- Competency in geospatial planning tools for quantitative, data-driven decision making

1.3.5 SWD Synthesis

Beyond expertise spanning CW Mission Areas, one of the key strengths across SWD is excellent relationships with stakeholders and sponsors who are eager to work with SWD in supporting the needs of the region. The Division has complemented this strength with advancement in key internal areas, such as the development of a Regional Planning and Environmental Center (RPEC) to provide centralized, robust support to CW projects across the AOR. In addition, each of the Districts possesses existing capacity for surge that can be leveraged and expanded to meet new challenges, along with vital experience and expertise across varying core CW Mission Areas. With these existing strengths serving as a firm foundation, SWD can be bold in shifting toward more innovative and integrated approaches to project planning and execution. Such a paradigm shift will be essential in addressing the unique challenges that affect the Division's CW Mission Areas in the face of an uncertain future. As a first step in this paradigm shift, the Division and its Districts must adequately understand, anticipate, and plan for the key drivers that affect, and will continue to affect, the region now and into the future.

2

Evolving Risks & Opportunities

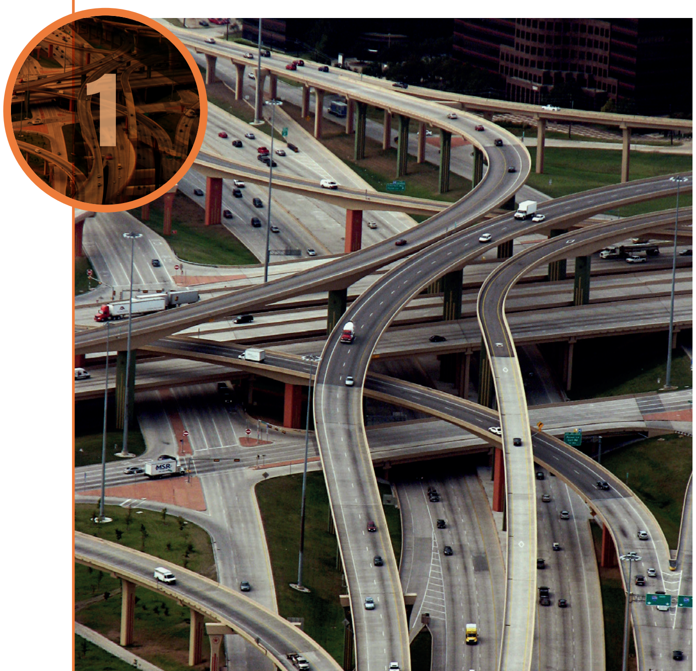
Key Drivers

SWD's AOR is rapidly changing. A series of socio-economic and bio-physical trends with global analogues are manifesting in complex ways at varying scales throughout the region. These trends, and their uncertainty, represent evolving risks and opportunities for the SWD Civil Works program, especially when analyzed in the context of a rapidly growing and urbanizing population, a changing regional landscape, changing extreme weather patterns, a water-food-energy nexus pressured by an uncertain energy future and competing uses, and aging infrastructure. These trends have been identified as key drivers for the Civil Works Program in the region, as their uncertainty and considerable implications for USACE Mission Areas present challenges that can only be met with a movement toward a more integrated and adaptive paradigm of water resources management. Additionally, the societal risks posed by these drivers are likely to disproportionately affect socially vulnerable populations. Therefore, such risks and opportunities cannot be divorced from the inequitable distributional impacts on communities lacking the resources to thrive in and adapt to difficult and changing circumstances.

The COVID-19 pandemic, which took hold across the country in early 2020, may have long-range impacts on global and regional socioeconomic trends, including oil production and demand. This strategic plan considers some volatility of these key drivers. However, this plan is limited in how it can consider COVID-19 impacts specifically without thorough additional study, particularly given the lack of precedent for understanding the full long-term impacts of this pandemic. More evident, however, is the sustained and added pressure this public health crisis imposes on communities already disproportionately vulnerable to the impacts of extreme weather variability and growing resource pressures. For these populations, uninterrupted access to potable water for drinking and sanitation as well as resilience to extreme weather events will be more important than ever in the years to come, especially as changes in habitats and weather patterns drive increases in future vector-, food-, and water-borne infectious disease risk.[1]

2.1 - Driver 1: Rapid Population Growth & Urbanization

Rapid rural-urban out-migration, combined with natural population growth, are driving a population explosion in major metropolitan areas like metro Dallas, Houston, Oklahoma City, and northwest Arkansas.



Source: Dallas High Five Interchange, Austrini

According to the American Community Survey (ACS) 5-year estimates, the total population of all counties contained within SWD's boundaries grew 12.4% from 2010-2018, from about 31.7 million to 35.7 million. Between 2010-2019, the DFW Metropolitan area exhibited the largest growth in population in the nation and was closely followed by the Houston Metropolitan area, which exhibited the second highest increases during this period.2 While the region's population growth is primarily driven by Texas with the highest projected growth rate in the nation through 2040, 3 other areas in the SWD such as northwest Arkansas are also experiencing rapid rates of growth, driven largely by rural-urban migration. 4 As of 2018, at least 60% of the population in the region encompassing Texas, Oklahoma, and Kansas is clustered around metropolitan areas. 5 This reflects a broader global trend in which population growth and urbanization are becoming increasingly synonymous (see Figure 5). 6

Correlated with this trend is increasing regional racial and ethnic diversity, particularly in areas experiencing rapid urbanization. In Texas, for example, the non-Hispanic Asian population is projected to grow at a rate of more than five times the 2010 population by 2050 and both the non-Hispanic black and Hispanic populations are projected to double in size by 2050 compared to 2010, while the non-Hispanic white population grows at a slower relative pace. 7 Many of these populations overlap with socio-economic and demographic indicators strongly correlated with higher levels of vulnerability to severe outcomes due to hazards such as flooding and drought. 8

Population growth and urbanization are also central drivers of economic activity and recent trends in key industries in the region. Many of these industries have significant implications for regional Integrated Water Resources Management (IWRM) and Civil Works, with their viability closely linked with future energy uncertainty and increasing demand on limited water resources. For instance, studies have found a correlation between electricity consumption and population growth, 9 which is likely to be even stronger given projected increases in annual average temperatures. Over the past decade, the oil, gas, and petrochemicals industries in Texas and Oklahoma have seen a boom as demand for energy continues to increase with population growth. However, since 2014, employment and drilling operations in energy production industries have seen a relative decline, possibly correlated with increasing global demand for, and availability of, renewable and diversified energy sources.

If current trends continue, Texas' urban population will double within 40 years and account for 94.6% of the state's population growth by 2050. Compare this with rural population growth, which at the 2017 rate would take 218 years to double its population.

Source: Texas Rural Funders Collaborative. 2018. The Future of Rural Texas: A Texas Tribune Symposium.

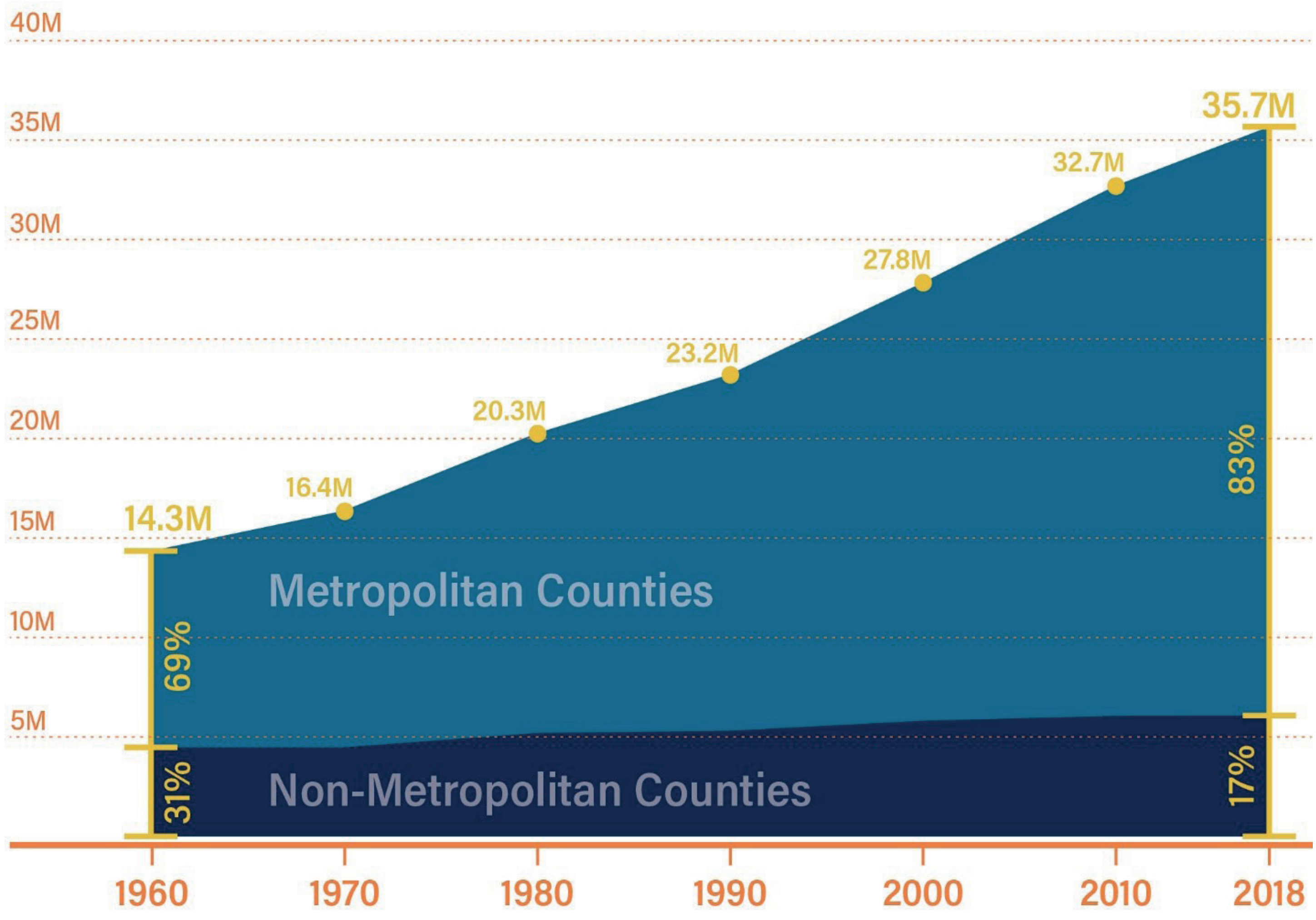


Figure 5 - Population Growth in All Counties in the SWD AOR from 1960 to 2018, by Urban vs. Rural Areas

2.1

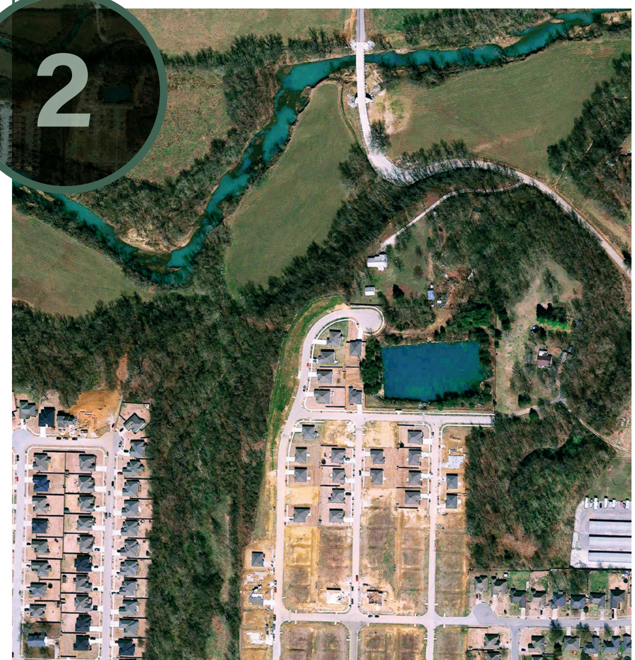
The growing wind turbine industry in southwest Oklahoma illustrates that these global changes are influencing the region and highlights the importance of the broader Southern Plains region for energy production even while the distribution of energy sources evolves. Notably, increasing demand for wind and solar energy is also likely to drive increased demand for existing hydropower plants to play a stabilizing role in power generation throughout the region; studies have shown that hydropower can facilitate the integration of wind and solar energy into power grids by compensating for their high variability.10

Similarly, population growth and urbanization are likely driving increased demand for food and agricultural products, timber products, and recreation, all of which represent major, growing industries in the region. Farm and agricultural land represents a substantial amount of landcover throughout Texas, Oklahoma, and Arkansas, and although some places have seen a recent decline in farm-related employment, this may be more a result of increased efficiency than shrinking production. 11 Between the three states, the region produces much of the nation's beef cattle, broilers, sheep and wool, cotton, rice, and other crops and commodities. There is also a heavy concentration of agricultural equipment operators and logging industry workers compared with the rest of the nation, and industries related to forestry, fishing, and related activities have seen a noteworthy increase in employment since 2008. Finally, outdoor recreation-related activities are a major and growing source of economic activity and employment in this area of the country, centered around Texas' coastal economy along with fishing, boating, hiking, and other activities associated with many lakes and waterways throughout the region. Water access and the recreational opportunities it provides raise the values of adjacent lands that are already increasingly valued for recreational usage as urban centers and population grow and expand.12

2.2 - Driver 2: A Changing Regional Landscape

Urbanization, resource demands, extreme weather, and coastal erosion are driving regional land use/cover changes, impacting flood risk, water quality, channel morphology, local water balance, biodiversity, industry & recreation.

2



Source: Northwest Arkansas, Google Maps

2.2.1 - Changing Land Use and Land Cover Dynamics

Rapid urbanization is driving changes to land use and land cover (LULC) in the region (see Figure 6). Accompanying the regional trend of rural-urban migration patterns is the transformation of many rural landscapes, including farmland, forests, and pastures, to more urbanized areas (for example, in Northwest Arkansas). 13 Studies around the world have consistently found that urbanization and increased impervious surface coverage transform fluvial landscapes, habitats, and natural hydrology with broad implications. 14 LULC impacts due to urbanization include impacts to flood discharge, water quality, channel morphology, local water balance, and biodiversity. 15 In particular, multiple studies have demonstrated that expansion of impervious surface coverage reduces an area's infiltration capacity, thereby leading to higher rates of downstream runoff, often carrying pollutants

2.2.1

and debris along the way. 16 Increased runoff can elevate rates of flood peak discharge, rates of total flood volume, as well as debris production, thereby exacerbating the flood risk associated with extreme precipitation while potentially decreasing water quality. 17 In some cases, this may result in USACE flood control projects receiving more runoff than they were designed for, accelerating the need to update outdated flood protection infrastructure downstream of areas experiencing LULC change in order to ensure they continue to meet their intended level of protection. Additionally, these LULC effects can alter channel morphology and riparian habitats in unpredictable ways, including increasing channel dimensions or decreasing headwater stream length. 18 This presents an additional challenge of uncertainty for various USACE Civil Works Mission Areas including Flood Risk Management, Navigation, Water Supply, and Environmental Stewardship, although these effects have not been as thoroughly studied.19

2.2.1

There is also some evidence that suggests urban land itself can directly influence the timing and magnitude of precipitation because of urban heat island (UHI) effect. 20 Such urban-influenced rainfall has been observed, for example, in Houston. 21 Urbanization's impacts to watershed hydrology can also result in changes to groundwater recharge. 22 This, combined with changing agricultural and energy production practices, poses even greater uncertainty to the region's future water supply and demand.

The Texas Gulf Coast is experiencing unique and substantial land cover changes in the form of coastal erosion driving the retreat of the coastline. Rates of beach erosion of up to nearly 10 feet per year are largely driven by storm surge and high tides combined with sea level rise (SLR). The consequent impacts to water quality and water depth are accelerating the disappearance of wetlands, marshes, barrier islands, and other coastal habitats, all of which can play a crucial role in protecting coastal areas against storm surge.23

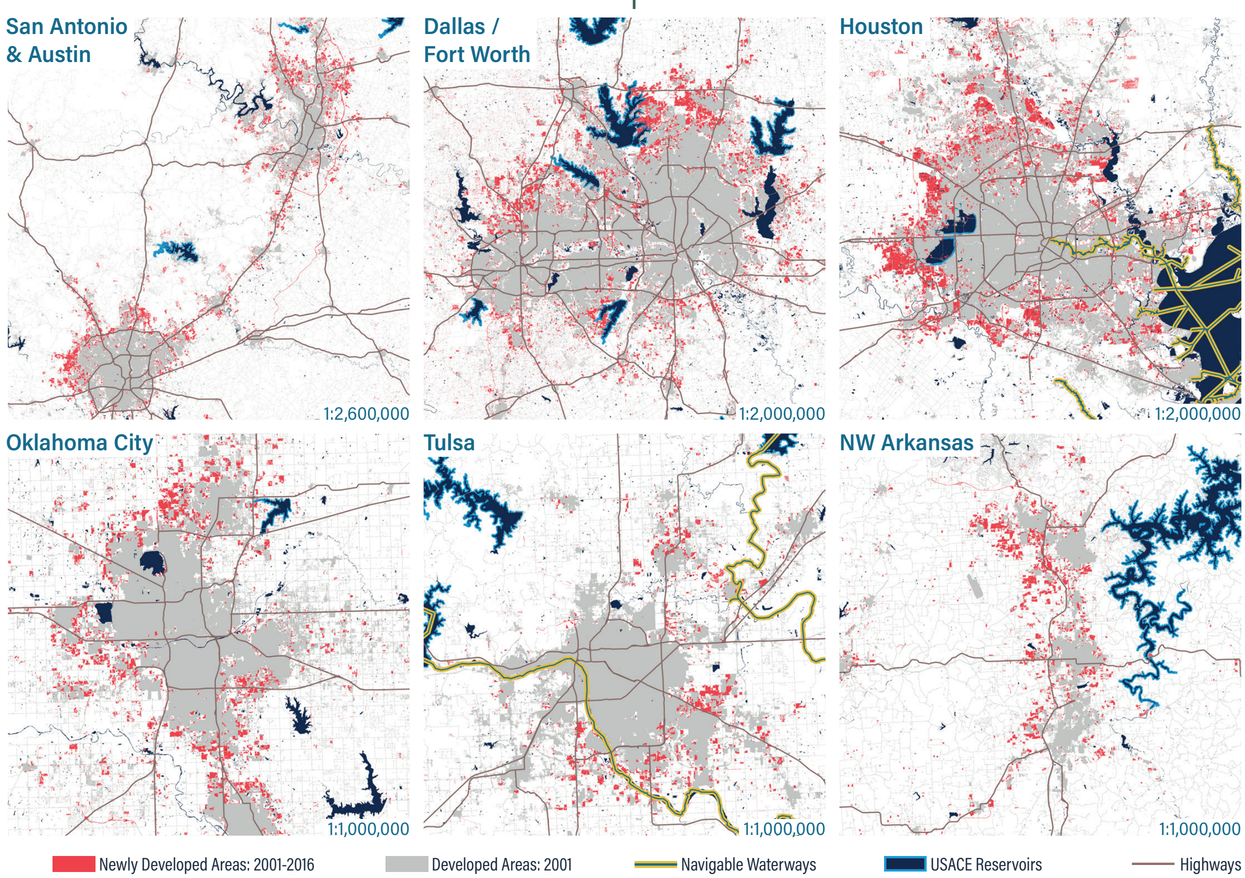


Figure 6 - Maps of New Development in Metropolitan Areas, 2001-2016

2.2.2 - Habitat Change

Many habitats in the region are sensitive to and directly impacted by increased variability in extreme weather; shifting food, energy, and water dynamics; and changing landscapes driven largely by urbanization. For example, as dipole events involving swings between periods of drought and heavy rainfall increase in frequency, length, and intensity, aquatic and estuarine ecosystems, including fish populations, are directly affected both by declining water availability as well as impacts to freshwater inflows. 24 Urbanization-driven changes to natural hydrology, in addition to increased sedimentation, likely exacerbate some of these effects.

Drought is also a key accelerator of habitat change in the region. Some habitats, such as those supported by playa lakes (shallow wetlands that form after rainfall events) and other natural wetlands, have been found to be nonexistent during periods of drought in the region. 25 Others, such as estuarine habitats, are negatively impacted by changes to freshwater inflows that moderate salinities and temperature and provide crucial nutrients. 26 Drought and temperature change also increase water temperatures, which places strain on aquatic habitats, especially in coastal bay waters, causing hypoxia and algal blooms. 27

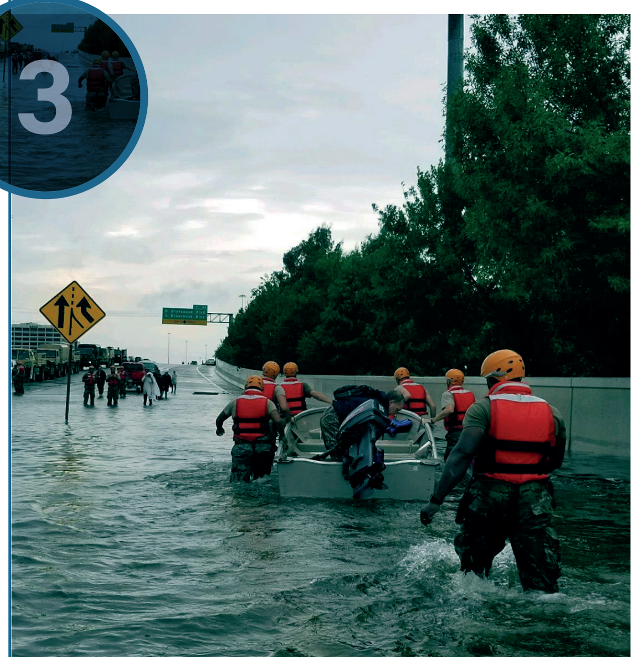
The continued integrity and stability of these ecosystems is of importance to Civil Works Mission Areas in multiple ways. In a national USACE survey, SWT reported the highest number of threatened and endangered species (TES) effecting on USACE projects of any District, which could include listings of TES present and/or situations in which TES impacted operations. 28 Biodiverse coastal and freshwater ecosystems furthermore play an important role in maintaining good water quality and managing pollutants; providing storm barrier protection to coastal infrastructure, ports, and energy production facilities; supplying fish and other seafood; and providing recreational and ecotourism opportunities. 29 As such, leveraging opportunities to conserve and restore habitat can positively impact multiple USACE Mission Areas.

Additionally, changing habitat patterns have allowed and continue to allow the introduction and establishment of invasive species that may increase risk to agricultural production, biodiversity, ecosystem stability, water quality, and various types of water infrastructure including dams, levees, hydropower systems, navigation channels, and lock chambers. 30 While increasing water temperatures, rising sea levels, and increases in extreme weather can facilitate the success of many aquatic invasive species 31, recent studies have also suggested that urbanization may increase the invasive potential of alien species. 32 Some invasive species of particular concern to USACE Mission Areas include zebra mussels, which can grow on many water infrastructure systems, impeding function; 33 blue-green algae, which pose hazards to water quality and health; 34 and water hyacinth, which negatively impact water quality and impede navigation and fishing.35

2.3 - Driver 3: Increases in Extreme Weather: Droughts & Floods

The frequency and intensity of droughts and inland and tropical storms are projected to increase, as are rapid swings between the two weather extremes. Sea level rise and subsidence will increase the risk of coastal flooding.

3



Source: Hurricane Harvey, Texas Army National Guard photo by 1st Lt. Zachary West

A Decade of Extreme Weather Events: 2010-2020

Rainfall-driven flooding in 2015 caused $2.6 billion in damages in Oklahoma and Texas alone. Other recent extreme weather events in the region exceeding $1 billion nationally in damages include:

- August 2020: Hurricane Laura (LA, TX)
- May 2020: Regional severe weather and flooding (AR, KS, MO, TX)
- April 2020: Regional severe weather and flooding (LA, OK, TX)
- January 2020: Regional severe weather and flooding (AR, LA, MO, TX)
- October 2019: Regional severe weather and flooding (AR, LA, MO, OK)
- September 2019: Tropical Storm Imelda (LA, TX)
- July 2019: Mississippi River and regional flooding (AR, KS, LA, MO, OK, TX)
- June 2019: Arkansas River flooding (AR, OK)
- April-May 2019: Regional severe weather and flooding (KS, MO, OK, LA, TX)
- Summer-Fall 2018: Regional drought (KS, MO, OK, TX)
- July 2018: Regional severe weather and flooding (AR, KS, MO)
- April-May 2018: Regional severe weather and flooding (AR, KS, MO, OK, TX)
- August 2017: Hurricane Harvey (LA, TX)
- May 2017: Regional severe weather and flooding (AR, MO, OK, TX)
- March 2017: Regional severe weather and flooding (OK, TX)
- May 2016: Regional severe weather and flooding (KS, MO, TX)
- March-April 2016: Texas and Louisiana flooding (LA, TX)
- December 2015: Regional severe weather and flooding (AR, MO, LA, TX)
- April-May 2015: Regional severe weather and flooding (AR, KS, MO, OK, TX)
- 2014: Severe regional drought (KS, OK, TX)
- September 2014: Regional severe weather and flooding (KS, TX)
- June 2014: Regional severe weather and flooding (AR, KS)
- April 2014: Regional severe weather and flooding (AR, KS, MO, TX)
- Spring-Fall 2013: Regional drought and heatwave (KS, MO, OK, TX)
- April-May 2013: Regional severe weather and flooding (KS, MO, OK, TX)
- 2012: Historic regional drought (AR, KS, MO, OK, TX)
- April-June 2012: Regional severe weather and flooding (KS, MO, OK, TX)
- Spring-Fall 2011: Regional drought, heatwave, and wildfires (KS, LA, OK, TX)
- May-June 2010: Regional severe weather and flooding (AR, KS, OK, TX)

Key
Extreme Rainfall, Coastal Storm Surge, Drought
Sources: NOAA National Centers for Environmental Information. 2020. Billion-Dollar Weather and Climate Disasters: Events. Available online at: https://www.ncdc.noaa.gov/billions/events. Accessed on September 10, 2020.
U.S. Global Change Research Program (2017b).

2.3.1 Severe Droughts

Combined with increasing annual average temperatures and increasing evaporation rates affecting soil moisture, precipitation change is causing droughts to become more frequent and more intense. Periods of drought are also increasing in length.

Increasing weather variability—driven by annual global temperature increases associated with elevated greenhouse gas (GHG) emissions—is linked to unpredictable swings, or dipole events, in precipitation patterns experienced in recent decades. Projections under the high GHG emissions scenario suggest an overall decrease in spring and summer precipitation in the region of 10-30% by the end of the century, 36 despite increases in the intensity of such events. Increasing intensity of precipitation events elevates flood risk, even during periods of drought. 37

Projections indicate an 80% chance that the region will experience a decade-long or multi-decadal drought in the latter half of this century.

Source: Cook, Bi.I., T. R. Ault, and J. E. Smerdon. 2015. Unprecedented 21st century drought risk in the American Southwest and Central Plains. Science Advances. 1(1).

2.3.1 Drought is exacerbated by, and often inseparable from, historical and projected increases in annual average temperatures in this region. Texas, Oklahoma, and Kansas together have seen an increase in annual average temperatures of 1-2°F over the past century, with the highest average warming experienced in winter months. 38 The Fourth National Climate Assessment projects an increase in annual average temperatures in the region of 4.4-8.4°F by the late 21st century. 39 Under the business-as-usual GHG emissions scenario, this would entail an additional 30-60 days per year above 100°F. This implies an increase in both overall average temperatures (e.g., in the winter months), as well as in the intensity and frequency of extreme multi-day heatwave events. Similar projections also hold in the state of Arkansas. 40

Increases in the severity, frequency, and duration of drought in the region will continue to strain the region's available sources of water supply. As the strain on water resources is further exacerbated by increasing tradeoffs for different uses, risk to food and energy production will grow as rapid population growth and rural-urban shifts increase demand.

Reservoir storage capacity is being lost due to increased sedimentation in the region, often as a result of flooding events. In conjunction with that loss, it is likely that drought-stressed surface water availability (see Figure 7) will increase the pressure to reallocate water storage at multi-purpose reservoirs to water supply purposes, 41 especially as overall demand for water is projected to increase significantly in the region over the next 50 years. These challenges to multi-purpose reservoir operations are consistent with USACE policy and guidance for drought contingency plans. 42

A drought in 2060 would put an estimated half of Texas' population at risk of a water shortage.

Source: U.S. Global Change Research Program (2017b).

Figure 7 - O.C . Fisher Reservoir during a period of extreme drought.

2.3.1 Water scarcity during drought increases the reliance of groundwater resources in the region, driven in part by the needs of the agriculture and energy production industries. Increased dependence on irrigation under drought conditions, for example, has also caused a shift toward less efficient agricultural practices such as center pivot irrigation for groundwater mining, which has been depleting the High Plains Aquifer System and changing natural hydrology and downstream runoff patterns. 43 In Arkansas, water levels in the Alluvial Aquifer, which is the state's primary source of groundwater, declined almost 4 feet from 2004-2014. 44

Reduced irrigation water in Oklahoma may result in as much as 69% lower crop productivity.

Source: Oklahoma Water Resources Board (2011).

In general, drought and increased heat, especially warmer winter night temperatures, have made winter crop productivity less dependable, increased soil moisture stress, and a exacerbated proliferation of invasive species, insects, and pests in some areas. 45 This not only has negative impacts to agricultural food production, but on stable regional biodiversity at large.

2.3.1

Higher temperatures are also driving growing demand for electricity for cooling purposes, especially in urban areas where the UHI effect is elevated. As demand for these resources grow, more intense and frequent heatwaves are likely to significantly strain energy utilities, potentially leading to failures and an inability to meet demand.46 Limited water resources for power plant cooling and thermoelectric power generation will intensify these challenges and associated tradeoffs.

Drought and water scarcity also have direct impacts on freshwater inflows that support a variety of habitats, including wetlands habitats for migrating waterfowl and a variety of coastal species.47 Warmer temperatures also impact water temperature and water quality. 48

2.3.2 - Extreme Rainfall and Tropical Storms

Although overall average annual precipitation is largely projected to decrease across most of the region, especially in the summer, both the frequency and intensity of extreme rainfall events and major tropical cyclones are projected to increase. 49

Flooding due to extreme rainfall events and tropical cyclones has been severely disruptive in the region, and this flood risk is expected to continue increasing. Tropical cyclones are associated with extraordinarily heavy rainfall rates, with the heaviest rainfall amounts from such events up 5%-7% over the past century. 50 Moreover, most rivers in the region are not fed from mountain snowpack and are therefore highly sensitive to flooding caused by seasonal rainfall (see Figure 8). 51

Significant rainfall followed periods of drought in the Southern Plains region approximately one third of the time over the past 50 years, compared to half that rate over the 50 years prior.

Source: Christian, J., K. Christian, and J. B. Basara. 2015. Drought and Pluvial Dipole Events within the Great Plains of the United States. Journal of Applied Meteorology and Climatology. 54(9):1886-1898

Figure 8 - MKARNS during a flooding event

Existing regional average annual precipitation trends vary widely from the western part of the region, with areas receiving less than 10 inches on average, to the eastern part of the region, with areas receiving more than 60 inches on average. 52 In general, the Fourth National Climate Assessment anticipates slightly wetter winters on average in the region, especially in the north, and drier summers with the increasing specter of drought. Nevertheless, dipole events, or rapid swings between severe drought and heavy precipitation, are on the rise, such as in 2015 when a period of drought abruptly ended with the onset of severe flash flooding and multiple episodes of extreme rainfall. 53 In the past 30 years, there has been a noteworthy increase in record-breaking flooding events despite an overall decrease in the frequency of flooding, 54 highlighting the seeming discrepancy between annual average trends and the reality of acute events. For example, according to updated National Oceanic and Atmospheric Administration (NOAA) Atlas 14 rainfall frequency values for Texas, the amount of rainfall in Houston that previously constituted a 100-year event is now considered a 25-year event. 55

2.3.2

Extreme rainfall events directly threaten lives, livelihoods, agriculture and energy production, and critical services and infrastructure, while also placing a heavy strain on aging infrastructure such as older dams and levees. Rapid population growth and urbanization also increase exposure to the hazards posed by heavy flood events while exacerbating flood hazard itself via increased stormwater runoff. Indeed, loss of life due to flooding in the region is higher, on average, than in much of the rest of the country. Texas in particular has experienced substantially more flood fatalities over the past decade than any other state. 56 Flood fatalities in the period 2010-2020 for Texas, Oklahoma, Arkansas, Missouri, Kansas, and Louisiana can be found in Table 1.

State	Flood Fatalities 2010-2020 57
Texas	225
Arkansas	67
Missouri	66
Oklahoma	58
Louisiana	27
Kansas	10

Table 1 - Flood Fatalities 2010-2020

Further, extreme flood events can exceed a reservoir's storage capacity, especially for those that have exceeded the analysis period for which they were designed and were constructed before extreme weather events began occurring more frequently. 58 This challenge is further complicated by a trend of increasing sedimentation buildup in reservoirs, affecting their ability to meet intended storage capacity. Many of these reservoirs may require recapitalization, updates to their operating plans, and improved sedimentation management to minimize the risk of catastrophic downstream releases of stored water (see Figure 9). 59 Hurricanes and rainfall events similarly impact coastal navigation, requiring significant post-storm dredging. 60

Given these rapidly changing conditions and increasing risk and uncertainty, it is essential that USACE SWD utilize existing guidance and tools, notably the USACE Engineering and Construction Bulletin (ECB) 2018-14 Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects, and rely on best-available science in determining whether existing and future projects should consider the effects of increased climate variability during planning, designing, and re-evaluation. 61

Figure 9 - Water being released from the Lake Eufaula Dam, May 13, 2015

2.3.3 - Storm Surge and Sea Level Rise

Extreme storm surge events combined with relative sea level rise (RSLR) increase flood and life safety risks along the Texas Gulf Coast. Over the past century, relative sea levels in the region have risen 5-17 inches. 62 The rates of relative SLR along the Texas Coast have shown substantial variability, from 0.08 inches per year from 1957-2011 at Port Mansfield to 0.26 inches per year at Galveston Pleasure Pier. 63 These variations are driven in large part by varying levels of vertical land movement, or subsidence, combined with global, or eustatic, sea level changes. 64 Upwards of 1,000 square miles of land along the Texas Coast are now within five feet of the high tide line. 65 Projections of these trends into the future vary due to uncertainties in weather and climate patterns, but are in general agreement that RSLR is expected to continue in this region. RSLR increases both the risk of severe storm surge from extreme weather events and the ongoing risk of chronic tidal flooding which, while having less catastrophic acute impacts, can drive major socio-economic shifts and impacts to existing facilities and infrastructure in the long-term.

SLR is also partially driving the retreat of the Gulf coastline, which is exacerbated by land-surface subsidence and beach erosion that pose their own risks while also intensifying the risk of flooding to populations and infrastructure. Subsidence is partially driven by activities such as the extraction of fossil fuels, for which the Texas Coast is a major hub, in addition to the
2.3.3 extraction of groundwater, driven largely by energy-producing industries in the region facing water supply shortages. 66 The dynamics between coastal SLR, subsidence, and water supply resources are indeed complex; the former also drives substantial saltwater intrusion of major aquifers such as the Gulf Coast Aquifer. 67 Additionally, in some areas, such as the Addicks and Barker Reservoirs in Houston, subsidence due to groundwater withdrawal negatively impacts reservoir storage capacity, exacerbating flood risk.

Rapid rates of beach erosion along the Texas Coast, meanwhile, are largely driven by storm surge and high tides combined with RSLR. The consequent impacts to water quality and water depth are causing a reduction in the extent of wetlands, marshes, barrier islands, and other coastal habitats, all of which play a role in protecting coastal areas against storm surge. 68

Relative sea level rise along the Texas Coast is 2x the global average, driving rates of beach erosion of almost 10 feet per year.

Source: U.S. Global Change Research Program (2017b).

Populations, critical infrastructure, port terminals, and petroleum and natural gas refining facilities along the Texas Coast are therefore highly vulnerable to both acute and chronic flooding events, and these risks will continue to grow. Oil and gas production and transportation facilities along the Texas Coast are directly exposed to extreme coastal events wind and flooding events and the effects of sea level rise and subsidence. 69

2.4 - Driver 4: Uncertain Future of Energy

The region has experienced a recent boom in oil and gas exports, but this boom may not last. Economic downturns and shifts to renewables may reduce global demand, while strained resources and risks to infrastructure may impact supply.

Source: Port of Houston, Colleen McHugh

2.4.1 - Global Energy Demand and Local Supply

In recent years, the oil and gas industry in Texas has seen a boom, driving fossil fuel exports. Nevertheless, downturns in global demand and falling oil and natural gas prices at an annualized rate of 6.9% from 2014-2019 have slowed this rate of growth. 70 This slowdown is corroborated by employment data produced by the Bureau of Economic Analysis (BEA), which shows a 12.9% drop in employment in the mining, quarrying, and oil and gas extraction industries between 2013-2018 compared with the 40.3% rise in the five years prior (2008-2013). 71 Simultaneously, global demand for renewable energy sources has increased, and there are signs that this industry may be growing significantly in Texas.72

Long-term energy production and local supply capacity is under pressure due to the combination of increased weather variability, limited supply of fossil fuels and water, and increasing demand due to population growth and urbanization. For example, increases in annual average temperatures and heatwaves drive demand for energy and water while increasing strain on energy infrastructure cooling systems and available surface water. 73 During the 2011 Texas drought, electricity demand and generation increased by 6% and water consumption for electricity increased by 9%. 74 Under such circumstances, peak electricity demand is increasing while increased air and water temperatures and limited water supply reduce capacity and efficiency of production for both electric and thermoelectric power generation, the latter of which produced 87% of Texas' net energy in 2011. 75 In the same year, studies showed a 30% decline in available reservoir storage for power plant cooling, a trend which has driven the energy industry to increasingly rely on groundwater resources 76 leading at times to unintended consequences, such as the need for emergency groundwater pipelines when primary water sources run dry. 77 Groundwater is also the primary water source for 90% of hydraulic fracturing industry in Texas. This reliance on groundwater has caused some aquifers to deplete at a rate of 2.5 times their rate of recharge, potentially threatening the sustainability this water supply solution. 78

2.4.1

Simultaneously, the increasing risk of extreme storm surge along America's Energy Coast in Texas places nearly 40% of national petroleum and natural gas refining capacity, in addition to port infrastructure critical for export, at risk. 79 An estimated 76% of anthropogenic GHG emissions in the U.S. come from carbon dioxide (CO2) emissions due to the burning of fossil fuels. 80 Current global scientific consensus identifies GHG emissions as the primary driver of extreme weather variability including heatwaves, droughts, and tropical storms. 81 Therefore, it is likely that oil and gas-driven energy production will increasingly enter into a positive (exacerbating) feedback loop with increasing energy demand and limited supply capacity due to extreme weather exposure and strained water resources.

2.4.2 - Demand on Exports

Demand for energy, food, and various primary and intermediate products is expected to continue growing as populations and urbanization expand, even as risks increase and new and emerging threats materialize. As such, demand for USACE channel deepening will likely continue to grow, especially for very large crude carriers (VLCC) and fully loaded deep-draft container vessels. The Gulf Intercoastal Waterway (GIWW), Texas' myriad of ports, and the McClellan-Kerr Arkansas River Navigation System (MKARNS) are paramount to the transportation of energy products, agriculture supplies, and food in and out of the region (see Figure 10 and Figure 11 on the following page).

The GIWW links ports along the Gulf Coast and 50% of its commercial traffic runs through the state of Texas. 82 The GIWW allows Texas' ports to serve as major shipping hubs for North America 83 and supports Texas' status as the nation's leading exporter of goods, with $330 billion of exports in 2019. 84 These ports, in turn, represent more than $82.8 billion in economic value to the state of Texas. 85 Further, many of these ports are also home to major hubs of energy production and export. In 2017, 72.5 million tons, or 91%, of the Texas portion of the GIWW's traffic by weight consisted of petroleum and chemical products 86 in a region that houses the 2nd-largest petrochemical complex in the world at the Port of Houston. 87

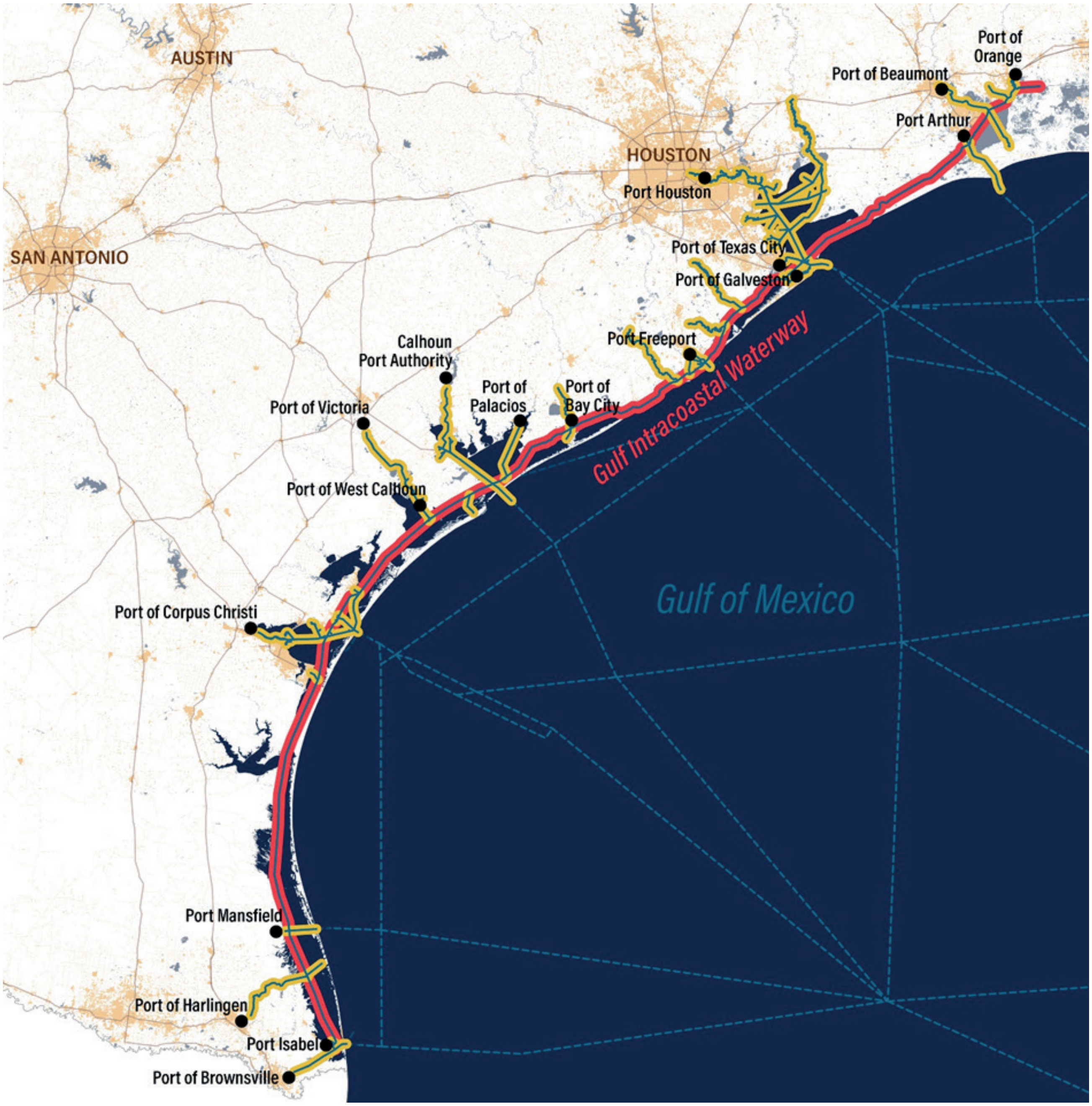


Figure 10 - Map of Texas Ports and the Gulf Intracoastal Waterway

More than 12.2 million tons of goods were also transported in 2017 via the MKARNS. 88 These goods include sand, rock, fertilizer, wheat, raw steel, petroleum products, and petrochemical processing equipment, demonstrating the MKARNS' central importance to the energy, chemicals, and agricultural industries in Arkansas, Oklahoma, Texas, and Kansas. 89 Activities along the MKARNS are also themselves significant drivers of economic output, employment, and tax revenue, collectively contributing approximately $8.5 billion to nationwide sales revenue and employing nearly 56,000 people in Oklahoma and Arkansas. 90

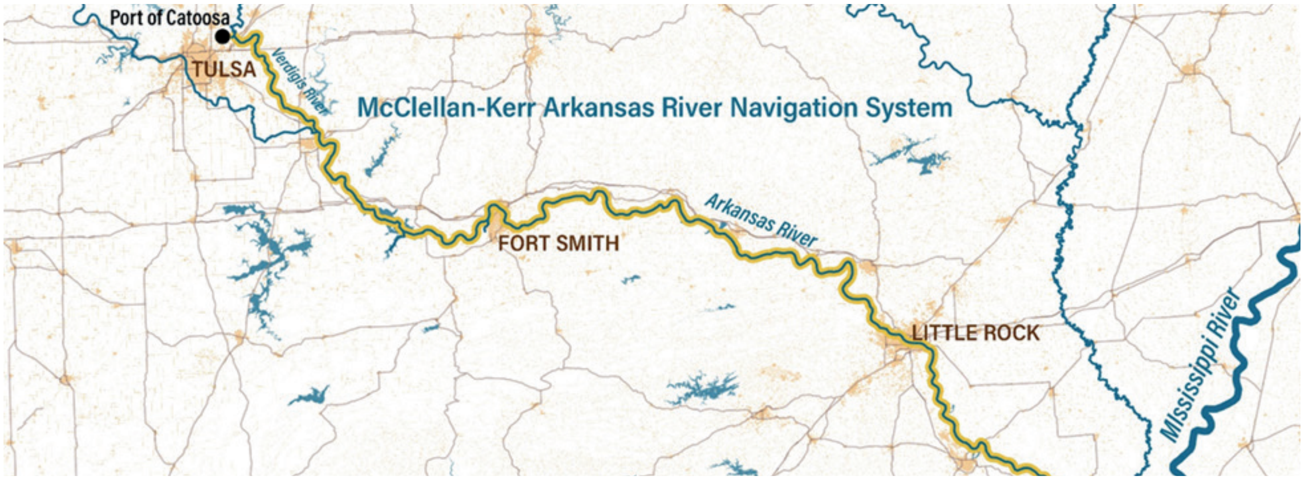


Figure 11 - Map of the McClellan-Kerr Arkansas River Navigation System

Despite uncertainties in the future of energy and future U.S. trade policy, Texas maintains a global competitive advantage in exports of energy products and various intermediate goods, [91] and represents a high 20.1% share of total U.S. exports in 2019. [92] Recent trends such as growing production of materials for wind energy in Texas demonstrate the region's adaptability as a locus of global energy production even in the face of changes in global demand. [93] Although representing a smaller proportion of nationwide exports, 2019 exports out of Oklahoma and Arkansas also demonstrate an upward trend of 14% and 12% over 2010 [94] and 2008 [95] levels, respectively. In all, demand for exports may continue growing despite uncertainties in future global energy demand and local supply and may require deeper channels in the GIWW and MKARNS to accommodate projected growth.

2.4.2

As demand for dredging and similar services increase in accordance with global energy demand, these activities will need to be carefully balanced with management of sediment suspension and contaminant releases. [96] Lock and dam structures will continue to play an important role in easing shipping access to portions of waterways where water elevation is impacted by precipitation changes. [97] Managing water levels will also need to be adaptively considered in the context of inevitable tradeoffs across SWD Business Lines. Decisions regarding the width and depth of channels also have implications across Mission Areas. For instance, larger navigation channels may be managed more adaptively in response to flood events, but simultaneously provide less opportunity for less adaptability to periods of drought.

2.5 - Driver 5: Increasing Demand on Limited Water Resources

Regional water supply is under severe pressure from drought and environmental change. Simultaneously, regional demand is increasing for water resources as well as water-dependent food and energy resources.

Source: Irrigation, Texas A&M AgriLife Research photo by Kay Ledbetter

2.5.1 - Water-Food-Energy Nexus

As suggested above, agricultural and energy production, both representing key industries in the SWD region, are highly interdependent with water availability. Water supply is crucial both for agricultural uses and irrigation as well as for energy generation activities such as oil and gas operations, power plant cooling, and thermoelectric and hydropower generation; in addition, the agriculture industry relies on adequate sources of energy. 98 Population growth and urbanization are therefore driving a redistribution of demand at the nexus of food, energy, and water, with urbanization-driven changes in consumption patterns linked to growing global demand for all three. 99 For instance, the current consensus is that, at its current pace, global population growth will likely require 70-100% more food production in the next several decades, 100 which will directly affect the extensive agricultural industries and exports in the region. Water demand for municipal, agricultural, and energy uses is therefore projected to increase substantially in the region over the next 50 years. 101 Further, rural-urban population shifts increase pressure to allocate limited water supply resources from traditional centers of agriculture and toward growing metropolitan centers. 102

Changes in extreme weather variability, in complex interaction with geomorphological and ecological changes, are simultaneously introducing challenges in meeting increasing and interdependent demand for food, energy, and water.

Water demand for municipal, agricultural, and energy uses over the next 50 years is expected to increase by:

- *17% in Texas*
- *21% in Oklahoma*
- *20% in Kansas*

Source: U.S. Global Change Research Program (2017b).

The dependence of agricultural and energy production on water availability has also led to the extraction of and increasing reliance on groundwater resources, thus rapidly depleting aquifers. 103 Pressure to shift supply of natural resources toward growing urban centers coupled with projected increases in food and energy production to meet growing demand are likely to strain water availability already threatened by drought. During the 2010-2011 drought, water demand in some Texas communities is reported to have already approached or exceeded maximum available freshwater supply. 104

Water supply is a relatively important Mission Area for SWD, comprising 75% of all USACE water supply storage. 105 SWD operates and maintains 50 major lakes providing one-third of all surface water supplies for Texas and Oklahoma and 20% of all supplies for Kansas, in addition to 10 lakes which provide significant water supplies in Arkansas. 106 As water demand for municipal, agricultural, and energy uses continues to climb in the context of increasingly strained water resources driving competition for water, SWD decisions regarding water availability will become increasingly consequential. This is especially true in multi-purpose reservoirs in which water allocation and releases must be carefully balanced with other Mission Area needs and as changing needs in regional water supply turn increasingly away from surface water and toward groundwater. Conflicts may especially arise with increases in dipole events of drought and flooding, wherein the threat of extreme rainfall events introduces challenges in managing reservoirs to decrease flood risk even as the increasing threat of drought stresses the region's water supply. It is challenging to optimize the reservoir operations under these conditions, entailing decisions such as when and how much water to release. These decisions will have significant positive and negative potential consequences across the Flood Risk Management, Water Supply, and Hydropower Mission Areas. In addition, these challenges can increase the need to construct new reservoirs or for inter- and intra-basin transfers, increasing USACE Regulatory demands.

2.5.2 - Recreational Land

Outdoor and water recreation across the region support a thriving ecotourism economy along the Texas Coast and the MKARNS system, both of which depend on water availability and freshwater flows. 107 Many popular water-related outdoor recreation activities in the region are made accessible by USACE projects and depend on biodiverse ecosystems supported by USACE. In addition, the USACE Environmental Restoration Mission Area plays a critical role in managing water releases to help maintain the stability of these ecosystems. For example, minimum flow and downstream thermal requirements for fish habitat as well as to prevent algal issues are included in management practice. [108] There is a growing challenge in managing these ecosystems due to uncertainties posed by increased demand for water resources in conjunction with increases in drought and other extreme weather events, changes in natural hydrology, ecological changes, and demand for non-federal hydropower facilities at USACE dams. [109]

2.6 - Driver 6: Aging Infrastructure

Degrading water infrastructure conditions across the region pose a threat to a growing population's safety, exacerbate limited water resources in the context of competing demands, and threaten the vitality of local industries.

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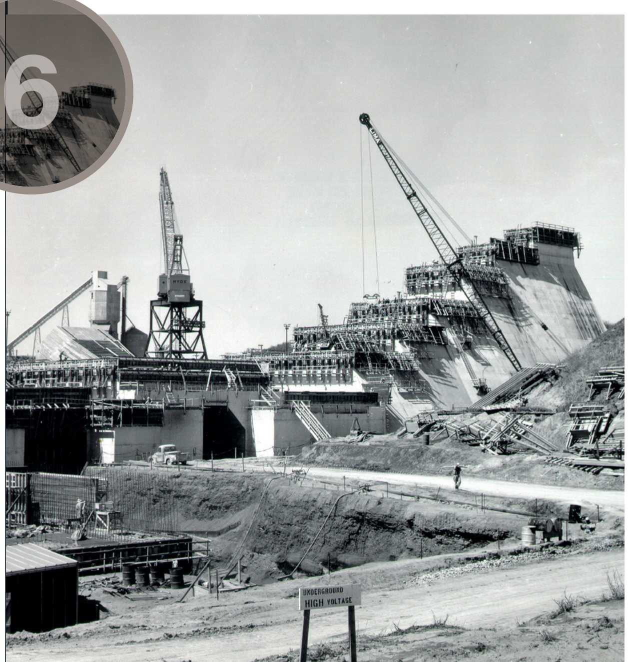

Source: Keystone Dam construction, USACE-SWT

Every USACE Civil Works Mission Area is faced with challenges related to aging infrastructure and a backlog of operations and maintenance. The majority of USACE dams throughout the country were constructed over 50 years ago and are beyond the planning life initially used in their design. [110] These dams play a central role in providing multiple benefits at USACE reservoirs related to Water Supply, Hydropower, Navigation, Flood Risk Management, Recreation, and Environmental Stewardship. Most federal reservoir storage projects are in need of substantial recapitalization and updates to their operating plans. [111] Further, changing trends such as population growth, drought, inland and coastal flooding, and habitat loss intensify competing water demands and the careful tradeoffs needed to balance multiple uses under future conditions.

Degrading water infrastructure conditions across the region pose a threat to a growing population's safety; exacerbate limited water availability in the context of competing demands; and threaten the continued vitality of the industries dependent on hydroelectric power generation, navigable waterways, recreational land, and ecosystem services provided by biodiverse habitats.

The American Society of Civil Engineers' (ASCE) 2017 infrastructure report card highlights issues endemic to the region, such as the prevalence of high hazard dams lacking regular maintenance and inspections, uncontrolled spillways, decreasing USACE funding for major flood reduction projects, inordinate timelines, and other challenges to planning, designing, and constructing new capital projects. [112] Inadequate maintenance heightens the threat of catastrophic downstream releases of stored flood water from critical infrastructure failure, an issue exacerbated by limited and decreasing flood storage capacity at reservoirs due to sediment accumulation as well as worsening degradation from heavy rainfall stress and downstream sedimentation. [113]

Lack of regular maintenance for sedimentation also limits the water available in reservoirs for Water Supply and Hydropower, and significantly impacts channel depth and width at inland waterways and ports. Aging navigation infrastructure, coupled with maintenance backlogs, also present a major challenge for the future viability of navigable waterways. Inconsistent maintenance at many ports and locks often lead to unscheduled outages, significant delays, and difficulties in adequately meeting traffic demand. [114]

> *As of April 2019, the MKARNS has a $235 million backlog of critical needs projects with a high chance of failure over the next several years.*
>
> *Source: State Chamber Research Foundation. 2019. Issue Brief: The McClellan-Kerr Waterway.*

2.6

Finally, recreational facilities such as boat launches, marinas, campground facilities, roads, parking lots, and other structures under the management of the Recreation Mission Area are degrading, threatening the continued vitality of the recreation and ecotourism industries. 115

2.7 - Inequitable Risk and Impacts

The societal risks posed by the six drivers described above will disproportionately affect socially vulnerable populations, especially those that have been historically marginalized and subject to structural inequities that have restricted their adaptive capacity. Existing disparities are likely to be further exacerbated by the direct and indirect impacts of increasingly extreme weather and competition for natural resources such as water, including cascading effects due to trends such as aging infrastructure and habitat loss. Presently, many of these existing disparities fall along racial lines, and the disproportionate risks incurred are likely to fall most heavily on the poor, the working class, communities of color, immigrant communities, and indigenous populations. Research on the relationship between community resilience and social vulnerability have demonstrated that the severity of outcomes of a disaster or disturbance for a community correlate with circumstances that either limit or enhance a community's ability to respond and adapt, as well as to the severity of the hazard and the level of exposure. 116 A community with little income and lack of ready access to robust infrastructure, food, energy, water, and other essential goods and services is more likely to experience devastating impacts that will further limit the resources and time required to recover and improve quality of life.

As urban populations grow, overall exposure of the population to the impacts of some hazards—especially flooding and the cascading hazards it causes—is likely to increase. Socially vulnerable communities, including many in historically marginalized racial and ethnic categories and those with lower levels of household income, will increasingly concentrate in particularly hazard-prone areas. Such areas may, for example, include aging public housing, limited evacuation routes, proximity to hazardous materials storage, lack of access to strong infrastructure, and direct exposure to flooding and extreme urban heat. 117

Additionally, many of the most socially vulnerable counties in the region are in heavily rural areas which comprise some of the highest rates of household poverty (see Table 2) and food insecurity in the nation. 118 As urban demand for water and water scarcity simultaneously increase, pre-existing issues of inequitable access to safe drinking water and sanitation, particularly concentrated in rural areas, will only get worse. Poverty and race have both been found to be strong indicators of lack of access to water and sanitation. For example, Native American households—of which there are a large concentration in the region, especially in rural Oklahoma—are 19 times more likely than white households to lack access to complete plumbing. 119 These populations are likely to experience the most direct and immediate impacts of drought, in addition to the pressures on water and other natural resources precipitated by rural-urban migration and the needs of a growing population to adapt to changing climate conditions. These communities and socially vulnerable urban populations will disproportionately bear the burden of the most severe impacts of increasingly extreme weather events and the increasingly strained water-food-energy nexus.

Table 2 - Percent of Households Living in Poverty, 2018 120

Percent of Households Living in Poverty, 2018 121				
Texas Rural	**Oklahoma Rural**	**Arkansas Rural**	**National Rural**	**National Urban**
18.1%	17.9%	19.5%	16.1%	12.6%

Poor and historically marginalized populations in the region are therefore experiencing a complex variety of challenges at the intersection of their overall higher levels of socio-economic vulnerability, increasing demand for the natural resources that rural areas in particular produce and depend on, high and increasing exposure and vulnerability to hazards such as drought and flooding, inequitable access to high-quality drinking water and sanitation, and land use and land cover (LULC) challenges posed by rapid population growth and urbanization, including increased flood and heat hazard and an explosion in development and urban sprawl, especially impacting rural areas. 122 Additionally, the region's many federally- and state-recognized indigenous tribes are known to be especially vulnerable to the changing water-food-energy and habitat change dynamics in the region driven by population shifts and extreme weather variability. Drought and water scarcity as well as increasing strains on natural resources and habitats will disproportionately impact these Native American communities in the coming decades. 123 In this context, addressing the water infrastructure needs of the 21st-century must consider and prioritize access to robust water infrastructure for populations at high risk.

2.8 - Increasingly Complex Regional Challenges

Significantly, the six drivers outlined in the previous sections are interconnected, with one driving or exacerbating another, often further amplified by positive feedback loops (see Figure 12). For example, increasingly extreme weather plays a large role in driving changes to the regional landscape, especially in its impacts to habitats and biological communities that are sensitive to drought and flooding. As these habitats change and in some cases disappear, various processes ensue that further exacerbate the hazards posed by extreme weather, such as disappearance of natural storm barriers and impacts of erosion and invasive species on water infrastructure—especially when combined with other changes to the natural landscape driven by urbanization. As such, these six drivers should not be considered independent of one another, but as part of one and the same unfolding process, integral with USACE Water Supply, Navigation, Flood Risk Management, Hydropower, Environmental Stewardship, and Recreation activities (see Figure 12 and Table 3). At the same time, there is considerable uncertainty associated with many of the future trends, as illustrated by the significant economic and human health impacts associated with the COVID19 pandemic. The interconnectivity of the drivers further magnifies the impacts of this uncertainty, creating a wide range of potential outcomes that SWD and its Districts must be prepared for and necessitating that the development of strategies that are both robust and adaptable in an uncertain future.

These challenges are interconnected, with one driving or exacerbating another, often further amplified by feedback loops.

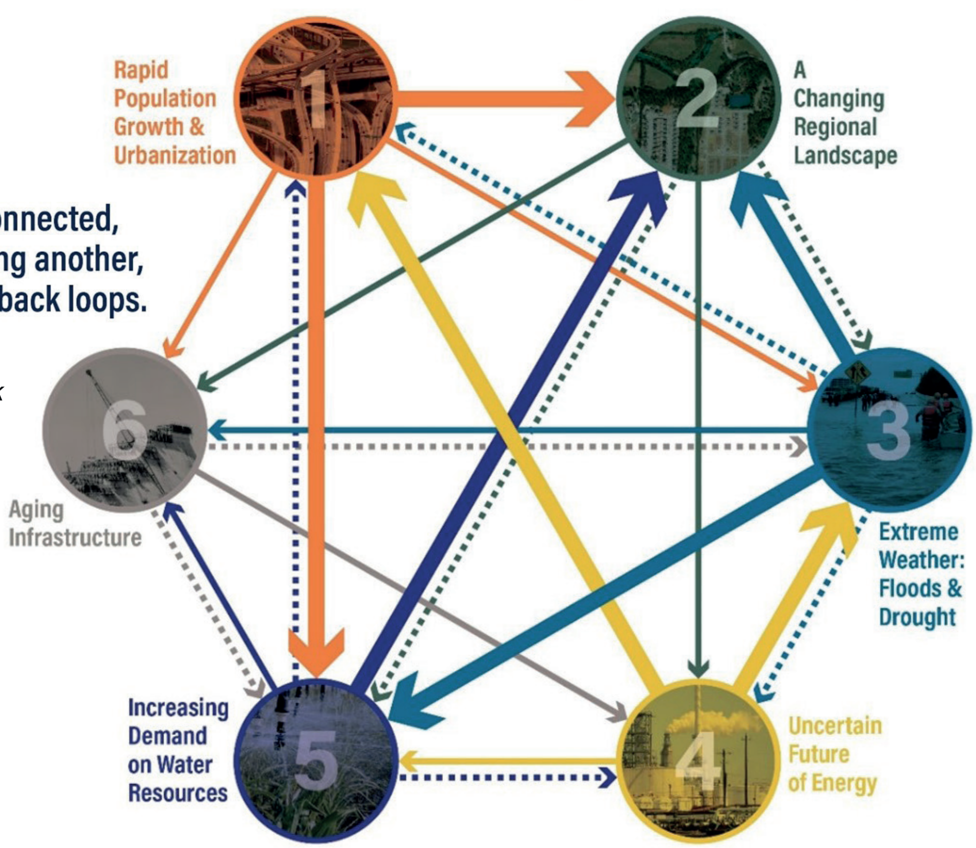

Figure 12 - Complex Interactions and Feedback Loops between Drivers

Table 3 - Drivers Impacts to Civil Works Business Lines

	Driver	Water Supply	Navigation	Flood Risk Management	Coastal Storm Risk Management	Hydropower	Environmental Restoration	Recreation
	Rapid Population Growth & Urbanization	X Increased demand for water, in addition to food and energy production which rely on water availability.	X Increased demand for natural resources driving increased demand for navigable waterways, channel deepening, and larger, more efficient vessels in international shipping to coastal ports.	X Increased exposure to extreme rainfall and flooding, particularly socially vulnerable populations.	X Increased exposure to coastal storm surge and tidal flooding, particularly socially vulnerable populations.	x Increased demand for energy production with growing demand for renewables, including increased reliance on hydropower for stability.	x Landscape-level impacts of urbanization-driven LULC.	X Increased demand for outdoor and water-related recreational opportunities.
	A Changing Regional Landscape	X Impacts to water quality, local water balance, and groundwater.	x Impacts to channel morphology and infrastructure operations.	X Increased flood discharge peak and volume rates as well as debris hazard.	X Beach erosion and sea level rise cause coastal habitats to disappear. This also eliminates natural coastal protection to storm surge.	x Impacts to natural hydrology and channel morphology.	X Pressures on natural resource boundaries, habitats, biodiversity, and ecosystem health.	X Declining biodiversity and ecosystem health in waterways potentially leading to decrease in recreational use.
	Extreme Weather Droughts & Floods	X Drought impacts to water levels and quality. Flooding straining reservoir storage capacity.	X Drought impacts to water levels. Increased exposure of navigation infrastructure and port terminals to flood risk, especially storm surge. Extreme storm impacts to channel conditions and vessel restrictions.	X Increased demand for more structural and nonstructural flood mitigation measures, and increased strain on existing flood control infrastructure.	X Increased risk of coastal storm surge and tidal flooding.	X Drought impacts to water levels, straining competing resource demands. Dependence on hydropower for power and first responder radio communications during major storm events.	X Impacts to water quality, salinity levels, water temperatures, sedimentation, and invasive species—threating ecosystem health and habitats.	x Increased exposure of recreation infrastructure to flood risk.

Table 3 - Drivers Impacts to Civil Works Business Lines

	Driver	Water Supply	Navigation	Flood Risk Management	Coastal Storm Risk Management	Hydropower	Environmental Restoration	Recreation
	Uncertain Future of Energy	X Increasing global demand for energy increases water demand for energy production purposes.	X Larger channels may be needed to meet demand for energy exports. Ports serving as hubs of energy production at risk of extreme storm surge.	N/A	X Extreme storm surge threatens 40% of national petroleum and natural gas refining capacity and port infrastructure for exports in Texas.	x Increases in global demand for renewable energy sources could lead to increased demand for hydropower.	X Pollution and other environmental impacts from continued reliance on hydraulic fracturing and fossil fuel extraction to meet growing demand.	N/A
	Increasing Demand on Water Resources	X Pressure to reallocate water storage at multi-purpose reservoirs to meet water supply demand.	x Low water levels can interrupt shipping and waterborne commerce.	x Pressure to reallocate water storage at multi-purpose reservoirs to water supply, while flood storage threatened by reduced reservoir capacity.		x Low water levels can interrupt hydropower generation. Pressure to reallocate water storage at multi-purpose reservoirs to water supply.	X Trade-offs in freshwater flows which moderate salinities and temperature and provide crucial nutrients.	X Trade-offs in freshwater flows which support a variety of habitats.
	Aging Infrastructure	X Most dams more than 50 years old. Dam safety is an issue.	X Aging navigation infrastructure and O&M, including channel depths, lack capacity or redundancy to meet growing demand.	X Aging dams, levees, and flood control structures with outdated policies, levels of protection, and planning life. Dam/levee safety is an issue.	X Aging levees and flood control structures with outdated policies, levels of protection, and planning life. Levee safety is an issue.	X Most dams more than 50 years. Dam safety is an issue.	x Aging levees and associated facilities require maintenance or upgrades to minimize impacts to the environment.	X Degrading facilities. Many recreation-related facilities constructed 50-70 years ago. Need for routine O&M.