SAN JACINTO
REGIONAL WATERSHED
MASTER DRAINAGE PLAN

SAN JACINTO REGIONAL WATERSHED
MASTER DRAINAGE PLAN

DECEMBER 2020

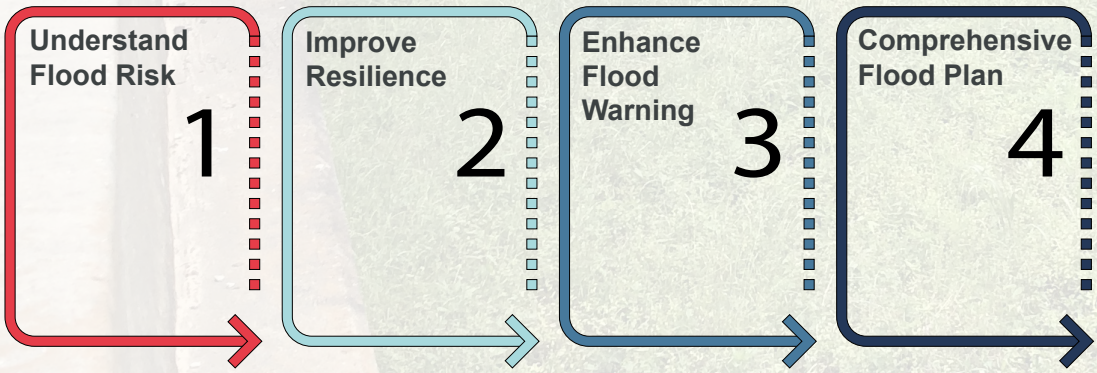
HARRIS COUNTY FLOOD CONTROL DISTRICT
SAN JACINTO RIVER AUTHORITY SJRA
MONTGOMERY COUNTY Birthplace of the Lone Star Flag
CITY OF HOUSTON TEXAS

INTRODUCTION

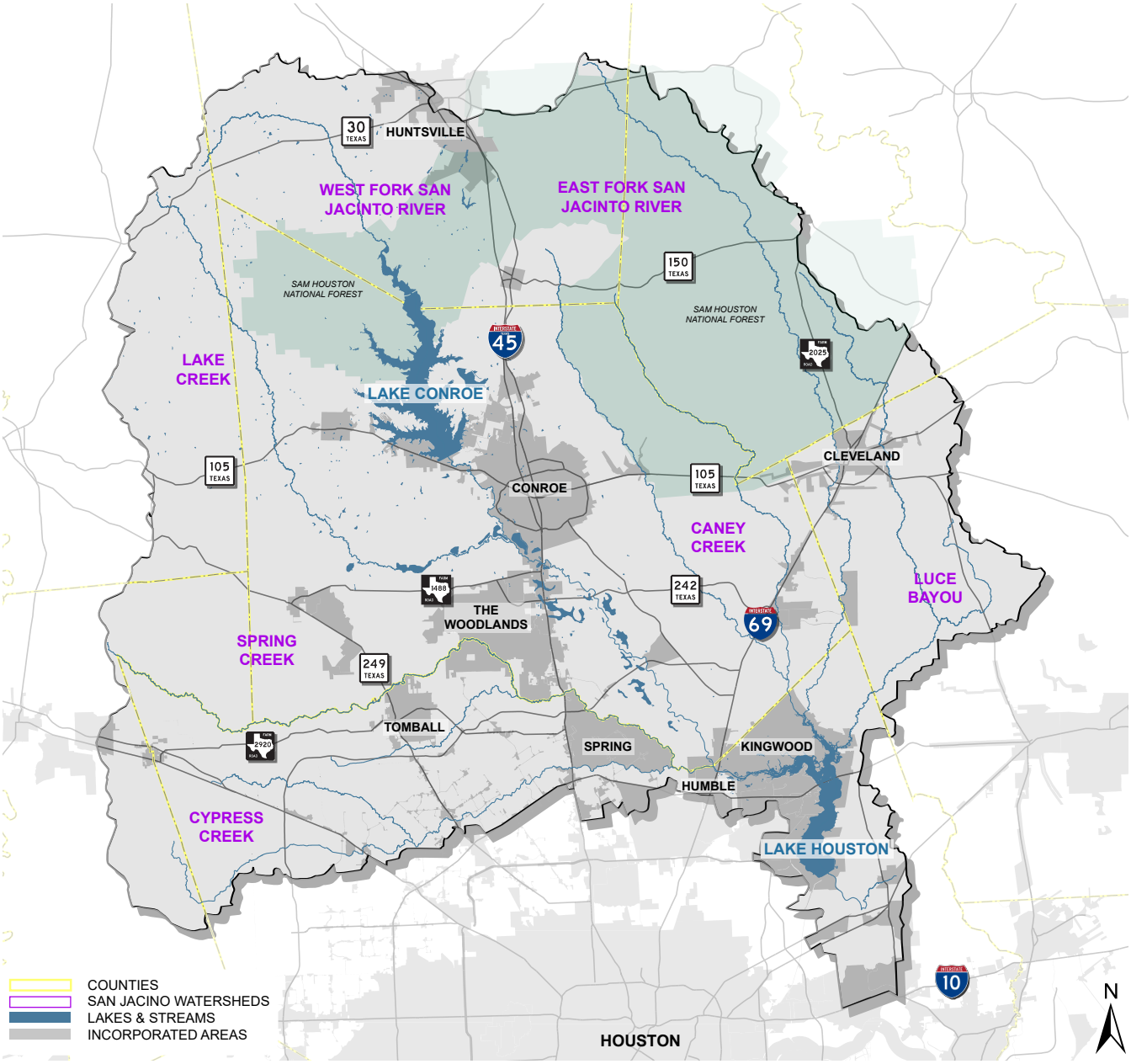
MASTER DRAINAGE PLAN VISION

PURPOSE OF THE PLAN

The San Jacinto Regional Watershed Master Drainage Plan (SJMDP) is a comprehensive regional study of the upper region of the San Jacinto River Watershed. The study is led by local partners including the Harris County Flood Control District, the San Jacinto River Authority, Montgomery County, and the City of Houston. The goals of the regional watershed master drainage plan are to:



UPPER REGION OF THE SAN JACINTO RIVER WATERSHED



MAP 1.1, SAN JACINTO WATERSHED MAP

STUDY PARTNERS

The Harris County Flood Control District (the District) is a special purpose district created by the Texas Legislature in 1937 and governed by Harris County Commissioners Court. The District was created in response to devastating floods that struck the region in 1929 and 1935. The District's jurisdictional boundaries are set to coincide with Harris County, a community of more than 4.5 million people (2015) that includes the City of Houston. The other boundaries in which we operate - those provided by nature - are of the 22 primary watersheds within Harris County's 1,777 square miles. Each watershed has its own independent flooding problems and presents unique challenges.

https://www.hcfcd.org/About

Created by the Texas Legislature in 1937, the San Jacinto River Authority (SJRA) is a government agency whose mission is to develop, conserve, and protect the water resources of the San Jacinto River basin. Covering all or part of seven counties, the organization's jurisdiction includes the entire San Jacinto River watershed, excluding Harris County. The SJRA is one of 10 major river authorities in the State of Texas, and like other river authorities, its primary purpose is to implement long-term, regional projects related to water supply and wastewater treatment. SJRA's mission also includes coordination of regional flood planning and informing and engaging the public on a wide range of water resources management topics.

https://www.sjra.net/about/

Montgomery County is roughly centered along Interstate 45 forty miles north of downtown Houston in the East Texas Timberlands Region. The center of the county is the county seat of Conroe. The county is bounded on the north by Walker and San Jacinto counties, on the east by Liberty County, on the south by Harris County, and on the west by Waller and Grimes counties. Montgomery County covers 1,047 square miles of flat to gently rolling terrain, with elevations ranging from 150 to 300 feet. The Montgomery County Engineering Department is charged with enhancing and protecting the public quality of life, health, safety, and well-being by providing, among other things, engineering services that promote the development of community facilities and infrastructure.

https://mctx.org/for_visitors/index.php

Houston is the fourth most populous city in the nation, with an estimated population of more than 2.3 million people (trailing only New York, Los Angeles and Chicago), and is the largest in the southern U.S. and Texas. Houston is expected to become the third most populous U.S. city during the second half of the decade of the 2020s. Houston Public Works provides many of the basic services that affect the daily lives of everyone who lives and works in Houston. Primarily, the department is responsible for all the things we take for granted on a daily basis: the administration, planning, maintenance, construction management and technical engineering of the City's infrastructure, including drainage infrastructure.

https://www.houstontx.gov/abouthouston/houstonfacts.html

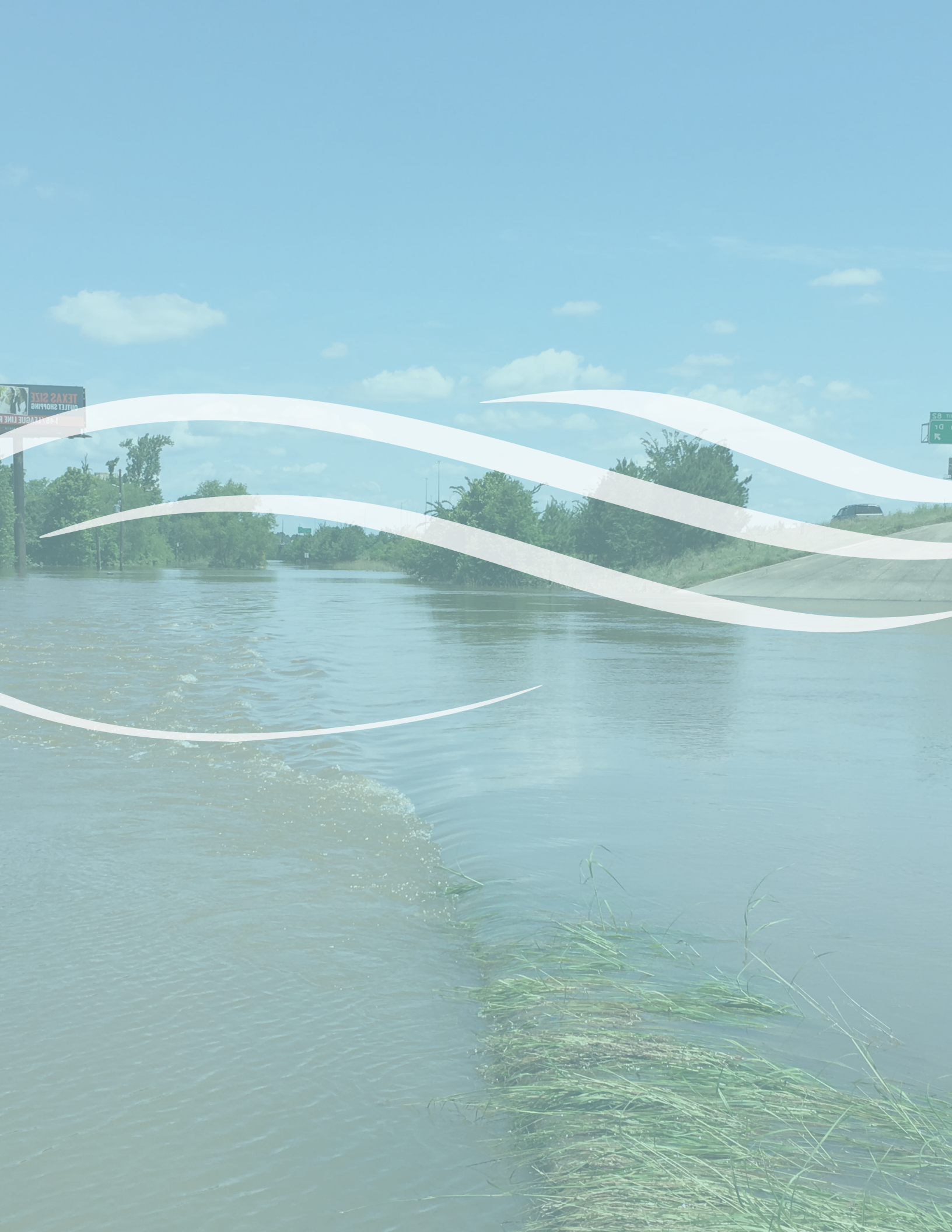
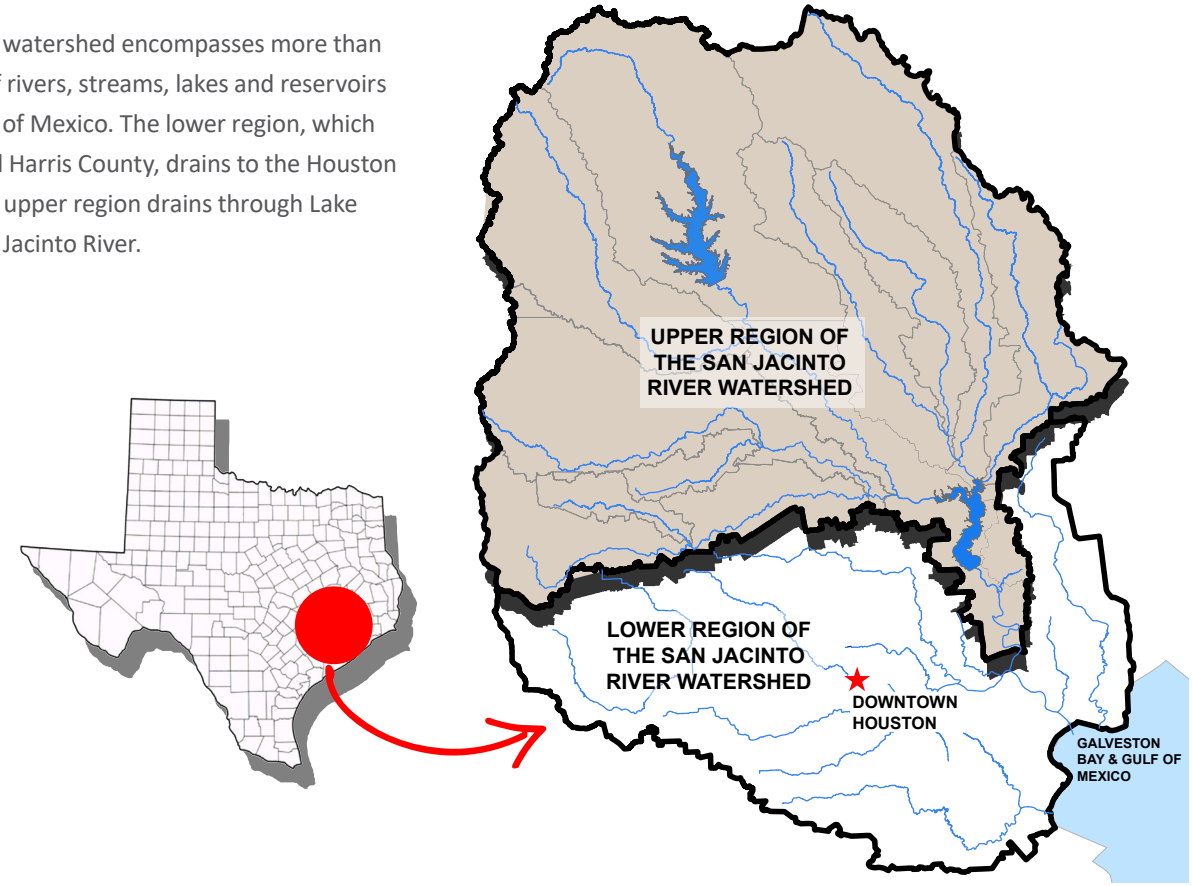


TABLE OF CONTENTS

OVERVIEW
SAN JACINTO WATERSHED

The San Jacinto River watershed encompasses more than 4,500 square miles of rivers, streams, lakes and reservoirs that drain to the Gulf of Mexico. The lower region, which includes Houston and Harris County, drains to the Houston Ship Channel and the upper region drains through Lake Houston into the San Jacinto River.



MAP 1.2, LOCATION MAP

INFORMATION
UPPER SAN JACINTO RIVER WATERSHED FACTS

- THE UPPER SAN JACINTO RIVER WATERSHED HAS A DRAINAGE AREA OF 2,880 SQ. MI. AND IS DRAINED BY THE EAST AND WEST FORKS.
- COMPRISES PORTIONS OF: HARRIS, MONTGOMERY, WALLER, WALKER, GRIMES, LIBERTY, AND SAN JACINTO COUNTIES.
- THE WATERSHED IS PRIMARILY COMPOSED OF RURAL AGRICULTURAL AND FOREST LAND. THERE IS APPROX. 450 FT OF ELEVATION DIFFERENCE FROM WALKER COUNTY TO LAKE HOUSTON.
- THERE ARE 2 WATER SUPPLIES, LAKE HOUSTON AND LAKE CONROE, WHICH PROVIDE WATER TO THE REGION
- THERE ARE 11 MAJOR WATERSHEDS INCLUDING THE WEST FORK SAN JACINTO RIVER, EAST FORK SAN JACINTO RIVER, LAKE CREEK, SPRING CREEK, CYPRESS CREEK, AND SEVERAL MAJOR TRIBUTARIES.
- THIS AREA EXPERIENCES AN AVERAGE ANNUAL RAINFALL OF 49 INCHES.
- WITH AN ESTIMATED POPULATION OF 1.9M, THERE IS AN ANNUAL MEDIAN HOUSEHOLD INCOME OF $77,420.

FIGURE 1.1 , WATERSHED FACTS

HYDROLOGY

The scientific study of water. It involves analyzing rainfall, soils, land use, and topographic data to calculate how much water is entering rivers, channels, and drainage systems.

HYDRAULICS

The study of water moving through conveyance systems. It involves analyzing the carrying capacity of the drainage system to calculate how fast, deep, extents.

WHAT ARE FLOODPLAINS?

From time to time, due to heavy rainfall, bayous and creeks naturally come out of their banks and inundate the adjacent land. This area is referred to as a floodplain. A floodplain is defined as any land area susceptible to being inundated by water from any source. Each bayou and creek has its own floodplain, where water collects, pools, and flows during the course of a storm event. As every flood is different, floodplains are typically expressed by stating their annual exceedance probability or the chance of a particular storm to occur in any given year.

WHAT IS A 100-YEAR FLOOD?

The term 100-year flood is misleading. The 1 percent floodplain or 100-year floodplain represents an area of inundation having a 1 percent chance of being equaled or exceeded in any given year. It does NOT mean that if a 1 percent flood event does occur, another 1 percent flood event will not happen for 99 years.

FLOODING FACTS:

It is a popular myth that, in Harris County's past, floodplains were contained within the channel banks, and that land development has caused all of the area's flooding problems. That is not necessarily true. Nature can and will provide more rainfall than the area's bayous, creeks, and channels can handle. Statistically, a 1 percent flood has a 26 percent chance of occurring during a 30-year period - the length of many mortgages.

RESOURCES FOR FLOODING RISK?

Floodplain maps produced by FEMA are a key tool used by the Harris County Flood Control District and FEMA to communicate flooding risks to citizens. Interactive maps are publicly accessible online, for Harris County at www.harriscountyfemt.org, nationwide at www.hcfcd.org.

LAKE CONROE AND LAKE HOUSTON

Lake Conroe and Lake Houston are man-made lakes, located in the upper region of the San Jacinto River Watershed. Both lakes are water supply reservoirs, meaning that normal pool water levels are maintained at a consistent elevation as much as possible to ensure a constant supply of water in times of drought.

Lake Conroe was built in 1973 and is located about 43 miles northwest of downtown Houston. The lake and dam are maintained by the San Jacinto River Authority. The lake has a normal pool elevation of 201 feet above mean sea level. Excess water is released from Lake Conroe through five gates on the dam and discharged into the West Fork San Jacinto River. The City of Houston owns two-thirds of the water rights in the lake.

Built in 1953, Lake Houston is located about 15 miles northeast of downtown Houston. The lake is owned by the City of Houston and maintained by the Coastal Water Authority. The lake has a normal pool elevation of 42 feet above mean sea level. Excess water spills over an uncontrolled 3,000-foot long spillway at the dam and travels down the San Jacinto River to Galveston Bay. The dam also has 2 gates which are occasionally used to make releases. The City of Houston owns all the water rights in the lake. The lake is a primary source of water for the City of Houston. While Lake Houston and Lake Conroe were included in this effort, they were only analyzed as part of the existing system. No improvements of the lakes, outfall structures, or operations were evaluated as part of this study.

LAKE CONROE

- **Completed in 1973 for water supply**
- **Drainage Area is 445 square miles**
- **Lake surface is 32 square miles**
- **Water supply capacity is 134 billion gallons**
- **Flow releases to Lake Houston are made through 5 gates**

FIGURE 1.2 , LAKE CONROE FACTS

LAKE CONROE AND LAKE HOUSTON

- **Completed in 1953 for water supply**
- **Drainage Area is 2,828 square miles**
- **Lake surface is 19 square miles**
- **Water supply capacity is 44 billion gallons.**
- **Releases are made through an uncontrolled spillway and 2 gates**

FIGURE 1.3 , LAKE HOUSTON FACTS

DEVELOPMENT AND DRAINAGE CRITERIA

The upper region of the San Jacinto River Watershed began to grow in population with Montgomery County being established in the 1830's. In the early 1880's the construction of several railroads brought economic growth to the region as well as the expansion of several towns such as Willis and Conroe. The construction of railroads developed lumbering into a major industry. Over the next four decades, continuous logging permanently altered the landscape, opening up the region for farming and raising livestock. The Sam Houston National Forest was established in the 1930's as part of the national forest system to preserve forest in the region.

The oil boom of the 1930's led to significant growth, with the population in Montgomery County reaching 23,000 by 1940. The main growth in the region was a result of the expansion of metropolitan Houston. By 1970, the population of Montgomery County was nearly 50,000, growing to more than 130,000 in 1980 and just over 182,000 by 1990. A significant amount of growth in flood prone areas occurred before standard principles & practices were established through drainage criteria for Harris County (1984) and Montgomery County (1989), the two most populous counties in the watershed. Much of the development also pre-dated FEMA flood maps. The 2019 Census data indicates that the population in the upper region of the San Jacinto Watershed, including Harris County increased from 1.4 million to 1.6 million in 5 years. Much of the once rural area has been converted to urban uses, including homes, business, and industries.

NATIONAL FLOOD INSURANCE PROGRAM

The National Flood Insurance Act of 1968 created the National Flood Insurance Program and was intended to encourage state and local governments to constrict development of land exposed to flood hazards. FEMA flood maps were developed to identify those flood-prone areas. Construction of many large planned developments, such as Kingwood and the Woodlands, began in the 1970's and 80's. The first Flood Hazard Boundary Maps for the City of Houston and unincorporated Harris County also came out in the mid-1970's with regulatory Flood Insurance Rate Maps (FIRM) introduced for Harris and Montgomery Counties in 1982 and 1984, respectively. These maps have been updated several times since for much of the watershed.

In the last 20 years, there has been significant attention paid to both the floodplain mapping and development criteria with the intent of reducing flood risk. Since Hurricane Harvey in 2017, that push has been further accelerated, with many communities updating development and floodplain criteria to be much more stringent. In response to this, significant floodplain modeling and mapping efforts, such as Harris County's MAAPnext program, have been initiated to provide better information about both riverine and urban flooding.

WATERSHED FLOODING HISTORY

Several historical rainfall events have resulted in significant flooding in the upper region of the San Jacinto River Watershed. Many of these floods have resulted from hurricanes or tropical storms, which are common along the Gulf Coast. Significant flooding events occurred in 1940, 1960, 1973, 1994, 2016, 2017, and 2019 along with numerous other smaller flood events.

Historical records in the watershed go back 100-years but the last 30-years have produced several devastating storms to the residents of the San Jacinto River watershed. The October 1994 storm was the storm of record for more than 20 years; with more than 18 inches of rainfall across the watershed, the elevation in Lake Houston increased over eight feet from the normal pool elevation.

The last four years have proven to be very challenging for residents of the watershed, with three major flood events causing disruption, property damage, and loss of life. The most notable of those events is, of course, Hurricane Harvey.

In 2017, Hurricane Harvey brought 22 to 34 inches of rainfall across the upper region of the watershed over a 6-day period. An estimated peak inflow of 190 million gallons per minute (410,000 cubic feet per second) entered Lake Houston from the Upper San Jacinto River watershed causing the lake to rise over 11 feet above the normal pool elevation. Lake Conroe also experienced record inflows and rose over 5 feet above the normal pool elevation during the rainfall event. Every major stream in the watershed exceeded previous record flow and stage elevations. Thousands of structures reported flooding in Harris County and Montgomery County.

Since Harvey, Tropical Storm Imelda has delivered another blow to the watershed, flooding homes and businesses that, in some cases, were still recovering from Harvey. In September of 2019, Tropical Storm Imelda brought upwards of 32 inches of rainfall over 2 days, primarily in the eastern part of the watershed, resulting in significant flooding along the East Fork and tributaries, including Kingwood and the Lake Houston area.

The purpose of this study is to develop strategies that can improve resiliency in the San Jacinto Watershed in the aftermath of these types of storms.

SOURCES OF FLOODING

There are two primary sources of flooding In the San Jacinto River Watershed, river flooding and drainage system flooding. Other sources of flooding are sheet flow and lakes. The focus of the San Jacinto Regional Watershed Master Drainage Plan is to address river flooding along the main channels in the watershed.

River or channel

River flooding occurs when a river or channel overflows its banks. River flooding can be a result of both intense bursts of rainfall and long duration rainfall events. Debris, sediment in the channels, and undersized road crossings can also contribute to river flooding. Areas like Kingwood and The Woodlands have flooded from channels overtopping their banks.

Sheet flow

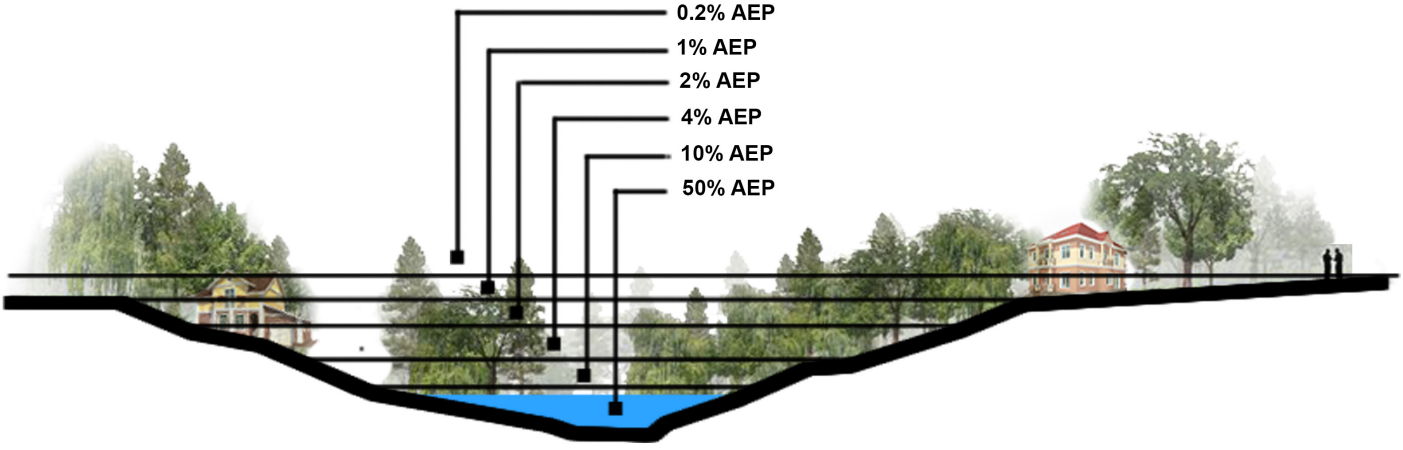
Sheet flow is the movement of shallow runoff across the ground during a rainfall event as the runoff makes its way to the drainage system or river. Natural sheet flow patterns can be altered by development causing some areas to flood that did not before. Accounting for sheet flow in the design of development projects can reduce the risk of unintentional flooding.

Drainage systems

Drainage systems include infrastructure such as ditches and storm sewers that carry runoff from local streets and ends up in nearby channels or collecting bodies of water. Drainage systems with limited capacity can surcharge or backup and cause flooding even when the receiving channel is not flowing full. Intense rainfall can also overload drainage systems. Proper drainage criteria can reduce the chance of drainage systems being overwhelmed. At times, the receiving water body, such as a downstream river or lake, may backup into the drainage system causing flooding. Other studies are ongoing by HCFCD and others to address internal drainage issues in this area.

Lakes

Flooding can occur when heavy rainfall and swollen rivers flow into a lake resulting in high water surface elevations. Excessive rainfall can cause lake elevations to rise and back up into structures around the lake within the drainage easement.



As part of the study, the team evaluated flood potential for a range of "frequency storms", which cover a variety of statistical probabilities for rainfall. These "frequency storms" range from the 50% Annual Chance Event (ACE), or 2-year storm, to the 0.2% ACE (500-year storm). Historical storms such as Hurricane Harvey and Tropical Storm Imelda were also evaluated.

THIS PAGE LEFT INTENTIONALLY BLANK

BASELINE CONDITIONS

A critical part of the San Jacinto Regional Watershed Master Drainage Plan was identifying the current vulnerability to flooding in the watershed and to determine what areas have experienced flood damages in the past or may in the future. The study team developed a single comprehensive model of the San Jacinto Watershed's major streams, the first of its kind for the region. This complex computer model was prepared to help assess this vulnerability and to establish a baseline for current flooding conditions. The baseline conditions refer to the current state of the watershed without implementing any of the projects that were considered as part of the study.

Hydrologic and hydraulic (H&H) analysis was performed by the study team to provide that baseline for the entire upper San Jacinto River Watershed. Once established, the baseline conditions models were compared to the models for the proposed projects to help understand the benefits. This comparison of pre-project and post-project helped identify reductions in flood elevations, flood extents, and the expected frequency of flooding when projects are implemented.

TABLE 1.2, STUDY STREAMS

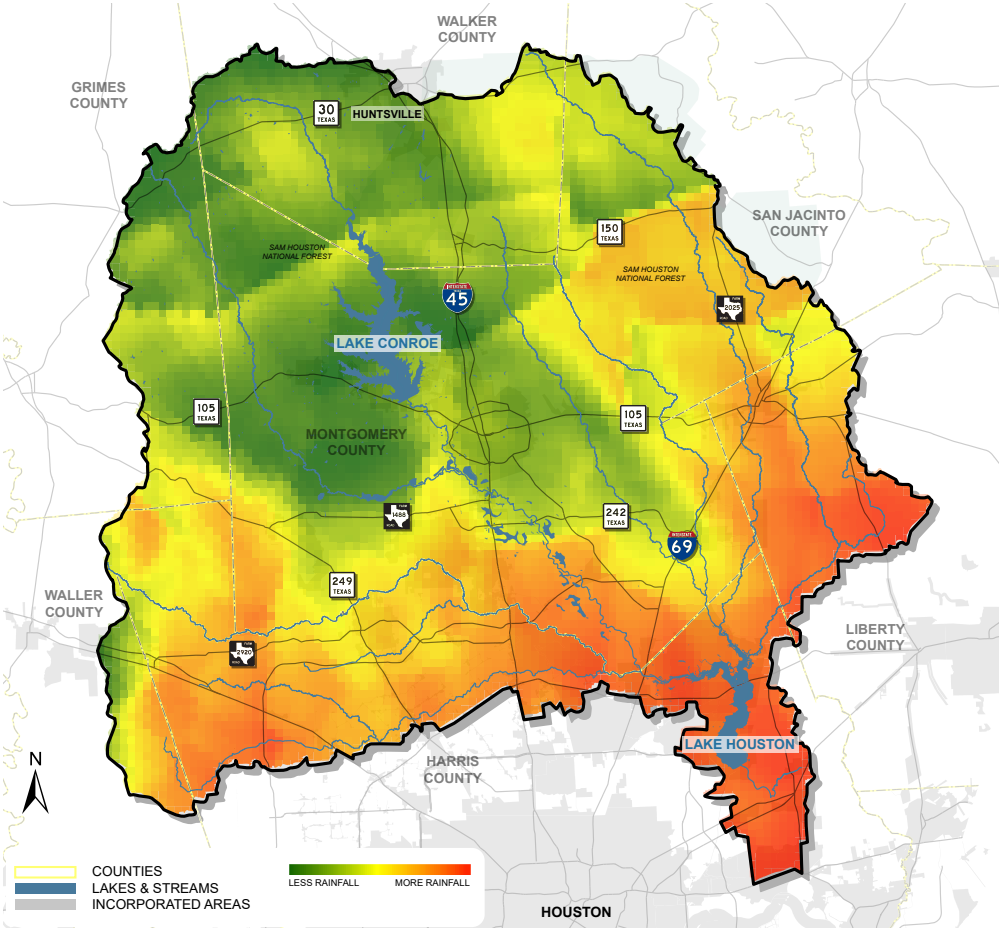
Study Streams	Length (Miles)
West Fork San Jacinto River	50.6
East Fork San Jacinto River	86.9
San Jacinto River	24.2
Lake Creek	69.5
Cypress Creek	51.2
Little Cypress Creek	21.7
Spring Creek	69.1
Willow Creek	20.5
Caney Creek	57.9
Peach Creek	49.6
Luce Bayou	31.1
Tarkington Bayou	50.4
Jackson Bayou	10.2
Total	**592.9**

H&H models were developed for the major tributaries of the Upper San Jacinto River Watershed (from the headwaters in Walker County to the Interstate 10 crossing at the San Jacinto River in Harris County). The models developed used the most current Atlas 14 rainfall data, digital terrain information, and modeling technologies to provide an understanding of the San Jacinto watershed. The baseline conditions modeling indicates that the 1% ACE (100-year) water surface elevations are generally higher than current Federal Emergency Management Agency (FEMA) floodplain maps indicate. Therefore, structures that are currently in a mapped 1% ACE floodplain may actually be at a higher risk of flooding than currently shown on regulatory maps assumed.

HISTORICAL STORM ASSESSMENT & CALIBRATION

The H&H models were compared to four historical storms, including Hurricane Harvey (2017), Memorial Day (2016), Tropical Storm Imelda (2019), and the October 1994 storm. Based on these simulations, adjustments were made using gage and high-water mark data to improve the accuracy of the models and ensure a realistic representation of the watershed. Gage adjusted radar rainfall (GARR) data was used for each of the historical storm. The rainfall depths were entered at specific time intervals and parameters within the H&H models were adjusted to match observed streamflow and elevation data at USGS gages.

Information developed from the models included flood inundation maps for the studied channels. These maps show the extent and depth of flooding of the modeled streams within the watershed for an array of simulated storm events. Additionally, information was gathered about the number of structures, acres of land, properties, and miles of roadway that are located within the modeled floodplains. Water surface elevation profiles were prepared comparing the 100-Year model results to the published FEMA water surface elevation profiles. This information provided an indication of the vulnerability to flow hazards.



MAP 1.6, RAINFALL DENSITY MAP (HURRICANE HARVEY, AUGUST 2017)

UPDATED MODELING VS FEMA EFFECTIVE

Comparison of the updated modeling with the current FEMA effective flood data indicated a general increase in both peak flow rates and average water surface elevations. Based on the comparison, it is likely that structures within or near the floodplain are at a higher flood risk than shown in the FEMA flood maps. This is largely due to having more accurate rainfall (Atlas 14, Volume 11) and model information. The table below provides information about the average increase in flow rate and elevation for the 1% ACE (100-year) annual chance event for FEMA effective and updated Atlas 14 modeling in each watershed.

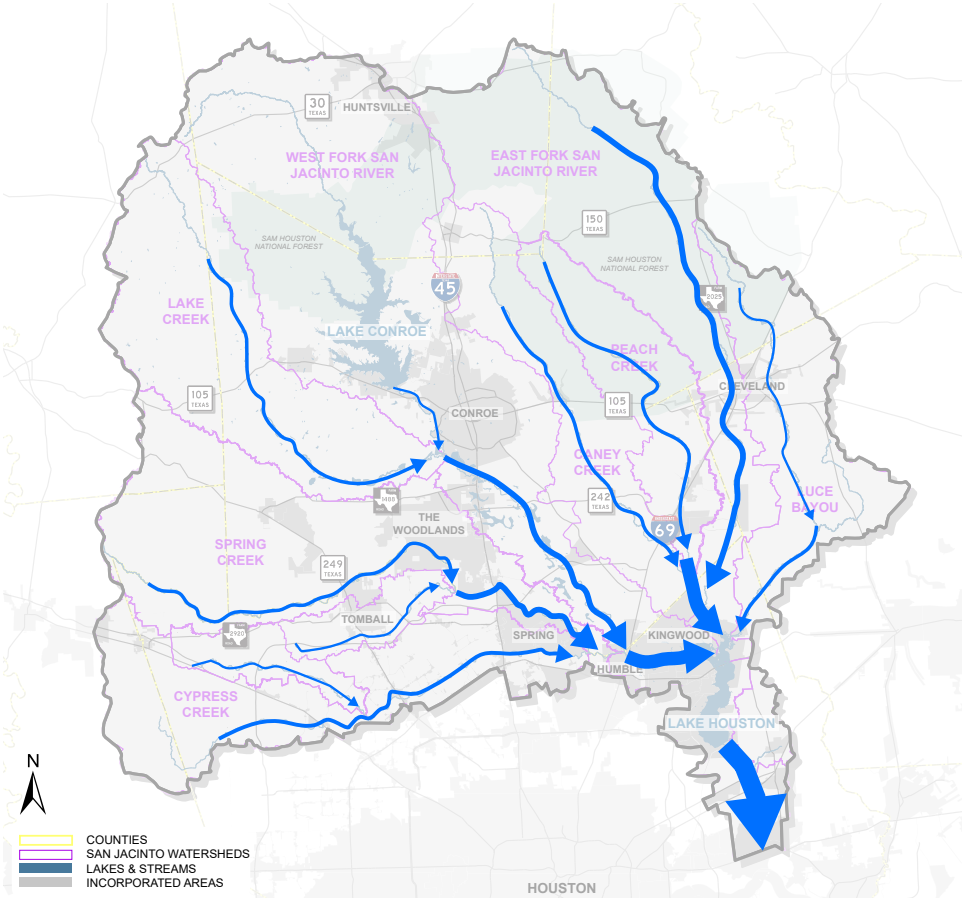
TABLE 1.3, COMPARISON OF FLOW AND ELEVATIONS

Stream Name	Average increase in flow (cfs)	% Increase	Increase in 100-year elevations (Feet)
West Fork San Jacinto River	8,400	5%	0.9
East Fork San Jacinto River	19,000	34%	2.7
San Jacinto River	60,500	22%	-0.9
Lake Creek	26,500	67%	4.5
Cypress Creek	900	-5%	0.8
Little Cypress Creek	4,400	115%	1.8
Spring Creek	5,600	23%	3.3
Willow Creek	3,500	26%	1.8
Caney Creek	13,500	46%	3.9
Peach Creek	5,400	22%	2.8
Luce Bayou	2,200	20%	1.4
Jackson Bayou	-10	-1%	0.8

FLOW ACCUMULATION

The modeling developed also helped the team understand flow patterns and flow accumulation in the watershed. The arrows in the map below show the direction of flow in the stream and the size of the lines qualitatively represents the peak flow experienced in a major storm. A larger line indicates a higher peak flow. The total Upper San Jacinto watershed area is approximately 2,880 square miles and more than 2,840 square miles of watershed are funneled through Lake Houston. The modeling showed that flows in the downstream portions of the watershed can come from several sources. Spring Creek, the West Fork, and the East Fork receive flow from both their own watersheds as well as others upstream. For example, the East Fork also receives flow from Caney Creek and Peach Creek. These additional flows can contribute to flooding on the East Fork.

Understanding flow sources and accumulation helped determine where potential improvement projects would make the greatest impact. With significant portions of the watershed flows coming from Spring Creek, Lake Creek, the West Fork, Peach Creek, Caney Creek and the East Fork, projects in those watersheds have higher potential for reducing flows downstream.



MAP 1.7, FLOW ACCUMULATION MAP

IDENTIFYING VULNERABILITY TO FLOODING

The results of the H&H models indicate that areas of concentrated flood damages exist throughout the upper San Jacinto River Watershed. These areas are not only predicted to have flooding based on modeling and mapping developed as part of this study, but also historical flood claim data provided to the team. Property owners often do not realize that if their home is in a 100-year floodplain, it has a 26% chance of flooding at least once over a 30-year mortgage. In a 50-year period, the predicted number of structures at risk of flooding within the watershed is approximately 5,000.

Historical flood information for the watershed is indicated by the heat map (see map below). The dark areas indicate locations where flood insurance claims have been made. The brighter colored areas indicate areas where repetitive flood claims have been made. The predicted flooding results are in line with the flood claims shown in the pie chart and the baseline conditions H&H modeling.

Understanding flood risk is important to make informed decisions about what actions to take during a disaster. By combining the historical flood data with the predicted flood data based on detailed modeling, the damage centers become evident, identifying flood vulnerability for decision makers and the public.

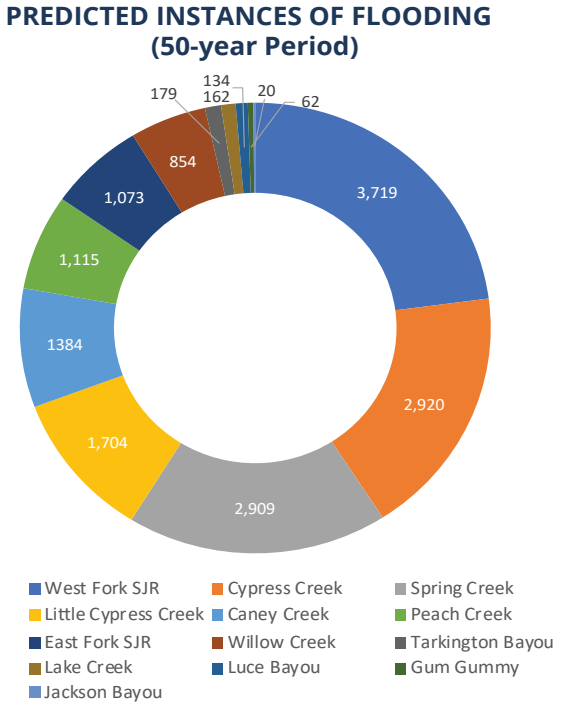
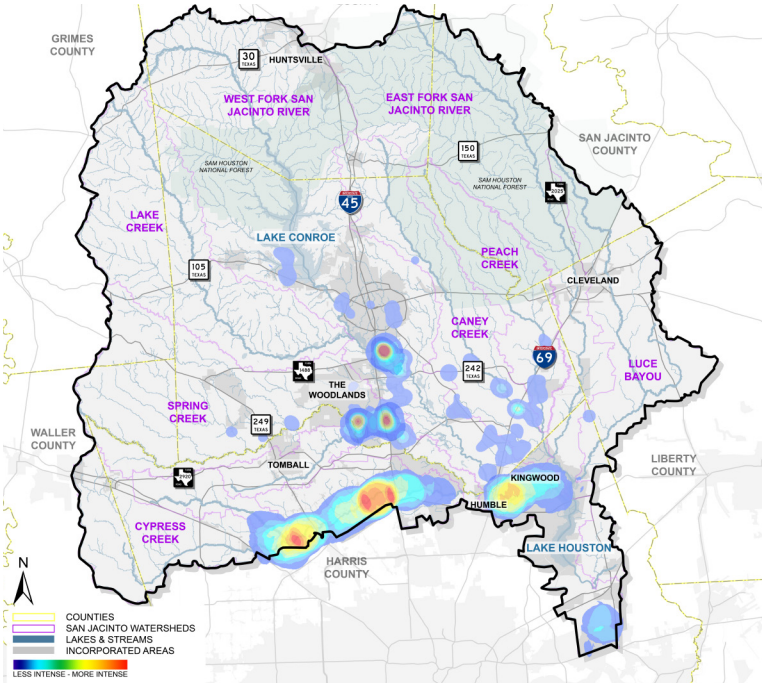
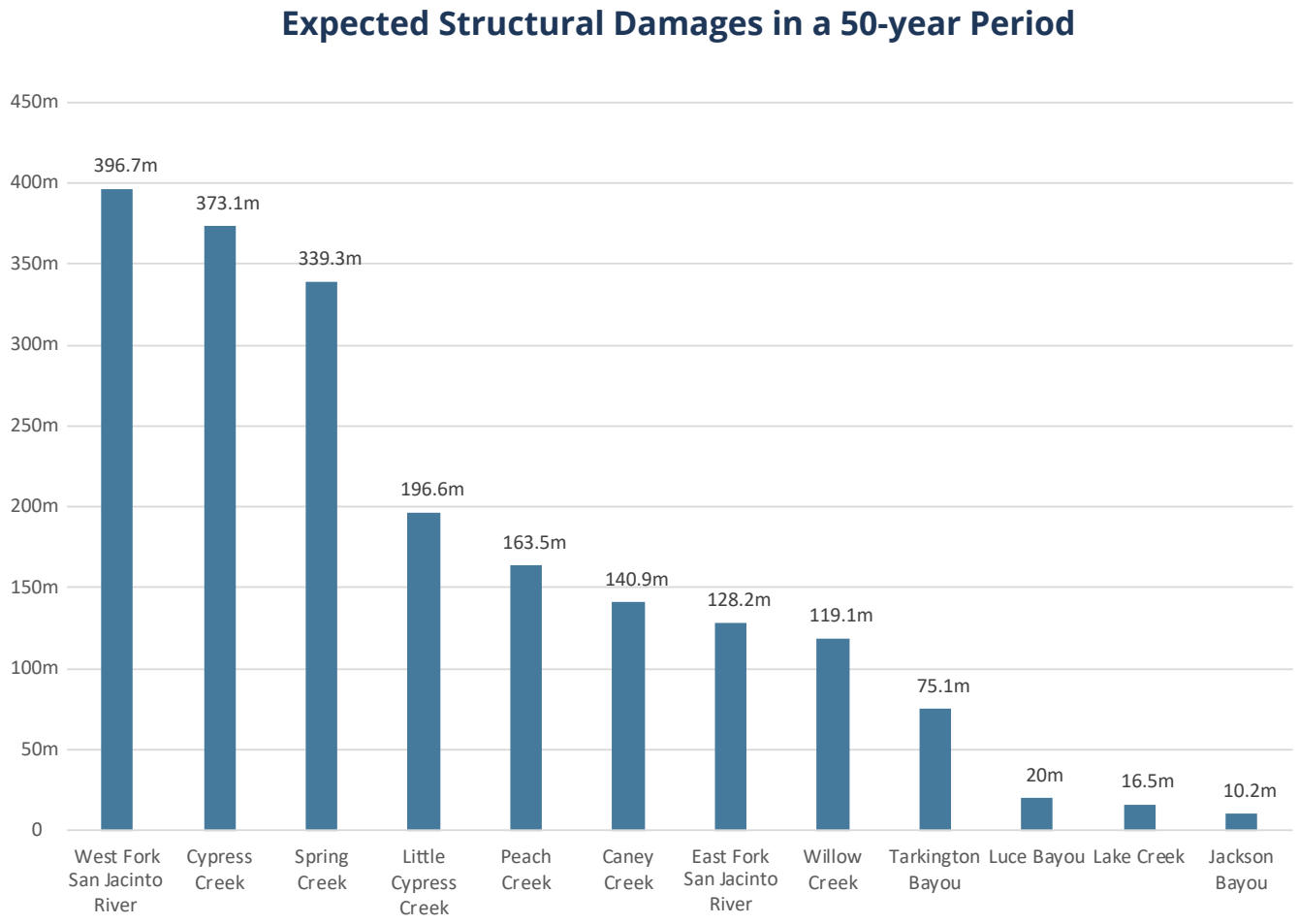


FIGURE 1.5, PREDICTED INSTANCES OF FLOODING



MAP 1.3, HISTORICALLY FLOODED AREAS

TABLE 1.4, DAMAGES IN A 50-YEAR PERIOD



The study results indicate that the flood risk for the watershed is greater than shown in current FEMA flood maps. Consideration should be given to update the current flood maps in order to inform the public of potential risks.

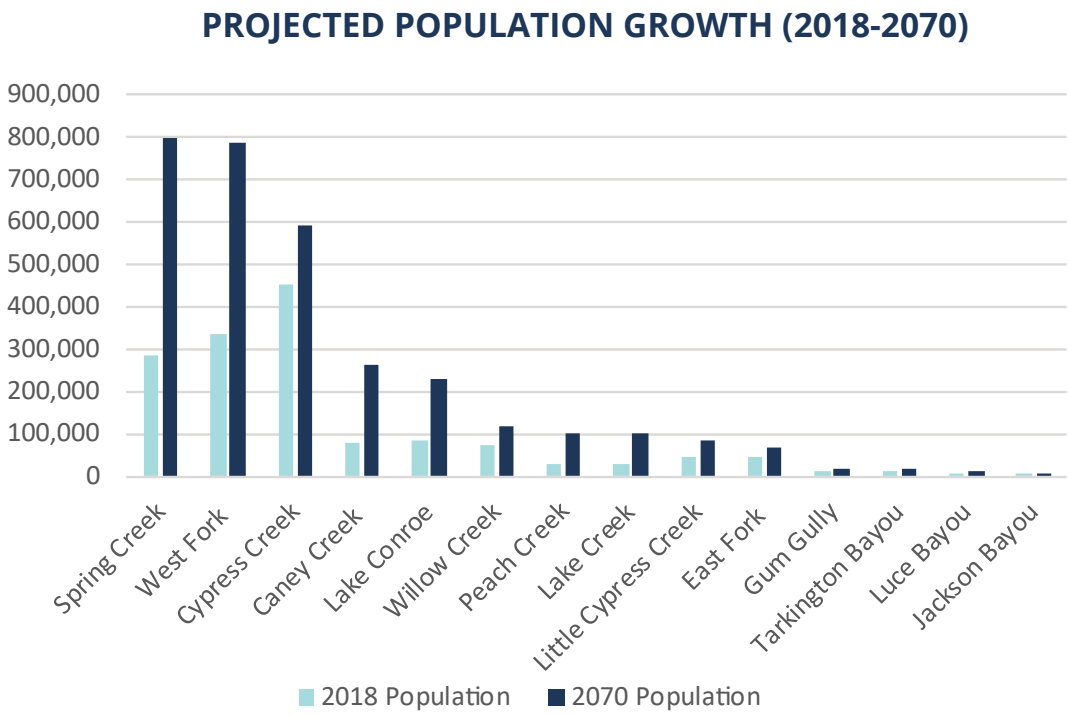
Structural damages represent the predicted cost associated with flooding based on the resulting flood depth at the structure location. The US Army Corps of Engineers (USACE) curves show that structures with higher depth of flooding incur more damage. The cost includes damages to the actual structure, contents, and vehicles for both residential and commercial. These predicted damages were summed based on the frequency of flooding and calculated damage.

EVALUATION OF FUTURE LAND USE CONDITIONS

The Houston Metro area, which includes the San Jacinto watershed, is expected to continue growing in the next several decades. According to Texas Water Development Board (TWDB) State Water Plan, the population could very well exceed 3.2 million by 2070, which would double the current population within a 50 year period. As shown below, the highest growth rates are expected within the Spring Creek, Caney Creek, Lake Conroe and West Fork watersheds. The projected growth could increase the impervious area an average of 30% across the watershed. In more heavily populated basins, the impervious cover could increase close to 20%. An increase in impervious cover results in less ability for rainfall to infiltrate into the ground, potentially increasing the volume of water that flows to channels.

With the anticipated growth, it is important for the regulating agencies to develop consistent drainage and detention criteria to minimize impacts of future development to streams and existing structures. Updating floodplain mapping using new rainfall rates is recommended to regulate development and provide better information for determining flood risk.

TABLE 1.5, PROJECTED POPULATION GROWTH



Population growth projection data was taken from the Texas Water Development Board (TWDB) Regional Water Plan (Region G and H) and from the Regional Groundwater Update Project, sponsored by the Harris-Galveston Subsidence District (HGSD), Fort Bend Subsidence District (FBSD), and Lone Star Groundwater Conservation District (LSGCD).

Improve Resilience 2

FLOOD REDUCTION STRATEGIES

One of the primary goals of the San Jacinto Regional Watershed Master Drainage Plan was to develop flood mitigation strategies to improve long-term resilience. These flood reduction strategies focused on ways that we can physically reduce flooding or remove people from flood risk. Following a watershed wide approach, flood reduction opportunities were developed by reviewing historically proposed flood reduction projects and identified flood damage areas. The flood reduction projects that had been previously proposed by others in historical reports were considered to see if they were implementable.

To start the process of identifying flood reduction strategies, the study team investigated watershed mitigation potential. This helped to determine what subwatersheds are the most likely candidates to provide not only local benefits, but regional benefits as well. The analysis considered the availability of open land to construct large detention basins, the potential flood reduction resulting from the basin, and the regional reduction in flood vulnerability downstream. This high-level analysis of the watershed mitigation potential determined that Spring Creek, East Fork San Jacinto, Caney Creek, Peach Creek, and Lake Creek are the subwatersheds that could both benefit locally from regional detention facilities and provide reductions in water surface elevations through the larger region. The flow volumes from each watershed that contribute to Lake Houston in a modeled 1% ACE event are shown below. Spring Creek and East Fork, which receives flow from Peach and Caney Creeks, are among the highest contributors (Figure 1.7).

Since The 1943 Master Plan, more than 30 projects have been proposed to reduce flood risk and/or provide water supply in the watershed. These historical projects primarily consisted of water supply reservoirs and reports did not provide any information regarding the location or magnitude of expected benefits for the proposed reservoirs. The projects generally had minimal flood mitigation storage.

Basins with highest potential for local and regional flood reduction

- **Spring Creek**
- **East Fork San Jacinto**
- **Caney Creek**
- **Peach Creek**
- **Lake Creek**

100-year Frequency Storm Event
Lake Houston Inflow Volume = 620 Billion Gallons

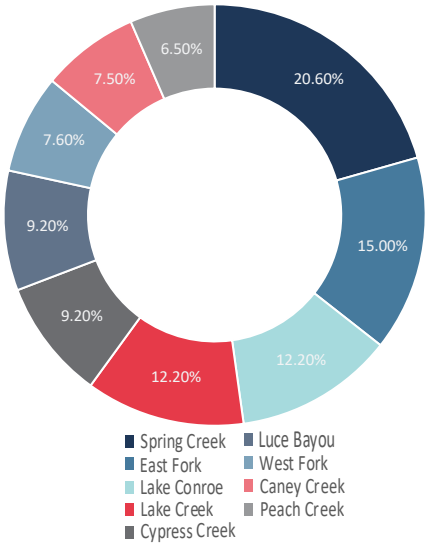


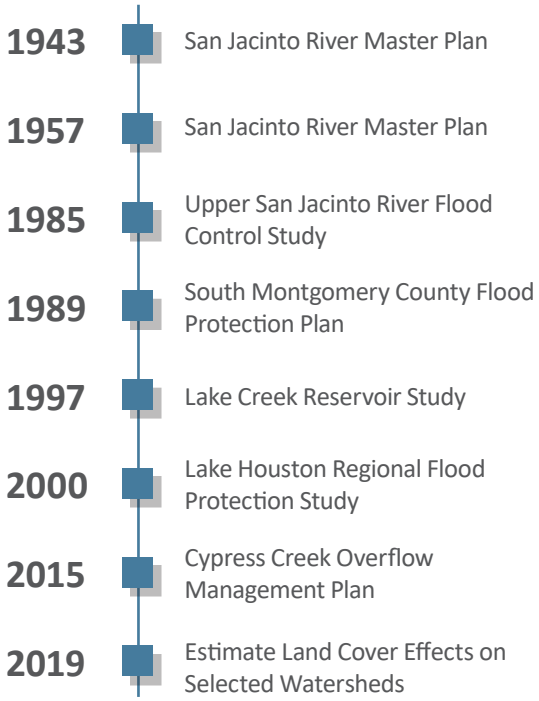
FIGURE 1.7, 100-YEAR FREQUENCY STORM EVENT

REVIEW OF DATA AND PREVIOUS PLANS

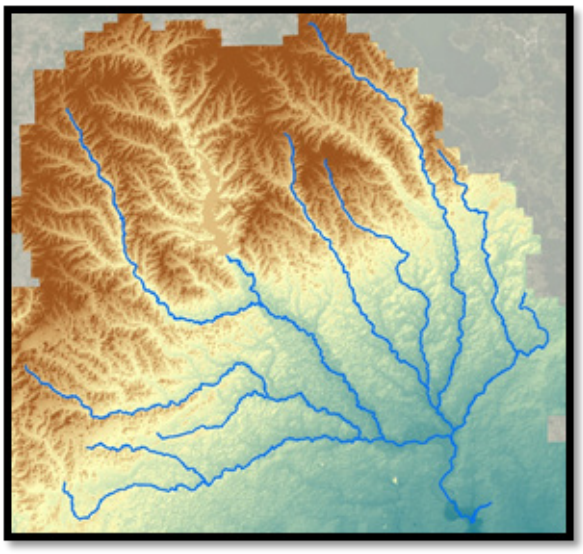
Several historical drainage studies for the watershed were reviewed as part of the San Jac study. These reports focused on analysis of the existing flood conditions and potential flood reduction alternatives, improvements aimed at managing the region's water supply, and evaluations of the potential impacts of sedimentation. These reports helped provide the team with a comprehensive understanding of the purpose and goals of past studies and identified proposed alternatives that were previously considered.

The reports assisted in the development and evaluation of flood mitigation alternatives as part of the master drainage plan. Each report was reviewed for pertinent information related to the master drainage plan, the alternatives considered and evaluated, and any final recommendations. The reports identified more than 30 potential flood reduction and water supply projects, with the majority of those coming from the 1943, 1957, and 1985 studies.

FIGURE 1.6, PREVIOUS STUDIES TIMELINE



MAP 1.4, REGIONAL CREEKS, RIVERS, AND LAKES (1957)



MAP 1.5, LIDAR TERRAIN DATA (2017/2018)

STRUCTURAL SOLUTIONS

With respect to large-scale flood reduction efforts, the study focused on two primary approaches; detention storage and channel conveyance improvements. After reviewing historical proposed projects, a total of 25 flood reduction projects were developed by the study team and conceptually modeled. These consisted of large dry-bottom inline detention facilities along the mainstem or tributary of one of the studied streams. Locations for channelization or channel benching of various streams were also identified.

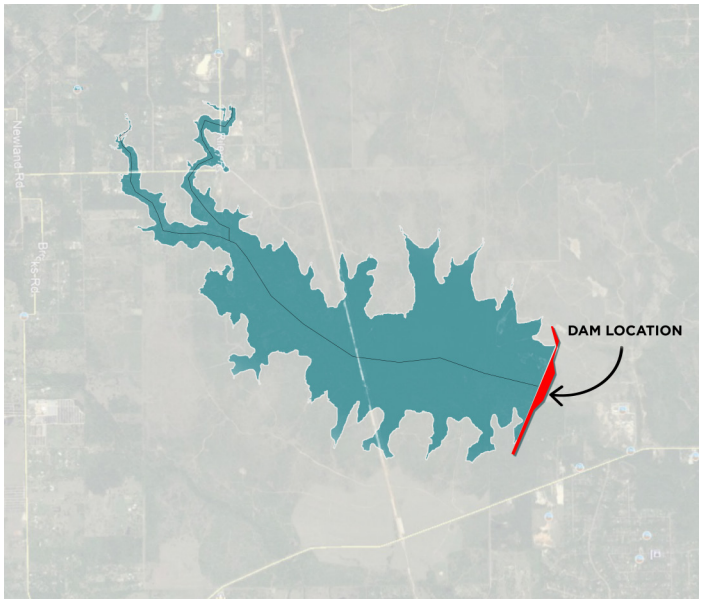


FIGURE 1.8, EXAMPLE INLINE DETENTION BASIN

Detention

Detention basins are man made impoundments that capture runoff, hold it, and release it at a lower flow rate. The result is lower water surface elevations downstream. For the purpose of this regional planning effort, the detention basins were modeled to optimize the flood damage reduction benefit to the main channels only.

Channel Improvements

Channel conveyance increases are accomplished through channel improvements. Excavation in the channel allows for more flow capacity and lower flood elevations. Channel improvements can provide significant reductions in flood elevations in the immediate project area. A similar option is channel benching, which widens the conveyance area by excavating above the normal channel bottom and outside the banks. The benching approach can minimize natural channel disturbance and protect natural habitat.

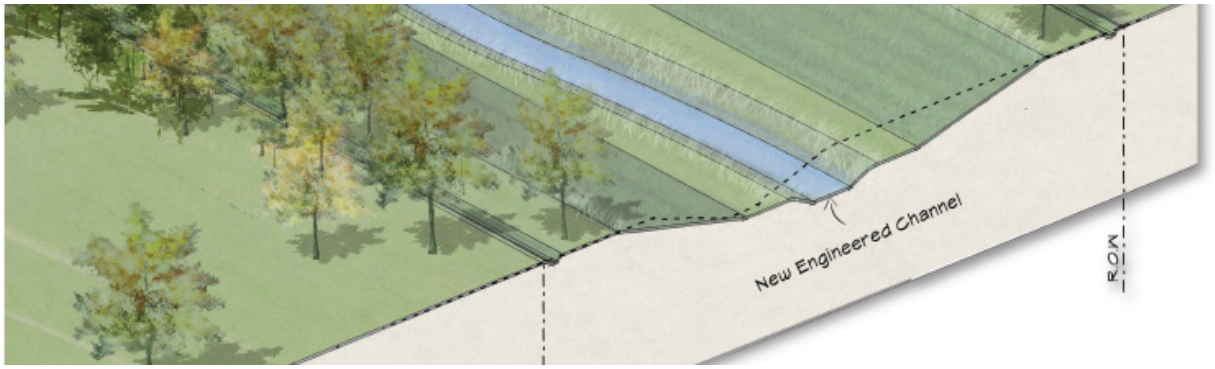
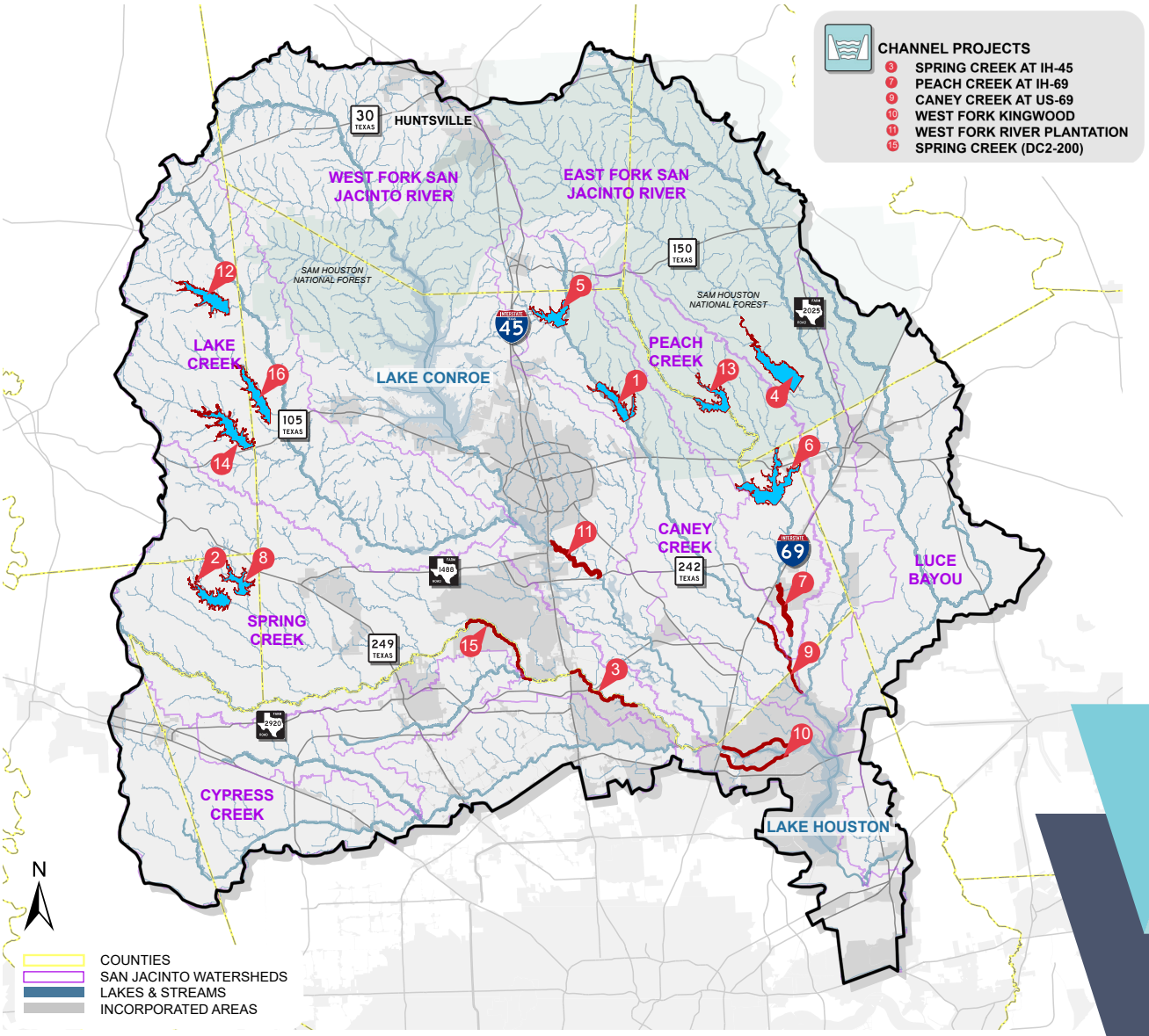


FIGURE 1.9, EXAMPLE CHANNEL IMPROVEMENT SECTION

RECOMMENDED FLOOD REDUCTION PROJECTS

Of the 25 projects evaluated, 16 were included in the long-term flood reduction plan. These are shown in red and numbered in the map below. The plan includes 10 large regional detention facilities comprising approximately 229,000 ac-ft and six channel projects covering about 38.5 stream miles.



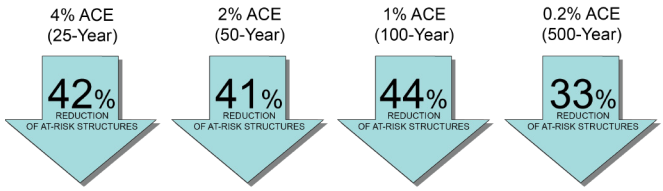
MAP 1.6, PROJECT LOCATION MAP

POTENTIAL FLOOD REDUCTION BENEFITS

With the implementation of the recommended projects, there are significant channel water surface elevation reductions expected at various points throughout the San Jacinto River Watershed. Along the West Fork, water surface elevation reductions for the 1% ACE storm range from 1.7 feet at SH99 to 6 feet at IH-45 and 5 feet at US59. Along the East Fork, reductions range from nearly 10' at the Peach/Caney confluence to nearly 3' at the East Fork/Caney confluence. These are significant changes in elevation that will reduce flood risk to a high percentage of structures.

The proposed projects will provide tangible benefits, including reduction in the number of at-risk structures for a range of storms as shown in Figure 1.10 below.

FIGURE 1.10, FLOOD REDUCTION BENEFITS



The overall plan (based on current cost estimates) costs between $2.9-$3.3 billion. These improvements result in significant costs, but provide enhancements for a nearly 3,000 square mile area. The estimated benefits to structures over a 50-year period are $755 million. The projects not only reduce structural flooding, but also improve roadway mobility during storm events and may facilitate growth by reducing the amount of flood prone property.

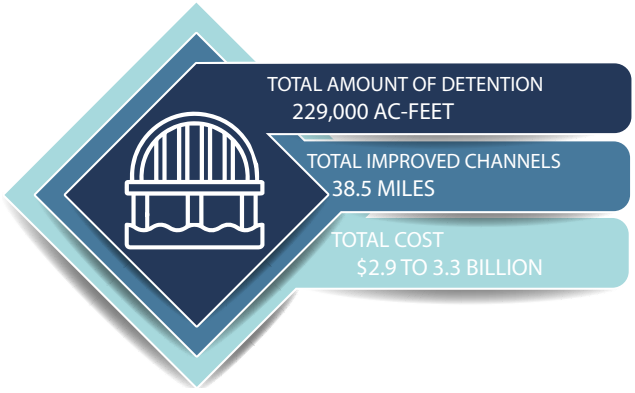


TABLE 1.6, FLOOD ELEVATION REDUCTIONS

San Jacinto River Master Drainage Plan	Combined 1% ACE WSEL Reductions (ft)
Confluence with Lake Creek	-2.38
West Fork I-45	-5.94
West Fork SH99	-1.67
West Fork I-69	-5.07
Lake Houston Parkway *	-0.75
Lake Houston Dam	-0.59
Confluence with Spring Creek	-4.82
Caney Confluence with Peach	-9.74
Caney Confluence with East Fork	-2.82
Confluence with East Fork	-0.79
*** WSEL influenced by Lake Houston Elevation**	

The structural flood mitigation projects above show that there is a high degree of improved protection up to and above the 100-year event if they are implemented.

POLICY RECOMMENDATIONS

STORMWATER DETENTION

Local detention is a critical flood mitigation tool for both development and capital projects. Allowing local development or drainage improvements to go undetained could potentially result in additional sheet flow, overburdened storm sewer systems, and higher water surface elevations in smaller streams that could exacerbate existing flood problems or create new ones. Many jurisdictions within the upper region of the San Jacinto Watershed have local detention policies in place to mitigate increases in impervious areas that result from building structures, streets, and parking lots. These local detention ponds can help offset the increase in flow from rain that cannot infiltrate into the ground.

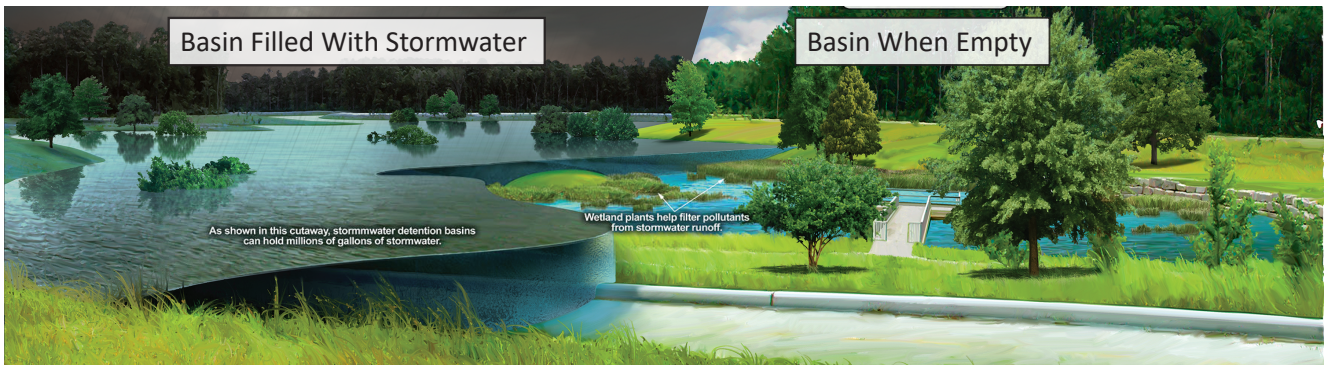
Detention has been demonstrated to be a valuable tool in the flood mitigation toolbox, both at a local and regional level. However, the study team found that there are some inconsistencies between jurisdictions for rainfall-runoff calculations and in the way that detention policies are implemented.

As the watershed continues to develop, counties and municipalities can help protect properties by implementing common detention criteria that limit post-development runoff rates to pre-development runoff rates in a consistent manner. Enforcing these local detention policies provides a significant local benefit to neighboring properties that could otherwise be harmed by more frequent flooding. Rainfall events are not bound by political boundaries.

The study team recommends that local jurisdictions consider adopting and implementing the following:

- Local policies that require detention for all new development and for capital improvements projects that increase conveyance;
- Requiring drainage analyses for development and capital improvement projects that demonstrate no adverse impact
- Requiring analyses be performed for multiple storm events ranging from frequent to infrequent to ensure sufficient detention is provided to prevent impacts.
- Using common criteria when analyzing detention and floodplain analysis being mindful that runoff does not consider political boundaries

FIGURE 1.12, HOW STORMWATER DETENTION WORKS



FLOODPLAIN PRESERVATION AND BUYOUTS

Floodplain preservation is another important measure that can help prevent increased risk of flooding as the region grows. The best way to protect people and property from flooding is to avoid building in those areas. It is well known that building in the floodplain without mitigation can create negative impacts upstream, and certainly downstream of the fill or development site.

That being said, preventing landowners from developing in the floodplain may not always be a feasible solution and the cost of acquiring ROW can be very high for public entities. The estimated property value in the 100-year floodplains, just along these major streams in the San Jacinto Watershed, is between $2-3B based on current appraisal data. The study recommends consistent policies across the various jurisdictions in the San Jacinto watershed that encourage limiting development in the floodplain, acquiring floodplain property when it is available, and requiring that fill placed in the floodplain be mitigated, so that adverse impacts can be avoided.

Another option is buyouts. During the course of the study, it quickly became apparent that, while the recommended projects could provide substantial benefit, many structures will still be at risk of flooding given their location and elevations. Structures at risk from inundation during the 50% and 20% ACE storm events, may see a reduced frequency of flooding but will likely continue to flood during longer or more intense storms.

In some cases, it is more cost-effective to buyout frequently flooded properties. Just as a point of reference, the estimated buyout costs of structures at risk from the 2- and 5-year storms just along these major streams to be approximately $190M. This study acknowledges that there is more to buyouts than just the cost because these are people's homes and businesses. **However, a comprehensive buyout strategy that includes communication with the property owners is an important step to eliminating these flood risks.**

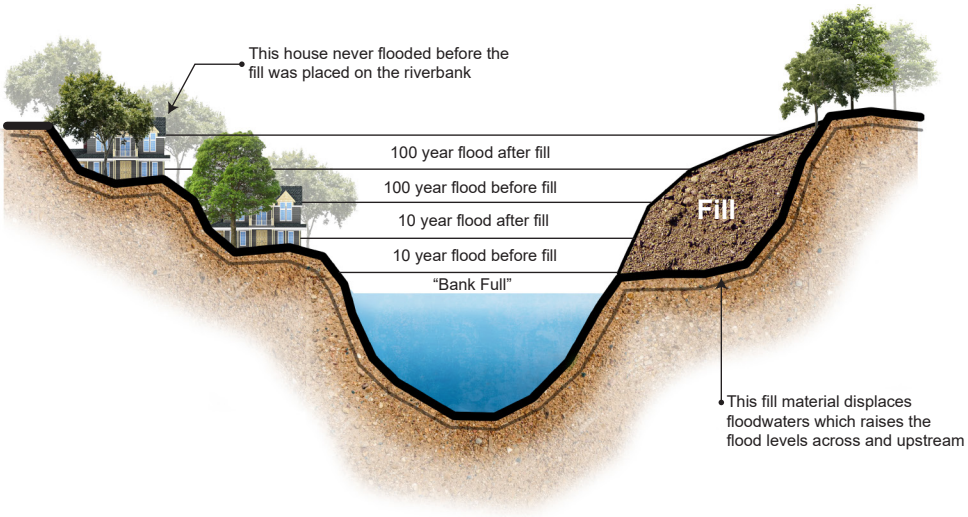


FIGURE 1.13, FLOODWATER DISPLACEMENT

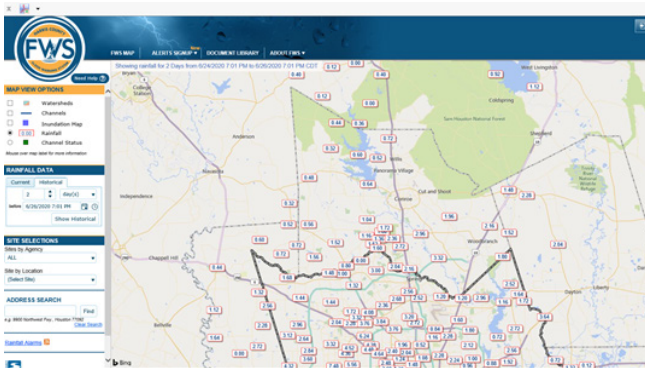
FLOOD WARNING PLANNING

While some areas are more prone to flooding than others, the establishment of flood warning systems near any major waterway or body of water provides critical information that can protect property and save lives. Stream gages are monitored by qualified staff and carefully designed procedures to provide the earliest warning about whether a flood should be expected, when it will occur, and how severe it will be.

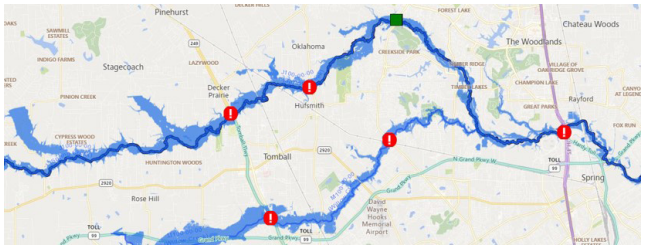
Flood Warning planning focused on expanding the flood warning capabilities that are already available in the San Jacinto watershed. The Harris County Flood Warning System (HCFWS) has a robust gage network within the county and the immediate surrounding area. SJRA has many of its own gages that are accessible through the HCFWS as well. Including the USGS there are rainfall gages, elevation gages, and flow gages, all of which provide valuable information and more lead time for emergency mangers and the public to make decisions during a flood event. In addition, the Flood Warning System includes inundation mapping capabilities as shown in the graphic, which shows portions of Spring and Willow Creeks during Hurricane Harvey. The modeling developed as part of this study could be leveraged to expand inundation mapping into the San Jacinto watershed.

The study team assessed the current HCFWS and identified additional rainfall, stage, and flow gage locations to be considered. With nearly 190 gages in the system, the majority in Harris County, the team considered areas outside of Harris County that contribute to the San Jacinto River and ultimately flow through Harris County. Local counties and agencies responsible for emergency management were consulted during this process.

MAP 1.7, HARRIS COUNTY FLOOD WARNING SYSTEM



www.harriscountyfws.org



FLOOD RESPONSE PLANNING

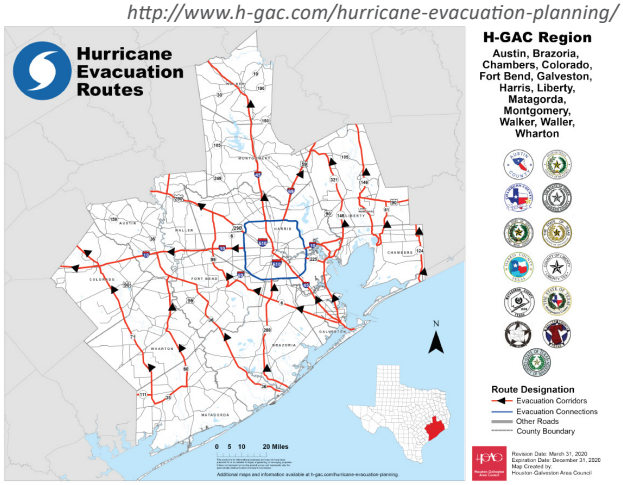
The purpose of flood response planning was to evaluate the current emergency management procedures in the watershed. Meetings were conducted with emergency managers from across the region and included discussions about their current protocols for both internal and public communication. In addition, the potential for flooding of critical infrastructure and roadways, including evacuation routes, was evaluated.

Based on the study, several recommendations were made for improvements to:

- Documentation and Staffing
- Communication (Internal and External)
- Flood Monitoring Capabilities
- Public Education

The investigation of critical infrastructure focused on city and county facilities, police stations, fire and EMS stations, public works facilities like water and wastewater treatment plants, hospitals, and others. Of the 1,460 facilities that were classified as critical, 239 of them are potentially at risk from flooding during a major storm, such as Hurricane Harvey. An evaluation of roadway flooding throughout the watershed looked at all types of roadways, including those classified as evacuation routes. The study findings show that four potential evacuation route crossings may be susceptible to flooding during a flood event.

http://www.h-gac.com/hurricane-evacuation-planning/



MAP 1.8, HOUSTON-GALVESTON AREA COUNTY HURRICANE EVACUATION ROUTES

FIGURE 1.14, FLOOD RESPONSE PLANNING

4
Evacuation Routes At risk for a 1% ACE event

1460
Critical facilities such as city/county facilities, police, fire, EMS, W/WWTP and hospitals in the San Jacinto Watershed

239
Critical facilities at risk of flooding during a 0.2% ACE storm

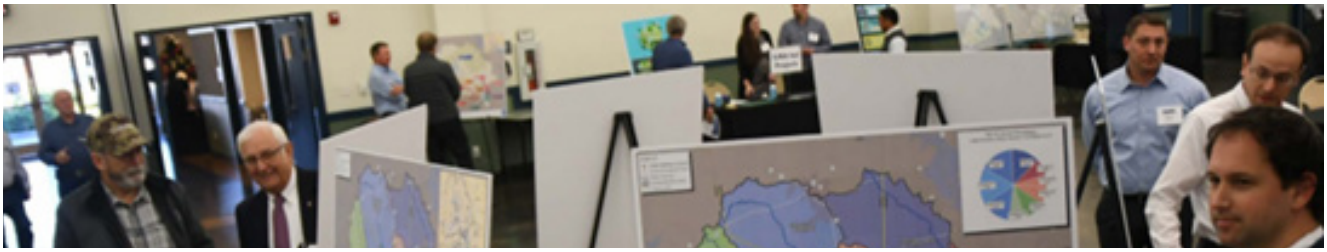
COMMUNITY STAKEHOLDER AND PUBLIC ENGAGEMENT

Community Stakeholder and public engagement is essential for the plan's success. The partners met monthly with other stakeholders to review progress and provide feedback. The team hosted three public open houses (Tomball, Kingwood, and Huffman) in December 2019 to encourage public participation and input in the SJMDP and provide information about other ongoing study efforts in the San Jacinto River Watershed. Over 200 people attended the meetings.

In August 2020, a second public engagement forum was held. In response to the COVID pandemic, the forum was held virtually and drew more than 265 participants. The study team received more than 179 comments from the public covering a range of topics. Some of the specific questions are included below in the Community Input Summary.

COMMUNITY INPUT SUMMARY

- Concerns regarding localized flooding issues
- Concerns regarding drainage blockage under FM 2100
- Requests to include communities located in the I-10 area in the study
- Comments both in support of and against the Lake Conroe temporary seasonal lake lowering program
- Requests to build gates on Lake Houston to reduce flooding
- Requests to deepen the river south of Lake Houston to increase the amount of water it can move to the Houston Ship Channel
- Concerns that sandmining and silting of rivers are making flooding worse
- Concerns that not enough is being done to protect businesses in the Kingwood Town Center area



PROJECT IMPLEMENTATION

With the vulnerabilities to flood hazards identified and flood mitigation strategies recommended, a clear path to project implementation is needed to move the master drainage plan forward. The master drainage plan identifies both policies and projects that can be implemented within the San Jacinto Watershed to reduce flood risk. The recommendations are categorized into short term and long term solutions.

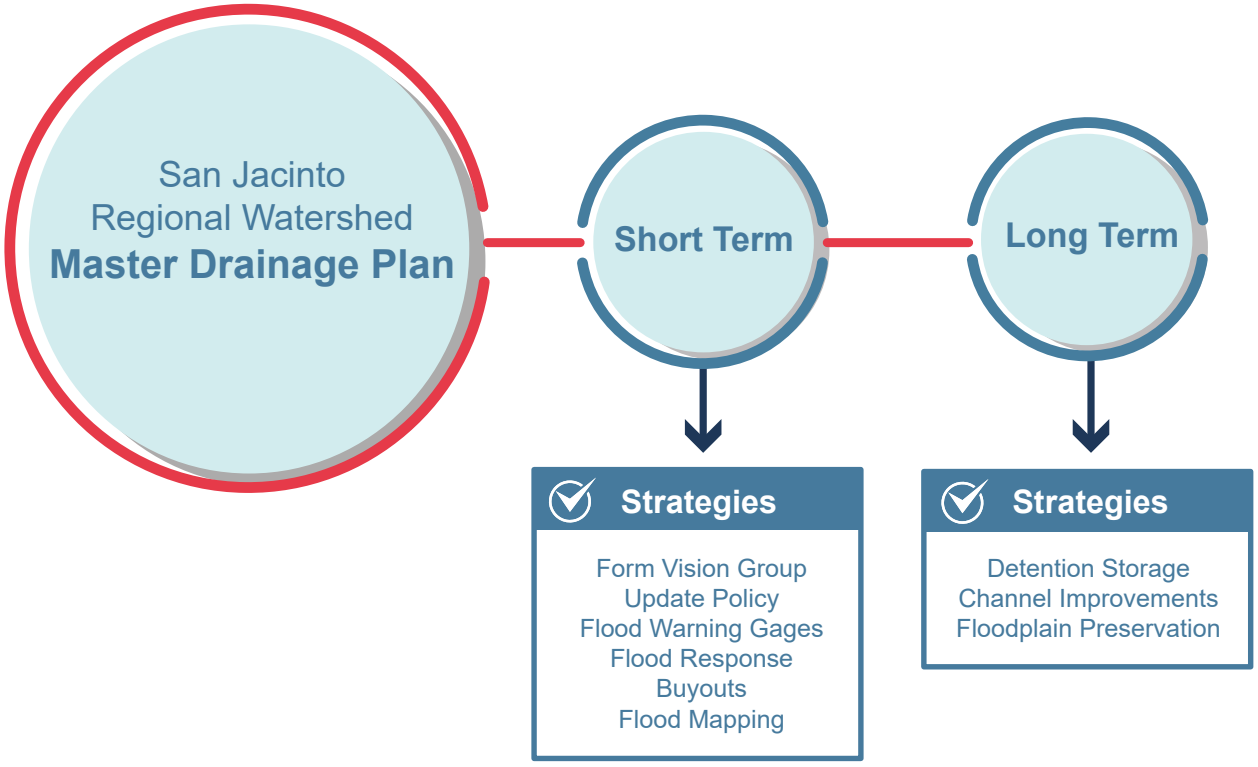


FIGURE 1.15, PROJECT IMPLEMENTATION

SHORT TERM SOLUTIONS

Short term solutions are ones that can be implemented within the next five years and require less funding or constraints for implementation.

- **Vision Group.** Forming a San Jacinto River Vision Group would promote collaboration amongst the various jurisdictions and interests in the watershed and help maintain the momentum of the study toward implementation. The Regional Flood Planning Groups as part of the State Flood Plan effort would be well suited to fulfilling the role of the vision group. This study will be submitted to the RFPG for their review and consideration
- **Policy**. While a word for word criteria may not be needed for each entity, a common base criteria for the San Jacinto Watershed would standardize the minimum requirements needed for future development. Policies that could be standardized would include: detention methodology requirements; hydrology and hydraulics methodology; floodplain analysis, and minimum finished floor elevations.
- **Floodplain Preservation.** Identify areas along major streams that could be set aside as conservancy areas to preserve the floodplain and prevent increase in flood risk.
- **Flood Monitoring/Warning Enhancement**s. Add rainfall and stage (elevation) gages to provide both emergency managers and the public with additional information to determine flood risk.
- **Flood Response**. Improve flood response by enhancing communication, identifying and prioritizing flood prone areas, and developing public education strategies.
- **Buyouts**. Acquiring the property and removing it from the floodplain and from potential flood risk is often the most cost-effective approach. There are over 400 structures identified within the 5-year floodplain at an estimated assessed value of $190 million dollars. The counties and regional groups should seek funding to develop a voluntary buyout program for these frequently flooded structures.
- **Floodplain Re-Mapping**. The updated modeling for the existing flood hazard assessment showed that current elevations and floodplains used within the basin are outdated. The 1% ACE (100-year) water surface elevations increased between 0.5 and 4.5 feet in the watershed meaning structures built to current standards could still be within the 1% ACE and are susceptible to flooding. Re-mapping the watershed would provide the agencies and public updated potential flood risk. The development of flood risk maps beyond the regulatory floodplain should also be considered.
- **Watershed Protection Studies**. Watershed protection studies for each of the San Jacinto Sub-Watersheds would further identify the flooding potential on the tributaries of the main streams and identify local drainage improvements needed. A recommended priority of studies would be Spring Creek, West Fork, Caney Creek, Peach Creek, Lake creek, Luce Bayou, and East Fork.

LONG TERM SOLUTIONS

Long term solutions consist of the recommended projects which will take longer than 5 years before implementation due to funding, environmental permitting, construction time, and other project constraints (Figure 1.16). The San Jacinto Regional Watershed Master Drainage Plan represents an important first step in the project life cycle; Planning. This effort lays the groundwork for future success. The next phases include Project Definition and Project Construction (Figure 1.17). The timeline on each of these phases may vary depending on a variety of factors; however, in general project definition should take between 2 and 5 years once started and project construction including property acquisition, permitting, and design may take 10 years or more. Funding is needed for each phase and will be a critical element of moving projects forward.

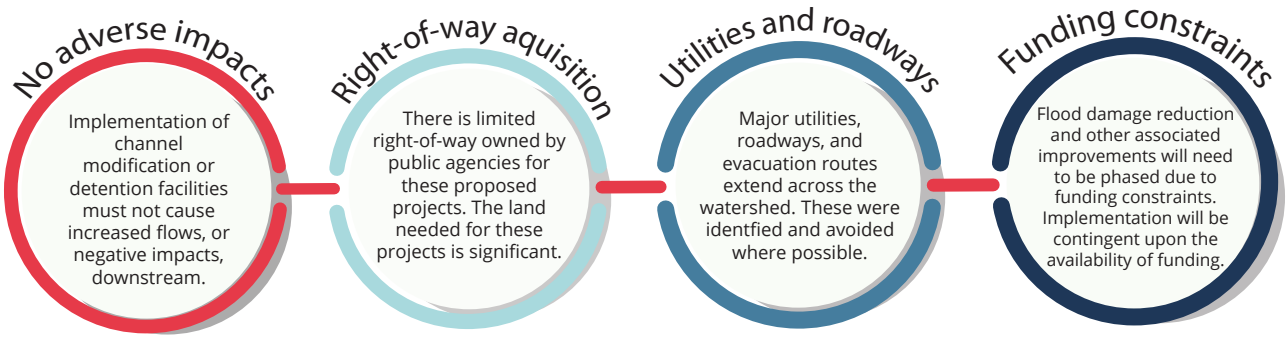


FIGURE 1.16, PROJECT CONSTRAINTS

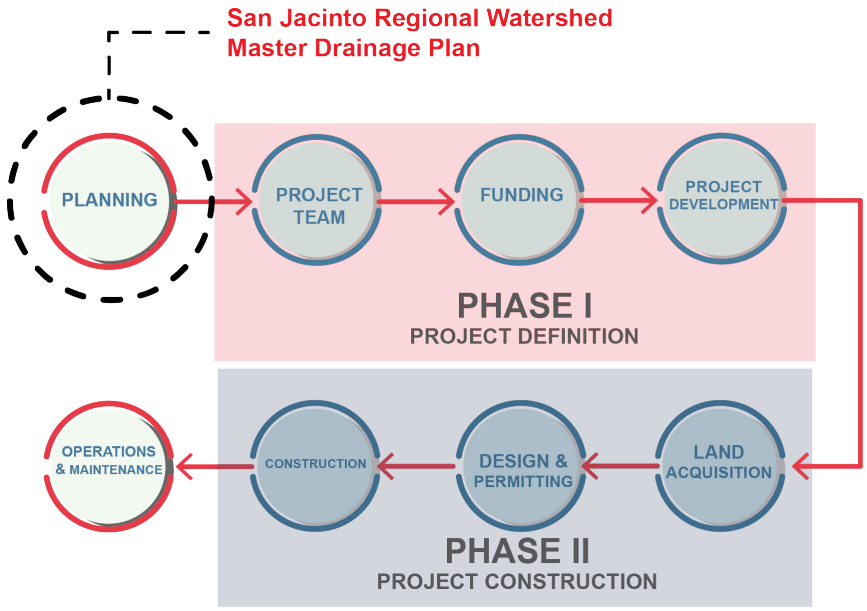


FIGURE 1.17, PROJECT PHASES

PROJECT SCORING AND RANKING

The Master Drainage Plan recommends that 16 projects could be implemented to reduce vulnerability to flood hazards on the main channels and improve watershed resilience. The study team evaluated several metrics to be considered in the ranking of the projects. The metrics considered are as follows: historical damages in the basin, predicted damages in the basin, the reduction structural flooding instances, the number of structures removed from flooding, the benefit to cost ratio of the project, the improvement to roadway mobility, benefits to socially vulnerable areas, benefits to low-to-moderate income areas, and project costs.

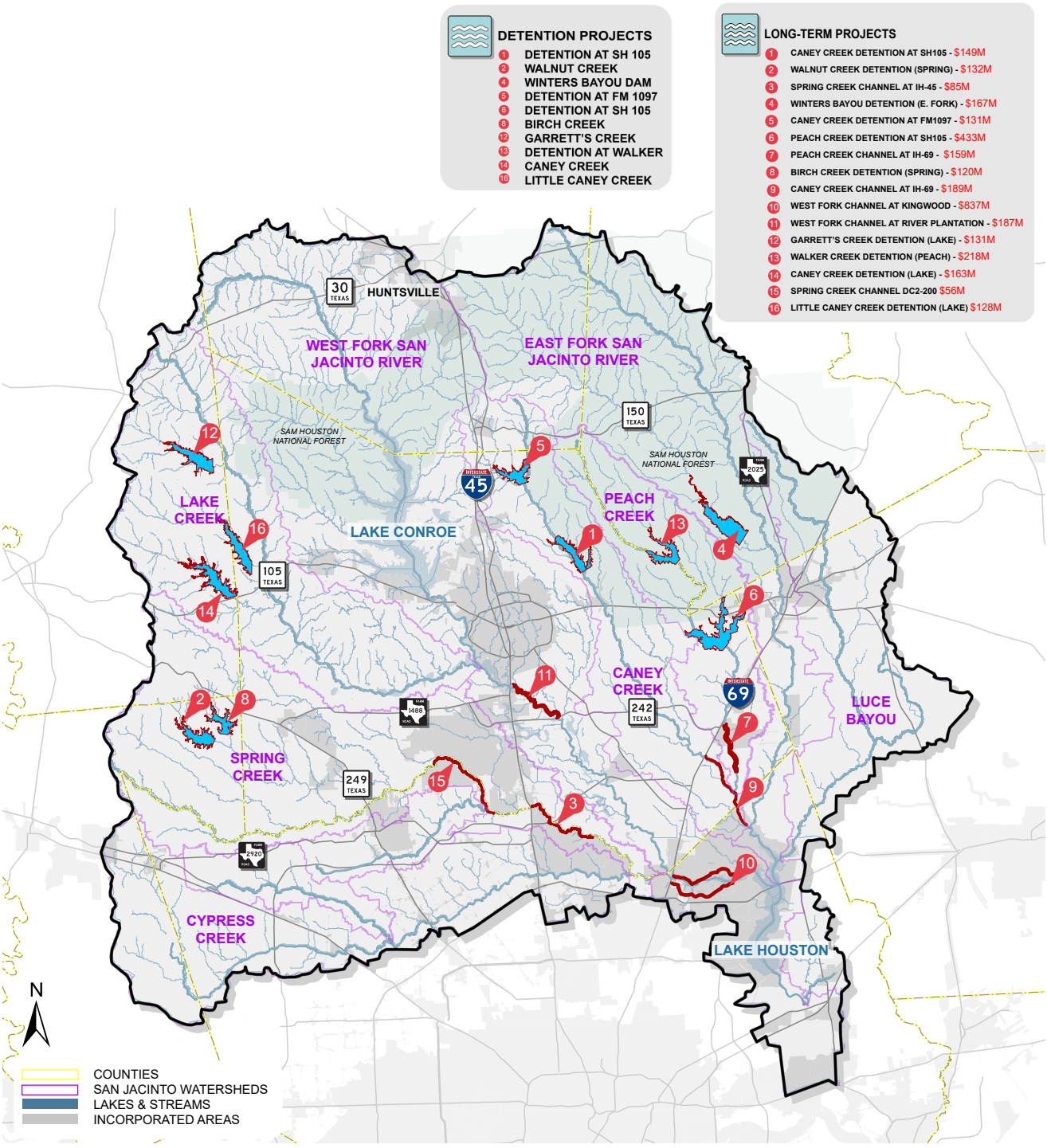
TABLE 1.7, FUTURE PROJECT RANKING

Ranking	Project	Score	Cost ($M) *
1	Caney - Detention at SH 105	3.00	179.0 - 208.0
2	Spring - Walnut Creek Detention	2.60	97.2 - 132.1
3	Spring - I-45 Channelization	2.60	81.2 - 231.0
4	Peach - I-69 Channelization	2.55	161 - 311
5	East Fork - Winter's Bayou Detention	2.40	134.0 - 166.6
6	Caney - Detention at FM 1097	2.25	105.0 - 131.0
7	Spring - Birch Creek Detention	2.10	81.6 - 121.6
8	Caney - US 69 Channelization	2.05	194.0 - 209
9	West Fork - Kingwood Benching	2.05	818.0 - 848.0
10	Peach - SH 105 Detention	1.75	356.0 - 433.0
11	West Fork - River Plantation Channel	1.75	148.0 - 593
12	Lake - Garret's Creek Detention	1.55	107.0 - 131.0
13	Peach - Walker Creek Detention	1.30	201.0 - 218.0
14	Lake - Caney Creek Detention	1.25	98.0 - 163.0
15	Spring - DC2-200 Channelization	1.05	53.6 - 203
16	Lake - Little Caney Creek Detention	0.95	98.0 - 128.0

* The costs are based on a range of ROW needs upstream of the proposed dam and will depend on the level of flood protection that is feasible.

PROJECT LOCATION MAP

Sixteen large flood mitigation projects have been prioritized to reduce flood risk across the watershed.



MAP 1.9, PROJECT LOCATION MAP

PROJECT FUNDING SOURCES

As projects move forward, there may be opportunities to leverage multiple funding sources, including through federal and state grant programs. The study team identified numerous potential grant funding sources. Each grant program may have different requirements for project type, administration and procurement procedures, and environmental and socio-economic requirements. Evaluation of these funding opportunities and applications for specific grants or other sources will be conducted during the implementation phase. While the availability of the various funding sources may change from year to year, having a plan in place with defined projects and benefits will allow the communities to take advantage of funding opportunities when they are presented.

POTENTIAL FUNDING SOURCES

FEDERAL

- FEMA
- US Housing and Urban Development (HUD)
- Natural Resource Conservation Service (NRCS)
- Environmental Protection Agency (EPA)

STATE

- General Land Office (GLO)
- Texas Water Development Board (TWDB)

LOCAL

- Bonds
- Ad Valorem Taxes
- Tax Increment Reinvestment Zones

Another option is to fund projects through local sources. These could include local tax revenue, bond funding, special purpose districts or other mechanism. Given the estimated costs of these projects, partnerships among the local jurisdictions who benefit are recommended. The graphic below from HCFCD shows that there are a variety of funding sources from a number of state and federal agencies that can be used to fund portions of the recommended projects.

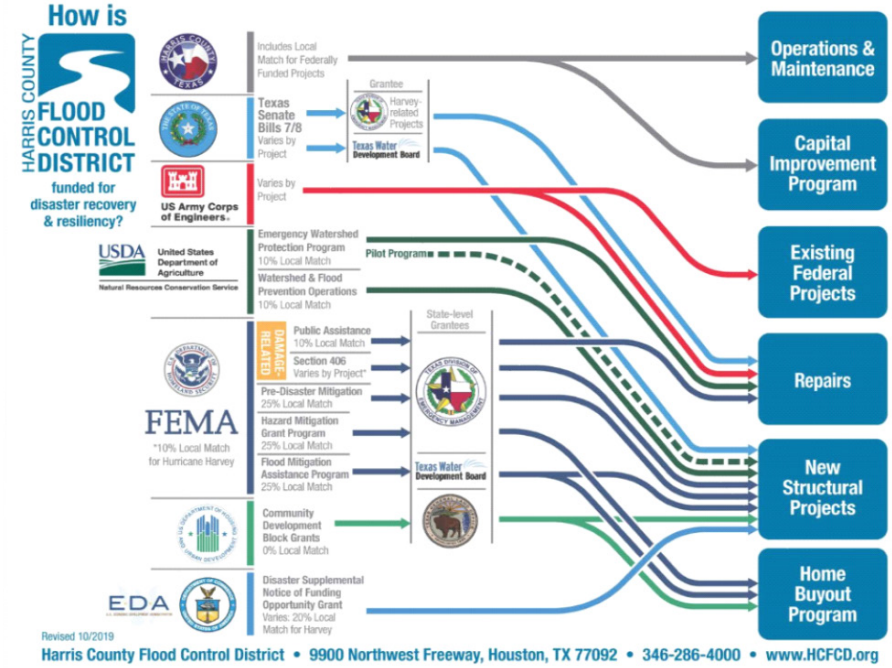


FIGURE 1.18, HCFCD FUNDING DIAGRAM

NEXT STEPS

The purpose of the San Jacinto River Regional Watershed Master Drainage Plan is to identify the basin's vulnerability to flood hazard, develop approaches to enhancing public information and flood level assessment capabilities, and recommended flood mitigation strategies for both the near and long-term and develop a comprehensive Flood Mitigation Plan that supports all regional partners. The next steps for the region and stakeholders include:

- Establishing a Vision Group to set both short term and long term goals for the region.
- Submitting this study to the regional flood planning group for inclusion in the Texas State Flood Plan.
- Identifying a Regional Facilitator to coordinate flood mitigation projects, policy, and procedures.
- Coordinating to develop common drainage criteria for hydrology, detention, and floodplain analysis.
- Installing rainfall, stage, and discharge gages to enhance the existing flood warning capabilities.
- Continuing a coordinated response among emergency managers during flood events.
- Developing a voluntary buyout program for frequently flooded structures.
- Re-mapping the floodplain within the basin for Atlas 14 rainfall consistency and accuracy of existing flood hazard.
- Developing watershed protection studies for the tributaries into the major streams to identify the flood risk and assess potential flood mitigation strategies.
- Developing a project team for each of the identified regional projects to assist in the implementation.

SAN JACINTO
REGIONAL WATERSHED MASTER DRAINAGE PLAN

HALFF

Halff Associates
14800 St Marys Ln, Suite 160
Houston, TX 77079
(713) 588-2450

FREESE AND NICHOLS

Freese and Nichols
10497 Town and Country Way, Suite 500
Houston, TX 77024
(713) 600-6800