Fifth National Climate Assessment: Chapter 26

Southern Great Plains

Chapter 26. Southern Great Plains

Authors and Contributors

Federal Coordinating Lead Author

Philip A. Fay, USDA Agricultural Research Service

Chapter Lead Author

Renee A. McPherson, University of Oklahoma, South Central Climate Adaptation Science Center

Chapter Authors

Susan G. Alvarez, City of Dallas, Texas

Darrian Bertrand, University of Oklahoma, Southern Climate Impacts Planning Program

Taylor L. Broadbent, South Central Climate Adaptation Science Center

Tianna Bruno, University of California, Berkeley

Ali Fares, Prairie View A&M University

Brian McCullough, Texas A&M University

Georgianne W. Moore, Georgia Southern University

Bee Moorhead, Texas Impact Foundation

Laura Patiño, City of Austin, Texas

Alexander "Sascha" Petersen, Adaptation International

Nicholas G. Smith, Texas Tech University

Jean L. Steiner, Kansas State University

April Taylor, Chickasaw Nation

Travis Warziniack, USDA Forest Service

Technical Contributors

Juan Pablo Carvallo, Lawrence Berkeley National Laboratory

Mark Junker, Sac and Fox Nation of Missouri in Kansas and Nebraska

Gary McManus, Oklahoma Climatological Survey

Lauren E. Mullenbach, University of Oklahoma

John W. Nielsen-Gammon, Texas A&M University

John A. Quinlan, NOAA Fisheries, Southeast Fisheries Science Center

Adrienne M. Wootten, University of Oklahoma

Review Editor

Mark Shafer, University of Oklahoma

Cover Art

Cody Norton

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Introduction

Residents and visitors in the Southern Great Plains—Kansas, Oklahoma, and Texas—benefit from the region's working coasts, sandy beaches, southern forests, grasslands, urban areas, rural towns, scrublands, rangelands, and croplands. The region spans 20 ecoregions,[1] each with distinct and diverse species of plants and animals. Those ecosystems provide clean air and water, healthy soils, landscapes for recreation and tourism, habitats for wild plants and animals, and other benefits.[2] The region's 47 Federally Recognized Tribes were forcibly relocated to the region from elsewhere or constricted to fragments of their traditional homelands (circa 1830–1890).[3] Contemporary immigrants from many countries have joined generations of Indigenous Peoples and those who trace their roots to Mexico, Europe, and Africa.[4] The region's distinct peoples and ecosystems experience the impacts of climate change differently, requiring unique responses to climate risk and resources for resilience.

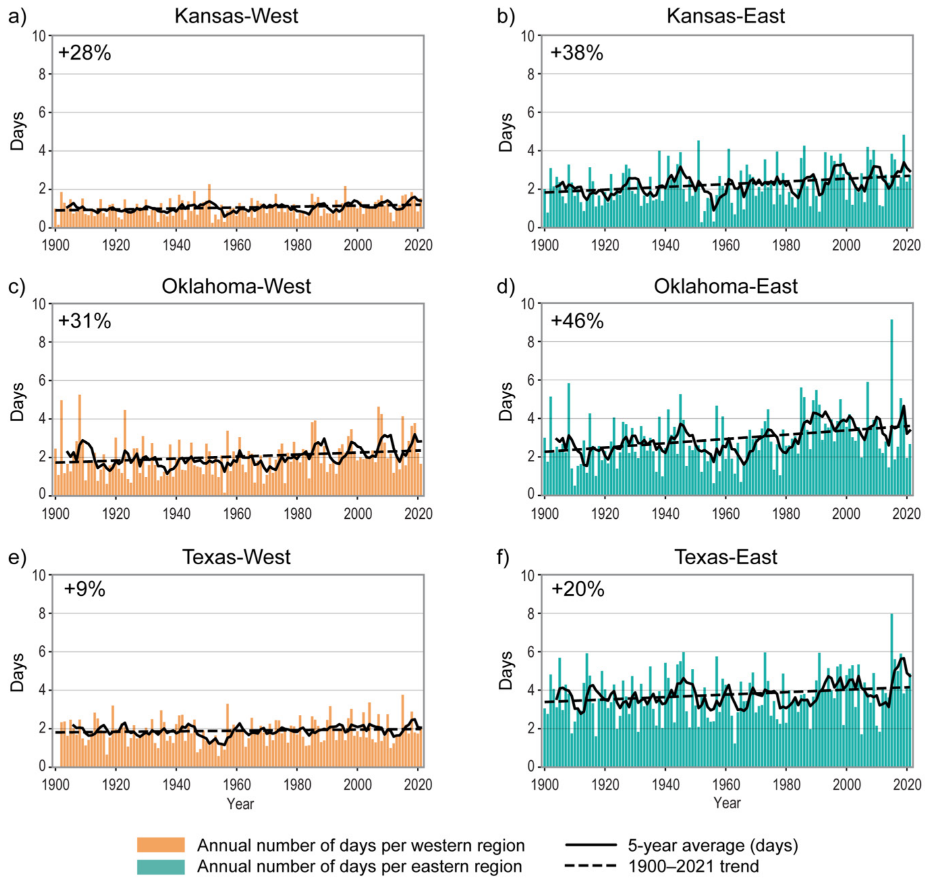
Water is unevenly available across the Southern Great Plains, contributing to distinct lifestyles, workforces, and social burdens. Annual precipitation amounts are lowest in the western portion of the region (10–15 inches) and increase substantially near the eastern boundary (over 50 inches), with high annual and seasonal precipitation variability everywhere.[4] Rivers generally flow from northwest to southeast, and shallow transient wetlands dot western landscapes. These surface waters are critical to sustain irrigation, livestock, and ecological diversity.[5,6] Groundwater is essential near and west of Interstate 35, with aquifers primarily supporting agricultural production and public water supply.[7] Although governments have created reservoirs for flood control, drinking water, irrigation, and recreation,[8] the region experiences some of the country's worst water shortages, and these are projected to increase in both intensity and duration.[9]

Energy is a dominant driver of the region's economy. The vast reserves of fossil fuels in the region have supported economic development nationwide and worldwide.[10] In the past two decades, wind and solar energy generation has proliferated across western lands. In 2021 Texas, Oklahoma, and Kansas ranked first (34,400 megawatts [MW] of installed capacity), third (10,400 MW), and fourth (8,300 MW), respectively, in the Nation in wind energy generation.[11] The reliability of renewable and nonrenewable energy generation and distribution is challenged by tropical storms, wildfire, heat, winter storms, flooding, and drought (KM 5.1).

The region encompasses some of the Nation's fastest-growing cities as well as many small rural communities with declining populations. Rural communities support much of the region's food, fiber, and energy production, in addition to recreational activities. The region's metropolitan areas are leaders in finance, research and development, service and energy industries, medical care, and tourism. Climate extremes and their impacts have harmed all communities, damaging infrastructure and agricultural production, disrupting commerce and price stability, and amplifying social inequities (KMs 11.1, 11.3, 12.2).

Although climate change is global (KM 3.1), its specific impacts are regional (KM 3.3). Thus far, the Southern Great Plains has seen fewer direct, large-scale impacts of climate change than other regions because of its relatively low latitude, flat terrain, and high natural climate variability. Even so, annual average temperatures have increased from 1900 to 2020: 1.5°F for Texas and Kansas[12,13] and 0.6°F for Oklahoma.[14] Annual precipitation has increased across most of the region except far west Texas (Figure 2.4). In addition, days with 2 or more inches of precipitation have become more frequent across the Southern Great Plains, with larger increases in the eastern half of the region than the western half (Figure 26.1).[15] Between 2000 and 2021, Texas endured its five wettest months on record, as well as 19 named tropical storms;[13] 8 of these storms were hurricanes, including Harvey (2017), Ike (2008), and Rita (2005). In contrast, over one-quarter of Kansas experienced severe to exceptional drought during 56 of the 156 months from 2010 to 2022. During this period, Oklahoma and Texas experienced 69 and 82 months, respectively, of these severe to exceptional drought conditions.[16] Between 2018 and 2022 NOAA reported 52 individual billion-dollar climate-related disasters affecting all or part of the region.[17]

Annual Number of Days with Precipitation of 2 Inches or More (1900–2021)



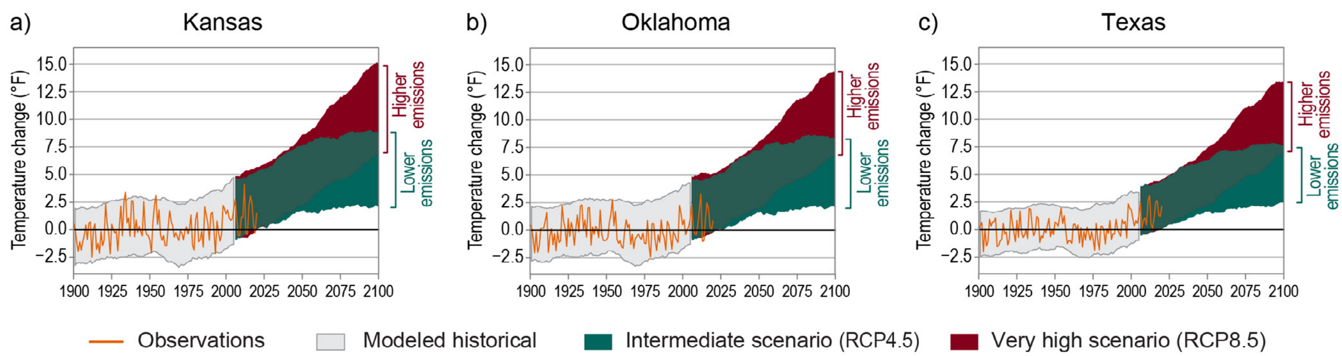
The frequency of days with precipitation of 2 inches or more has increased across the Southern Great Plains.

Figure 26.1. These graphs show the annual number of days (colored bars) with daily precipitation of 2 inches or more from 1900 to 2021 in (**a**) western Kansas (28% increase for the long-term, linear trend), (**b**) eastern Kansas (38% increase), (**c**) western Oklahoma (31% increase), (**d**) eastern Oklahoma (46% increase), (**e**) western Texas (9% increase), and (**f**) eastern Texas (20% increase). (Station data were unavailable for 1900 and 1901 in western Texas.) Solid black lines show five-year averages; dashed black lines denote the 1900–2021 trend. The number of days has been highly variable from year to year, with fewer 2-inch events in the west (gold bars) on average than in the east (green bars; divided at 97.5° west, near Wichita, Oklahoma City, Fort Worth, and Corpus Christi). Days with precipitation of 2 inches or more have increased in all six regions. Figure credit: NOAA NCEI and CISESS NC.

Since the Fourth National Climate Assessment in 2018, there has been substantial growth in utility-scale electricity generation from wind energy across the region and from solar energy in Texas. At the same time, there has been a significant decrease in the use of coal for electricity in Oklahoma and Texas,[18] although Texas's greenhouse gas emissions still far exceed those of any other US state.[19] The February 2021 cold outbreak and the COVID-19 pandemic highlighted the fragility of the energy and healthcare systems to large-scale stressors. Many of the largest cities in the Southern Great Plains have released climate resilience or sustainability plans since 2018. As research has grown on the disproportionate impacts of climate change on overburdened populations, these cities also have started incorporating social justice concepts into their planning processes.

Future temperatures are expected to be historically unprecedented in the instrumental record in all three states (Figure 26.2). By midcentury, annual average temperatures are projected to exceed historical record levels regardless of emissions pathway. In addition, the number of extremely hot days and the intensity of drought conditions are projected to increase, and the number of extremely cold days is expected to decrease (KM 2.2). In general, southwestern and southern areas of the Southern Great Plains are projected to become drier, and northeastern areas are expected to become wetter (Figure 2.10). The changes in timing, intensity, and frequency of certain climate conditions and extreme events are expected to influence how we—the residents of the Southern Great Plains—live with family and friends (KM 26.1), work in business and industry (KM 26.2), play sports and enjoy leisure activities (KM 26.3), heal existing environmental inequities and injustices (KM 26.4), and serve residents through public infrastructure and services (KM 26.5).

Historical and Projected Changes in Air Temperature (1900–2100)



Air temperatures for Kansas, Oklahoma, and Texas are projected to be historically unprecedented by the end of the century.

Figure 26.2. These graphs show observed and projected changes (compared to the 1901–1960 average; thick black line) in near-surface air temperature for (**a**) Kansas, (**b**) Oklahoma, and (**c**) Texas. Annual average temperature observations (orange line) are plotted with the range of temperatures from climate model output (light gray shading) for the historical period. The overlap of observed and modeled temperatures indicates that the models represent the region's climate reasonably well. Climate projections out to 2100 use an intermediate scenario (RCP4.5; green shading) and a very high scenario (RCP8.5; red shading), showing a range of possible future temperatures. Results from both scenarios indicate substantial warming in Kansas, Oklahoma, and Texas by midcentury and historically unprecedented warming by the end of the century. (a, b) Adapted from Frankson et al. 2022[12] and Frankson et al. 2022;[14] (c) adapted from Runkle et al. 2022.[13]

Key Message 26.1

How We Live: Climate Change Is Degrading Lands, Waters, Culture, and Health

Climate change is beginning to alter how we live in the Southern Great Plains, putting us at risk from climate hazards that degrade our lands and waters, quality of life, health and well-being, and cultural interconnectedness (*high confidence*). Many climate hazards are expected to become more frequent, intense, or prolonged; to broaden in spatial extent; and to result in more people experiencing costly, deadly, or stressful climate-related conditions (*very likely*, *high confidence*). To address the growing risk, effective climate-resilient actions include implementing nature-based solutions; valuing Indigenous, traditional, and local knowledges; and infusing climate change solutions into community planning (*medium confidence*).

Lands and waters of the Southern Great Plains are important to people's ways of life, shaping the stories of family and community successes and struggles. Climate change has added stress to lands and waters that already contend with invasive species, land-use change, and land fragmentation (KM 8.2).[20] Rangeland and grassland health is being degraded by woody plant encroachment from precipitation changes[21] or fire suppression.[22] Wetlands are suffering from high evaporation rates or excess nutrient inputs from flood runoff.[23] Ice storms, drought, and high temperatures have stressed forests, making them susceptible to post-event trauma (e.g., disease, pests, fire) and mortality.[24,25,26]

Urban landscapes are being harmed by air and water pollution, extreme heat, drought, and flooding (KM 12.2). As climate change brings heavier rainfall, cities and towns are increasingly at risk of high-impact floods. The extensive impervious surfaces (e.g., parking lots, roofs) of metropolitan areas such as Houston (Box 26.1) increase the likelihood of widespread flooding because of increased runoff.[27] Coastal cities have added risk from sea level rise. By 2100, under a projected 3.3 feet of sea level rise along the Texas Gulf Coast, a Category 2 hurricane is estimated to cause 3–10 times more damage to buildings and be $10.4 billion (in 2022 dollars) more costly (from averages of $3.7 to $14.1 billion) than a similar storm today.[28]

Traditions, heritage, and culture related to land and water are also at risk because of changes forced by novel climatic conditions.[29,30] Warming temperatures are shifting ranges of culturally significant species, making them absent or rare on lands where Indigenous People have access.[31] Heavy rainfall and resulting flooding have inundated archaeological sites.[32] Large-scale or repetitive damages from sea level rise, tropical cyclones, drought, and flooding have increased displacement of people and migration at the Texas–Mexico border and from coastal communities (KM 9.3).[33,34,35,36]

Tribes are revitalizing their cultural practices and relationships with nature to find solutions that resonate with their traditions (KMs 16.2, 16.3). For example, the Tribal Alliance for Pollinators is building on Indigenous cultural and medicinal traditions to preserve and restore grassland ecosystems for monarch butterflies and other threatened pollinators.[31] To reduce harmful algal blooms that proliferate with hot temperatures,[37] the Chickasaw Nation has teamed with local landowners and agriculture producers in southern Oklahoma to remove invasive junipers, improve fertilizer application methods, and restore native habitats for ground-nesting birds.[38]

Box 26.1. Place Matters: A Case Study of Houston, Texas

Adaptation and mitigation actions occur at the local level, where people's values and the neighboring landscape matter. Houston, Texas, illustrates how urban communities are starting to incorporate climate-smart actions into their planning efforts.

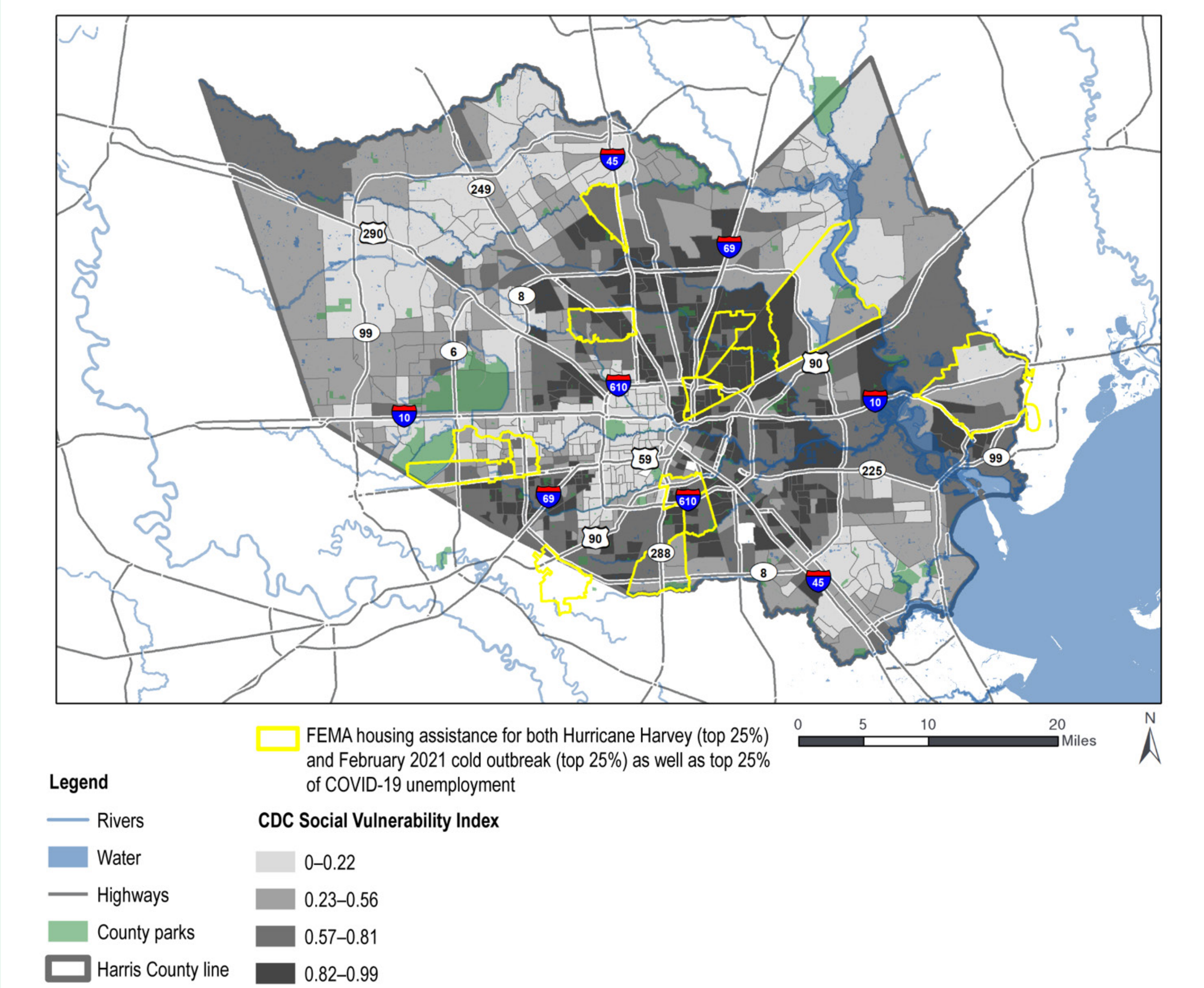
Houston is a city of 2.3 million people within a broader metropolitan area of 7.2 million.[39,40] It became a major port city because the navigable depth and orientation of the Buffalo Bayou supported the export of products from fertile inland croplands.[41] By the early 1900s, oil and gas production emerged, and companies moved into Houston to shelter from coastal storms after the catastrophic 1900 Galveston hurricane.[42] Now, Houston is one of the Nation's fastest-growing cities, and its port is the Nation's largest by tonnage. It is home to NASA's Johnson Space Center and the world's largest medical complex, the Texas Medical Center.

Demographically diverse, Houston residents are predominantly Hispanic (38%), White (35%), Black (17%), and Asian (8%).[43] One-quarter of Houstonians are foreign born, speaking almost 150 different languages. Social inequities and historic racism exacerbate many Houstonians' ability to prepare for, respond to, and recover from climate impacts. For example, 45% of Black and Hispanic residents do not have cash available to cover an unexpected $400 expense during an emergency, as compared to 13% for Whites and 7% for Asians.[44]

Houston experienced 35 federally declared disasters during 1982–2022; one-third of these were since 2015. Devastating floods occurred in April 2016 (the "Tax Day Flood"), August 2017 (Hurricane Harvey), September 2019 (Tropical Storm

Imelda), and September 2020 (Tropical Storm Beta). In August 2011, residents experienced 24 days of air temperatures above 98°F.[45] The February 2021 cold outbreak (Box 26.2) crippled much of Houston's energy and water systems. The effects of these disasters compound (Figure 26.3; Focus on Compound Events), amplifying harm to populations especially at risk.

Compounding Damages in Houston, Texas, from a Hurricane, Cold Outbreak, and Pandemic



Damages from compounding events—a hurricane, cold outbreak, and pandemic—disproportionately impacted socially vulnerable populations in Houston, Texas.

Figure 26.3. Several areas in Houston (yellow outlines) that were most affected by Hurricane Harvey, the February 2021 cold outbreak (unofficially named "Uri"), and COVID-19 unemployment coincided with census blocks with high scores on the Social Vulnerability Index (SVI) from the CDC (darker gray shading). (The SVI measures 16 social factors that describe socioeconomic status, household characteristics, racial and ethnic status, housing type, and transportation access.) For the weather events, zip codes were ranked by number of valid registrants to FEMA's Individual and Households Program for financial assistance; for COVID-19, zip codes were ranked by percentage of population claiming unemployment insurance due to COVID-19, according to Texas Workforce Commission data from May 2020 to June 2021. The zip codes in the top 25% by those metrics are outlined in yellow. Adapted from Map 5 of Rice University's Kinder Institute for Urban Research 2022.[46]

Houston acted in response to these experiences and the scientific consensus on climate change. The city established a chief resilience officer in 2019. It published its Resilient Houston strategy and climate action plan in 2020[47] to prepare for, withstand, and recover from sudden catastrophic events and slow-moving disasters, including those worsened by climate change. In August 2020, Houston hosted the Nation's largest single-day, community-led effort to measure and map where urban heat was most severe. One month later, the city released its climate impact assessment,[48] illustrating how climate change is expected to affect Houston's future. Other initiatives included an urban prairie resilience project and a green stormwater tax-abatement program.

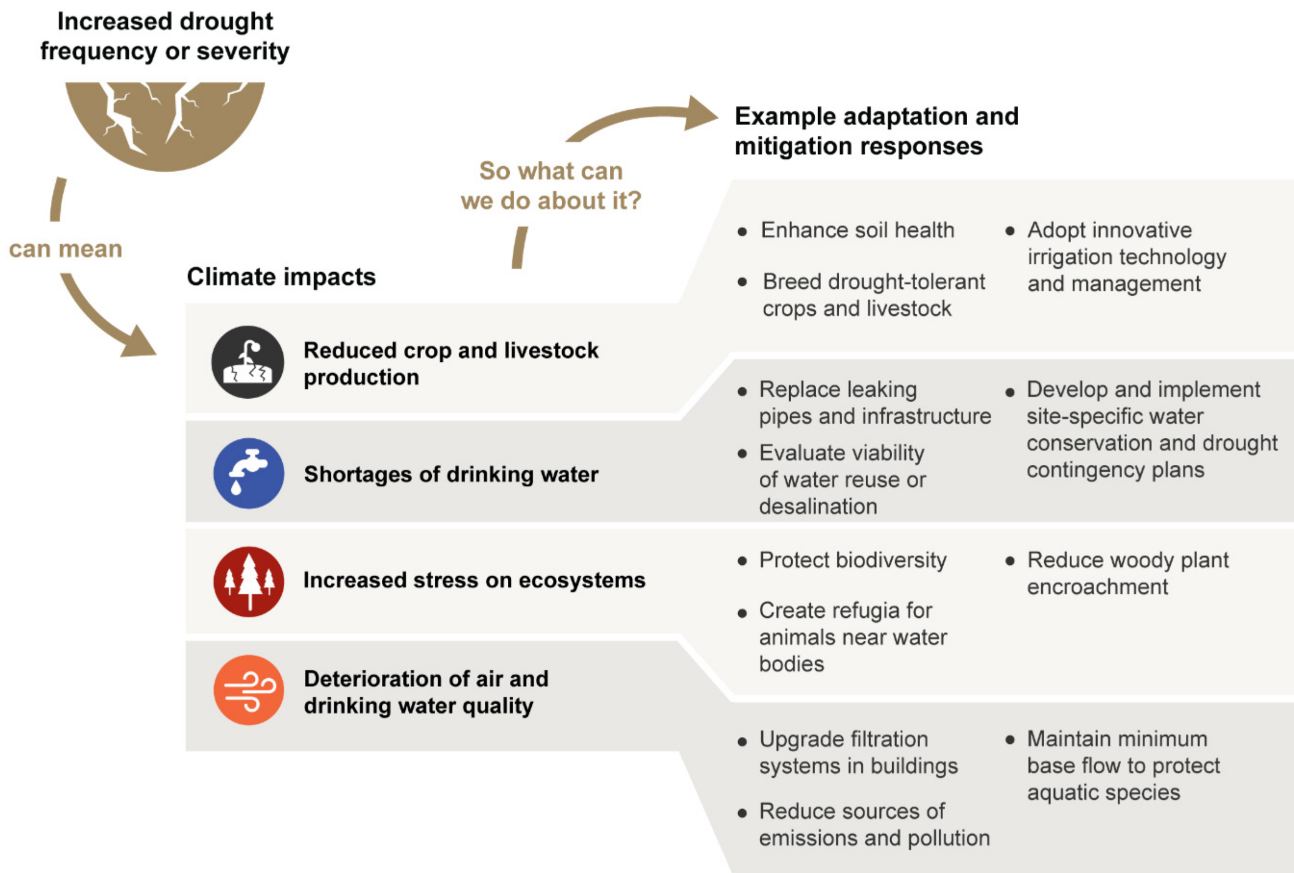
Climate change is also affecting public health through cardiovascular stress from temperature extremes, respiratory diseases enhanced by allergens and pollutants, increases in transmission of vector-borne diseases (e.g., via mosquitoes), and illnesses caused by poor water quality (KM 15.1). Many of these risks are compounded by ecosystem and land-use change. For example, global warming has induced earlier and longer pollen seasons, with consistent changes during the past three decades in Texas.[49] From 1987 to 2020, expansion of eastern red cedars was associated with a 205% increase in allergenic pollen intensity in Tulsa, Oklahoma.[50] During grass-pollen season, the region's emergency medical facilities are expected to see an average of 720 (under an intermediate scenario [RCP4.5]) to 980 (very high scenario [RCP8.5]) more asthma patients annually by 2050.[51]

High temperatures, particularly when combined with high humidity, have impaired human health. In Oklahoma, most heat-related deaths have occurred from July to September during heatwaves.[52] People who are male, Black, 65 years or older, diabetic, unmarried, without air-conditioning, or living below the poverty line have been at higher risk of heat-related death (KM 15.2).[52,53] Warmer temperatures also have worsened air pollution by increasing near-surface ozone.[54] In 2023, 18 Texas counties in the Dallas–Fort Worth and Houston–Galveston metropolitan areas exceeded national ozone standards (i.e., 8-hour ozone concentrations of 0.100 – 0.113 parts per million), affecting more than 12 million people.[55]

Rising temperatures are extending the ranges and lengthening the active seasons of ticks, mosquitoes, and other disease vectors (KM 15.1).[56] For instance, host-seeking activities of ticks, which usually suspend in cold temperatures, were reported during January and February 2017 in eastern Kansas and Oklahoma.[57] Warmer temperatures in the future are expected to support the range expansion of tropical diseases, including dengue, West Nile virus, Chagas disease, and chikungunya.[58] Across western parts of the region, future warmer and drier conditions are projected to support an increased incidence of Valley fever,[59] which is endemic in parts of Texas.[60]

Climate-smart planning (Figure 26.4) is alleviating some harmful consequences of climate variability and change that threaten residents' health. Urban tree canopy assessment,[61] planning,[62] and planting[63] efforts are aiming to reduce the negative impacts of increased temperatures, air pollution, and variable precipitation on urban landscapes.[64] Community food forests, such as the Osage Orchard in Pawhuska, Oklahoma, provide food sovereignty and security, climate resilience, and public health benefits.[65] Still, a lack of resources among many Tribes,[66] outdoor and migrant workers,[67] and overburdened populations[68] has limited the ability of these groups to respond to climate-related health risks.

Resilience Actions to Address the Impacts of More Frequent or Severe Droughts on Communities



Resilience actions can help alleviate harmful consequences to communities of more frequent or severe drought.

Figure 26.4. The increasing frequency or severity of drought has negative impacts on lands and waters across the Southern Great Plains, including reduced crop and livestock production, shortages of drinking water, increased stress on ecosystems, and deterioration of air and drinking water quality. The example adaptation and mitigation actions can increase resilience and reduce negative impacts. Figure credit: See figure metadata for contributors.

Key Message 26.2

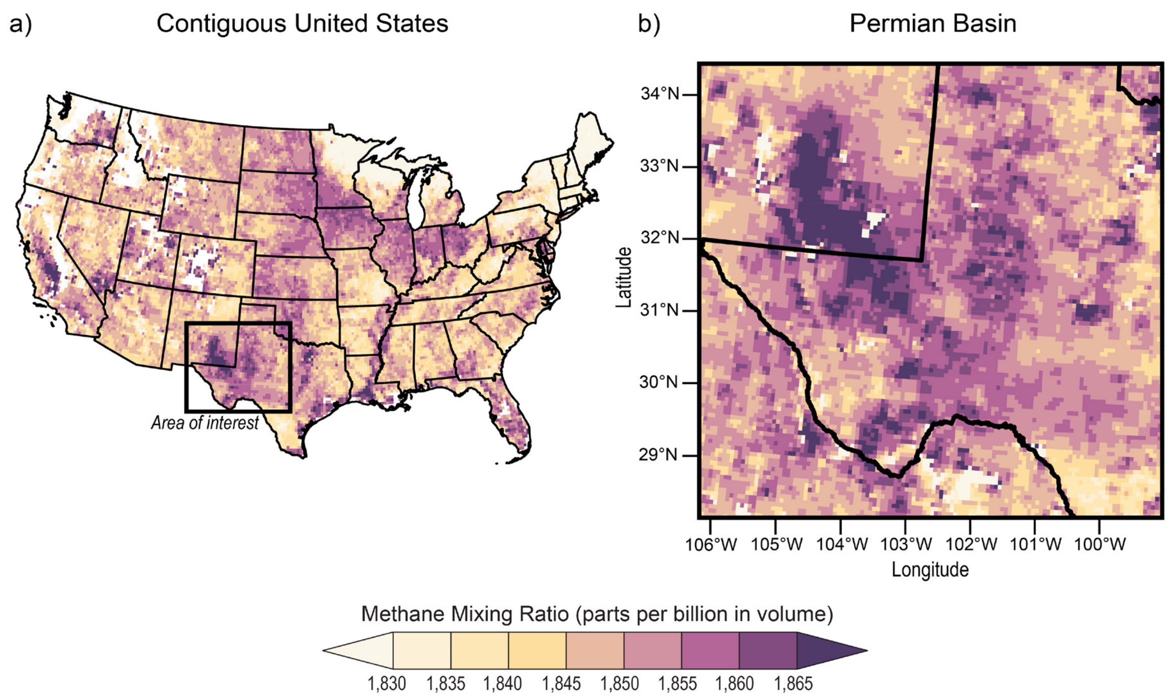
How We Work: Climate Changes Are Creating Economic Challenges and Opportunities

As climate conditions change, businesses and industries across the Southern Great Plains are experiencing disruptions and losses in productivity and profits—but also new economic opportunities (*high confidence*). In coming decades, warmer temperatures, more erratic precipitation, and sea level rise are expected to force widespread and costly changes in how we work (*very likely*, *high confidence*). Businesses and industries have opportunities to harness their diverse knowledge, resources, and workers to develop products and services in climate mitigation technologies, adaptation strategies, and resilient design that will enhance the region's economy (*medium confidence*).

The region's economy provides for daily needs of residents, supports their long-term aspirations, and addresses societal needs inside and beyond the region. Hotter temperatures, heavier precipitation, stronger tropical cyclones, and other climate changes (App. 4) have harmed workers' health and productivity, inflated product or building costs, and disrupted supply chains (Focus on Risks to Supply Chains). Extreme weather events, such as the February 2021 winter storm (Box 26.2), have exposed gaps in the resilience of businesses to climate extremes while also highlighting opportunities to develop products and services in response to worldwide demand for resilient solutions.

The energy industry in the Southern Great Plains is a global leader in fossil fuel exploration and production, serving a large fraction of global energy demand and supporting rural towns through local employment and tax revenues.[69] Fossil fuels release greenhouse gases when burned, contributing substantially to atmospheric warming (KM 2.1). In 2020 Texas led the Nation in emissions of carbon dioxide (CO_2; 667 million metric tons)—double that of the next-highest emitting state.[19] Texas also had the highest methane emissions (94 million metric tons of CO_2 equivalent in 2020).[19] Natural gas operations in the Permian Basin leak the largest amount of methane per year from any US gas-producing region, an amount sufficient to supply natural gas to 7 million Texas households annually.[70] Atmospheric methane concentrations are high across the Permian Basin as compared to the rest of the US (Figure 26.5) and are attributed primarily to natural gas production.[70]

Methane Across the Permian Basin (May 2018–March 2019)



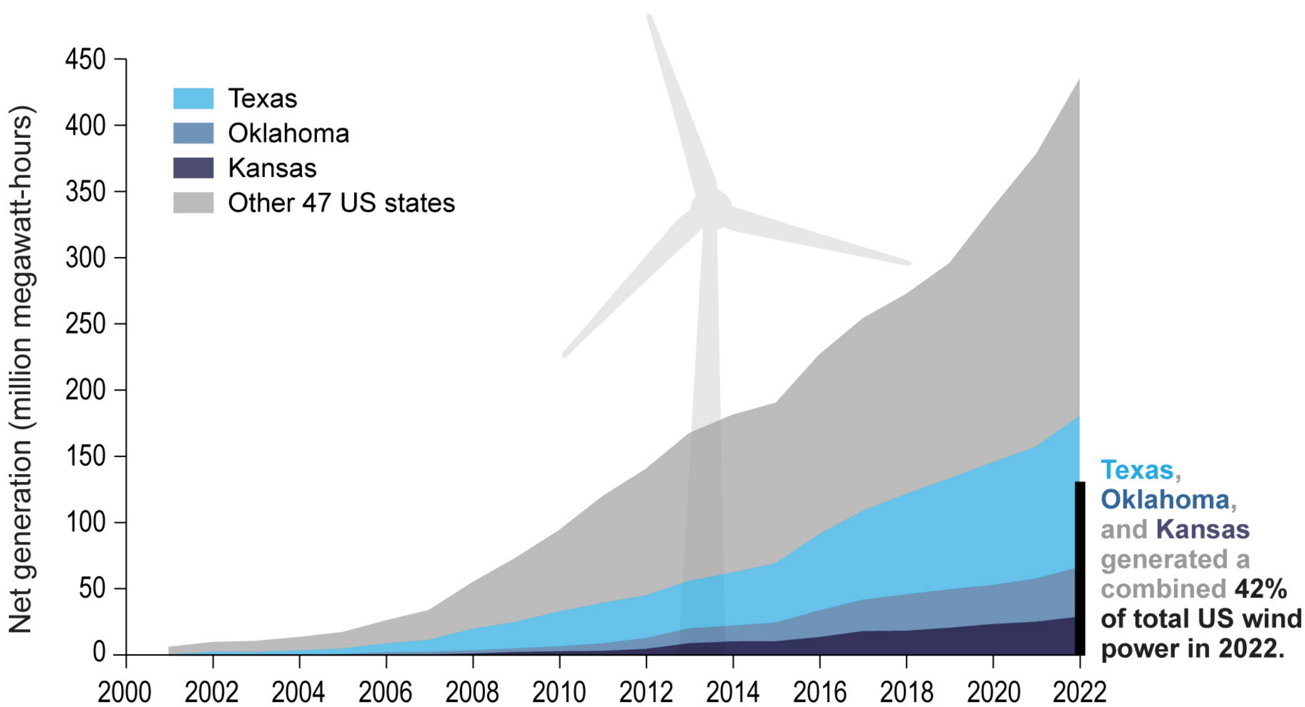
Natural gas operations in the Permian Basin leak large amounts of methane.

Figure 26.5. The maps show satellite-estimated methane mixing ratio (in parts per billion by volume [ppbv]) across (**a**) the contiguous United States and (**b**) the Permian Basin (black box and inset map), averaged from May 2018 to March 2019. Mixing ratio is a measure of the concentration of a gas such as methane in the air. Darker shading represents higher methane mixing ratios; missing data are shaded white. Accounting for atmospheric transport, the spatial pattern of methane mixing ratio across the basin is closely associated with gross (before processing) natural gas production and, to a lesser extent, with oil production. (The original published source did not include data for Alaska, Hawai'i and the US-Affiliated Pacific Islands, and the US Caribbean.) Natural gas operations in the Permian Basin leak a large volume of methane, contributing to atmospheric warming. Adapted from Zhang et al. 2020[70] [CC BY-NC 4.0].

Throughout the region, a major shift in energy generation from fossil fuels toward renewables (KM 5.3) is underway, creating new jobs, cleaner air, and climate change mitigation benefits. For example, the Electric Reliability Council of Texas (ERCOT; Texas's main power supplier) estimates that installed capacity for electricity generated by wind from their suppliers alone will increase from 31,100 MW in 2020 to 41,700 MW in 2025.[71] During the same time, ERCOT expects growth in solar generation capacity from 6,000 MW to 46,400 MW, and in battery storage from 275 MW to 14,500 MW. Electricity generated from gas and coal, however, is not planned to increase substantially.[71,72] In the third quarter of 2022, about 285,000 workers were employed in fossil fuel extraction, distribution, and support activities across the three states.[73] A transition of this workforce from a carbon-intensive to a low-carbon economy is expected to affect some Southern Great Plains communities disproportionately.[74] Within Tribes, a just transition also means a strengthening of Tribal sovereignty, economic independence, and nonextractive, Indigenous-based restoration of ecosystems.[3] For Tribes and communities facing this transition, there generally is a lack of planning, infrastructure, financing, and workforce training in new careers (including in renewable energy) across the region (e.g., Williams et al. 2021[75]).

The Southern Great Plains accounts for 42% of the Nation's wind-generated electricity (Figure 26.6).[18] Major wind installations in rural communities support the local tax base, stabilizing funding for public services such as education, road maintenance, and emergency services, as well as for infrastructure such as hospitals, jails, and parks.[76] Wind-turbine productivity across western Kansas, western Oklahoma, and the Texas Panhandle is projected to increase with climate change because of a more stable low-level jet stream—a regional atmospheric feature that generates strong winds at turbine height, particularly at night during spring and summer.[77]

Net Generation of Electricity from Wind (2001–2022)



The Southern Great Plains contributes a large share to total US wind-generated electricity.

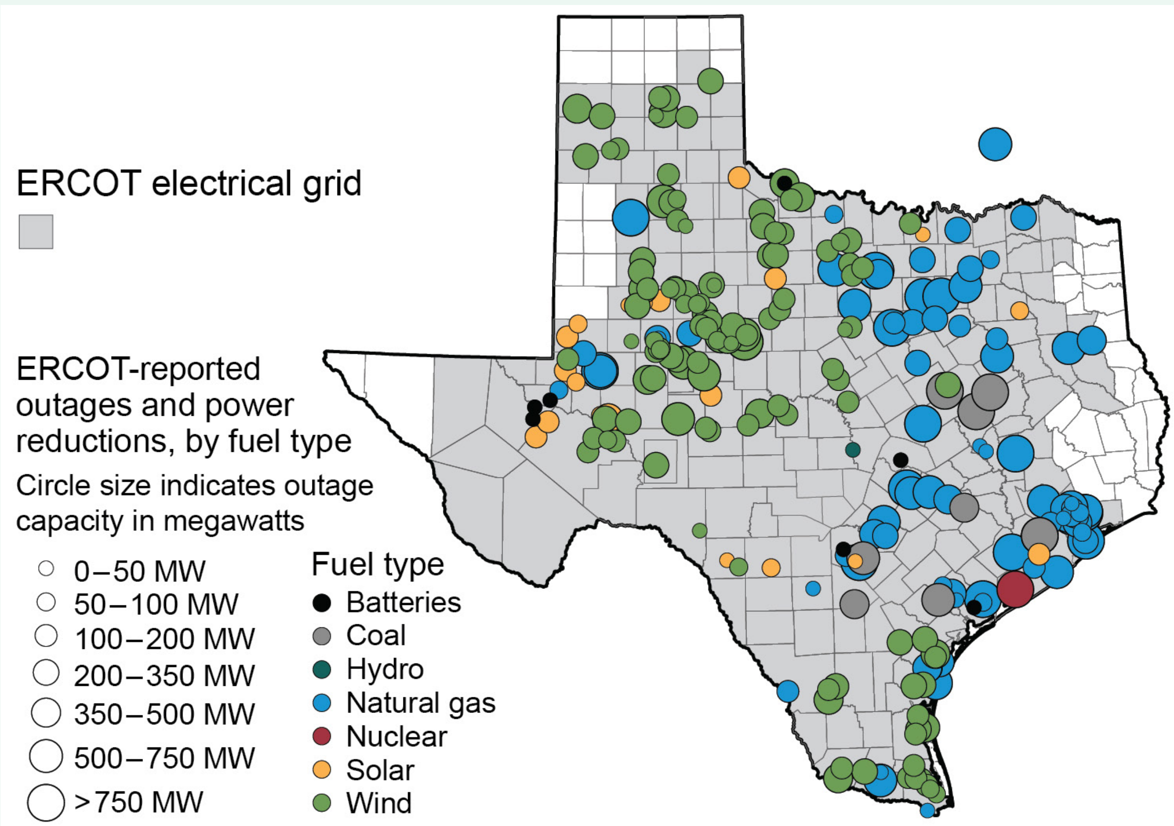
Figure 26.6. US producers in the 50 states generated 435 million megawatt-hours of electricity from wind power in 2022. Together, Texas, Oklahoma, and Kansas contributed 159 million megawatt-hours, or 42% of total US production. Data were not available for the US-Affiliated Pacific Islands or the US Caribbean. Figure credit: See figure metadata for contributors.

Box 26.2. February 2021 Severe Cold Outbreak

Cold outbreaks occur when the jet stream weakens, causing Arctic air to advance southward. From February 8–20, 2021, Arctic air moved far into the Southern Great Plains.[78,79] Wind chills were below 0°F from central Texas northward on Valentine's Day, snow fell along the Texas Gulf Coast, and almost 3,000 daily minimum-temperature records were tied or broken across the region.[80] The prolonged cold caused large-scale power disruption, left 14.4 million households without tap water, and led to more than 200 deaths.[81,82]

Electricity-generation units failed in large numbers during the frigid conditions (Figure 26.7), requiring grid operators to implement rolling blackouts to try to avoid widespread, uncontrolled outages.[81,83] Most of the unplanned outages and reductions in available capacity were associated with problems with natural-gas (58%) and wind (27%) generation units.[83] The Electric Reliability Council of Texas (ERCOT) was particularly devastated, losing up to 34,000 megawatts of capacity—almost half of its all-time peak load for the winter—from February 15–17.[83] As a result, more than 4.5 million people lost power, some for up to four days. Millions had to boil water for drinking and cooking, and many cities issued water conservation orders because of low water pressure.[81] In Houston, data indicate that non-White populations disproportionately experienced outages, regardless of their income level (Figure 26.8). Economic losses in Texas were estimated at $85.6–$139.1 billion (in 2022 dollars).[84]

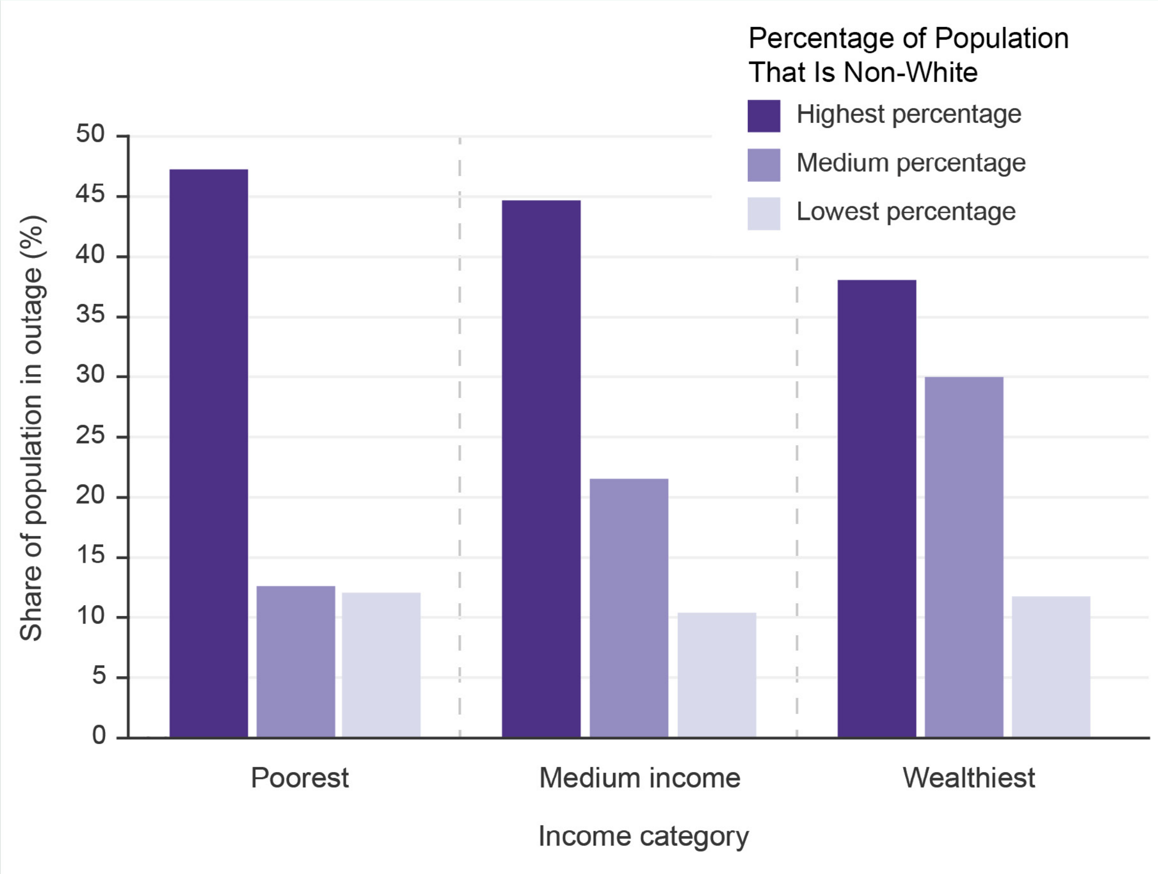
Power Generation Outages During the Cold Outbreak in February 2021



A severe cold outbreak in February 2021 led to extensive outages for electricity generation plants serving the Electric Reliability Council of Texas (ERCOT).

Figure 26.7. The map shows the maximum outage or power reduction (in megawatts, MW) by location and fuel type for electricity generation facilities serving ERCOT during February 10–24, 2021, amid the cold outbreak across portions of the south-central US. Circles are colored by fuel type; larger circles represent larger values of maximum outage or power reduction. One generation facility is in Oklahoma. Shaded counties denote the ERCOT service area. In Texas alone, loss of generation capacity caused more than 4.5 million customers to be without power at some time during the cold outbreak.[83] Figure credit: See figure metadata for contributors.

Income and Racial/Ethnic Disparities Related to Power Outages in Texas, February 2021



Regardless of income level, non-White populations experienced a disproportionate share of outages during the February 2021 cold outbreak.

Figure 26.8. This graph shows the percentage of the Texas population that experienced power outages during the February 2021 cold outbreak based on income level (poorest, medium income, and wealthiest) and race/ethnicity (lowest, medium, and highest percentage of non-White people in the population) by census block group. Non-White people are those individuals whose race was listed as other than White alone or who list their ethnicity as Hispanic or Latino. Regardless of wealth status, data indicate that areas with the highest populations of non-White people were the most likely to be impacted by power outages due to long-standing marginalization. Adapted with permission from Carvallo et al. 2021.[85]

The severe cold outbreak was not historically unprecedented, and widescale outages were avoidable.[78] To illustrate how good adaptation enhances resilience, the City of El Paso, Texas, had prepared for extreme cold following widespread energy and water disruptions in 2011. The city invested in winterization of power infrastructure and built a new power plant that could operate with different fuel types.[86] These adaptations, along with the city's connection to a different power grid, resulted in few outages during the 2021 event.

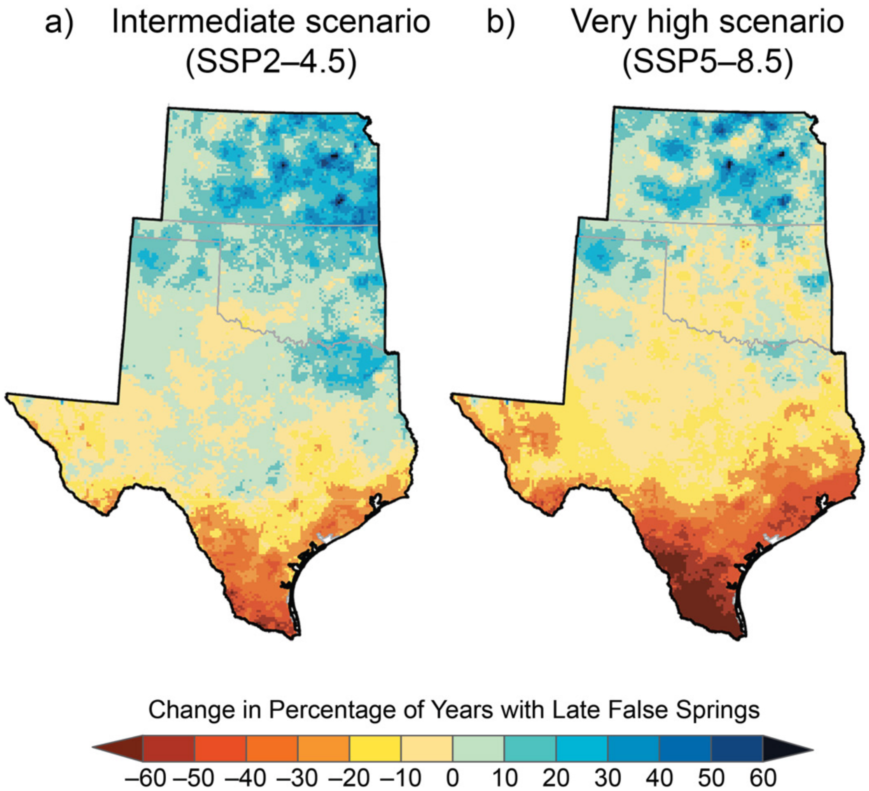
Although the effect of climate change on the jet stream's strength is an ongoing area of research[87] and extremely cold days are expected to decrease, projections indicate that the region will still experience extreme cold events in a warming world.[88] These events are expected to result in considerable costs if businesses are not adequately prepared.[78] In June 2021, the Texas legislature passed Senate Bill 3, which focused on improving emergency communication and gas infrastructure as well as other winter preparedness actions.[89] Grid operators also developed recommendations to improve energy reliability, grid operations, and communications for future winter weather events.[83]

Agriculture, including crop and livestock production and forestry, is an essential industry in the region. In 2022, Kansas led the Nation in grain sorghum production and ranked second nationally in all wheat production.[90] In 2023, Texas was first in head of cattle and calves, with Kansas and Oklahoma ranking third and fifth, respectively.[91] In 2017, the region's agricultural industry generated $60.5 billion (in 2022 dollars) in agricultural product sales, 70% of which was animal based.[92]

Agricultural producers are experiencing loss of livestock and crops, reduced income, and negative public health outcomes as climate extremes increase in magnitude and frequency (KMs 11.1, 11.2). Warmer average temperatures are leading to longer growing seasons, which affect different species differently and potentially disrupt the long-term natural connection between plants and their pollinators or between insects and their predators (KM 8.2).[93] Historical plant hardiness zones are predicted to continue migrating northward as the annual average minimum winter temperature warms (Figure 11.3). High temperatures have reduced plant growth and diminished productivity.[94] In western Kansas and the Oklahoma and Texas Panhandles, the combination of cold fronts and earlier springs is projected to increase the potential for bud burst before the last freeze (Figure 26.9),[95] threatening plant-leaf and wood-tissue damage.[96]

Compound events (Focus on Compound Events) that encompass hot, dry, and windy conditions have increased in southwest Kansas and the Panhandles of Oklahoma and Texas, reducing wheat yields proportionally to the number of hot-dry-windy hours.[97,98] Producers also are expected to experience drier conditions (Figure 26.10) and more frequent or intense drought by midcentury in western and southern parts of the region, lowering crop productivity or increasing irrigation costs.[99] By 2070 across a range of climate change scenarios (from low [RCP2.6] to very high [RCP8.5]), the Southern Great Plains is projected to lose cropland acreage, as these lands transition to pasture or grassland.[100]

Projected Change in Annual Risk of Late False-Spring Events



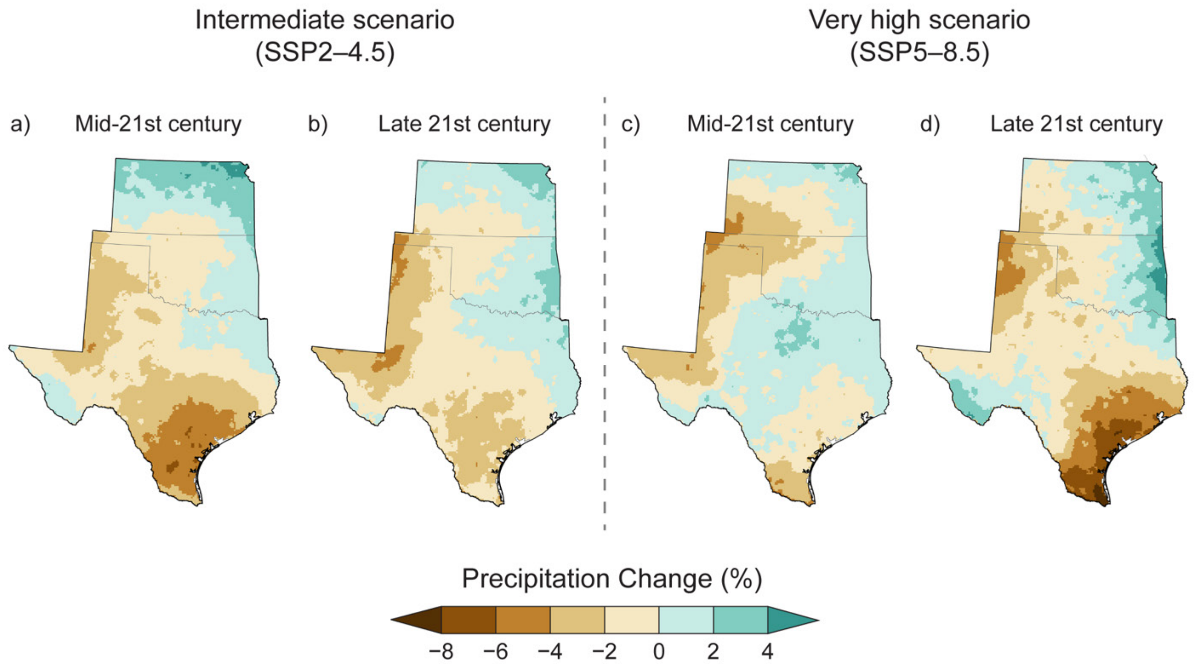
The risk of plant bud burst before the last freeze is projected to increase for the northern portion of the Southern Great Plains. The risk decreases for the southern portion of the region.

Figure 26.9. Freezing temperatures after plants begin growth in spring (late false spring) can damage crops and nursery plants. Risk of a late false spring is projected to increase in northern parts of the Southern Great Plains by the end of the century (2071–2100) as compared to the 1991–2020 average. The risk of late false springs increases by up to 20% across most of Kansas, Oklahoma, and northern Texas under an intermediate scenario (SSP2-4.5; panel **a**) and across most of Kansas, the Texas Panhandle, and parts of Oklahoma under a very high scenario (SSP5-8.5; panel **b**). Risk decreases for the remainder of the region, especially in southern and far western Texas under a very high scenario. Figure credit: See figure metadata for contributors.

Although increasing irrigation during drought can help maintain productivity, it reduces groundwater available for other ecological or societal needs and for future generations. Growers can produce similar yields using less water by adopting more efficient irrigation technologies and management practices.[101] Neighbors also can help neighbors. For example, irrigators in Sheridan and Thomas Counties (Kansas) self-imposed annual water restrictions that reduced water usage by 26%, with no reduction in crop acreage.[102]

Drought also has reduced the capacity of native rangelands and planted pastures to support livestock and has increased labor demands for feeding, forcing producers to sell genetically valuable animals. High temperatures also pose risks to animal health.[99] In June 2022, for example, thousands of cattle died in southwestern Kansas during a heatwave combined with high humidity and low wind speeds.[103,104] The additional stressors from climate change are anticipated to be especially difficult for multigenerational ranchers who strive to earn a profit while preserving the health of lands for their descendants.[105] For large-scale livestock production, successful adaptation to a changing climate includes enhancing soil health and reducing the number of animals per acre.[106]

Projected Change in Total Annual Precipitation



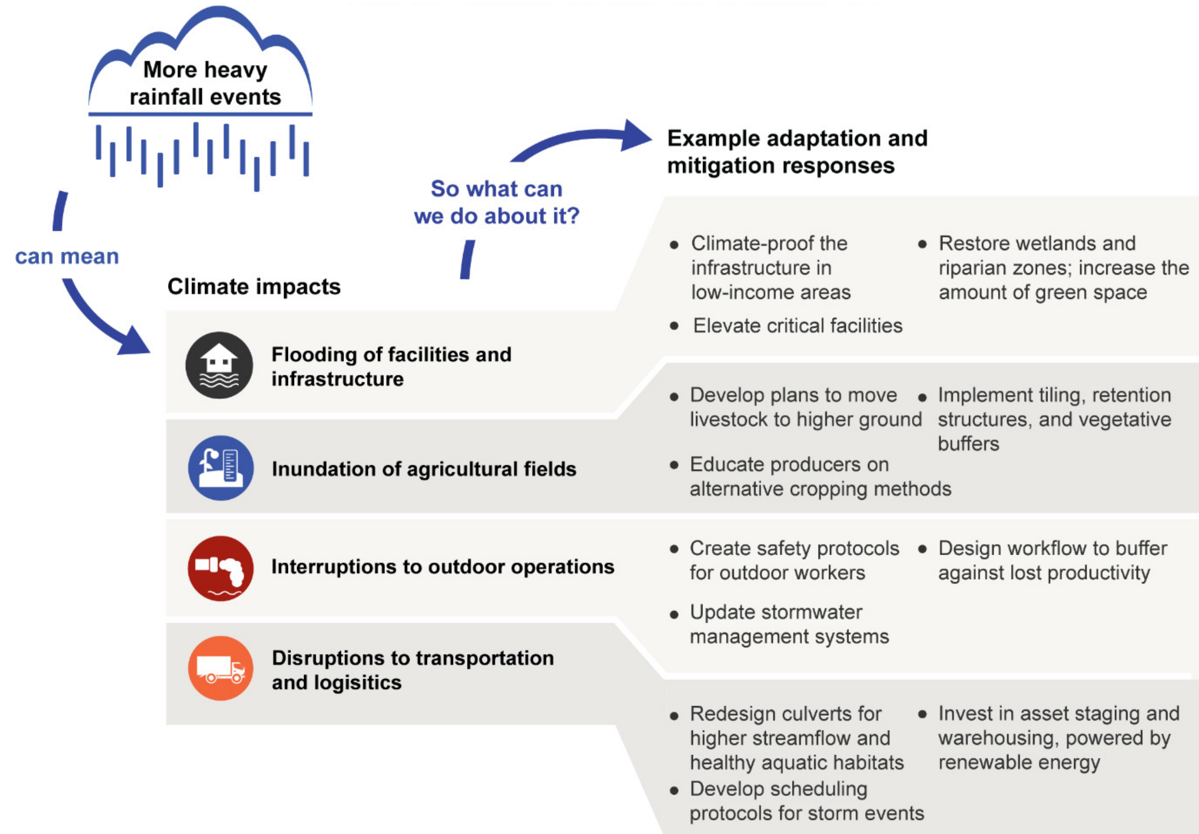
Slightly drier conditions are projected for much of the western and southern portions of the region by the end of the century.

Figure 26.10. In the future, drier conditions threaten agriculture and water supplies in parts of the Southern Great Plains (brown), while more precipitation is projected near the northern and eastern boundaries of the region (green). Under an intermediate scenario (SSP2-4.5), total annual precipitation is projected to decrease by 4% or more (as compared to the 1991–2020 average) in southern Texas by midcentury (**a**), with smaller differences expected by century's end (**b**). Under a very high scenario (SSP5-8.5), annual precipitation is projected to decline slightly in western portions of the region by midcentury (**c**) and by 4% or more in southeast and far northwest Texas by the century's end (**d**). Figure credit: See figure metadata for contributors.

More broadly, climate change–related damages to businesses have threatened the continuity of operations, increased insurance costs, disrupted supply chains, and shifted customer demand (KM 19.3). Many small businesses in the US do not have business disruption insurance, and 20%–40% of small businesses that temporarily close after a natural disaster do not reopen.[107] Small businesses owned by women, non-Whites, and veterans have a higher likelihood of closing after experiencing a natural disaster.[108] These closures have negatively affected the economy and well-being of local communities.[109]

Large and small businesses and industries have started efforts to mitigate greenhouse gas emissions. For example, in 2021 Amazon piloted an electric-vehicle fleet in Tulsa, Oklahoma, and in 2022 Frito-Lay did likewise in Carrollton, Texas. The need to reduce emissions on a worldwide scale presents economic opportunities for energy-related businesses in the region to pilot and develop new technologies. NRG Energy and JX Nippon, for example, partnered to create a commercial-scale carbon capture facility at NRG's coal-fired Petra Nova power plant in Thompsons, Texas.[110] It was the US's first and only facility to capture over one million tons of CO_2 per year. It suspended operations in 2020, however, because oil prices were too low to justify the expense of using the captured CO_2 for enhanced oil recovery.[111] Houston's Sage Geosystems is testing how to generate geothermal energy at commercial scale by repurposing an existing oil well in San Isidro, Texas,[112] and groups like Kansas Soil Health Alliance and Texas Coastal Exchange are supporting carbon storage through soil and land stewardship.[113,114] Mitigation and adaptation actions by businesses and industries promote resilience and offer long-term benefits to employers, employees, and the surrounding community (Figure 26.11).

Resilience Actions to Address the Impacts of Heavier Rainfall Events on Businesses



Resilience actions can help businesses and industries reduce the negative consequences of more heavy rainfall events.

Figure 26.11. An increased number of heavy rainfall events affects business and industry across the Southern Great Plains through flooding of facilities and infrastructure, inundation of agricultural fields, interruptions to outdoor operations, and disruptions to transportation and logistics. The example adaptation and mitigation actions can increase resilience and reduce negative impacts. Figure credit: See figure metadata for contributors.

Key Message 26.3

How We Play: Climate Extremes Are Endangering Sports, Recreation, and Leisure

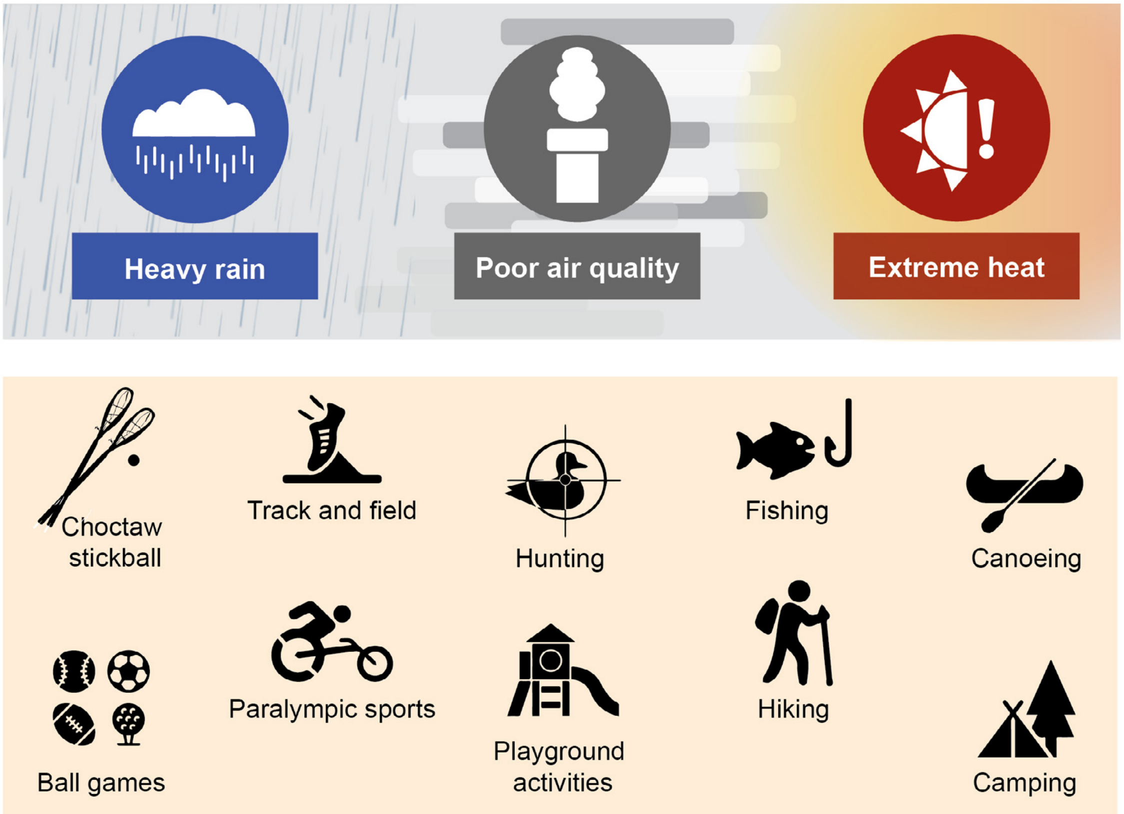
Extreme climate-related events are negatively influencing how we play and participate in outdoor sport, recreation, and physical activities in the Southern Great Plains (*very high confidence*). Climate change is expected to increase heat-related illness and death, reduce outdoor physical activity, and decrease athletic performance (*very likely*, *high confidence*). Individuals, communities, and sports organizations can adapt to these hazards through strategies such as modifying the timing, location, intensity, or monitoring of activities (*high confidence*).

Sports, recreation, and leisure activities are part of life in the Southern Great Plains. Hunting, fishing, jogging, playing on the playground, and other activities help maintain participants' physical and mental health. Organized sports, such as football, soccer, and softball, bring together spectators to cheer for their favorite athlete or team, encouraging social cohesion.[115] Climate extremes have affected many of these activities, diminishing their benefits (Figure 26.12). For example, sports fields across southeastern Texas were closed because of flooding after Hurricane Harvey in 2017.[116] Although superintendents of unaffected schools offered Harvey-displaced students the opportunity to play on their teams, these athletes were reluctant to forfeit their home-team eligibility, reducing their broader scholastic involvement.[117]

Athletes of all ages experience decreased performance, do less outdoor physical activity, and are at higher risk of severe to fatal health issues because of extreme heat, air pollution, and weather hazards.[118,119] These risks especially apply to older adults, those with chronic disease or higher body mass index, and those under prolonged environmental exposure (e.g., marathon runners) who conduct high-intensity sports or wear clothing or equipment that prevents heat loss.[120,121] Heat injuries can damage organs (e.g., liver, muscle, kidney) or disrupt the central nervous system.[122]

All dimensions of environmental injustice (i.e., recognitional, distributional, and procedural; Figure 20.1) intersect with climate change to disproportionately harm people who have been marginalized (KM 15.2), reducing their participation in and health benefits from outdoor physical activities. These people include low-income populations, those living in areas with higher levels of air pollution, and those with less access to places to engage in sports, recreation, and leisure.[123,124] Non-English-speaking recreationists are at increased risk because health communication about climate-related hazards (such as the dangers of swimming in a harmful algal bloom) likely is not presented in their native language.[125]

Climate Change Impacts on Outdoor Activities

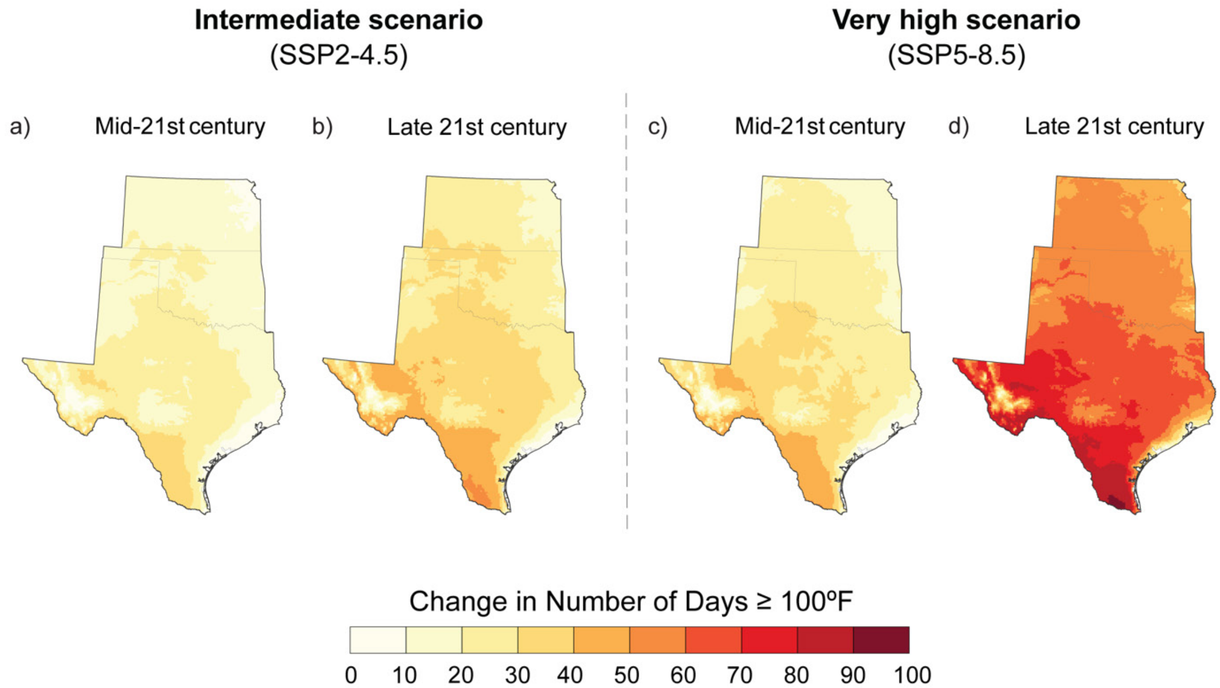


Climate change is expected to affect many outdoor sports, recreational, and leisure activities.

Figure 26.12. Outdoor sports, recreational, and leisure activities for people of all ages are being affected by climate extremes. Heavy rainfall, poor air quality, and extreme heat are expected to increase with climate change. These stressors impair athletic performance, damage sports facilities, and alter landscapes for recreation and tourism. Figure credit: See figure metadata for contributors.

Nationally, heat-related illnesses are the third-highest cause of death among high school athletes[126] and are the most preventable cause of death in youth sports.[127] Heat-related deaths can occur outside of a typical heatwave. For players of organized football at any level, these types of death occurred most often in the south-central and southeastern United States.[128] These risks apply to any outdoor sport, especially those that involve training or competition during summer and fall. Future increases in the number of very hot days and warm nights are expected to exacerbate health concerns (Figure 26.13). For example, the number of 100-degree days is projected to increase by the end of the century under a very high scenario (SSP5-8.5) by 30–60 days in Kansas and Oklahoma and more than 80 days in parts of southwestern Texas (Figure 26.13c, d). By contrast, under an intermediate scenario (SSP2-4.5), the number of 100-degree days per year would remain close to the recent average (Figure 26.13a, b).

Projected Change in Annual Number of Days of 100°F or Higher



The number of extreme-heat days is projected to increase.

Figure 26.13. Outdoor physical activity becomes more dangerous in extremely hot temperatures. By midcentury, the number of days per year with temperatures at or above 100°F across the Southern Great Plains is projected to increase (**a**) by 10–40 days under an intermediate scenario (SSP2-4.5) and (**c**) by 10–60 days under a very high scenario (SSP5-8.5) above the 1991–2020 average. By late century, projections indicate that the number of these extreme-heat days would increase (**b**) by 10–60 days (SSP2-4.5) or (**d**) by 30–90 days (SSP5-8.5), depending on scenario. The historical average ranges from fewer than 10 days per year in Kansas to fewer than 20 days across most of Oklahoma and Texas, with 40–60 days along the Mexican border. Figure credit: See figure metadata for contributors.

Extreme temperatures have threatened the health of young athletes and their ability to practice and compete outdoors in sports like cross-country, track and field, tennis, golf, softball, soccer, and lacrosse.[129,130,131] In schoolyards or playgrounds, the time spent playing in warm or hot environments and the physical environment (e.g., shade, vegetation) have affected the perceived discomfort of youth while they are active outdoors.[132] Unhealthy heat stress is occurring even at ambient temperatures of 80°–85°F where play areas are unshaded and have artificial surfaces (e.g., asphalt or artificial turf).[133] Children from non-White and lower-income families have less access to high-quality, sizeable urban parks,[134] putting them at higher risk of heat illness and other adverse health outcomes (i.e., physical and mental health problems).[123]

Heavy rainfall and extreme temperatures cause sports teams to depend more on artificial or indoor environments, increasing participation costs and decreasing access to sports, especially for lower-income populations.[120] The Texas Rangers replaced their structurally sound stadium earlier than expected because extreme temperatures suppressed attendance.[135] The new stadium has a retractable roof for a climate-controlled environment. Sports events across all levels—from youth and interscholastic to collegiate and professional—have been halted or moved because of the unusual timing or intensity of storms (Figure 26.14, left), resulting in scheduling challenges, economic costs, and reduced social interactions.[136,137] All people who enjoy the outdoors as part of their healthy lifestyle are expected to face more days with dangerous extreme heat (Figure 26.14, right).

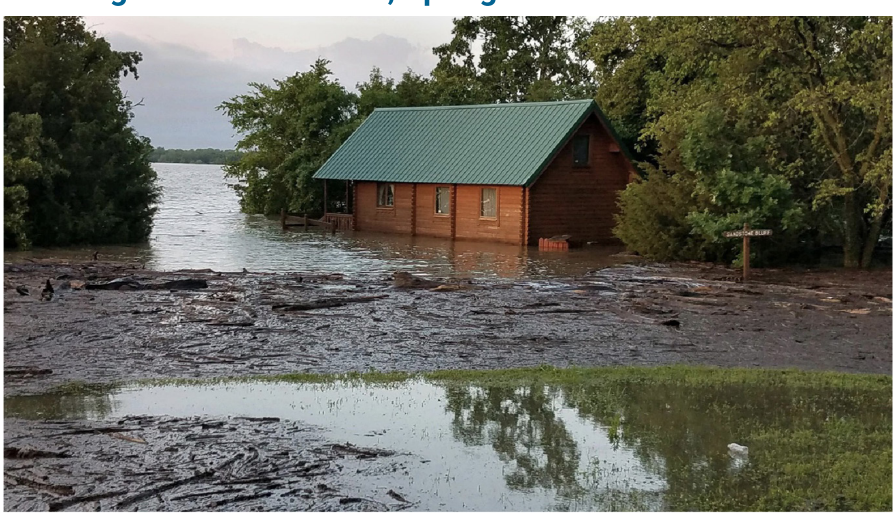
Extreme Event Impacts on Sports and Recreation

Outdoor sports and recreation of all kinds are challenged by extreme events.

Figure 26.14. (**left**) University of Oklahoma staff paint the Green Wave of Tulane University on their football field for a September 4, 2021, matchup. The game was relocated after Hurricane Ida left Tulane's stadium powerless and damaged. (**right**) As people enjoy the outdoors as part of a healthy lifestyle, warmer temperatures are expected to cause them to adapt by drinking cool liquids, reducing strenuous exercise, or exercising during cooler times of the day. Photo credits: (left) ©University of Oklahoma Athletics; (right) ©Emma Kuster.

Lakes, streams, and reservoirs support fishing, hunting, and other outdoor recreation; however, more variable or heavier rainfall, flash or prolonged droughts, and higher temperatures have jeopardized recreation by reducing the quality and quantity of water.[138] In 2019, for example, southeast Kansas and northeast Oklahoma experienced historic spring flooding after multiple storm systems brought almost 2 feet of rain.[139] The flooding caused more than $12.5 million (in 2022 dollars) in damages for the Kansas Department of Wildlife, Parks, and Tourism (Figure 26.15), primarily through lost revenues from park closures.[140] Texas State Parks amassed a $5.9 million (in 2022 dollars) funding deficit when drought, wildfires, and record heat prompted fewer visitors in 2011–2012.[141]

Flooding of Park in Kansas, Spring 2019



Historic spring flooding in 2019 closed parks and recreational areas in southeastern Kansas.

Figure 26.15. Sandstone Bluff Cabin along Toronto Lake in Cross Timbers State Park was flooded from spring 2019 storms, as the lake level exceeded prior historic records. The extreme rainfall closed parks and created an estimated $12.5 million (in 2022 dollars) in damages. Photo credit: ©Kansas Department of Wildlife and Parks.

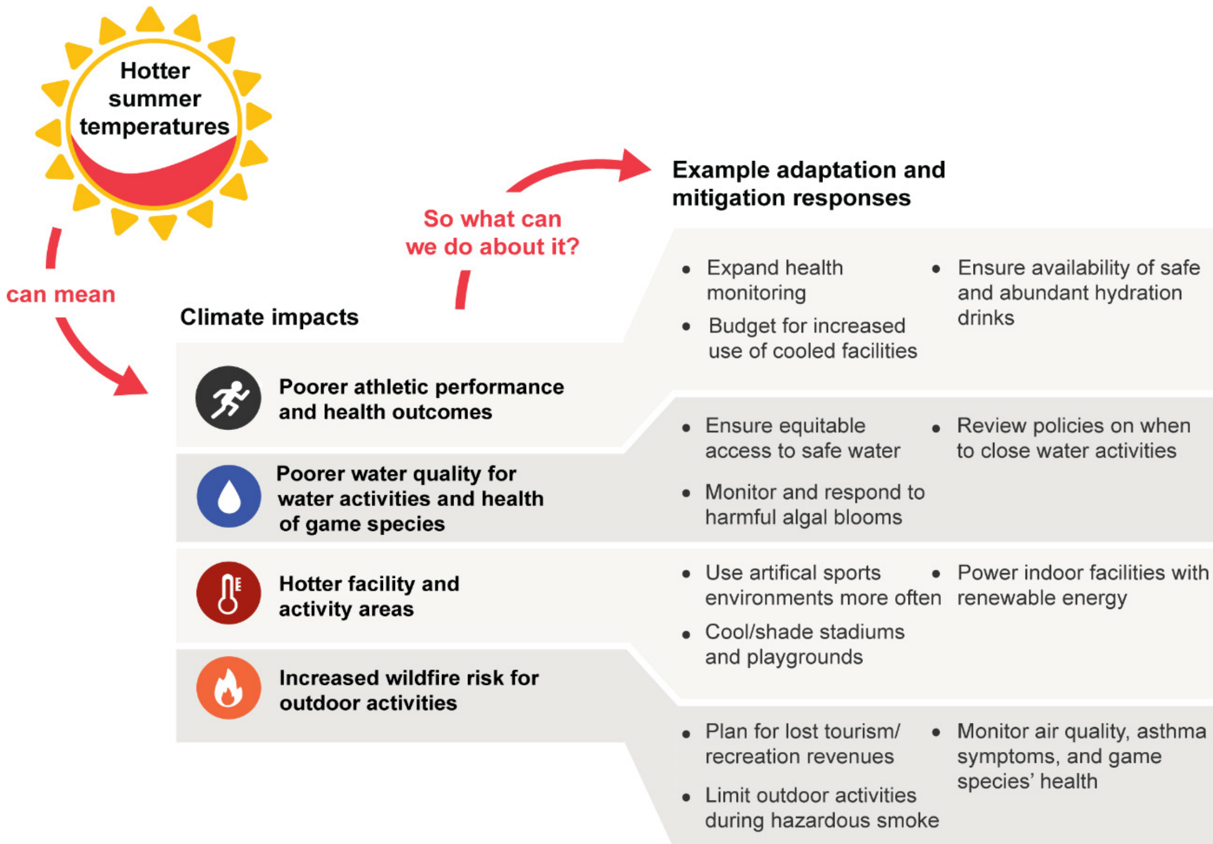
Along the Texas Coast, recreational opportunities are expected to change as coastal ecosystems transform, degrade, or disappear as a result of sea level rise (KM 9.1), warming temperatures,[142] and more powerful or rainier tropical cyclones.[143] After the destruction from Hurricane Harvey (2017), coastal ecotourism collapsed across the Coastal Bend, where ecotourism supports 8% of the local workforce and generates over a billion dollars in economic value annually.[144] Sea level rise has caused erosion of coastal beaches. Sand erosion on Galveston Island, for instance, has increased by 45% in comparison to geologic rates.[145] Sea level rise is also increasing saltwater inundation of coastal marshes that support birdwatching and angling.[146]

Changes in the timing and amount of precipitation have affected freshwater runoff and its associated salinity of bays and coastal ecosystems.[147] In the winter of 2008–2009 at the Aransas National Wildlife Refuge, a combination of inundation, drought, and upstream water use resulted in the loss of 10% of blue crabs, the main food source for the whooping cranes that draw legions of birdwatchers to the refuge.[148] Other impacts are favorable for coastal fisheries. Fewer extreme freeze events have caused the northward expansion of mangroves,[142] increasing fish diversity in Texas bays.[149] The diversity and prevalence of marine fish for sport fishing has also increased along Texas coasts as tropical fish expand their range northward.[150]

In 2020, hunting, shooting, and trapping generated $1.3 billion (in 2022 dollars) in Texas, ranking it first in the Nation.[151] Competition for limited food and water resources during drought is anticipated to alter animal migration, reproduction, and behavior (e.g., Cady et al. 2019;[152] Porro et al. 2020[153]). As a result, with warming temperatures, hunters are expected to see shifts in wildlife habitats and species ranges and decreases in the size and weight of prey.[154,155] For example, the Texas Parks and Wildlife Department has noted a decline in wintering mallard duck populations because open waters and food remain available farther north as winters warm.[156]

Sport, recreation, fish, and wildlife managers can plan for climate change by considering ways to alleviate negative impacts or enhance benefits (Figure 26.16). For example, to reduce health risks resulting from extreme heat, athletes can acclimatize to heat by slowly increasing the duration and intensity of exercise, scheduling strenuous outdoor activities during cooler hours, and reducing their core body temperature by applying ice packs and drinking cold water.[122] To maximize public outreach, communication of these risk-reduction methods should reflect the languages spoken throughout the community. Communities can support local sports, leisure, and recreation through landscape design by adding shaded green spaces as shelter from extreme heat. Park amenities, such as trees and splash pads, can also cool people on hot days. Despite the potential for temporary closures, siting parks and recreational areas along streambeds can reduce flood losses by buffering floodwaters in downstream developed areas.[157]

Resilience Actions to Address the Impacts of Hotter Summer Temperatures on Outdoor Activities



Resilience actions can alleviate the effects of hotter temperatures on outdoor activities.

Figure 26.16. Hotter temperatures affect athletic, recreational, and leisure activities outdoors across the Southern Great Plains, leading to poorer athletic performance and health outcomes, poorer water quality, hotter facilities and activity areas, and increased wildfire risk. The example adaptation and mitigation actions can increase resilience and reduce negative impacts. Figure credit: See figure metadata for contributors.

Key Message 26.4

How We Heal: Climate Change Is Exacerbating Existing Social and Environmental Disparities

Some neighborhoods and communities in the Southern Great Plains are suffering disproportionately from climate-related hazards because of long-standing marginalization, discrimination, and governmental policies (*very high confidence*). As a result, climate change will compound existing social and environmental burdens on the people, neighborhoods, and communities with the fewest resources to prepare and adapt (*very high confidence*). Our institutions and governments can play a role in improving outcomes for these people and places by adopting climate adaptation and hazard-mitigation practices and policies that prioritize social equity and justice, aim to reduce community risks, build resilience, and repair past injustices (*medium confidence*).

Climate change does not affect all people in the same ways; society's most under-resourced and overburdened face harsher experiences (KMs 15.2, 20.1)[158] and have less access to climate-resilient infrastructure and recovery support,[159,160] typically as a result of power imbalances or discriminatory policies and practices.[161,162] This unequal distribution of harms and benefits is climate injustice. Those most impacted by climate inequities and injustices include people with low incomes; rural residents; disabled persons; older adults; Black, Indigenous, and People of Color; those who identify as other than cis, straight men; immigrants; those living in *colonias* (Texas-border housing developments lacking basic infrastructure and services); and unhoused individuals (KM 15.2).

Governments and organizations trying to heal historical traumas, injustices, and disparities are expected to face increasing urgency for equitable solutions and resources, as exposure to climate change impacts is projected to increase by midcentury. Lack of resources, political power, and technical expertise inhibit effective planning for and implementation of climate mitigation and adaptation.[3,163] Without intervention, climate change is expected to continue limiting equitable access to resources, services, and economic opportunities.

In many cases, housing stocks that serve low-income communities and communities of color lack adequate weatherization, air-conditioning, structural resistance to high winds, or adequate tree canopy, shade, and green spaces to provide heat relief due to long-standing under-resourcing and marginalization.[164,165] Lack of access to reliable and affordable energy increases the vulnerability of low-income communities to intense heat events. Severely marginalized groups, such as unhoused, detained, or incarcerated people, have experienced considerable suffering during extreme heat events with little relief.[166,167] For example, Texas inmates and correctional officers have endured heat stress or heat mortality from lack of air-conditioning and proper ventilation.[168]

Low-income communities and communities of color often lack access to adequate and maintained flood infrastructure, which reduces resilience, limits recovery, and contributes to increased flood vulnerability.[169,170] In Houston and other Gulf Coast communities, for example, these populations often live in lower-quality housing in flood-prone areas, placing them at a higher risk than those living in surrounding areas.[171]

In addition, low-income residential areas and residents of color tend to be in closer proximity to petrochemical plants or chemical storage facilities than their higher-income or White counterparts,[172] putting them at higher risk of industrial accidents caused by extreme weather events that release toxins into the air and water (KM 15.2).[173] For instance, facilities that reported chemical releases after Hurricane Harvey tended to be near predominantly Hispanic neighborhoods and revealed patterns of societal inequity.[174] Exposure is particularly acute near Superfund sites[175] and across industrial areas of the Texas Gulf Coast (Figure 26.17).[176]

After a disaster, many people who are poor, uninsured, and without access to climate recovery and adaptation programs, such as voluntary buyouts, have not rebuilt.[159,177] Efforts to recover from compounding hazards (Focus on Compound Events) can quickly exhaust resources and strain mental well-being in low-income populations (KM 15.1).[178]

Increased Climate Risks in Port Arthur, Texas

Historically underserved communities near chemical facilities face increased risks from weather hazards associated with climate change.

Figure 26.17. These scenes from Port Arthur, Texas, reveal (**top**) a low-lying landscape of petrochemical facilities and residential neighborhoods, representative of many communities along the Texas Gulf Coast. After Hurricane Harvey (2017) made landfall near Port Aransas, Texas, neighborhoods (**bottom left**) and transportation infrastructure and petrochemical facilities (**bottom right**) were flooded, exposing residents to contaminated waters spreading across the landscape. With climate change projected to intensify hurricanes and bring heavier rainfall, the risks to communities along the Gulf Coast are even higher when hazardous facilities, such as petrochemical plants, are nearby. Photo credits: (top) halbergman/iStock via Getty Images Plus; (bottom left) US Air National Guard Staff Sergeant Daniel J. Martinez; (bottom right) ©Alison A. Tarter.

Communities with insufficient capacity to evacuate prior to coastal storms are at greater risk from tropical cyclones, which are projected to be stronger by midcentury (KM 2.2). These communities also face increased likelihood of house abandonment as Gulf waters rise and rainfall becomes more intense.[160] After Hurricane Ike (2008), for example, over half of Galveston's public-housing apartments sustained damages, displacing almost 600 households. Most of these apartments were demolished and not replaced, and displaced residents confronted barriers to participating in post-disaster decision-making.[179]

Settler colonialism and policies to eradicate Indigenous Peoples, cultures, and practices have contributed to current inequalities in climate mitigation and adaptation resources (KMs 15.2, 16.2, 20.2).[3] Through the Indian Removal Act and treaties with the United States,[180] Tribes became bound geographically to predetermined jurisdictions, often in areas now at higher risk of climate change impacts (KM 16.2) or more exposed to climate hazards than their historical lands.[181] Self-determination, sovereignty, and self-governance, however, empower Tribes in the region to lead their own climate adaptation planning, transforming themselves into thriving communities of their own design (Box 26.3). Indigenous Peoples have knowledges and experiences to share with all peoples about how to live sustainably and adapt to climate changes.[182]

Box 26.3. Adaptation Planning Led by the Tribes of Kansas, Nebraska, and Iowa

The Iowa Tribe of Kansas and Nebraska, Kickapoo Tribe in Kansas, Meskwaki Nation, Omaha Tribe of Nebraska, Ponca Tribe of Nebraska, Prairie Band Potawatomi Nation, Sac and Fox Nation of Missouri, Santee Sioux Nation, and Winnebago Tribe of Nebraska recognized the need to be #Rezilient (the social-media notation for Tribal resilience) in the face of climate change. Using grant funding obtained by the Sac and Fox Nation of Missouri, the Tribes worked to blend their cultural values, Indigenous Knowledges, and adaptation experience with Western science to create Tribal climate adaptation plans. They convened a series of workshops (Figure 26.18) to guide Tribal environmental professionals to customize plans for their unique communities. Beginning in 2019, Tribal elders, council members, environmental professionals, and subject-matter experts initiated Tribal Technical Teams to identify knowledge sources and prioritize risks.

Collaboration to Develop Tribal Climate Adaptation Plans

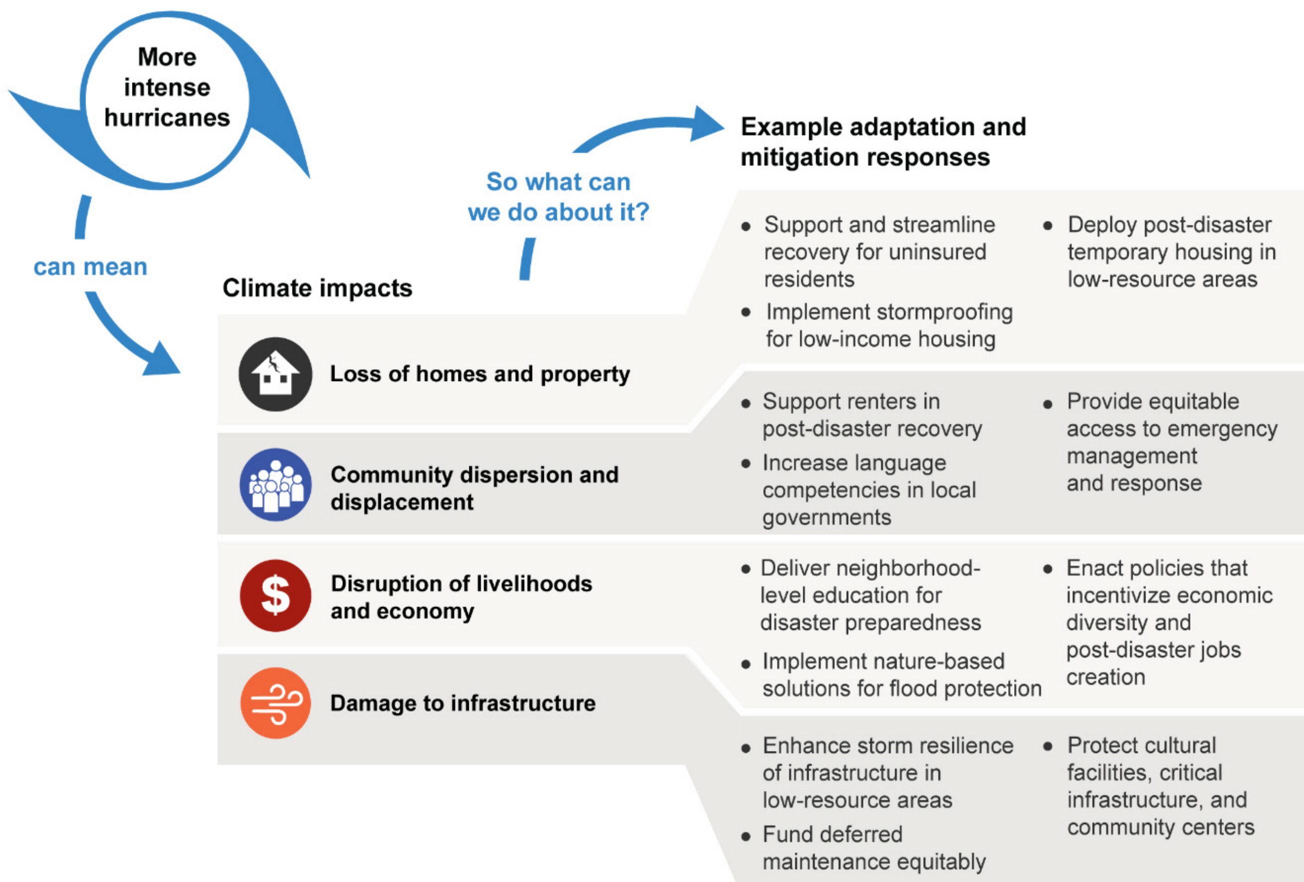
Nine Tribes of Kansas, Nebraska, and Iowa work together to create customized climate action plans for their individual communities.

Figure 26.18. (**top**) In 2022 Mayetta, Kansas, was the site of a climate resilience workshop for the nine Tribes of Kansas, Nebraska, and Iowa. (**bottom**) Technical teams worked together to create and present specific climate adaptation plans for each Tribe and to share their experiences with one another. Photo credit: ©Mark Junker.

Then the Tribes developed a drought early-warning system for each Tribe. The systems focused on more than 20 drought-related indicators, including precipitation, soil moisture, fire danger indices, and evapotranspiration. Next, the teams wrote summaries of their individual regions' climates in the Winnebago language. They discussed how to communicate local climate change impacts in relevant ways for the people on and near the reservations. The teams also met to create maps showing what areas were projected to be most at risk. By 2022, the groups were sharing how they collected data, analyzed trends, and researched impacts and solutions to climate change on their lands and peoples. The resulting nine climate adaptation plans will strengthen resilience of the Tribes of Kansas, Nebraska, and Iowa for years to come.

Residents, businesses, organizations, and governments in the Southern Great Plains can work together to repair prior societal damage and build community resilience by incorporating justice and equity principles in climate resilience strategies and actions (Figure 26.19).[183] For example, the Resilient El Paso strategy includes social stability, security, and justice among the 12 drivers in its resilience framework.[184] The strategy recognizes El Paso's unique attributes, including one-quarter of El Pasoans living in poverty, a large bilingual population, and its location in the largest binational metroplex in the Western Hemisphere. Development of the strategy involved 70,000 residents participating in 95 community engagement events, ensuring that a range of voices were at the table. These adaptation efforts are complicated, however, by historical trauma, which has diminished trust in government, and the marginalization of various populations (e.g., Norton-Smith et al. 2016[185]).

Resilience Actions to Address Equity and Justice Issues Related to Increasing Hurricane Risk



Resilience actions centered on justice and equity can help overburdened communities respond to increasing hurricane risks.

Figure 26.19. More intense hurricanes increase challenges for justice and equity actions across the Southern Great Plains, including loss of homes and property, community dispersion and displacement, disruption of livelihoods and economy, and damage to infrastructure. The example adaptation and mitigation actions can align justice and equity work with climate resilience. Figure credit: See figure metadata for contributors.

Key Message 26.5

How We Serve: Climate Change Is Straining Public Infrastructure and Services

The institutions that serve our communities have been challenged to respond and adapt to more frequent and intense weather events (*medium confidence*). Without significant adaptation, climate change is expected to strain water supplies, transportation infrastructure, and emergency services across the Southern Great Plains (*high confidence*). Actions that can enhance our community resilience include substantially reducing greenhouse gas emissions, installing or retrofitting climate-resilient infrastructure, educating students and the public on climate change, and cultivating the capacity of faith- and volunteer-based aid organizations to assist hazard planning, response, and recovery (*medium confidence*).

Communities throughout the Southern Great Plains rely on basic physical infrastructure and public services, from roads and water treatment facilities to healthcare and education. However, the efficiency, effectiveness, and equitable distribution of these fundamental services are being affected by climate change.[186] These services are not available equally across the region. For example, in 2018 along the Texas–Mexico border, only 77% of the Texas *colonia* population had wastewater service.[187] Although *colonia* residents may have access to an electrical connection, many households remain without energy services because of limited income.[188]

Public utilities depend on reliable, safe, and abundant surface water and groundwater. These sources are at risk from increasing air and water temperatures, more frequent and severe drought, more intense rainfall events, and changes in rainfall frequency and timing (Figure 4.2; KM 4.2).[189,190] For example, heavy rainfall events have caused higher concentrations of pollution[191] and more sedimentation in reservoirs.[192] Winter storms have led to the loss of water pressure and electricity at utility facilities (Box 26.2). The average annual number of boil-water notices and sanitary-sewer overflows across Texas increased substantially between 2011 and 2016, mostly because of infrastructure damage following extreme drought that caused clay-soil contraction.[193]

Along the Texas coast, massive water withdrawals from coastal aquifers currently cause most of local sea level rise.[194] Precipitation carrying salt spray remains the major source of brackish waters in the Gulf Coast aquifer, as rising seas have yet to cause significant saltwater intrusion.[195] However, rates of average sea level rise from global warming have accelerated since 1992,[196] and western Gulf Coast sea levels are projected to rise 19–27 inches by 2050 using the full range (low to high) of global mean sea level rise scenarios.[197] The resulting saltwater intrusion is expected to pose challenges for drinking-water suppliers, as costs for desalinating seawater are twice those for brackish groundwater.[195]

The region's transportation systems, including its major airport hubs, ports, and highways, are critical for international and domestic commerce. Transportation infrastructure—much of which is aging and in significant need of repair—has been damaged by extreme weather events associated with climate change (KM 13.1).[198] Extreme heat has reduced passenger and cargo loads for aircraft and buckled roadways and railways; heavy rainfall has eroded road, bridge, and rail foundations (Figure 26.20); and coastal storms have interrupted shipping and caused mass evacuations on roadways. When transportation systems fail, the impacts have been particularly devastating for people living in systematically underserved and under-resourced neighborhoods.[171] As of 2022, Oklahoma's and Texas's state transportation plans do not address threats to transportation services or infrastructure from climate change impacts;[199,200] Kansas's plan does include threats to infrastructure from extreme weather.[201]

Extreme Rainfall Impacts on Transportation

Heavy downpours associated with Hurricane Harvey (2017) caused bridge damage.

Figure 26.20. Extreme events associated with climate change are expected to threaten transportation infrastructure, as demonstrated by past experiences. Here, widespread heavy rains associated with Hurricane Harvey (2017) caused the collapse of a section of Farm to Market Road 762 in Fort Bend County, Texas. Photo credit: Kevin Stillman, Texas Department of Transportation.

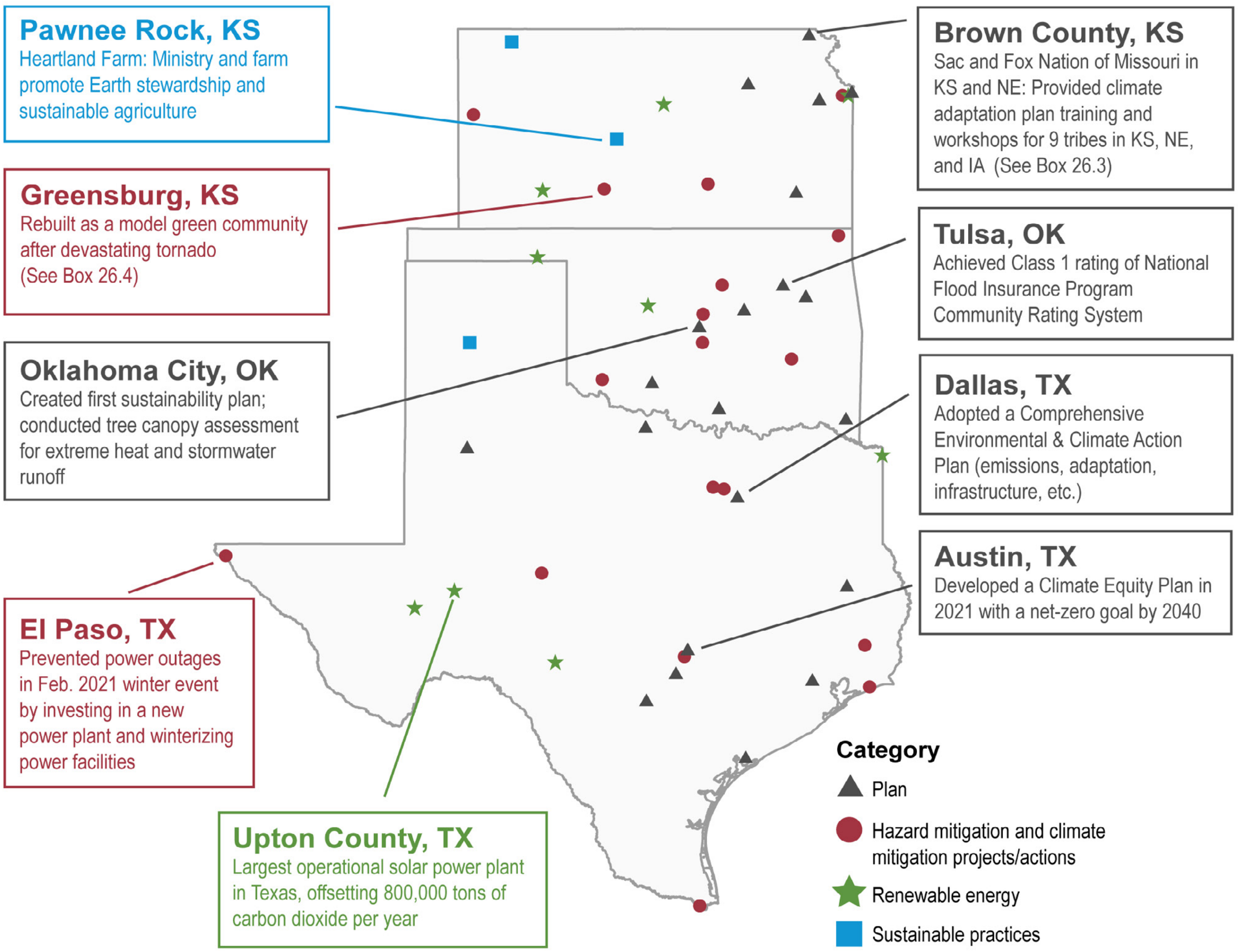
Climate change is also affecting public safety systems and their ability to serve community members. For example, during extreme heat events in 2018, the San Antonio Fire Department received significantly more requests for emergency medical services from neighborhoods with higher rankings on social vulnerability indices.[202] From 2000 to 2018, firefighters in the Southern Great Plains fought 16 megafires—fires that encompass over 100,000 acres, overwhelm local response capacity, and are extinguished only when weather conditions become favorable.[203] These fires are associated with extremely dry vegetation,[204] unusually warm temperatures, and strong winds aloft[203]—conditions projected to become more prevalent as the region warms and soil water evaporates more quickly.

In addition to providing resources for infrastructure, utilities, and public safety, local communities support public education systems. These systems serve learners of all ages and support scientific literacy and social cohesion while serving meals and providing other community services—key steps in enabling public engagement solutions.[205] As of 2022, only Kansas clearly incorporates human-caused climate change in its K–12 state curriculum standards.[206,207,208] Educators rarely receive formal education on the subject, leading many K–12 science teachers to have misconceptions and critical gaps in climate change knowledge. In a survey of teachers and education students in Dallas–Fort Worth,[209] for example, most educators were neutral regarding whether climate scientists disagree about the causes of global warming, even though 97% of these scientists agree (KM 2.1).[210] Informal education programs fill some climate change literacy gaps left by public education through short courses online (e.g., Martin et al. 2020[211]) and Tribal youth education programs.[3] Educators can apply successful strategies for teaching the complexities of climate change by actively engaging learners[212] and infusing lessons with place-based knowledge.[213]

Environmental monitoring and associated data quality assurance and sharing are important to track changes in climate over time, support evidence-based decisions, and warn people of imminent danger. High-resolution, regional weather and water monitoring networks[214,215,216,217] supply critical local measurements for decision-makers. However, understanding local impacts of climate extremes and how to adapt is hampered by a lack of systematic, region-wide observations of species, habitats, economic costs and damages, resource demand and consumption, decision processes, and adaptation and mitigation strategies.[218,219,220,221] Such data would help researchers better understand complex systems and managers develop better local management strategies.

Even without these regional data, cities across the Southern Great Plains are addressing risks to public services through hazard mitigation work and climate adaptation and mitigation actions (Figure 26.21; KM 12.3). Greenburg, Kansas, for example, chose environmentally resilient designs for rebuilding after it was hit by a violent tornado on May 4, 2007 (Box 26.4). In 2020, Oklahoma City produced its first sustainability plan, known as adaptokc, which addressed climate change.[222] Austin, San Antonio, and Dallas also adopted plans that included both mitigation and adaptation actions and have started to address local equity issues as related to climate change impacts (Climate Resilience Action Plan;[223] Climate Ready, Action and Adaptation Plan;[224] and Comprehensive Environmental and Climate Action Plan[225]). Smaller communities that lack resources for stand-alone climate plans are integrating actions into hazard mitigation or comprehensive plans. Results of city actions are becoming evident. For example, in response to frequent flooding that occurred prior to the 1990s, Tulsa enacted flood management actions that resulted in the National Flood Insurance Program awarding Tulsa its highest rating under the Community Rating System, reducing flood insurance premiums by 45%.[226]

Mitigation and Adaptation Actions Across the Southern Great Plains



A wide array of actions are being conducted across the region to address the impacts of climate change.

Figure 26.21. Communities and Tribes across the Southern Great Plains are acting in response to the challenges associated with climate variability and change. Actions include developing plans for hazard mitigation, climate action, and climate resilience (black triangles) or undertaking activities related to hazard mitigation (e.g., building resilient infrastructure) and climate mitigation (e.g., reducing energy usage; red circles). Renewable energy projects (green stars) and agricultural or environmental practices that support sustainability (blue squares) are also beginning. For actions under multiple categories, the main category was mapped. These actions aim to increase community resilience to hazards now and in the future. The mapped examples are representative of others occurring elsewhere across the region. See details at https://arcg.is/0yGjKm. Figure credit: See figure metadata for contributors.

The water policies of the three states encourage consumptive use, generally exclude the physical interactions between groundwater and surface waters, and are overseen by multiple agencies across different levels of government. These constraints make water resource solutions difficult in a rapidly changing climate. Nonetheless, Kansas's 2022 statewide water plan includes climate change, its impacts, and associated recommendations, providing a scientifically credible guide for adaptation and mitigation options.[227] The 2012 Oklahoma Comprehensive Water Plan went further by incorporating quantitative climate projections to assess future streamflow, municipal and industrial demand, crop irrigation demand, and water storage.[228] The resulting information was applied in the plan's recommendations. For Texas, however, the 2022 State Water Plan did not consider climate change.[229] Researchers have spotlighted this crucial omission in Texas's water planning process, especially its lack of planning for droughts worse than the previous record drought.[190]

Communities are beginning to welcome nature-based or green infrastructure solutions for water resource challenges. The City of Austin has implemented water catchment systems, bioswales, and other green infrastructure at libraries, schools, and other city properties to reduce stormwater flows.[230] In Norman, Oklahoma, the Division of Utilities is testing how to augment water supplies during drought by returning highly treated water from its water reclamation facility to a nearby reservoir (Figure 26.22).[231] Cities of all sizes, from Houston (see Box 26.1) to Lenexa, Kansas (population under 50,000),[232] are adopting green infrastructure programs.[233]

Water Treatment Plant in Norman, Oklahoma

Wastewater treatment services in the region are addressing water resource challenges.

Figure 26.22. The City of Norman's wastewater treatment facility is testing how to supplement water during drought by returning highly treated water from its water reclamation facility to its nearby reservoir. Water reuse is a well-established adaptation method that is especially useful in semiarid climates. Photo credit: ©City of Norman, Oklahoma.

Faith-based organizations also are responding to climate impacts by raising charitable donations, serving as communication and distribution centers, and recruiting volunteers to assist with both physical and emotional disaster recovery.[234] After Hurricane Harvey (2017), for example, faith communities provided over $242 million (in 2022 dollars) to help flood victims.[235] Interfaith and ecumenical organizations, denominational bodies, local worshipping communities, and individual believers are teaching about climate change and environmental stewardship with their sacred texts or oral traditions[236] and leading environmental actions such as recycling and tree planting.[237] Sharing spiritual beliefs within a local community is an important way to increase social capital for climate adaptation.[238]

Box 26.4. Building a Sustainable City: Greensburg, Kansas

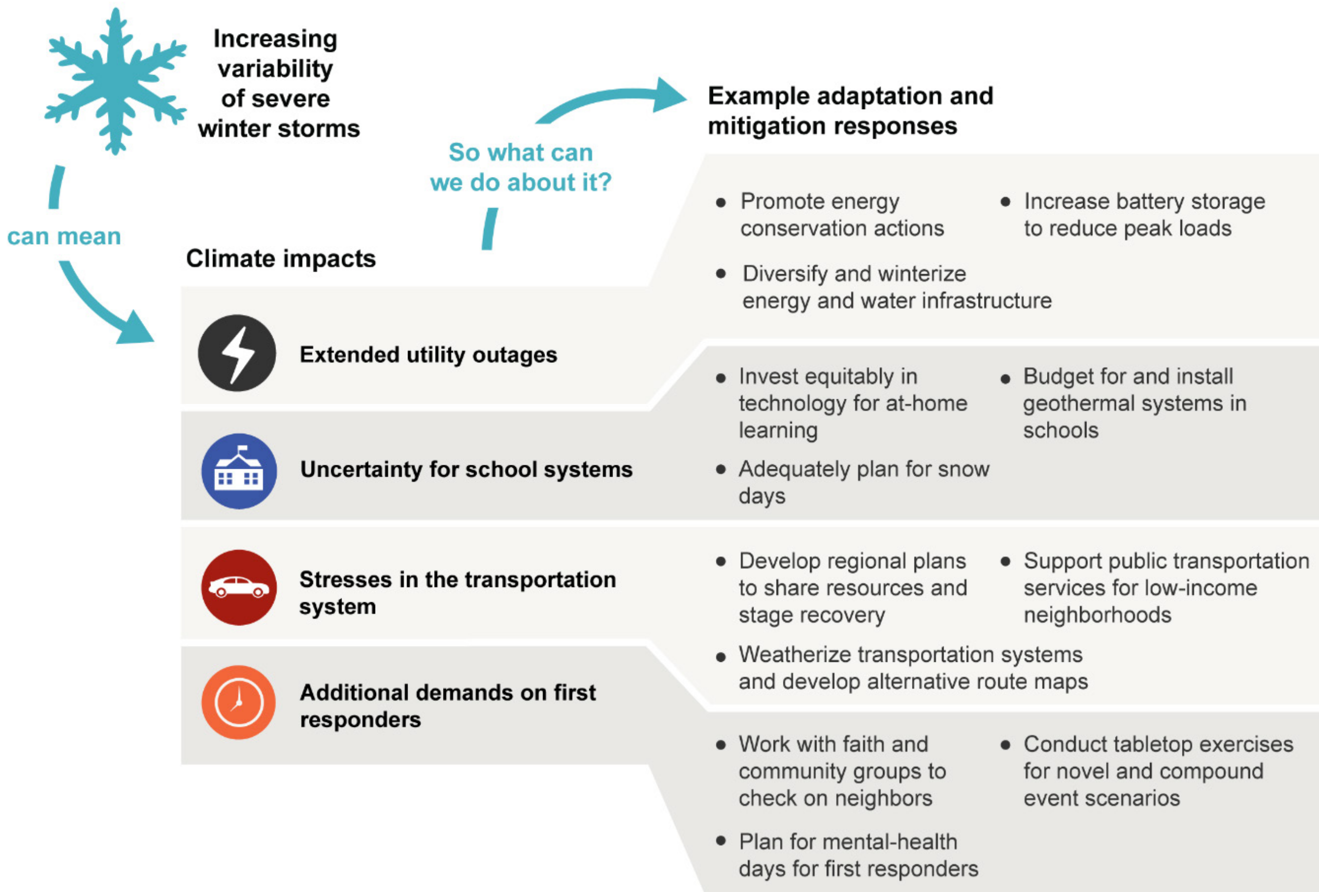
After 90% of the structures in Greensburg, Kansas (population: 1,400), were destroyed by a 2007 tornado, the town's residents rebuilt with an emphasis on resilience and sustainability—elements important to climate change adaptation. The community planned to "green Greensburg" following four visioning meetings that averaged 400 participants each.[239] The resulting 2008 Sustainable Comprehensive Plan reflected their discussions through a focus on children and future generations, a strong community and sustainable economy, and living off and with the land.[240]

Rescoping and rebuilding the city required support from federal, state, university, private, and nonprofit organizations, as well as community groups and individual leaders.[241] The city council provided backing through a resolution requiring that city-owned buildings of 4,000 square feet or larger adhere to "platinum" building standards of the Leadership in Energy and Environmental Design program.[239] This decision led to the creation of a platinum-certified city hall, county school, public hospital, county commons, arts center, and business incubator.[242] Energy-efficient lighting along Main Street reduced energy and maintenance costs; a 10-turbine wind farm generated enough power for 4,000 homes; and native plants, green roofs, and bio-retention areas reduced stormwater runoff.[243] Attracting sustainable businesses to the remote city, however, remains challenging.[241]

During the transformation process, residents' attitudes have changed about sustainability. Many who were initially reluctant found that environmental stewardship was consistent with their values and made common sense, leading them to adopt sustainable practices and technologies for their own homes and landscapes.[243]

Overall, actions in the region have been too slow in pace, and investments have been inadequate in scale and scope, compared to what would be needed[244] to minimize strongly negative consequences of climate change by midcentury (KM 32.1), within the lifetimes of today's young adults. For mitigation, calculations indicate that CO_2 emissions would have to decline by about 25% from 2010 levels by 2030 and reach net zero around 2070.[244] While Kansas and Oklahoma reduced carbon emissions 14%–17% between 2010 and 2019, Texas increased emissions by 11%.[245] Transformative adaptation (KM 31.3) and climate equity and justice (KMs 20.1, 20.3) provide holistic frameworks for climate adaptation actions. Many actions that enhance the resilience of public services and infrastructure (Figure 26.23) also are expected to reduce future financial costs from extreme events.

Resilience Actions to Address the Impacts of Severe Winter Storms on Public Services



Resilience actions can reduce risks to public services caused by increasingly variable severe winter storms.

Figure 26.23. The increasing variability of severe winter storms causes uncertainty and increases risk in public services and infrastructure across the Southern Great Plains, including extended utility outages, uncertainty for school systems, stresses in the transportation system, and additional demands on first responders. The example adaptation and mitigation actions can increase resilience and reduce negative impacts. Figure credit: See figure metadata for contributors.

Traceable Accounts

Process Description

The author team for the Southern Great Plains chapter was selected using a standardized rubric on candidate biographies acquired from nominations and an internet search. Rubric elements were 1) subject-matter expertise relevant to the Southern Great Plains; 2) diversity in discipline or type of experience to ensure breadth in chapter content; 3) role that reduced the risk of chapter structural problems, including breadth of perspectives (e.g., gender, ethnicity, race, organization type, career stage, and geographical location); and 4) experience engaging with partners across the region (e.g., government agencies, nongovernmental organizations, practitioners, academics, churches, businesses). Candidate authors were screened by their willingness and ability to work on a team, write well, and commit the necessary time. A few original authors left the team during the Zero Order and First Order Draft stages (either to transfer to another chapter or to address changes in their jobs) and were not replaced.

The author team met virtually for an hour at least biweekly during writing periods to discuss assignments, answer questions, prepare for stakeholder workshops, discuss figures, and reach consensus on topics and written text. The coordinating lead author, chapter lead author, and point of contact met virtually, typically weekly during writing periods, to review due dates, answer questions, and ensure that the team was progressing adequately.

Chapter authors developed initial chapter themes by brainstorming a list of values and interests demonstrated by people living and working across the diverse landscapes of the region. Impact-based statements focused on these values and were clustered by common attributes to reduce redundancy.

Consensus-building occurred through deliberations and by addressing questions during author meetings and through discussions using the comments feature in the shared online draft of the chapter. The lead author checked regularly with the author team for concurrence on any statements drafted by one or more team members. Disagreements on priorities or wording were discussed openly. Confidence was determined through initial, independent assessments of several author team members and finalized after oral discussion during a virtual meeting of the full author team. Concerns were debated until no one disagreed with the stated confidence level. All members of the author team approved of the document for each draft through the Fourth Order Draft. The lead author finalized the Fifth Order Draft, with minimal changes from the Fourth Order Draft, to respond to three minor reviewer comments, suggest copy edits, add missing citations, and address inconsistent figure captions.

The author team chose to hold four 90-minute online stakeholder workshops over two days to provide opportunities for people with different work schedules to participate. Workshops were held at various times of day, including during the noon lunch hour (Central Time) and at 5:30 p.m. for those unable to join during the normal workday. Each workshop began with a 30-minute overview of the full National Climate Assessment (NCA) process and the specific chapter content, followed by six concurrent one-hour breakout sessions—one for each of the five sections of the chapter and one additional session open for any discussion. The author team facilitated the breakout sessions using specific questions to engage participants and obtained feedback through interactive presentations and discussion.

Input from the stakeholder meetings, agency reviews, and internal reviews by the Technical Support Unit (TSU) were addressed through the consensus-building process noted above. The author team discussed content of newly developed graphics during regular meetings and iterated on design with the TSU. Metadata for all graphics and images were collected and documented by the chapter lead author and approved by the TSU. Technical contributors provided specific expertise in the following ways: 1) to alert the author team of local examples of impacts of, adaptation to, or mitigation of climate change; 2) to suggest peer-reviewed literature in areas where the author team had a disciplinary gap; or 3) to aid in the description of an author-selected figure. Climate projections were available only to 2100; as a result, the author team was not able to assess the impacts of climate change out 100 years, as required by the Global Change Research Act of 1990.[246]

Key Message 26.1

How We Live: Climate Change Is Degrading Lands, Waters, Culture, and Health

Description of Evidence Base

Several topics have an extensive research base both nationwide and within the Southern Great Plains. For these, the author team selected citations that were most relevant for the region. Physical impacts, such as species range shifts, changes in water quality, and stormwater runoff, have sufficient evidence within the region to make well-documented statements (e.g., Howell et al. 2019;[23] Bragg et al. 2003;[24] Moore et al. 2016;[25] Will et al. 2013;[26] Whyte et al. 2021[31]). Literature on human health and climate change was relatively abundant (e.g., Anderegg et al. 2021;[49] Levetin 2021;[50] Neumann et al. 2019;[51] Johnson et al. 2016;[52] Mallen et al. 2019;[53] Bell et al. 2018;[54] Caminade et al. 2019;[56] Raghavan et al. 2021;[57] Hotez 2018;[58] Gorris et al. 2019[59]). The body of literature in climatic regions similar to the Southern Great Plains also supports the statements (e.g., Chs. 6, 8). Studies of human and societal impacts, such as climate impacts to culture, or the intersection of climate and other ecological or human drivers of the system, such as woody encroachment or racial disparities, were more difficult to find. In these cases, the members of the author team used their expert judgment to develop the section text.

Studies for Houston, Dallas, and Austin, Texas, were relatively abundant, as was research on impacts of climate change on both natural ecosystems and agroecosystems in Texas. Research for the case study on Houston was abundant and consistent, although the diversity of peoples and environments across the metropolitan area was extremely broad and had to be condensed in a manner that did not capture the city's nuances to the degree that the authors preferred.

Major Uncertainties and Research Gaps

Major gaps included lack of research on 1) a wide variety of communities (i.e., the same handful of cities are well documented and others are not), 2) human impacts outside of human morbidity and mortality (e.g., what traditions or cultural practices are changing because of climate change), 3) attribution of climate change to impacts that were driven by multiple stressors (e.g., urban flooding caused by heavier rainfall, changes in land use, and water management practices), and 4) long-term signals of climate change along the Gulf Coast and in Gulf waters (i.e., insufficient observational data over time and space).

There are major uncertainties in individual, family, neighborhood, and community responses to different climate-related impacts, such as higher temperatures, heavier rainfall events, or more intense hurricanes. Adaptation methods are not commonly measured throughout the region, so the circumstances under which different adaptation strategies are most beneficial are highly uncertain (KMs 31.1, 31.3). Although specific Tribes are knowledgeable about climate-related impacts to their relatives and culture, many understandably choose to protect their intellectual property as sovereign nations; thus, some impacts to Tribes are uncertain.

Documentation of impacts and actions for Kansas and Oklahoma was substantially limited in comparison to inland Texas. In fact, peer-reviewed literature focused on or inclusive of Kansas was limited outside of the Kansas City metropolitan area. Literature on changes in waters along the Texas Gulf Coast as related to climate change was sparse, and data sampling was insufficient in space and time to determine long-term trends in red tide harmful algal blooms, mass mortalities of aquatic organisms (e.g., from cold outbreaks), or freshwater discharge.

Description of Confidence and Likelihood

For the first statement in the Key Message, the author team had *very high confidence* in risks associated with degradation of lands, waters, and health. However, a lack of data for privately owned areas within the region, notably in Texas, where 93% of land is privately owned,[247] limits the authors' confidence slightly for these areas. The author team had lower confidence in risks associated with quality of life, well-being, and cultural interconnectedness. As a result, the team lowered the confidence level from *very high* to *high*. Confidence in future projections of temperature-related hazards (e.g., extreme heat days) is *very high*; however, confidence is substantially lower (i.e., *medium*) for precipitation-related hazards because projections are mixed on the trends, depending on location. As a result, the team lowered the confidence level from *very high* to *high*. In the third sentence, the author team agreed that all actions were viable and well documented in the literature as resilience activities, but the effectiveness of the actions has not been vetted thoroughly, leading to an assessment of *medium confidence*.

The evidence base was not sufficient to determine quantitative probabilities for the first and third statements in this Key Message; thus, no likelihood is specified. For the second statement, there is sufficient evidence from multiple sources of climate projections across the region to indicate that it is *very likely* that weather hazards will increase (in size, number, or intensity). There also is sufficient evidence in the literature to indicate that these types of changes generally result in negative consequences for human lives, because most US families, neighborhoods, and communities are equipped to handle average climate conditions, but they struggle to be resilient during extremes.

Key Message 26.2

How We Work: Climate Changes Are Creating Economic Challenges and Opportunities

Description of Evidence Base

Impacts of, and mitigations and adaptations for, climate change in the energy and agriculture industries have an extensive research base both nationwide and within the Southern Great Plains (e.g., see Chs. 5, 11; Challinor et al. 2014;[94] Miller et al. 2021;[248] Rojas-Downing et al. 2017;[249] Shoeib et al. 2021;[76] Wimhurst and Greene 2019[77]). For these topics, the author team selected citations that were most relevant for the region. Robust literature was not available for many other businesses and industries across the region. In these cases, the author team selected examples specifically from the region. Research that focused on other regions of the country, even if robust, was not used because the context for resources, culture, and values of the Southern Great Plains differs from other regions of the United States. Thus, the author team chose to respect the place-based nature of impacts and solutions.

Literature on the February 2021 winter storm and its impacts has grown rapidly, and the author team assessed sufficient documentation to discuss the event (e.g., Bolinger et al. 2022;[78] Busby et al. 2021;[86] Doss-Gollin et al. 2021;[250] FERC 2021;[83] Ghosh et al. 2021[84]). Figure 26.8 applied the first, third, and fifth quintiles of the data for both income level (poorest, medium income, wealthiest) and race (low, medium, and high non-White) to demonstrate inequities related to the percentage of power outages during the event.[46] Employment statistics for the fossil fuel industry were calculated for September 2022 using the following categories from the North American Industry Classification System: 211, 2121, 213112, 213113, 22112, 2212, and 3241.[73]

The literature on topics such as geothermal energy production and carbon capture and storage has grown in academic and federal government publications; however, commercial-scale implementation of these technologies was considered of more interest to the chapter audience even though the literature was scarce.

Major Uncertainties and Research Gaps

In addition to government services (KM 26.5), energy, and agriculture, major economic sectors in the region that may be affected by climate change include manufacturing, retail services, construction, hospitality, real estate, insurance, wholesale trade, and social assistance. Little to no peer-reviewed literature was found related to impacts, adaptation, or mitigation for these sectors.

As in other sections, literature was substantially sparser for Kansas and Oklahoma than for Texas. Most of the literature on climate-change impacts and actions related to business and industry, except for agriculture, was focused on major metropolitan areas; thus, rural areas were less studied. The literature on climate impacts to women- or minority-owned businesses or small businesses in the region was minimal. Research was limited on adaptation and mitigation actions in the region, including the evaluation of their effectiveness.

Peer-reviewed literature on the impacts of the February 2021 winter storm was limited except for the storm's impact on energy generation, transmission, and distribution. News articles discussed a wide range of other impacts, from transportation and the economy to recreation and mental health, but few studies analyzing non-energy impacts were available in the literature at the time of writing.

Description of Confidence and Likelihood

In the first statement for the Key Message, the author team determined that the literature was limited regarding how business and industry experience new employment opportunities as climate conditions change across the Southern Great Plains. Thus, the author team lowered the confidence level from *very high* (i.e., the level that would be assigned to the US as a whole) to *high* (for the Southern Great Plains region). For the second statement, confidence was assessed as *high* based on substantial evidence from available climate projections but less evidence for costs to businesses and industry. For the third statement, the literature was thin with respect to how actions by business and industry result in positive economic outcomes; hence, the team concluded that *medium confidence* was most appropriate.

The evidence base was not sufficient to determine quantitative probabilities for the first and third statements in this Key Message; thus, no likelihood is specified. For the second statement, there is sufficient evidence from multiple sources of climate projections to indicate that it is *very likely* that warmer temperatures, more erratic precipitation, and sea level rise will occur across the region in the future. These types of changes are linked to costs and losses in business and industry.

Key Message 26.3

How We Play: Climate Extremes Are Endangering Sports, Recreation, and Leisure

Description of Evidence Base

The author team considered the topic of climate change and sports (i.e., sports ecology) to be an emerging area that will be of great interest to readers in the Southern Great Plains. Discussion about climate change and organized sport, from youth to professional, has been limited in prior NCAs. Yet the literature on how climate affects health outcomes in sports and other physical activities has been growing (e.g., Bernard et al. 2021;[120] Bergeron et al. 2011;[130] Yeargin et al. 2017;[127] Vanos et al. 2017;[132] Orr et al. 2022;[118] Thomas et al. 2013;[141] Brocherie et al. 2015[122]). The lack of access to parks is a major theme in environmental justice and public health literature (e.g., Heynen et al. 2006;[251] Sister et al. 2010;[252] Rigolon 2016;[134] Mullenbach and Wilhelm Stanis 2022[253]). Negative impacts of climate change on ecosystem services, including hunting, fishing, and other types of recreation, also are well documented (KM 8.3); however, positive impacts are less studied. Studies in the Southern Great Plains are abundant on health outcomes and ecosystem services in the face of climate change.

Literature on the economic impacts of specific extreme events on recreation can be found, especially for Texas, but comprehensive literature on these impacts across the region or across recreation, sports, and leisure does not exist. In these cases, the author team gave examples from specific activities, events, and locations from the literature or provided examples from multiple news reports. As in other sections, peer-reviewed literature related to this section was most abundant for Texas, especially the Texas Gulf Coast, and least abundant for Kansas. Although examples were available for specific adaptation actions, literature evaluating the effectiveness of these actions was limited.

Major Uncertainties and Research Gaps

Documentation of how climate change affected the amount, timing, and intensity of physical activity on a community or larger scale is limited. Prior research focused primarily on the impacts of climate on football players. Research remains lacking on the impacts on other sports (e.g., soccer, lacrosse, cross-country). Comparative studies across the region are rare for impacts of climate change on sports, recreation, and leisure activities. Literature regarding climate change impacts and adaptation actions for recreational activities in Texas Gulf waters is minimal.

Research is limited on the convergence of environmental justice, climate, and sports and recreation, especially among Indigenous communities and in rural settings. Economic impact studies tend to focus on singular extreme events in limited regions and thus do not provide a comprehensive understanding from state to state, activity to activity, or sport to sport. Research is limited on the climate adaptations of sports organizations to reduce climate vulnerabilities, as well as on the outcomes (positive or negative) of those adaptations.

Description of Confidence and Likelihood

Peer-reviewed literature was abundant and consistent, leading the author team to an assessment of *very high confidence* for the first statement in the Key Message. The other two statements were assessed at *high confidence* based on a smaller evidence base on climate change impacts on reduction of outdoor physical activity and on the types of adaptation strategies used by individuals, communities, or sport organizations.

The evidence base was not sufficient to determine quantitative probabilities for the first and third statements in this Key Message; thus, no likelihood was specified. For the second statement, there was sufficient evidence from multiple sources of climate projections to indicate that it is *very likely* that heat extremes will increase across the region in the future. The literature is sufficient to recognize that heat extremes are linked to heat-related illness and death and that they also result in a reduction of outdoor physical activity.

Key Message 26.4

How We Heal: Climate Change Is Exacerbating Existing Social and Environmental Disparities

Description of Evidence Base

Social science literature regarding justice and equity as related to climate hazards was abundant and consistent, especially as related to extreme heat, flooding, and tropical cyclones (e.g., Benevolenza and DeRigne 2019;[68] Flores et al. 2021;[254] Maldonado et al. 2016;[255] Prudent et al. 2016;[256] Smiley et al. 2022[257]). Research on low-income communities and communities of color was extensive for many metropolitan and industrial areas in the region (e.g., Collins et al. 2019,[258] 2013;[259] Flores et al. 2021;[254] Li et al. 2022[260]). There is a cluster of research on tropical cyclones, sea level rise, and infrastructural disparities in marginalized communities in Texas coastal metropolitan and industrial areas, with some studies focusing on South Texas, where many *colonias* are located (e.g., Atisa and Racelis 2022;[261] Martinich et al. 2013;[160] Flores et al. 2021;[254] Chakraborty et al. 2019[169]). The *Status of Tribes and Climate Change Report*[3] provided extensive examples and documentation of challenges and opportunities, and it was useful for content and context across the entire chapter. Evidence-based solutions were limited, especially those over a sufficient time period to evaluate long-term effectiveness.

Major Uncertainties and Research Gaps

In comparison to research on the physical impacts of climate change, there is significantly less research in the Southern Great Plains on climate change through the lens of justice and equity. Those most impacted include people and families with low incomes; rural residents; historically marginalized populations; disabled persons; older adults; Black, Indigenous and People of Color; those who do not identify as cis, straight male; immigrants; those living in *colonias*; and unhoused individuals; however, the author team found no studies that analyze the impacts on these populations systematically across any of the three states. In addition, although there are several studies assessing challenges for Spanish-speaking individuals, those who speak other non-English languages generally are not included. In some cases, literature diagnoses disparities without explaining the reasons for them (e.g., Carvallo et al. 2021[85]), indicating that additional research is needed to analyze the root causes so that they can be addressed alongside climate adaptation and mitigation actions (i.e., to avoid maladaptation; KM 31.4).

Peer-reviewed research has tended to focus on cities, with less emphasis on rural communities or small- to medium-sized cities in the region. Even for locations near the Southern Great Plains, there is little literature on climate justice as it relates to rural communities (e.g., Gutierrez and LePrevost 2016[262]). Knowledge is limited regarding the evaluation of climate mitigation and adaptation strategies that seek to incorporate climate justice and equity (e.g., Mullenbach and Wilhelm Stanis 2022[253]). Because of their sovereignty, Tribes have chosen, in many circumstances, to document their work through oral traditions, which are not shared with outsiders.[3]

Description of Confidence and Likelihood

Based on the abundance of research and consistency of results across the US and within the region, the author team assessed the first two Key Message statements with *very high confidence*. How the specific demographics or location of the neighborhoods and communities relate to a higher risk of impacts remains to be studied more completely, but the first two statements were intentionally general to highlight what is known from the literature. The third statement was assessed with *medium confidence* because rigorous evaluation of outcomes from policies, practices, and programs is more limited in the literature.

Although the literature is compelling for many of the physical impacts of climate change, impacts to individuals, neighborhoods, and communities were not as robustly documented and certainly did not cover the entire region. Hence, no likelihood is specified for any statement, as the author team could not assess quantitative probabilities through case studies or analyses of small regions within the Southern Great Plains.

Key Message 26.5

How We Serve: Climate Change Is Straining Public Infrastructure and Services

Description of Evidence Base

Public infrastructure and services topics related to water supply (KM 4.2), infrastructure (KMs 12.2, 13.1), public health and safety (KM 15.1), and education[212] had an extensive research base nationwide and across specific regions of the United States. Research in the Southern Great Plains was less robust. In this case, the authors, many of whom have worked for or with municipalities across the region for decades, used their expert judgment to communicate the message and to select the most relevant citations. Other evidence for this Key Message included state water plans,[227,247,263] state transportation plans,[199,200,201] and state science curriculum standards[207,208,264] for each of the three states.

Scholarship is abundant regarding agricultural water needs and uses across the Southern Great Plains; however, peer-reviewed literature regarding climate change and municipal water supplies or water sustainability was sparse for all three states. How climate change affects public infrastructure and services in the region is an emerging topic, with much of the research done only in the past decade. News media covered local impacts after extreme events, including the damage to public infrastructure and response by service agencies and organizations. Because cities and towns are important locations where climate mitigation and adaptation occur, the author team chose to cover this topic even though the evidence base was smaller than that for the other sections.

In addition, the author team chose to discuss the emergent topic of the role of faith-based organizations, as it was well aligned with values in the region. These organizations also can use content in this report to plan for community service before, during, and after climate hazards. Although major religions have statements regarding climate change (e.g., *Laudato si'* encyclical from Pope Francis, "Islamic Declaration on Climate Change," "Buddhist Climate Change Statement to World Leaders," and "Interfaith Climate Statement"),[265] literature regarding the interactions of faith, religion, and climate change is limited.[238,266] Peer-reviewed literature was sparse on how faith-based organizations conduct adaptation or mitigation actions or the scope and effectiveness of these activities.

Information about what actions communities were taking in the region was primarily documented in state or municipal reports rather than the peer-reviewed literature (e.g., City of San Antonio 2019;[224] City of Oklahoma City 2020[222]). Hence, no evaluation of the effectiveness of or public support for the actions was available. State transportation plans did not have detailed articulation of threats to transportation services or infrastructure as related to climate change. The 2020–2045 Kansas Long Range Transportation Plan;[201] Oklahoma Long Range Transportation Plan: 2020–2045;[199] and the Texas Transportation Plan 2050[200] did not provide goals or objectives that addressed climate-change impacts. Although Kansas and Oklahoma acknowledged the need to support electric-vehicle charging stations, climate-change adaptation and mitigation were minimal elements of these plans and provided little context for the author team. For water resources management, significant content was available in the 2022 Kansas Water Plan[227] and the 2012 Oklahoma Comprehensive Water Plan.[263] Conversely, the Texas Water Development Board[229] did not acknowledge climate change or plan for its impacts on water resources management, thus limiting the content for Texas.

Major Uncertainties and Research Gaps

Data for and analyses of climate change impacts on public services and infrastructure in the region were sporadic, even though research, data, and projections for temperature, precipitation, and other physical climate indicators over land were generally plentiful. Also, although coastal and offshore data were available for the Gulf of Mexico from the Gulf of Mexico Coastal Ocean Observing System[267] and Texas Automated Buoy System,[268] these observing systems were not established to monitor long-term climate trends (e.g., ocean acidification, saltwater intrusion), and thus there was a scarcity of literature on how these observing systems aided decision support for climate change.

Few studies on public infrastructure and services focused on Kansas and Oklahoma, with most research in Texas. Of those on Kansas and Oklahoma, many were decades old. For all states, most studies examined specific facilities or communities; there were few synthesis or comparison studies that helped present a larger picture of climate change impacts across the region. Documentation of how climate change is projected to affect the healthcare system or healthcare facilities was sparse, although research on climate change and public health was relatively abundant (see Traceable Account for KM 26.1). Similarly, broad syntheses across the region of the impacts of climate change on roadways, railways, ports, pipelines, and airports, or the reliability and safety of transportation systems, were unavailable. In addition, with the region's residents and visitors heavily dependent on automobiles and trucks, there was a large gap in the research on what mitigation and adaptation measures were recommended for moving into a next-generation, climate-smart transportation system.

Few peer-reviewed publications existed, specific to the region, regarding the intersection of public safety and climate change, including current planning processes, effective adaptation, and economic costs. The documentation available primarily focused on historical events and rarely on projections into the future. Similarly, information was minimal regarding how climate change was incorporated into the curriculum at various education levels across all three states, whether in formal or informal programs.

Even though faith-based organizations play significant roles locally, regionally, and globally when crises occur, most of the literature on climate change and faith focused on individual knowledge, opinions, or actions based on religious affiliation. The scope of what these organizations were doing (or not doing) and how they were accomplishing their works were unclear.

Description of Confidence and Likelihood

Confidence was assessed to be *medium* for the first statement, which was the consensus after acknowledging both the dearth of peer-reviewed literature (which would have led to *low confidence*) and the experience of members of the author team who served one or more communities and networked with others who do the same (which would have led to *high confidence*). In this case, much of the work being conducted across the region is relatively recent (e.g., since the publication of NCA4 in 2018); thus, ongoing research has yet to reach publication stage. For the second statement, the *high confidence* level was chosen primarily because of the authors' knowledge of the climate projections and those events that have most affected public infrastructure and services in the past. As with other sections, evaluation of mitigation and adaptation options in the region is sparse (KM 31.1). The effectiveness of solutions is generally place-based, so the author team chose *medium confidence* based on these uncertainties.

Although climate projections indicate that more frequent and intense climate-related events are *very likely* in the future for the region, the author team did not find sufficient literature on the reliability, cost, and distribution of community services to generate quantitative probabilities of likelihood. Thus, no likelihood is specified for any statement in the Key Message.

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