State Flood Assessment

Report to the Legislature

86th Legislative Session

STATE FLOOD ASSESSMENT

Texas Water Development Board

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Texas Water Development Board

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Executive summary

Though Texas has experienced flooding throughout its history, losses of life and property in recent years—from the 2015 Memorial Day Flood in Wimberley to Hurricane Harvey along the Gulf Coast region in 2017—highlight the state's vulnerabilities. These disasters, along with six other federally declared flood declarations since 2015, call attention to the need for a clearer understanding of flooding in Texas, from the events themselves to the resources needed to mitigate them.

This report provides an initial assessment of Texas' flood risks, an overview of roles and responsibilities, an estimate of flood mitigation costs, and a synopsis of stakeholder views on the future of flood planning. It does not seek to fund specific strategies or projects related to flood planning, mitigation, warning, or recovery. Preliminary findings summarized in this assessment are derived from stakeholder input and organized according to three key pillars of comprehensive flood risk management: (1) mapping, (2) planning, and (3) mitigation.

Flood risks, impacts, and mitigation costs have never been assessed at the statewide level. Texas has a long and storied history of flood events, but until this effort by the Texas Water Development Board (TWDB), the state's risks and needs have not been evaluated. For the foundation of this assessment, we conducted surveys, workshops, and meetings with stakeholders across the state, the results of which, both quantitative and qualitative, are integral to better preparing for future Texas floods.

Flood risks pose a serious threat to lives and livelihoods. Most communities in Texas use Flood Insurance Rate Maps (FIRMs) to communicate local flood risk. Created and maintained by the Federal Emergency Management Agency (FEMA) to establish insurance rates, these maps currently are the state's most utilized tool for assessing flood risk. Based on FEMA data and the *State of Texas Hazard Mitigation Plan*, roughly 1 in every 10 Texans is exposed to moderate or high risk of riverine flooding each year; coastal flooding is projected to become the costliest weather-related hazard to the state; and more than half of recent flood insurance claims occurred outside of areas identified as high-risk flood zones.

Much of Texas is either unmapped or uses out-of-date maps, leading to widespread confusion. Mapping is the first step in identifying and communicating flood risk. FEMA's flood insurance rate maps show the boundary of inundation for the 1 percent annual chance flood event—commonly referred to as the *100-year flood* and often misinterpreted as the line

between safe and not safe. However, these maps may not reflect flood conditions based on the most current topographic, land use, or rainfall data. Creating flood risk maps using the most recently collected scientific data and models for all watersheds in the state could cost up to $604 million. Stakeholders prioritized up-to-date flood risk mapping, including collection and distribution of supporting data and addressing local drainage issues.

Rainfall drives most flood events in Texas, but rainfall data used to inform planning and design are decades old. An updated version of the rainfall depth-duration-frequency data (Atlas 14, Volume 11) used to model and predict how frequently a specific flood event might reoccur was published in September 2018. The data showed that in areas with significant increases in estimated rainfall, flood risks are likely to be greater than previously thought. However, new analyses and modeling will be needed to determine the impacts these updated rainfall estimates may have.

Texas does not have a statewide strategic plan to address flood risk management. Flood mitigation involves any combination of actions taken to prevent or reduce the impacts of flood events. Though individual planning efforts take place across the state, there is no unified, coordinated process to assess and plan for the state's flood-related needs. As such, project implementation occurs piecemeal. Mitigation without sound scientific data, proper mapping, and coordinated planning may be ineffective or, worse, may intensify flood impacts in upstream or downstream communities. Stakeholders expressed a preference for locally led flood planning at a watershed scale. This sentiment is consistent with stakeholder calls for increased collaboration, coordination, and leadership among all entities with flood responsibilities. Watershed-based planning seeks to identify multi-benefit solutions to common flooding problems and to bring about efficiency in implementing projects.

Significant funding is required to mitigate flooding in Texas. Though the responsibility to prepare for and mitigate flood impacts is primarily local, most communities do not have the economic resources required to accomplish their goals. Stakeholders engaged with this assessment cited funding to support implementation of mitigation projects as their greatest need. Anticipated statewide flood mitigation costs over the next 10 years are estimated to be more than $31.5 billion. Due to potential shortfalls in local funding, communities may need access to an estimated $18.0 to $26.6 billion in financial assistance. These estimates account only for mitigation costs based on stakeholder input. They do not account for projects associated with Hurricane Harvey recovery, other large federal projects such as the Coastal Spine, or rehabilitation of high hazard dams within the state.

Stakeholders identified the need for additional resources directed toward floodplain management and mitigation. Specifically, stakeholders requested in order of priority: (1) additional financial assistance for implementation of flood mitigation activities; (2) improvements to flood risk mapping and modeling; and (3) a preference for collaborative, locally led, watershed-based flood planning. In addition, the TWDB heard a call to expand educational outreach and technical assistance opportunities throughout the state. These priorities emerged from myriad suggestions and reflect areas of broad consensus among stakeholders.

Sound science and data are the core elements of effective planning and flood mitigation. Through support from the Office of the Governor and the Texas Legislature, the TWDB has implemented new initiatives in recent years to better prepare the state for flood events. To continue expanding these efforts and to improve data collection, mapping, and monitoring of conditions across the state, the agency has requested an additional $4.45 million in appropriations from the 86th Texas Legislature.

The TWDB's legislative flood recommendations. The legislature should pursue proactive statewide flood mitigation by first developing foundational flood risk management policies and goals that will support three key pillars of investment: (1) improved and updated flood mapping and modeling; (2) coordinated watershed-based planning; and (3) mitigation efforts, such as policy enhancements, increased technical assistance, and financial assistance for project implementation.

1. Introduction

- **To date, Texas has never conducted a statewide assessment of flood risks and needs.**
- **Input from stakeholders across Texas forms the foundation of this report.**
- **Stakeholders identified a need for greater investment in mapping, planning, and mitigation—three pillars of comprehensive flood risk management.**

Floodwaters rise and fall on every creek, draw, bayou, coast, and river shoreline in Texas at some point in time. Floods, like drought, are a natural part of the water cycle. During a drought we anxiously await a rain event big enough to finally end the dry spell. A *drought buster* arrives eventually. But rain events large enough to end a drought, as well as smaller events, can lead to flooding.

On September 9, 1921, an intense but short-lived downpour occurred in Williamson County. The small town of Thrall received more than 36 inches of rain in 18 hours, setting a national record that remains today (Slade and Patton, 2003; NWS, 2018a). Widespread rainfall in the spring of 1957 broke a statewide, multi-year *drought of record* but also brought flooding across the state from the Pecos to the Sabine (TBWE, 1957; TWRI, 2011; Burnett, 2012). In October 1998, a stalled front brought up to 30 inches of rain to south-central Texas in two days, causing historic flooding along the San Marcos, Guadalupe, and San Antonio rivers (Slade and Patton 2003). Most recently in August and September 2017, Texans witnessed the continuous rain bands of Hurricane Harvey unleash up to 60 inches of rain over 8 days, causing devastation for residents from Rockport to Orange, some of whom are still recovering today (Watson *et al.*, 2018).

Stakeholder input

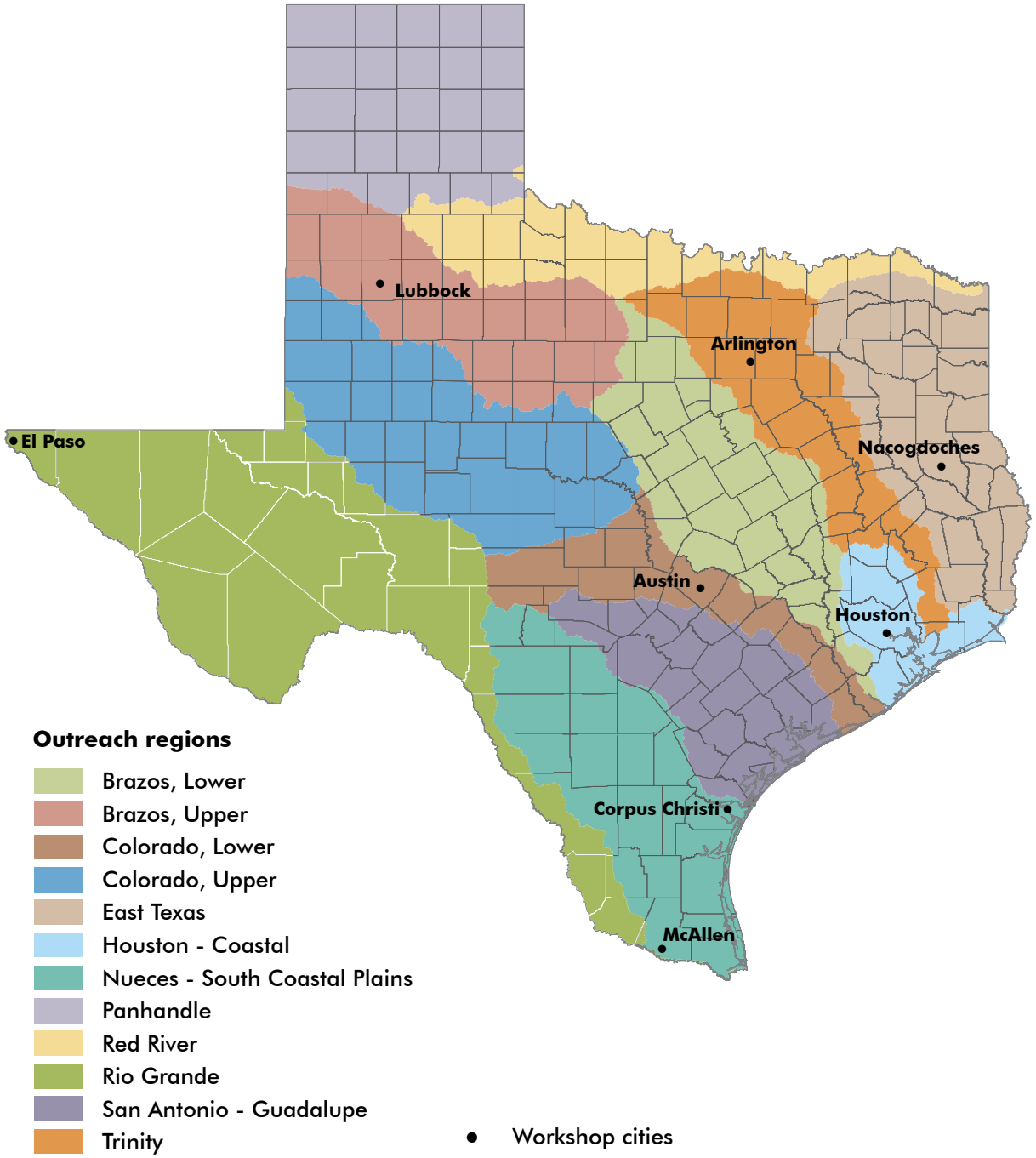
The Texas Water Development Board conducted extensive outreach to floodplain administrators and stakeholders in the spring of 2018 to gather both qualitative and quantitative information to form the basis of this assessment. Two surveys, eight regional workshops, numerous conversations at water-related conferences, and individual meetings with eight state and federal agencies allowed many Texans to contribute to this effort.

We conducted surveys in two phases. First, we distributed an initial survey to all stakeholders via email and online. Then, we sent a second, more detailed survey to stakeholders who self-identified as willing to provide additional information, particularly about the financial component of flood mitigation. For outreach purposes, we divided the state into 12 watershed-based regions generally corresponding to the state's major river basins and conducted workshops in seven of these regions *(Figure 1.1)*.

Stakeholders from across Texas were well-represented by this process. Survey 1 received 1,026 individual responses, and Survey 2 received 208 individual responses. Most respondents (69 percent) identified themselves primarily as public-sector employees who hold flood-related responsibilities for their community, nearly 43 percent of whom identified as floodplain administrators. Both small communities and urban centers were well represented in both surveys. Specifically, small communities represented 38 percent and 40 percent of total respondents, respectively, for Surveys 1 and 2. Across the 12 regions, Survey 1 captured responses representing up to 45 percent of communities within each region. Additionally, the eight workshops attracted a total of 267 attendees. Lastly, we offered an opportunity for stakeholder input by soliciting public review and comment, receiving 89 comments. The comment period included the October 3 meeting of the TWDB where the public was invited to provide comments in person.

Survey responses, workshop data, and public comments are posted as online appendices to this report at www.TexasFloodAssessment.com.

Figure 1.1 Stakeholder outreach was organized by 12 watershed-based regions generally corresponding to the state's major river basins. Stakeholder workshops were held in March and April 2018 in Arlington, Austin, Corpus Christi, El Paso, Houston, Lubbock, McAllen, and Nacogdoches.



Anywhere it rains in Texas, it can flood—a lesson that we often forget too quickly. Despite extensive flood awareness and mitigation efforts, flooding is a hazard that remains. Through 2023, three of the top five most expensive hazards in the state are anticipated to result from severe coastal flooding, hurricanes and tropical storms, or riverine flooding. Coastal and riverine flooding combined are expected to cause more than $6.87 billion in property losses—or 41 percent of the projected economic loss from all natural hazards during this period (TDEM, 2018).

On July 31, 2018, the President signed into law the Consolidated

Appropriations Act of 2018, which reauthorized the National Flood Insurance Program (NFIP) through November 30, 2018, but did not address the more than $20 billion shortfall facing the program (USGAO, 2018).* The federal government formalized the current framework for managing flood-prone lands in 1968 with passage of the National Flood Insurance Act creating the NFIP. Through three complementary efforts—flood hazard mapping, floodplain management regulations, and flood insurance—the NFIP aims to reduce risk to human life and damage to property (44 CFR Chapter I, Subchapter B). However, despite 50 years of concerted effort and extensive participation by Texas communities, we find ourselves repairing and rebuilding instead of planning and preventing.

Why a statewide assessment?

Texas is the second most populous state and the second largest in terms of land area. We also currently rank second behind Louisiana in terms of flood-related damage payments. Despite these facts, there has never been a thorough statewide assessment of flood risk, flood planning, or the need for mitigation activities and financial assistance in Texas. While aspects of flood risks are assessed in both local hazard mitigation plans and the *State of Texas Hazard Mitigation Plan* (TDEM, 2018), neither addresses the full spectrum of complexities that characterize our flood issues. This assessment likewise does not address all aspects of flood protection, such as the myriad components related to flood disaster readiness, emergency operations, or response.

In the summer of 2016, discourse began with stakeholders and the legislature on the need for a state flood plan—a long-term strategic document to identify flood mitigation needs and solutions to reduce flood risk statewide. Subsequently, with funding provided by the 85th Texas Legislature, the TWDB conducted a survey of floodplain administrators and related stakeholders to better understand flood planning, mitigation needs, and associated costs for communities across the state. This *State Flood Assessment* represents the outcome of that process.

The information presented in this assessment is derived from stakeholder input and is organized according to the three areas of need they described as being most important: (1) increased state resources for implementation of mitigation activities, which may include support for policy considerations, increased technical assistance, and data collection; (2) improved and updated flood mapping activities; and (3) coordinated, watershed-based flood planning.

Stakeholders consistently voiced a need for the state to support investments in these areas. Though the TWDB estimated financial costs for such investments from a variety of sources, we relied solely on stakeholder input when deriving anticipated costs and funding shortfalls for mitigation and infrastructure needs.

Captured as vignettes throughout, this assessment includes additional stakeholder input on floodplain management and mitigation as well as on training and education needs. Often constrained by a lack of financial resources, stakeholders believe that increased financial support will enhance existing local floodplain management efforts and will allow for greater leverage of funding from federal programs. Further, they suggest that the best approach for mitigating flood risk involves a solid foundation of science and flood risk mapping upon which collaborative planning can be used to better inform mitigation strategies. The TWDB concurs with this viewpoint. Thus, this first *State Flood Assessment* is organized according to such a linear progression of effort—mapping, planning, mitigation—to serve as a roadmap for flood risk management across Texas.

** On December 7, 2018, the President signed legislation passed by Congress that extends NFIP's authorization to December 21, 2018.*

2. Texas floods

- **Flooding is a natural phenomenon that impacts all areas of the state.**
- **Rainfall is the driver of most flood events, though land use change can magnify its impacts.**
- **Updated rainfall frequency estimates, released in September 2018, show parts of the state will be affected by increased rainfall.**

Floods are a natural and regular occurrence, having shaped the Texas landscape for millennia. The main attraction at the Waco Mammoth National Monument is fossilized remains of mammoths that perished in floodwaters—an estimated 67,000 years ago. Early settlers experienced flooding as a frequent hazard. The Mission San Antonio (the Alamo) was moved twice to avoid destruction from floods: first in 1719 and again in 1724 (Schoelwer, 2018). The City of Houston, incorporated in August 1836, experienced its first recorded flood in April 1837 (Johnston, 1991). The first cabin in what would eventually become the City of Dallas was damaged in a flood along the Trinity River in 1844 (Butler, 2011). Entire towns have been wiped off the map or moved. In 1882, the town of Ben Ficklin (then the county seat of Tom Green County) experienced extreme flooding that killed 22 percent of local residents and destroyed almost all structures (Tufts, 2017). The hurricane that struck Galveston in 1900 killed an estimated 6,000 people and created a 15-foot storm surge that destroyed most structures (Ramos, 1999). Historically, all areas of the state have been and continue to be impacted by flooding (USGS, 2001). In fact, each of our 254 counties has endured at least one federally declared flood disaster, according to FEMA. Clearly, living in Texas comes with some risk of flooding.

2.1 Types of floods

The water cycle, also called the *hydrologic cycle*, is the natural process by which moisture from oceans and other water bodies moves into the atmosphere as evaporation and then falls back down to land as precipitation in the form of rain, sleet, hail, or snow. Due to our state's varied landscape and location along the Gulf of Mexico, Texas' version of the water cycle frequently results in flooding, with rainfall serving as the driver of most events. The primary types of flooding that impact the state are summarized below.

Riverine flooding – Abundant rainfall can result in more runoff entering a river channel than can be contained within its banks. When water levels exceed the capacity of a channel, the river overflows onto adjacent lands,

Visitors to Waco Mammoth National Monument can view fossilized remains of mammoths that perished during a flood approximately 67,000 years ago.

called the floodplain. On steep, narrow floodplains, these excess overflows can create flood conditions suddenly (see *flash flooding* below). Where land is flat and floodplains are more expansive, greater volumes of runoff are required to cause flooding, the impacts of which may take hours or days to reach locations downstream (see *slow-rise flooding* below).

Flash flooding – A type of riverine flooding, flash flooding is characterized by a short time lag (less than six hours) between the rain event and rapidly rising water levels (NWS, 2018b). Flash flooding can occur anywhere rainfall intensity exceeds the infiltration capacity of the soil, causing rapid surface runoff. Areas with large amounts of impervious surfaces, exposed bedrock, or other solid surfaces that reduce infiltration and increase runoff, are especially susceptible to flash flooding. Near El Paso, runoff from steep slopes flows rapidly over dry, impenetrable soils transporting and depositing eroded materials across the landscape.

Slow-rise flooding – This second type of riverine flooding occurs when rain events near the top of the watershed, or far upstream, cause flooding that continues unabated downstream, impacting communities where no rain fell. For example, slow-rise flooding occurs along the Guadalupe River. When intense rains in the Hill Country cause the river to swell in New Braunfels, the City of Victoria, located 230 river miles downstream, can expect floodwater to arrive roughly one to two days after it passes underneath Interstate 35.

Coastal flooding – Low pressure systems may gain strength as they travel across the warm waters of the Gulf of Mexico, sometimes developing into tropical storms or hurricanes. As these systems approach the Texas coast, stronger winds combined with changes in water surface elevation can produce a storm surge that drives ocean water inland across the flat coastal plain. High tide events also may cause frequent, localized flooding of low-lying coastal lands.

Stormwater flooding – This type of localized flooding occurs when rainfall overwhelms the capacity of engineered drainage systems to carry away rapidly accumulating volumes of water. It typically dissipates quickly, except in situations such as when pumping equipment fails due to loss of power, inflows exceed pumping or conveyance capacity, or debris blocks the passage of water. The solid surfaces of buildings and streets (also called impervious cover) prevent rainfall from soaking into the ground, resulting in runoff. Because this type of flooding is most common in urban environments, it is sometimes called urban flooding.

Structural failure flooding – Though uncommon in Texas, failure of man-made infrastructure, such as dams or levees, can occur when intense or extensive rainfall results in the uncontrolled release of floodwaters. Failures may arise if a rain event exceeds the design capacity of a structure, such as when Callaway and McGuire dams failed in Robertson County in May 2004 (TDEM, 2013).

2.2 Precipitation influences

Culturally, Texas is viewed as a dry state perpetually lacking rain and plagued by drought. Yet, Texas holds the record for the highest rainfall totals for an individual storm recorded in the contiguous United States. The 60.58 inches of rainfall recorded at Nederland, Texas, during Hurricane Harvey in 2017 broke the *single tropical storm* record for the United States, which was set in 1950 in Hawaii (Blake and Zelinsky, 2018; NWS, 2018c). Rainfall intensity and duration records in Texas approach the maximum values recorded anywhere in the world (Slade, 1986; Asquith, 1998).

To better prepare, we rely on historical records and rainfall patterns to model and predict future rainfall, subsequent flood events, and potential impacts. These data are also used to create infrastructure design standards. Atlas 14, compiled by the National Weather Service, provides estimates of the maximum rainfall that can be expected for most locations in the United States, based on historical rainfall measurements (NWS, 2018d). An update to Atlas 14 for Texas (Volume 11) was released in September 2018 (NWS, 2018e), incorporating decades of additional rainfall data, improving the accuracy of rainfall information, and superseding all previous estimates for rainfall events in the state (primarily USDC, 1961; USDC, 1964; NOAA, 1977).

Atlas 14, Volume 11, which incorporates data from Hurricane Harvey, shows increases of more than 5 inches for the 1 percent

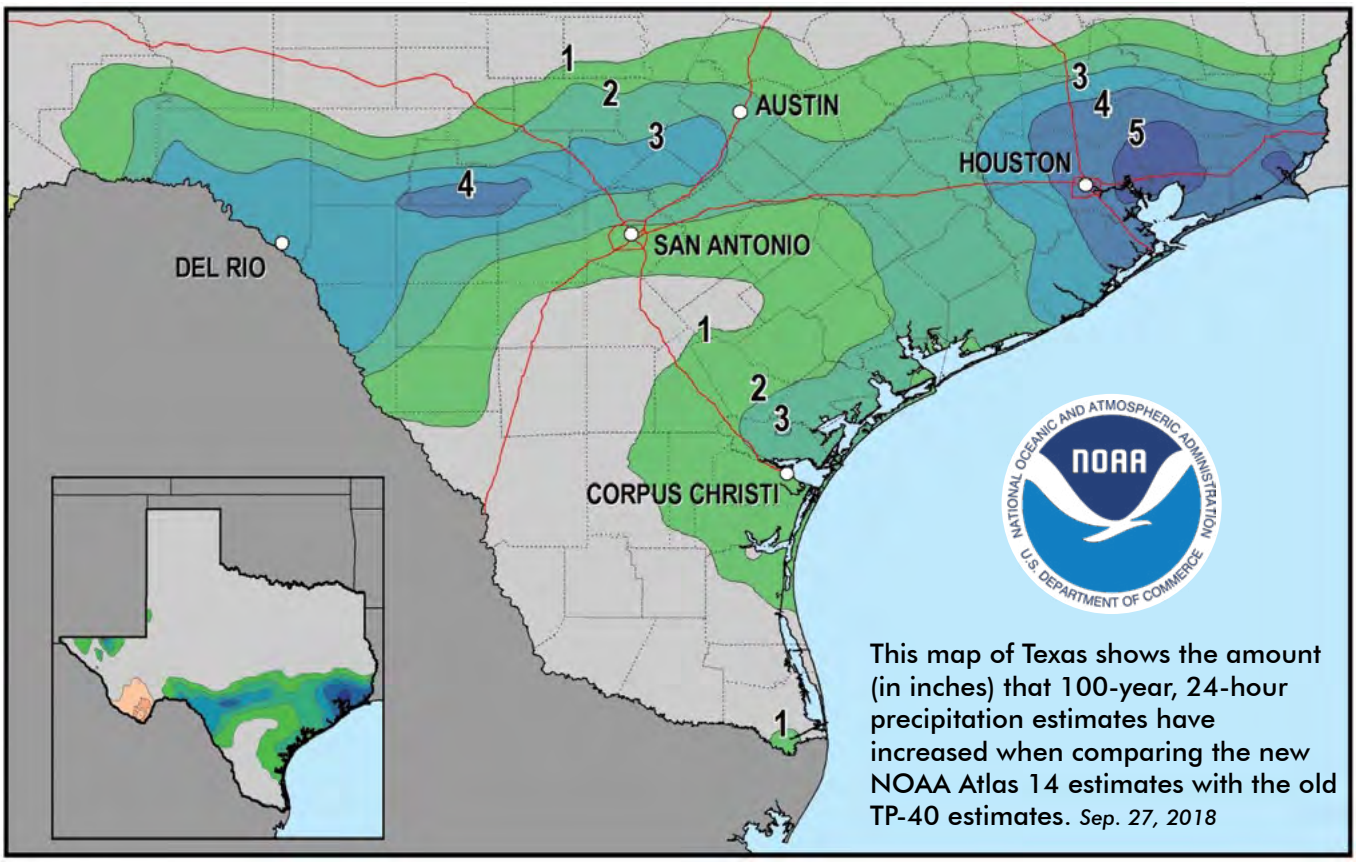


Figure 2.1 Comparison of new rainfall values to old estimates (NOAA, 2018).

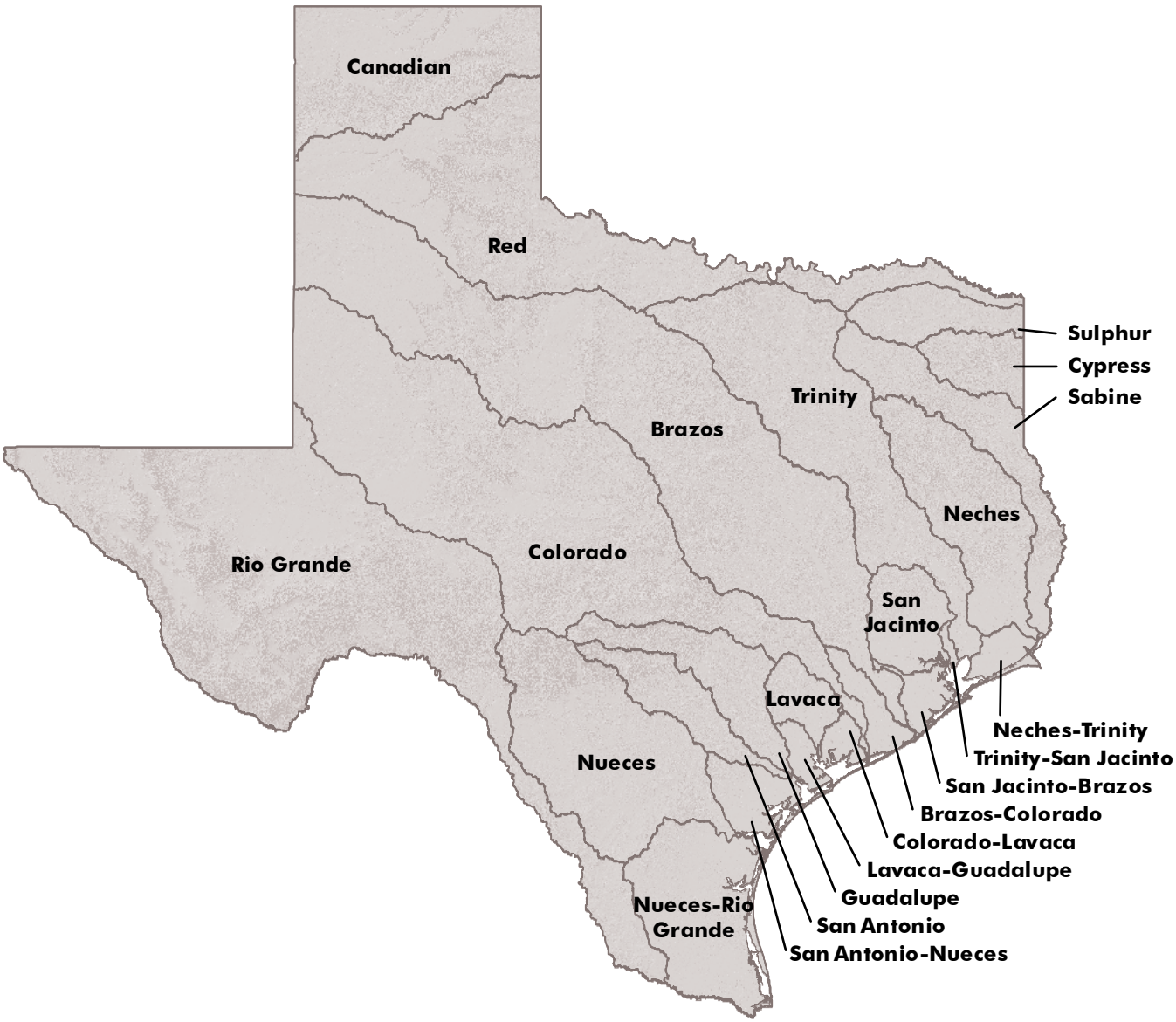
annual chance, 24-hour rainfall event in areas near Houston, as compared to existing historical records (NWS, 2018e). Elsewhere in Texas, new rainfall estimates also may differ significantly. Del Rio, San Antonio, Austin, and Corpus Christi are some of the areas where the depths of rainfall associated with many storms are expected to increase *(Figure 2.1)*.

Although the rainfall frequency data have been updated, additional studies are needed to determine the consequences of changes in the estimates. New analyses will be required to determine and revise the extent of flood inundation that can be expected and the appropriate design standards for infrastructure to withstand or convey floodwaters. In general, for areas where rainfall estimates have been lowered, there will be greater confidence that existing infrastructure will perform as intended. In areas where estimates of rainfall have been raised, flood risks are likely to be greater than previously anticipated. Increased rainfall totals over a short time span means that storms will have more significant impacts than previously predicted, thereby translating to larger discharges of water into drainage ditches and under bridges, larger volumes of water in detention ponds and behind flood control structures, and larger regulatory floodplains associated with a specific duration and frequency of storm.

2.3 Geography of floods

Texas rivers are born of the water from surface runoff or groundwater discharge and take shape as they erode, transport, and deposit sediments over many miles in their journey toward the Gulf of Mexico. Beyond their headwaters and moving downstream, rivers widen and meander as they drain more and more land area. Texas has 15 major river basins, each with unique combinations of precipitation and evaporation patterns, geologic and topographic features, and local soils, vegetation, and land use practices. In addition, eight designated coastal basins, nested between each major river basin, drain the nearly flat coastal plain *(Figure 2.2)*.

Figure 2.2 Major river basins and subbasins of Texas. A river basin, also called a watershed, is an area of land whose runoff drains to a common outlet.



In Far West Texas where intense but infrequent rains fall on steep slopes and crusted soils hardened by the sun, water runs off quickly and powerfully—often carving new paths across the landscape. Flash flooding and stormwater flooding events are most common there. However, the history of extremely large flood events on the Rio Grande, a river whose basin drains more than 48,000 square miles, is well documented and has led to the development of numerous flood control structures (Wermund, 1996).

An area known as "Flash Flood Alley" stretches from Del Rio across to San Antonio and then up through Waco to the Dallas-Fort Worth metroplex. In the southern portion of this region, the steep terrain, shallow soils, and constricted river channels carved into the Edwards Plateau result in runoff that is quickly concentrated in the river channels of narrow floodplains. Floodwaters here tend to be deep, fast, and highly erosive (Caran and Baker, 1986). Moving northward toward the metroplex, short-duration, high-intensity rain events also result in flash flooding, especially in urbanized areas.

In the Panhandle, storms may cause local flooding in and

around playa lakes and in the urbanized areas of this region. In East Texas, flood events typically arrive slowly and can linger for days or even weeks before swollen rivers return to normal.

Most of our major rivers drain the Coastal Plain as they meander toward the Gulf of Mexico. As the rivers approach the flat topography of the coast, they typically slow down and spread out. This can result in expansive but shallow flooding in this region. Living at or near sea level also means exposure to the possibility of coastal flooding from wind-driven storm surge and extreme precipitation associated with tropical storm systems. Elevated ocean and bay water surface levels during such events may counteract the downstream flow of rivers and streams, slowing the outflow of surface runoff from the land and further aggravating flooding in the low-lying coastal plain.

2.4 Benefits of floods

Floods are part of the natural environment. They shape and form the natural floodplains along streams and rivers, which in turn provide flood risk reduction benefits such as storing excess water, reducing peak flows, and slowing runoff (FEMA, 2018a). Vegetation on floodplains slows the rate of overland flow, which also acts to reduce flood peaks and erosion. Slower runoff can lead to increased infiltration and recharge of aquifers in certain areas.

Flood events provide numerous ecological benefits, including the maintenance of habitats for many plants and animals, the exchange of nutrients and organisms between the main river channel and floodplain, and the deposition of sediments, nutrients, and organic matter that enrich soils (TIFP, 2008; MEA, 2005). Certain species are adapted to the natural rhythm of floods and depend on their regular occurrence to complete their life cycles. The agricultural sector also may benefit from improved soil fertility via the sediments and nutrients deposited by floodwaters. As a result, floods, particularly those of lower magnitude that occur regularly, provide numerous benefits.

Rivers in Texas can experience both flash floods and slow-rise floods.

3. Flood risk

- **Flood events are common but only capture our attention when they impact lives and livelihoods.**
- **At least 2.8 million people (11 percent of Texas' population) are exposed to high or moderate riverine flood risk.**
- **A majority of recent flood insurance claims occurred outside of high-risk flood zones.**
- **Severe coastal flooding is projected to become the costliest hazard to Texas in the coming years.**

Nearly every Texan faces some level of risk related to flooding. The flood risk in any community, regardless of the type of flooding, reflects a combination of natural and human-made factors. Though flood risk is ever-present, flood events usually garner attention only when impacts affect our livelihoods by destroying crops, buildings, roads, bridges, vehicles, or worse, causing injury or death.

3.1 Flood risk to Texans

A key to understanding flood risk in Texas is the *State of Texas Hazard Mitigation Plan*, which is updated every five years by the Texas Department of Emergency Management. The report investigates weather-related hazards that regularly impact the state by examining financial and other impacts to people and property (TDEM, 2018). Of particular interest to this assessment are data presented on riverine flooding and severe coastal flooding; stormwater and structural failure flooding are not covered by that report.

The mitigation plan reveals that the Houston-Galveston-Beaumont region experiences the most frequently occurring and costly property damage from severe coastal flooding as compared to the rest of the state, owing to its high population density and vast petrochemical industry. Central Texas, well known across the nation for flash flooding, experiences frequent flood losses as well, with rapid growth in the area along the Interstate 35 corridor potentially exacerbating risk in this region.

About 95 percent of floodplain administrators surveyed reported that they determine and communicate flood risk in their community using Flood Insurance Rate Maps (FIRMs). Created and maintained by the Federal Emergency Management Agency (FEMA), and discussed in the next chapter, FIRMs identify areas exposed to moderate or high-risk of riverine or coastal flooding. The TWDB used data gleaned from FIRMs to describe flood risk in Texas and to explore the reasons why Texans cannot fully rely on FIRMs alone to understand flood risk.

Risk from riverine flooding

Based on available FIRMs and 2010 census data, an estimated 2.8 million people, or 11 percent of the state's population, are exposed to high or moderate risk of riverine flooding in any given year. The Houston-Coastal region has the most residents exposed, with 23 percent of the 2010 population living or working in one of these risk zones. The Nueces-South Coastal Plains region has nearly the same percentage of people facing such risk of riverine flooding, with most of those Texans living in the high-growth Lower Rio Grande Valley *(Figure 3.1)*.

Of the 12 weather-related hazards investigated during development of the *State of Texas Hazard Mitigation Plan*, riverine flooding accounted for 7 percent of average annual property losses from 1996 through 2016. TDEM's plan also includes hazard impact forecasts for the 2019 through 2023 time-period, during which riverine flooding is expected to account for 8 percent of all annual property losses and 6 percent of all crop losses (TDEM, 2018).

Risk from coastal flooding

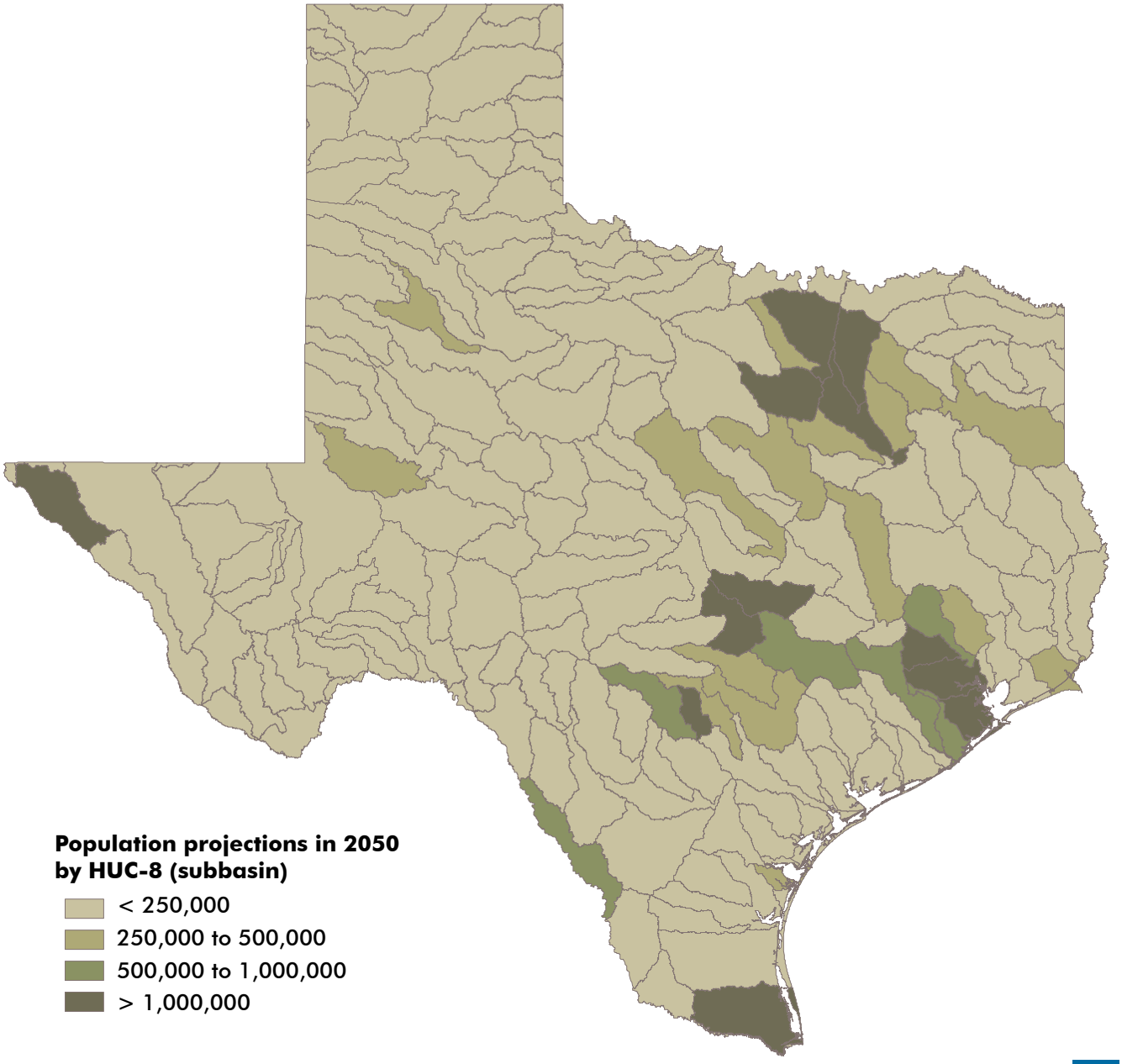
High or moderate coastal flood risk, also displayed on FIRMs, poses the greatest threat, again, to the Houston-Coastal and the Nueces-South Coastal Plains regions. Note that within the *Hazard Mitigation Plan*, storm surge damages are examined under severe coastal flooding; whereas, hazards posed by hurricanes and tropical storms are associated with wind impacts. Severe coastal flooding accounted for 25 percent of the average annual property loss across the state from 1996 through 2016. This type of flooding

is projected to surpass all other weather-related hazards, including hurricanes and tropical storms, to become the costliest hazard to the state in coming years (TDEM, 2018). TDEM anticipates $5.6 billion in potential property losses from coastal flooding during the period from 2019 through 2023, accounting for 34 percent of all expected weather-related losses (TDEM, 2018).

Risk from stormwater flooding

Impacts from stormwater flooding include damage to vehicles, structures, roads, and related drainage infrastructure. Roadways pose an additional threat if drivers, unaware of the depth of flooding, proceed through the water. Similarly, flooded roads prevent and limit emergency response operations. FIRMs do not capture this type of localized flooding; therefore, historical impacts and current risk posed by stormwater flooding are difficult to quantify. Communities typically develop master drainage plans to identify and address issues related to stormwater flooding, but the statewide picture of exposure from this hazard remains incomplete.

Figure 3.1 Population projections for 2050 by subbasins corresponding to U.S. Geological Survey 8-digit Hydrologic Unit Code (HUC). Texas has 207 HUC-8 subbasins (TWDB, 2018).



Residual risk

Residual risk relates to the likelihood of flood impacts occurring within an area despite the presence of a nearby flood control structure. Sources of residual risk are most often associated with flood events that exceed the design capacity of a levee, dam, or drainage system, as opposed to those resulting from actual structural failure. Though quantifiable, it often is presumed to be negligible or non-existent, creating a false sense of security. The National Levee Database identifies nearly 2 million Texans subject to residual flood risk associated with levees (USACE, 2018). No such data exists for the residual risk to Texans associated with dams.

A non-conventional source of residual risk is related to the static nature of FIRMs and how information is presented on these maps. Because FIRMs are intended to represent the flood risk associated with conditions at the time the map was created, any land use, development, or mitigation changes that occur after map publication are not accounted for. Further, the binary presentation of flood risk on FIRMs conveys the sense that if one is outside the demarcated *100-year flood zone* there is no risk of being flooded.

3.2 Flood risk to the economy

Commerce exists near water when flows are considered dependable, but flood events can disrupt a local economy, both in the immediate aftermath of an event and over longer time-periods. Damages to critical infrastructure such as bridges, roads, water and wastewater treatment plants, critical care facilities, and power plants may lead to vital service interruptions, causing ripple effects upon the economy in the affected area and nearby region long after floodwaters recede. For example, in 2010, flooding along the Rio Grande disrupted international trade for nearly a week as the main highway between Laredo, Texas, and Nuevo Laredo, Mexico, remained submerged, stranding people, trucks, and goods (USDA, 2010).

The threats to livelihoods, reduction in purchasing power, impacts to critical infrastructure, and loss of property values associated directly and indirectly with flooding may increase economic risks to communities. A recent analysis by Standard & Poor's Financial Services (2018) noted that improper planning for weather-related risks can impact a municipality's credit rating, with specific emphasis on hazard impacts to the local population and the associated tax base. This analysis also called out the importance of realistic financial assumptions and projections that account for the disruptions caused by natural hazards and the benefits from implementing mitigation strategies to increase resiliency. Further, recurrent flooding may discourage long-term investments by the government and private sector alike.

Historic flooding during Hurricane Harvey in 2018 caused billions of dollars of damage in Houston and other coastal communities.

3.3 Future risk

Texas is projected to increase from 29.7 million people in 2020 to 42.3 million by 2050 (TWDB, 2018). Much of this growth will occur upstream and downstream of major metropolitan areas *(Figure 3.1)*. According to U.S. Census data, Texas grows by over a thousand people each day. Without a concerted focus on "encouraging sound land use by minimizing exposure of property to flood losses," per Texas Water Code § 16.312, it stands to reason flood events will impact more lives and cause more damage in the future.

According to FEMA data, since 1978 Texans have filed more than 361,000 flood insurance claims totaling just over $15.7 billion in damages. Just over half of those claims, representing $12.7 billion in damages, have been filed since 2008. Further, 53 percent of the more recent flood insurance claims occurred outside of high-risk flood zones.

FEMA defines repetitive loss as properties that have flooded two or more times with a claim payment of $1,000 or more. Between 1978 and 2018, 48 percent of repetitive loss claims occurred outside of mapped high-risk flood zones. The Houston-Coastal and East Texas regions had the greatest number of repetitive loss properties within the state, with the San Jacinto River basin being particularly hard hit. Other basins with high numbers of repetitive loss properties included, in descending order, the San Jacinto-Brazos and Neches-Trinity coastal basins and the Trinity, Brazos, and Guadalupe river basins.

Similarly, in the same time-period severe repetitive loss claims, as identified by FEMA, occurred in every major river basin in the state, except for the Canadian basin, totaling 6,776 such properties statewide. Frequency of claims and losses for these perpetually flooded properties mirrored those described above.

In the absence of a full statewide flood risk analysis, the TWDB relied on these insurance claims data, plus hazard impact projections, to understand our risk. If the past is any indication, these numbers reveal a concerning trend. Stakeholders likewise noted that despite ongoing efforts, more resources are devoted to disaster recovery than to proactive mitigation and damage prevention. Further, recent flood events across the state and newly released Atlas 14, Volume 11, revised precipitation estimates suggest that the frequency—and therefore the risk—of being flooded may be greater than Texans realize.

3.4 Awareness in Texas

Flood awareness encompasses knowledge of basic concepts of the water cycle, watershed science, weather patterns, flood risks, and emergency preparedness and response. Most public education campaigns, however, focus only on situational awareness and preparedness in the event of a flood. Recent events across the state point to widespread confusion related to the meaning of the *100-year flood* (further explained in Chapter 4).

Officially trademarked by the National Oceanic and Atmospheric Administration (NOAA) since 2004, the National Weather Service's *Turn Around, Don't Drown*™ campaign is perhaps most familiar to Texans. The campaign highlights the danger of driving or wading into floodwaters (NWS, 2014). The Texas Department of Transportation employs the well-known message on road signs, social media, and other venues. The Texas Floodplain Management Association also uses it in public outreach materials, including a poster illustration contest for grade school students.

While these collective efforts encourage safe behaviors and reduce the need for emergency response, the need remains for long-term educational campaigns to increase pre-situational awareness. Efforts to teach the public to understand flood risk within their watershed can be accomplished by developing user-friendly websites and publications based on observed data from local, memorable events and general floodplain management concepts.

These campaigns could also re-interpret flood risk data to better communicate the true potential for inundation by floodwaters. Flood maps for public education could display the full spectrum of risk from various sized riverine and coastal flood events and—where possible—communicate the potential risk of stormwater flooding. To prevent loss of life and damage to property to the greatest extent possible, Texans must understand that the high-risk zone shown on a flood insurance rate map relates to the requirement to purchase flood insurance. It does not demarcate whether one is safe or not safe from the next flood event.

4. Floodplain management and mapping

- **Flood hazard mapping is the first step in identifying flood-prone areas and communicating risk to stakeholders.**
- **The regulatory floodplain is distinct from the natural floodplain.**
- **Floodplain maps are complex and are often misinterpreted.**

Floodplain management encompasses any part of the strategic effort to identify areas subject to flooding and to protect the natural function of those areas. Flood risk mapping represents the critical first step in identifying flood-prone lands and in communicating that information to residents, decision makers, and emergency responders. In Texas, complementary efforts focused on flood risk mapping, planning, and mitigation do not exist. This chapter explains the differences between a natural and a regulatory floodplain and describes the process and applications of flood risk mapping—the first pillar of sound flood risk management.

4.1 What is a floodplain?

A floodplain is the land adjacent to a water body that is subject to inundation during a flood. The size and shape of a floodplain influences the characteristics of a flood event. The boundaries of a *natural* floodplain can change with each flood event as sediments are scoured and deposited within the river channel and upon adjacent lands. Similarly, the coastal shoreline changes frequently. A *regulatory* floodplain, however, is determined by modeling a specific storm event and depicting the boundaries of inundation resulting from that storm on a map. As a result, a regulatory floodplain only changes when a new study or mapping effort is conducted.

For the past 50 years, regulatory oversight for floodplain management has followed the principle that adequate flood protection for the public can be achieved by building infrastructure and adopting floodplain ordinances to protect against a flood event with a 1 percent probability of occurring in any year. Because such an event has a 1-in-100 chance of occurring or being exceeded in any given year, the phrases *100-year flood* and *100-year-floodplain* are commonly used. However, these colloquial terms are misleading. Their use stems from a simplification of the statistical process for calculating the probable recurrence of flood events of a given magnitude. Neither term is meant to indicate that such a flood event will occur only once per 100 years. It is quite possible for a *100-year flood* to occur several years in a row. In fact, for a structure exposed to this likelihood of flooding, the statistical probability of incurring flood damage during the span of a 30-year mortgage equals 26 percent.

Further, the boundary of the 1 percent annual chance flood event, shown on a FIRM as the special flood hazard area (SFHA)—another name for the regulatory floodplain—often is misinterpreted as a dichotomy between safe and not safe. That line, much like the demarcation for a 0.2 percent annual chance flood event—commonly termed a *500-year flood*—instead shows the boundary of potential inundation from a very specific flood event based on the land use conditions that existed when the modeling and mapping were completed. Beyond either boundary line, the risk of flooding still exists, just with a lower probability of occurrence. As noted previously, any land use changes subsequent to the modeling alter the movement of water and thus the probability of flooding.

4.2 Mapping a floodplain

Understanding the extent of the natural floodplain can be accomplished by observing local conditions. Rivers carry and leave behind fine sediments during floods. The presence of such sediments, deposited repeatedly over time, denotes an area that was previously inundated and may be subject to inundation in the future. Every county in Texas has a detailed soil survey showing locations of frequently flooded soils (see the Natural Resources Conservation Service (NRCS) Web Soil Survey at https://websoilsurvey.nrcs.usda.gov/). Similarly, the University of Texas

Bureau of Economic Geology maintains an archive of surface geology map sheets where alluvium, or sediments deposited by moving water, can indicate the extent of historical flooding.

Along river edges, riparian ecosystems withstand, and in fact rely on, periodic inundation by floodwaters. Similarly, stable dune systems along the coast support certain plant species that when absent indicate shoreline areas subject to frequent change and thus heightened flood risk from wave action. In the aftermath of a flood, the height of floodwaters can be determined via high water marks left on walls of homes or detritus left perched in trees, bridges, and even road signs. Though useful to building a narrative of local flood hazards, on their own these observational signs are inadequate for certain mapping activities unless properly surveyed.

In floodplain management, engineers and hydrologists investigate channel or shoreline features to determine how floodwaters will move. They also use hydrologic and hydraulic modeling to provide the detailed analyses required for specific design, construction, and regulatory applications. Hydrologic modeling considers how the unique characteristics of a watershed (the soils, surface geology, terrain, land use, etc.) respond to a rain event or how much rain will soak into the soil versus run off into drainage systems and rivers. These models also estimate the lag time between when the rain falls and when the resulting runoff reaches the stream.

Whereas hydrologic models simulate the quantity and timing of the flow of water, hydraulic models simulate the forces that affect water flow, specifically how friction and pressure interact to determine the height to which floodwaters will rise. Here, the characteristics of the stream channel itself—as opposed to the watershed—are most important. For coastal storm surge analysis, three-dimensional hydrodynamic circulation models are used to evaluate wave height. Together, these models can describe the inundation, or spread and depth of water over the floodplain, associated with the storm event selected for analysis.

Purpose of the National Flood Insurance Program (NFIP)

The NFIP operates by voluntary agreement between the federal government and local political subdivisions (cities, counties, villages, special purpose districts, and tribal nations, hereafter referred to as communities). Established by Congress in 1968 and administered by FEMA, the NFIP aims to mitigate future flood damage through three efforts:

Flood mapping. FEMA generates and approves flood insurance rate maps (FIRMs), which identify areas of high, moderate, or low-risk of flooding along rivers, the coast, and other water bodies but not for areas impacted by local drainage issues. FIRMs identify land areas with a high-risk of flooding (areas subject to inundation during a 1 percent annual chance event) denoted on the map as the regulatory floodplain or the Special Flood Hazard Area (SFHA). Participants in FEMA's Cooperating Technical Partners program assist by identifying watersheds in need of mapping and by conducting mapping activities; however, the final approval of a regulatory floodplain map is completed by FEMA. View approved FIRMs at msc.fema.gov.

Community-enforced regulation. NFIP communities must adopt and enforce floodplain management regulations that meet or exceed FEMA's minimum standards (for full criteria, see 44 CFR 60.3), which include issuing permits for development within SFHAs; conducting field inspections and citing violations; maintaining records of floodplain development; and assisting in the preparation and revision of FIRMs.

Flood insurance. Within NFIP communities, all residents gain the option to purchase federally backed flood insurance; however, certain homes and businesses in designated SFHAs with mortgages from federally regulated or insured lenders are required to maintain insurance. Flood insurance also can be required as a condition for receiving federal disaster aid. FIRMs are used to determine insurance premiums for properties in flood-prone areas.

4.3 Mapping the regulatory floodplain

FEMA, with assistance from local partners, creates and maintains FIRMs and their modern digitized equivalents, DFIRMs. Hydrologic and hydraulic or hydrodynamic models, using local watershed and channel or coastal shoreline data, as described above, are simulated to identify areas at high, moderate, or low risk of flooding. FIRMs show land areas subject to inundation by riverine flood events or coastal storm surge for the 1 percent annual chance event (high-risk or special flood hazard area) and the 0.2 percent annual chance event (moderate risk area).

Only 20 percent of survey respondents describe their FIRMs as recently updated. The remaining described their maps as old, outdated, incomplete, or insufficient.

Beginning in 2003, FEMA's map modernization initiative sought to digitize as many existing flood hazard maps as possible. *Figure 4.1* shows the status of FIRMs in Texas, as of April 2018. Approximately half of the counties in Texas had no digital flood insurance rate maps and most of the remaining counties had not updated FIRMs within the last five years.

FIRMs exist as individual panels corresponding to U.S. Geological Survey quadrangle and quarter-quadrangle boundaries. At the county level, a FIRM can be comprised of panels forming a mosaic of different dates corresponding to when specific mapping activities were completed and adopted by FEMA. When a minor map revision within one panel is adopted, the effective date of the FIRM changes even though the remainder of the panel reflects flood hazard information derived from older data. Or, a FIRM may be revised based on recently acquired elevation data (*i.e.*, lidar, or light detection and ranging) but still use precipitation data from a previous decade. In certain instances, the date shown on a county FIRM may not reflect the more recent updates of individual panels. Smith County, for example, shows an effective date of 2008, but the City of Tyler updated its panels in 2014. In short, the effective date of a FIRM may not equate to the age of all data used to create the flood hazard zones displayed therein.

Cooperating Technical Partners Program

FEMA launched the Cooperating Technical Partners (CTP) Program in 1999 to enhance the rate of mapping activities and to increase local involvement in the process. All mapping activities follow a four-phase process, which may take a minimum of 5 years to complete *(Table 4.1)*. CTPs assist in three of the four phases of mapping activities as laid out by FEMA and must follow *FEMA Guidelines and Standards for Flood Risk Analysis and Mapping* (FEMA, 2018b).

Phase 0 – Base level engineering consists of compiling existing data, information, and modeling to prioritize watersheds for further study and ultimately to produce regulatory flood hazard boundaries. To proceed to Phase 1-Discovery, a watershed must have base level engineering completed.

Phase 1 – Discovery includes outreach and information gathering within the watershed, including information on areas of mitigation interest and areas in need of detailed mapping. Detailed mapping includes creation of base flood elevations.

Phase 2 – Flood risk study includes the compilation of datasets for hydrology, hydraulics, infrastructure, and land use, as well as existing base maps and, if available, floodplain maps. A flood risk

Table 4.1 Summary of the four phases to produce a regulatory flood map, or FIRM, and the role of FEMA and Cooperating Technical Partners (CTPs) at each phase, plus estimated length of time to progress through each phase.

Phases	Entities authorized to conduct work	Production time
0 – Base level engineering	FEMA and CTPs	9 months
1 – Discovery	FEMA and CTPs	12 months
2 – Flood risk study	FEMA and CTPs	24 months
3 – Map production	FEMA	18–24 months

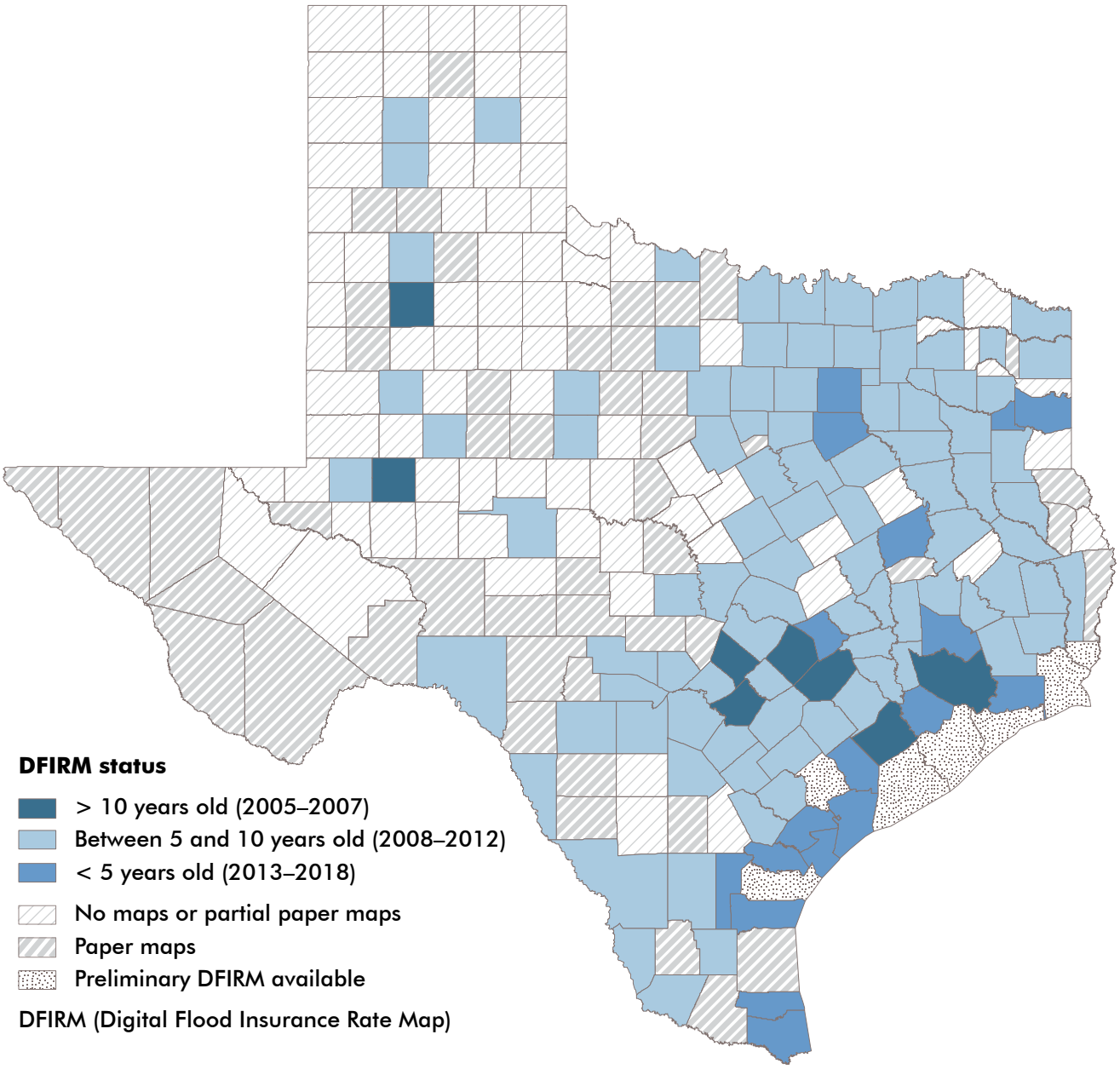


Figure 4.1 Type and age of Flood Insurance Rate Maps (FIRMs) by county. Digital flood insurance rate maps (DFIRMs) exist for 47 percent of Texas counties, and the majority of those were completed more than five years ago. Preliminary DFIRMs are available in some counties where initial modeling has been completed, but mapping updates have not yet been approved. Paper maps indicate flood zone designations were made prior to 2003, and the data used to create them are often much older. In certain areas, no FIRMs exist, so no flood hazard information has been determined. FIRMs are created and updated by FEMA or through partnership with one of 11 Cooperating Technical Partners (CTPs): the cities of Arlington, Austin, Dallas, Fort Worth, and Grand Prairie; the Guadalupe-Blanco and San Antonio river authorities; the Harris County Flood Control District; the North Central Texas Council of Governments; and the Texas A&M University-Texas Community Watershed Program. The TWDB supports mapping assistance for all regions of the state not represented by a CTP and serves as the state coordinator.

study determines accurate surface elevations and may include developing models for riverine flooding or coastal storm surge as well as special assessments related to alluvial fans and levees. A flood risk study delineates the 1 percent and 0.2 percent annual chance event inundation boundaries.

Phase 3 – Flood insurance rate map production completes the process for developing a regulatory flood map, including a public comment period, an opportunity for appeal and protest, and approval of the map. Phase 3 does not involve CTPs and is exclusively completed by FEMA.

4.4 Mapping needs in Texas

Throughout Texas, flood risk remains largely undefined and unquantified. Though useful for regulatory applications and flood insurance determinations, FIRMs show only the potential hazards posed by a flood event as modeled for a very specific set of conditions. Further, FIRMs do not capture the risk of stormwater flooding unless a community chooses to conduct the studies necessary to incorporate that data into their hazard map. A key purpose of this flood assessment is to better understand the resources needed by communities in Texas to properly manage floodplains and mitigate flood risks.

The TWDB heard from NFIP-participating communities that the path to a FEMA-approved FIRM is arduous, often controversial, and lags behind the pace of growth in their communities, thereby limiting their ability to protect lives and property. However, an NFIP community has the authority to set and enforce local floodplain ordinances. Though typically based on FEMA-approved FIRMs, communities may choose to base their permitting and related requirements on any other best available data, such as preliminary FIRMs, existing high-water marks, historical accounts of inundation extents, and similar information. Some communities in Texas utilize this type of data for local planning and emergency preparedness. Others do not have the resources to acquire such information and instead wait for the FEMA approval process.

Several states have taken an alternate route to flood hazard mapping. The Iowa Flood Center completed a statewide inundation mapping project over the course of six years by developing their own hydraulic models and mapping all streams that drain an area greater than one square mile. Iowa collected the elevation (lidar) and related channel-specific data necessary to complete mapping studies that meet FEMA quality standards. In this way, the Iowa Flood Center ensured the information was made available to the public relatively quickly (via a web portal used only for non-regulatory purposes such as emergency response and preparedness planning) while also advancing efforts by NFIP participating communities to pursue updating their local FIRMs.

North Carolina chose a different path. In 2000, North Carolina became a Cooperating Technical State, as opposed to partnering community, and undertook full responsibility for collecting updated flood hazard data and for maintaining current FEMA-approved FIRMs. Through a three-phased Statewide Floodplain Mapping Program, local, state, and federal partners committed the financial, staffing, and technical resources necessary to successfully provide updated maps for every watershed within a 10-year timeframe.

Alternative approaches to determining and communicating flood risk also exist. Though less comprehensive than the FEMA risk mapping process, these alternatives may offer a faster path to providing flood risk information for Texans. A recent effort by Wing and others (2017) developed a flood hazard model harnessing publicly available data for the conterminous United States and found the results compared favorably enough to FEMA FIRMs to inform decision making at a fraction of the cost.

Stakeholders' Top 3: financial resources for flood hazard mapping

Stakeholders identified flood hazard mapping as the second most important area for the state to invest resources.

Cost to produce regulatory FIRMs

An estimated cost for the state to conduct mapping activities following FEMA's phased approach to producing FIRMs for riverine flooding in *all* watersheds is about $604 million. Calculated using published FEMA cost estimates (FEMA, 2017), this number includes an estimated $62.4 million to conduct base level engineering (Phase 0); $15.6 million for discovery (Phase 1); and $525.8 million to conduct flood risk studies (Phase 2) for all watersheds in the state. The U.S. Geological Survey uses the HUC (hydrologic unit code) designation to describe the nested hierarchy of watersheds, from major river basin to smaller subbasins. This cost estimate is based on conducting mapping for the 207 8-digit HUC subbasins (often called HUC-8 watersheds) in the state.

However, some watersheds have begun or have recently completed the mapping update process (*e.g.*, all of the Guadalupe and Neches river basins and other individual HUC-8 watersheds), reducing the need to invest in a complete remapping of the state at this time. A true cost for developing and updating all FIRMs in Texas has yet to be determined, but example costs from recent mapping activities ranged from $1.2 million for the Lower Colorado Cummins basin (most of Bastrop and Fayette counties) to $2.6 million for Upper Brushy Creek (part of Williamson County). These estimates include both state or local in-kind services and existing data and modeling products as well as federal grant funding. Estimates do not include the cost associated with updating FIRMs on a regular basis. For these projects, federal grant contributions provided an average of 26 percent of the overall cost.

As the state CTP coordinator, the TWDB focuses on areas in need of mapping assistance. In 2015, the TWDB partnered with FEMA to fund development of a prioritization tool to aid in the selection of watersheds for study. Using this tool, the TWDB can identify areas with needs based on an array of factors such as a high flood risk or a lack of resources to initiate mapping activities. The TWDB prioritizes funding for flood mapping projects using weighted geospatial data aggregated according to HUC-8 watershed boundaries. Thus far, the datasets used, in order of relative importance, include lidar availability, number of flood insurance claims, number of repetitive and severe repetitive loss claims, FIRM status, population, projected population change, lack of a CTP, and available in-kind resources that can be leveraged for the study.

National Flood Insurance Program in Texas

In 1999, the 76th Texas Legislature directed cities and counties to adopt ordinances or orders necessary to be eligible for participation in the NFIP (Texas Water Code § 16.3145). When communities meet eligibility requirements (44 CFR § 59.22), residents gain access to federal assistance, including federally backed flood insurance and post-disaster assistance.

As of September 2018, Texas has 1,252 NFIP participating communities: 1,011 cities, towns, or villages; 220 counties; and 21 special purpose districts, including water control and improvement districts, local improvement districts, bayou improvement districts, municipal utility districts, and drainage districts. The State of Texas itself does not participate.

All political subdivisions are "authorized to take all necessary and reasonable actions that are not less stringent than the requirements and criteria of the NFIP" (Texas Water Code § 16.315). If desired, communities can implement federal, state, or local initiatives and higher regulatory standards. The Community Rating System (CRS), a voluntary FEMA program, encourages efforts that exceed minimum standards by offering a discount of up to 45 percent to flood insurance policy holders. Example activities that generate a discount include preserving open spaces in flood-prone areas, monitoring flood conditions and issuing warnings, and enforcing stricter development standards through flood damage prevention ordinances.

As of September 2018, only 62 NFIP communities in Texas were participating in the program. Dallas, Grand Prairie, Houston, Pasadena, and Plano each earn a 25 percent discount, the highest in the state. Some Texas communities that do not participate in the CRS program have adopted higher standards via flood damage prevention ordinances, which could translate into credits and associated insurance discounts if they chose to apply.

5. Planning for floods

- **Mitigation without proper mapping and coordinated planning may be ineffective, or worse—intensify flood impacts in upstream or downstream communities.**
- **Effective planning includes core elements:**
  - **Data, models, and sound science**
  - **An inclusive vetting process**
  - **Defined levels of acceptable risk and standardized benchmarks**
  - **Quantifiable outcomes**
- **Stakeholders strongly support watershed-based flood planning driven by local communities.**

Texas first considered the idea of a statewide planning process for floodplain management in 2002. Following a series of natural disasters, the 76th Texas Legislature established a Blue Ribbon Committee to examine ways to improve state, federal, and volunteer coordination and to provide streamlined disaster assistance (BRC, 2001). This was followed by a report from the Senate Interim Committee on Natural Resources, which recommended statewide planning for floodplain management in its interim report to the 78th Texas Legislature (SICNR, 2002). The report also recommended that flood mitigation programs be consolidated within a single agency. The TWDB has served as the state's NFIP coordinator since 2007.

Following the historic drought of the 1950s, the Texas Legislature enacted the Texas Water Planning Act of 1957 to accomplish a vision for preparing the state to meet the projected future water supply needs of its rapidly growing economy. This vision and its legacy evolved over time to a sophisticated, regionally comprehensive evaluation of future water availability and needs, with recommended projects to specifically meet those needs. Not unlike the early implementation of water supply projects prior to the 1961 *State Water Plan*, present day flood mitigation and mapping projects tend to be locally driven and not coordinated at broader regional scales. Although the state has yet to develop a common vision for flood risk management or an associated flood planning process, this assessment reveals that initiatives are already in motion in some parts of the state.

With broad consensus from floodplain administrators and other stakeholders, through this assessment the TWDB learned about the need for more coordinated flood planning efforts and about the numerous options available for supporting communities in evaluating their flood risks and mitigation activities. Further, stakeholders requested increased support for and financial investment in coordinated, watershed-based flood planning—a second pillar of flood risk management.

Stakeholders' Top 3: financial assistance for flood mitigation planning

Stakeholders identified flood mitigation planning as the third most important area for the state to invest resources.

5.1 Current planning efforts in Texas

Texas has several ongoing planning efforts that address some element of flood protection that can be applied toward a more concerted statewide flood planning effort.

Hazard mitigation planning. The *State of Texas Hazard Mitigation Plan* provides a high-level overview of statewide strategies to reduce exposure to all weather-related hazards, including riverine and coastal flooding. Once every five years, with guidance from the State Hazard Mitigation Team, the Texas Division of Emergency Management (TDEM) identifies the state's

Only half of stakeholders reported that their jurisdiction has identified flood risk and conducted local planning efforts to develop mitigation solutions. Communities, special purpose districts, and multi-jurisdictional regions accomplish this through development of plans addressing hazard mitigation, comprehensive land-use, drainage, watershed protection, emergency operations, or some combination of these efforts.

priorities for funding types of flood hazard mitigation actions (*e.g.*, drainage projects, acquisition and demolition of properties, etc.) and planning projects (*e.g.*, watershed-level mitigation plans), as well as a repetitive loss strategy of specific actions meant to reduce potential losses to properties with a history of flood damages. The 2018 State of Texas Hazard Mitigation plan was approved by FEMA in October 2018.

The state plan lays out priorities based on feasibility, cost effectiveness, capacity to be executed, and conformance to the goals of the plan itself. The state plan does not compile or prioritize *specific* projects, and there is no organized process to ensure the prioritized actions are implemented. However, beyond local hazard preparedness benefits, the state and communities have incentive for developing hazard mitigation plans, because the plans are required for eligibility to receive federal assistance through FEMA's Flood Mitigation Assistance (FMA), Pre-Disaster Mitigation (PDM), and Hazard Mitigation (HMGP) grant programs. Once a community's plan is approved by FEMA, the community becomes eligible for federal assistance through these programs (TDEM 2013).

As of July 2018, 117 counties had communities with FEMA-approved hazard mitigation plans covering about 81 percent of the state's population (D. Jackson, *pers. comm.*). Many communities had an expired local plan or no approved plan (FEMA, 2018c). Barriers to creation of local hazard mitigation plans are similar to those reflected in our survey of stakeholders: limited financial resources, lack of staff dedicated to this process, and difficulty navigating the process.

Local hazard mitigation planning, given its focus on addressing all types of natural hazards and its voluntary nature, is not sufficiently scoped to provide collaborative, watershed-based strategic flood planning. The process, as carried out, is important but limited. Further, the entities that participate in this process may vary, leaving no guarantee that participants will have experience in dealing with flood risks.

River basin planning. Regional entities and partnerships, such as development councils, river authorities, and councils of government, may conduct planning activities, guide development, and assist local governments in implementing plans regarding land use, water supply, drainage, and open spaces (Local Government Code, Chapter 391). Each river authority's enabling legislation is unique, but generally all have powers related to flood control (Texas Constitution, Article XVI, Section 59). The San Jacinto River Authority publishes a basin-wide plan that includes discussion of flood protection, flood control reservoirs, and flood retarding structures. The San Antonio River Authority has implemented holistic

Many Texas reservoirs were built to provide flood control.

watershed planning across the basin to assist the responsible local entities to manage land use change and maintain water quality. The effort also includes incorporating FEMA's Risk Mapping, Assessment, and Planning (RiskMAP) approach to identifying flood risk for every watershed in the basin. Funding for these initiatives is supported by the San Antonio River Authority's ability to levy an ad valorem tax, which is limited to $0.02 per $100 of assessed property valuation.

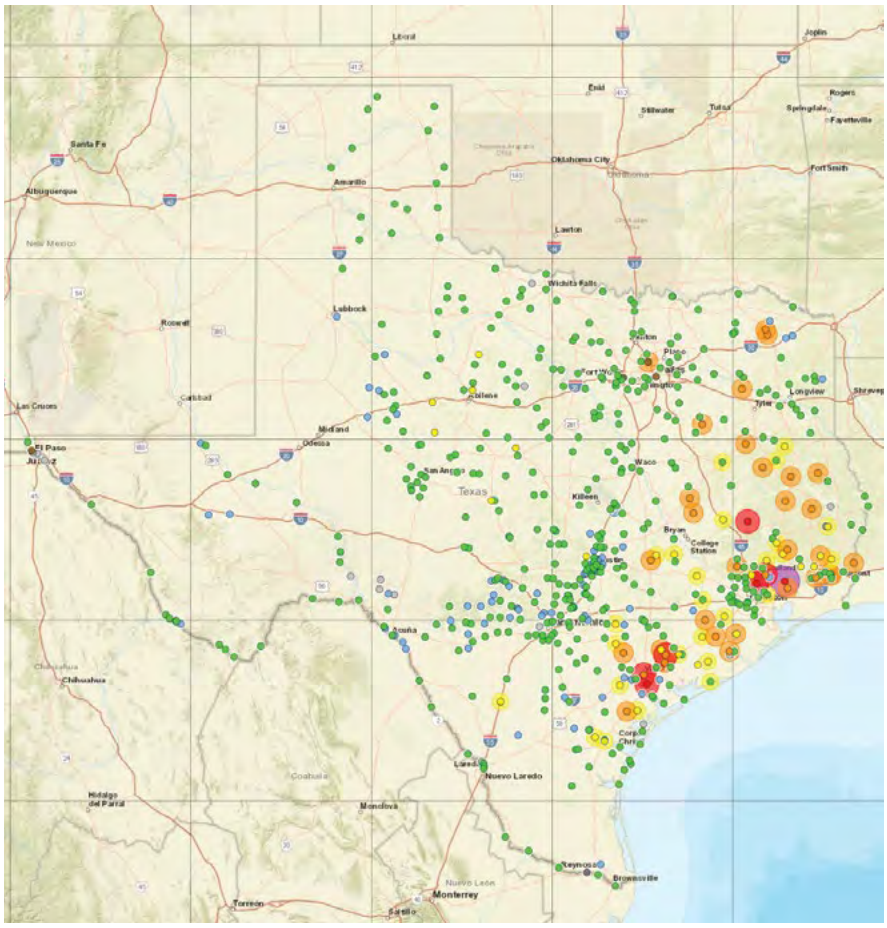
The Texas State Soil and Water Conservation Board (with support from the NRCS Watershed and Flood Prevention Operations Program) works with rural landowners to develop watershed protection plans to address flood prevention, erosion and sediment control, and planning for priority dams, among other activities. Similarly, Texas A&M University conducts training for watershed planning to ensure plans meet the Environmental Protection Agency's requirements by identifying nonpoint source pollution and proposing local solutions to improve water quality.

Coastal resiliency planning. The Texas General Land Office has developed the *Coastal Resiliency Master Plan*, a multi-year, stakeholder planning process to identify structural and non-structural mitigation (termed "grey" and "green", respectively) strategies, including policy recommendations, to enhance resiliency and to better protect coastal infrastructure, natural resources, and economic activities from natural hazards (TGLO, 2017). To date, this process has yielded a suite of specific projects largely focused on habitat restoration and conservation that can provide specific starting points for expanding comprehensive flood planning along the coast.

The U.S. Army Corps of Engineers (USACE) recognizes that Texas' natural and economic resources are of national importance and may be significantly impacted by floods and storm surge. The USACE, therefore, has committed to conducting planning studies within the state. The *Coastal Texas Protection and Restoration Feasibility Study*, conducted in partnership with the Texas General Land Office, is a long-term, comprehensive coastal planning effort focused on coastal storm risk management and ecosystem restoration. As of late 2018, the USACE has narrowed its list of viable projects to several storm risk management scenarios that provide a barrier system for the Houston-Galveston and Galveston Bay region, plus a suite of shoreline protection and habitat restoration projects along the Texas coast. The final feasibility report is expected to be delivered to Congress in 2021 for consideration to authorize and fund. Additionally, the USACE has announced studies of Buffalo Bayou and its tributaries, as well as the Houston Regional Watershed Assessment to determine solutions for local flood issues. Other USACE studies will consider resiliency solutions for the Brazos River in Fort Bend County and for the Guadalupe and San Antonio river basins.

Flood protection planning. Since 1983, the TWDB has provided state financial assistance, requiring up to a 50:50 cost share, to communities to conduct

Severe coastal flooding is projected to become the costliest hazard to Texas in the coming years.



The TWDB's TexasFlood.org displays river conditions around the state.

detailed studies of known or potential flood-prone areas to better inform the development of flood protection strategies through structural and non-structural solutions. This grant program allows communities to conduct hydrologic and hydraulic studies of current and future conditions and to identify potential mitigation solutions, including estimated costs and benefits. The process ensures opportunities for broad stakeholder education and input for each project, as well as consistency with relevant plans, laws, and regulations. Between 1995 and 2017, over $20 million in state funding, in addition to $30 million provided in local matching funds, was committed to flood protection planning in Texas through this program. Further, communities have been able to leverage their efforts from these flood protection planning studies to obtain additional funding through FEMA Flood Mitigation Assistance grants. Considering any future flood planning efforts, there are elements of the TWDB's flood protection planning grant program that can be modeled—elements such as inclusive stakeholder forums, multi-jurisdictional cooperation, modeling flood risk under future development conditions, identifying structural and non-structural solutions, and requiring local financial contribution through dollars or in-kind services.

5.2 Approaches used in other states

Coordinated watershed-based planning occurs throughout the nation but appears in different forms among the states. Statewide flood planning, in the format of a cyclical, multi-regional evaluation to identify projects, is a relatively uncommon process. Instead, many states have chosen to focus on specific tasks, such as statewide mapping or policy implementation, to build strong floodplain management programs that can provide services and mitigation beyond those of FEMA and the NFIP alone.

California, Illinois, Iowa, Maryland, Minnesota, Montana, Nebraska, New Jersey, Oklahoma, and West Virginia have published formal plans related to watershed-based or statewide flooding concerns, floodplain management, or flood hazard mitigation operations.

California, in partnership with the USACE, has completed the most extensive flood planning effort in the nation, the outcome of which yielded California's *Flood Future Report*, a comprehensive overview of the state's risk of flooding, approaches for mitigating risk, recommendations for action, and existing financial investment, as well as an estimate of future financial need based on input from regional entities (CDWR, 2013).

In 2014, Minnesota used $4.9 million in state funding to initiate a watershed-based pilot program to comprehensively address water resources issues, including flooding, within six watersheds—with a goal of implementing the

program statewide by 2025. The program operates on a 10-year planning cycle, requires 10 percent local matching funds, and is based on formal, voluntary partnership agreements among entities in a given watershed. The purpose is to encourage these entities to work collaboratively to identify policies, projects, or strategies to protect, enhance, or restore their basin. An approved plan (whether individually or as part of this initiative) allows access to state funding. Without an approved plan, entities will only have access to limited, competitive grant funding. Long-term funding for the program is provided by revenue from a three-eighths of one percent increase in the state sales tax.

Nebraska similarly completed a statewide Flood Hazard Mitigation Plan, which is used in part to determine whether local mitigation activities are effective (NDNR, 2013). The Iowa Watershed Approach program coordinates watershed management authorities and encourages local watershed-based planning through voluntary interlocal agreements (IWA, 2017).

Most existing flood plans, however, do not recommend specific projects for funding and are not supported by dedicated state funding sources. Maryland's flood damage vulnerability assessment, for example, requires communities to submit annual lists of projects and watershed-wide flood damage plans to receive supplemental state funding, but the associated grant program does not have a dedicated, reliable funding source (Joyce and Scott, 2005).

Other states without formal, comprehensive flood plans emphasize specific programs related to flood warning or mapping. Iowa, for example, emphasizes real-time flood warning and inundation mapping capabilities, published via web-based viewers for both the public and decision makers. North Carolina focuses on floodplain mapping; as a FEMA Cooperating Technical State, they assume ownership of their FIRMs and publish associated hazard data, models, maps, and risk assessments. Oklahoma and New York, on the other hand, developed statewide mesonets (weather monitoring networks) focused on gathering and providing weather data to inform both flood response and drought forecasting.

Some states conduct flood planning primarily through the FEMA hazard mitigation planning process, which can potentially increase access to additional resources from FEMA. As of June 2018, 12 states, including California, Florida, Iowa, North Carolina, Washington, and Wisconsin, had comprehensive mitigation programs along with a FEMA-approved Enhanced State Mitigation Plan. Approval allows access to additional Hazard Mitigation Grant Program funds (FEMA 2018). To achieve this status, a state must demonstrate an ability to effectively use available funding and to manage increased funding (44 CFR § 201.5). Texas is currently seeking to earn this same status. Florida also maintains a delegation of authority from FEMA to approve local hazard mitigation plans via the Program Administration by States pilot initiative. Florida thus requires all counties to update and seek approval for multi-jurisdictional, multi-hazard plans on an annual basis. As a result, Florida is one of the few states with 100 percent coverage of approved local hazard mitigation plans (FEMA, 2018c).

Through state code, Wisconsin, Washington, and Florida seek to lower flood risk by restricting building construction in flood-prone areas. For example, Wisconsin requires structures to be constructed to the Flood Protection Elevation, which is 2 feet above the base flood elevation (Mittler *et al.*, 2006). Florida requires uniform, comprehensive land use policies of all jurisdictions and enforcement of the state's minimum building codes (Brody *et al.*, 2009).

Funding sources used by states to implement and maintain floodplain management activities are as varied as the programs described above. All states utilize available federal funding, though some, such as Florida, have implemented activities that enable access to greater post-disaster federal funding. Many strong state programs across the U.S. were developed following natural disasters, whether directly through federal funding or through each state's own commitment to improve preparedness.

Following disastrous flooding in 2008, Iowa used a combination of a $15 million grant from the U.S. Department of Housing and Urban Development (HUD), $2.2 million from the U.S. Army Corps of Engineers Planning Assistance to States, existing state and federal commitments for lidar data collection, and a portion of $2 million in state

floodplain management funds (allocated over several years) to support floodplain mapping and the production of FIRMs for 86 percent of the state. Iowa also took advantage of a $97 million HUD disaster resilience grant to create the Iowa Watershed Approach program. The Iowa Flood Center, founded following the 2008 floods, continues the state's efforts to map floodplains, provide flood-inundation maps, and maintain a network of stream flow sensors for communicating potential risk of flooding to the public. The state provides an annual budget of approximately $1.2 million, which is combined with significant funding from other federal and state agencies, to support the center's research and ongoing operations.

California has utilized bonds, a partnership with the USACE, and state investment to support its comprehensive regional and statewide planning process, as well as a floodplain mapping program. North Carolina responded to Hurricane Floyd in 1999 by allocating $25 million the following year to establish a floodplain mapping program. The state has since partnered with FEMA to become a Cooperating Technical State. In the first nine years of the program, North Carolina mapped 100 percent of watersheds, investing a total of about $70 million and receiving $73 million from FEMA. The state maintains this program via a transaction fee associated with the recording of deeds and mortgages.

In May 2018, Louisiana's Governor created a Council on Watershed Management to encourage interagency collaboration and the implementation a watershed-based floodplain management program. The resulting Louisiana Watershed Initiative serves to coordinate floodplain management and mitigation, including outreach, data management, policy development, technical assistance, and planning, across federal, state, and local entities. Using $1.2 billion in funding from HUD, the state will begin implementing a variety of activities for strong floodplain management (LWI, 2018).

5.3 Elements of sound planning

Natural resources planning represents an agreement among parties to identify the purpose, objectives, and paths to implementation (Fallding, 2008). The purpose of flood planning, generally speaking, is to manage flood risk in a fiscally viable way. However, flood planning conducted at any scale, whether at a project level or watershed level, is most successful when the objectives for managing risk are developed using the same standards, benchmarks, and quality data, and when solutions (or mitigation strategies) can be compared in the context of one another. Holistic or integrated watershed management, as exemplified by the San Antonio River Authority's basin-wide efforts to develop watershed

Texans' views for future flood planning

Stakeholders strongly favor a watershed-scale planning process for coordinating and guiding local efforts related to short-term and long-term flood planning, mitigation, and response (70 percent of responses).

Stakeholders noted a watershed-scale flood planning process should include opportunities to

- pro-actively identify and prioritize projects with the greatest ability to reduce flood risk;
- assess both upstream and downstream effects of projects to minimize adverse impacts and develop regionally based, multi-benefit solutions;
- develop consistent policies and guidelines for floodplain management within a watershed; and,
- evaluate the impact of future scenarios influenced by population growth and associated land use changes, plus variations in the frequency and duration of rainfall events.

A stakeholder from the El Paso workshop described future flood planning as "an effective tool to protect the well-being and property of Texans."

master plans that also promote flood risk management, offers an opportunity to evaluate whether a specific objective or solution may negatively impact flood risk for an upstream or downstream community and to consider potential impacts on water quality, erosion, water supply, etc. Although the TWDB does not conduct flood planning, beyond support of flood protection planning grants for communities, the TWDB does require grant awardees to work at the watershed-scale and engage all stakeholders. Additionally, the TWDB adheres to Texas Water Code §§ 17.774 and 17.776, requiring a determination that a requested project will have no upstream or downstream effect before awarding financial assistance.

Sound planning is based on a number of core elements. First, effective planning is based on quality data, robust models, and sound science coupled with a vetting process that is inclusive of all interested parties (stakeholders). Second, appropriately scaled planning areas must be established. Stakeholders within these areas must be encouraged to participate, to determine their vision for the future, and to set goals according to an established timeline. Third, empowered by sound data and a common vision, stakeholders need to consider acceptable levels of risk and use standardized benchmark(s) and protocols to consistently evaluate alternative strategies to reduce or eliminate risk within the planning area. If prioritization of strategies is a goal of the planning process, management outcomes must be quantifiable and use a common set of metrics. Further, the planning process must be adaptable—able to incorporate changes in population, data, models, project viability, and policies (TWDB, 2016). Finally, consistent support of any planning process is important to ensure that plans are updated and implemented according to stakeholder needs (Brody *et al.*, 2009).

What about regional water planning?

It is no surprise that the effectiveness of the statewide regional water supply planning process in Texas leads some to draw parallels between it and any potential statewide flood planning process. However, there are critical, fundamental differences in the purpose and goals of each effort.

Planning for water supply projects focuses on providing reliable water supply throughout extended periods of low rainfall. Thus, planning for drought-of-record conditions, by definition, does not consider or attempt to address flood risks. Flood risk assessment and mitigation planning aims to achieve an entirely different purpose—reducing or preventing loss of life and property during high precipitation events—using a set of parameters and technical analyses that are distinct from those used in water supply planning.

Flood planning activities are best conducted at the watershed or basin-scale. Whereas the geographic units for drought and water supply planning are based in part on river basins, they also consider aquifer delineations, water utility development patterns, political subdivision boundaries, and other factors not necessarily relevant for flood planning. Water supply planning, even across basins, has a degree of predictability in terms of available sources and target delivery location that typically does not exist when planning for flood events.

Flood planning requires different benchmarks, corresponding to high water levels created by, for example, the 1 percent annual chance flood event under present day or future build-out conditions. Flood planning also requires different datasets and models for evaluating potential risk reduction strategies. Groundwater and surface water availability models used in regional water planning are not applicable to evaluating the distribution and timing of flood events. For reasons such as these, the water supply and flood planning processes are distinct; hence, flood mitigation projects rarely appear in local water supply and wastewater infrastructure project lists.

Nonetheless, there may be benefits for both processes to at least consider strategies that simultaneously address water supply and flood risk reduction (*e.g.*, aquifer storage and recovery or variable reservoir flood pool capacity) or to evaluate proposed strategies in the context of hydrological extremes from drought to flood (*e.g.*, the siting of water supply or wastewater infrastructure). *Section 7.3* includes more discussion on the possible synergies between water supply and flood mitigation.

6. Flood mitigation in Texas

- **Flood mitigation, which is any activity undertaken to prevent or reduce the impacts of flood events, is needed and can be expensive.**
- **Flood mitigation is primarily a local activity that could benefit from greater state and regional coordination.**
- **Estimated from stakeholder input, an additional $18.0 to $26.6 billion is needed to complement existing funding for flood mitigation in Texas.**

Throughout the 20th century, the United States invested heavily in flood control infrastructure in response to devastating floods along major rivers across the nation. Between 1901 and 1991, 51 major reservoirs were constructed in Texas for flood control or with flood storage capacity (TWDB data). In addition, the Natural Resources Conservation Service (NRCS) constructed approximately 2,000 smaller reservoirs to also provide flood control throughout the state. Over time, the national approach to addressing reoccurring flood events and the hazards they pose to people, property, and the economy has evolved to encourage a wide-range of locally driven solutions. Flood mitigation involves any combination of actions taken to prevent flooding, reduce the likelihood of catastrophic flooding, or lessen the impact of flood events—and represents a third pillar of comprehensive flood risk management.

In Texas, mitigation activities have largely been implemented through funding from federal programs. With the exception of a long-standing commitment to funding Flood Protection Planning grants, the state historically only provided matching funds required to support the administration of several FEMA programs focused on flood mitigation grants, community assistance for the NFIP, and mapping assistance. However, in recent years Texas has greatly increased its support for flood risk management—first through funding made available to the TWDB from the Disaster Contingency Account No. 453 ($6.8 million in the 2016–2017 biennium) and then via funding from the Floodplain Management Account ($6.1 million) and general revenue ($1.7 million) during the 2018–2019 biennium. The TWDB anticipates current funding to continue and has requested an additional $4.45 million from the 86th Texas Legislature to expand the agency's flood science efforts to better prepare for and recover from flood events.

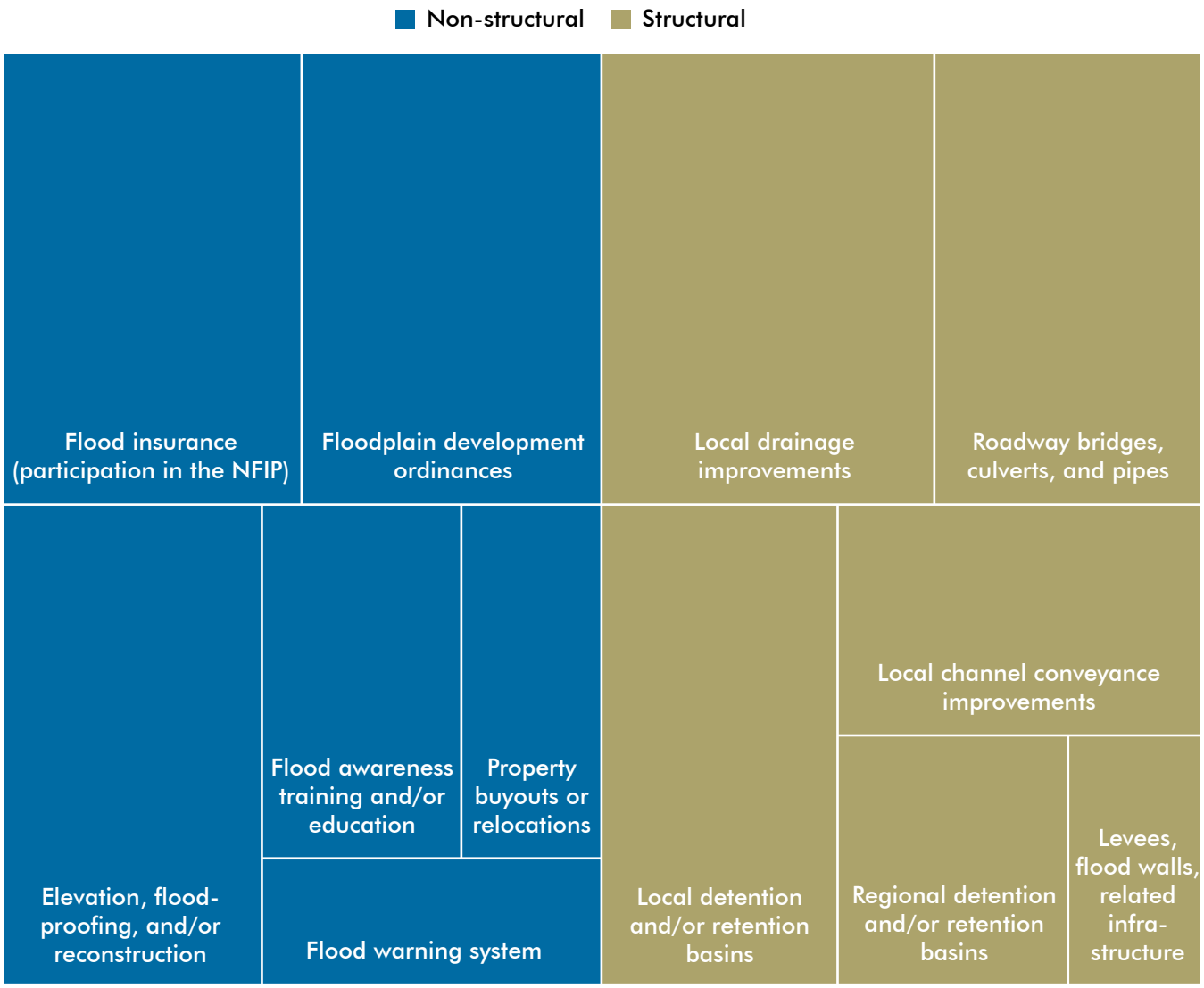
6.1 Types of flood mitigation activities

Flood mitigation activities fit into one of two broad categories: structural or non-structural. Structural activities typically involve placement of a new structure in or near a river channel or along the coastline to act as a physical barrier to water. The removal of those same types of physical barriers is also considered a structural activity. All other activities qualify as non-structural. In Texas, most communities employ some combination of both *(Figure 6.1)*.

Structural approaches may be further divided into major and minor activities. Major structural activities, also termed flood risk management infrastructure, include the construction of levees, dikes, floodwalls, dams, and other channel alterations to provide larger-scale flood benefits. These projects generally require more time and effort to complete due to regulatory requirements related to environmental protection, their multi-jurisdictional nature, and the project scale. Minor structural activities provide local-scale stormwater management benefits via grey and green infrastructure, such as culverts, gates, diversions, vegetation (including trees), and detention and retention basins, aimed at protecting critical facilities (water supply infrastructure, utilities, sanitary sewer systems, roads, and bridges) and other properties by retaining or diverting floodwater which accumulates during rain events.

A wide array of flood mitigation activities is considered non-structural: educational efforts that increase public awareness, professional training, or technical assistance related to flooding; creation of local flood hazard mitigation plans; installation of flood early warning systems; collection and analysis of geographic, hydrologic, and atmospheric data to identify flood risks or monitor conditions; restoration

Figure 6.1. Examples of mitigation activities implemented by stakeholders. Rectangle size corresponds to frequency of survey responses.



and conservation of wetlands, forests, and open space; and completion of local feasibility, design, and engineering studies.

Policy and regulation activities, also considered non-structural, include setbacks, building codes, zoning ordinances, subdivision rules, and special purpose ordinances. The state periodically adopts certain building codes related to scientific and safety standards for residential and industrial construction. Local governments may adopt amended versions of these codes to fit local needs. Zoning ordinances are enacted at the local level to regulate development and land-use in flood-prone areas.

Participation in the NFIP is a non-structural mitigation activity. In fact, the NFIP requires structures to be built "reasonably safe from flooding" (44 CFR 60.3) by either guiding development (*e.g.*, elevating structures or anchoring manufactured homes) or discouraging it in flood-prone areas (*e.g.*, through high insurance premiums or by designations of a floodway or special coastal zone). Floodproofing and property buyouts, including acquisitions and relocations, round out the list of non-structural activities to mitigate flood impacts.

Flood mitigation strategies considered by communities across Texas represent a wide variety of project types, from non-structural, lower cost strategies such

Stakeholders' Top 3: financial assistance for flood mitigation

Stakeholders identified financial assistance for implementation of structural and non-structural flood mitigation projects as the number one area for the state to invest resources.

as open land preservation and implementation of building codes to large-scale, higher cost infrastructure projects such as reservoirs and drainage improvements. Between 1996 and 2016, FEMA's Hazard Mitigation Assistance grant program invested $1.4 billion in support of 753 mitigation projects in Texas (Economist Intelligence Unit, 2018). This program includes post-disaster funding for Hazard Mitigation Grants, Pre-Disaster Mitigation (both administered by TDEM) and pre-disaster Flood Mitigation Assistance grants (administered by the TWDB). Projects included buyouts and elevation of structures (186 projects totaling $655.4 million), critical infrastructure and flood control (109 projects totaling $455 million), and mitigation planning (163 projects totaling $23 million). The program also funded several other types of projects ranging from early warning systems (34 projects totaling $4.7 million) and public awareness (23 projects totaling $6.4 million) to technical assistance at $438,000, among other activities (Economist Intelligence Unit, 2018). This represents only some of the activities that have been carried out in Texas.

6.2 Cost of mitigation

Flood mitigation is sometimes necessary and often expensive. The details and nuances related to implementation also may be as complex as the funding mechanisms that make implementation possible. For this report, the TWDB assessed the financial resources, both existing and unavailable, that communities need to implement a variety of activities to reduce flood risk.

Analysis of the cost for project mitigation and the availability of local funding for this section is derived exclusively from information provided by stakeholders through financial survey questions, which generally represent a 10-year planning horizon. As such, the financial analysis does not include long-term cost or funding need projections for the state, does not yield a list of ready-to-implement flood mitigation strategies, and involves estimates with certain limitations (discussed in Chapter 8). However, the analysis provides insight into the overall anticipated costs for mitigating flood risks and the statewide funding shortfall, which prevents the implementation of strategies. We did this by accounting for the availability of local funds and non-local (state and federal) financial programs. For details of the methodology, see Appendix A, posted online at www.TexasFloodAssessment.com.

Estimating financial need for flood mitigation

Financial information to estimate costs for flood mitigation activities comes from two sources:

(1) Reported estimates of mitigation costs and available funding based on survey responses representing 60 percent of the state's population, and

(2) A statistical analysis developed to estimate costs and available funding for the remaining 40 percent of the population not represented by survey responses.

More details are available in Appendix A at www.TexasFloodAssessment.com, but the basic methodology is as follows:

Flood Funding Shortfall
= *Anticipated Costs – Available Local Funds – Available Non-Local Funds*

6.2.1 Anticipated mitigation costs

Anticipated statewide mitigation costs, $31.5 to $36.0 billion

Based on the mitigation needs reported by survey respondents, the estimated total statewide cost for future flood mitigation ranges between $31.5 and $36.0 billion *(Table 6.1)*. This range comes from the amount reported by communities that responded to the survey, totaling about $23.4 billion, combined with a range of $8.1 billion to $12.6 billion as estimated from a statistical analysis to capture the costs associated with mitigation needs for the communities not represented by survey responses (the non-responding communities).

The TWDB compared this estimate of anticipated mitigation costs for Texas to the flood funding needs identified by California and found figures to be comparable. California has a stated need of $32 to $52 billion to implement projects identified in its current planning cycle, including $6 billion in flood management projects recommended by the USACE (CDWR, 2013). Because the methods of this assessment are based solely on responses from the two stakeholder surveys, we did not factor in cost estimates for very large federal projects or costs identified by the state for rehabilitating high hazard dams, estimates that combined would add another $14 billion to the state's mitigation needs. We also recognize that the methods used in this assessment, as well as the mitigation activities needed to reduce flood risks, differ between California and Texas.

6.2.2 Available mitigation funding

Locally available funding, $7.1 to $8.2 billion

The amount of local funding communities may have available to contribute to flood mitigation activities ranges from $7.1 to $8.2 billion. We base this estimate on information provided by respondents, as well as the statistical estimates of available funding for the non-responding communities. Specifically, survey respondents in cities and counties reported having about $4.8 billion in local funds to implement flood mitigation activities, based on their historical and anticipated availability of local funds.

Available non-local funding, $2.3 to $5.3 billion

We estimate the total funding available from existing state and federal financial assistance programs to range from a low of $2.3 billion to as much as $5.3 billion over a 10-year period. Of the potential $5.3 billion of assistance available, approximately $2.3 billion is estimated to be in the form of grants, generally requiring some degree of local cost-share. The remaining $3.0 billion is in the form of loans

Cost of recovery versus mitigation

Since the focus of this assessment is mitigation of future flood events, the TWDB has not considered costs related to disaster recovery. Given the extent of devastation from Hurricane Harvey in 2017, the costs of recovery from this event alone are staggering. In October 2017, Governor Abbott's Rebuild Texas Commission requested $61 billion in federal appropriations above current federal expenditures for rebuilding public infrastructure damaged or destroyed by Hurricane Harvey and for projects designed to mitigate the impact of future storms on the Texas Gulf Coast. Congress responded to this request with a significant amount of federal funding in the Bipartisan Budget Act of 2018, which included $90 billion in disaster aid for Texas, Florida, and Puerto Rico. Thus far, Texas has received significant funding for Harvey recovery activities, including:

- The U.S. Army Corps of Engineers Civil Works Long-Term Disaster Recovery Investment Program received $4.9 billion for five ongoing construction projects and five new-start construction projects in Texas, along with $15.1 million for five studies.
- As administered by the Texas Department of Public Safety, FEMA will provide an estimated $1 billion for hazard and flood mitigation projects through the Hazard Mitigation Grant Program.
- The Texas General Land Office is administering $5.024 billion in Community Development Block Grant–Disaster Recovery funds provided through the Department of Housing and Urban Development for Hurricane Harvey recovery.

Stakeholders need to implement a variety of mitigation activities

Stakeholders indicated that the majority of funds spent in the last 10 years went to local drainage infrastructure. Roadway crossings, regional detention or retention basins, and property buyouts also represent a large component of local spending.

Looking ahead, stakeholders indicated a need for more funding to support implementation of local drainage improvements, local and regional detention and retention basins, improvements to bridges/culverts/pipes and channel conveyance, as well as non-structural solutions such as buyouts, warning systems, and educational programs.

from the TWDB with interest rates either considerably below market levels or reflecting the state's low cost of funds.

Given that flood mitigation projects do not generate revenue, repayment of these loans likely would require local fees or ad valorem taxes. Estimating the available funding for existing financial programs is difficult, due in part to the fact that some federal funds are available only following a presidentially declared disaster. These estimates are further complicated as we must assume continued availability at the current and historical rates of funding; speculate on the timing and allocation of federal appropriations; and anticipate policy and funding choices made on behalf of local, state, and federal programs. Limitations of the existing programs considered for this analysis are discussed in *Section 6.3*, *Funding sources;* a summary of these programs and the range of funding availability is provided in Appendix A at www.TexasFloodAssessment.com.

6.2.3 Mitigation funding shortfall

Statewide flood funding shortfall, $18.0 to $26.6 billion

After determining the statewide anticipated cost for mitigation and factoring in both local and non-local funds that are potentially available to offset this cost,

Table 6.1 Summary of statewide flood funding needs (in $billions), estimated using information on anticipated mitigation costs and local funding availability as provided by stakeholders via financial survey questions and information on available non-local funding from existing state and federal financial programs.

	Range (in $billions)
Anticipated mitigation costs	$31.5 – $36.0
Available local funds	$7.1 – $8.2
Available non-local funds	$2.3 – $5.3
Statewide flood funding shortfall	**$18.0 – $26.6**

Stakeholder preferences for types of non-local funding

Survey respondents describe needing anywhere from 0 to 100 percent of project costs covered by outside financial assistance. Small communities and regions that are primarily rural indicated the highest need for non-local funding.

When asked what types of financial assistance stakeholders might pursue, the most preferred choices were either a 90/10 cost-share program (90 percent non-local contribution/10 percent local match) or a 75/25 cost-share program. Less popular but of equal interest to about 20 percent of respondents are programs with either a 50/50 cost-share or a zero percent interest loan. Few stakeholders opted for assistance via market rate loans, subsidized loans, or state participation in projects. Nearly 40 percent of respondents did not know what mechanism to choose.

the TWDB estimates the statewide flood funding shortfall ranges from approximately $18.0 to $26.6 billion. The lower value of $18.0 billion accounts for access to the highest amount of available local and non-local funding, while the upper value of $26.6 billion accounts for access to the least amount of available local and non-local funding.

6.3 Funding sources

Communities across the state use a variety of funding sources, from local funding to state and federal financial assistance to implement flood risk mapping and flood mitigation, planning, and protection activities. However, the types and availability of funding vary widely. Though not exhaustive, this section describes common financial programs and sources of funding available to communities.

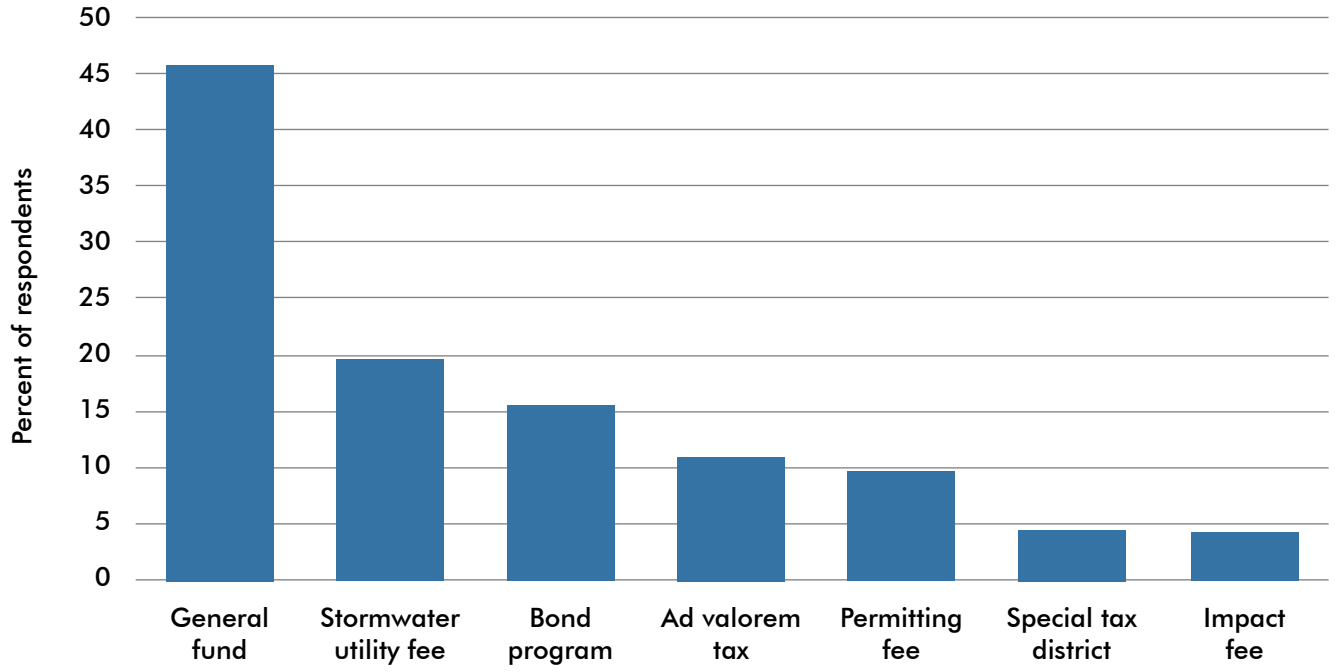
6.3.1 Local funding

Stakeholders identified the top three sources of local funding used in their communities to be general funds, stormwater utility fees, and bonds *(Figure 6.2)*. Below we describe the most common local revenue sources used for flood management activities.

General fund: General fund revenue is largely from property, sales, and other taxes, which provides a substantial amount of money. Though this is the primary source of funds, as reported by stakeholders, often it is not enough to adequately cover flood management activities in addition to all other municipal programs. Special tax districts are sometimes used to tax only the portion of the population that will benefit from a specific project. Our survey, however, indicates that only a few communities in Texas have implemented such tax districts for flood mitigation.

Stormwater utility fees: Over the past several decades, the stormwater utility model has increasingly been used as a tool to raise local funding for stormwater management both in Texas and the country. Creation of a stormwater utility allows a municipality to have a dedicated revenue stream for stormwater management that is directly based on how much a property contributes to stormwater runoff. Survey respondents reported this is the second highest source of funding for flood management activities in their community. An annual survey conducted by Western Kentucky University identified more than 1,600 stormwater utilities in the country and at least 114 in Texas. Of the 40 cities in Texas with populations greater than 100,000, 31 have a stormwater utility. The statewide average stormwater fee is $4.28 per month (Campbell, 2018; U.S. Census Bureau, 2018).

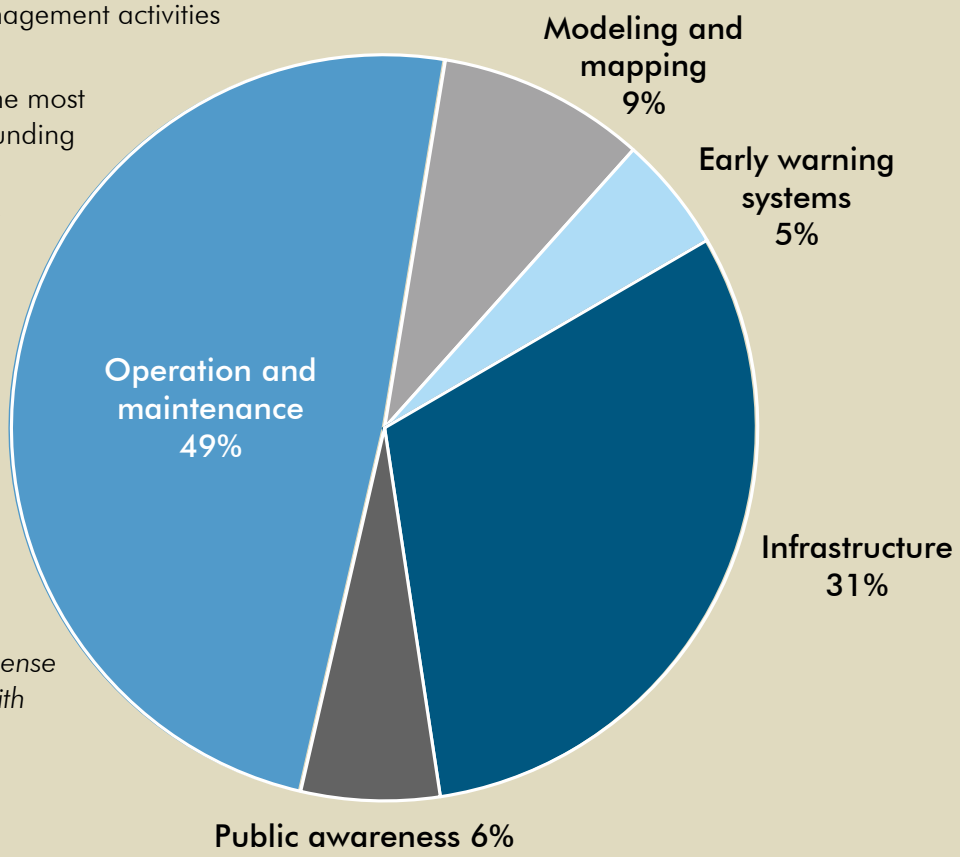
Figure 6.2 Sources of local funding used to support flood management activities as identified by survey responses (percent of respondents). In addition, 24 percent or respondents stated they had no local funding source dedicated to such activities.



Facts about local funding for flood management activities

- 24 percent of respondents said their community does not fund flood management activities with local funding.
- Rural communities are the most likely to not have local funding for these activities.
- 17 percent did not know if their community uses local funding for such activities.
- On a per capita basis, large cities spend more than twice as much as small cities on flood mitigation activities.

Displayed to the right are expense categories for communities with budgets allocated to flood management activities.



Bonds: Survey respondents selected bonds as the third most often used funding source. Communities typically use either stormwater revenue bonds or general obligation bonds for this type of funding. Bonds can fund various activities, such as home buyouts, upgraded early warning systems, and infrastructure repairs.

Ad valorem taxes and other fees: Though less frequently a source of funding, some survey respondents report using impact fees, permitting fees, or *ad valorem* taxes, respectively, to fund activities. For example, communities can fund their floodplain management program through floodplain development permitting fees. Impact fees are sometimes assessed as a one-time payment for new developments to offset their anticipated impact to the community. Another program is a *fee-in-lieu* in which developers pay a fee to the community rather than building a site-specific stormwater mitigation project in their development.

6.3.2 State and federal funding

Financial assistance programs are categorized as state or federal based on the original source of funds. Many federal programs are administered at the state level and may have a state contribution, but herein they are presented as federal programs. Estimates for available state and federal funding for mitigation projects in Texas range widely, from about $2.3 billion to just over $5.3 billion, and involve inherent uncertainty, as described in *Section 6.2.2, Available mitigation funding*. These resources are geared toward planning for and implementing mitigation activities, and few provide opportunities to fund mapping efforts or planning beyond the project level. Appendix A, available at www.TexasFloodAssessment.com, contains a summary of existing programs with the associated projected available funding. A number of these financial assistance options, however, are not fully

utilized. Hence, we briefly discuss some of the factors limiting access to and use of the relevant programs.

State programs

State programs generally have fewer requirements than federal programs. However, state programs that can finance flood mitigation generally only offer smaller amounts of grant funding or no substantial reduction in the interest rate on loans. This results in a high demand for grant programs and a low demand for loan programs to finance flood mitigation activities. Workshop participants underscored this point by noting that more state financial resources with substantial subsidies would serve to benefit implementation of flood mitigation projects.

The TWDB's *Flood Protection Grants* program, for example, funds detailed studies of floodplains, among other activities. The program, funded via the Floodplain Management Account, is frequently oversubscribed, meaning that there is more demand than available funding. In 2016, the TWDB received 41 applications requesting funding of $7.26 million, though there was only $3.5 million in grant assistance available. In 2018, 38 applications requesting $5.6 million in assistance were submitted, but only $1.8 million was available.

The *Texas Water Development Fund* (DFund), also administered by the TWDB, has funding available through the agency's existing $6 billion evergreen general obligation bonding authority. But since the program offers a subsidy only in the form of a credit benefit, which may not be of value to many higher rated borrowers, it is typically not an attractive option for flood mitigation projects. DFund has funded only two flood-related projects within the last 10 years.

The *State Water Implementation Fund for Texas* (SWIFT) program[1], the state's most prominent financial assistance program for water projects, is designed for and restricted to addressing water supply strategies. Though some synergies with flood mitigation may exist (see *Section 7.3, Synergies with existing programs*), state water plan projects typically do not include components that address flood mitigation, and no flood-related projects have been funded through the SWIFT program to date. Furthermore, opportunities for loan forgiveness or grants under this program are expressly prohibited in statute (Texas Water Code § 15.435).

Federal programs

Federal programs related to flood mitigation and mapping typically offer much greater financial assistance than is available at the local or state level, but the funding often has many limitations. Funding is typically restricted to post-disaster projects located in federally declared disaster areas. For programs and projects not tied to disaster, Texas competes with other states such as for Cooperating Technical Partners funding for mapping activities. In some cases, flood-related projects also compete with other types of projects. Federal funding through the Clean Water State Revolving Fund (CWSRF), administered by the TWDB, can fund flood-related (pre-disaster) mitigation projects, but applicants must compete with wastewater and water supply projects. However, following Hurricane Harvey, the TWDB set aside funds in the CWSRF, as well as in the Drinking Water State Revolving Fund, to provide post-disaster funding options to communities for projects related to water supply, wastewater, or stormwater management facilities for disaster recovery and other urgent need situations.

Federal programs also have complicated and extensive application and reporting requirements, coupled with a high degree of uncertainty in both the timing and distribution of funds. These factors make applying for funding and complying with associated requirements challenging for communities, particularly for those that cannot support staff or contractors dedicated to these tasks.

Funding provided by the Floodplain Management Account

In each state fiscal year, the first $3.05 million of maintenance taxes imposed on authorized insurers and deposited into the general revenue fund are reallocated to the Floodplain Management Account, administered by the TWDB (Texas Insurance Code § 251.004). This funding supports grants, data collection, stream gaging, and outreach efforts.

[1] *The SWIFT program includes two funds, the State Water Implementation Fund for Texas (SWIFT) and the State Water Implementation Revenue Fund for Texas (SWIRFT). Revenue bonds for the program are issued through SWIRFT.*

7. Roles and other considerations

Floodplain management encompasses a broad spectrum of challenging issues and, as is true of any interdisciplinary topic, requires a diverse group of individuals working collaboratively toward a common goal. Whether before, during, or after a flood event, a complex web of local, state, and federal entities contributes resources—time, staff, data, funding—in an effort to address flooding impacts to lives and property. This chapter summarizes those entities with responsibility for mitigation in Texas and discusses barriers to floodplain management, as well as potential synergies with water supply.

- **Responsibilities for floodplain management and mitigation lie with local decision makers.**
- **A diverse group of local, state, and federal entities play a role in the collective effort to mitigate flooding.**
- **Stakeholders cite lack of financial assistance as the biggest barrier to undertaking floodplain management activities at the local level.**

7.1 Responsibilities for flood mitigation

The responsibility of preparing for and mitigating flooding in Texas lies with local decision makers. Texas Water Code § 16.315 lists actions that political subdivisions of the state of Texas are authorized to take related to the NFIP. For example, each participating community must designate a floodplain administrator (often called a floodplain manager) who must understand, interpret, and explain local floodplain management regulations and review them for compliance. Specific to floodplain management (Texas Water Code § 16.315), communities in Texas also may

- apply for grants and financing to support mitigation activities,
- collect reasonable fees to cover the cost of administering floodplain management activities,
- use regional or watershed approaches to improve floodplain management, and
- cooperate with the state to assess the adequacy of local structural and non-structural mitigation activities.

In reality, however, a diverse group of local communities, regional groups, and state and federal entities plays a role in the collective effort to reduce flood impacts. In Texas, federal, state, and regional entities have some flood-related role—in addition to the local communities on the frontline *(Table 7.1)*. Overlapping jurisdictions based on political rather than watershed boundaries and differing missions among the various entities create a multi-layered, complex environment, which sometimes leads to unclear responsibilities and uncoordinated efforts.

Table 7.1 Select entities with flood-related responsibilities. (Special purpose districts include river authorities, soil and water conservation districts, water control and improvement districts, flood control and improvement districts, municipal utility districts, and levee improvement districts.) The Texas Water Development Board also represents the responsibilities related to the Texas Natural Resources Information System.

		Stream gaging	Weather forecasting	Flood insurance rate mapping	Flood inundation mapping	National Flood Insurance Program floodplain regulation enforcement	Hazard mitigation planning	Emergency operations planning (State and Local)	Dam/reservoir ownership and management	Levee ownership and management	Stormwater and drainage management
Local	City governments	P		S	S	P	P	P	P	P	P
	County governments	P		S	S	P	P	P	P	P	P
	Special purpose districts	P		S	S	P	P	S	P	P	P
	Councils of government	S		S	S		P	S			S
State	Texas Commission on Environmental Quality						S	S	S	S	S
	Texas Department of Transportation	S					S	S			P
	Texas Division of Emergency Management				P		P	P			
	Texas General Land Office						S	S			
	Texas State Soil & Water Conservation Board						S	S	S		
	Texas Water Development Board	P		S	P	S	S	S			
Federal	Federal Emergency Management Agency			P	P	S	S	S			
	National Weather Service	P	P	S	P		S	S			
	U.S. Army Corps of Engineers	S		S	P		S	S	P	P	P
	Natural Resources Conservation Service						S		S	S	
	U.S. Geological Survey	P		S	P		S				

P = Primary role; in charge or takes the lead

S = Secondary role; provides data or technical support or has regulatory responsibility

= Entities take on responsibility

= Some, but not all, entities take on responsibility

Stakeholders call for increased collaboration and coordination

Stakeholders called for increased collaboration and coordination between jurisdictions responsible for flood mitigation. Sixty percent of respondents noted that they work with other entities in their region to address flood risk; an additional 17 percent believe they would benefit from coordinated efforts.

State agencies serve as intermediaries between local and federal partners, facilitating cooperation, administering federal programs and grant dollars to local communities, and offering technical assistance for certain floodplain management activities. The TWDB houses the State Coordinator's Office for the NFIP in Texas; is responsible for aiding, advising, and coordinating the efforts of local communities wishing to participate in the program; and is responsible for administering the following FEMA programs (44 CFR § 60.25; Texas Water Code § 16.316):

Community Assistance Program-State Support Services Element provides technical assistance, floodplain management education, assistance meeting NFIP compliance requirements, and post-disaster assistance—all to encourage floodplain management expertise and capability in Texas communities.

Cooperating Technical Partners Program enhances collaboration between communities, FEMA, and other local partners in efforts toward creating or updating their FIRMs.

Flood Mitigation Assistance Grant Program provides planning grants to communities to develop or update the flood hazard component of a jurisdiction's Multi-Hazard Mitigation Plan and project grants for mitigation through localized flood risk reduction projects or the acquisition (buyout), relocation, floodproofing, or elevation of structures insured under the NFIP.

The TWDB also has authority to evaluate floodplain management activities and flood control programs within the state; to study the adequacy of existing public and private measures, laws, regulations, and ordinances in flood-prone areas; to evaluate available engineering, hydrologic, and geologic data; and to conduct and make available floodplain studies and mapping (Texas Water Code § 16.316). These authorities are consistent with the agency's Flood Protection Grants program and with more recent initiatives supported by funding from the Office of the Governor and the Floodplain Management Account to enhance flood notification systems and support floodplain management planning. Requests from stakeholders to have access to more technical support and updated flood hazard mapping align with these capacities.

Certain types of mitigation activities, such as the construction and ongoing maintenance of dams and levees, dictate specific responsibilities. Texas has 37 federal dams owned by either the USACE, the International Boundary and Water Commission, or the U.S. Bureau of Reclamation.

Non-federal dams are owned and maintained by the state, counties, cities, water districts (including soil and water conservation districts or water control and improvement districts), river authorities, private organizations, or individuals. The Texas Commission on Environmental Quality (TCEQ) sets regulatory safety standards for and is charged with inspection of more than 7,000 non-federal dams in Texas, including 2,000 built by the NRCS. Approximately 60 percent of the non-federal dams are privately owned and maintained.

Per Texas Water Code, Chapter 57, local levee improvement districts may construct and maintain levees near rivers, creeks, and streams; provide for drainage and improvements to lands reclaimed from overflows; and straighten or improve rivers to control water. Municipal utility districts also have similar authority for the control and drainage management of excess floodwater (Texas Water Code, Chapter 54). The TCEQ is authorized to inspect levees under construction, but there is currently no state funding or staff dedicated to a levee safety/inspection program. An effort underway by the USACE seeks to develop a complete inventory of levees as the first step toward certification of levees constructed to provide flood protection.

Stormwater and drainage-related mitigation activities are carried out individually or collaboratively by local entities such as cities, counties, river authorities, municipal utility districts, drainage districts, stormwater control districts, and flood control districts across the state. The U.S. Environmental Protection Agency's Municipal Separate Storm Sewer System (MS4) regulations require certain owners or operators of municipal separate storm sewer systems to acquire permits to discharge stormwater into surface waters of the state. Though primarily related to water quality, certain flood protection benefits do exist. Presently, Texas does not have statewide standards to

guide mitigation of local drainage issues; thus, adopted criteria for local drainage standards vary across communities, even within the same watershed.

In a few cases, communities are moving toward an integrative approach that factors in hydrology, hydraulics, water quality, and open land areas at the watershed scale to collectively address drainage issues. The North Central Texas Council of Governments developed a voluntary, 16-county watershed management initiative with *"a goal to allow for sound development through regional consistency; to recognize cost savings associated with the investment in effective watershed management to reduce or prevent flooding; to slow water quality decline; and to avoid loss of opportunity that is a result of rapid growth"* (NCTCOG, 2017).

Stakeholders cited a range of limitations preventing communities from identifying risks or solutions. Listed in order of relative importance, they are

- a lack of financial resources to conduct studies, update flood maps, hire staff, and develop expert local knowledge for proper floodplain management and decision making;
- the prolonged timeframe and complex process for implementing projects;
- a lack of public interest, competing local priorities, lack of coordination and cooperation within a local area, lack of community leadership to implement projects; and,
- a lack of broad authority to enforce regulations.

7.2 Barriers to implementation

Stakeholders reported that financial assistance is the most essential resource needed by their communities to implement floodplain mapping, mitigation, and management activities. Next to this, the biggest barriers communities face include navigating available funding options and associated application processes and protecting communities while waiting through the drawn-out timelines for receiving funds or completing projects. If left unresolved, these barriers can prevent communities from successfully implementing floodplain management activities, even if new funding becomes available.

Local share funds. The local share requirement for state and federal financial assistance creates a deterrent for communities that do not have access to a local funding source. Survey respondents indicated needing non-local (outside) funding to cover up to 100 percent of total cost for flood mitigation activities, including structural projects, mapping, early warning, and public awareness activities. Only one in five floodplain administrators stated that their community has a revenue stream to accumulate funds for the local share requirements of grant programs or to repay loans provided by the state. Responses from urban areas and larger cities reported having slightly better access to a local revenue stream (greater than one in four respondents); whereas, county-level and small communities reported having substantially less access.

Confusing funding options. Public awareness of the range of funding programs is limited. Currently five state agencies and five federal agencies share responsibilities for administering 16 funding programs. Communities seeking financial assistance must self-navigate through these disparate options to determine which program best addresses their specific needs, minimizes strain on local resources, facilitates project implementation, and ultimately provides the best overall value. Further, eligibility criteria differ among the various programs, which split funding into multiple categories—each with their own qualifications, schedules, and application process.

Complicated application processes. Stakeholders communicated that the process of applying for and obtaining federal assistance is prolonged, complicated, and confusing. Stakeholders also expressed a desire for a simplified, faster funding application process, which may be easier to achieve for state financial assistance programs. Small communities often cannot afford a dedicated floodplain administrator position and therefore may lack the staff resources to submit grant applications. As a result, 42 percent of stakeholders requested that the state provide additional technical training and guidance in navigating the complex deadlines, requirements, and paperwork associated with both state and federal funding programs. Currently, both TDEM and the

TWDB offer technical assistance as part of their administration of FEMA grant funding, and FEMA provides online and in-person trainings related specifically to grants administration.

Stakeholders identified education, training, and technical assistance as a top priority for state level action. Their responses characterize a wide gap made up of a lack of financial resources and access to training, which contributes to an ongoing lack of basic knowledge of floodplain management principles, a misunderstanding of flood risk, and difficulty successfully applying for and managing grants.

Lack of staffing. Stakeholders expressed that insufficient staffing at all levels of government slows down the flood mitigation process. Chokepoints exist at every step of project timelines, which can exacerbate this issue. While administratively burdensome for FEMA and state agencies, communities bear the greatest burden as the lack of adequate and timely mitigation can have real-world consequences. Understaffing—and its consequences—becomes especially acute during disaster events when resources are diverted to emergency response. Specific types of stakeholder requests, beyond the above-mentioned need for assistance in navigating financial programs and application processes, included the need for access to state engineers and surveyors to provide project-specific technical guidance and planning assistance. Small communities prefer this option over contracting out for these services.

Lack of training. No state-level requirement exists for training or certifying floodplain administrators or others with flood-related responsibilities. However, more than 2,000 Texans are professionally certified floodplain managers (CFMs) through the Texas chapter of the Association of State Floodplain Managers, known at the Texas Floodplain Management Association. Accessibility to professional development appears to be easier and more affordable for floodplain administrators in more populated or urban areas. Respondents from small communities report difficulty in attending classes because of a lack in staff availability, travel funding, or related resource constraints. In general, stakeholders requested increased availability of low-cost or free training. Stakeholders also suggested including floodplain management topics as part of the routine training required of state and local officials with job duties related to emergency management within their first 180 days in office (per Texas Government Code, Chapter 418).

Prolonged timelines. Project timelines for flood mitigation grant programs can take anywhere from months to years from the start of an application to the start of construction or project implementation (if non-structural). A range of factors, particularly the source of funding and required amount of documentation and authorization, determines the length of these timelines. The more complex the processes, the lengthier the application review and disbursement period. Stakeholders expressed frustration with this aspect of project implementation, requesting more streamlined processes and increased transparency.

Patience is key to implementing a federally funded project. The application review and approval process can take up to one year. Once approved, project implementation may be further delayed for a variety of reasons, including weather conditions or even unanticipated changes in funding allocations. For structural activities, projects may require extensive permits for environmental protection, historic preservation, and related land use development. If a community does not have sufficient in-house staff to navigate these disparate permitting requirements, it may be forced to hire an outside consultant and that procurement process can add months to an already lengthy process.

State-funded programs typically have fewer requirements. For example, Flood Protection Grants administered by the TWDB have a relatively fast path to funding. Aside from requiring assurances that the principal applicant has the authority to plan and implement projects and that the proposed project does not duplicate existing projects, these state funds do not require federal coordination nor approval (beyond existing requirements such as those related to wetlands permitting). However, these funds are limited and are only offered once a biennium.

Similarly, the federal timeline for creating or updating FIRMs through the FEMA adoption process requires years of participation and patience by communities. But as observed in this assessment, opportunities exist for

Tom Miller Dam, near Austin, opens the flood gates during flooding in 2018.

the state to enhance flood hazard mapping for the benefit of floodplain management, mitigation, and emergency response.

7.3 Synergies with water supply

Despite recent interest in managing floodwaters to augment water supplies, particularly in water scarce areas, it is not easy to achieve such synergies. The type and scope of activities involved in planning for floods can vary significantly from those designed for drought preparedness. Droughts may begin slowly and develop over an extended time period; whereas, floods are sudden, sometimes violent, events. Despite this, opportunities may exist to simultaneously increase flood protection for communities while providing additional water supply.

During times of flooding, the goal is to safely retain or divert excess water away from communities. During drought, the goal is to provide communities with reliable water supplies, which often requires storing water during times of plenty for later use. Despite these two distinct goals, projects that can meet both flood protection and water supply objectives range the spectrum from very large, such as reservoirs or aquifer storage and recovery facilities, to relatively small, such as low-impact development practices. For large projects, such as water supply reservoirs, it may be difficult or impossible to repurpose their use, thus limiting the potential for beneficial synergies with flood control post-construction. Once residential areas develop around a reservoir, it may be impossible to expand flood storage capacity. Likewise, considerations for changing reservoir operations to allow for seasonally adjustable flood and conservation pool elevations are complex and require extensive study by operators to weigh potential risks of either diminishing water supply or aggravating downstream flooding in the case of prereleases from storage. Whether undertaken during project design or post-construction, balancing flood protection and water supply objectives for big projects requires careful study of the physiographic setting of the project. Even for large projects, improvements in secondary objectives while meeting primary objectives can be modest. For example, reallocation of flood storage within Lake Texoma added only 103,003 acre-feet per year to water supplies—less than 3 percent of the total volume of the reservoir (Brougher and Carter, 2012).

At the other end of the spatial scale, small actions, such as adoption of low-impact development practices, can reduce excess runoff during storm events, and when stored may increase water supplies or reduce water demands later. Examples of low-impact development practices include rooftop rainwater capture, v-cuts in curbs to allow stormwater to drain to landscaped areas, and permeable pavements that allow infiltration to aquifers. Though individual projects may be small, cumulative effects can be significant. Garrison and others (2014) estimated such green infrastructure projects could provide an additional 420,000 to 630,000 acre-feet per year to water supplies in the state of California. The Texas Section of the American Society of Civil Engineers recommends considering these types of practices and related alternative flood mitigation strategies in their recently released report on flood risk (TexASCE, 2018).

8. Preliminary findings and stakeholder priorities

For this statewide flood assessment, the TWDB surveyed floodplain administrators and many other stakeholders to better understand local flooding issues, strategies for mitigating flood risk, and the financial resources allocated at all levels of government toward the common goal of protecting lives and property. Through online surveys, workshops, and related meetings, we also asked for input on the future of flood planning. The preliminary findings and stakeholder priorities provided herein reflect the sentiments of the majority of the more than 1,000 Texans who contributed their time to this effort.

8.1 Preliminary findings

Stakeholder feedback and information gathered throughout the development of this report suggest broad consensus around a number of key points.

- **Flooding is a fact of life in Texas:** Texas experiences some of the most severe flooding impacts in the U.S., yet critical data sets and public awareness are lacking.
- **Outdated maps:** Smaller communities tend to either have outdated flood hazard maps or no maps at all, and they often lack the data and models needed to create or update the maps for use in floodplain management, planning, and emergency response.
- **Local drainage issues:** Stormwater flooding was identified as a top concern among stakeholders from every corner of the state, but risk of this type of flooding is not displayed on FIRMs. The statewide risk from stormwater flooding remains undetermined.
- **Varying mitigation needs:** Communities across the state experience different types of flooding that require different mitigation strategies. Communities also are in different stages of need or preparedness—some have completed local mapping and planning efforts to inform their mitigation needs while others reported struggling with how to get started.
- **Need for collaboration and coordinated planning:** A web of independent federal, state, and local agencies and jurisdictions are involved in floodplain management. Coordination and collaboration are needed to avoid redundancies, simplify administrative processes, and increase the effectiveness of ongoing and future flood mitigation efforts.
- **Fiscal concerns:** Two common impediments to more effective flood planning and project implementation are meeting local cost-share requirements and lack of a consistent revenue stream to pay off loans.
- **Lack of access to trained professionals:** Floodplain management and understanding of flood risk in Texas are hindered by a lack of training at all levels.

- **Texas stakeholders most strongly recommended that the state**
  - **provide funding for flood mitigation activities,**
  - **improve flood risk mapping,**
  - **encourage watershed-based flood planning, and**
  - **expand education outreach and technical assistance.**
- **Failure to act continues to expose Texans to significant levels of flood risk.**

Stakeholder feedback reveals that communities experience financial limitations in hiring and training local floodplain administrators; need greater access to technical experts with knowledge of financial programs, application processes, and science and engineering; and desire better understanding of flood risk and floodplain management principles among state and local officials.

8.2 Limitations and uncertainties in estimating costs

Limitation 1: Texas has no central repository of planned or implemented flood mitigation projects or activities. Without an existing statewide catalog, this assessment relied primarily upon two stakeholder surveys. Medium and large cities and special districts created for flood management purposes

typically have robust plans to address local and regional flood and drainage issues. Cost data collected from these entities is considered reasonably reliable. Smaller communities, in contrast, typically lack plans and do not have the resources required to produce them. Cost estimates for mitigation activities in these communities are considered less reliable because they may not have been associated with detailed planning or feasibility studies.

Limitation 2: Sole reliance on voluntary survey responses weakens the source data for estimating financial needs. Voluntary surveys tend to oversample the people who feel strongly about a subject and under-sample the people who have less interest or opportunity to respond. While our surveys have good geographic coverage and represent needs for over half the state's population, not every community was willing or able to participate. In total, Survey 1 gathered responses from 34 percent of communities in the state. Survey 2 captured only a small subset of those responding to the first survey, and thus represents 11 percent of communities in the state.

Limitation 3: Lack of comprehensive, up-to-date maps and information to aid communities in their planning efforts. Without adequate maps, models, data, and information, communities struggle to address flood issues. Without planning efforts and identified solutions, many communities are unable to accurately estimate flood mitigation funding needs. Without a thorough understanding of exactly how much of the state is in need of mapping (whether based on age of FIRM, unmapped stream miles, or watershed-scale studies), it is difficult to estimate mapping costs.

Limitation 4: Lack of a standard benchmark for flood planning and mitigation. Flooding is generally regarded as an event that causes property damage or loss of life, but communities experience different types of flooding that require different mitigation strategies. Yet, there is no standard to which all communities in Texas base their management efforts, which represents another difficulty in estimating costs. Unlike regional water planning groups, which develop water management strategies to meet future needs during a repeat of the drought-of-record (the benchmark) and use a standardized cost analysis methodology to ensure consistency, mitigation costs provided by stakeholders for this assessment may be over- or under-estimated depending on a community's circumstances.

Limitation 5: Lack of framework for statewide planning. Texas has never undertaken statewide planning for flood, and myriad options exist for how to do so. Additionally, the timeframe for developing a planning process has yet to be determined. The high level of uncertainty surrounding future flood planning efforts—from timeframe, to scale, to structure—and lack of precedent in this realm make estimating costs for any planning effort imprecise.

In our analysis, the TWDB took a variety of steps to minimize the impact of these limitations. We present financial estimates for mitigation as ranges to reflect statistical confidence intervals and to convey the uncertainty in both the source data and statewide totals as extrapolated. Limitations from survey results were addressed with quality assurance and control measures, including follow-up calls to verify responses and a statistical analysis of survey results to qualify confidence in statewide estimates. These uncertainties must be kept in mind when considering the cost estimates presented in this assessment.

8.3 Stakeholder priorities

Outreach across the state in March and April of 2018 provided valuable qualitative and quantitative data on the status of flood risk, floodplain management, and flood mitigation in Texas. After reviewing all responses, the following stakeholder priorities emerged. These priorities reflect input received from stakeholders, not necessarily the opinions of the TWDB.

1 - Provide financial assistance for flood mitigation: Stakeholders resoundingly identified access to more financial assistance as the most important factor to meeting flood hazard mitigation goals. Access is limited primarily by (1) the availability of non-local funds, (2) the difficulties associated with securing those funds, and (3) the limited ability to generate local revenue to meet grant match requirements and support flood mitigation activities. As noted herein, statewide flood mitigation costs over the next 10 years are anticipated to be more than $31.5 billion. Due to shortfalls in local funding streams, communities

potentially need access to more than $18.0 billion in additional financial assistance.

Communities depend heavily on state and federal dollars to supplement local flood budgets. As a result, flood issues may persist and projects may remain on hold for years until a catastrophic event results in an allocation of post-disaster funding. Stakeholders expressed a desire to proactively address flooding issues rather than wait for post-disaster recovery funds.

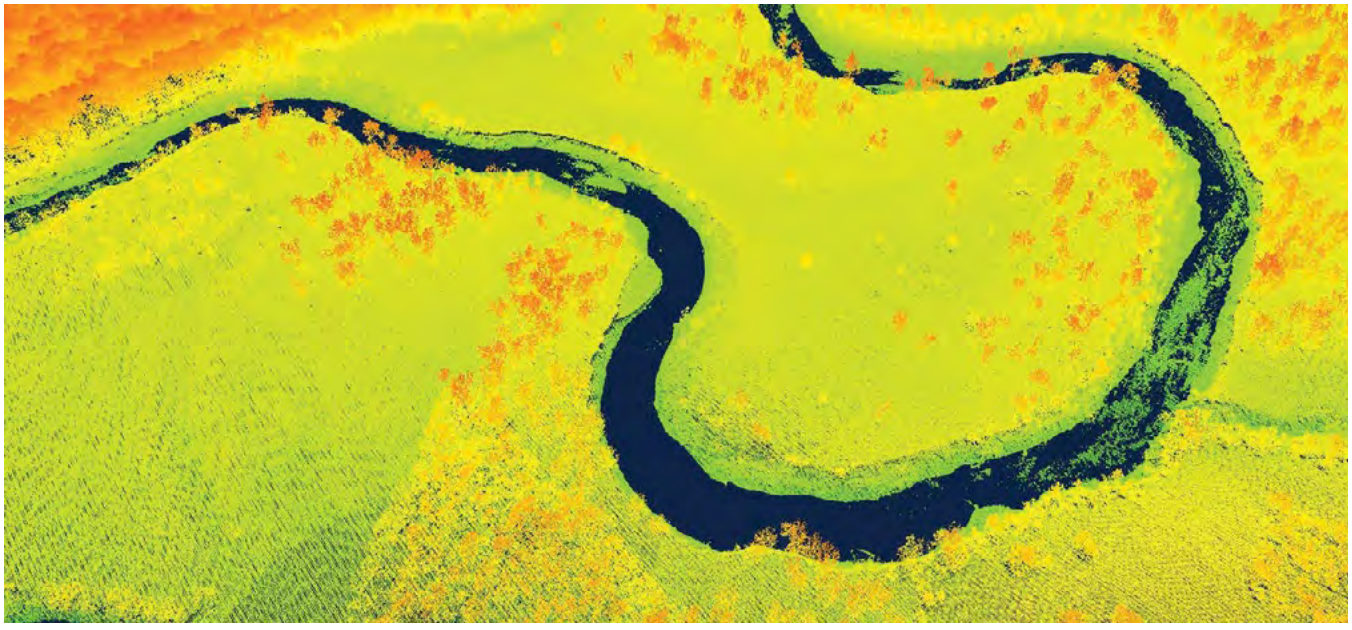
Stakeholders also identified a lack of funding as an impediment to conducting the planning studies necessary to identify solutions to known flooding issues. Many communities further lack the staff and ability to hire for these services, a situation which leaves the risk of flooding potentially unidentified as well as unresolved.

Ultimately, implementation of more robust financing for flood mitigation also will require broad public support. The public must understand the benefits of flood mitigation and the risk of inaction. Local and regional governments will need public support to finance costly projects and to support wider implementation of flood mitigation and floodplain management strategies.

2 - Improve flood risk mapping: Communities in Texas rely on FIRMs to identify and mitigate local flood risk. The average age of a Texas FIRM is 13 years old, though FIRM age varies widely across the state. An urban city typically has a FIRM that is less than 11 years old; contrast this with a 27-year old FIRM in the Panhandle. Many FIRMs, therefore, do not account for the last decade or more of development.

Stakeholders strongly supported all aspects of the flood risk mapping process—including collection and use of updated topographic (lidar), rainfall, streamflow, and related data—on an ongoing basis and with distribution of that data through an online repository. Efforts to improve flood risk mapping would support the creation of new and updated FIRMs, as well as the development of inundation maps to aid in land-use planning and emergency response. In addition to updated FIRMs, stakeholders desire additional modeling to determine base flood elevations and floodway designations, especially in light of the recent publication of Atlas 14, Volume 11. This information is essential for floodplain administrators to develop and enforce floodplain ordinances.

Stakeholders recognized the importance of improved mapping for use in communicating the full spectrum of flood risk, beyond the simplified information provided by FIRMs. They also listed the need to develop maps to represent the flood risk posed by stormwater flooding as a top priority.



Mapping is the first step to identifying and communicating the full spectrum of flood risk.

3 - Encourage watershed-based flood planning: Stakeholders consistently expressed a preference for a regional approach to flood planning, whereby watershed boundaries define the planning areas. This sentiment is consistent with stakeholder calls for increased collaboration, coordination, and leadership among all entities with flood responsibilities. Further, state and federal agencies indicated that a regional process would increase the potential for greater inter-agency collaboration.

Stakeholders strongly believe flood planning should be focused at the local level with funding support from the state and administrative support carried out by a regional entity. The process should include a wide variety of stakeholders and expertise, including local decision makers, emergency managers, regional development councils, transportation planners, realtors, scientists, engineers, businesses, industry, and private citizens to join floodplain administrators in studying and determining the most appropriate solutions for their unique flooding issues. A goal of watershed-based planning is to identify multi-benefit solutions to common flooding problems and to bring about efficiency in implementing projects.

4 - Expand educational outreach and technical assistance: Stakeholders expressed consensus about the need for flood-related education in Texas and the importance for the state to invest resources for this purpose. Floodplain administrators, local officials, and emergency response personnel all identified education—in the form of public awareness, floodplain management training, and technical assistance—as a top concern.

Recent flood disasters highlight the lack of understanding of the true risks posed by flooding. Risks are poorly communicated by limited outreach tools and a misunderstanding of the information provided on FIRMs. Effective outreach begins by reimagining FIRMs to communicate gradients of risk, not simply boundaries between safe and not safe.

Floodplain administrators specifically voiced concerns about how misinformation leads to questionable permitting decisions or even violations of existing floodplain development ordinances. They recommended expanding floodplain management outreach for homeowners and renters, homebuyers and sellers, insurance agents, decision makers, and everyone in between through broad public awareness campaigns and

Floodplain administrators, local officials, and emergency response personnel all identified education—in the form of public awareness, floodplain management training, and technical assistance—as a top concern.

targeted professional training for specific interest groups.

Technical assistance related to the NFIP, hazard mitigation planning, and grant procurement and administration also featured prominently in stakeholder views. Floodplain administrators requested access to more free and low-cost options for completing training courses for continuing education purposes and for more technical guidance in navigating state and federal financial programs.

8.4 Impact of doing nothing

Due to a combination of population growth and related development, Texas can be certain that without proper planning, flood events will impact more lives and cause more damage in the future. This statement is just as true on the High Plains near Post as it is along Dickinson Bayou near Galveston. We acknowledge the limitations of using only FIRMs while simultaneously relying on them to communicate flood risk locally. In addition, FIRMs represent conditions at the time the map was approved. Any changes related to land use or mitigation that occur after map publication are not included, further limiting our view of risk. A recent analysis by Berg (2018) highlights an additional consideration: peak flows at stream gages in urban areas have increased in many areas across the state over the past several decades. As our population continues to grow rapidly, and because most of that growth is projected to occur in and around urban centers, we must consider overlapping stormwater, riverine, and coastal hazards and the complexities they pose for flood risk identification and mitigation. This risk can only be reduced through mitigation of existing problem areas and avoidance via proper planning and preparedness.

8.5 Benefits of acting now

Flood mitigation activities, not unlike scientifically supported water supply projects, can be expensive but ultimately represent sound financial investments. Many of our state's reservoirs, originally built as flood control and water supply measures, have contained catastrophic floods, sometimes shortly after their construction. These types of projects were sited and developed using broadly accepted models and datasets that served as common foundations for project development and evaluation, affording the opportunity to evaluate impacts on neighboring communities. Using such sound science throughout the process ensures that projects have long-term, positive benefits for communities.

Once implemented, many flood mitigation projects save far more money and provide more benefits related to damage prevention than the cost to implement them. In fact, studies have shown that mitigation strategies for riverine flooding save $7 for every $1 spent (Multihazard Mitigation Council, 2017). Implementation of flood mitigation strategies, developed through sound mapping and modeling built on accurate, up-to-date data, can reduce or prevent property damage and loss, death and injury, and impacts to all sectors of the economy.

8.6 Laying a foundation with science and data

Sound science and data, identified as core elements of effective planning, are needed to inform flood-related decision making. As such, the TWDB has requested an additional $4.45 million in appropriations from the 86th Texas Legislature to support the agency's current efforts to gather data and monitor conditions across the state and to develop new initiatives that will further our understanding of flooding in Texas and our capacity to share that information. Specifically, the funding requested would allow the TWDB to develop hydraulic river models for priority watersheds; update reservoir flood pool measurements; expand the TexMesonet earth observation network; acquire high-resolution land surface (lidar) data to better predict floodplains and flooding levels; develop coastal circulation and rainfall-runoff models; and create a web-based flood dashboard/water data hub.

The information developed through these efforts will assist flood forecasters, emergency responders, floodplain administrators and their local governments, and all Texans in making informed decisions when preparing for, responding to, and recovering from floods. With better data and better science, Texas can continue working toward the common goal of protecting lives and property from the next flood event.

9. Recommendations to the 86th Texas Legislature

General flood recommendations: The legislature should pursue proactive statewide flood mitigation by first developing foundational flood risk management policies and goals that will support three key pillars of investment: (1) improved and updated flood mapping and modeling; (2) coordinated watershed-based planning; and (3) mitigation efforts, such as policy enhancements, increased technical assistance, and financial assistance for project implementation.

9.1 Background

Preliminary findings from the 2018 *State Flood Assessment*—an overview of flood-related roles and responsibilities, an estimation of flood mitigation costs, and a synopsis of stakeholder views on the future of flood planning in Texas—support the need for three key pillars of state investment: (1) mapping and science, (2) planning, and (3) structural and non-structural mitigation. Stakeholders involved in the assessment identified the need for additional resources directed toward floodplain management and mitigation. They also expressed a need for expanded educational outreach and technical assistance opportunities throughout the state.

These priorities emerged from myriad suggestions and reflect areas of broad consensus among stakeholders. The recommendation to invest in the following three pillars will be guided by foundational flood risk management policies and goals supported by the 2018 *State Flood Assessment* and is based on these underlying core principles:

- Up-to-date data, science, and technical tools are necessary to inform decision making by local, regional, and state leadership.
- Planning should be conducted at a watershed level with the common, minimum aim of addressing flood risk management policies and goals, using the best technical tools available, according to a standardized state framework.
- Financial assistance should be provided to those mitigation projects that meet the statewide flood risk mitigation goals and that (1) will have no harmful effects on upstream or downstream neighbors and (2) are the product of a planning process based on a standardized state framework.

9.2 Specific flood recommendations and further background

Develop a statewide flood risk management policy: The legislature should develop a state flood risk management policy and goals by which to guide state-funded investments in flood mapping, flood planning, and flood mitigation. These policies and goals will

- provide the foundation upon which the other flood recommendations will rest;
- serve as a statewide minimum threshold for addressing flood risks that may, however, be exceeded by local entities using their own resources to further reduce local flood risks;
- largely determine the framework, scope, and nature of the work tasks that must be performed as part of any state or regional flood planning process, irrespective of the format or stakeholder membership of such a planning process; and
- guide the responsible stewardship of any future investments by the state in flood mitigation.

The legislature should identify specific flood risk reduction goals and an acceptable level of risk that will remain even after the state goals are fully met. Absolute protection against all potential flood hazards is not possible and state resources to protect against or mitigate flood risk are limited. So, Texas must decide both to what end and to what degree it is willing to invest state resources to reduce certain flood risks. An achievable statewide risk reduction goal might be, for example, to focus on ensuring the protection of all lives at risk from up to a 0.2 percent annual chance event (often

Mapping can save lives. In 2015, this map was used to identify a safe evacuation route for livestock.

called the *500-year flood*), or the goal might be to minimize loss of property and lives at risk from a 1 percent annual chance event (the *100-year flood*).

These goals, once established, will provide a foundation for the three pillars of state investment as outlined below.

(1) Mapping

The legislature should provide additional financial investment in modeling, mapping, and flood-related science to ensure that Texas better understands flood risk and is better prepared when flooding events occur. The legislature should set a goal of developing or updating flood risk maps across the state, using current data and technology standards, by 2030.

Much of Texas is either unmapped or uses out-of-date flood insurance rate maps, leading to widespread misunderstanding about true flood risks. Mapping is the first step in identifying and communicating the full spectrum of flood risk. However, FEMA's insurance maps show the boundary of inundation for a specific annual chance flood event—often misinterpreted as the line between safe and not safe. These maps are narrowly focused on one level of flood risk; may not reflect flood potential based on the most current topographic, land use, or rainfall data; and effectively limit the picture of flood risk.

Above and beyond mapping, sound science and data are the core elements of effective planning and flood mitigation.

Through support from the Office of the Governor and the Texas Legislature, the TWDB has implemented new initiatives in recent years to better prepare the state for flood events. To continue expanding these efforts and to improve data collection, mapping, and monitoring of conditions across the state, the agency has requested an additional $4.45 million in appropriations from the 86th Texas Legislature. The requested funding represents a small step toward the goal of ensuring that Texas is better informed and prepared when flooding events occur, but a more significant investment will be needed to ensure that all areas of the state have accurate flood models and associated flood risk maps.

(2) Planning

The legislature should invest in coordinated, watershed-based flood planning to meet state flood risk management policies and goals. The format and structure of a flood planning process should be largely determined by state flood risk policies and goals and should rely on the best available science.

Although local planning efforts already take place across the state, there is not a unified, coordinated process to assess risk and plan for the state's flood risk goals. Instead, planning and project implementation occurs based on varying risk acceptance levels and in a piecemeal fashion. Implementing flood mitigation without a coherent approach or sound scientific data, proper mapping, and coordinated planning may be ineffective, or, worse, may intensify flood impacts in upstream or downstream communities.

The foundation of a standardized planning framework should be flood risk management policies and goals as accomplished through a stakeholder-driven process. A state flood planning process would require clearly establishing

- the defined roles for local, state, regional, and federal entities in flood planning;
- a common vocabulary of terms;
- the purpose, scope, scale, time frame, and priorities of state flood risk planning and mitigation;
- an appropriate state flood planning benchmark;
- planning principles, processes, products, and responsibilities; and
- a methodology for estimating costs and, as necessary, determining cost-benefit ratios.

(3) Mitigation Assistance

The legislature should develop a long-term, affordable, and sustainable method to provide financial assistance and other incentives for developing and updating flood maps, statewide flood planning, and implementing flood mitigation projects that are recommended to meet state flood risk management goals. Additional financial investment is needed to support training and educating floodplain administrators, elected officials, emergency responders, and others involved in flood-related issues and to provide technical assistance to local governments seeking state and federal funding for projects.

Prior to any formalized statewide or regional flood planning process, the legislature should establish a near-term funding option to allow communities' access to local match funding to support future mitigation activities or to respond quickly to federal funding opportunities following disaster events.

Significant investment is required to mitigate flooding in Texas. Though the responsibility to prepare for and mitigate flood impacts is primarily local, most communities do not have the economic resources required to accomplish their goals. Statewide flood mitigation costs over the next 10 years are estimated to be more than $31.5 billion; however, that estimate is derived from limited stakeholder data and not based on any common, statewide flood risk mitigation goal. Due to shortfalls in local funding, communities may need approximately $18 to $27 billion in financial assistance. (These estimates account only for mitigation costs based on stakeholder input. They do not account for projects associated with Hurricane Harvey recovery, other large federal projects such as the Coastal Spine or third reservoir being discussed for the Houston area, or rehabilitation of high hazard dams within the state.)

It is imperative that any financial assistance or other incentive provided by the state for flood mitigation implementation should be conditioned on a requirement that projects will have no harmful effects on upstream or downstream neighbors and are recommended to meet state flood risk mitigation goals as part of a state flood planning process.

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