease, and pests. In 2000, the average growing season in the lower 48 U.S. states was about 10 days longer than the 100-year average, due to a combination of later first frosts and earlier last frosts. Interestingly, the increase in the growing season for the past 30 years is almost a mirror image of shorter growing seasons which occurred in the early 20th century (http://www.epa.gov/climatechange/indicators/pdfs/CI-society-and-ecosystems.pdf.

Nardone et al (2010) hypothesized that livestock systems based on grazing and mixed farming systems will be more affected by global climate change than more intensive confinement systems. However, the effects may differ by region and more intensive systems may be able to adapt more easily to changes than extensive systems. Although it has not been studied in depth, Nardone et al (2010) suggested that climate change may affect the health of farm animals both directly and indirectly by the effects on disease vectors and(or) on host resistance to disease. Adapting to the stressors of climate change may result in altered nutrient intake (via effects on feed intake and quality of forages) and decreased animal performance.

An increase in drought could potentially lead to increases in rangeland and/or forest fires. NASA estimates that fires annually consume 1.8 billion to 10 billion metric tonnes of biomass and release billions of tonnes of GHG annually (Cawood, 2011). Scientists at the Australian Commonwealth Scientific and Industrial Research Organization estimated the GHG emissions from burning or feeding one tonne of grass to cattle. In short, GHG intensity of burning grass was approximately 3.6x greater than if the grass was consumed by cattle (Cawood, 2011).

4.2.1 MITIGATION STRATEGIES: Livestock production

Moss et al (2000) noted that world methane sources totaled about 689 Tg/year with an annual excess of about 84 Tg. They suggested that atmospheric methane is increasing at a rate of about 30 to 40 million tonnes annually. To decrease this rise will require reductions in methane generation and/or increases in methane sinks (such as oxidation in soils). They estimated that without temperate forest and grassland eco-systems the increase would be approximately 1.5x the current rate. Moss et al (2000) calculated that the reduction in CH4 generated annually, required to stop these accumulations and to stabilize atmospheric methane concentration at current levels is approximately 10% of anthropogenic emissions.

Grasslands have the capacity to sequester carbon and to oxidize methane (Ojima et al 199xx, Mosier et al xxx, Soussane et al., 2010). However, C sequestration is both reversible and vulnerable to disturbance and climate change. A number of management practices are capable of affecting C sequestration including: 1) soil tillage and conversion of grasslands to crops, 2) moderately intensifying nutrient-poor permanent grasslands, 3) using light, rather than heavy, grazing, 4) converting grassland to grass-legume mixtures (Ojima et al 199xxx, Soussane et al., 2010).

Soil organic matter is generally greater in soils of the Northern Great Plains than the Southern Great Plains suggesting that soil respiration and organic matter decomposition are greater in warmer areas than colder regions (Epstein et al., 2002). However, Epstein et al (2002) reported that temperature accounted for less than 8% of the variation in organic matter decomposition rate and that increased soil moisture (> 30%) and decreased clay content were major drivers in soil organic matter content. Plant productivity declined with increasing temperature suggesting that the lower soil OM in the south was not directly due to temperature, but indirectly to less biomass production.

An estimated 102,000 tons of excess N are applied to cropland in the Great Plains annually (84,000 in the North , 18,000 in South) compared to 298,000 in the Corn Belt, 185,000 in the Lake States, 36,000 in Appalachia, and 44,000 in the Northeast (Ribaudo, 2011). More efficient use of fertilizer N on crops and pasturelands can potentially decrease the cost of production and simultaneously decrease N2O emissions (Liebeg et al., 2010).

Beauchemin et al (2011) estimated the effect of numerous strategies on the GHG emission of a beef herd (cow-calf through finish) using the HOLOS model and noted the greatest possibility of reductions occur in the cow herd, rather than in the feedlot (Table). A number of practices such as feeding of ionophores, supplemental fat, increasing dietary grain content, grinding forages, increased grain processing etc. have been shown to decrease enteric methane emissions from cattle; whereas, a number of other methods (feeding organic acids (fumarate, malate), probiotics, tannins, saponin) have been tested with mixed success, (Haaland et al. ,1981; Martin et al., 2010; Beauchemin et al.,2010; Grainger and Beauchemin, 2011; Hales et al., 2012). A number of these strategies are already used in many feedyards (Table)

Table 3 . Effects of management strategies on GHG emissions (Beauchemin et al., 2011)

Scenario	Total CO2e	Total carcass wt(t)	GHG,CO2e/kg carcass	Change in GHG intensity from baseline, %

Baseline	5446	250.6	21.73	--
Feedlot:				
Increased forage use	5925	256.1	23.14	+ 6.59
Extended grain feeding	5277	247.2	21.35	-1.76
Feeding oilseeds to stockers	5371	250.6	21.43	-1.37
Feeding oilseed to finishers	5360	250.6	21.39	-1.57
Feeding DDG to stockers	5390	250.6	21.51	-1.02
Feeding DDG to finisher	5404	250.6	21.56	-0.77
Breeding stock:				
Feeding oilseeds	4986	250.6	19.89	-8.44
Feeding DDG[a]	5140	250.6	20.51	-5.62
Improved forage quality	5182	250.6	20.68	-4.85
Increased longevity	6191	286.2	21.63	-0.44
Increased calves weaned	5561	265.9	20.92	-3.74

[a] DDG= distillers grains. When dietary fat levels are held constant, the feeding of distiller's grains will not affect enteric emissions or increase emissions (Hales et al., 2012: and unpublished data)

ADAPTATION STRATEGIES: Livestock production

In the future, due to increases in world population, there will be increasing competition for land to produce human-edible food, bioenergy crops, and feed for livestock. Livestock producers may need to modify their nutritional and management strategies in order to compensate for changes in the quantity and quality of feed resources caused by climate change. In addition, they may increasingly adopt mitigation strategies in order to decrease GHG emissions and/or earn Carbon credits. Factors such as consumer beef demand, and government policies and regulations could also affect the strategies adopted.

These modifications may include changes in the dominant species used on rangelands (cattle, vs. sheep/goats vs. wildlife), increased use of mixed species grazing, changes in stocking rates, or to changes in the phenotype and/or genotype of the animals used. For example, smaller cows with lower milk production have lower nutrient requirements than larger cows or cows with high milk production and thus require less forage and less supplemental feed. Selecting for smaller cows may be favorable in some regions.

Environmental factors will potentially affect how cattle and calves move through the beef cattle production sectors. For example, in periods of drought, the quantity of forages available will be limited; thus, stocker calves may spend less time on pasture (i.e. and more time in the feedlot) and/or producers may sell portions of their cow herd in order to have sufficient forage for the remaining animals.

In some cases, higher CO2 concentrations may increase forage production but may decrease protein (and possibly other nutrients) in the forages (King et al., 2004). Thus, changes in supplementation strategies (i.e., greater protein supplementation of cows or stockers), and grazing management may be required.

A decrease in forage production could result in a decrease in cow numbers or movement of cows from one region to another, where more favorable weather conditions occur. The number of cows plus calves and stocker calves (i.e. carrying capacity) that can be maintained on different rangelands and

pastures vary depending upon the species of grasses, season of the year, size of cows/calves, and precipitation. A general rule of thumb is that cow-calf producers stock sufficient cows to consume 75 to 80% of forage available in a typical year. In a typical year, the producer will retain some of his calves and/or purchase stocker calves to graze the remaining 20-25% of forage. In "wetter than normal" years, they may purchase more stocker calves and in drier years will purchase fewer (or no) stocker calves. Thus, in drier than normal year's calves may enter feedlots at an earlier age due to a shortage of forage.

Using an economic model, Torell et al (2010) calculated that under relatively constant environmental conditions the optimal cow:stocker ratio on native range in eastern New Mexico was about 80:20 – the ratio typically seen in much of the Great Plains. However, under highly variable conditions the optimal ratio was about 50:50. In the same vein, Okayasu et al (2011) discussed differences between equilibrium and non-equilibrium environments in pastoral systems. In equilibrium environments where rainfall is relatively stable, the ratio of grazing animals to vegetation are "density dependent," and thus, it is appropriate to calculate average carry capacities and to use them to define sustainable animal populations. In contrast, non-equilibrium environments are characterized by large fluctuations in factors such as rainfall and forage production, and thus in the carrying capacity of the rangeland. Under non-equilibrium environments, livestock producers have to adapt by moving animals between pastures with better conditions. They suggested it is important to identify and monitor boundaries between equilibrium and non-equilibrium environments so that managers can respond to climate change. Similarly, using their economic model Torell et al (2010) noted that for optimal economic returns, producers need to have a flexible grazing management system, where livestock numbers are adjusted to match the available forage.

Bailey (2004), Haan, et al (2010), and others have noted that grazing and supplement management can alter cattle distribution on pastures, the distribution of urine and feces on the pasture, and the efficiency of forage harvesting/utilization. By improving management strategies, grazing distribution and utilization of available forage may be improved.

Intensive livestock production systems will also have to adapt to climate change. Because of social issues, geography, topography, nutrient management, and environmental constraints, the Great Plains will remain a major cattle feeding area although some movement from the Southern Plains to the Northern Plains, where bio-ethanol and corn starch industry byproducts are more available and feed costs are lower, may occur. In addition, many climate change projections estimate the Southern Plains may be more negatively affected by climate change than the Northern Plains. Increased use of grains and forages for bioenergy and/or human food will limit the quantity of feed grains available and will

result in increased use of byproducts and other feeds ingredients unacceptable for use in bioenergy or human consumption.

4.3 Tribal and rural landscapes: contrast and comparison vulnerability, opportunity, and adaptive capacity

The Native American people of the Great Plains have lived in this region for thousands of years and have learned to cope with many changes in the environment. However, as the region deals with the current challenges of the 21st Century, the added stress of climate change and a socio-economic and political situation of the Great Plains may further exacerbate the degrading conditions of many of these tribal communities. This section examines how these potential climate changes may impacts tribes in the Great Plains with a focus on water, health, and energy and look into ways that several of these tribes are finding ways to meet these challenges. The section also provides examples of how tribes in this region, drawing on their cultural values, have already started developing strategies than can be used to adapt to and mitigate climate change.

A number of tribal communities living in the rural areas have limited capacities to respond to climate change. Many reservations already face severe problems with water quantity and quality – problems likely to be exacerbated by climate change and other human-induced stresses. However, a number of communities and tribal governments are establishing strategies to cope with these social-ecological challenges related to environmental and climate changes taking place on their lands. These activities recognize the socio-economic challenges faced by these communities, isolated areas where housing lacks electricity and running water, communities dealing with high poverty rates and poor health levels are indictors of communities more at risk to climate change. Native populations on rural tribal lands have limited capacities to respond to climate change. Tribes are disproportionately impacted by rapidly changing climates, manifested in ecological shifts and extreme weather events, as compared to the general population, due to the often marginal nature and/or location of many Tribal lands. The high dependence of Tribes upon their lands and natural resources to sustain their economic, cultural, and spiritual practices, the relatively poor state of their infrastructure, and the great need for financial and technical resources to recover from such events all contribute to the disproportionate impact on Tribes. Nevertheless, Indian Tribes have significant strengths and resiliency to meet these challenges.

Indian tribes are exceedingly vulnerable to, and disproportionately impacted by climate change.[6, IPCC] Tribal communities are deeply connected to local ecosystems and are economically and culturally

dependent on the fish, wildlife plants, and other resources of their lands. Though, this connection to the local ecosystems and ecosystem services also provide a forward to deal with climate changes in their social-ecological system.

Water

Water is vital for drinking, agriculture, economic activities, ecological habitats - for life. And while tribes have adapted to the water cycles of the Great Plains over generations, with population growth, increased industrialization in the entire region, and climate change, the already variable water supply and regimes in this area are becoming more uncertain. Tribes already face significant challenges in providing adequate water supply and wastewater treatment for their communities. Climate change will add to these.

In addition, the uncertainty associated with undefined tribal water rights result in constraints to determine strategies to deal with water resource issues. These water right issues are made even more complicated by the fact that these are often cross-jurisdictional, cutting across intersecting tribal, municipal, state, and federal boundaries. Various court cases have attempted to resolve these issues (e.g., Winters vs. U.S. 1908, Arizona vs. California 1963), however, questions still are unsettled.
In many areas of tribal lands, water infrastructure are in disrepair or lacking (37, 38). According to a 2007 Indian Health Services Report, approximately 40,000 tribal homes in the Great Plains region had water supply deficiencies and 24,000 had deficiencies related to wastewater treatment (39). Roughly 9,700 homes completely lacked either a safe water supply system or a sewage disposal system or both (39). These conditions lead to increased vulnerability to climate extremes, and emergency fixes may take time to implement and can be costly. For instance, during a 2003 drought in the Missouri River Basin, Lake Oahe levels dropped so low that silt and sludge clogged the sole intake pipe at Fort Yates, ND, cutting off the water supply for residents of the Standing Rock Sioux Tribe for several days and causing an Indian Health Services hospital to be temporarily shut down. A temporary intake system was installed at a cost of about $3 million (40, 41). These situations across the Great Plains further affects the people's well-being and constrains their ability to further cope with other stresses in their socio-ecological system.

Although the challenges can be numerous, tribes have initiated water-related projects that can help them prepare for climate variability and change. These strategies cover a range of actions which can be identified as assessment, diversification, restoration, and emergency planning. The assessment

strategy provides a way to analyze the future needs of a community to various environmental stresses. The Bureau of Reclamation for the Wind River Reservation examined current municipal and rural water supply systems and wastewater disposal, as well as assessed the reservation's future needs (45). The assessment incorporated water for enhanced fire protection capabilities as part of the future needs, and recommendations included the installation of metering to help identify where water leaks in the system were occurring and the development and implementation of a watershed protection plan to maintain the quality of source waters.

In other communities, actions have taken to diversify water sources to reduce vulnerability to drought or other catastrophic impact to their sole water source. The Rosebud Sioux Reservation in South Dakota working to become part of the Mni Wiconi, "Water is life" in the Lakota language, Rural Water Project (46, 47) expanded their access to the Missouri River sources. Restoration of degraded watersheds and wetlands have also been undertaken to reduce risk to water quality and to flood abatement measures. The Potawatomi Reservation in Kansas has worked with Kansas State University to establish several demonstration projects showcasing riparian forest buffers and streambank stabilization techniques for streams that drain cropland. These streams have been subject to erosion and may contain high levels of nutrients and pesticides. Emergency planning has also been effective in reducing risks. In 2007, the Northern Cheyenne Tribe in Montana worked with a consulting firm to develop a Drought Mitigation Plan (48). The plan outlined action items such as identifying emergency water supplies for each public drinking water system and for the Indian Health Services Clinic. The tribe also plans to continue working with the USGS, USEPA, and the Montana Bureau of Mines and Geology to monitor water quantity and quality on the reservation.

Health

Tribes currently face a variety of health care issues, and climate change may act to exacerbate those. Expected increases in hot extremes and heat waves may put the elderly and the very young at an increased risk of illness and death (18,20,24). As life spans increase, people in the elderly category will increase as well (16). Another group of people vulnerable to heat extremes are those with diabetes (18,20), and in Native American communities the adult-onset of diabetes has become pandemic (16). In tribes in North and South Dakota, one study found the prevalence rate of type 2 diabetes for people aged 45 to 74 to be 33% among men and 40% among women (22,23) which over 4 times the national average. Another factor that makes tribal communities more vulnerable to extreme heat is the high proportion of inadequate housing that provides little protection against excessive temperatures (16).

Many tribal homes also lack air conditioning and residents may not be able to afford the additional costs air conditioning would entail. Moreover, nationwide about 14% of Indian households have no access at all to electricity, which is ten times the national average (1.4%) (2000 EIA report).

As well as extreme heat, other anticipated consequences of climate change in the Great Plains include increases in drought severity and frequency as well as greater wildfire risks. This could lead to a rise in respiratory ailments from increases in dust and smoke (16). Asthma sufferers may be particularly vulnerable, and as with diabetes, rates of asthma among Native Americans are higher the national average. According to the Office of Minority Health, data from 2004-2008 show that American Indian/National Native adults over 18 years of age were 20% more likely to have asthma than non-Hispanic white adults (14.2% vs. 11.6%) and 40% more likely to die (1.3 vs. 0.9 deaths per 100,000). Climate change health adaptation strategies include programs such as the diabetes prevention demonstration project in which the Winnebago Tribe in Nebraska is participating. This project sponsored by the Indian Health Service's Division of Diabetes Prevention and Treatment involves a series of 16 group education sessions using a specially prepared curriculum as well as individual coaching and monitoring (21).

Another strategy is the public health campaigns such as the Native American Asthma Radio Campaign launched by the EPA in 2001 to educate listeners on how to reduce environmental triggers of asthma attacks in Native American languages. Further adaptation measures include the development of tribal energy efficiency codes and weatherization programs (24), the building of new housing units to decrease overcrowding, and the construction of better quality housing units overall to protect against the elements. Improvements in infrastructure as such road-paving and drainage and strengthening communication links and power supplies would help decrease health risks from natural disasters (16). Recent efforts by Native Great Plains tribal communities to protect medicinal plants and transporting them to safe areas, developing sustainable agriculture to address nutritional issues in Native diets, obtaining information about social and environmental stress management as climate change action strategies, and obtaining training from the Federal Emergency Management Agency on the development of Emergency Response Plans are taking place. (24)

Energy

Energy concerns on reservations can be framed both in smaller-scale terms of energy use, including supply for residences and vehicles, and in larger-scale terms of energy production as a source of economic development and jobs (see Energy section 2). In a climate change context, energy concerns

center primarily around energy usage as a source of greenhouse gas emissions. On Great Plains reservations, many synergies exist for addressing the two sets of small-scale and large-scale concerns.

One of the major concerns in the energy usage can be framed in access and efficiency of usage. In many regions, availability of reliable power to many households is lacking. Secondly, due to substandard housing and buildings energy is wasted in cooling and heating costs. The improved in affordable and accessible housing materials would greatly alleviate some of the chronic stresses these communities experience.

Development of small to large scale energy sources, such as wind, solar, and hydro, would lead to improved access and possibly dependable power. This could also lead to improved economic viability of tribal communities, if for instance tribal wind energy operations were sold through the sale of renewable energy certificates or “green tags” (30). Through green tags, the environmental benefits of wind or other renewable energy sources are quantified and sold as a commodity separate from the electricity itself, which is sold as a second commodity with no particular environmental attributes and at a price comparable to its fossil-fuel based counterparts. An advantage of green tags is that they may be bought by individuals, organizations, or utilities anywhere in the U.S. that would like to support renewable energy development. The tags thus allow consumers to support green power even if their local utility does not directly offer it, and they broaden the potential market for a renewable energy project. The revenue generated through the sale of green tags can significantly boost a project’s financial feasibility.

Despite the challenges, the rewards of large-scale tribal renewable energy development in terms of creating long-term sustainable livelihoods, reducing greenhouse gas emissions, and addressing the future energy needs of the Great Plains region could be great both on and off the reservation.

Rural Housing

Sustainable, affordable, and energy efficient housing is key for creating community resilience to climate change. It provides major opportunities for both adaptation and mitigation by supplying protection against climate and weather extremes, promoting human health, and reducing greenhouse gas emissions through energy efficiency. In the rural Great Plains, there are a variety of housing issues including rural foreclosures, the rehabilitation of housing, the preservation of affordable rental properties, manufactured housing, rural homelessness, and more. However, in this section the focus is

on the inadequate housing that is pervasive among certain groups in the Great Plains, in particular Native Americans and those living in colonias along the U.S.-Mexico border.

These two groups share certain characteristics including lower median incomes, higher rates of poverty, and younger populations. According to the 2000 Census, the median on-reservation/Oklahoma Tribal Statistical Area (OTSA) Native household income was about $26,700, which was roughly 36% below the national average of $42,000. Census data strictly for colonias are not available because colonias typically cross Census-designated geographical units. However, according to a 2002 Housing Assistance Council (HAC) report, the median household income for border region as a whole was $28,000. According to the 2000 Census, the percentage of individuals of partial or full Native American descent living below the poverty level on reservations or OTSAs ranged from 13.7% in Kansas to 50.5% in South Dakota and averaged 26.6% for reservations/OTSAs over the entire Great Plains region. This latter percentage was a little over twice the national average of 12.4%. According to the 2002 HAC report, for the border region as a whole, 18% of residents had incomes below the poverty level. The percentage for Hispanic residents living in nonmetro areas was 32%. Again, according to the 2000 census, the median age for Native Americans living on reservations/OTSAs in the Great Plains was close to ten years below the national average or 15 years in the case of North Dakota, South Dakota, and Nebraska. According to a 2011 HAC fact sheet, the colonia region contains a higher concentration of youth and elderly individuals than the U.S. overall. Additionally, both groups have been experiencing some in-migration (12, HAC 2002).

The lower median incomes, higher poverty rates, and geographic remoteness as well as the distinct histories of each group all contribute to issues with housing quality, affordability, and availability. These are described below. In addition, the younger age demographic and any inmigration could contribute to an increase in housing needs in the future. Also described below are several innovative approaches being used to address housing issues that include establishing sustainable housing enterprises, micro-financing programs, and self-help housing initiatives.

Native American Housing

American Indian reservations are currently suffering from a severe shortage of health, safe, and affordable housing and have been since they were established over a century ago. The need for

adequate housing stems back to the 18th and 19th centuries during the eras of removal, reservation, and later, allotment (12). During this time, tens of millions of acres of tribal lands were either forcibly surrendered or were lost through sometimes unknowing sale to white settlers. Many native peoples from east of the Mississippi River were relocated from their traditional woodland homelands to unfamiliar, undeveloped, and often barren areas in the southern Plains. In the northern Plains, once nomadic tribes were confined to much smaller portions of their traditional homelands or settled onto lands allotted for farming or ranching requiring a shift away from tipis to more permanent housing.

All of the states within the Great Plains are home either to American Indian Reservations or to Oklahoma Tribal Statistical Areas (OTSAs), and according to the 2000 Census, close to 450,000 people claiming at least part Native American descent lived on reservations/OTSAs in the Great Plains. With others returning (**12**) and with a median age close to ten years below the national average as noted above, a younger, more rapidly growing tribal population will require much more in the way of housing over the next thirty to fifty years, than is currently the case.

Because of growing demand on limited budgets, Native housing units are often constructed quickly and cheaply (12**).** According to reports published in 1996 and 2003, approximately 40 percent of reservation housing is considered inadequate as compared with roughly 6 percent nationwide (**11,12**). Moreover, owing to economic hardship, many residents may not be able to afford to properly maintain their homes, further leading to deteriorating conditions (**12**). Native homes may lack complete plumbing, which, according to the 2000 Census, is the case for close to 6% of reservation housing units in South Dakota and Texas. Native homes may also lack telephone connections, which, again according to the 2000 Census, is the case for about 15% of reservation housing units in the Great Plains overall and 20% in North Dakota and Wyoming.

In addition to poor building conditions, more than 30% of reservation households nationwide are considered to be crowded and 18% are considered to be severely crowded (**12**). Twenty five to thirty people, for instance, may share a single home (**12**). The percentages of overcrowding may be underestimated as no extensive study has ever been done. Also**,** the census relies on self-reporting, and public housing tenants may not provide an accurate accounting of occupancy for fear of violating occupancy rules (**12**). Homelessness, in which families may live in cars, tents, storage sheds, or abandoned buildings, is also being increasingly observed on reservations (**12**). However, no firm statistics for homelessness on reservations are currently available.

In addition to carry over from previous generations, housing continues to be an issue today for a variety of reasons. Many Native communities are geographically isolated and distant from urban centers increasing the costs of both supplies and labor. Harsh climates may limit the construction season. The construction of public housing on reservations can be very time consuming because efforts may have to be coordinated among several federal agencies (HUD, BIA, USDA, HHS) and among state agencies as well (**12**). Also, there are a variety of complicated and unique land tenure issues in Indian Country. In terms of home ownership, issues such as predatory lending, insufficient credit ratings, and a general lack of banks and mortgage lenders are barriers (**12**). Additionally, land held in federal trust status, such as land on reservations, cannot be used as collateral for loans. Banks may thus not be inclined to make loans to tribal members for permanent homes, but may provide loans for mobile homes, which they would then have the ability to repossess.

In order to address some of the Indian Country housing issues from the public housing perspective, the Native American Housing Assistance and Self-Determination Act (NAHASDA) was passed in 1996 separating Native American Housing from other public housing both administratively and financially. The act recognizes Native rights to self-determination and allows the tribes to plan, manage, and monitor housing assistance programs rather than the U.S. government. This should permit each tribe to take into account its unique situation and provide some leeway for tribes to address their housing needs as they see fit. From the private housing perspective, some recommend trying to attract more private mortgage lending to Indian Country (**11**). However, new housing strategies implemented without simultaneous economic development likely won't work because tribal residents won't be able to pay the rent needed or be able to afford to maintain their homes.

One BIA-funded program on the Crow Reservation in Montana is using the housing shortage as an opportunity to create on-reservation jobs by both producing building materials and constructing high quality, resilient housing on Crow lands. Awe'-Itche Ashé (Good Earth Lodges) has partnered with the University of Colorado's Mortenson Center to start manufacturing compressed earth blocks using resources from the local area, the location furthest north in the U.S. to do so. Awe'-Itche Ashé is using these blocks to build houses with a passive solar design, thermally efficient windows and doors, and a geothermal system for radiant heating and cooling. The aim is to create long-term, high quality careers for tribal members and create hundreds of sustainable, energy efficient homes on the Crow reservation.

A second innovative project is taking place on the Pine Ridge Reservation in South Dakota where Oglala Lakota College (OLC), the Thunder Valley Development Corporation, the Oyate Omnicye Regional

Planning Project, and the University of Colorado's Environmental Design Program are all partnering on a Native American Sustainable Housing Initiative starting in January 2012. The initiative will provide energy efficient housing for Pine Ridge residents and hands-on learning experiences for students. A research component to the project will involve constructing four houses made of different building materials on the OLC campus in Kyle, SD and monitoring them for indoor air temperature, humidity, and air quality, for energy performance, and also for durability. The homes will be designed with cultural appropriateness as a major consideration, and life cycle cost analyses will be performed that will account not only for financial costs but also for greenhouse gas emissions as embodied in creating the housing materials, constructing the house, and living in and maintaining the house. The ultimate goal of the project is to identify housing options within the community that are healthy, affordable, and sustainable.

Colonias

Colonias are rural, mostly unincorporated communities along the U.S.-Mexico border, within 150 miles according to the federal definition, that are characterized by high poverty rates, inadequate infrastructure, and substandard housing. Colonias can be found in California, Arizona, and New Mexico. However, it is Texas that has the largest number (TBR, 2008). As of 2008, approximately 400,000 Texans, predominantly Hispanic and nearly 65% of them U.S. born, lived in over 2,290 colonias (TBR, 2008). According to a 2005-6 article Housing Assistance Council article, 24% of colonias households in Texas were not connected to treated water for drinking and cooking, 44% had outhouses or cesspools, and 44% experienced flooding due to unpaved roads and poor drainage (Rural Voices, Winter 2005-6).

The term colonias derives from Spanish in which the word means neighborhood or community. The majority of colonias started during the 1950s as low-income workers and others who could not afford homes in local communities looked for other options. Developers purchased tracts of land in isolated rural areas on floodplains or areas with no agricultural value. Weak land use regulations and lack of enforcement allowed them to divide the land into small lots and sell them without undertaking any subdivision process and providing little or no infrastructure (HAC 2002). The lots were then sold to low-income buyers who were attracted by the low prices and who then proceeded to build their own homes little by little using available materials (HAC 2002, Cisneros 2001). Homes often start as tents or makeshift shelters made from cardboard, wood, or other materials (Cisneros 2001). Then as finances allow, owners add improvements (Cisneros 2001). Houses in older colonias are thus usually better

developed than those in newer communities (Cisneros 2001).

Employment for colonia residents may be seasonal and consists primarily of low-wage jobs in manufacturing, food processing, agriculture, or agriculture-related businesses (HAC 2002). Because many colonia residents do not have credit history or resources to qualify for conventional financing, a large number of colonia properties have been financed under a contract-for-deed system in which the developer maintains ownership of the property until the full purchase price, often including a high rate of interest, is paid (HAC 2002). This means that a developer can foreclose and reclaim a property even after just one missed payment (HAC 2011). In such cases, any investment the purchaser made to improve the property would be lost (HAC 2011). Recently, as states have enacted legislation prohibiting developers from selling lots without water and wastewater treatment services and as they have exercised their power to regulate the subdivision of land, the development of colonias has slowed or stopped (Cisneros 2001; HAC 2011).

One innovative program for addressing some of the needs in the colonias is the Nuestra Casa Home Improvement Lending Program of the nonprofit Community Resource Group. The program is a revolving fund, short-term micro-credit loan system in which a low-income homeowner can borrow $2,500 to be repaid over a two-year period at a 9% interest rate (RV Winter 2009; TBR 2008). There are no loan-related fees such as an application fee (RV Winter 2009; TBR 2008). There is also no penalty if a loan is not repaid. Instead the program provides an incentive in that if a borrower makes timely payments during the first 12 months, he or she is eligible to increase the loan amount up to $3500 at the same interest rate for additional home improvements (RV Winter 2009; TBR 2008). The “one-size fits all” approach simplifies the loan process and cuts down on managing costs (TBR 2008). Loan approval times typically take only 2-3 weeks (TBR 2008; RV 2009).

The Nuestra Casa program provides a great deal of flexibility in the how the borrower can use the funds (TBR 2008). Funds can be employed to build a home or to renovate one (website), and they can be spent on a single project or for a wide variety of multiple projects (TBR 2008). Delinquency rates are low. They were 8% when the program first started in 2000 and had fallen to 3% by 2005 (TBR 2008). The program has made over 1300 loans in South Texas (website). Additional side benefits of the Nuestra Casa loan program include increases in property values and the local tax base, job creation when borrowers hire local colonias residents to help with renovations, improvement of public health when borrowers choose to invest in safe water and sanitation services, and increased financial literacy (TBR 2008, website).

Another innovative program is Proyecto Azteca's Self-Help New Construction program. Proyecto Azteca is a nonprofit rural housing development organization that serves colonias residents and is based in San Juan, Texas (2005 Casey Foundation; Rural Voices 2003). Through a combination of no interest loans, mortgage payments that are often as low as $100 a month, and a mutual self-help building program, Proyecto Azteca helps low-income residents with annual household incomes sometimes as low as $4500 become homeowners (2005 Casey – mortar; 2011 LGRV, 2008 OFN). Mutual self-help housing is a housing model in which home buyers contribute labor or sweat equity to help one another construct their houses. In the case of Proyecto Azteca, six to ten families typically work together in a "tanda" or traditional Mexican collective in which members combine resources for the common good (Casey Foundation 2005).

The families receive materials, tools, and instruction, and work together under the supervision of construction trainers to build homes in Proyecto Azteca's construction yard, learning new potential job skills in the process (2011 LGRV, 2008 OFN). Each family may contribute an average 500 hours of sweat equity and homes may be completed in about six weeks (2005 Casey Foundation; RV 2003). The finished houses are then moved to their final destination and placed on permanent foundations (2011 LGRV). The total cost to a family for a house may be around $18,000 (2005 Casey Foundation). To encourage a sense of community, Proyecto Azteca sponsors shared meals and celebrations to mark progress (2005 Casey Fdtn – mortar). When the homes are completed a traditional Mexican blessing and pachanga (fiesta) takes place (RV Fall 2003). Since its start in 1991, Proyecto Azteca has built homes for 600 families in 120 colonias (2011 LGRV).

4.4 Case Studies on Urban and Rural Communities

Green Infrastructure

Urban areas including those in the Great Plains currently face a wide variety of environmental challenges. Many of these such as the urban heat island effect (UHI), ground level ozone, storm-water management and flood control, and combined sanitary and storm sewer overflows may be exacerbated by climate change (Section 2.X). Green infrastructure is one approach that cities can use to simultaneously address these issues as they upgrade aging, outdated infrastructure. Although the term green infrastructure can have alternative meanings in different contexts it often refers to landscapes that have been specially conserved or sometimes designed and engineered to mimic natural processes and provide ecosystem services such as flood control. (EPA-arid; CCAP 2011). Sometimes the definition

of green infrastructure is expanded to include additional approaches (not always vegetation-related) that cities use to try and achieve environmental goals (CCAP 2011). In the text below, it is this broader definition that is considered.

Green infrastructure benefits associated with climate change adaptation are generally related to its ability to curb the impacts associated with the anticipated increases in air temperatures and in extreme precipitation events (Section 2) (CCAP, 2011). Benefits associated with climate change mitigation are generally related to the ability of green infrastructure to decrease energy usage and sequester carbon. In addition, green infrastructure can also contribute to recreational space and aesthetic value that can improve health and provide a better quality of life (Tzoulas 2007; CCAP 2011).

Green infrastructure approaches can be incorporated into new developments, done as a retrofit, or included as repairs or replacements are made, and they can be implemented at an assortment of spatial scales ranging from individual house lots to entire metropolitan regions (CCAP 2011). Although green infrastructure may be implemented to meet a single, specific goal such as reducing ambient air temperatures, it often provides additional benefits, and the full value of a project stems from the multiple functions that green infrastructure performs. A variety of cities within the Great Plains are beginning to incorporate green infrastructure into existing building codes and city plans, as a pragmatic way to update current infrastructure to meet climate challenges.

Ecoroofs

In Austin, Texas, a variety of eco-roof related efforts are underway. Austin's building code currently includes cool roof requirements for new buildings (Dallas UHI 2009). -Cool roofs, also known as white roofs, are either painted white or surfaced with a reflective material and significantly decrease roof temperatures, thus helping to decrease ~~lowering~~ the UHI effect (CCAP, 2011). Austin Energy provides a rebate for commercial customers who retrofit their existing roofs with a spray-on or paint-on coating that increases roof reflectivity. (EPA – UHI Compendium; Austin Energy rebate fact sheet). Additionally, an Austin Green Roof Advisory Group put together a five-year implementation plan to systematically promote the increased use of green roofs in the city, which are completely covered with vegetation and can address both heat and stormwater concerns (CCAP, 2011).

Bioretention

Changes in extreme precipitation and increasing temperatures are expected to influence both the amounts and the quality of stormwater runoff. Some cities in the Great Plains are using a green infrastructure approach known as bioretention (Box X) to address flood control and water quality protection as well as improve recreational opportunities and community aesthetics.

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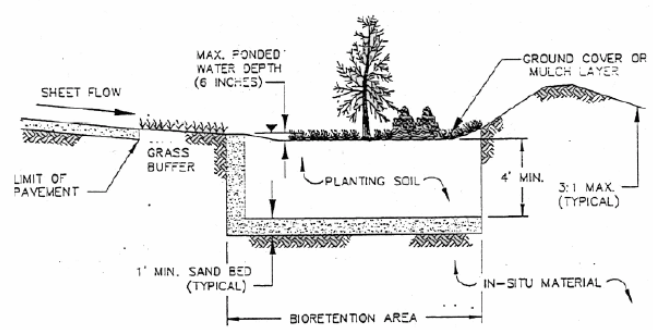
Bioretention cells

Bioretention cells or rain gardens are vegetated depressions that receive, absorb, and treat stormwater runoff from impervious surfaces such as roofs or parking lots (CCAP, EPA-arid). It captures and removes contaminants and sedimentation from runoff. The stormwater is collected and organically treated by filtering through groundcover and soil.



Example of the Basic Lay-Out of a Bioretention System

Bioretention cells can be used in a variety of settings such as parking lots or residential areas where soils do not filter water well. Plants with a wide range of moisture tolerance are used and provide both aesthetics to urban landscapes and help maintain soil quality and percolation (Green Topeka website; WPCD, 2002).

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~END SUB-BOX~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Green Topeka is an effort that includes city, state, and federal agencies, nonprofit organizations and private stakeholders to implement green infrastructure projects in Topeka, Kansas. It has begun installing bioretention cells and swales throughout the city as retrofit projects to address historical flooding issues, add green space, and revitalize urban areas (Green Topeka website; WPCD, 2002). An inaugural site was used as a study area to investigate what types of plants were most suitable for bioretention in Topeka. Native plants work well as they are able to handle flood-like conditions as well as periods of hot, dry weather (Green Topeka website). For more information visit: http://www.greentopeka.org/.)

Although bioretention areas are often installed by city governments or commercial property-owners, they can also be created and put in by individual homeowners. This has been the focus of the Lincoln, Nebraska Rain Garden Project. Designed as a public education outreach program to empower residents to improve the quality of water in their local water bodies (NET, 2010 Annual Report), an early

stage of the project provided a 80:20 cost share in which homeowners contributed 20% of the funds needed to install rain gardens. The initial project goal was to fund 90 rain gardens. Ultimately a total of 132 gardens were installed (NET, 2010 Annual report). Now a second phase of the project is taking place in which Lincoln's Watershed Management Division is providing a 50:50 cost share up to $1000 for expenses. The city is also providing rain garden classes in which homeowners can learn how to design and build the gardens and also get some hands on experience with an actual installation, with a goal of helping residents install an additional 50 rain gardens by Fall 2012 (http://lincoln.ne.gov/city/pworks/watrshed/educate/garden/rgp/).

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~END BOX~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Urban Forests and Greenways

Urban forestry and greenway initiatives are being implemented in Great Plains cities to achieve ecosystem solutions to a variety of climate-related problems. Denver's Mile High Million program, developed in 2006, aims to gather community partners and individuals in an effort to plant and look after 1,000,000 new trees in the metropolitan area by 2025. Project goals include sequestering greenhouse gases, providing natural cooling to buildings and pavement, improving air quality, reducing energy bills, decreasing storm-water runoff, controlling erosion, and adding beauty to Denver neighborhoods (Mile High Million fact sheet; website).

Greener Nebraska Towns is an initiative to help communities across Nebraska use intensive tree planting to improve the canopy cover, stormwater management, increase biodiversity, and create more attractive, liveable communities. The program also emphasizes waterwise landscaping to reduce water consumption. Thus far seven towns have been selected to participate including: Scottsbluff, Chadron, North Platte, Hastings, Grand Island, Fremont and Bellevue (Nebraska Community Forestry Conference, 2011).

The Greater Grand Forks Greenway was a response to severe 1996-7 flooding in the Red River Valley. The cities of Grand Forks, ND and East Grand Forks, MN worked with the Army Corps of Engineers to create a green floodway or "greenway" in the city centers. During times of extreme river level rising, the floodway fills with water. However, most of the time the floodway does not act as a control project but as a recreational amenity with almost 20 miles of paved multipurpose trails and 2200 acres of open space. (Greenway Fact Sheet, City of Grand Forks).
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MetroGreen is a long-term vision for an interconnected system of public and private open spaces and greenways linking natural resources and communities across the greater Kansas City region. (2009 Conservation Fund report). The plan's multipurpose goals include improving flood control and water quality, providing an alternative non-motorized transportation network, improving air quality and health, enhancing recreational and cultural opportunities, providing economic benefits to the region, and improving the overall quality of life. The MetroGreen Plan ultimately conceives of 1,144 miles and more than 75 separate corridors linking the two states (Kansas and Missouri) and seven to nine of the counties in the Kansas City region (MARC 2009; 2009 Conservation Fund).

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a new standard for other rural and urban communities. It has become a net zero energy community, generating as much electricity from renewables as it consumes. The city council passed a resolution requiring all new city buildings larger than 4,000 square feet to reduce energy consumption by 42% (compared to standard buildings) and pass U.S. Green Building Council LEED Platinum certification. A 12-megawatt wind energy system will be installed near Greensburg that will meet its pre-tornado electricity needs. Additionally, the city has entered into a power purchase agreement from a renewable energy provider that will deliver 100% renewable electricity from wind, hydro, and other renewable energy electricity generation sources.

Greensburg citizens acknowledge that there is potential for similar disasters in the future and have adopted building code standards to be better prepared for severe wind events. It has also embraced tornado preparedness education within the community and schools have implemented programs to educate students about storm safety and sustainable living. (Greensburg, 2008; NREL, 2009)

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Great Plains Urban Water Supply Strategies

In the face of both population growth and greater uncertainty in precipitation and runoff regimes stemming from climate change, cities throughout the Great Plains are starting to explore and implement ways to diversify their water sources. Strategies include water conservation, the use of nonpotable water, aquifer storage and recovery, desalination, and water reuse with the latter approach being the subject of more in depth discussion in this section.

Water conservation is becoming a priority throughout Great Plains Cities. Cities including Austin, Dallas, Denver, and San Antonio all have water conservation plans or programs. The resulting decrease in demand can act as an “effective” new water source. Components of the plans vary and include indoor residential, commercial, and industrial approaches as well as outdoor conservation approaches. An example of an indoor residential conservation measure is Dallas Water Utilities’ (DWU), “New Throne for Your Home” program that provides vouchers to change out older, pre-1992 toilets for newer, more efficient models (DWU Conservation Plan, 2010). An example of an outdoor conservation measure is Denver Water’s soil amendment program that requires property owners to till compost into their soil before Denver Water will set meters so that the soil will retain water more efficiently reducing irrigation requirements (Solutions, Denver Water, 2011; http://www.denverwater.org/Conservation/SoilAmendmentProgram/).

The use of nonpotable water in situations when water of drinking water caliber is not required is a strategy being implemented in Norman, Oklahoma. The city, for example, is using wells not suitable for drinking water to help irrigate the Westwood Golf Course and the Griffin park complex (Norman Water Conservation Plan, 2011).
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Aquifer storage and recovery (ASR) involves the injection of water into a well when water is available for storage underground. When needed, the water is then recovered from the same well (NRC 2008). If water is recovered via a different well, the process is called aquifer storage transfer and recovery. The cities of El Paso, Kerrville, and San Antonio in Texas all have ASR programs making use of treated wastewater, treated river water, and groundwater for injection, respectively (TWDB, 2011). San Antonio, for instance, pumps water from the Edwards Aquifer during wet periods and stores it underground in the Carrizo Aquifer. During times of drought, the stored water is then recovered to help meet peak water demands (SAWS 2009 fact sheet).

Desalination generally involves treating brackish surface or groundwaters or treating seawater to produce freshwater. The process also results in a separate saltier concentrate stream (NRC 2008). El Paso is home to the Kay Bailey Hutchison Desalination Plant, the largest inland desalination plant in the country (plant website). The plant is a joint El Paso/U.S. Army effort and makes use of brackish groundwater from the Hueco Bolson aquifer (NRC 2008).

A variety of Great Plains cities are starting to implement or augment water reuse strategies involving municipal or domestic wastewater that has been treated to a standard adequate for various beneficial uses (TWDB, History Reuse, 2011). This treated effluent is referred to as reuse, recycled, or reclaimed water. Water reuse strategies may consist of direct or indirect use.

For direct reuse, effluent is piped from a wastewater treatment plant to a location where it is used, typically for irrigation or for commercial or industrial purposes (TWDB, 2010; Denver Water, Solutions, 2011). Sometimes the wastewater effluent is treated further prior to reuse (Denver Water, Solutions, 2011). Indirect reuse occurs when wastewater effluent is discharged into a water body such as a stream or lake and is then diverted and reused further downstream (TWDB, 2010). Reuse can also be divided into potable and nonpotable categories. Potable water meets all applicable federal, state, and local requirements for safe drinking. Nonpotable water, while not suitable for drinking, may be useful for other purposes that will vary depending on its quality (TWDB, History Reuse, 2011).

In urban settings, recycled water can be used for a variety of applications including landscape irrigation, decorative water features, car washes, dust suppression, and street washing among other uses some of which are described below (NRC 2011). Recycled water can also be used for groundwater recharge and ecological enhancement (NRC 2011). However, agricultural irrigation currently comprises the largest use of recycled water in the U.S. (NRC 2011; Jimenez and Asano, 2008). The planned water recycling projects discussed here consist of direct nonpotable reuse or indirect potable reuse. However, unplanned or de facto potable and nonpotable reuse may occur in effluent-dominated surface waters. This occurs, for instance, in the section of the Trinity River (Sec. 1) south of Dallas/Fort Worth, which is comprised almost entirely of wastewater effluent under base flow conditions (NRC, 2011; Fono et al., 2006, TRA, 2010).

Water reuse in Dodge City, Kansas goes back to the 1980s when the city made an agreement with nearby farmers. The city pipes its municipal wastewater about 10 miles south to large ponds where it undergoes aerobic and anaerobic treatment. After treatment, the water is used by a farming

operation for irrigating crops. The nutrients in the effluent save the farmers the cost of buying nitrogen and other crop nutrients. In exchange for the use of the wastewater for a 40-year period, the farmers agreed to lease their groundwater rights to the city. Until recently the city has not needed to use the groundwater. However, population and industrial growth has changed this. Development in groundwater rights since the 1980s provides some challenges in that permission from the Department of Water Resources (CHECK) is required to change the type of, place of, and point of groundwater use from irrigation, farms, and irrigation wells to municipal, city, and municipal wells. The increase in wastewater generation is also necessitating that farmers acquire additional croplands to irrigate. A final challenge is maximizing nutrient uptake by crops for instance through crop selection and watering schedules in order to minimize any pollution of the groundwater from wastewater application (Giordano, 2007).

In El Paso, Fred Hervey Water Reclamation plant was built in 1984. Reclaimed water from the plant is used for maintaining wetlands of ecological interest, for the irrigation of parks and a golf course, and for industrial uses such as cooling tower makeup water. The reclaimed water is also used for aquifer recharge via infiltration basins and injection wells. Currently, the city reclaims about 10% of the combined wastewater generated at El Paso's four wastewater facilities and would like to increase this to 15% (NRC, Water Reuse, 2011).

In 2004, Denver Water opened a recycled water treatment plant with the ultimate goal of delivering 17,500 acre-feet of water per year. Current customers include school grounds, street medians, parks, the CommonGround Golf Course, and the Xcel Energy Cherokee Power Station. The power station, which is currently the water recycling plant's largest customer, combines the recycled water with raw water and then uses it for the station's cooling towers, to wash an onsite ash silo, and for fire protection. The use of recycled water helps ensure that the power station will be able to obtain adequate water even during drought years (NRC, Water Reuse, 2011). The Rocky Mountain Arsenal National Wildlife Refuge is starting to receive recycled water to fill lakes and wetlands for wildlife and vegetation habitat. Recycled water will also be sent to the Denver Zoo to provide bathing water for one of North America's largest elephant habitats and for the zoo's Asian Tropics exhibit expected to open in 2012. In the future, Denver Water plans to provide recycled water service to the Denver Museum of Nature and Science and to Denver International Airport (DIA) among other customers (Denver Water, Solutions, 2011; NRC, Water Reuse, 2011). The museum intends to use the water in a new geothermal heating and cooling system (NRC, Water Reuse, 2011). DIA was built with dual potable/nonpotable plumbing in anticipation of Denver Water extending the recycled water transmission lines to the airport (Denver Water, Solutions, 2011; NRC, Water Reuse 2011).

In 2005, Dallas Water Utilities (DWU) developed a Recycled Water Implementation Plan. As part of this plan, DWU is currently sending treated wastewater effluent to the Crest Golf Course for irrigation (Dallas 2009 Annual Report). As of 2010, DWU also planned to make recycled water available for the Dallas Zoo and for industrial uses and irrigation in the White Rock Creek corridor (Dallas Conservation Strategic Plan, 2010). DWU has also agreed to an exchange of recycled water with the North Texas Municipal Water District (NTMWD). DWU will use portions of the recycled water discharged by NTMWD

wastewater treatment plants (WWTPs) into Lewisville Lake and Lake Ray Hubbard. In exchange, recycled water from DWU WWTP's will be diverted from the Trinity River to NTWMWD's East Fork Wetland (Dallas 2010 Conservation Strategic Plan). Trading recycled water generated in different parts of a watershed in this fashion can sometimes help utilities decrease costs associated with pipeline construction or with pumping water to different elevations (NRC, Water Reuse, 2011).

NTMWD's East Fork wetland is an indirect water reuse project. A portion of wastewater treatment plant effluent discharged into the East Fork of the Trinity River is diverted into a constructed wetland for nutrient removal and water quality polishing. After passage through the wetland, the cleansed water is then piped 40 miles back upstream to the north end of Lavon Reservoir for storage, blending, and eventual reuse in NTMWD's water supply (USACE, 2006; East Fork Reuse Project Fact Sheet). According to NTMWD's website, the 1,840-acre project is the largest constructed wetland using reclaimed water to supplement a surface water supply source in the U.S. Designed to resemble a nature preserve and include a nature center, the wetland is providing wildlife habitat and recreational and educational opportunities as well as treat water (East Fork Reuse Project Fact Sheet).

As of 2009, San Antonio has built the largest recycled water delivery system in the U.S. with more than 100 miles of pipe beneath city streets (SAWS, 2009, plan and fact sheet). The reclaimed, non-potable water is used by factories, golf courses, and athletic complexes among other customers. CPS Energy also makes use of reclaimed water for cooling water via indirect reuse through a "bed and banks" conveyance permit (SAWS 2009 plan). The Texas "bed and banks" statute allows a water utility to discharge treated wastewater into a stream while maintaining the rights to withdraw that water downstream for reuse (NRC, 2011). This allows reclaimed water to be transported significant distances without the associated direct piping infrastructure costs that might otherwise be required (NRC, 2011). During non-drought years, direct and indirect use of reclaimed water may provide up to 20% of San Antonio's water supply needs and helps alleviate pumping demands on the Edwards Aquifer, which is San Antonio's primary source of water (SAWS 2009 plan fact sheet).

In addition to taking place on a city-wide scale, water reuse can also occur at the scale of an individual building or facility. This is what's happening at EPA's Science and Technology Center in Kansas City, Kansas. The building is equipped with a graywater collection and reuse system that collects rain water from 18,000 square feet of roof, air handler condensate discharge, and water rejected from a reverse osmosis system used to provide pure water for laboratory experiments. The graywater generated is first sent to a 1,500-gallon underground sediment tank and then to a 10,000-gallon underground storage tank. The graywater is then used for toilet flushing, landscape watering, and cooling tower make-up water as needed (Kansas City Science and Technology Center Water Management Plan, 2010).

In Fort Carson, Colorado, the U.S. Army's Central Vehicle Wash Facility performs over 10,000 washes on tactical and support vehicles on average per year. The facility treats the wash water onsite by putting it through a grit- and oil- separation basin, intermittent sand filters, and extended aeration and then reuses the water in a closed loop, decreasing the annual consumption of potable water by about 200 million gallons (FEMP Fact Sheet, 2009). The Fort Carson wastewater treatment plant also

reuses some of its effluent water onsite for process water needed various operations including for the sludge belt filter press (FEMP Fact Sheet, 2009).

Advantages of water reuse include improved water supply reliability in particular during droughts and reduced dependence on imported water supplies. In some instances, reuse may increase the amount of water for the environment, for example if it replaces some existing surface or groundwater supplies thereby increasing instream flows or decreasing groundwater pumping. Water reuse may also improve surface water quality when nutrient-laden effluent is diverted for the irrigation of landscapes and crops (NRC, 2011).

At the same time water reuse could also potentially have negative effects on downstream flows and on water quality. Depending on its extent and context, reuse may also decrease downstream flows adversely affecting downstream users and ecosystems, in particular in water-limited environments. If irrigation application rates exceed the ability for plants to make use of the nutrients in the reclaimed water, this could result in excess nutrient levels in ground or surface waters, which could lead to human health and environmental effects (NRC, 2011). Irrigation with reclaimed water could possibly produce excess levels of salinity in soils, which can be detrimental to plant growth. Denver Water has been studying this and exploring options for decreasing impacts (Denver Water, Recycled Water for Soil and Trees). Depending on project design and energy sources, reuse projects also have the potential to increase the carbon footprint of water supplies (NRC, 2011).

The financial costs of water reuse projects vary and are highly site specific (NRC, 2011). They depend on a variety of factors including the degree, if any, of additional treatment needed before reuse, pumping requirements, timing and storage requirements, and the extent of any new transmission lines. This latter factor is related to the distance between a wastewater treatment plant and reclamation plant, the need for and sizing of any piping for the conveyance of non-potable water, which has to be kept separate from the potable transmission lines already in place, and the distances between the reclamation plant and any non-potable water customers (NRC, 2011). In combination with water conservation, water reuse could potentially decrease seasonal peak demands, which can reduce capital and operating costs (NRC, Water Reuse, 2011).

A 2011 NRC report on water reuse in the U.S. notes that if utilities decide to start placing more emphasis on water reuse, moving towards having multiple smaller, decentralized wastewater treatment plants could start making more sense. Currently wastewater treatment plants are generally constructed at low elevations near a discharge point such as a river or lake. Consequently, reclaimed water must generally pumped uphill for use. A more decentralized system in which reclaimed water is closer to potential customers could reduce pumping costs as well as the cost of transmission and distribution infrastructure. In addition, such a system might be able to better accommodate demand fluctuations in contrast to a large, centralized plant.

The 2011 NRC report on water reuse in the U.S. also notes a variety of research needs. Included among these are conducting an analysis of the extent of de facto potable water reuse in the U.S. and improving our understanding of the health impacts of human exposure to constituents in recycled

water. The report also notes that while water reuse for ecological enhancement is promising, few studies have examined possible environmental risks.

Human Health and Disease Considerations:

POTENTIAL EFFECTS OF CLIMATE CHANGE ON DISEASE: IMPLICATIONS FOR THE GREAT PLAINS REGION OF THE U.S.

In terms of climate change, the primary concern is with *infectious diseases* (those resulting from the presence and activity of a pathogenic microbial agent that can be spread among hosts) and *vector-borne diseases* (those resulting from an infection transmitted by blood-feeding arthropods, such as mosquitoes, ticks, and fleas), which will be the focus here. In addition, diseases affecting vertebrates will only be considered here, although recognizing that the effects of climate change on plant species can have equally far-reaching effects. In general, these diseases involve a pathogen, one or more hosts, and the environment, which makes these diseases particularly sensitive to changes in conditions. Concerns about infectious and vector-borne diseases in vertebrates can be categorized as affecting:

- Human health because they cause illness and mortality in humans.
- Agricultural health because they cause illness and mortality in livestock and plants, which have direct economic effects on producers and consumers.
- Wildlife conservation and biodiversity because they threaten population viability of native species, especially those that are currently considered threatened and endangered, through changes in life-history traits.

Diseases can be specific to one of these categories or involve all three. For example, West Nile virus is a vector-borne pathogen introduced into the U.S. in 1993 that causes disease in humans, livestock (primarily horses) and wildlife (primarily birds) (McLean 2008). In addition, wildlife are associated with a number of diseases that are zoonotic (disease normally existing in animals that can infect humans) and play a key role in both the emergence of novel diseases but in the maintenance and spread of pathogens causing currently known diseases. Of the 1,415 infectious organisms known to cause disease in humans, 61% are zoonotic (Taylor, Latham and Woolhouse 2001, Jones et al. 2008). In addition, the incidence of emerging diseases (EDs) has increased dramatically since 1940 and primarily has been caused by 1) newly-evolved strains of pathogens, such as drug-resistant strains of bacteria and the Asian-strain H5N1 avian influenza virus, 2) pathogens that have recently entered populations for the first time, such as a corona virus-causing SARS in humans and Nipah virus in domestic swine, and 3)

pathogens that have been present historically but have recently increased in incidence, such as Lyme disease in humans (Wolfe, Dunavan and Diamond 2007, Jones et al. 2008).

Wildlife also plays a critical role in both the emergence and increased prevalence of new pathogens in livestock and humans. Recent increases in incidence of EDs in humans have largely been of zoonotic origin (60.3%) and of these, 71.8% were caused by pathogens that originated in wildlife (Jones et al. 2008). In addition, there is an inextricable linkage among pathogens affecting wildlife, domestic animals, and humans, with these pathogens often originating in wildlife and subsequently moving to domestic animal hosts and then humans (Wolfe et al. 2007, Dobson and Foufopoulos 2001). In general, the effects of climate change on creating environments in the U.S. for pathogens emerging outside of the U.S. (e.g., Africa and Asia) has largely been overlooked. For example, if climate change fosters conditions for pathogens, such as Rift Valley fever virus from east Africa (Gerdes 2004), in the U.S., then introductions of those pathogens are more likely to take hold.

Thus, understanding the effects of climate change on disease requires an understanding of those effects on a wide variety of ecological processes, ranging from pathogen persistence in the environment to vector and host population dynamics to the ability of pathogens to infect new hosts and become established in new environments.

GENERAL PREDICTIONS

There is general consensus that climate change will affect the geographic distribution of diseases, seasonality of disease incidence, and variation and magnitude of disease outbreaks. Beyond this, there is little consensus on how and where this will occur. While conventional wisdom suggests that climate change will result in the expansion of tropical diseases, especially vector-borne diseases, into more temperate regions (Lafferty 2009, Epstein 2001), there is considerable debate of whether this will occur, at least on a global scale. Randolph (2009) argues that the assumption that climate change will result only in a worsening of worldwide health have become unsubstantiated dogma.

Predictions on the effects of climate change on pathogens and diseases are predicated on the assumption that climate constrains the range of infectious and vector-borne diseases while extreme weather events affects the timing and intensity of outbreaks of those diseases (Epstein 2001). Some of the general hypotheses considered (Harvell et al. 2002) on predicting how climate warming will affect host-pathogen interactions include:

- Increasing pathogen development rates, transmission and number of annual generations;
- Relaxing overwintering restrictions on pathogen life cycles;
- Modifying host susceptibility to infection
- Disproportionately affect pathogens with complex life cycles

In general, the effects of climate change are considered to be positive for disease emergence, spread, and incidence; vector-borne diseases appear to be the strongest candidates for increased abundance and geographic range shifts because many of these are climate-limited with pathogens or parasites that cannot complete development before the vectors die (Harvell et al. 2002). Harvell et al. (2002) also suggest that the greatest impacts of disease due to climate change may result from a small number of emergent pathogens.

Climate Change and Geographic Shifts in the Distribution of Diseases

Vector-borne diseases are especially correlated with changes in climatic conditions (Epstein 2001), primarily in response to the ability of insect vectors to increase in abundance, survive, and transmit pathogens to susceptible organisms. In general, temperature thresholds limit the geographic range of vectors; expanding tropical conditions can enlarge geographic ranges of vectors and extend the season of pathogen transmission, given precipitation conditions remain equal (Epstein 2001). A number of vector-borne diseases have expanded their geographic ranges into more northern latitudes along with their relevant vectors (see (Harvell et al. 2009). However,

Warm nights and warm winters favor insect survival (Epstein 2001) and warm winters tend to facilitate overwintering of both vectors and the pathogens they carry. For example, ticks carrying tick-borne encephalitis and Lyme disease have expanded northward and are predicted to expand even further (Ogden et al. 2008), especially when wild birds are included as a potential transport mechanism for ticks. In addition, conditions during heat waves (high temperatures and high humidity) that often challenge human and livestock health are also the conditions that may favor insect vectors, such as mosquitoes (Epstein 2001).

Of particular concern to all sectors (human, agricultural, and wildlife) of health are diseases transmitted by mosquitoes. Dynamic models on the effects of climate change on the global distribution of malaria predicted that climate change will expand the geographic distribution of malaria into North America (Martin and Lefebvre 1995, Rogers and Randolph 2000, Martens, Jetten and Focks 1997).

However, the predictions on the extent of this spread vary considerably (Figure 2), depending on model structure and which climate change models were used. For example, (Rogers and Randolph 2000) predicted that malaria will occur only in the southern portion of the Great Plains region, whereas (Martin and Lefebvre 1995) predicted that, at least under one model, malaria would be more patchily distributed across the entire Great Plains region. Contrary to Epstein (2010, 2001), Lafferty (2009, 2010) argues that there is little evidence that existing climate changes have favored infectious diseases and more recent process-based models suggest range expansions or shifts, but little net increase in actual area because increases in habitat suitability for pathogens and vectors have been offset by decreases in habitat suitability. This is supported by the models developed by Rogers and Randolph (2000) for malaria spread (see Figure 12).

A

B

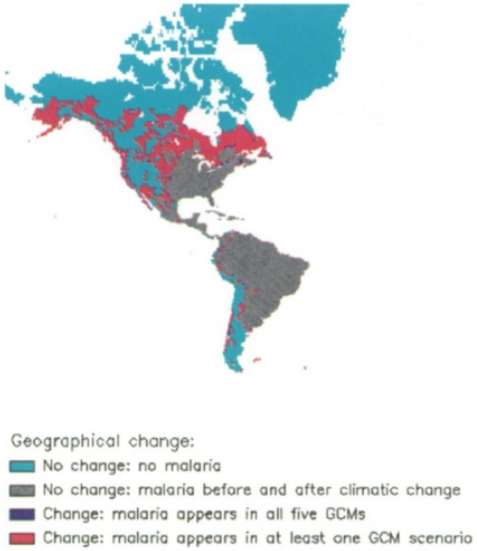


Figure 2. Predictions for spread of malaria in the western hemisphere (including the U.S.) based on models incorporating vector, parasite and climate change attributes. Panel A represents predictions based on a model developed by Rogers and Randolph (2000) where red areas are predicted to be presently suitable but becoming unsuitable by 2050, green areas are presently unsuitable but predicted to become suitable by 2050 and the cross-hatched areas is the current distribution of malaria. Panel B represents predictions based on models incorporating 5 different atmospheric general circulation models from Martin and Lefebvre (1995).

One factor rarely considered in predicting the effect of climate change on disease is the effect of restructuring of ecological communities concomitant with changes in environmental conditions that promote pathogen spread and persistence. If climate change reduces the diversity of wild hosts, then pathogens invading a new area will focus on fewer novel hosts and have the capability to have a larger impact, spread further, and have stronger seasonal effects because the 'dilution effect' of multiple potential hosts will be reduced (Swaddle and Calos 2008, Schmidt and Ostfeld 2001, Johnson and Thieltges 2010, Garrett et al. 2009). Thus, there may be synergistic linkages with climate effects on both biodiversity and disease.

CLIMATE CHANGE AND SEASONAL EFFECTS ON DISEASE

In temperate zones, both temperature and precipitation vary seasonally, which has strong effects on diseases transmission, especially with vector-borne diseases. Since changes in seasonal patterns are expected with climate change, theoretically this should also affect disease transmission, either in a positive or negative fashion (Lafferty 2009). There are a number of hypotheses on how climate change could affect seasonal frequency of disease. For example, vector abundance can increase while staying within the same seasonal time period (hypothesis 1 in Figure 3), extend the season of high abundance (hypothesis 2 in Figure 3), or the season of peak abundance is shifted later in the year (hypothesis 3 in Figure 3). Two of the hypotheses were also further explored by Harvell et al. (2002) in terms of R_0 (basic reproductive ratio of a disease), which defines the number of secondary cases produced by an infected individual in an entirely susceptible population. When $R_0 < 1$, the infection will die out in the long run and when $R_0 > 1$, a pathogen will increase and the infection will be able to spread in a

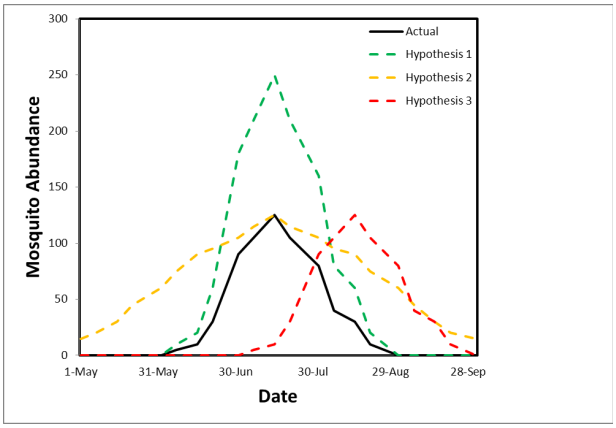


Figure 15. Four schematic hypotheses on the effects of climate change on seasonal *Culex tarsalis* (the mosquito most strongly tied with West Vile virus infections) populations. Actual are actual numbers captured in light traps near Loveland, Colorado.

population. Hypothetically, increases in temperature not only allow the peak value of R_0 to increase, but also lead to an increased annual duration of the period during which the pathogen is a problem (Figure 4).

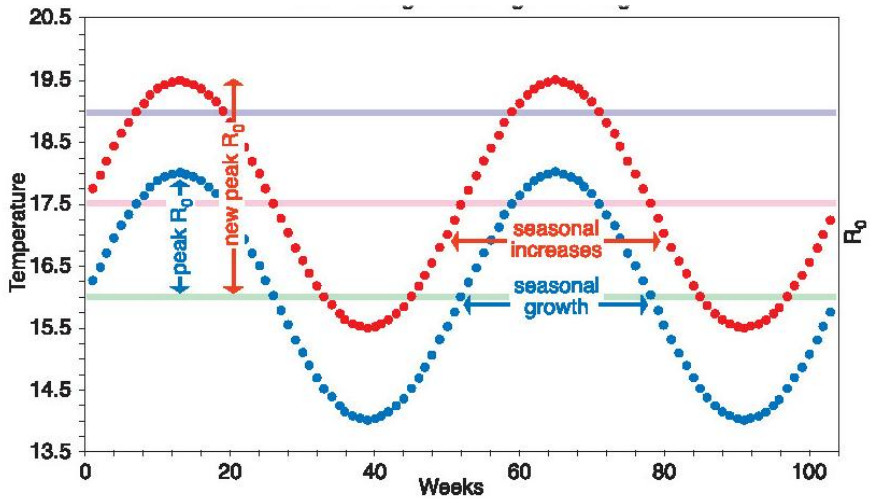


Figure 16. Hypothetical influence of an average 1.5˚ rise in temperature on the basic reproductive number (R_0)of a hypothetical pathogen (from Harvell et al. (1999). The dotted blue line is the average weekly temperature before climate change; the dotted red line illustrates average weekly temperature after an average 1.5 ˚ temperature increase. The lower green line corresponds to R_0 = 1; below this temperature the pathogen declines in abundance. The pathogen increases at temperatures above this, and disease problems become severe when temperature exceeds the pink line and epidemic above the purple line.

CLIMATE CHANGE AND DISEASE OUTBREAKS

While increased warming may encourage changes in geographical distributions of diseases and shifts in seasonal incidence, Epstein (2001) argues that extreme weather events would have the most profound impacts on health issues. However, Pascual and Bouma (2009) point out that variability in infectious disease incidence can be intrinsically cyclic, non-linear and variable in the absence of any relationship with interannual climate variability. Even so, interannual climatic variability has been shown to influence the size of outbreaks for a number of infectious diseases, especially vector borne diseases (Pascual and Bouma 2009).

Although higher than average precipitation levels are usually associated with mosquito outbreaks, drought conditions also can play important roles. Landesman et al. (2007) found that West Nile virus outbreaks in humans in the western U.S. were more strongly associated with below-average precipitation in the preceding year. Through wetland surveys and mesocosm experiments, Chase and Knight (2003) found evidence that elimination of mosquito predators in semi-permanent wetlands during droughts allowed populations of mosquitoes to increase substantially in following years which allowed standing water because mosquito predators were unable to recolonize faster than mosquito production.

Insurance Industry Perspective: Vulnerability, Risk, and Economy

In recent years, the implications of climate change have gained recognition among business leaders worldwide. The insurance and reinsurance sector is no exception, and has a lot at risk from the impacts of climate change. These impacts include such things as sea level rise, melting permafrost, floods, heat waves, and an increase in wildfires, drought, and extreme precipitation events (USGSRP, 2009). Although the scientific community cannot yet prove a definitive link between the planet's warmer climate and individual extreme weather events, the insurance industry has not waited for this causal link to react (Mills, 2009).

As the vanguard of risk management, the insurance industry helps society understand and adapt to emerging and evolving risks. Insurers have channeled this expertise into the field of climate change. They have been utilizing data collection, catastrophic modeling, and risk analysis as a means to track trends, define the risks, and formulate solutions for their industry and society at large (Mills, 2009). Because of this analysis, they have come to view climate change as a significant cost to their industry, which has resulted in changes in insurance underwriting, investments, and lending credit (Innovest, 2007). A lack of action in response to climate change would constitute a threat to the economy and their industry as a whole (Mills, 2009).

The American insurance industry has recently begun to be more engaged in spearheading initiatives and actions on climate change. The National Association of Mutual Insurance Companies (NAMIC) have initiated climate change related action plans and initiatives, and are urging their members to reflect this risk in their policies (NAMIC, 2011). Despite the climate-related products and policies

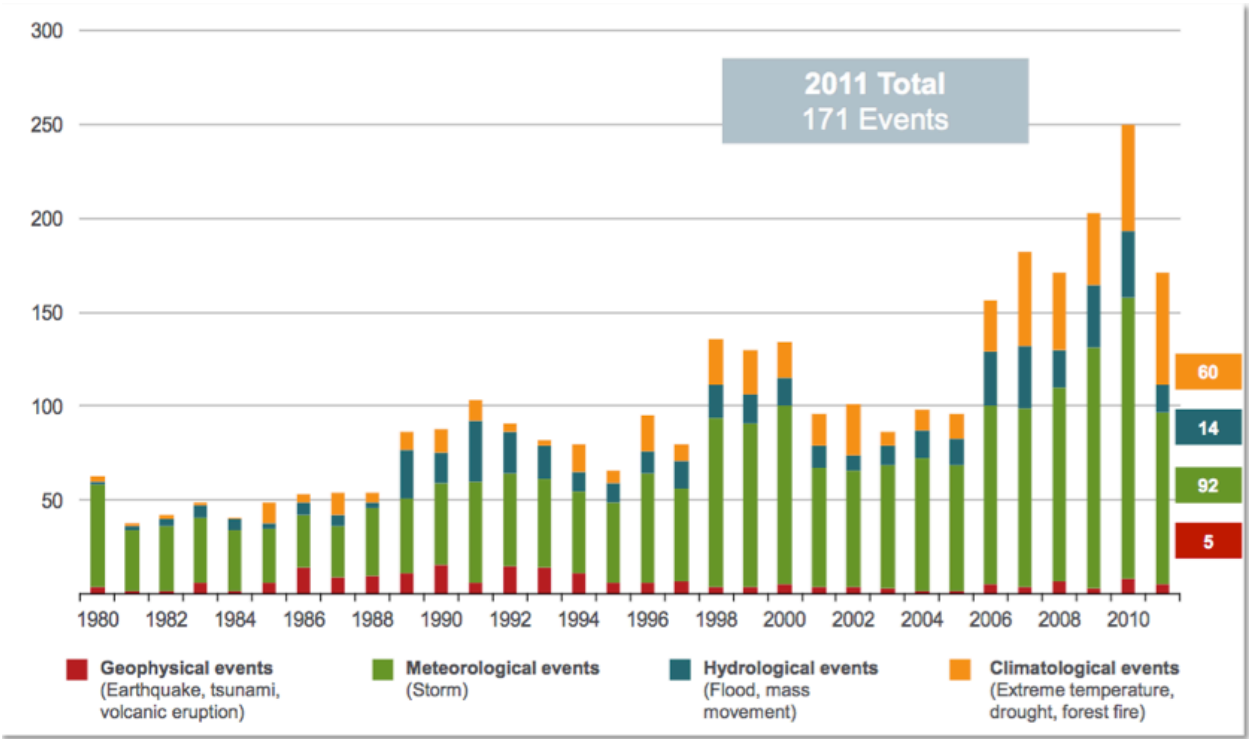
now widely available, many insurers initially focused on financial means for limiting their exposure to losses related to extreme weather events and natural disasters. This included limiting the availability of policies in certain areas, tightening terms, and raising premiums (Mills et al, 2006).

An example of the industry rationale behind these policy losses and premium hikes can be found with Allstate Insurance. Allstate recognizes that there is a relationship between increased extreme weather, catastrophic events, and climate change (Mills, 2009). An insurance company that insures one in every nine vehicles and one in every eight houses in the United States, Allstate concedes that climate change contributes to rising temperatures and changing weather patterns. The company believes that these contributions will impact the frequency and severity of extreme weather occurrences and wildfires. Allstate uses this rationale to justify impacts on the affordability and availability of homeowners insurance in the United States (Allstate, 2008).

As risks associated with extreme weather events have lowered the availability and the affordability of homeowners insurance in high-risk areas, the responsibility has fallen on the shoulders of the federal government. This scenario is best illustrated by the National Flood Insurance Program (NFIP), which is managed by FEMA. The NFIP is a federal subsidy-backed public flood insurance program. It was created in response to a lack of private sector policies for American citizens that live within close proximity to flood plains. Policies are sold by private insurers, but the premiums go directly to FEMA (Drawbaugh, 2011). The NFIP has continually been rendered insolvent by extreme weather events

The NFIP currently is running a deficit of $18 billion and cannot cover its losses without increasing the government's debt burden. In October 2011, the NFIP was renewed through September 2016, which was set to expire in November 2011. This new bill lowers government subsidies for high-risk property owners, while allowing for the insurance industry to raise its premiums in flood areas to reflect the actual risk (Drawbaugh, 2011). Heightened participation by the insurance industry in the NFIP is expected to strengthen land use planning and hazard mitigation through market-based signals on risk and remediation (Nutter, 2011).

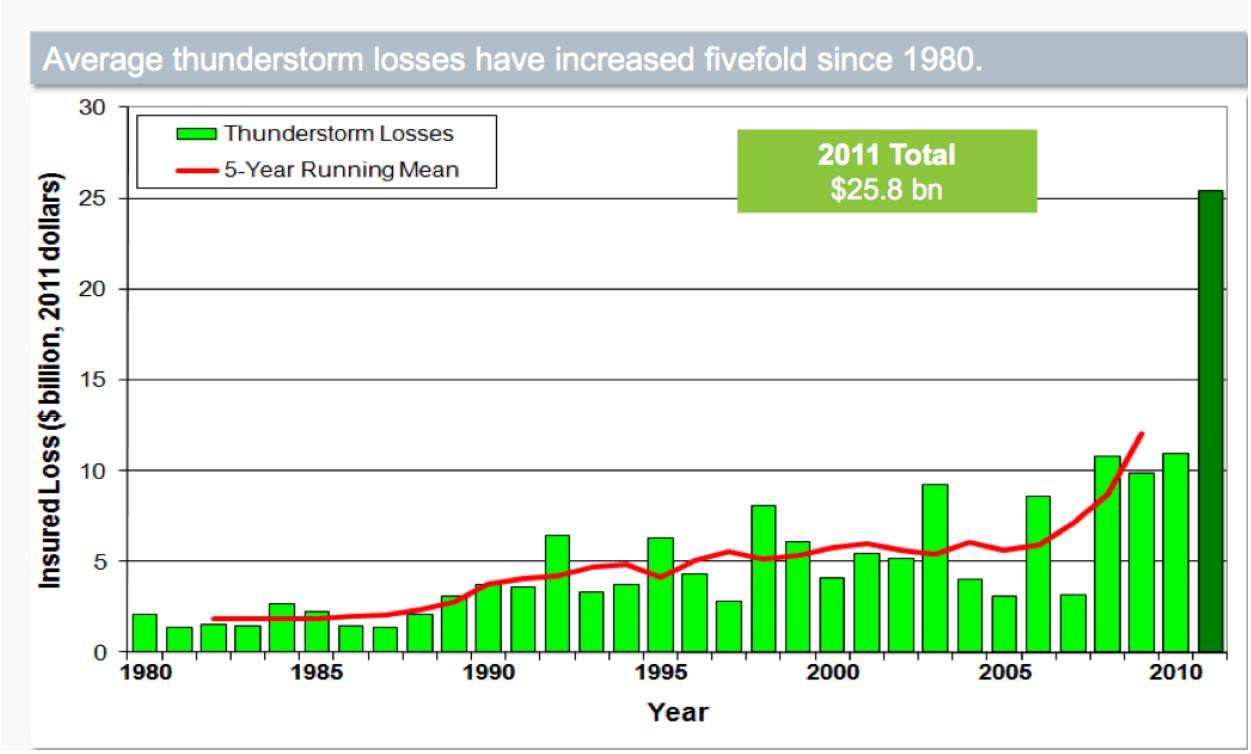
Figure 17: Natural Disasters in the United States, 1980 - 2011. Number of Events, Annual Totals



Source: Munich Re. "2011 Natural Catastrophe Year In Review," *Munich Reinsurance America, Inc* (January 4, 2012) http://www.munichreamerica.com/webinars/2012_01_natcatreview/munichre_iii_2011natcatreview.pdf

Even though 2010 had more total events than 2011, 2011 was more expensive. From **extreme drought**, **heat waves** and **floods** to unprecedented **tornado outbreaks**, **hurricanes**, **wildfires** and **winter storms**, a record 14 weather and climate disasters in 2011 each caused $1 billion or more in damages — and most regrettably, loss of human lives and property, according to the National Oceanic and Atmospheric Administration (NOAA) (NOAA website http://www.noaa.gov/extreme2011/ accessed February 24, 2012) . The Great Plains experienced damages associated with spring flooding along the Missouri and the Souris Rivers in the northern portion of the Great Plains, drought and fire losses in the southern Great Plains, and tornados in the central and southern Great Plains, adding to this total. These occurrences of natural disasters and extreme weather events are consistent with scientific predictions related to climate change.

Thunderstorms, which are common in the Great Plains, are beginning to receive the attention of the



insurance industry as high risks. Figure V illustrates the increase in frequency of thunderstorms throughout the United States. Allstate, the largest publicly traded insurance company in the United States, is predicting an increase in violent thunderstorms, which are known as “non-model catastrophes” (Lehmann, 2011). Allstate views the increase of these non-model catastrophes as permanent changes and understands the need to recover the costs associated with these events (Lehmann, 2011). This permanence will likely be reflected in rate increases for areas affected by thunderstorms. Figure V: United States Thunderstorm Loss Trends – Annual Totals 1980 - 2011

Source: Munich Re. "2011 Natural Catastrophe Year In Review," *Munich Reinsurance America, Inc* (January 4, 2012)

The insurance and reinsurance industries operate their businesses with the perspective that the climate system is in the process of changing due in large part to human emissions of greenhouse gases. The world's largest insurance and reinsurance companies see the risk posed by climate change as one that poses a risk to the sustainability of their bottom line. While the link between climate change and extreme weather events is still being studied by the scientific community, these industries have already adapted their business to the realities and uncertainties associated with these impacts.

Insurance and reinsurance companies are sending a clear market signal as to the economic impacts of climate change. They have changed their risk analyses for extreme weather events and natural disasters to include macroeconomic modeling and catastrophic risk modeling. It is no surprise that this industry works hand in hand with the scientific community reporting on climate change to develop new risk models for trends deviating from historical realities. Their prioritization of the risks associated with climate change signifies that the insurance and reinsurance industries view the escalating impacts of climate change as definitive aspects of the world's future.

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Section 5. Collaborative Research and Management Interactions in Response to Climate Change

Various actions have been carried out during the past several decades in the Great Plains since the legislation of the U.S Global Change Research Act of 1990. These activities included the first Great Plains regional climate assessment carried out during the latter portion of the 1990's which contributed to the first US National Climate Change Assessment (2000), establishment of Regional Integrated Science and Assessment (NOAA/RISA) Centers, National Institute of Global Environmental Change (DOE/NIGEC) which has been restructured as National Institute on Climate Change Research (DOE/NICCR) , and various other activities supported by state, federal NGO, and local entities in support of understanding, communication, and responding to climate change impacts and consequences. Actions across the Great Plains have included mitigation efforts to reduce emissions of greenhouse gases and to sequester more carbon in geologic, soils, and vegetation components of various ecosystems; and more recently, actions dealing with adaptation strategies to cope with climate change in local communities, land and water natural resource management, and infrastructure. Given the scope of these activities and the number of institutions involved, including federal, state, local and non-governmental entities; there has been little effort made to establish a mechanism for systematic, effective communication, coordination, sharing of knowledge and methods, or co-development of new information to inform decision making, management options, and research directions.

This section 5 of the Great Plains Climate Change Assessment Report will categorize activities recently conducted to prepare different sectors and communities for climate change. This will be followed by a summary of methodologies and resources available to further develop responses to climate change. Finally the report will present a framework for greater collaborative and integrative efforts to deal with the impacts and consequences, develop strategies to meet the opportunities and challenges of climate change, and to better monitor and assess the continued climate change impacts in the region.

5.1 Assessment of current climate change response strategies

Research efforts have brought attention to the role ecosystems have on the provisioning of key economic goods, and also in the ecosystem services[1] that sustain, regulate, and support life on Earth

[1] "ecosystem services" are the benefits provided to humans by nature such as, for example, production of goods e.g., food, fiber, water, fuel, genetic resources, pharmaceuticals, etc.; regeneration processes e.g., purification of air and water, seed dispersal and pollination; stabilizing processes e.g., erosion control, moderation of weather

(Costanza et al. 1997, Daily 1997, Daily and Ellison 2002). Terrestrial ecosystems provide a wide array of goods and services upon which human well-being, even survival, depends. Whereas consumptive goods provided by land systems, such as grains, animal protein, and fiber and wood products, are typically valued through well-developed markets, the contributions to society and ecosystem functioning of the 'underpinning' services provided by ecosystems often remain 'invisible' and unvalued (or undervalued). The array of such services is broad, from those services that regulate critical human-environment processes (e.g., climate, disease, flooding, detoxification) to services that support economic activity (e.g., soil formation, primary productivity, nutrient cycling, pest control, pollination).

Understanding effects of land use and management depends on being able to better incorporate ecosystem services into the decision making process. In addition, evaluating changes in the state of ecosystem services (i.e., maintaining soil fertility, supplying water resources, and food and fiber production) is critical to development of appropriate coping or adaptive strategies under different human-environment stresses. Some impacts may present only temporary disruptions, but in some cases, such as plowing out grasslands, conversion of Conservation Reserve Program (CRP) lands, or introduction of novel species for bioenergy production, they could push ecosystems to critical thresholds (meaning a point at which a transition to a less desirable or less productive state could occur). Such system dynamics are indicative of complex adaptive systems[2] and therefore are not easily managed to meet the complexity of human-environmental systems. An optimal management approach may in fact be counterproductive to developing a more robust adaptive management approach that recognizes the existence of transitioning landscapes (e.g., shrub invasion of grasslands) and the importance of change as a basic component of the system dynamic (Berkes and Folke 1999; Gunderson and Holling 2002; Walker and Meyers 2004; Tschakert et al. 2007).

Available case studies provide a wealth of data on the social, biological, and physical components of coupled human-environment systems. Data from these intensive case studies will enable us to evaluate conditions determining the vulnerability or resilience of these systems to different scenarios of social and environmental conditions. Characterizing and determining ecological thresholds are challenging to resource managers and to society due to the sudden and often irreversible nature of the changes in ecosystem services and the new conditions that emerge (Hobbs et al. 2006). Socio-

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extremes; life-fulfilling functions e.g., aesthetic beauty, cultural value; and conservation of options e.g., maintenance of ecological systems for the future http://www.resalliance.org/index.php/glossary#T

[2] Systems of people and nature in which complexity emerges from a small set of critical processes which create and maintain the self-organizing properties of the system http://www.resalliance.org/index.php/glossary#C.

ecological thresholds due to environmental and socio-economic drivers are being triggered in many semi-arid systems around the globe. Basic understanding of where and when a threshold will be crossed is still unclear (Julius et al., 2008), however, the inherent sensitivity of the semi-arid system to climate variability and land use changes have been documented (Ojima et al, 1993, Parton et al 1994, Archer et al 2001, Reynolds et al 2001). The fragmentation of landscapes and the discontinuity of landscape processes also contribute to ecosystem and biodiversity vulnerability in ways which contribute to triggering social-ecological thresholds (Lackett and Galvin, scale 2009).

Observations Monitoring

Forecasting technologies have advanced which incorporate field observations, remote sensing, and modeling systems to provide seasonal forecasts of crop and ecosystem productivity. Monitoring of key climate characteristics, combined with improved forecasting, related to temperature maxima or minima, seasonality of precipitation patterns, and interactions among climate characteristics will provide greater forewarning of impending critical thresholds in currently healthy and functioning ecosystems. In addition, observations of ecosystem indicators associated with biotic assemblages (e.g., host-pest relationships), ecosystem functions (e.g., water use efficiency, nutrient cycling, and carbon assimilation), and structural changes (e.g., woody to herbaceous ratio, bare soil exposure) can provide clues to emerging dangerous thresholds. A number of ecosystem services can also be monitored to assess the impacts of change to society and vice versa.

Critical to knowledge about ecological thresholds is an integrative, prognostic capability to better utilize a suite of observations to derive an ecological forecast that estimates the probability of a threshold being crossed in one or more ecosystem processes (Walker and Meyers 2004; Hobbs et al. 2006; Lyytimäki and Hildén 2007). Complex multi-dimensionality of ecological thresholds can be resolved through the use of integrative modeling and analytical approaches. Development of a threshold prognostic or ecological forecasting tool to evaluate probabilities of achieving a threshold event would be extremely helpful in managing natural resources and developing adaptive management strategies to maintain ecosystem services.

Social-ecological vulnerabilities can be assessed using various approaches (Adger et al., 2001, Moss et al., 2000; Turner et al. 2003 (Ford et al. 2010, Adger et al. 2007, Adger et al. 2004, Fussel and Klein 2006, Smit and Wandel 2006). Some approaches provide a framework to correlate social outcomes, such as poverty reduction, against measures of capital assets or other measure of available resources (Eriksen and O'Brien 2007, Eriksen et al. 2007). Other approaches analyze societal needs, such

as food availability, water access, health care, etc, in the context of various stresses such as commodity price volatility or climate variability (Lal, Alavalapati and Mercer 2011, Luers 2005, Thomas and Twyman 2005). Such approaches allow for better integration of environmental and societal metrics and variables to evaluate social-ecological vulnerability. The choice of coping strategies are determined by the capital resource assets (i.e., natural, human, social, financial, and built capital) available to different community members in a particular location and time(IISD, IUCN and SEI 2003). Decisions are based on multiple criteria related to various cultural worldviews, economic and other values, and societal goals for various communities (Etkin and Ho 2007). Regional and local decisions to cope with stress and to overcome vulnerable conditions will reduce the impacts of these stresses and make decisions that will benefit some and affect others differentially (Adger, Arnell and Tompkins 2005, Dolan and Walker 2006).

Adaptation and Mitigation Strategies

Climate change adaptation in human societies requires both responding to climate stimuli such as recent events in the Great Plains associated with extreme weather events and droughts, but perhaps more importantly at this point in time, through anticipating and planning for potential changes (Smit et al. 2000) especially where early warning signs are present (Glantz 1988). Adaptation here refers to a fundamental, systemic change in response to environmental conditions, change through adjustment that maintains or strengthens the viability of the system (Smithers and Smit 1997). Climate change adaptation of the social-ecological systems need to operate across various scales from local to global, and requires the proper functioning of social, ecological and institutional systems. Thus, *sustainable adaptation* emphasizes strategic, collective action to respond to or anticipate harmful climate change to reduce disruption to *key resource flows* and adverse effects on general human and ecosystems *well-being*; in other words, the ability of the natural environment to meet current needs and also continue to provide ecosystem services for future generations (McNeeley 2011, O'Brien and Leichenko 2008, Eriksen and O'Brien 2007, Eriksen and Brown 2011, Eriksen 2011).

Adaptive capacity is constrained by factors that restricts peoples' reservoir of options from which to choose when environmental (and social) conditions change (Berkes and Folke 1998, Gunderson and Holling 2002). Adaptive mechanisms operating at the community level are often constrained by institutional hierarchies determining in part how adaptation to climate change manifests through the policy processes (Adger and Kelly 1999). Institutional responses to climate change are often best suited for mitigation of emergency situations and isolated events rather than to slower onset, cumulative or systemic climate related problems leading to disruption of ecosystem services. Institutional and

regulatory entities are even less well-suited to working with underlying social factors that determine vulnerability (Handmer et al. 1999). Where institutional rule-making occurs in a compartmentalized and fragmented framework, responses to climate change have been either nonexistent in the worst case, or case-based mitigation in the best case (McNeeley 2011).

The ability to respond to environmental change vulnerability and risks is typically determined by a series of livelihood decisions that depend on the household assets endowments and the allocation of these assets to generate benefits and well-being (Kelly and Adger 2000, Barrett, Reardon and Webb 2001). Adaptation actions are choices within a "response space" (See Figure 1 below) that includes coping but also longer-term adaptation actions, and define success as those actions which promote system resilience, promote legitimate institutional change, and hence generate and sustain collective action (Osbahr et al. 2010). Decisions, in reality, are constrained by the wider economy and political milieu, as well as by prior decisions that partly lock people into particular livelihood pathways; and actions are driven by objectives such as income diversification, risk minimization, and capital accumulation (Allison and Hobbs 2004, Lorenz 2010). Decisions are also informed by people's worldviews and the cultural values they hold, which also inform their perceptions of how the natural world (including climate) functions over time (Douglas and Wildavsky 1982, Thompson, Ellis and Wildavsky 1990, Verweij et al. 2006). Adger et al 2009 assert that adaptation has social limitations yet does not have to be limited by uncertainty of future risks (Adger, Eakin and Winkels 2009). In that case, what are the opportunities for adapting natural resource management and livelihood strategies for climate change in the Great Plains region?

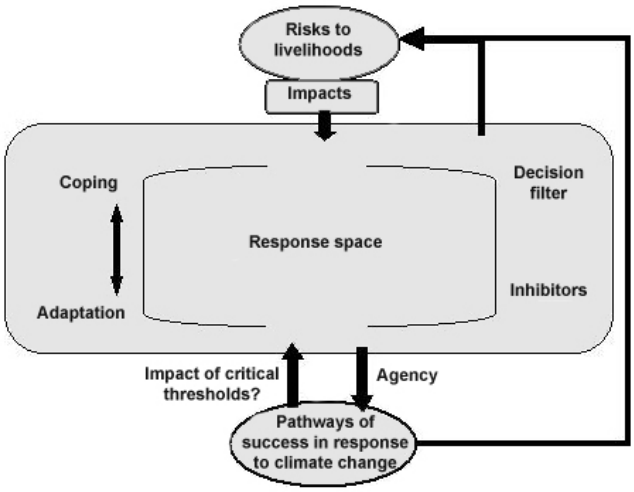


Fig. 1 Conceptual Model for the "response space" of adaptations (Osbahr et al. 2010)

5.2 Approaches to Enhance Great Plains Climate Change Research and Adaptation

Land use and other resource decision-making processes provide a foundation for evaluating factors that influence human activities and their effects on ecosystem services. The relationships of the coupled human-environment system can be defined through the nexus of the decision making process and delivery of ecosystem services. The environmental context of the system can be determined by the state of ecosystem services and the reliance of the decision maker on these services. Instability in the system may arise when unforeseen loss of an ecosystem service occurs, such loss of as soil stability and vegetative cover during a drought resulting in a massive dust storm (as in the 1930s Dust Bowl), or lack of water flow leading to desertification or diminishing stream flow (e.g., Rio Grande River not always reaching the Gulf). The effect on the coupled human-environment system may seem to appear rapidly, although the underlying changes have been occurring over time (i.e., "creeping environmental problems"), undetected until a critical threshold had been met (Glantz 1999, Smit and Wandel 2006).

From the rich literature on developing and implementing climate adaptation we can identify a small set of common principles (Willows and Connell 2003; Hansen and Hoffman 2010; Halofsky et al. 2011; Mawdawsky 2011). A first principle is that the scope and scale of climate impacts and adaptation typically requires considering issues expressed at multiple scales of space, time, and complexity. These issues must be addressed by decisions that occur in very different ecological, economic, social, and organizational contexts. To do so, it is usually necessary to involve communities and decision-makers at multiple scales appropriate to addressing changes in the social-ecological system. A diverse community of participants facilitates identification of the full range of issues and potential policy and management decisions (Joyce et al 2009, Robinson and Berkes 2011, Adger et al 2011). This integrative approach incorporates uncertainty and risk assessments, links modeling analyses and decision making at appropriate spatial and temporal scales, and provides a mechanism for sharing resources and knowledge across affected communities and planners (Joyce et al 2009, Ojima and Corell 2010). It explicitly recognizes that impacts of climate change cross jurisdictional and disciplinary boundaries, and that effective partnerships is essential for addressing climate change.

Elements common to climate adaptation planning processes are illustrated in Figure 2 (adapted from NPS 2010). This climate adaptation framework incorporates elements common to more traditional adaptive management (e.g., Holling 1978; Williams et al. 2007), and is useful to identify an integrated set of activities that, in aggregate, lead to effective climate adaptation. While the framework presents

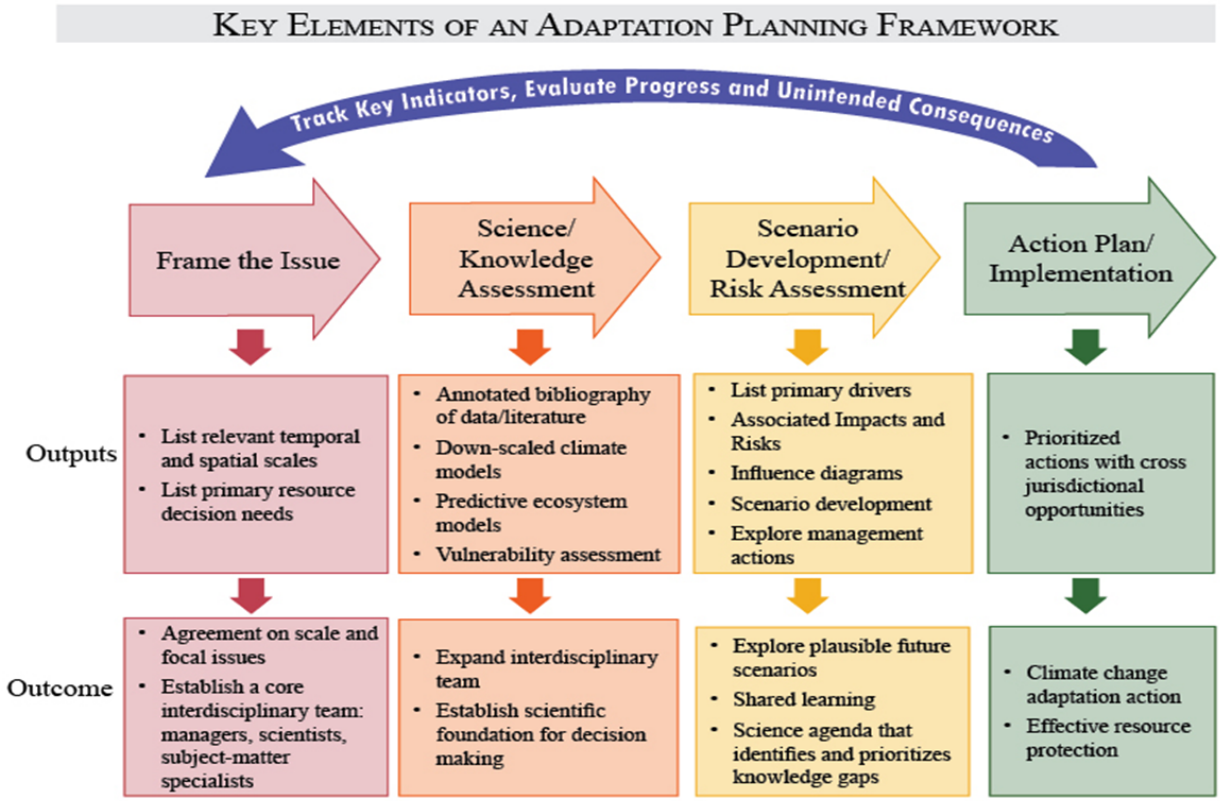
these activities in a logical order, in most cases specific activities will occur when the opportunity presents itself, rather than in the linear order suggested by Figure 2. This framework articulates key steps that apply generally to decisions under high uncertainty, and specifically to decisions under rapid climate change.

The first steps in "Framing the Issue" focus on identifying specific concerns and issues the community faces within the prescribed social, ecological, and scale-dependent context (Ojima and Corell 2010; (Smit and Wandel 2006). Appropriate scales of analysis in space and time can be identified with assistance from the stakeholder community and incorporating local knowledge and observations. The time scale of analysis needs to be matched to issues that respond at different scales, such as forage growth and livestock production, filling of reservoirs and other hydrological responses, vegetation recovery or transition, or other climate triggers that affect maintenance of infrastructure or delivery of ecosystem services. This phase of the adaptation planning process emphasizes key resources and values.

Assessments are logically conducted once the scale and scope of the issues have been articulated (Figure 2). An assessment can focus on a specific geographical unit, sector, or domains defined by key resources. The Badlands National Park vulnerability assessment includes the park and surrounding landscape necessary to support biodiversity and other processes (Hansen et al. 2011; Drazkowski et al. 2012). This assessment is unusual in that it includes species, habitats, selected infrastructure, and cultural resources. Other Great Plains assessments addressed key species (Zack et al. 2010), crops (Weiss et al. 2003), fish (Perkin et al. 2010), water (Stone et al. 2003), or other sectors. River basins often define relevant social, economic, and ecological units, and northern Great Plains river basins are the focus of an ongoing assessment that involves climate model downscaling, runoff modeling, and an assessment of ecological consequences (Skagen and Melcher 2011).

Vulnerability assessments and other activities in the second column of Figure 2 focus on synthesizing and evaluating information that helps identify resources at risk, why they are at risk, and the information that guides these evaluations. While these processes inform decision, other steps and activities are necessary to identify potential management or policy actions, and select or rank alternative decisions and actions.

Activities in the third column of Figure 2 focus on identifying and ranking potential actions and decisions. A variety of methods can be used in this process, and scenario development (as identified in Figure 2) is only one of the alternatives (Willows and Connell 2003; Peterson et al. 2003; Williams et al. 2007; Nichols et al. 2011). While existing processes will contribute to risk



1Figure 2 Conceptual framework for collaborative adaptation planning (modified from NPS 2010).

assessments and decisions on climate adaptation, considerable work is needed in this area to address the different ways of knowing and understanding risk and uncertainty (Renn, Klinke and van Asselt 2011, Whitmarsh 2011, Pidgeon and Fischhoff 2011, Eakin and Patt 2011).

The final step is to design and implement adaptation plans that address changes in climate and effects on the socio-environmental system. In almost all cases, will be a recursive or iterative in process (Fussel 2007, Dessai, Lu and Risbey 2005, Wilby et al. 2009, Preston, Westaway and Yuen 2011). Any (or all) step(s) in the planning process may need to be be revisited as information accumulates and priorities change (Jones and Preston 2011) .

Knowledge of threshold changes in the socio-environmental system is difficult to predict, and policy or decision makers may not always be able to anticipate all impacts (Lyytimäki and Hildén 2007). Effectiveness of selected actions is highly dependent on institutional setting and level of engagement by institutions in the planning and implementation processes (Lyytimäki and Hildén 2007). Development of strategies and analysis of thresholds are only effective if there is an appropriate set of agents or institutions to take appropriate actions; without this, collapse is most likely.

========== BEGIN - Breakout Box on Scenario Applications ==========

Scenario Applications: Using Scenarios to Explore Assumptions and Test Management Alternatives as Conditions Change

Scenarios are plausible, internally consistent stories about the future that challenge us to consider how we would operate under novel conditions. Scenario thinking is a structured process by which groups can organize perceptions, assumptions, and complex data about how the future may evolve over time into sets of scenarios, which they can then use to explore unknowns; test strategies; generate new ideas; improve organizational flexibility; or inform decision making in situations of risk, uncontrollability, complexity, and uncertainty.

The U.S. National Park Service (NPS) and partners are using multivariate climate change impact scenarios to address future risk and uncertainty in resource management. The NPS develops scenarios through a participatory process that integrates quantitative, model-driven data about climate change with qualitative and practical information about how environmental impacts and future socioeconomic conditions could interact and affect park resources and operations. The resulting multivariate, management-relevant scenarios allow resource managers to explore and understand the range of potential future environmental, social, and economic conditions, and to develop flexible management actions and strategies in spite of uncontrollable and irreducible uncertainties.

In its initial application, scenario development and application in the NPS has proven successful at fostering rich interactions between climate scientists and decision-makers; broadening decision-makers perceptions of potential climate impacts; inspiring robust management actions and strategies; and identifying inefficient or counterproductive management policies and actions.

The NPS is continuing to develop and refine methods for applying scenarios to management questions, but the scenario planning techniques developed to date are already being incorporated into the NPS planning framework, and are helping to evolve that framework to support adaptive management. Moreover, NPS staffs are using the compelling place-based narratives generated during the scenario process to communicate climate change information with a variety of audiences, from NPS scientists and facility managers to park visitors, stakeholders, and the general public.

Case Example: Wind Cave National Park

In 2009, NPS conducted a scenario-thinking project that focused on Wind Cave National Park in South Dakota. Researchers and resource managers used downscaled regional climate projections, published information on potential climate change impacts in the Midwest, and national socioeconomic trends to develop a set of four, park-scale, multivariate climate change impact scenarios.

Park managers and researchers used these scenarios to identify threats to park resources and operations, areas for additional research, and opportunities to foster resiliency in park resources, operations, and infrastructure. Specifically, managers discussed potential threats to park resources and

operations such as water resource shortages and archeological resource exposures; areas for additional research, such as climate change effects on cave environments or climate induced changes to visitation; and opportunities for strategic capacity building, such as integrated research and monitoring partnerships with local universities, agencies, and volunteer groups.

========== END – Breakout box on Scenario applications ==========

Impact studies and climate analysis (monitoring of social-ecological systems, synthesis studies, threshold analysis)

Effectively addressing climate change and its effects on ecosystems, resources, and society will require coordination in the research and observation capabilities of multiple organizations, institutions, and government programs. Many organizations have ongoing monitoring and evaluation programs relevant to detecting and responding to climate-driven changes (Table 5.Monitoring). A key issue is that each agency has developed monitoring systems with a specific mission orientation which have not always had climate change effects in mind. Now that efforts are moving forward to organize observations to specifically address climate change , it is critical to evaluate the manner in these observing systems provide information and to seek synergies among the various efforts to develop a comprehensive system of observations and assessments. Figure 3 illustrates one existing example of a functional, integrated system consisting of multiple observing, modeling, and evaluation components that addresses the societal need to assess sources and fluxes in CO2 and other carbon pools.

Table 1.Monitoring. Examples of existing Federal programs that monitor and evaluate Great Plains resources and processes relevant to assessment of climate changes and vulnerabilities. (JEG – it looks like this table is supposed to support Figure 3IntegPrgms. It does not currently do so).

Organization & Program	Relevant Foci	Reference
U.S. Department of Agriculture		
SNoTel	Snow and water monitoring.	http://www.wcc.nrcs.usda.gov/snow/
Animal and Plant Health Inspection Service (APHIS)	Pests, diseases surveys and monitoring.	http://www.aphis.usda.gov/
Natural Resources Inventory (NRI)	Land use, land cover, erosion, wetlands.	http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri
Forest Inventory and Analysis (FIA)	Forest extent, composition, condition, invasive species	http://www.fia.fs.fed.us/
Agricultural Statistics Service	Crops, demographics, livestock, economics	http://www.nass.usda.gov/index.asp
U.S. Department of the Interior		
National Water-Quality Assessment Program (NAWQA)	Monitoring and assessment of ground and surface water composition, attributes, and quality.	http://water.usgs.gov/nawqa/
National Water Information System	Real-time and historical flows, levels, meteorological data, and associated attributes of surface and subsurface waters	http://waterdata.usgs.gov/nwis

Inventory and Monitoring Program	Key indicators of natural resources in national park units	http://science.nature.nps.gov/im/
Environmental Protection Agency		
Climate change indicators	Greenhouse gases, climate indicators, ecosystem responses	http://www.epa.gov/climatechange/indicators.html
National Oceanic and Atmospheric Administration		
National Weather Service	Local to global weather, hydrology, storms, and other hazards	http://www.nws.noaa.gov/
National Integrated Drought Information System	Information on historical, current, and emerging drought	http://www.drought.gov
MultiAgency		
National Land Cover Data	National land cover trends (MRLC)	http://www.mrlc.gov/
National Atmospheric Deposition Program (NADP)	Atmospheric composition, deposition.	http://nadp.sws.uiuc.edu/

++++++++++box ON INTEGRATED SCHEMA FOR BIOGEOCHEMICAL OBSERVATIONS+++++++++++++

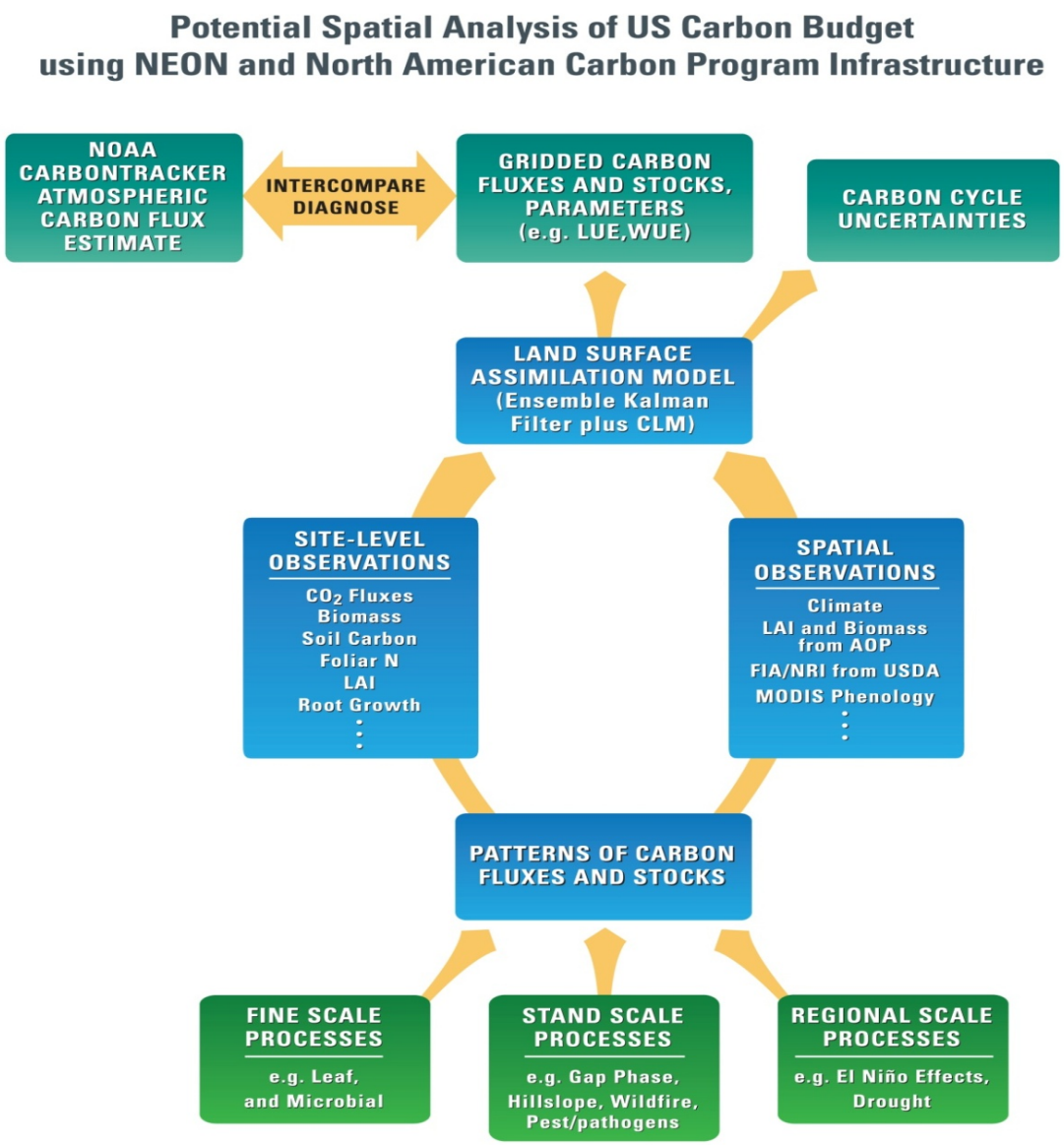


Figure 3. A conceptual analysis and forecast of the U.S. ecosystem carbon budget derived from multiscale observations and an integrated carbon assimilation model. LUE = Light use efficiency, WUE = water use efficiency, CLM = the NCAR Community Land Model (Bonan et al., 2002), LAI = leaf area index, FIA = Forest Inventory and Analysis of the USDA, NRI = Natural Resources Inventory of the USDA, MODIS = the Moderate Resolution Imaging Spectroradiometer satellite instrument, Foliar N = foliar nitrogen. CarbonTracker is a NOAA tool that estimates carbon fluxes from atmospheric CO2 measurements and related meteorology (Source: NEON Observatory Design, 2009).

An important feature of the ecosystem carbon models is that they can be compared to the time varying concentrations of atmospheric carbon dioxide as a means toward model validation (Carbon Tracker). This comparison requires bridging across time scales of model response where measurable atmospheric variations occur on much shorter time scales (seconds to days) as opposed to measurable

ecosystem fluxes and stock changes (hours to decades). Even with this timescale mismatch, the atmospheric constraints provide an important test for ecosystem model predictions.

+++++box on research – management dialogue and participant engagement++++

Case Study: Scientists and Managers Working Together to Find Solutions for our National Grasslands

Recent efforts to engage a more effective dialogue between resource managers and researchers have taken place around the country, including the Great Plains. One such effort was recently conducted by the US Forest Service, through coordination efforts of the Rocky Mountain Research Station and the Rocky Mountain Region of the Forest Service, and include researchers from the Agricultural Research Service, Forest Service, and academic institutions. This effort initiated a sharing of knowledge among Great Plains scientists and managers on the topic of climate change by hosting two events: a day-long webinar on the science findings and a follow-up workshop via video teleconference with a group of invited managers and scientists to discuss issues critical to managers and potential decision-support tools.

Webinar and Workshop

The webinar was a great way to engage managers and scientists from across the Great Plains with a common interest in the future of the region's grasslands. Experts on climate change effects applicable to Great Plains grasslands presented research findings. Participants represented a broad range of affiliations from federal and state agencies to non-profit organizations, universities, and private consulting firms. Recordings of the presentations are available at http://www.fs.fed.us/rm/grassland-shrubland-desert/events/climate-change-webinar.

The goal of the follow-up workshop was to identify products or tools needed to assist managers to promote sustainability of national grasslands in the face of climate variability and change. National Grassland managers were particularly interested in presentations that gave specific guidance or suggestions for management (e.g, types of vulnerability assessments, technology applications) or that predicted outcomes of complex interactions (e.g, plague and prairie dogs, vegetation shifts, demographics). Talks on vulnerability and risk assessments were highlighted by a number of participants who requested assessments covering almost every topic, but also as integrated assessments that

consider multiple sectors simultaneously. Participants noted topics of interest that were not covered. One was the inclusion of a more global perspective on climate change, including how global change may affect local issues and vice versa, and what lessons could be learned from international efforts. Another was more detailed projections for water, including changes to aquifers and effects on aquatic species. Along with needs and priorities, workshop participants shared barriers to effective integration of climate change into decisions. These included:

- Uncertain and limited funding
- Lack of knowledge on how to manage grasslands for resilience
- Lack of guidance on how to apply projected climate change effects to management decisions
- Inertia and resistance to shifting from old management strategies
- Politics distracting from integration of climate change into programs
- Different land ownerships and policies on adjacent lands
- How to accommodate variability, extreme events, and uncertainty in management decisions
- Large number of existing stressors in a highly fragmented landscape with many species in decline

Solutions

Both scientists and managers suggested solutions or products that could reduce management barriers and improve climate change response. The reinforcement of partnerships was a common theme that was promoted through the workshop. Managers noted the need for a centralized mechanism to communicate current and ongoing research projects in the region. Products that promote education and awareness of local climate change issues, including additional webinars and workshops, were seen as critical to engage stakeholders and inspire action. Climate change can also present opportunity as, for example, carbon sequestration can be a driver for implementing grassland restoration projects. Others suggested more specific measures, such as implementing changes in breeds or species of grazers to cope with changes in forage productivity or composition. New technologies can be integrated into management such as the transmission of real-time remote-sensing data through wireless devices to better inform day-to-day management decisions or use of social networking to bring together stakeholders.

Lessons for Scientists

Publishing research findings in scientific journals and presenting at conferences primarily attended by colleagues will not adequately disseminate information to managers. Consultation with managers during the study design phase can improve the utility of research findings to on-the-ground actions. Finally, National Grasslands provide opportunity for climate change studies.

Lessons for Managers

Although preparing for climate change may seem daunting, managers can start with current management strategies that are applicable to climate change issues such as reducing potential for soil erosion and protecting riparian corridors. Scientists are eager to help managers and see their research applied, but are often hesitant to extrapolate findings to make specific management recommendations. Managers need to discuss options and include input from scientists during planning phases. Managers also need to be aware of the limitations of individual studies or assessments and how that affects their applicability to local issues.

Next Steps

The workshop and webinar served as a catalyst for creating a productive partnership that uses a science-based approach to incorporating climate change into land management. Finding climate change solutions and encouraging dialogue among scientists, managers, and stakeholders requires an ongoing effort. Having created momentum through the workshop and a core group of participants, we must continue to engage and update participants on research proposals, science findings, and products relevant to the Great Plains grasslands.

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CASE STUDY National Park Service Climate Adaptation Activities and Needs Workshop

The National Park Service (NPS) recognizes that gaps in climate literacy of staff and stakeholders is a significant limitation to identifying and implementing climate adaptation actions. Workshops with presentations by local, regional and national managers and scientists have been held to provide general information, facilitate relationships within and between organizations, and help motivate actions focused on specific locations. Two recent examples, from areas with very different resources and circumstances, clearly illustrate the need for these workshops, and serve to identify ongoing activities that will likely be necessary to make more rapid and efficient progress toward climate adaptation.

Case 1: Rocky Mountain National Park (ROMO) and the surrounding Arapahoe, Roosevelt, and Routt National Forests are located in northern Colorado, close to more than 1 million people, four major research universities, and a plethora of research agencies. These areas receive intense recreational use and have been the focus of many short- and long-term studies. There is a wealth of local scientific expertise and knowledge. In addition, considerable effort has been directed to establish and maintain working relationships between the federal, state, county, and local municipalities and organizations. Drawing on the reservoir of talent and infrastructure, a climate adaptation workshop held in NovemberJuly 20101 presented information on climate adaptation, facilitated interactions among participants, and identified and documented priorities and opportunities for better multi-agency coordination and collaboration (Thompson et al. 2011; https://sites.google.com/site/climatechangeadaptationnoco/). Workshop participants generally knew (or knew about) each other, but an additional effort would be required to organize and coordinate the multi-agency and multi-disciplinary groups and activities that would best address broad-scale climate adaptation needs. The 2010 workshop was very well attended, it received high praise, and it generated excitement and enthusiasm. More than a year has passed since the workshop without identifiable follow-on events. Participants would surely agree that the workshop increased literacy and knowledge, but the follow-on activites needed to sustain momentum and enthusiasm have not occurred.

Case 2: Black Hills and surrounding parks, forests, and grasslands. More than 90 participants from the Great Plains areas attended a workshop in April, 2011 in Rapid City, SD (Thompson et al. 2011; https://sites.google.com/site/bordercrossingworkshop/executive-summary-of-the-workshop-outcomes). The workshop included presentations and group activities that facilitated learning, identified climate related priorities, and follow-on actions. In comparison to ROMO, Rapid City is isolated, close to a small population, has access to few local climate experts, and is the focus of a far less intense research effort. But a year after the workshop, the long-term results are similar. Participants clearly gained a better understanding of climate issues, but further engagement is needed to sustain action.

These results emphasize a key issue: land management staff, generally, do not have the time or resources to organize and sustain the broad-scale, multi-agency, multi-disciplinary efforts that best facilitate climate adaptation. There is a key need for help to establish and sustain community-level activities. The goal needs to be to empower local residents and organizations, and to provide specific expertise where needed. Help is needed to organize meetings, facilitate activities, and to expand the geographical and disciplinary scope of work that is necessary to identify, implement, and sustain climate

adaptation. The NPS and other organizations are conducting activities focussed on parks or other units, and these activites usefully contribute to broader-scale efforts. But staff at specific units do not have the resources, and often the authority, to organize and motivate broader mulit-stakeholder communities.

Case 3. Eastern New Mexico Carbon Sequestration. A small group of northeastern New Mexico ranchers, working in collaboration with the National Carbon Offset Coalition, banded together to apply to the Chicago Climate Exchange (CCX) for a rangeland carbon offset project. CCX has published protocols for the organization, implementation and verification of rangeland carbon offset projects. The ranchers, with technical support from USDA-NRCS, ARS-Jornada Experimental Range, the Department of Energy Southwest Regional Carbon Sequestration Project and New Mexico State University provided baseline information, 5 year management plans and monitoring schemes to meet the protocol requirements. The focus of the project was proper livestock grazing management (stocking rate, distribution and season of use) to maintain net primary productivity within the herbaceous component of plant communities, provide adequate fine fuel to allow for strategic burning to reduce shrub cover and to minimize losses of soil carbon during drought periods. Although the prices for greenhouse gas mitigation activities have been at historic lows over the life of the project, the ranchers involved have received annual payments (see de Steiguer et al 2008 for a description of the project).

More Examples of adaptation in the Great Plains

In the agricultural sector farmers are experimenting with various conservation strategies to adapt and cope with climate variability and change. Some of these include: conservation tillage systems and methods to retain soil organic matter to limit erosion and increase water retention capacity (Knutson 2008a). Another transition many farmers are making is switching from flood irrigation to sprinkler systems to conserve water. However, in some surface irrigated basins this has the unintended consequence of limiting return flows that are important to both the riparian ecosystem as well as downstream users. As part of the Environmental Quality Incentives Program (EQIP) in Nebraska the National Resources Conservation Program (NRCS) has a special initiative in the water-stressed Pumpkin Creek watershed where farmers are offered financial incentives to transition from irrigated cropland to dryland (Knutson 2008a). This program has helped reduce pumping from groundwater to restore the watershed, groundwater to restore the watershed, and it is helping the watershed residents to proactively adapt to a dryer future rather than having to cope a transition toward rainfed agriculture

under crisis conditions (Pope 2007). Livestock producers in the Great Plains are also experimenting with new strategies such as rotational grazing where cattle are rotated to smaller pastures to allow for grass regeneration (Knutson 2008a).

The USDA Natural Resources Conservation Service administers a variety of conservation cost-share and technical assistance programs that could be refined and redirected to more effectively cope with climate change. From 2005-2009, NRCS rangeland-based conservation programs provided almost $130 million to private landowners and public land managers to improve management in 6 central U.S. states (KS, NE, ND, OK, SD and TX) which compose the majority of the Great Plains (Tanaka et al 2011). The application of defined conservation practices such as Brush Management, Prescribed Grazing, Range Planting, Riparian Buffers and Wildlife Habitat Management affected management on more than 30 million acres in those same states over the same period. In addition to the cost-share funds provided, significant amounts of technical assistance resources were applied to support the proper application of mechanical and management technologies. Although there were likely significant benefits derived from the application of these practices (Briske et al 2011), climate change mitigation and/or adaptation were not explicitly considered in program design. Similarly, there is a relatively poor quantification of the impacts of existing conservation programs on climate change response (Bestelmeyer et al 2011). Including the results of climate change analysis and projections to improve landowner's ability to respond could dramatically improve the effectiveness of these and similar programs. In addition, integrating ongoing programs and research at large spatial scales could greatly improve the cost-effectiveness of public funds (Briske and Thurow 2008).

On the western edge of the Great Plains, Denver Water has implemented a host of innovative strategies for drought planning, climate change adaptation, and conservation strategies http://www.denverwater.org/SupplyPlanning/DroughtInformation/UncertainFuture/. This includes an Integrated Resource Plan initiated in 2008 to guide efforts for the next 40 years. In addition, they are also negotiating a historic collaborative water sharing agreement -"Colorado River Cooperative Agreement: Path to a Secure Water Future" - with a number of Colorado West Slope entities to ensure sustainable water resources into the uncertain future. This visionary agreement proposes three main areas to move forward from conflict to adaptive collaboration: 1) Resolution of historic conflicts and a holistic approach to resolving Colorado water disputes; 2) Cooperative, long-term efforts to improve the health of the Colorado River mainstem and its tributaries; 3) Additional water supply for those who live, work and play on the west slope and for customers of Denver Water.

Innovative inter-state watershed alliances are also developing to address long-term sustainability of water resources and maintaining healthy riparian ecosystems in the face of uncertain social and environmental changes. In the Republican River Basin watershed, three states who all share the river – Colorado, Nebraska, and Kansas – have come together through seven resource conservation and development (RC&D) councils to create the Republican River Restoration Partnerhsip (Knutson 2008a). Through this partnership they created the Republican River Basin Water and Drought Portal (http://www.rrbdp.org/index.html) to provide stakeholders with a tool for forecasting, climate and water information, planning tools and knowledge sharing.

The National Drought Mitigation Center (NMDC) based at the University of Nebraska-Lincoln works closely with stakeholders in the Great Plains region. One study they conducted with over 160 local, state, tribal and federal water authorities to look at low flow impacts in different areas of the Great Plains in an effort to develop a low flow early warning system with the NOAA National Weather Service (Knutson 2008b). Studies have been carried out in the Upper Trinity River Basin in Texas, the Souris-Red River in North Dakota, and the Missouri River Basin. One outcome of these types of partnerships was the creation of a drought risk management web site for ranchers http://drought.unl.edu/ranchplan/Overview.aspx.

Several multi-agency and/or multi-state climate change planning initiatives include states from the Great Plains. Many of these have been spearheaded by the Western Governors' Association (WGA) sustainability initiatives that include the Water Needs and Strategies for a Sustainable Future that began with reports in 2006 and 2008 that gave consensus recommendations for how the Western states should work with federal, local, and private sector partners to address a range of issues. These issues include providing water supply to meet future demands, maintaining water supply infrastructure, resolving Indian water rights, preparing for climate change, and conserving endangered species (Western Governors' Association 2006, Western Governors' Association 2008). In the 2008 report they recommended the creation of WestFAST (Western Federal Agency Support Team to assist states in implementing the reports' recommendations. This created a partnership between the Western States Water Council (WSWC) and eleven federal agencies that have water resource responsibilities in the western U.S. The agencies created a work plan in 2011 to address three key areas: 1) climate change; 2) water availability, water use, and water reuse; and 3) water quality. To date they have produced the WestFAST Water-Climate Change Program Inventory http://www.westgov.org/wswc/westfast/reports/climateinventory.pdf, the Federal Agency Summary http://www.westgov.org/wswc/westfast/reports/westfastsummary.pdf, and a Water Availability

Studies Inventory http://www.westgov.org/wswc/westfast/reports/federalwateravailabilitystudies.pdf. Another outcome was the 2006 Shared Vision Partnership Agreement between the WSWC and the U.S. Army Corp of Engineers that produced the Western States Watershed Study (WSWS), demonstrated how federal agencies could work collaboratively with western states on planning activities (USACE 2009). Multiple state and federal agencies and entities were involved and the study accomplished the adoption of shared vision, identification of water data needs and gaps, federal and local water managers working together to evaluate new flood storage rule curves under a changing climate, and enhancing federal inter-agency collaboration with the WSWS. Multiple additional goals and planning were identified for the continued collaboration through the WSWS and WestFAST.

In 2009, the Western Governors' Association (WGA) adopted a policy resolution titled *Supporting the Integration of Climate Change Adaptation Science in the West* that created the a Climate Adaptation Work Group, composed of western state experts in air, forests, water and wildlife to recommend next steps, and in 2010 they published their scoping *Climate Adaptation Priorities* report (Western Governors' Association 2010). The report lays out priorities and recommendations for adaptation planning that includes increased collaboration and coordination among agencies and local stakeholders, support and sharing of appropriately scaled climate science and adaptation strategies, and working with Congress to educate them on the priorities for Western states and support needed for implementing adaptation, among others (Western Governors' Association 2010).

5.3. Framework for integration of research, analysis, assessment, and communication activities: Steps Forward

In the Great Plains, and throughout the nation, efforts to respond to climate change have emerged during the past decade. Strategies to reduce activities that contribute to climate change have been developed for longer time and are further developed than those strategies dealing with adaptation to climate change (ACC 2011). However, a growing recognition that adaptation strategies to respond to climate change are needed has emerged in a number of sectors and communities around the world and the US (Wilby and Vaughan 2011). Being "climate smart" means implementing specific, measurable, achievable, realistic, and time-bound activities to reduce sensitivity to climate and increase resilience to climate variability and change. Wild and Vaughan (2011) identified nine hallmarks of organizations that are adapting to climate change, which include:

1. Visionary leadership
2. Objective setting

3. Risk and vulnerability assessment
4. Guidance for practitioners and to research groups
5. Organizational learning
6. Low-regret adaptive management
7. Multi-partner working groups
8. Monitoring and reporting progress to inform adaptive management actions
9. Effective communications

The preceding topics of this section provide a number of examples of the efforts on-going in the Great Plains. Examples, which in many ways, embrace the 9 points identified above. These examples are not a full compilation of efforts, however, these indicate a rich and varied set of activities. What is apparent from these examples that there are few well-coordinated efforts between agencies or institutions. In addition, it is difficult to learn about these efforts and to share knowledge of activities to monitor, analysis of impacts, sources of climate information, or development of response strategies to climate change. This lack of coordination and communication of climate response strategies and analysis of climate information and impact studies results in a great inefficiency and ability to assess climate change impacts and focusing research activities more strategically in the region.

Currently efforts through NOAA Research Integrated Science and Assessment (RISA) nodes and the DOI Regional Climate Science Centers (CSCs) have been established to serve as a resource to regional efforts to provide better regional information on climate dynamics, regional impacts of climate changes, vulnerability and risk assessments, and information to guide climate change responses across multiple sectors and supporting various management and decision making communities. These entities (RISAs and CSCs) are developing strategies to better coordinate and provide a more comprehensive information portal where managers and decision makers can more readily find the scientific information and analysis of impacts and consequences to guide development of specific strategies to cope with climate change.

In general, risk is defined within the National Climate Assessment as the product of the likelihood of some climate impact plus the consequence of that event or climate stress. Global climate change projections help us to understand the range of possible future climates and the impacts of climate change to some degree, but on smaller, local or regional scales there is considerable uncertainty on the time and spatial scales needed for decision making. Additionally, the possible future climate and its impacts social-ecological systems depends on how we as a society adapt and mitigate climate change.

Therefore, decisions we make now about how to plan for climate change are inherently uncertain. The NCA risk framework is designed for scientific analysis, however, social science risk analysis and decision science shows that most risk decisions are made based on emotions and experience versus analytical processes or scientific evidence, for example, and that emotions and experience dominate the analytical when making decisions about risk, especially in uncertain situations (Balstad et al. 2009).This is important to understand when linking probabilistic risk assessments with decision making. It accounts for the disconnect that occurs sometimes between what scientists think should be done and the reality of how decisions are made. Conversely decision makers need to recognize this and try to incorporate scientific findings in planning where possible. However, there are times when analytical processes can predominate, especially when discussed in a group (ibid). This calls for participatory research, iterative risk-based analysis between researchers and stakeholders, and collaborative decision making.

The efforts discussed in this report are aimed to meet societal needs to respond to climate change, and research efforts at these centers will guided by user needs, in addition to scientific directions to better reduce or communicate more clearly the uncertainties in the information available. Engagement with managers and decision makers from a variety of sectors will be undertaken to ensure knowledge sharing between communities and the researchers. The Great Plains is fortunate to have a number highly respected centers, not only the RISA's or the CSC's, but also, the National Center for Atmospheric Research (NCAR), NOAA Earth System Research Laboratory, High Plains Drought Center, National Drought Impact Science Center, EROS-Data Center, USFS Rocky Mountain Experimental Station, DOE regional offices for Region 6, 7, and 8, the DOE National Renewable Energy Laboratory, and many others.

There are lessons to be learned from efforts of the Western Governors' Association from which can be drawn illustrations of how state, federal, tribal, and academic communities can work in a coordinated fashion to develop and implement strategies to deal with critical regional needs related to climate change. Issues responding to water resource, land use, forest fire, and conservation needs over the years have been proactively addressed as mentioned above. The WGA has helped to define issues and to provide a framework to address these across the West. Other regional efforts include river basin initiatives, such as the Missouri River Basin efforts and the various agency coordination efforts to deal with flood control, land use practices, and conservation efforts. These bodies have a goal to provide better communication and where needed, coordination of actions to deal with a specific issues. The energy sector also have regional actions groups as mentioned in previous sections of this report.

However, development of assessment of climate change impacts and development of long-lasting solutions to climate change need to be developed across sectors and include multiple stakeholders. We need to create a platform to support this more integrative effort in the research and the management activities implemented across the Great Plains.

The multi-agency approach of the US Global Change Research Program can assist to enable this coordinated effort across the region. However, real and lasting engagement with local leaders and communities will be necessary to better assess the vulnerability and adaptive capacity of the local to regional stakeholders to deal with opportunities and challenges in the region resulting from climate changes. Establishing a collaborative network with the responsibility to communicate and establish a forum for dialogue between communities will greatly enhance the region to respond to changes in the climate and to better create opportunities as the climate changes.

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