23. Southern Great Plains

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Executive Summary

Key Messages

Key Message 1: *The region's growing population, the migration of individuals from rural to urban locations, and climate change will increase and redistribute demand and result in resource contention at the intersection of food consumption, energy production, and water resources. This "nexus" is inextricably linked to quality of life, particularly in rural areas as well as across both national and transnational borders.*

Key Message 2: *Higher temperatures, extreme precipitation, and rising sea levels associated with climate change make the built environment in the Southern Plains increasingly vulnerable to disruption, particularly as infrastructure ages and populations shift to urban centers. Coastal infrastructure remains particularly at risk as most climate projections suggest sea level rise of up to four feet if emissions are not reduced.*

Key Message 3: *Climate change affects terrestrial and aquatic ecosystems, influencing extreme droughts, unprecedented floods, and wildfires that directly and indirectly alter ecosystems and impact species. Some species adapt to changing climates, while others cannot, resulting in significant impacts to both services and people living in these ecosystems.*

Key Message 4: *Climate change will increase exposure to certain health threats, including extreme heat and diseases transmitted through food, water, and insects. These health threats may occur over longer periods of time, or at times of the year where these threats are not normally experienced. Given the widespread changes expected in the Southern Great Plains, health threats will be both varied and widespread.*

Key Message 5: *Tribal nations and indigenous communities in the Southern Great Plains are particularly vulnerable to the effects of climate change, including water resource impacts, extreme weather events, higher temperatures, and other public health issues. Efforts to adapt and build community resilience may be hindered by economic, political, and infrastructure limitations. Traditional knowledge and intertribal organizations provide opportunities to respond to the challenges of climate change.*

Summary Overview

The Southern Great Plains, composed of Kansas, Oklahoma and Texas, experiences weather that is dramatic and consequential. Hurricanes, flooding, severe storms with large hail and tornadoes, blizzards, ice storms, relentless winds, heat waves, and drought—its people and economies are often at the mercy of some of the most diverse and variable weather hazards on the planet. These events cause significant stress to existing infrastructure and socioeconomic systems and can result in significant loss of life and the loss of billions of dollars in property. Understanding the potential for future changes in the frequency and severity of these events and their impacts will ultimately determine the sustainability of economies, cultures, ecosystems, health, and life in the region.

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Climatic regimes in the Southern Great Plains vary dramatically from the arid, high-elevation borders with the mountainous states of Colorado and New Mexico on the west, to the humid states of Missouri, Arkansas, and Louisiana in the Mississippi River valley on the east. Average annual precipitation ranges from less than 10 inches in the western reaches of the region to over 60 inches in the southeastern corner. A large west-to-east contrast in surface water availability results, with large reservoirs in eastern parts of the region and few reservoirs in the west. Except for the Platte River, Arkansas River, and upper Rio Grande, rivers in the region do not draw from mountain snowpack and are sensitive to seasonal rainfall amounts. The region is vulnerable to periods of drought, historically prevalent during the 1910s, 1930s, 1950s, and 2011–2015, and periods of abundant precipitation, particularly the 1980s and early 1990s. The region has experienced an increase in annual average temperature of 1°–2°F since the early 20th century, with the warming maximizing during the winter months.

With the Gulf of Mexico to its southeast, parts of the Southern Great Plains are vulnerable to hurricanes and sea level rise. Relative sea level rise along the Texas Gulf Coast is twice as large as the global average, and an extreme storm surge in Galveston Bay would threaten much of the U.S. petroleum and natural gas refining capacity. Variations in freshwater flows and evaporation affect the salinity of bays and estuaries along the coast, and have the potential to alter coastal ecosystems and affect the fishing industry. Tropical cyclones are also responsible for exceptional rainfall rates in the region. The U.S. record for greatest 24-hour rainfall is 43 inches, set in Alvin, Texas in July of 1979. Houston, Texas in particular experienced several record-breaking floods in 2015, 2016 and 2017, with Hurricane Harvey rewriting the U.S. rainfall record book for tropical cyclones. Cedar Bayou, Texas, 30 miles from Houston recorded 51.88 inches of rain during Hurricane Harvey, breaking the contiguous-US rainfall record in a tropical cyclone of 48 inches.

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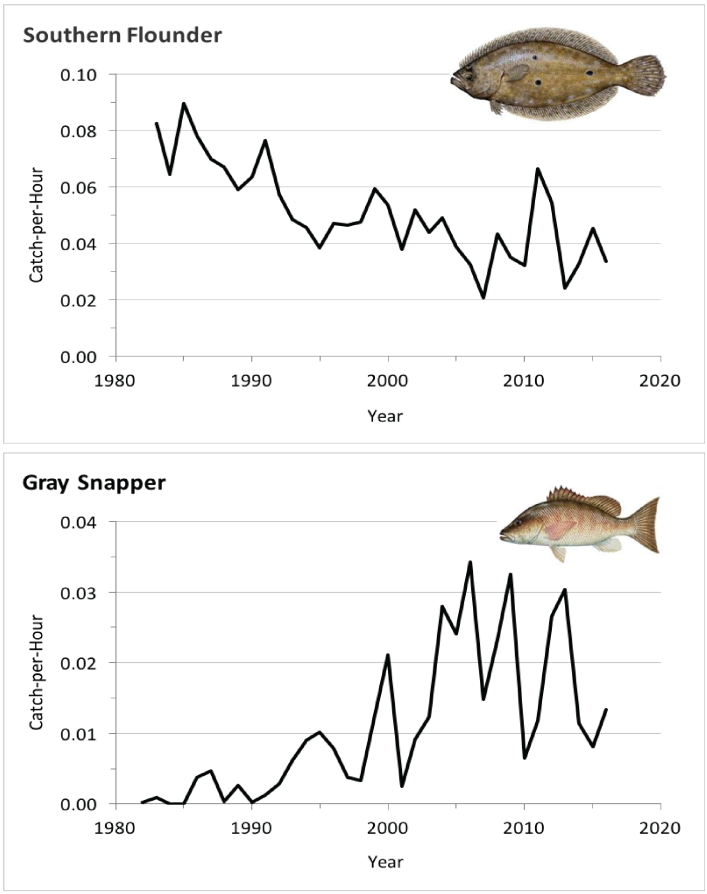
Figure



Title: Climate Winners and Losers (Gray Snapper and Southern Flounder

Figure 23.2: Trends in annual abundance of gray snapper (bottom) and southern flounder (top). As water temperatures increase along the Texas Gulf Coast, gray snapper are expanding northward along the Texas coast, while popular southern flounder are becoming less abundant, impacting recreational and commercial fishing industry. Source: Texas Parks and Wildlife Department Coastal Fisheries Resource Monitoring Data.

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Background

The Southern Great Plains, composed of Kansas, Oklahoma and Texas, experiences weather that is dramatic and consequential. Hurricanes, flooding, severe storms with large hail and tornadoes, blizzards, ice storms, relentless winds, heat waves, and drought—its people and economies are often at the mercy of some of the most diverse and variable weather hazards on the planet. These events cause significant stress to existing infrastructure and socioeconomic systems, and can result in significant loss of life and the loss of billions of dollars in property. Understanding the potential for future changes in the frequency and severity of these events and their impacts will ultimately determine the sustainability of economies, cultures, ecosystems, health, and life in the region.

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BOX 23.1: Hurricane Harvey

Hurricane Harvey was a Category 4 hurricane on the Saffir-Simpson scale when it made landfall on the central Texas coast (near Rockport) late in the evening of August 25, 2017. After making landfall, the storm moved inland, stalled, and eventually moved back over the coastal Gulf of Mexico waters before making landfall a final time as a tropical storm several days later in

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southwestern Louisiana.

Widespread flooding affected dozens of communities, including those in the Houston and Beaumont metropolitan areas. The immediate effects included deaths from drowning and trauma that claimed the lives of at least 63 individuals. Additionally, over 30,000 individuals were evacuated. The dispersal of patients from their communities and health providers lead to interruptions in medical treatment. Texas has one of the lowest rates of health insurance in the country and over 11% of the population of Texas is diabetic (TDSHS, 2017a). Additionally, chronic kidney disease rates in Texas are higher than the national average with a prevalence of over 17% in the adult population, and 1,524 per million inhabitants require routine dialysis (TDSHS, 2017b). In the aftermath of the hurricane, dialysis centers struggled with staffing shortages and centers in outlying areas worked around the clock to attempt to meet the needs of evacuated patients (Newkirk, 2017). Additionally, hospitals and pharmacies faced critical shortages of essential medications (including insulin and respiratory inhalers) secondary to the inability of suppliers to make deliveries. Hospitals faced critical power shortages and loss of indoor air and temperature controls. At least 15 area hospitals evacuated their patients (Fink and Blinder, 2017).

Preliminary damage estimates place Harvey as one of the two most costly U.S. natural disasters in inflation-adjusted dollars, rivaling Hurricane Katrina. Overall rainfall totals across southeastern Texas may have exceeded those of any known historical storm anywhere in the continental United States. Flooding from Harvey resulted in the overflow of sewage systems and breaches at numerous waste treatment facilities (Kaplan and Healy, 2017), resulting in untreated infectious human waste entering surface waters and resulting in a spike in skin and gastrointestinal infections (Astor, 2017).

No studies have specifically examined whether the likelihood of hurricanes stalling near land is affected by climate change. Projected trends in the mean steering flow over the northwest Gulf of Mexico are weak and not robust across models (Colbert et al. 2013). More general research on weather patterns and climate change suggests competing influences (Brewer and Mass 2016; Lucas et al. 2014; Mann et al. 2017; Tang et al. 2014). Weather patterns related to the jet stream may be more likely to become locked in place, possibly including the mid-tropospheric wind pattern that resulted in Harvey stalling along the Texas coast, while at the same time climate is causing the jet stream to move farther from the tropics, which would make it less likely for a storm such as Harvey to have its motion affected by the jet stream.

The ability of Harvey to continue to draw tropical moisture northward is related to its intensity and size at landfall. Research suggests that intense hurricanes will become more frequent in a warmer climate, although such storms are so rare that such a trend, if already present, would not clearly be detectable in the existing climate record.

Multiple lines of evidence, including observations, model simulations, and basic thermodynamics, indicate that the intensity of heavy rain is increasing in Texas and elsewhere in the United States, including heavy rain produced by tropical cyclones. This intensity increase is

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closely related to increases in sea surface and atmospheric temperatures that allow more water vapor to be present in the atmosphere. Based on past trends and recent sea surface temperatures, the heaviest rainfall amounts from intense storms such as Harvey are about 5%–7% greater now than what they would have been a century ago (USGCRP, 2017).

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Across the region, significant flooding and rainfall events followed drought in approximately one-third of the drought-affected periods in the region (Christian et al. 2015). Understanding this rapid swing from extreme drought to flood is an important and ongoing research question in the region. As major metropolitan areas in the region continue their rapid population growth, overall exposure to extreme rainfall events will increase. Yet, even while record breaking flooding events increased over the past 30 years, the Southern Great Plains experienced an overall decrease in flood frequency (Hoerling et al 2013), possibly related to the decrease in total precipitation over the same period.

The Southern Great Plains is a critical thoroughfare for rail and road freight, supports numerous ocean and river ports within its borders, and is a major energy producer and exporter (USEIA, 2015). Combined, the three-state region accounts for 25% of all U.S. energy production. The world's largest oil-storage tank facility is located in Cushing, Oklahoma, with 13% of total U.S. storage and a convergence of several major pipelines. Over 550,000 miles of roads connect rural and urban communities, and serve as vital infrastructure supporting state and local economies (USCB 2016, USDOT 2017, OHSO 2017). The vast and dispersed nature of the region's infrastructure makes investment in maintenance and rehabilitation of deficient and aging infrastructure difficult. Since infrastructure is in part designed based on the local climate and is perennially exposed to the environment, climate-related stressors such as extreme heat, drought, and flooding, along with severe local storms, have caused adverse and costly impacts to the region historically, and climate change is projected to increase the frequency of heatwaves, extreme precipitation, drought, and sea level rise. Existing vulnerabilities and limited adaptive capacity compounds the impacts of climate change. The Southern Great Plains ranks near the top of states with structurally deficient or functionally obsolete bridges, while others are nearing the end of their design life (ASCE-OK 2013, ASCE-KS 2013, ASCE-TX 2012). Road surface degradation in Texas urban centers is linked to an extra $5.7 billion in vehicle operating costs annually (TXDOT 2014). The region has tens of thousands of dams and levees; however, many are not subject to regular inspection and maintenance, and have an average age exceeding 40 years (ASCE-OK 2013, ASCE-KS 2013 ASCE-TX 2012). Most state and local budgets are unable to meet the funding needs for infrastructure improvements, particularly in rural towns where funding is largely derived from municipal revenue. In urban centers, population growth is anticipated to require expansion of transportation infrastructure and services and revisions to flood control structures and policies (ASCE-OK 2013, ASCE-KS 2013 ASCE-TX 2012) and result in increased water resource needs and a growth in building demand (Vision North Texas 2010, Combs 2012).

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Projections

Climate change is expected to lead to an increase in both average temperatures and frequency, duration, and intensity of extreme heat events, but with a reduction in extreme cold events. Annual average temperatures in the Southern Great Plains are projected to increase by 3.6°–5.1°F by the mid-21st century and by 4.4°–8.4°F by the late 21st century, compared to the average for 1976–2005, and dependent on emissions pathway, with higher emissions leading to greater and faster temperature increases. Extreme heat will become more common. Temperatures similar to the summer of 2011 will become increasingly likely to recur, particularly with higher emissions. By late in the 21st century, the region may experience an additional 30–60 days per year above 100°F than it does now (USGCRP 2017).

The role of climate change in extreme weather trends, such as severe local storms, tropical storms and hurricanes, ice storms, and tornadoes, remains difficult to determine based on the current science. Indirect approaches suggest a possible increase in the circumstances conducive to such severe weather, but the evidence is far from conclusive and changes are unlikely to be uniform across the region (Brooks, 2013).

Along the Texas coastline, sea levels have risen 5–17 inches over the last 100 years, depending on local topography and subsidence (Runkle et al. 2017). Sea level rise along the western Gulf of Mexico during the remainder of the 21st century is likely to be greater than the projected global average of 1–4 feet or more (USGCRP 2017).

Annual average precipitation projections suggest generally small changes in the region, with slightly wetter winters, particularly in the north of the region, and drier summers (USGCRP 2017). However, the frequency and intensity of heavy precipitation is anticipated to continue to increase, particularly with higher emissions and later in the century (USGCRP 2017). The expected increase of precipitation intensity implies fewer soaking rains and more time to dry out between events. Studies that have attempted to simulate the consequences of future precipitation patterns consistently project less future soil moisture, with future conditions possibly drier than anything experienced by the region during at least the past 1,000 years (Cook et al 2015).

While past hydrologic extremes have been driven largely by climate variability, climate change is likely to exacerbate the frequency, duration, and intensity of drought in the Southern Great Plains, largely associated with drying soils due to increased evapotranspiration caused by higher temperatures (USCGRP 2017).

Key Message 1: Food, Energy, and Water Resources

Key Message 1: *The region's growing population, the migration of individuals from rural to urban locations, and climate change will increase and redistribute demand and result in resource contention at the intersection of food consumption, energy production, and water resources. This "nexus" is inextricably linked to quality of life, particularly in rural areas as well as across both national and transnational borders.*

Food, energy, and water systems are inseparable. Any change in demand for one will impact

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demand on the other two. The quality of life of the 34 million people residing in the Southern Great Plains is dependent upon the resources and natural systems for the sustainable provision of food, energy, and water. At least 60% of the region's population is clustered around urban centers, which are experiencing population growth outstripping those of rural communities, where population is generally stable or declining. The remaining population is spread across vast areas of rural land (USCB 2016, Potter and Hoque 2014, KSA50 2016, Hayden 2011, OKDC 2012). As the population in the region grows, rapid urbanization and economic development opportunities will drive an increase in the demand for food, energy, and water. Water is used in every aspect of agricultural production and electricity generation. Energy is required to extract and deliver water of sufficient quality for diverse human and agricultural use, as well as healthy consumption and wastewater treatment. Both water and energy are required to irrigate and process agricultural products and livestock to feed the region's increasing population. The complex interdependencies at the food, energy, and water "nexus" create enormous challenges.

When severe drought affected the Southern Great Plains in 2011, limited water availability constrained the operation of some power plants and other energy production activities. Contention for water developed between consumers associated with the food, energy, and water nexus. The recent boom in domestic unconventional oil and gas development brought on by hydraulic fracturing and horizontal drilling represents another stressor to this nexus. This development has added complexity to the regional dialogue about the relationship between food, energy, and water resources.

Superimposed on the existing complexities at the food, energy, and water nexus is the specter of climate change. During 2012–2015, the multiyear regional drought resulted in no irrigation water for the Texas Rice Belt farmers on the Texas coastal plains. The reduced quantity of available water along the Colorado River basin had to be rationed among multiple stakeholders and uses, including the municipal and recreational needs for the City of Austin; the coastal plain rice farmers requiring it for irrigation to support their livelihoods; the need to replenish cooling reservoirs for the South Texas Project's two nuclear reactors that supply power to two million households in Austin, Dallas and San Antonio; and the Fayette Power Project coal plant that supplies power to 320,000 homes in the Austin area. In one year, planted acres of rice in Matagorda County, Texas, dropped from 22,000 acres to 2,100 acres (Badour 2014). The ripple effect on the local economy was severe, with a 70% decline in sales of farm implements and machinery. Some family-owned establishments that had survived for decades closed permanently (Baddour 2014). Irrigation strategies shifted from river-based to pumping water from the Gulf Coast Aquifer, and dozens of new wells were drilled. Drilling water wells then resulted in declining groundwater levels, adding stress to water levels that had historically been falling in the region (Chaudhuri and Ale 2014). Some farmers were forced to make the difficult transition to other crops such as corn. When flooding rains inundated the region in 2016, 15% of the corn crop in the region was swept away in flood waters (Hawkes 2016).

Climate change has significant negative impacts on agriculture in the United States, causing

substantial economic costs (Backlund et al 2008). The effects of drought and other occurrences of extreme weather outside the Southern Great Plains also affects the food–energy–water nexus in the region. The neighboring Southwest region is especially vulnerable to climate change due its rapidly increasing population, changing land use and land cover, limited water supplies, and long-term drought (Garfin et al 2013). States in the Southern Great Plains import over 20% of their food-related items from Arizona, and El Paso, Texas, receives 25% percent of consumable foods (mostly vegetables) and 18% of its animal feed supplies from Arizona (Berardy and Chester 2017). In addition, relationships across the border of the Southern Great Plains with Mexico will be critical to a better understanding of the food–energy–water nexus (See Case Study: Rio Grande Valley and Trans Border).

BOX 23.2: Case Study: Rio Grande Valley and Trans Border Issues

In the U.S.–Mexico transboundary region of the Southern Great Plains, no hydrologic resource is more critical than the Rio Grande River and its attendant tributaries. Partnered, bi-national management of the basin's water supply is essential to supporting the agricultural, industrial, and community infrastructure in place along the Rio Grande valley. Proactive and collaborative water management strategies allow for effective flood control, mitigation of drought impacts, and maximization of water quality, among other benefits (Garrick 2016).

The Rio Grande is highly sensitive to variations and changes in the climate of the Southern Great Plains, where changes can have marked impacts on the valley's extensive agricultural productivity (Steiner et al 2017). Increasing regional temperatures (Kunkel 2013) consistent with global trends will enhance the severity of drought impacts via the acceleration of surface water loss driven by evaporation, particularly in large Rio Grande reservoirs such as Lake Amistad. The impacts of extreme high temperatures during drought conditions were evidenced in Texas during the historic 2011 drought (Hoerling et al 2013). Changes in regional precipitation patterns, including observed increases in extreme rainfall events as part of a regional "dipole" dry-wet-dry again pattern (Christian et al 2015), will affect both drought and flood occurrence and intensity along the Rio Grande channel. Other climate-driven impacts, such as changes in wildfire frequency (Muth et al 2017) and increased vulnerability to heat events (Garfin et al. 2013) will further challenge the preparedness and resiliency of communities on both sides of the border.

A growing number of adaptation strategies (Nava et al 2016) and an increasing provision of regional climate services in the Southern Great Plains (Shafer et al 2011) bode well for an improved future ability to effectively manage the Rio Grande's trans-boundary water interests. Frequently, extreme weather and climate events, such as the 2011–2012 La Niña and 2015–2016 El Niño episodes, serve as catalyzing opportunities to develop new and refine existing information delivery pathways from climate services providers to stakeholder audiences. Recent examples in the Rio Grande trans-boundary region include seasonal climate outlooks and impact assessments (Shafer et al 2014), drought and wildfire outlooks (Muth et al 2017), and aquifer assessments (Alley 2013). The delivery of regional climate services is being more rigorously

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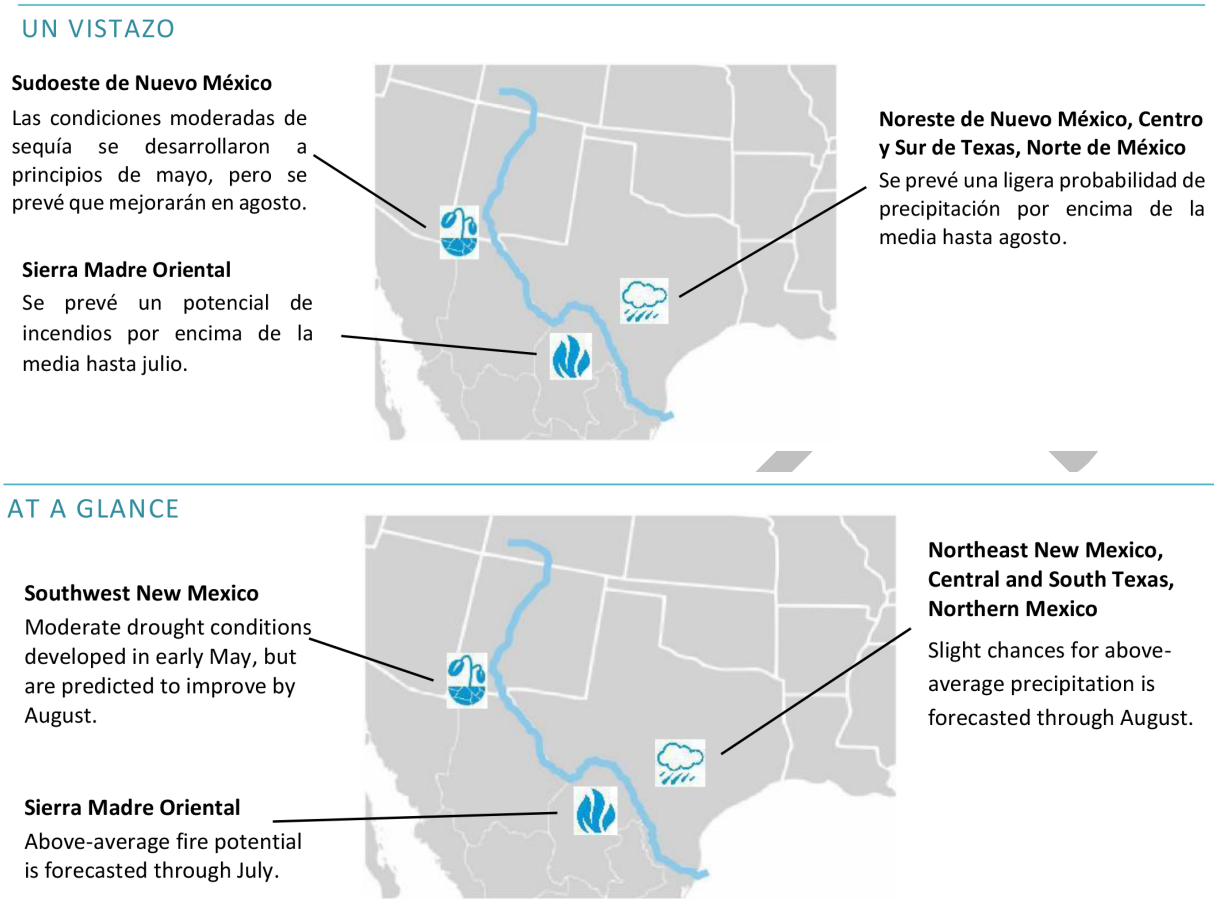
evaluated (Eastwood et al submitted) and many resources are now available bilingually (Steiner 2015b).



Title: CLIMAS Spanish and English Language Pages

Figure 23.1: Spanish and English language versions of the May 2017 Climate Assessment for the Southwest (CLIMAS) Rio Grande-Bravo Climate Impacts and Outlook "At A Glance" summary. http://www.climas.arizona.edu/sites/default/files/RGBO_May_2017_Final.pdf.

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The 2017 Texas State Water Plan (TWDB 2017) indicates that the growing Texas population will result in a 17% increase in water demand in the state over the next 50 years. This increase is projected to be primarily associated with municipal use, manufacturing, and power generation, owing to the projections of population increase in the region. Likewise, water use projections in Oklahoma are expected to increase by 21% for municipal use, 22% for agricultural use, and 63% for energy use (OWRB 2012). A preliminary assessment of projected water demand in Kansas also shows an increase of 20%, but with the expected variability depending upon rural versus urban areas (KWO 2014). Throughout much of western Kansas, western Oklahoma, and the Texas Panhandle, groundwater from the Ogallala Aquifer is the dominant water source (ASCE-KS 2013, Winter and Foster 2014), benefitting the agricultural sector in particular. This resource

is known to be shrinking faster than it is replenishing, and some portions are likely to become an insufficient source or become completely depleted within the next 25 years, particularly at its southernmost extent (ASCE 2013). Drought more persistent than that experienced in the region's recent history would trigger large social and economic consequences, including shifting agriculture, migration, rising commodity prices, and rising utility costs (Combs 2012).

The importance of groundwater as a resource will increase under climate change as the intensification of hydrologic extremes decreases the reliability of precipitation, soil moisture, and surface water, and as surface water supplies are becoming increasingly over-allocated (Taylor et al 2013, Castle et al 2014, Green et al 2011).

BOX 23.3: Case Study: Edwards Aquifer

The Edwards aquifer is a limestone aquifer that provides groundwater to the central Texas region. It serves more than two million people, including the cities of San Antonio, San Marcos, and Austin, which are three of the fastest growing cities in the country (USCB 2015). The aquifer is a source of water for drinking, industry, agriculture, livestock, and recreation. It is also a habitat for a number of endemic and endangered species.

The Edwards aquifer is particularly sensitive to climate change. It fills and drains quickly and its shallow depth enhances the responsiveness to droughts and floods. This high susceptibility and exposure to climate change is a major challenge for managing the Edwards aquifer as a resource (Wong et al 2012). The probable impacts of climate change for the Edwards aquifer include a decrease of water supply during droughts, a degradation of habitat for species of concern, economic effects, and the interconnectivity of these impacts.

Water availability and demand. The population of Texas will grow by more than 70% between 2020 and 2070, with the majority of the increase projected to occur in urban centers (TWDB 2017). Increased demand for water will come from municipal, power generation, agriculture, manufacturing, and livestock uses (TWDB 2017). Over this same time period, water availability in the U.S. Southwest is projected to decrease due to a shift to a more drought-prone climate state (Cook et al 2015, Banner et al 2010). History shows that population growth during the drought of the 1950s led to unsustainable use of water from the Edwards aquifer (Sharp and Banner 1997) The lessons learned from the 1950s and the more intense 2011 drought provide a particularly well-suited test for models of how the aquifer and associated ecosystems will respond to projected climate change (NAS 2017).

Habitat. Plants and animals are sensitive to a variety of changes related to the Edwards aquifer groundwater system, including changes in habitat, water levels, spring flows, and water quality. An example of the latter is an analysis of dissolved oxygen concentrations (DO) in water in Barton Springs, a major point of discharge from the Edwards aquifer. Most notable is the Barton Springs salamander (*Eurycea sorosum*), a federally listed endangered species native to these springs. Data on DO levels at the springs indicate that low DO episodes that correspond to salamander mortality could result from 1) lower discharge from the springs resulting from

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increased water withdrawals or decreased recharge as a result of drought, and/or 2) increased water temperature as a result of climate change (Mahler and Bourgeais 2013). A key challenge is understanding and modeling the extent to which endangered and native species can be protected in their habitats associated with the aquifer (NAS 2017, Mahler et al 2014, Stamm et al 2015).

Impacts. Dramatic drawdowns of groundwater levels by human activity combined with climate change in many regions illustrate the challenges of their non-renewable nature and the multiple dependencies of some ecosystems and agricultural systems on groundwater (Klove et al 2013). Multiple, integrated solutions will be needed to address the impacts on the Edwards aquifer. These will necessarily involve ways to increase supply, through technological approaches such as desalination of brackish groundwater and aquifer storage and recovery, and ways to decrease demand, such as conservation and regulation.

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Research into the intersection, or "nexus" of food, energy, and water is in its early stages, and historically tends to examine only one or two components (Bazilian et al 2011, Beck and Villarroel-Walker 2013, Hellegers et al 2008, Hussey and Pittock 2012, Ringler et al 2013, Villarroel-Walker et al 2014, Zhang 2013). It is clear that tradeoffs and cascading complexities exist between sectors, and changes in one sector are likely to propagate through the entire system. There are significant gaps in the scientific understanding regarding the role climate change will play as a disruptive force and a threat to food, energy, and water security (Beck and Villarroel-Walker 2013, Ringler et al 2013, Giupponi and Gain 2016, Godfray et al 2010, Yang et al 2016).

Key Message 2: Infrastructure

Key Message 2: *Higher temperatures, extreme precipitation, and rising sea levels associated with climate change make the built environment in the Southern Plains increasingly vulnerable to disruption, particularly as infrastructure ages and populations shift to urban centers. Coastal infrastructure remains particularly at risk as most climate projections suggest sea level rise of up to four feet if emissions are not reduced.*

Climate change is anticipated to lead to year-round higher average temperature and an increase in the frequency of very hot days (days with maximum temperatures above 100°F), with the number of such days possibly doubling by the mid-21st Century (USGCRP 2017). An increase in temperatures is virtually certain for the Southern Great Plains. Longer and more intense summers will place strain on cooling systems and energy utilities, road surfaces, and water resources, particularly during drought, although warmer winters are likely to reduce heating demands and winter road maintenance costs. The rate of temperature rise may be especially large within urban centers due to possible intensification of the urban heat island (UHI) effect, although the degree of heating likely varies by city and it is difficult to obtain precise quantitative estimates. During excessive heat in July 2011, Dallas experienced late-evening temperatures 6.1°F higher in the downtown urban canopy, versus downstream 36 miles away

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(Winguth and Kelp 2013). Population growth, increased urban density, and expansion will intensify the UHI for many Southern Great Plains cities, necessitating more energy use for cooling. This in turn can further enhance the UHI, and strains energy utilities (Estrada et al 2017). If prolonged power failure occurs during high heat conditions, the future impact to human health and comfort may be notably more detrimental in a warmer climate (Sailor 2014).

Increased frequency of drought is also projected for the Southern Great Plains with climate change, due to enhanced evapotranspiration and depleted soil moisture associated with increased temperatures (USGCRP 2017). During past drought, surface water availability (for example, in reservoirs) decreased, and groundwater use increased, in some cases requiring new pipelines or importing of water (Combs 2012). Compounding infrastructure challenges for the region include aging and over-capacity water pipelines (OWRB 2011). The Texas Water Development Board (TWDB 2012) suggests that by 2060, municipal water use will increase to 41% of available supply (versus 9% in 2010), based on projected population growth and that if a record drought, *based only on recorded historical conditions,* occurred in 2060, many areas of the state, and as much as half of the state's population, could face less water availability. Additionally, water infrastructure can be damaged by drought. During summer 2011, water main breaks were common, with 200 breaks in Fort Worth, Texas, in one month and over 1,000 in one month in Houston, Texas (Combs 2012), associated with shrinkage of clay soil, a common soil type throughout the Southern Great Plains. Soil shrinkage can damage both surface and subsurface infrastructure, including roads, water and sewer lines, and building foundations. Periods of abundant precipitation followed by drought and high temperatures are also linked to increased wildfire activity in the region (Scasta et al 2016). Texas experienced several major wildfire outbreaks during the drought of 2011, including the Bastrop fire that destroyed more than 1,500 homes. More recently in 2016 and 2017, fires in Kansas and Oklahoma have exceeded 400,000 acres and were among the largest in the region's history. These events killed thousands of cattle, contributed to several fatalities, and damaged, displaced, or isolated rural communities (Hutchinson Post 2017). Wildfire risk may increase with climate change throughout the region, associated with higher temperatures, particularly in the summer, and an increase in duration of the fire season (Gan and Cho 2015).

Following the abrupt cessation of persistent drought in 2015, the region suffered extensive damage associated with river and flash flooding (Christian et al 2015, Erdman 2016, Wolter et al 2015). Precipitation totals for a 120-day period during the spring of 2015 in south-central Oklahoma were above 40 inches, approximately the average annual amount in many locations (Oklahoma Mesonet 2015, Chickasaw Nation 2015), largely associated with multiple episodes of very heavy rain. Numerous state and U.S highways experienced regional detours or closures (Chickasaw Nation 2015). A rockslide on Interstate Highway 35 closed portions of the road for several weeks (Chickasaw Nation 2015, NCEI 2015). Flooding in Oklahoma and Texas caused an estimated $2.6 billion in damage (NCEI 2015), with $1 million in emergency relief funds provided by the U.S. Department of Transportation's Federal Highway Administration to assist repair of damaged roads (ODOT 2015). The increasing frequency of extreme precipitation that is

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projected by climate models is anticipated to contribute to further vulnerability of existing highway infrastructure, although the magnitude and timing of projected precipitation extremes remain uncertain (USGCRP 2017).

Changing precipitation frequency and increases in the magnitude and frequency of heavy precipitation will place more stress on existing water resource infrastructure. The region has a large number of older dams and levees—Texas is ranked first in the Nation for the number of dams, and Oklahoma is ranked fourth (ASCE-OK 2013, ASCE-TX, 2012). The American Society of Civil Engineers (ASCE) has assigned dams and levees poor grades (ASCE 2013, ASCE-KS 2013, ASCE-TX 2012). Between 1982 and 2012, 82 dams failed in Texas, and during 2015 the high-hazard Lewisville dam was of concern due to observed seepage (ASCE-TX 2012, Getschow 2015). Climate change is likely to shift the frequency distribution of rare events, such as 100-year floods, to become more common (USGCRP 2017). Future extremes may exacerbate flooding and wear and tear on existing flood control infrastructure and could necessitate revisions to design standards for flood infrastructure and a reevaluation of floodplains. Floodplain management and mitigation of flooding is currently left largely to local governments and cities, and is thus reliant on local funding and resources for successful implementation (ASCE 2013, ASCE-KS 2013, ASCE-TX 2012). While there are clear implications of more variable and extreme precipitation on infrastructure, the precise links between specific events and their resulting damage is uncertain as most infrastructure is exposed to both climatic and non-climatic stressors whose effects are difficult to separate without a high degree of monitoring.

As the energy industry undergoes, to some extent, a reinvention, it is taking climate and extreme weather events into consideration in design, operations, and reliability. An Edison Electric Institute study estimated that by 2030, the U.S. electric utility industry will need to make a total infrastructure investment of between $1.5 trillion and $2.0 trillion, of which transmission and distribution investment is expected to account for about $900 billion (Edison 2008). These investments increasingly include renewable energy and distributed generation, smart grid technologies, and storage. From 2008 to 2013, the amount of electricity generated from wind has more than tripled and the amount from solar has increased by more than tenfold (EIA 2015). These enhancements would need to be reliable (able to operate within limits so that instability, uncontrolled events, or cascading failures do not result if there is a disturbance), resilient (able to adapt to changing conditions and withstand and rapidly recover from disruptions), safe, flexible and affordable.

Coastal regions are among the most vulnerable to climate change due to the scale and certainty of substantial sea level rise without reductions in greenhouse gas emissions. Within Texas alone, 1,000 square miles of land is within 5 feet of the high tide line, including $9.6 billion in current assessed property value and homes to about 45,000 people. Sensitive assets include 1,600 miles of roadway, several hospitals, schools, 4 power plants, and 254 EPA-listed contamination sites (hazardous waste and sewage) (Strauss et al 2014). The coastline in the vicinity of Galveston and Texas City is also a critical oil refining and transport hub. Sea level rise of at least two feet

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would affect numerous coastal assets, including residential communities, roads, waterways, and energy generation facilities, and move the risk of damaging storm surge well inland of present areas of impact, exposing cities such as Galveston and Corpus Christi to more frequent flooding (Strauss et al. 2014, Carlson et al. 2016, Murdock and Brenner 2016, Bradbury et al. 2015). Disruption to coastal oil-refining facilities can cause cascading failures throughout the region, including fuel shortages and higher prices. Up to $20.9 billion in coastal property may be flooded at high tide by 2030, and by 2050 property values below the high-water mark may be in excess of $30 billion (RB Project Report 2015). Saltwater intrusion of aquifers has been observed in the Gulf Coast Aquifer, the second most utilized aquifer in Texas that supports eight million people. Although this was in part associated with heavy pumping (Mace et al 2006), the Gulf Coast Aquifer remains vulnerable to further saltwater intrusion resulting from sea level rise, and storm surge exacerbated by climate change (Anderson and Al-Thani 2016).

Due to the historical frequency of drought, water conservation activities are already recognized as important and encouraged in many municipalities. Common strategies include rainwater harvesting, encouraging improved residential water-use efficiency, water audits, and restricted water use in times of drought (Combs 2012). Other proactive measures currently in place in some communities aim to mitigate longer-term risks and involve wastewater treatment and reuse, aquifer storage and recovery, and desalinization (Combs 2012) (see Case Study: El Paso Desalinization).

BOX 23.4: Case Study: El Paso Desalinization

El Paso, Texas, is vulnerable to drought, being situated in the Chihuahua desert with a growing population and with limited water resources derived largely from the Rio Grande river and regional aquifers. The city is part of the Rockefeller Foundation's 100 resilient cities initiative. Prior to, and as part of, El Paso's climate adaptation planning, the city's water utility program implemented programs on water conservation, reclamation, and supply diversification. In 2007, the city completed construction of a 27.5 million-gallon-per-day desalinization plant. The desalinization is applied to brackish waters, which is less intensive than applying desalinization to ocean water. The plant is designed with excess capacity to meet the needs of the city in times of drought. The plant was found to be more cost effective in the long term compared with importing water from remote sources. A climate change analysis of the future viability of this infrastructure suggested that it could meet the needs of the city through the next 50 years (Vogel and Juliana 2016).

END BOX

Climate change is likely to require modification and updating of design standards in order to accommodate changes in risk for which historical data cannot fully account. For example, in transportation design, these modifications may include changing the minimum and maximum temperature rating for binders used in asphalt roads to improve durability; structural modifications to bridges to meet the demands of higher summer temperatures; updating the data used for calculating flooding of dams and neighborhoods; restricting rail speeds during hot

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temperatures; and shifting timing of maintenance activities. Many technological solutions exist or are in development to build resiliency to these climate-related challenges. However, the aforementioned stressors and budgetary challenges will continue to present notable challenges to adaptive capacity in the Southern Great Plains.

Many studies have documented economic impacts of climate change on different sectors in the United States and worldwide (Adams et al. 1989, Deschenes and Greenstone 2007, Stern 2007, Mendelsohn and Neumann 2004, Tol 2002). For example, predictive analyses estimate that climate change and coastal development will cause hurricane damage to increase faster than the U.S. economy is expected to grow. The number of people facing substantial expected damage will, on average, increase more than eightfold over the next 60 years (Dinan 2017). However, economic analyses for specific regions, sectors, and states in the Southern Great Plains are still limited. Moreover, holistic methodology is missing to evaluate the socioeconomic impacts of climate change at a larger regional scale due to varying geographic, meteorological, and hydrological conditions in each of the Southern Great Plains states/regions.

The role of economics is increasingly recognized as being critical for advancing the resilience of households, businesses, and local governments, and also for the broader economic adaptation of entire regions. Establishing economic resilience in a local business or a regional economy requires the ability to anticipate risk, evaluate how that risk can impact key economic assets, and build a responsive adaptive capacity. At the regional or community level, economic development practitioners can build capacity for economic resilience.

Key Message 3*:* Ecosystems and Ecosystem Services

Key Message 3: *Climate change affects terrestrial and aquatic ecosystems, influencing extreme droughts, unprecedented floods, and wildfires that directly and indirectly alter ecosystems and impact species. Some species adapt to changing climates, while others cannot, resulting in significant impacts to both services and people living in these ecosystems.*

The Southern Great Plains encompasses diverse ecoregions stretching from the High Plains to the Edwards Plateau and the Tamaulipan Brushlands to the Gulf Coast Prairie (Omernik 2014). The region is prone to periods of drought punctuated by heavy rainfall events, with evidence that these events are occurring more frequently (Christian, Christian and Basara, 2015). These precipitation patterns influence water availability and aquatic habitats such as lakes, rivers, springs, and streams. Freshwater inflows from rivers flowing to coastal estuaries provide important nutrients and sediments while moderating salinities to create and maintain productive estuarine ecosystems.

Climate Change Impacts to Species

Climate plays a key role in the distribution of species. Species' response to climate change is complex and variable (Staudinger 2013). As temperatures increase, the geographic distribution of some species tends to shift to adapt to thermal tolerance ranges. Rising temperatures are also causing changes to growing seasons and migration patterns of birds and butterflies (NFWPCAP

2012). In Texas, white-wing dove, originally confined to the Lower Rio Grande Valley, have been expanding northward (Butcher 2014) and are now common across Oklahoma. However, other factors including habitat loss also influence species distributions, making it difficult to pinpoint specific causes for the distribution change.

It is unclear how climate change will affect species directly, but the effects of increased drought will likely have negative impacts. In addition, ecosystem services—the materials and processes that ecosystems produce that benefit people—will also be affected (NFWPCAP 2012). In general, drought forces wildlife to travel farther to locate food, water, and shelter, which can deplete body condition going into winter or spring migration when food sources are typically scarcer, making them more vulnerable to other stresses. The highly endangered Houston toad was negatively impacted during the 2011 drought and devastating wildfire in Bastrop County, Texas. Whooping crane numbers, which depend on sufficient freshwater inflows for a reliable food source (primarily blue crabs), were also reduced. In addition, a lack of freshwater can force whooping cranes to fly to uplands to drink, using more energy and exposing birds to more threats from predators and other mortality factors.

Drought exacerbates stress in highly isolated habitats and fragmented lands, diminishing the ability for species to persist if they cannot move to better conditions. Migratory birds are better able to move to areas with better habitat conditions, but may be in a weakened condition to do so. Migratory waterfowl can also be negatively impacted by reductions in wetland habitat areas during drought. Loss of irrigated rice fields in Texas contributed to significant declines in wintering waterfowl along the Gulf Coast. The most significant decline was documented for snow geese, with a 71% decline for 2011–2014 as compared to the long-term average (GCPLCC 2014). Playa lakes in the High Plains serve as important habitat for migrating waterfowl, but during the drought these wetlands were virtually nonexistent.

Plant community changes are also occurring, possibly due to climate change and other factors, and these changes in turn affect fish and wildlife. In the Southern Great Plains region, winters are warmer and spring is arriving earlier. Along the Texas coast, black mangroves, which are sensitive to cold, are expanding northward along the coast, and red mangroves, formerly not found in Texas, are now appearing there (Schmandt 2011). Warmer winters with fewer freezes are also conducive to pests and diseases. Woody shrubs invading prairie grasslands are favored by increases in concentrations of CO_2, changes in soil moisture cycles, fire suppression, and soil disturbances (GCPLCC 2014). The 2011 drought produced a direct and indirect tree mortality rate of over 6%—many times the normal rate (Moore et al 2016).

Aquatic Ecosystems

Climate change impacts to aquatic ecosystems include higher water temperatures in lakes, wetlands, rivers, and estuaries that can result in lower dissolved oxygen, leading to more fish kills. Impacts to reservoirs include fluctuating lake levels, loss of habitat, loss of recreational access, increase in harmful algal blooms, and disconnectedness from upstream and downstream riverine habitats. Localized declines in fish populations have been documented in rivers due to

lack of water or water confined to increasingly narrow pools; in some cases, these declines prompted biologists to capture and relocate some endangered species to fish hatcheries (TPW 2012). Extended or more frequent drought can have a number of negative impacts on freshwater mussel populations, including increased predation pressures, hypoxia (low oxygen conditions), increasing water temperature, and ultimately, anoxia (no dissolved oxygen in water) or emersion (stranding the organism out of water and exposing it to air).

Coastal/Bays and Estuaries

The Texas coast, with 6.5 million people contributing over $37 billion to the region's economy, relies on its natural features, bays and estuaries that serve as storm barriers to protect coastal infrastructure, and its climate amenities to spur ecosystem services, such as fishing, ecotourism, and the ocean economy. These coastal ecosystems not only provide protection for people but also for 25% of the Nation's refining capacity, four crucial ports, much of the strategic petroleum reserves, and strategic military deployment and distribution installations. This protection was clearly on display with the recent impacts of Hurricane Harvey, where it has been estimated that natural coastal habitats protected about $2.4 billion worth of property in Texas and thousands of lives, with the suggestion that these habitats are potentially our first lines of defense (Narayan et al. 2017).

A rising sea level impacts over 74% of Gulf-facing beaches in the upper Texas coast. The average rate of beach erosion is almost 10 feet per year (Paine, 2014). Sea level rise means more frequent and longer-lasting flooding of marshes that eventually could be permanently flooded, becoming open water (Schmandt 2011, Subedee 2016). Higher tides and storm surges cause inundation of freshwater areas and beach erosion, leading to a potential decrease or loss of barrier islands and coastal habitats, including nesting habitats and submerged habitat such as seagrass beds affected by changes in water quality and changing water depths.

The warming of Texas bay waters has been documented for at least 35 years. This mostly reflects warmer winters, not warmer summers. The increase in water temperature directly affects water quality, leading to the higher potential for low dissolved oxygen, or hypoxia. Hypoxic events and harmful algal blooms have caused fish kills, leading to lower productivity, and diversity of estuarine ecosystems (Schmandt 2011).

Freshwater inflows are critical to both aquatic ecosystems and wetlands in the Southern Great Plains. Both surface and ground water depletion have led to dramatic changes of the aquatic and wetland communities in Kansas (Perkin et al 2017) that not only impact inland species but have a dramatic effect on coastal species relying on the freshwater inflow to ensure the integrity of the coastal ecosystem. Whooping Crane and many other migratory species flying through this region during both spring and fall are impacted (Mooney and McClelland, 2012). Climate change and human use have impacted these aquatic systems and wetlands, and ultimately the vital flow of freshwater to the coastal marshes and estuaries.

Changes to freshwater inflows to estuaries lead to changes in salinity and in flows of nutrients

and sediment, resulting in impacts to oysters and other sensitive estuarine species. In addition, harmful algal blooms have been increasing and are expected to worsen (NFWPCAP 2012). Reduced freshwater inflows during 2011 led to record high salinities in Texas estuaries that contributed to a coast-wide "red tide" harmful algal bloom event. Red tides, a type of harmful algal bloom, most commonly occur during drought years, as the organism that causes red tide does not tolerate low salinity. Red tide blooms cause fish kills and contaminate oysters. In addition, oysters and other shellfish can accumulate red tide toxins in their tissues. People who eat oysters or other shellfish containing red tide toxins may become seriously ill with neurotoxic shellfish poisoning. Once a red tide appears to be over, toxins can remain in the oysters for weeks to months. The 2011 bloom started in September and lasted into 2012. Fish mortality was estimated at 4.4 million. The commercial oyster season was closed and disaster declarations issued. The total economic loss was estimated at $7.5 million (Loeffler 2015).

Gray snapper have been ranging farther north since the 1990s; once found only in the lower Laguna Madre and off the extreme southern shore of Texas, they are now migrating northward along the upper Texas Coast. Conversely, flounder abundance has been declining due to the negative effect warmer winters have on recruitment (Montalvo 2010, Tolan and Fisher 2009), since sex ratios are influenced by temperature during flounder development and increases in temperature produce increasingly male-skewed sex ratios in southern flounder from Texas.

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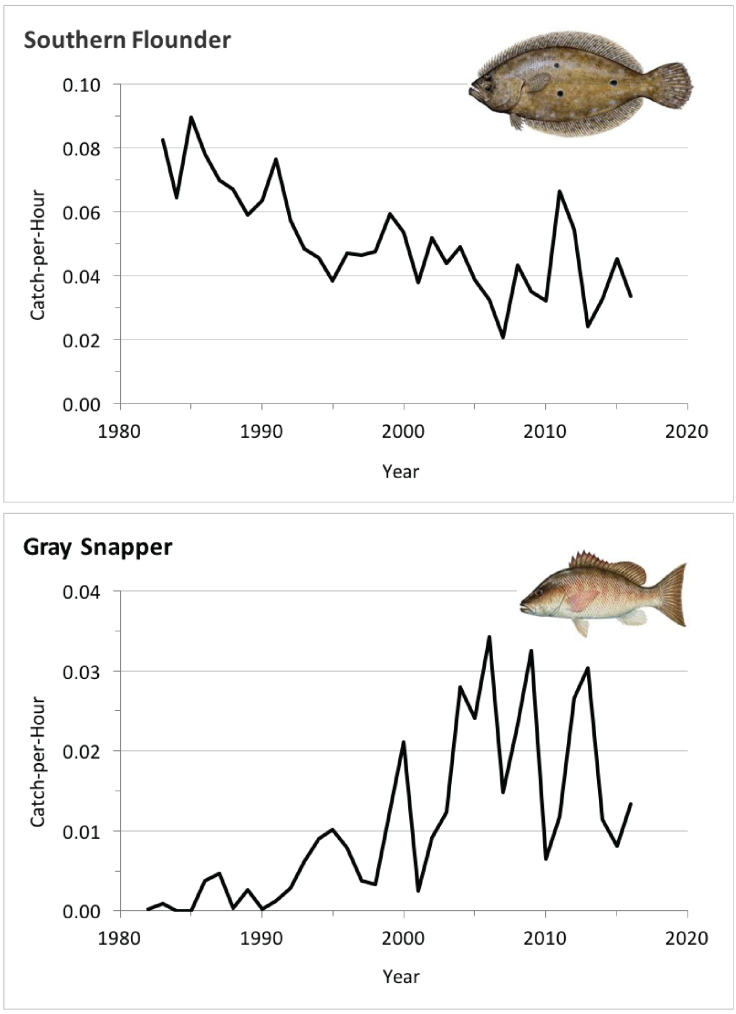

Title: Climate Winners and Losers (Gray Snapper and Southern Flounder)

Figure 23.2: Trends in annual abundance of gray snapper (bottom) and southern flounder (top). As water temperatures increase along the Texas Gulf Coast, gray snapper are expanding northward along the Texas coast, while popular southern flounder are becoming less abundant, impacting recreational and commercial fishing industry. Source: Texas Parks and Wildlife Department Coastal Fisheries Resource Monitoring Data.

What options exist for managing risk?

The National Fish, Wildlife and Plants Climate Adaptation Strategy (NFWPCAP 2012) was developed to provide natural resource managers and decisionmakers the strategies and tools to address climate change impacts. The Strategy offers a guide for actions that can be taken in spite of remaining uncertainties over how climate change will impact living resources.

The Texas Edwards Aquifer Implementation Program Habitat Conservation Plan (Recon et al. 2012) balances water pumping and use of the aquifer with protection of eight federally-listed threatened and endangered species that depend on San Marcos Springs and Comal Springs, two

of the largest springs in the southwestern United States. These springs are the headwaters of the San Marcos and Comal Rivers and provide important water flow especially during drought, to the Guadalupe River and Estuary.

Environmental flows—instream flows and freshwater inflows to bays and estuaries—are critical for sustaining aquatic ecosystems. In 2007, the Texas Legislature passed Senate Bill 3, which established a comprehensive, statewide process to protect environmental flows (Loeffler 2015). The process relies upon input from local stakeholder groups, composed of balanced interests ranging from agricultural water users to commercial anglers. The Texas Commission on Environmental Quality has adopted environmental flow standards intended to protect flow regimes that will help ensure healthy rivers, streams, and estuaries for Texas. The focus now is on adaptive management to refine standards, address research needs, and identify voluntary strategies to meet environmental flow standards.

Texas Coastal Resiliency Master Plan—Texas General Land Office 2017 (TGLO 2017): The Plan promotes coastal resiliency, defined as the ability of coastal resources and coastal infrastructure to withstand natural or human-induced disturbances and quickly rebound from coastal hazards. This definition encompasses the two dimensions of resiliency: 1) taking actions to eliminate or reduce significant adverse impacts from natural and human-induced disturbances, and 2) responding effectively in instances when such adverse impacts cannot be avoided. To keep pace with the dynamic Texas coastline, the Plan will be updated regularly to allow the state to continually assess changing coastal conditions and needs, and to determine the most suitable way to implement the appropriate coastal protection solutions.

Key Message 4*:* Human Health

Key Message 4: *Climate change will increase exposure to certain health threats, including extreme heat and diseases transmitted through food, water, and insects. These health threats may occur over longer periods of time, or at times of the year where these threats are not normally experienced. Given the widespread changes expected in the Southern Great Plains, health threats will be both varied and widespread.*

Extreme Heat

Extreme heat causes both direct and indirect impacts on human health and acts as a threat multiplier to the medically vulnerable. The increase in extreme heat due to climate change will exacerbate the medical issues associated with heat illness. More detail can be found in Chapter 14: Human Health.

Notably, heat stress is strongly correlated with complications of lung disease, such as asthma and emphysema, as well as dehydration and injurious electrolyte abnormalities. It is estimated that each approximately 1.8°F (1°C) degree increase in summer temperature increases the death rate for elders with chronic conditions by 2.8% to 4.0% (Zanobetti 2012). During heat waves, concrete, blacktop, and the low ventilation capacity of urban "canyons" created by tall buildings can add 7°–12°F to the urban heat load (Harlan et al 2006). The heatwave of 2011 exemplifies

the human health and health care system impacts of extreme heat in the Southern Great Plains. The average temperature from June to August in Texas was 86.7°F (30.4°C), which broke all previous single-month records and was 5.2°F (2.9°C) higher than the long-term climatological average (Hoerling et al 2013). Studies demonstrated a 3.6% increase in emergency room visits and a 0.6% increase in deaths, with the largest effect on the elderly (Zhang et al 2015, Chien et at 2016).

Vector-Borne Disease

Rising temperatures and precipitation alter the habitats of vectors (mosquitoes, ticks, rodents and fleas) that transmit a variety of human diseases. In the Southern Great Plains, Hantavirus (USCDC 2016a), Rocky Mountain Spotted Fever (USCDC 2016b), Leptospirosis (USCDC 2016c), and West Nile Virus (USCDC 2016d) are all currently endemic and may be impacted by climate change (Ebi and Nealon 2016, Klempa 2009). A warmer world will create newly hospitable habitats for tropical and subtropical insect vectors and the diseases they carry. Historically, disease-free areas have been protected from becoming hazardous by cold environmental temperatures. That is, with extreme low temperatures of winter, insect (and in particular, mosquito) populations are decimated. However, as the average global temperature increases, mosquitoes will thrive longer and reproduce more successfully at higher latitudes and altitudes. Tropical diseases, such as Dengue virus (DENV), Chikungunya virus (CHIKV), and Zika virus are transmitted by *Aedes* mosquitoes which are currently expanding their geographic range in the southern United States (Ebi and Nealon 2016). In southern Texas, sporadic, locally acquired outbreaks of Dengue have been reported (Thomas et al 2016). In 2005, there were 59 cases of DENV in southern Texas which met criteria for Dengue Hemorrhagic Fever (USCDCP 2005), indicating that inhabitants were exposed to multiple viral serotypes, a condition necessary for the development of severe manifestations of DENV. In 2014, locally transmitted cases of Chikungunya began to be reported in Texas (USCDC 2016e). Zika virus has also recently appeared in the region. In 2016, the U.S. Centers for Disease Control and Prevention issued a travel warning for Cameron County, Texas, after the first case of local, person-to-person transmission of Zika was reported (USCDC 2016f). The ecology of vector-borne diseases is complex, and the future risk for proliferation and expansion of the ranges of these diseases is possible under future climate scenarios (Gubler et al 2001, Butterworth et al 2017). Along the Southern Gulf Coast, stronger hurricanes could increase the likelihood of favorable ecologic niches for emerging infectious diseases that infect humans and animals (Steiner 2015a).

Drought

As water evaporates during periods of drought, the remaining water can have higher concentrations of chemicals and solid particles, lower dissolved oxygen levels, and a higher density of germs that cause infectious diseases. Fewer and smaller water sources during drought means that there are many more users (humans and animals) for a given (limited) resource, which makes germ transmission and outbreaks of infectious disease more likely. Waterborne diseases that have been linked to drought include amoebiasis, hepatitis A, salmonellosis,

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schistosomiasis, shigellosis, typhoid and paratyphoid fevers, infection with *E. coli*, cholera, and leptospirosis (Murray 2009, Effler et al 2001, Tauxe et al 1988, Bradley et al 1996). Skin infections, such as scabies and impetigo, and eye infections, including conjunctivitis, are also correlated with drought due to a lack of water available for personal hygiene (Stanke et al 2013).

Downstream—Food Stability and Access

Droughts, floods, and higher temperatures will change the balance of ecosystems, allowing invasive species such as animal pests, plant weeds, and algae blooms to proliferate and harm existing agriculture (Pimentel 1993). Such conditions favor fungal species that can overwhelm crops and contaminate animal feedstocks. An example is the fungal strain *Phytophthora infestans*, which was responsible for the great Irish potato famine of the 1840s, and its variation that currently causes $6 billion in crop damage per year in the United States alone (Callaway 2013, Barford 2013). Additionally, increases in CO_2 are changing the nutritional composition of food crops (Myers et al 2017). Elevated CO_2 levels have been shown to reduce the protein composition of grains, tubers, rice, wheat, and barley (Myers et al 2014). Micronutrient contents are also affected by rising CO_2 levels, with atmospheric CO_2 concentrations of 550 parts per million being associated with reductions in zinc, iron, phosphorus, potassium, calcium, sulfur, magnesium, copper, and manganese across a wide range of crops (Loladze 2014).

Key Message 5: Indigenous Peoples

Key Message 5: *Tribal nations and indigenous communities in the Southern Great Plains are particularly vulnerable to the effects of climate change, including water resource impacts, extreme weather events, higher temperatures, and other public health issues. Efforts to adapt and build community resilience may be hindered by economic, political, and infrastructure limitations. Traditional knowledge and intertribal organizations provide opportunities to respond to the challenges of climate change.*

The 46 federally recognized tribes (48 if state-recognized tribal nations are included) located in the Southern Great Plains show considerable economic, social, cultural, and linguistic/language diversity (Hoxie and Iverson 2014, Tribble 2014, Wilkins and Stark 2017). The 4 tribes of Kansas (59,130 people), 39 tribes of Oklahoma (482,760 people), including 1 state-recognized tribe, and 5 tribes of Texas (6,210 people), including 2 state-recognized tribes, experience the same climate change impacts as the rest of the Nation (USCB 2016). However, these sovereign nations within the United States are faced with infrastructure (social and physical), economic, political, and cultural challenges as well as unique opportunities in their response to climate change impacts.

Climate Change Threats to Tribal Cultural Traditions and Community Resilience

No climate change threats are as significant to the tribal nations of the Southern Great Plains as those that threaten the ability to procure food, water, shelter, and preserve ancient cultural activities (Maldonado et al 2014, NCAI 2016, Adger et al 2013). Given the ancient symbiotic relationship between environment and culture that shapes tribal identities and life-way practices,

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climate-induced changes to the seasons, landscapes, and ecosystems pose an existential threat to tribal cultural traditions and community resilience (Daigle et al 2014, Deloria and Wildcat 2001, Wildcat 2009). For example, climate change, including the impacts of excessive heat, drought, and the disappearance of native species, is already disrupting ceremonial cycles in Oklahoma (Blanchard 2015; Yellowman 2017).

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Physical and Organizational Infrastructure

The region's tribal nations vary greatly in size, from small nations with fewer than 1,000 enrolled members to larger nations with over 50,000 enrolled members; the largest of the tribes is the Cherokee Nation with more than 317,000 enrolled members (Cherokee, 2016). The smaller nations, given their population size and respective size of government, often struggle to exercise their sovereignty to respond to climate change due to a lack of organizational and physical infrastructure (Warner and Kronk 2014, McNeely 2017). The social organizational infrastructure needed to adapt to climate change impacts like extreme weather events, rising temperatures, shifting seasons, invasive species, air and water quality issues, and a host of health impacts is often lacking or underdeveloped in small tribal nations. Consequently, the smaller tribes depend largely on the services, grant programs, and technology transfer capabilities of the Bureau of Indian Affairs and other Federal government departments, agencies, and bureaus to assist in their climate adaptation efforts. There are exceptions—larger and wealthier tribal nations, such as the Chickasaw Nation, Citizen Band Potawatomi, and Muscogee Creek Nation can develop and shape, to a much larger extent, their own climate adaptation strategies (Bierbaum et al 2013).

Lack of physical infrastructure, tied directly to limited economic resources and power, poses a substantial obstacle to climate change adaptation for the tribes of the region. While cities and other governmental jurisdictions make plans to build resilient physical infrastructure by using

bonds, public-private partnerships, and taxes and tax instruments, only a handful of tribal nations have the ability to use these tools for climate adaptation. Most tribal nations remain dependent on underfunded federal programs and grants for building and construction activities that could improve the resiliency of their infrastructure in the face of climate change threats. Many larger and wealthier tribes have modeled construction and design of homes and large commercial building best practices on "green" or resilient net-zero carbon footprint designs. Increasing activity in community gardens, food recovery, recycling, water conservation, land-use planning, and investment in climate-resilient community design all signal opportunities for tribal nations to "leap-frog" significant obstacles other city, county, and state governments face when dealing with the costs of existing physical infrastructure that often make climate change adaptation difficult and incremental.

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Traceable Accounts

Author Process Description

The initial Southern Great Plains author team was selected such that expertise from each of the state's officially recognized climate offices in the region (Kansas, Oklahoma, and Texas) was included. The offices of the state climatologist in Kansas, Oklahoma and Texas are each members of the American Association of State Climatologists (AASC). AASC was founded in 1976 and is the recognized professional scientific organization for climate expertise at the state level. We are fortunate to have each of the AASC-recognized state climatologists from the region on our author team.

In addition, the Southern Great Plains is host to several regional hubs of national and regional climate expertise. These include the U.S. Department of Agriculture Southern Plains Climate Hub located in El Reno, OK; the U.S. Department of the Interior South Central Climate Science Center in Norman, OK; and the National Oceanic and Atmospheric Administration Regional Integrated Sciences and Assessments (RISA) Southern Climate Impacts Planning Program (SCIPP) in Norman, OK. One representative from each of these centers expertise was included on the author team.

After assessing the areas of expertise of the six author selectees from the state and regional centers above, a gap analysis was conducted to prioritize areas of expertise that were missing. Because of the importance of the sovereign tribal nations to the Southern Great Plains, an accomplished scholar with expertise in indigenous knowledge on the environment and climate change was also selected. The selectee was from the premiere tribal university in the U.S., Haskell Indian Nations University in Lawrence, KS. An additional need was to gain expertise at the complex intersection of coupled atmosphere-land-ocean systems, climate, and humans (population and urbanization). We selected an individual from the Environmental Science Institute at the University of Texas at Austin with this expertise. We also needed someone with expertise in the electric utility industry. To fill this need we added expertise from the Oklahoma Association of Rural Electric Cooperatives. This individual has a long history of working with rural and urban populations, and with researchers and forecasters in weather and climate.

It was then determined that we would allow Southern Great Plains stakeholders to drive additional priorities. A multi-state, multi-modal listening engagement workshop was held. The productive dialog at this workshop identified important needs in environmental economics, ecosystems, and health. Scientists working at the cutting edge of research in these three areas were selected. The ecosystems expert was from the Texas Department of Wildlife. The environmental economist was from the Department of Geography and Environmental Sustainability at the University of Oklahoma. The health experts are from the University of Colorado School of Medicine and the Aspen Global Change Institute, and have significant expertise in interdisciplinary global and regional health and climate change research.

This diverse collection of doctors, academicians, researchers, scientists and practitioners give the

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Southern Great Plains chapter a wealth of expertise across the many ways in which climate change will affect people in our region.

Key Message 1: Food, Energy, and Water Resources

Key Message 1: The region's growing population, the migration of individuals from rural to urban locations, and climate change will increase and redistribute demand and result in resource contention at the intersection of food consumption, energy production, and water resources (*likely*, *high confidence*). This "nexus" is inextricably linked to quality of life, particularly in rural areas as well as across both national and transnational borders. (*likely*, *high confidence*).

Description of evidence base

The connection between food, water and energy are inextricably linked, yet this connection also creates great challenges in managing and distribution of resources. People need food, energy and they need water, yet all sectors pull from each and allocation is a challenge. There are many references of the competitive nature revolving around these resources and the demand by people (Berady & Chester 2017). The management and application of these issues are social in context and require significant communication and collaboration to resolve. As demands for these resources become more acute, development of collaborative processes to ensure integrated use and allocation will be required.

Major uncertainties

Complexities of the water, food, and energy nexus creates a level of uncertainty that is difficult to document and establish high certainty. It is likely, and with significant certainty, that the completion and use of the resources for people will continue; however, the likelihood of developing a means to manage this situation is another matter. The added complexities of people and cultures, a rapidly growing population, and a diminishing availability of resources (water especially) in this geography, will be at the forefront of many political efforts and the very fabric of the southern great plains.

Description of confidence and likelihood

The southern Great Plains will continue to grow rapidly and with high probability of significant competition. Water is the major concern and political inability to develop a system to allocate water in an equitable manner will continue to build this competitive and contentious issue among all users—energy, food, and water.

Key Message 2: Infrastructure

Key Message 2: Higher temperatures, extreme precipitation, and rising sea levels associated with climate change make the built environment in the Southern Plains increasingly vulnerable to disruption, particularly as infrastructure ages and populations shift to urban centers (*likely*, *high confidence*). Coastal infrastructure remains particularly at risk as most climate projections suggest sea level rise of up to four feet if emissions are not reduced

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(*likely*, *high confidence*).

Description of evidence base

The existing infrastructure and projected models for growth are well established and documented. Population growth models are refined and high degree of certainty exists for these efforts to have major impacts on our culture. Population growth is linked to the budgets which cannot keep up with demand and climate-related issues will take significant maintenance resources.

Major uncertainties

Ground transportation during floods is susceptible to environmental factors which clearly reduce life expectancy and use. With reduced maintenance, these issues could become acute, but the outcomes are less certain than the actual impacts.

Description of confidence and likelihood

Cities like El Paso and Austin, Texas are and will continue to be significantly impacted by climate.

Key Message 3: Ecosystems and Ecosystem Services

Key Message 3: Climate change affects terrestrial and aquatic ecosystems, influencing extreme droughts, unprecedented floods, and wildfires that directly and indirectly alter ecosystems and impact species (*likely*, *high confidence*). Some species adapt to changing climates, while others cannot, resulting in significant impacts to both services and people living in these ecosystems (*likely*, *high confidence*).

Description of evidence base

The Ecosystem Key Message was developed through technical discussions developed within science teams and collaborators of the Gulf Coast and Great Plains LCCs, using scientific literature, relevant evidence and expert deliberation by the authors.

The author team also engaged in targeted consultations during exchanges with contributing authors, who provided additional expertise on subsets of the Traceable Accounts associated with each Key Message.

Major uncertainties

Ecosystems and the species that occur in these ecosystems have witnessed a rapid decline in many “common species” as well as certain rare species. Increases in many non-native species have led to both concern and opportunity. Continued habitat and population shifts and the impact of interactions between people, other resources and available habitat stressors are vague. Indirect impact to livestock and agricultural systems is also unknown. The uncertainty of animal and plant diseases and parasites impacting commercial production and the interaction with wild species is anticipated, but the degree of impact is uncertain.

Description of confidence and likelihood

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There is *high confidence* that rising temperatures and increases in flooding, runoff events, and drought will *likely* lead to changes in the aquatic and terrestrial habitats supporting many regional species. Flooding has changed the complex of many riparian habitats. Increases already seen in extreme drought have caused downturns in the fish and wildlife related industries, with losses in traditional fish (crab and oysters) and wildlife species (waterfowl) important for both recreational and commercial purposes.

In contrast, habitat created by invasive species due to climate changes has improved populations of other species. The expanded stress due to a rapidly growing population in this region increases the likelihood (*high confidence*) of negative natural resource and ecosystems outcomes in the future.

Key Message 4*:* Human Health

Key Message 4: Climate change will increase exposure to certain health threats, including extreme heat and diseases transmitted through food, water, and insects. (*highly likely*, *high confidence*) These health threats may occur over longer periods of time, or at times of the year where these threats are not normally experienced (*likely*, *medium confidence*). Given the widespread changes expected in the Southern Great Plains, health threats will be both varied and widespread (*likely*, *high confidence*).

Description of evidence base

The health Key Message was developed with a thorough connection between the Human Health Chapter (Ch. 14) team and many highly skilled scientists keenly aware of the recent past, current, and projected future changes. Many of the health-related issues are very well documented with strong evidence of impacts to all living organisms. Multiple lines of research have shown that changes in weather extremes, such as increased extreme precipitation (leading to flooding and runoff events), can result in increased microbial and chemical contamination of crops and water in agricultural environments, with increases in human exposure (Ch. 7: Ecosystems & Biodiversity).

Major uncertainties

The direct health impacts to people and livestock are clearly expected, and there is consensus that this has a high level of certainty. The uncertainty develops when there are many connected actions that influence how those indirect and combined effects of these changes will promote or change in new and unknown health-related issues. It is now and will be expected to remain unclear in the future, whether the impact of climate change on any one disease organism will be good or, in contrast, will be detrimental to that specific organisms' impact on people and animals. Parasites continue to develop further north, impacting many animals that were not influenced by those organisms in the past. Likewise, many beneficial organisms may reveal an unexpected change as ecological conditions change.

Description of confidence and likelihood

There is *very high* confidence that rising temperatures and increases in flooding, runoff events,

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and drought will likely lead to change for health and disease considerations. The very young and old, as well as those without air conditioning, will be disproportionately affected by the heat, in part because they cannot protect themselves and because their bodies do not regulate body temperature very well.

Key Message 5: Indigenous Peoples

Key Message 5: Tribal nations and indigenous communities in the Southern Great Plains are particularly vulnerable to the effects of climate change, including water resource impacts, extreme weather events, higher temperatures, and other public health issues (*likely, high confidence)*. Efforts to adapt and build community resilience may be hindered by economic, political, and infrastructure limitations. Traditional knowledge and intertribal organizations provide opportunities to respond to the challenges of climate change (*likely, medium confidence*).

Description of evidence base

The tribal Key Message was developed through dialogue and discussions developed among indigenous communities and the social sciences. With indigenous communities varying in size from smaller nations to large well-formed governments, they all are in need of communication about the changes and realities of climate. There is strong evidence that because of the unique nature of the indigenous, including previous and ongoing experiences of the communities, the collective economic and political power for enacting efficient and effective climate adaptation responses may be limited at best. There seems to be a high to extremely high consensus among the nations that impacts of climate will be a direct threat to the symbiotic connection between environment and the tribal traditions connecting the people with the land.

Major uncertainties

Communicating with clarity and connecting with the widely variable size of tribal communities leads to a great deal of uncertainty regarding how climate change will be integrated into their cultures. It is likely adaptation strategies will vary greatly as knowledge and communication may not be widely supported within all nations. Due to disproportionate rates of poverty and access to information and collaborative support, some communities may suffer more than others; however, the degree and the impacts are very unclear.

Description of confidence and likelihood

There is *high confidence* that extreme events and long-term climate shifts will lead to changes in the SGP Indigenous communities. Environmental connections will be direct, but the degree is uncertain, and how the shifts in climate impact each nation will vary widely. How changes will be perceived and managed, and what steps are taken to adapt, are vague and come with a *low* level of confidence that adaptation will be a successful mechanism among all peoples.

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