SAN JACINTO

REGIONAL WATERSHED MASTER DRAINAGE PLAN

Prepared for:
Harris County Flood Control District
San Jacinto River Authority
Montgomery County
City of Houston

REPORT

San Jacinto Regional Watershed
Master Drainage Plan
REPORT

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by

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Executive Summary

In August 2017, Hurricane Harvey struck the Texas coast, bringing a historic amount of rainfall to the Houston metro region. The storm produced unprecedented precipitation depths in Harris and Montgomery Counties, as well as several surrounding counties. Like other watersheds in the region, the San Jacinto River basin experienced widespread flooding which resulted in loss of life, significant property damages, and disruption to people's livelihoods.

In the wake of the storm, the Harris County Flood Control District (HCFCD), San Jacinto River Authority (SJRA), Montgomery County (MOCO), and the City of Houston (COH) recognized the need to mitigate and prevent structural flooding and improve coordination, communication, and response among the responsible agencies along the San Jacinto River during major flooding events. These study partners were awarded a grant through the FEMA Hazard Mitigation Grant Program (HMGP) to perform a comprehensive study of the Upper San Jacinto River basin. The San Jacinto River Regional Watershed Master Drainage Plan (SJMDP) was initiated in order to evaluate the current conditions in the basin and develop a watershed-wide plan to address the flood-related needs of the region.

The goals of the plan include: Identifying the region's vulnerabilities to flood hazards, developing approaches to enhance public information and flood level assessment capabilities during a flood disaster event, evaluating flood mitigation strategies to improve community resilience, and providing a comprehensive flood mitigation plan that supports the needs and objectives of each both the regional partners and the watershed as a whole.

The San Jacinto River drains the northern, or upper, region of the watershed. From its headwaters in Walker County, the San Jacinto River drains 2,880 square miles southeast through Montgomery County to Lake Houston in Harris County. The San Jacinto River then joins Buffalo Bayou at the Houston Ship Channel south of IH-10 before finally emptying into Galveston Bay.

An existing conditions flood hazard assessment was conducted to determine the flood risk for the basin. The calibrated models were simulated with Atlas 14 rainfall and showed that 1% annual chance of exceedance (ACE) discharges increased by an average of 30% from the FEMA effective discharges throughout the basin, and water surface elevations increased by 0.5 to 4.5 feet.

Sixteen structural flood mitigation alternatives are recommended for future implementation. These include large dry dam regional detention facilities and stream channelization. A summary of the recommended options for each watershed including the benefit, cost, and BCR, is provided in the table below. The total cost of the recommended solutions ranges from $2.9 billion to $3.3 billion with a total structural benefit of $731 million when all projects are fully implemented. The regional plan provides a 44% reduction in structures at risk of flooding during a 50-year period for the 1% ACE storm event throughout the San Jacinto River basin.

Additional recommendations include floodplain preservation, buyouts, and detention strategies for mitigating flood risk. Flood warning recommendations include 26 new rainfall, stage, and discharges gages to enhance the existing flood warning network and a list of best management practices from emergency managers throughout the watershed.

Table ES1: Recommended Flood Mitigation Projects

Stream	Alternative	Benefit ($M)[1]	Cost Range ($M)	Benefit-Cost Ratio Range
Spring Creek	Walnut Creek Detention	101.2	97 - 132	0.77 - 1.04
	Birch Creek Detention	66.0	80 - 120	0.55 - 0.83
	Woodlands Channel (200-ft)	34.7	56	0.62
	I-45 Channelization	99.4	85	1.17
Lake Creek	Caney Creek Detention	42.1	98 - 163	0.26 - 0.43
	Little Caney Creek Detention	35.0	98 - 128	0.27 - 0.36
	Garrett's Creek Detention	39.8	107 - 131	0.31 - 0.37
Peach Creek	Detention at Walker	56.3	201 - 218	0.26 - 0.28
	Detention at SH 105	81.5	356 - 433	0.19 - 0.23
	Channelization at I-69	73.6	159	0.46
Caney Creek	Detention at FM 1097	27.7	105 - 131	0.21 - 0.26
	Detention at SH 105	55.2	114 - 149	0.37 - 0.48
	Channelization at I-69	57.4	189	0.30
East Fork SJR	Winters Bayou Dam	63.5	134 - 167	0.38 - 0.47
West Fork SJR	Highway 242 Channelization	45.5	157	0.29
	Kingwood Bench	60.5	837	0.07

The next recommended steps for the region and stakeholders include:

- Establishing a Vision Group to set both short-term and long-term goals for the region such as the newly established TWDB Regional Flood Planning Group
- 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 FEMA regulatory floodplain within the basin for Atlas 14 rainfall consistency and accuracy of existing flood hazard
- Developing watershed protection studies for the tributaries to the major streams to identify the local flood risk, to provide localized regulatory data for future development analysis, and assess potential flood mitigation strategies
- Developing a project team for each of the identified regional projects to assist in project implementation

[1] Benefit is identified over 50-year period and is for each individual project. The complete master plan benefit is slightly less than the sum due to benefit overlap.

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APPENDICES

ABBREVIATIONS AND ACRONYMNS

AC-FT – Acre-feet

BLC – Bayou Land Conservancy

BLE – Base Level Engineering

CDBG-DR – Community Development Block Grants Disaster Recovery

CDBG-MIT – Community Development Block Grants Mitigation

CFS – Cubic Feet per Second

COH – City of Houston

FEMA – Federal Emergency Management Agency

HCFWS – Harris County Flood Warning System

H-GAC – Houston Galveston Area Council

HUD – United States Department of Houston and Urban Development

HMGP – Hazard Mitigation Grant Program

MOCO – Montgomery County

NRCS – Natural Resources Conservation Service

OEM – Harris County Office of Emergency Management

RFC – National Weather Service West Gulf Coast River Forecast Center

RFPG – Regional Flood Planning Group

SJMDP – San Jacinto Regional Watershed Master Drainage Plan

SJR – San Jacinto River

SJRA – San Jacinto River Authority

TWDB – Texas Water Development Board

TxDOT – Texas Department of Transportation

USGS – United States Geological Survey

WWA – Woodlands Water Agency

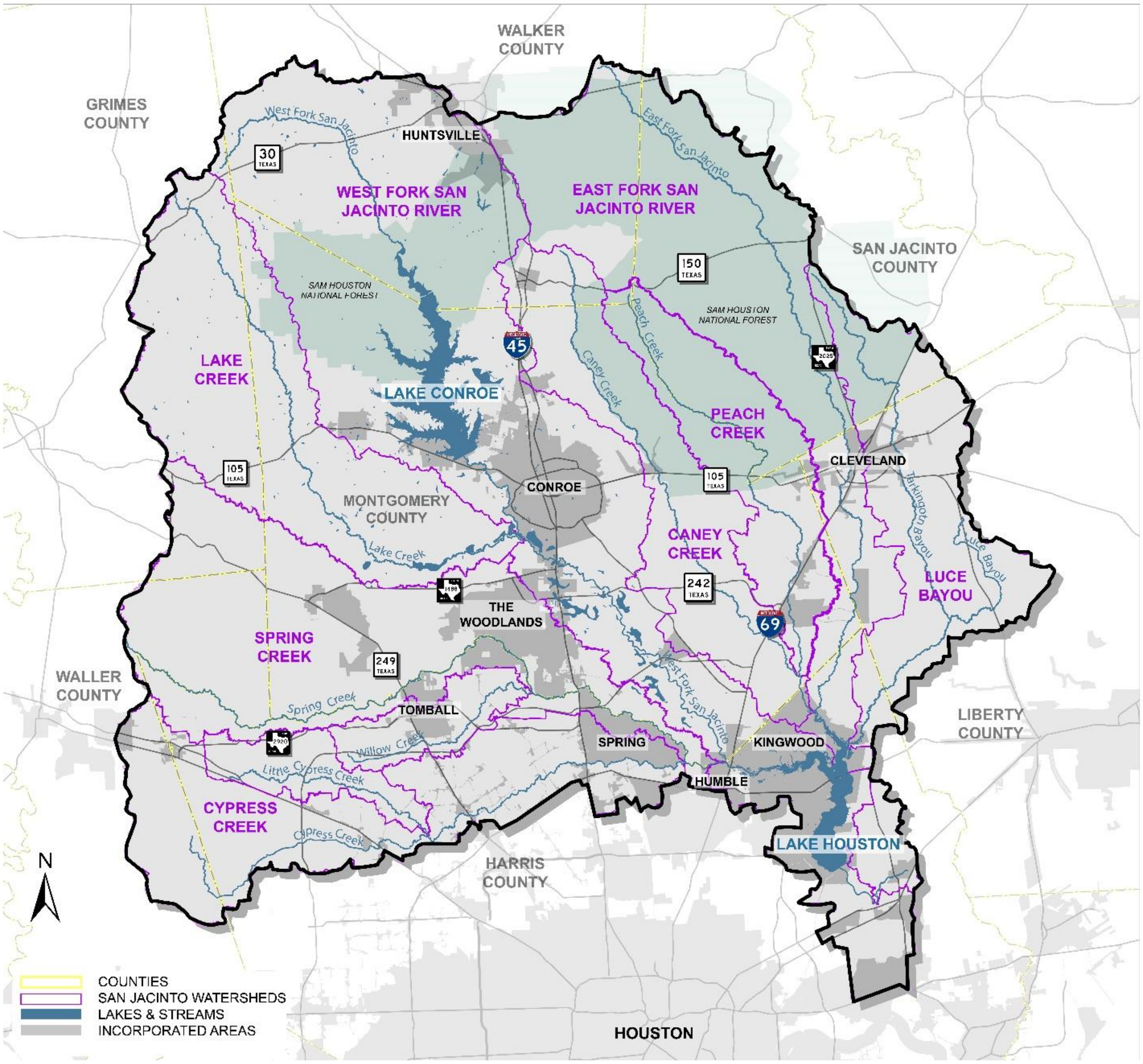


Figure 1: Upper San Jacinto River Basin Map

1.0 Introduction

In August 2017, Hurricane Harvey struck the Texas coast, bringing a historic amount of rainfall to the Houston metro region. The storm produced unprecedented precipitation depths in Harris and Montgomery Counties, as well as several surrounding counties. Like other watersheds in the region, the Upper San Jacinto River basin (**Figure 1**) experienced widespread flooding which resulted in loss of life, significant property damages, and disruption to people's livelihoods.

In the wake of the storm, the Harris County Flood Control District (HCFCD), San Jacinto River Authority (SJRA), Montgomery County (MOCO), and the City of Houston (COH) recognized the need to mitigate and prevent structural flooding and improve coordination, communication, and response among the responsible agencies along the San Jacinto River during major flooding events. These study partners were awarded a grant through the FEMA Hazard Mitigation Grant Program (HMGP) to perform a comprehensive study of the Upper San Jacinto River basin. The San Jacinto Regional Watershed Master Drainage Plan (SJMDP) was initiated in order to evaluate the current conditions in the basin and develop a watershed-wide plan to address the flood-related needs of the region.

1.1 Study Goals and Objectives

The San Jacinto Regional Watershed Master Drainage Plan is a comprehensive regional study led by local partners including the Harris County Flood Control District, the San Jacinto River Authority, Montgomery County, and the City of Houston. The overall goal of the San Jacinto Regional Watershed Master Drainage Plan is to:

> *Conduct a comprehensive flood mitigation master drainage plan of the San Jacinto River Basin's major streams that will identify vulnerability to flood hazards that result in loss of life and property, develop approaches to enhance public information and flood level assessment capabilities during a disaster, and evaluate flood mitigation strategies that can be implemented both near-term and over the long-term to improve community resilience.*

To achieve this goal, the study involves four key components outlined below:

- **Identify** the region's **vulnerabilities** to flood hazards
- Develop approaches to **enhance public information and flood level assessment** capabilities during a flood disaster event
- **Evaluate flood mitigation strategies** to improve community resilience
- Provide a **comprehensive flood mitigation plan** that supports the needs and objectives of each regional partner and provides benefits to watershed communities

More specifically, these key components consist of several scope items, each with a defined set of tasks that were completed in order to provide a comprehensive plan for the basin:

- **Existing Conditions Modeling and Calibration:** Update and prepare new hydrologic modeling for the watershed and develop hydraulic models for each of the major streams included in the study. Leverage recent, high-quality terrain data and Atlas 14, Volume 11 rainfall for the most up-to-date modeling information. Calibrate the storms to two historical events (Memorial Day 2016, Hurricane Harvey 2017) and validate the model with two additional storms

(October 1994, Tropical Storm Imelda 2019) to ensure that the models reflect real-world conditions and to provide confidence in the models as a baseline for evaluating improvements.

- **Sedimentation and Vegetation**: Develop a sediment management strategy to identify opportunities along the West Fork of the San Jacinto River (West Fork) and Spring Creek to decrease sediment deposition in the West Fork channel between its confluence with Spring Creek and Lake Houston.
- **Future Flood Risk Planning Assessment**: Update the calibrated existing conditions models to reflect potential future development. Document the impact of projected future development on flood risk in the watershed.
- **Primary Mitigation Planning:** Recommend action strategies to reduce or eliminate long-term flood risk to people and property including large regional detention facilities, channel conveyance improvements, and property buyouts. Prioritize the flood risk reduction strategies and provide them to local communities to update their respective Hazard Mitigation Plans.
- **Secondary Mitigation Planning:** Work with HCFCD, SJRA, MOCO, and COH to develop a strategy to gather and share flood level assessment information that can be utilized by all parties to make informed decisions. Recommend additions to the existing Harris County Flood Warning System gage network and recommend gages at locations throughout the Upper San Jacinto River Watershed.
- **Other Mitigation Actions:** Coordinate with flood responders including Harris County Office of Emergency Management (OEM), Montgomery County OEM, SJRA, City of Houston, and the Harris County Flood Control District's Hydrologic Operations Department, and emergency managers service in counties and major cities within the study watershed to review communications protocols and action plans. This master drainage plan should help facilitate sharing timely and pertinent information across all agencies so that emergency services can be deployed, and information such as flood conditions, evacuation routes, and shelters can be conveyed to the public to help protect people and property.
- **Community Outreach and Education:** Develop programs and/or materials that educate decision makers and the public on the Upper San Jacinto River general drainage patterns, maintenance programs, potential flood reduction projects, and where to find information about major stream flooding in the watershed. Share and distribute the study outcome with study partners and communities located in the study area on a per-request basis.

A key piece of the plan is a comprehensive list of improvement projects aimed at reducing flood risk in the basin. The results of this flood mitigation plan will be used by the participating communities to update their Hazard Mitigation Plans. The map provided in **Figure 1** above shows the Upper San Jacinto Basin which encompasses an area of more than 2,880 square miles and generally drains southeast through Lake Houston with the study area capped at I-10, just north of the San Jacinto River's confluence with Buffalo Bayou before entering Galveston Bay.

This study focuses on flooding at a regional scale, which includes identifying and mitigating riverine based inundation from the major streams. It does not focus on smaller tributary or local drainage issues that have been identified in the basin. In addition, while Lake Houston and Lake Conroe are included in the models, the study does not consider modifications to the dam structures or operations of the facilities for flood reduction, sedimentation, or water supply purposes.

1.2 Study Area

The San Jacinto WMDP encompasses several watersheds that contribute to the San Jacinto River (SJR) upstream of IH-10. The study does not include the portions of the SJR watershed that drain to the Houston Ship Channel or directly into the Gulf of Mexico. Study watersheds include:

- West Fork of the San Jacinto River (Includes Lake Creek and the Lake Conroe watershed)
- East Fork of the San Jacinto River (Includes Peach Creek and Caney Creek)
- Spring Creek Watershed (Includes Willow, Cypress, and Little Cypress Creeks)
- Luce and Tarkington Bayous
- Jackson Bayou and Gum Gully

1.2.1 General Area Description

Figure 1 above provides an overview of the study area, which encompasses 2,880 square miles and generally drains through Lake Houston to Galveston Bay. **Table 1** below shows the total stream length included in this study.

Table 1. Modeled Stream Reaches

Stream Name	Stream Length (miles)
West Fork San Jacinto River	50.6
East Fork San Jacinto River	90.1
San Jacinto River	24.2
Lake Creek	69.5
Cypress Creek	51.9
Little Cypress Creek	21.8
Spring Creek	69.7
Willow Creek	20.5
Caney Creek	58.3
Peach Creek	49.8
Luce Bayou	30.8
Tarkington Bayou	50.8
Jackson Bayou	4.9
Total	**592.9**

As part of the study, more than 535 miles of major rivers and bayous were modeled in detail. The study area covers all of Montgomery County and portions of Harris, Waller, Grimes, Walker, San Jacinto and Liberty Counties. The streams in the basin generally flow from the northern and western regions of the watershed, south toward Lake Houston and Galveston Bay. The estimated population within the watershed is approximately 1.5 million.

The watershed consists of rural agricultural and forest land with the exception of the urban centers near the City of Houston, The Woodlands, and the City of Conroe. The highest ground elevations in the watershed are in Walker County at approximately 490 feet above sea level. The basin is divided into 11 watersheds, which are summarized below in

Table 2. Summary of Watershed Characteristics.

Table 2. Summary of Watershed Characteristics

Watershed	Basin Size (sq. mi.)	Stream Length (mi.)	Land Use	Channel	Floodplain
Cypress Creek	266	60.5	Mix of agriculture and urban	Relatively constant depth of 20–30' with average channel width of 150'; urban portions of channel include levees to protect primarily residential areas	Width varies between 2,000–4,000' from mouth to approx. river mile 37; floodplain expands and eventually overflows south basin boundary at a maximum width of 17,800' at river mile 47.6
Little Cypress	52	20.8	Mix of agriculture and urban	Channel depth varies between 10'-20'; natural channel with average slope of 2.5 ft/mi.	Width varies between 1,400' to 4,500'
Willow Creek	52	19.8	Mix of agriculture and urban	Relatively constant depth of 30'; widths of 60'-300'; relatively flat, consistent slope	width varies from 2400' at mouth to 4500' at U/S end
Spring Creek	392	69	Primarily forest	Relatively constant depth of 30'; widths of 60'-300'; relatively flat and consistent slope	width varies from 2400' at mouth to 4500' at U/S end
Lake Creek	330	58.9	Primarily forest and agricultural	Moderate XS change with two general slopes; large variations within sections	10' to 18' deep and 350'-1600' wide
West Fork San Jacinto River	787	61.4	Primarily forest and agricultural	Wide, shallow channel at mouth; narrow and deep at Lake Conroe (12'-25' deep; 200'-600' wide)	Heavily vegetated, wide floodplain (1-2 miles in some areas)
Caney Creek	218	49.3	Primarily forest and pasture	Depth varies from 5'-15' and 40'-100' wide	Wide floodplain on both sides
Peach Creek	158	53.5	Primarily forest	Depth varies greatly from 4'-25'; channel slope varies from 4-18 ft/mi	varies greatly from 3750' wide at mouth to 36' wide at U/S end
East Fork	413	73.2	Primarily forest and pasture	Depth remains fairly constant between 22'-27'; TW varies from 85'-450'	Width varies significantly from 3300' at mi 9.4 to 850' at mi 30.4
Luce and Tarkington Bayou	214	31.2	Primarily forest and pasture	Luce: Channel depth is relatively constant between 5–10' deep; channel top width varies between 25–300'	Luce: width varies from 2,000' at mouth to 11,000' at mi 23.9; overflows south basin boundary at mi 16.4
		17.1		Tarkington: Channel depth is relatively constant between 5–10' deep; channel top width generally varies between 25–60'	Tarkington: width varies at Luce from 1,600'-9,300' at mi 37.3; varies from 500'–2500' upstream of mi 40.6; overflows into Reese Bayou at mi 35.1
Jackson Bayou	25	4.6	Mix of agriculture and urban	Typical channel width further upstream is 20-30' with a depth of 5-10' before widening to 70'-100'.	Floodplain width varies between 600' to 7,000'

1.2.2 Historical Flooding

Several historical rainfall events resulted in significant flooding in the region. Hurricane Harvey in 2017 resulted in 22 to 34 inches of rainfall across the basin over a 6-day period, producing significant inflow from the Upper San Jacinto River basin into Lake Houston. This resulted in Lake Houston rising over 11 feet from its normal pool elevation. Lake Conroe also experienced record inflows and rose over 5 feet above normal pool elevation during the rainfall event. Every major stream in the watershed exceeded previous record flow and stage elevations. Over 8,000 structures reported flooding in Harris County and over 3,000 in Montgomery County.

The Memorial Day storm of 2016 resulted in 6 to 13 inches of rain in a 24-hour period with the northwest portion of the watershed receiving the highest rainfall intensity. The elevation in Lake Houston increased 6 feet over the normal pool and Lake Conroe rose over 3 feet due to the intense rainfall in the upper basin. Harris County had over 400 flooded structures and Montgomery County had over 1,000.

The previous event of record for the watershed prior to Hurricane Harvey occurred in October 1994 when over 18 inches of rainfall inundated the watershed. The elevation in Lake Houston increased over 8 feet from the normal pool elevation. Every USGS gage at the time exceeded the previous known maximum readings. The discharge in Spring Creek exceeded 78,000 cfs, the East Fork exceeded 74,000 cfs, and outflow from Lake Houston was approximately 360,000 cfs.

Tropical Storm Imelda in September 2019 brought 32 inches of rain in a 48-hour period primarily on the eastern half of the watershed. The elevation in Lake Houston increased 6 feet from the normal pool elevation. USGS gages on the East Fork, Caney Creek, and Peach Creek reach near record levels and resulted in significant structural flooding along the major streams.

1.3 Planning Partners

Four primary partners contributed both funding and resources to the master drainage plan. The lead agency was the HCFCD which provided managerial, technical, and data resources for the study. MOCO, the SJRA, and the COH were cooperating partners that provided technical input and information needed for the study. All cooperating partners attended monthly progress meetings to discuss the project status and goals.

Other partners and agencies were engaged to obtain resources and information as well as policy and implementation strategies. These agencies included:

- Houston Galveston Area Council (H-GAC)
- Texas Department of Transportation (TxDOT)
- City of Conroe
- The Woodlands Township
- The Community of Kingwood
- Liberty County
- San Jacinto County
- Sam Houston National Forest
- Houston Galveston Subsidence District
- Walker County
- Waller County
- Grimes County
- City of Tomball
- City of Cleveland
- City of Porter
- United States Geological Survey (USGS)
- National Weather Service West Gulf Coast River Forecast Center (RFC)
- Bayou Land Conservancy (BLC)

2.0 Project Management

2.1 Project Coordination Meetings

Numerous coordination meetings have occurred with the primary partners to discuss the project status and receive input regarding the master drainage plan. Sign-in sheets, agendas, presentations, and meeting minutes for each meeting are included in **Appendix A**.

2.1.1 Methodology Meeting (3/19/2019)

Prior to the study kickoff, a meeting was held with the HCFCD to discuss methodologies for the master drainage plan. Items that were discussed included the status of the 2018 terrain that was in the process of development, available survey of the Lake Houston spillway which can influence lake elevations in the model, application of Atlas 14 rainfall across a basin as large as the San Jacinto, use of the Basin Development Factor (BDF) methodology for hydrologic calculations, basin size, and loss rates. The HCFCD requested additional investigation into future conditions and estimating the FEMA Benefit Cost Analysis (BCA). The following decisions were made regarding study methodology:

- Use Green and Ampt losses for models in Harris County, and use initial and constant losses for models developed in the plan
- Use the Hurricane Harvey 2017 and October 1994 storm events for calibration and consider using the major storm events that occurred in 2015 or 2016.

2.1.2 Kickoff Meeting (4/8/2019)

The primary goal of the kickoff meeting was to discuss the project goals and scope with all participating partners. The master plan's project scope, schedule, and deliverables were presented. The project team discussed the study methodologies and requested the data needed from each agency to begin the existing conditions hazard assessment portion of the study. The data that was requested included historical reports, historical flooding, dredging and bathymetry, terrain, and available hydrologic and hydraulic models.

2.1.3 Progress Meetings (May 2019 to September 2020)

Monthly progress meetings were held regularly with the consultant team and the study partners to discuss the project status as well as administrative, technical, and communications items. The consultant team provided a presentation each month covering tasks completed in the previous month, tasks in progress, discussion on communication, and technical items relevant to that month. A schedule update was also provided. The intent of the meetings was to ensure that the team was on the same page and that the study was progressing as intended.

2.1.4 Weekly Coordination

The study team communicated regularly via phone and email. Weekly progress emails were sent to HCFCD and study partners were included in more frequent discussion as needed. Regularly scheduled calls were conducted to check progress and discuss any technical or administrative items.

2.2 Executive Briefings

As part of the study, Executive Briefings were conducted with each of the study partners as well as with all of the Harris County precincts. The initial Executive Briefing was delivered to HCFCD in February 2020 and included discussion of the study's progress through model development and calibration, as well as the future conditions and initial damage center identification for primary mitigation planning.

The second Executive Briefing included an overview of the study progress with particular focus on the flood mitigation planning elements, project and policy recommendations, and the path to implementation. These Executive Briefings were provided to HCFCD, SJRA, COH, and MOCO in June and July of 2020. Finally, briefings were given to each of the four Harris County precincts at the request of the Commissioner's staff. All Executive Briefing materials are included in **Appendix A.2**.

2.3 Supporting Partner Meetings

As part of the Community Outreach effort, which is discussed in detail in Section 9 of this report, supporting partner meetings were conducted with each of the surrounding counties and other jurisdictions within the basin. Meetings included the following jurisdictions:

- Grimes County
- Waller County
- Walker County
- San Jacinto County
- Liberty County
- City of Conroe
- USGS

SPRING 2019

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FACT SHEET

The San Jacinto Regional Watershed Master Drainage Plan is a comprehensive regional study led by local partners including the Harris County Flood Control District, the San Jacinto River Authority, Montgomery County, and the City of Houston.

This integrated effort, kick started in April 2019, will identify future flood mitigation projects that can be implemented in the near- and long-term to reduce flood risks to people and property throughout the San Jacinto River regional **watershed**.

The goals of the San Jacinto Regional Watershed Master Drainage Plan are to:
- Identify the region's vulnerabilities to flood hazards using Atlas 14 rainfall
- Develop approaches to enhance public information and flood level assessment capabilities during a flood disaster event
- Evaluate flood mitigation strategies to improve community resilience
- Provide a comprehensive Flood Mitigation Plan that supports the needs and objectives of each regional partner

The goals of the project will be achieved by developing a set of hydrologic and hydraulic models for the major tributaries of the Upper San Jacinto River regional watershed (from the **headwaters** in Walker County to the Interstate 10 crossing at the San Jacinto River in Harris County). The models will use consistent, cohesive methodology and rainfall rates, regardless of the county in which those channels are located.

Information to be developed includes *non-regulatory* **inundation maps** (not intended to replace current effective maps) for the studied streams that show the extent and depth of **riverine flooding** of the larger rivers within the watershed for an array of simulated storm events . Additionally, information will be gathered about the number of structures, acres of land, properties, and miles of roadway that are located within the modeled floodplains. Study results will be used to inform and update **Hazard Mitigation Plans** for each of the participating partners and to provide guidance on regulations for future growth within the study area.

The project area covers nearly 3,000 square miles. The expected completion time frame is Fall 2020. The project is budgeted at $2.7 million.

Contact Us

The participating project partners are interested in hearing from you. Please contact your local representative with comments and questions:
- **Harris County Flood Control District** – Jing Chen, jing.chen@hcfcd.hctx.net
- **San Jacinto River Authority** – Matt Barrett; mbarrett@sjra.net
- **Montgomery County** – Darren Hess, darren.hess@mctx.org
- **City of Houston** – Adam Eaton, adam.eaton@houstontx.gov

GLOSSARY

Watershed: A geographical region of land or "drainage area" that drains to a common channel or outlet, mostly creeks and bayous. Drainage of the land can occur directly into a bayou or creek, or through a series of systems that may include storm sewers, roadside ditches, and/or tributary channels.

Headwaters: Headwaters are simply the initial source of the water in a river.

Inundation maps: Maps that show where flooding may occur over a range of water levels in a community's local stream or river.

Riverine flooding: Flooding that is the result of creeks and bayous leaving their banks due to heavy rainfall.

Hazard Mitigation Plans: Hazard mitigation is the effort to reduce loss of life and property by lessening the impact of disasters, such as flooding. Governmental organizations engage in hazard mitigation planning to identify risks and vulnerabilities associated with natural disasters, and develop long-term strategies for protecting people and property. Mitigation plans are key to breaking the cycle of disaster damage, reconstruction, and repeated damage.

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN FACT SHEET | Spring 2019 Page 1 of 2

The meetings provided an overview of the study goals and objectives, process, and intended findings. Each of the supporting partners provided input on their concerns and interests in the study. A study fact sheet was provided, which provided an overview of the study area, goals, contact info and timeline. A similar meeting was conducted for the four funding partners. The notes for each of the study and supporting partner meetings are included in **Appendix A.3**.

3.0 Data Collection and Review

Data collection is the process of requesting, organizing, and reviewing information that is needed to complete the existing conditions flood hazard assessment as well as develop and prioritize mitigation alternatives. The data collection task includes field reconnaissance efforts as well as desktop reviews of data and is typically performed at the beginning of a drainage master plan study prior to the existing conditions flood risk assessment. Collected data types included terrain data, gage information, historical high-water marks, existing models, precipitation data, historical flooding complaints, sedimentation data, historical reports, field reconnaissance, and field survey. The collected data was then compiled and reviewed to extract relevant information and prepare for the utilization of the data for the master drainage plan.

3.1 Data Collection and Review

3.1.1 Terrain Information

Topographic data provides a basis for the flood hazard assessment. Data were compiled from a variety of sources and combined into a seamless terrain dataset. Topographic data sets were collected from the following sources:

- Houston-Galveston Area Council (H-GAC)
- Texas Natural Resources Information Systems (TNRIS)
- Texas Water Development Board (TWDB)
- United States Geological Survey (USGS)

The mosaic DEM of the San Jacinto River basin is a collection of data sets from the 2011 Universal Transverse Mercator (UTM), 2017 UTM, 2018 UTM, and 2018 State Plane LiDAR surveys.

3.1.2 Gage Information

A total of 27 mainstem United States Geological Survey (USGS) discharge gages are in the SJR Basin. These gages provide elevation and discharge information for each of the studied streams, except Jackson Bayou, for various storm events. **Appendix B** summarizes the gage information, and **Appendix D** contains a full description of each USGS gage.

The Harris County Flood Warning System measures rainfall amounts and monitors water levels in bayous and major streams on a real-time basis. The system relies on 184 gage stations placed throughout the region’s bayous, streams, and tributaries. The system also includes data transmitted from a number of partner agencies including the San Jacinto River Authority and the Texas Department of Transportation.

Both the USGS and HCFCD gages were used as primary data in the calibration effort.

3.1.3 Historical High-Water Marks

The USGS collected over 197 high water marks for the Hurricane Harvey 2017 storm event throughout the SJR basin. The information collected by the USGS includes the high-water mark’s location, surveyed elevation, description, and potential quality of the mark.

The HCFCD collected high-water marks for Harris County bayous, channels, and streams during major storm events. The high-water marks are surveyed at bridge crossings for the Hurricane Harvey, May 2016, and October 1994 storm events.

3.1.4 Precipitation Data

The National Oceanic Atmospheric Administration (NOAA) published the Precipitation-Frequency Atlas of the United States Volume 11, Texas (Atlas 14) in 2018 which provided the precipitation frequency estimates for storm events based on the latest rainfall information. The partial-duration rainfall estimates were obtained from NOAA's website for the 50%, 20%, 10%, 4%, 2%, 1%, and 0.2% ACE for each of the watersheds.

3.1.5 Existing Models

Five of the eleven studied streams are located within the HCFCD jurisdictional limits. HCFCD has developed and maintains a model inventory for the major creeks and bayous located in their jurisdiction. Cypress Creek, Little Cypress Creek, Willow Creek, Spring Creek, and Jackson Bayou have hydrologic and hydraulic models that were calibrated to previous historical storm events and are used by HCFCD for both new development and project planning. The models include the HCFCD standard hydrologic and hydraulic parameters and methodology for steady state modeling. Each model was obtained from the HCFCD M3 website (m3models.org). The HCFCD models for these streams were used as a basis for the study.

The San Jacinto River Authority along with Montgomery County and the City of Conroe conducted a study of West Fork of the San Jacinto watershed from the headwaters near Huntsville to the confluence with Lake Creek known as the West Fork San Jacinto River Flood Protection Planning Study. This included updated hydrologic and hydraulic models that could be leveraged for this effort.

3.1.6 Historical Flooding Complaints

The HCFCD and Montgomery County provided a Graphical Inventory System (GIS) inventory of flood-damaged structures identified in the April 2016, May 2016, and August 2017 storm events. The information included the location and address of each damaged structure. The data provided by the two entities includes more than 10,000 flood-damaged structures within the study area as shown in **Figure 2**. The majority of these structures are located within the main river special flood hazard areas included in this master drainage plan.

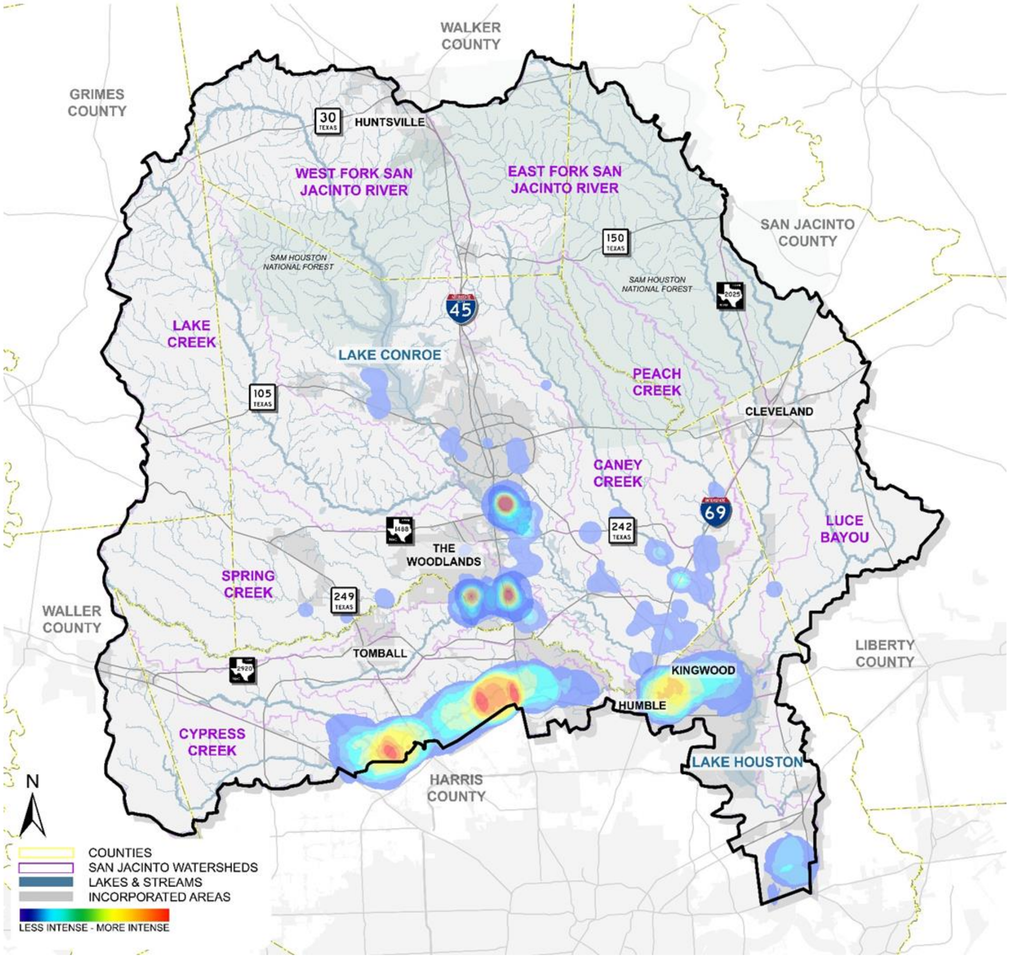


Figure 2: Historical Flood Claims (Montgomery and Harris Counties)

3.1.7 Sedimentation Data

One of the strategies evaluated as part of this study is the development and implementation of a sediment management strategy to help control sedimentation and vegetative growth along the major streams in the San Jacinto River basin. As part of that effort, existing sedimentation studies were reviewed and analyzed. The full sedimentation plan is provided in **Appendix F**.

Sixteen reports that contained information regarding sedimentation or the factors that contribute to it within the SJR basin were obtained and reviewed to determine the potential impacts of sedimentation in the region. The provided reports were parsed into three categories: sediment (twelve reports), hydraulics (two reports), and digital elevation models (two). Sediment reports were further subdivided into a sediment measurement subcategory (seven reports) and a sediment management subcategory (five reports). The former subcategory contained information on field measurements such as bathymetry or extent of dredging, while the latter summarized the relationship between sediment accumulation and flood risk and provided sediment management alternatives.

The bulk of the provided reports focused on Lake Houston and the West Fork San Jacinto River. For the development of the sediment management strategy, the study area of the West Fork started approximately one-half mile upstream of US Highway 59 and extended downstream to one-half mile upstream of the FM

1960 bridge over Lake Houston. This definition mirrors the definition used in the 2018 TWDB bathymetric survey of the West Fork.

In general, these previous studies have identified the amount and rate of sedimentation in Lake Houston. These studies suggest that this sedimentation will continue in perpetuity unless addressed. This study does not include detailed hydraulic modeling of the effects of sedimentation on flood risk. Previous studies have reported potential increases of the 1% ACE water surface elevation between 0.2 and 1.2 feet.

3.1.8 Historical Reports

Several historical drainage studies that focused on identifying existing flood risk and evaluating flood risk reduction alternatives within the San Jacinto River watershed were provided by the planning partners. The reports included both analysis of the existing conditions watershed and potential mitigation alternatives to improve flood risk, manage the region's water supply, and determine the impacts of sedimentation. The previous reports provide 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 reviewed included:

- Master Plan Report for the Full-Scale Development of the San Jacinto River (1943)
- Master Plan Report for the Full-Scale Development of the San Jacinto River (1957)
- San Jacinto Upper Watershed Drainage Improvement and Flood Control Planning Study (1985)
- Comprehensive Flood Protection Plan for Southern Montgomery County, Texas (1989)
- Lake Creek Reservoir Report (1997)
- Regional Flood Protection Study for Lake Houston Watershed Program (2000)
- West Fork San Jacinto River Flood Protection Planning Study (2019)
- Spring Creek & West Fork Study – Estimating Land Cover Effects on Selected Watersheds (2019)

3.1.9 Field Reconnaissance

Field reconnaissance was performed for the entire study area to observe and document the condition of existing structures and channels. During the field reconnaissance effort, streams, hydraulic structures (culverts and bridges), outfalls, detention ponds, and other features were visually identified, measured, and photographed for all major streams. Field documentation predominantly occurred at publicly accessible locations, such as crossing of public roads over the streams. In addition to photographs, sketches of the structures were prepared to document the structure opening measurements, the channel location and condition, and any relevant information about the surrounding area.

3.1.10 Field Survey

Field survey data were collected at designated bridge crossings within the San Jacinto River Basin, specifically along Caney Creek, Lake Creek, Luce/Tarkington Bayou, Peach Creek, East Fork San Jacinto River, and West Fork San Jacinto River. These crossings were surveyed to obtain updated information for the channel crossing structures and channel topography for use in hydraulic modeling. Elevation data as well as the dimensions and material were noted for each survey location and photographs were taken to document structure and channel conditions.

The horizontal position of all the survey data was referenced to the Texas State Plane Coordinate System, Central Zone (4203), North American Datum: NAD 83(2011) Epoch 2010.00. Data positions are Grid Values in U.S. Survey Feet. Elevations are referenced to the North American Vertical Datum of 1988 (NAVD88). The survey data is contained in **Appendix B**.

4.0 Existing Conditions Flood Hazard Assessment

The existing conditions flood hazard assessment established the existing watershed conditions along the 11 major streams modeled in this study and analyzed the current flooding risks and vulnerabilities necessitating mitigation projects. The task consisted of determining the runoff risk, which includes developing discharges for the major streams, and flood hazard assessment which includes determining the resulting water surface elevations and floodplains for the study area. The models were then calibrated as part of the historical storm evaluation.

4.1 Runoff Risk

The available FEMA effective models for the SJR and its tributaries were obtained from various agencies and were utilized as a starting point for the existing flood risk assessment effort. A description of the source of the baseline models is provided below.

- FEMA effective models for the SJR, Spring Creek, Willow Creek, Cypress Creek and Little Cypress Creek, Luce Bayou and Jackson Bayou were downloaded from the HCFCD Model and Map Management (M3) website.
- Models for the drainage area upstream of Lake Conroe, as well as a dam breach model of the West Fork San Jacinto River downstream of Lake Conroe, were provided by SJRA.
- Base Level Engineering (BLE) models were obtained for East Fork San Jacinto River, Peach Creek, and Caney Creek from FEMA.

4.1.1 Existing Runoff Model Conversion

Basins that had available hydrologic models were updated to HEC-HMS version 4.3 to be consistent with this study. HCFCD models were obtained from the HCFCD M3 website and upgraded to the latest version. Watershed parameters including subbasin areas, channel slopes, watershed slopes, percent impervious, detention values, and Clark Unit hydrograph parameters were not changed from the original HCFCD models. Green & Ampt remained the selected loss method but the loss parameters were updated due to reclassification of soils in the northwestern portion of the Harris County as stated in the *HCFCD white paper*[2].

4.1.2 New Runoff Model Development

New hydrologic models were developed for previously unstudied watersheds (Lake Creek, West Fork, Caney, Peach, East Fork, Luce/Tarkington Bayou) to establish existing watershed conditions and analyze current flooding risks. New model development included delineating watersheds, defining runoff losses, defining BDF values, and developing the hydrologic model.

4.1.2.1 Watershed and Subbasin Delineation

Watershed and subbasin boundaries for the studied streams were initially delineated using the GIS tool HEC-GeoHMS. Delineated boundaries were then manually revised using high-resolution Near Map aerial imagery, 2018 H-GAC LiDAR, FEMA Base Level Engineering (BLE), and field reconnaissance data. The drainage areas were further subdivided to develop discharge rates through the studied streams. Stream

[2] HCFCD White Paper 3 “Replacing Green & Ampt Loss Function in HEC-HMS with Initial & Constant Loss Method, dated 07/20/2018”

confluences and gage locations as well as major existing drainage features such as bridges, culverts, detention basins, and major outfalls were used as guides in the drainage area delineation process. Future potential gage locations were also considered as drainage area divides. The target size for the subbasins ranged from approximately 10 to 15 square miles.

4.1.2.2 Initial and Constant Losses

Initial and constant losses calculate the rainfall infiltration, interception, and depression storage in the watershed. The initial loss (abstraction) is the amount of precipitation that is immediately infiltrated into the soil and vegetation. The pre-calibrated initial loss for all basins was assumed to be 1 inch and was adjusted during the historical storm calibration portion of the study.

The constant loss rate represents the ultimate infiltration capacity of the soils. The constant loss rate was based on the hydrologic soil group (HSG), which affects the potential of an area to produce runoff. The SSURGO soils database downloaded from NRCS was used to determine the soil groups in each subbasin.

4.1.2.3 Basin Development Factor

The basin development factor (BDF) is one of the parameters that is used in an alternate methodology for developing the time of concentration (Tc) and storage coefficient (R) parameters which are required when using the Clark Unit hydrograph method. BDF is a measure of the extent and efficiency of the drainage system in the basin. BDF values range from 0 (representing areas with no drainage infrastructure) to 12 (representing areas with fully effective drainage systems). The type and efficiency of the drainage system within each basin was estimated using NearMap aerial imagery, 2018 H-GAC LiDAR data, and street view from Google Earth. BDF values were determined based on the step-wise method recommended in *HCFCD White Paper*[3]. The BDF value is determined by dividing the basin into thirds and assigning a value of 0, 0.5, or 1 to each of the four categories of each third: channel improvements, channel lining, storm sewers, and curb-and-gutter streets. The values for each category are summed for each third, and then the thirds are summed to determine the overall BDF value.

The overall BDF in the basin is the sum of the four indices. BDF does not directly account for impervious cover, but changes in BDF reflect improvements in drainage systems that accompany urbanization.

4.1.2.4 Clark Unit Hydrograph Transform

The transform method in HEC-HMS simulates the process of converting precipitation into a runoff hydrograph. As discussed previously, time of concentration (Tc) and storage coefficient (R) are the two required parameters for this method and are calculated using a combination of the computed BDF and watershed parameters. Watershed parameters include subbasin drainage area, BDF value, length of longest watercourse (miles), channel slope (feet/mile), watershed slope (feet/mile), percent impervious (%), detention volume (acre-feet), and percent ponding (%).

4.1.2.5 Impervious Percentage

Land cover data was acquired from the Houston-Galveston Area Council (H-GAC). The land use classifications were verified by using GIS and NearMap aerial imagery. Impervious percentages were assigned to each land use based on recommendations by the HCFCD. The HCFCD categories of land

[3] HCFCD White Paper 6 “Tc and R Methodology in Harris County, Revised 03/06/2019”

cover consisted of water, high density, light industrial/commercial, residential/urban average, developed green areas, undeveloped, residential/rural lots, high density, and isolated transportation.

4.1.2.6 Muskingum-Cunge Routing

Stream routing was used to route flows through major tributaries that were not included in the hydraulic modeling effort. The tributary routing was used to determine the hydrograph attenuation due to storage in the subbasins of the non-studied tributaries. For this study, Muskingum-Cunge routing methodology was selected.

4.1.2.7 Rainfall

The Atlas 14, Volume 11 rainfall data, released by NOAA in 2018, represents the best available design rainfall data for Texas. It shows a significant increase in rainfall depths across the Texas region compared with previous precipitation data.

To best represent NOAA Atlas 14 rainfall, the average rainfall depth was calculated across each basin based on the NOAA Atlas 14 partial-duration precipitation frequency rasters. **Figure 3** shows the recommended 1%-ACE, 24-hour rainfall depths for each basin. Existing conditions models included rainfall data for a range of annual chance storm events: 50%, 20%, 10%, 4%, 2%, 1% and 0.2% events which are summarized in **Table 3**. The storm duration was set to 24-hours, the intensity duration, which is the length of the highest rainfall amount, was 5-minutes, and the intensity position was 67 percent, meaning the storm would peak at approximately hour 16 of a 24-hour storm event. These standards are part of HCFCD criteria. The rainfall depths were spatially averaged for each watershed, and thus vary throughout the SJR basin.

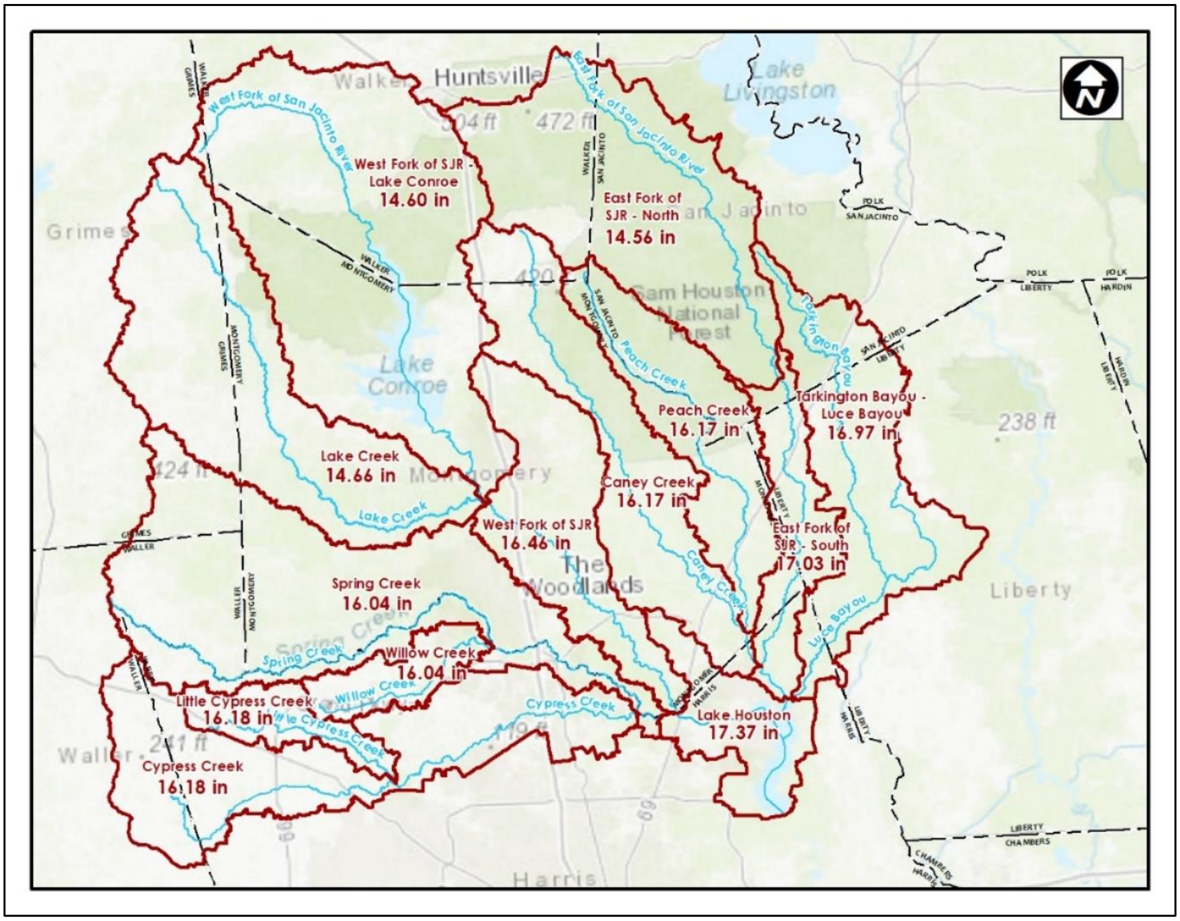


Figure 3: Atlas 14 Rainfall Depths by Watershed

Table 3: Watershed 24-hour Precipitation Totals for Frequency Storm Events

Watershed	Frequency 24-hour Rainfall Totals						
	50%	20%	10%	4%	2%	1%	0.2%
Cypress Creek	4.83	6.50	8.21	10.89	13.33	16.18	19.34
Little Cypress	4.83	6.50	8.21	10.89	13.33	16.18	19.34
Spring Creek	4.76	6.39	8.08	10.73	13.18	16.04	19.25
Willow Creek	4.76	6.39	8.08	10.73	13.18	16.04	19.25
Lake Creek	4.55	6.06	7.59	9.98	12.14	14.66	17.51
Lake Conroe	4.59	6.12	7.65	10.02	12.14	14.60	17.39
West Fork SJR	4.44	5.83	7.15	9.15	10.88	12.85	15.08
Lake Houston	5.20	7.06	8.91	11.79	14.36	17.37	20.81
Caney Creek	4.91	6.64	8.35	11.02	13.40	16.17	19.29
Peach Creek	4.91	6.64	8.35	11.02	13.40	16.17	19.29
East Fork SJR - N	4.69	6.27	7.80	10.14	12.20	14.56	17.26
East Fork SJR - S	5.06	6.88	8.70	11.53	14.07	17.03	20.42
Luce/Tarkington	5.06	6.88	8.69	11.51	14.03	16.97	20.39

4.1.2.8 HEC-HMS Model Development

A new hydrologic model was developed for Caney Creek, Peach Creek, Lake Creek, Luce Bayou, EFSJR and WFSJR in HEC-HMS version 4.3 to simulate runoff for existing conditions. Computational methods used in the HEC-HMS model were selected based on the HCFCD H&H Guidance Manual. The subbasins used the Initial and Constant loss method and the Clark Unit Hydrograph transform method. Routing reaches between subbasins used the Muskingum-Cunge method. Input parameters for each subbasin required for the Clark Unit Hydrograph are the time of concentration (Tc) and storage coefficient (R). Each model run combines a basin model, meteorological model, and control specifications. The model is shown in **Figure 4**.

Figure 4: HMS Model Layout

4.2 Flood Hazard Assessment

The flood hazard assessment estimated the extent and frequency of flooding for each of the major streams. Hydraulic models were updated or developed to assess the existing flood hazard for each stream. The models provided sufficient information to identify flood risks along the studied streams and to develop inundation data sufficient for local communities to utilize when updating their Hazard Mitigation Plans. All hydraulic models were created in or updated to HEC-RAS version 5.0.7, the most recent version released by USACE at the time of this study. Current FEMA effective models for the streams located in Harris County were converted from a steady flow analysis to an unsteady flow analysis to be incorporated into the watershed wide model. The conversion for these models involved incorporating updated topography, new cross section alignments, and additional bridge and culvert crossings. New models were created for the remaining streams which involved development of new stream centerlines, cross sections, Manning's roughness values, and boundary conditions. These new models were also analyzed under unsteady conditions.

4.2.1 Flood Hazard Model Conversion

The HCFCD maintains the FEMA effective models for Spring Creek, Willow Creek, Cypress Creek, and Jackson Bayou. Each of these models is maintained in HEC-RAS v. 3.0.1. The effective models were updated to HEC-RAS v 5.0.7 and converted to an unsteady flow analysis for each storm event. In general, the unsteady conversion consisted of applying flow boundary conditions at the respective cross sections, assigning HTab parameters, adding pilot channels for stability, updating the bridge modeling methods, and changing the ineffective area assignments.

Bridge modeling methods were adjusted to achieve model stability and to accurately model the bridge conditions. The energy method was selected for low flows while for high flows energy or pressure/weir methods were chosen depending if the bridge was overtopped. Ineffective areas were also changed in cross sections bounding structures to provide stability to the model which consisted of "stepping" the ineffective areas to gradually increase the conveyance at the structure. Ineffective areas were also removed in areas that caused instabilities and in areas that were deemed unnecessary based on the terrain. Interpolated cross sections were added to better capture the water surface elevations occurring at structures and to reduce instabilities in the model.

4.2.2 New Flood Hazard Model Development

New hydraulic models were developed for Lake Creek, West Fork San Jacinto River, Caney Creek, Peach Creek, East Fork San Jacinto River, and Luce Bayou/Tarkington Bayou to assess the existing conditions flood risk. Hydraulic model components were developed using ArcGIS software, specifically the HEC-GeoRAS toolset. HEC-GeoRAS is a tool in ArcMap where hydraulic features can be created in GIS and imported directly into HEC-RAS. GeoRAS was used to create stream centerlines, cross sections, flow paths, bank stations and roughness values.

- Stream centerlines represent the approximate alignment of the channel along the channel invert and is used to assign stationing for cross sections. Stream centerlines were drawn in ArcGIS along the thalweg for each stream based on the H-GAC LiDAR.
- Cross sections consist of station-elevation data extracted from the terrain along a line drawn across the channel and extending into the overbanks. Cross sections provide the model with information

about the shape and dimensions of the channel and adjacent overbank areas which are used by HEC-RAS for hydraulic calculations.

- Flow path centerlines determine the reach lengths between cross sections for both the channel and left and right overbanks. Flow paths were drawn along the stream centerline parallel to the direction of flow for both the channel and overbanks.
- Bank stations are used to classify the channel and overbanks in a given cross section and to assign changes in Manning's n values. A two-step process was performed to assign bank stations for each cross section. First, bank lines were drawn in GIS to follow along the terrain break between the channel and overbank and were assigned to each cross section using the GeoRAS toolset. Second, cross sections with the bank points from the first step were then imported into HEC-RAS and were adjusted manually for each cross section using the graphical cross section editor.
- Manning's n values were assigned to each cross section based off the land use from the aerial imagery and documentation of Manning's n values for each land use. A shapefile of land use was derived from the 2018 H-GAC Land Cover Dataset and was used to assign Manning's n values.

Table 4: Manning's N Values

Land Classification	Manning's N Value
Open Water	0.02
Channel	0.04
Pasture/Grasslands	0.05
Forest	0.10
Low/Medium Intensity Development	0.12
High Intensity Development	0.15

- Ineffective areas are used in HEC-RAS to either temporary or permanently block conveyance in specified portions of cross sections. Ineffective areas were used to model the bridge contractions and expansions as well as sand pits located along the banks of several streams within the study area. The ineffective areas for bridges followed HCFCD guidance[4] and were placed at a 1:1 and 2:1 (distance: width) ratio on both sides of the bridge or culvert opening for the contraction and expansion, respectively.
- Boundary conditions were set up in the model to simulate runoff from the drainage basins and to establish a downstream condition for flow to leave the model. For the first cross section, a flow boundary was applied to represent the runoff from the most upstream drainage basin. Uniform lateral inflow hydrographs were used to introduce subbasin flows within the reach where the terrain indicated a need to distribute the flow across a range of cross sections. Tributary flows were modeled using a

[4] HCFCD Unsteady Modeling Guidelines – Draft (2018)

lateral inflow hydrograph, which applies flow at a single cross section acting as a point discharge rather than uniformly distributing flow along the reach.

4.2.2.1 HEC-RAS Model Development

A new project was established for each reach in HEC-RAS v 5.0.7 to model the unsteady flow conditions for each storm event. After the model components were developed in HEC-GeoRAS, the data was imported in the geometry editor within HEC-RAS. **Figure 5** shows a graphic of the complete HEC-RAS model.

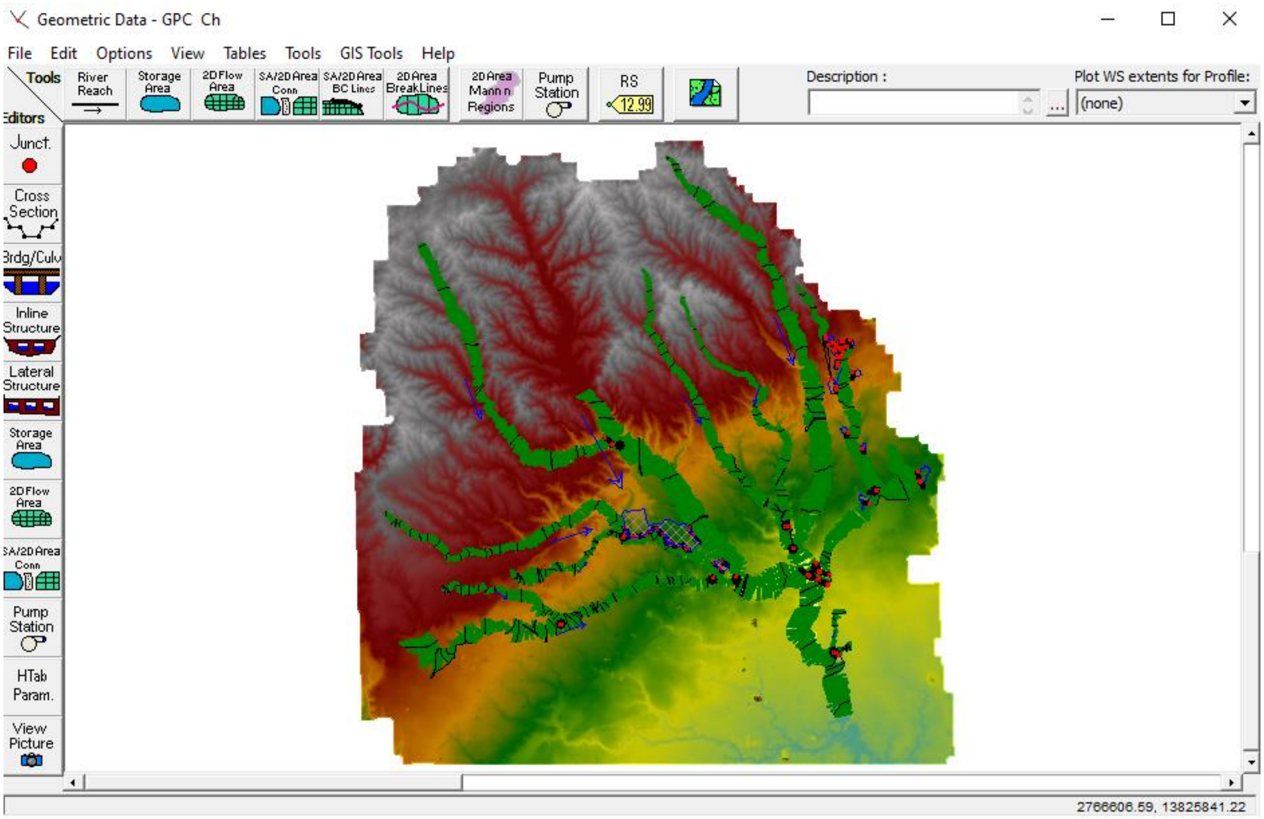


Figure 5: HEC-RAS Model Layout

5.0 Analysis of Historical Storms

5.1 Analysis of Historical Storms

The analysis of historical storms was performed to ensure that the existing conditions flood hazard assessment provided reasonable results by comparing observed data from past flooding events to the model results for the same events. The analysis establishes a sound basis for risk identification and mitigation needs throughout the San Jacinto River Watershed. The analysis consisted of obtaining and analyzing the historical storm data, calibrating the existing conditions models to match the historical data obtained from the existing flow and stage gages, and simulating the calibrated models for frequency storm events to assess the flood hazard risk throughout the basin.

5.1.1 Rainfall Information

The San Jacinto River Watershed has experienced multiple large rainfall events in the last several decades. Four of these rainfall events were selected to calibrate and validate the hydrologic and hydraulic model parameters. Hurricane Harvey (August 2017) and Memorial Day (May 2016) were selected for calibration since they generally impacted the entire upper San Jacinto River Watershed and provided significant recent calibration data. October 1994 and Tropical Storm Imelda (September 2019) were selected for validation of the calibration models. Once the calibration was complete, the models were run using the recently updated Atlas 14, Volume 11 rainfall.

HCFCD provided gauge-adjusted radar rainfall (GARR) data from Vieux & Associates, Inc. for August 2017, May 2016, and October 1994. This data included gridded rainfall depths across the watershed at 15-minute increments. The rainfall grid size is approximately 1 kilometer by 1 kilometer. The figures below depict the general distribution of rainfall across the watershed for each of these storms.

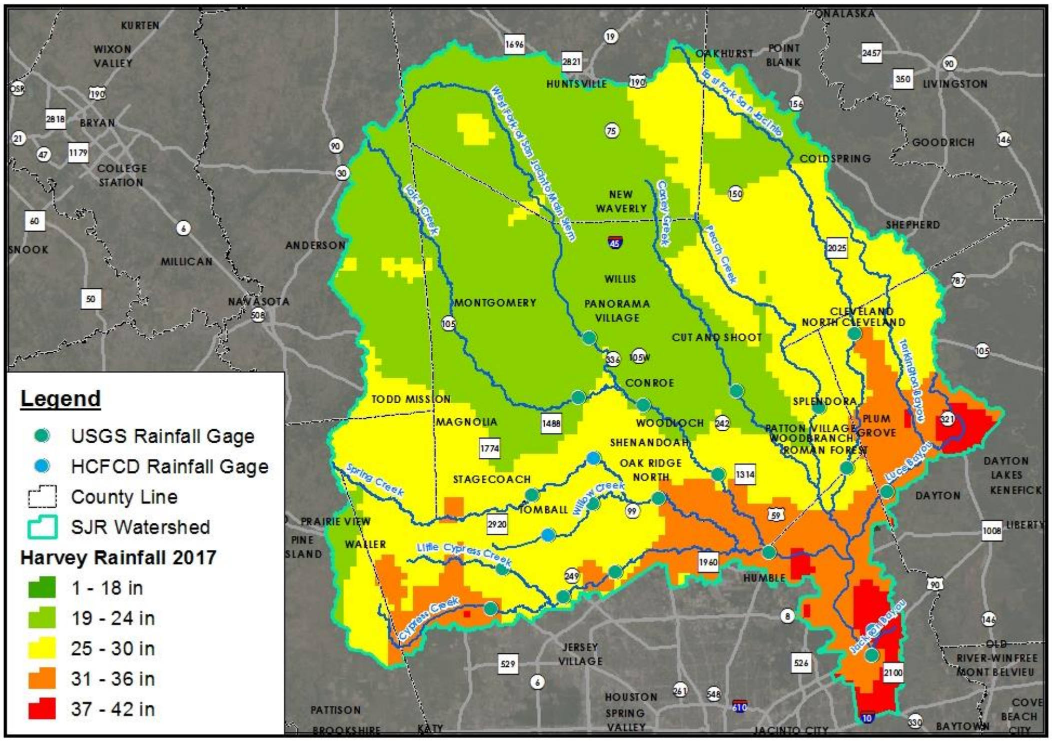


Figure 6: August 26, 2017 – September 1, 2017 Rainfall Totals (Hurricane Harvey)

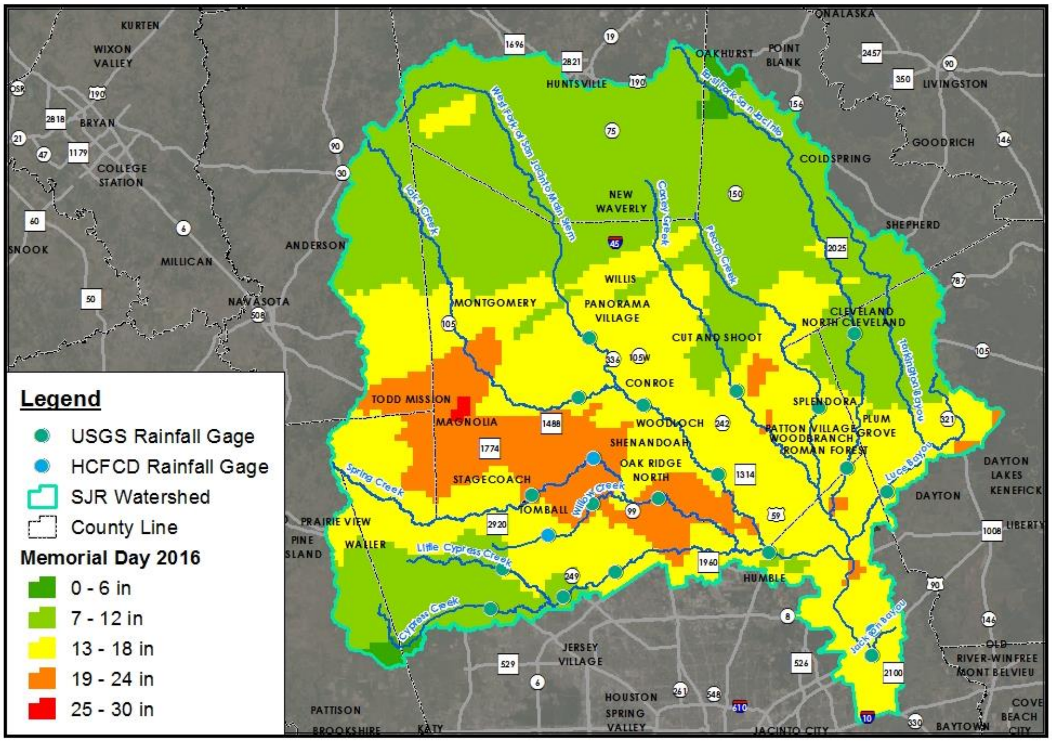


Figure 7: May 25, 2016 – June 2, 2016 Rainfall Totals (Memorial Day 2016)

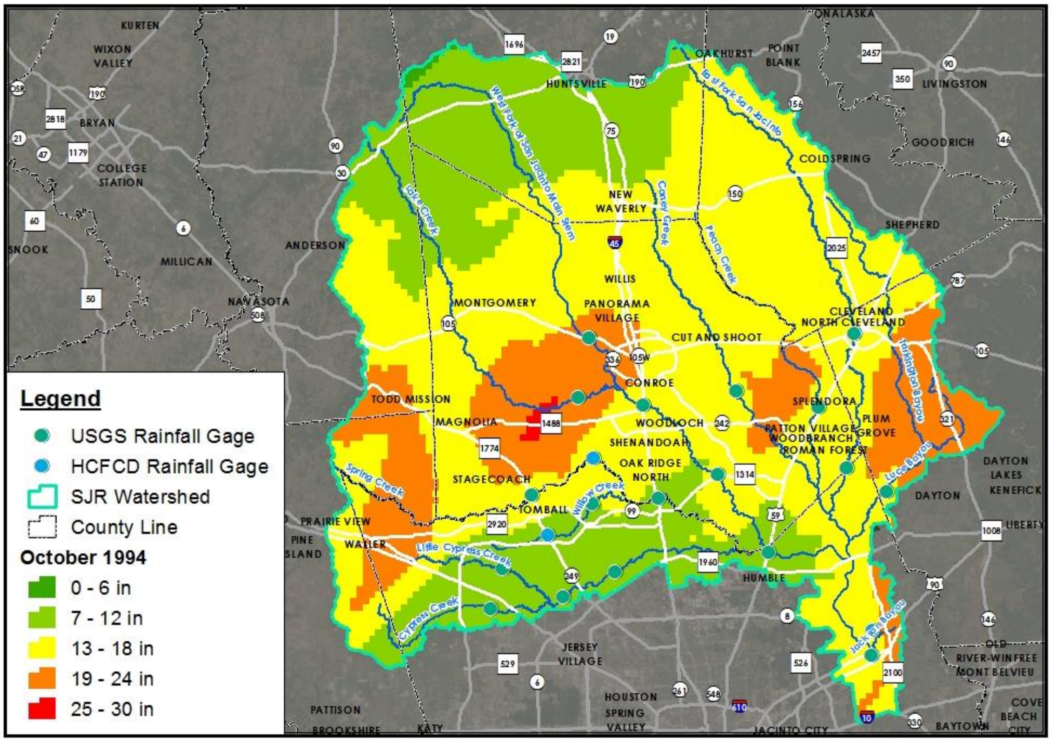


Figure 8: October 15, 1994 – October 19, 1994 Rainfall Totals (October 1994)

For Tropical Storm Imelda, Multi-sensor Precipitation Estimates (MPE) were obtained from the National Weather Service. These precipitation estimates are based on radar data and precipitation gages with preliminary quality control performed by the National Weather Service. **Figure 9** below depicts the general distribution of rainfall across the watershed during Imelda.

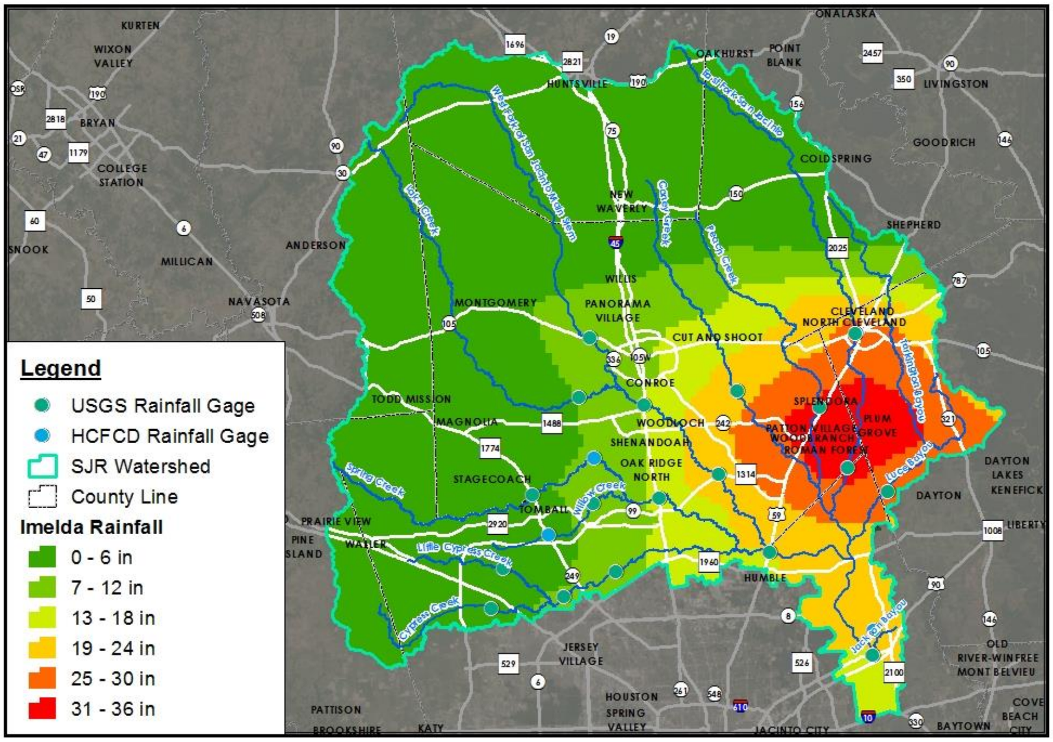


Figure 9: September 18, 2019 – September 19, 2019 Rainfall Totals (Tropical Storm Imelda)

5.1.2 USGS Gages

USGS gages provide stage information for major creeks throughout the San Jacinto River Watershed. The USGS develops discharge-stage rating curves from flow measurements and water surface elevations at each of these locations. The rating curves are adjusted over time as the USGS continues to collect the field measurements. Twenty-two of the twenty-nine USGS gages in the Upper San Jacinto River Watershed were used to calibrate hydrologic and hydraulic models to the historical storm events. Six gages were not used either because they did not have sufficient data or were not on a stream that a model was developed for.

5.1.2.1 USGS Gages

The following section contains information about each of the USGS gages used for the calibration effort. **Table 5** lists the Gage ID, stream name, and location of each gage. Gages highlighted in yellow were not used because there was not a sufficient period of record for calibration. The start date for historical observations for gages 08069800, 08067690, and 08068310 is 12/2019, 02/2018, and 12/2019, respectively, meaning there are no records for either of the calibration storms at those gages.

Calibration of hydrologic and hydraulic models relies heavily on the availability and accuracy of historical data. The study team engaged the USGS during the calibration process to understand the collection of the gage information and the development of the discharge-stage rating curves. Below is a summary of notable discussion points.

- The USGS obtains both direct and indirect measurements of flow rates during storm events. Direct measurements involve radar or traditional sensors being measured by boat in the stream during the rain event. These are classified with ratings to convey the accuracy of the measurement.
- A "Good" measurement has +/- 5% accuracy, a "Fair" measurement has +/- 8% accuracy, and a "Poor" measurement has greater than 8% accuracy.
- An indirect measurement is generally taken by collecting high water marks within the vicinity of the gage and developing a hydraulic model to determine the flow that is required to match the water surface elevations. The indirect measurements generally have an accuracy of +/- 20%.
- The rating curves typically use all points collected in the field or with indirect measurements.

Table 5. Summary of USGS Gages in the Upper San Jacinto River Watershed

Gage Number	Stream Name	Site Location
08071280	Luce Bayou	above Lake Houston near Huffman, TX
08070000	East Fork San Jacinto River	at SH105 near Cleveland, TX
08070200	East Fork San Jacinto River	at FM1485 near New Caney, TX
08069800	East Fork San Jacinto River	at SH150 near Coldspring, TX
08071000	Peach Creek	at FM2090 near Splendora, TX
08070500	Caney Creek	at FM2090 near Splendora, TX
08067920	Lake Creek	at Sendera Ranch Dr. near Conroe, TX
08067690	Lake Creek	at SH105 near Dobbin, TX
08068500	Spring Creek	at IH-45 near Spring, TX
08068275	Spring Creek	at SH249 near Tomball, TX
08068310	Spring Creek	at Kuykendahl Rd. near the Woodlands, TX
08068325	Willow Creek	at Kuykendahl Rd. near Tomball, TX
08068740	Cypress Creek	at House-Hahl Rd. near Cypress, TX
08068800	Cypress Creek	at Grant Rd. near Cypress, TX
08068900	Cypress Creek	at Steubner Airline Rd. near Westfield, TX
08069000	Cypress Creek	at IH-45 near Westfield, TX
08068720	Cypress Creek	at Katy-Hockley Rd. near Hockley, TX
08068780	Little Cypress Creek	at Cypress Rosehill Rd. near Cypress, TX
08067650	West Fork San Jacinto River	at SH105 near Conroe, TX
08068000	West Fork San Jacinto River	at IH-45 near Conroe, TX
08068090	West Fork San Jacinto River	at SH99 near Porter, TX
08069500	West Fork San Jacinto River	at IH-69 near Humble, TX
08067548	West Fork San Jacinto River	at FM1791 near Huntsville, TX
08072050	San Jacinto River	at US90 Business near Sheldon, TX
08072000	San Jacinto River	at Lake Houston
08068390	Bear Branch	at Research Forest Blvd, The Woodlands, TX
08068400	Panther Branch	at Gosling Rd, The Woodlands, TX
08067600	Lake Conroe	at Conroe, Texas
08068450	Panther Branch	at Spring, Texas

Gages highlighted in yellow were not used because there was not a sufficient period of record for calibration.

5.1.3 USGS Gage Summaries and Conclusions

The USGS gages in the watershed were reviewed to determine the availability of stage and discharge data and the reliability of the data for calibration. The summary below lists the gages and the focus of the calibration effort based on the availability and reliability of data. Specific information related to each of the gages is provided in **Appendix D.**

- USGS Gage: Luce Bayou (08071280) above Lake Houston near Huffman, TX - Although the measurements appear inconsistent and have a "fair" and "poor" rating, they were both obtained through direct measurements. Therefore, the calibration effort considered both the discharge and stage.
- USGS Gage: East Fork San Jacinto River (08070000) at SH105 near Cleveland, TX - Since discharges above 34,200 cfs are only estimated by the USGS using an extrapolated rating curve and the August 2017 measurements were indirect, the focus of the calibration effort was on reproducing the stage only and not flow.
- USGS Gage: East Fork San Jacinto River (08070200) at FM 1485 near New Caney, TX - Since discharges above 23,000 cfs have never been directly measured and are only extrapolated based on the rating curve, the focus of the calibration effort was on matching the stage only and not flow.
- USGS Gage: Peach Creek (08071000) at FM2090 near Splendora, TX - Since discharges have been adjusted by the USGS for the August 2017 event, the focus of the calibration effort was on matching the recorded stage.
- USGS Gage: Caney Creek (08070500) at FM2090 near Splendora, TX - Since the calibration storm events all recorded elevations above the highest field measurement of 140.84 feet, the recorded discharge is only estimated from an extrapolated rating curve and may not accurately represent the actual discharge for these events. Therefore, the focus of calibration was on matching the recorded stage.
- USGS Gage: Lake Creek (08067920) at Sendera Ranch Dr. near Conroe, TX - Even though some measurements have a poor rating, they were obtained through a direct measurement method. Therefore, the calibration effort considered both stage and discharge.
- USGS Gage: Spring Creek (08068500) at IH-45 near Spring, TX - Since direct measurements were obtained for both the August 2017 and May 2016 events, the calibration considered both discharge and stage.
- USGS Gage: Spring Creek (08068275) at SH249 near Tomball, TX - Since the flow measurements for the calibration storm events were obtained through a direct measurement and classified as a "good" rating, the calibration considered both discharge and stage.
- USGS Gage: Willow Creek (08068325) at Kuykendahl Rd. near Tomball, TX - Since the highest measured discharge was obtained through an indirect method, the focus of the calibration effort was on matching the stage only and not flow.
- USGS Gage: Cypress Creek (08068740) at House-Hahl Rd. near Cypress, TX - Since the discharge for August 2017 storm event was not measured by the USGS and the recorded stage for this event is three feet above 146.19 feet, the focus of the calibration effort was on matching the recorded stage only.
- USGS Gage: Cypress Creek (08068800) at Grant Rd. near Cypress, TX - Since USGS used an indirect method to obtain the highest measured flow at this gage and the associated peak discharge

rates differ by 2,000 cfs for the same peak elevation, the focus of calibration was on matching the recorded stage only.

- USGS Gage: Cypress Creek (08068900) at Steubner Airline Rd. near Westfield, TX - Since the August 2017 event calibration storm events recorded stages several feet above 108.88 feet, the focus of the calibration effort was on matching the recorded stage.
- USGS Gage: Cypress Creek (08069000) at IH-45 near Westfield, TX - The inconsistency in the discharge and stage relationship shows that the gage rating curve has changed over time, resulting in significantly different peak discharge rates. Since the August 2017 calibration storm event recorded an elevation above 96.36 feet, the focus of the calibration effort was on matching the recorded stage.
- USGS Gage: Cypress Creek (08068720) at Katy-Hockley Rd. near Hockley, TX - The peak stage from the August 2017 historical event is two feet higher than the stage recorded with the highest measured discharge. Therefore, the focus of calibration was on matching the recorded stage.
- USGS Gage: Little Cypress Creek (08068780) at Cypress Rosehill Rd. near Cypress, TX - The difference in discharges and stages show that the rating curve for the gage has changed over time, resulting in significantly different peak discharge rates. Therefore, the focus of calibration was on matching the recorded stage.
- USGS Gage: West Fork San Jacinto River (08067650) at SH105 near Conroe, TX - All other historical events are less than the highest measured discharge and stage during the August 2017 event. Since direct measurements were obtained for both the August 2017 and May 2016 events, the calibration effort considered both discharge and stage.
- USGS Gage: West Fork San Jacinto River (08068000) at IH-45 near Conroe, TX - Since the USGS obtained direct measurements for both the August 2017 and May 2016 events, the calibration effort considered both discharge and stage.
- USGS Gage: West Fork San Jacinto River (08068090) at SH99 near Porter, TX - The discharges for August 2017 and May 2016 were obtained through direct measurement good accuracy. Therefore, the calibration effort considered both discharge and stage.
- USGS Gage: West Fork San Jacinto River (08069500) at IH-69 near Humble, TX - Although the USGS obtained direct measurements for the August 2017 event, the measurement has a poor rating. In addition, stage recorded at the gage in during the August 2017 event is more than 6 feet over the stage measured by the USGS. Therefore, the focus of the calibration effort was on matching stage.
- USGS Gage: West Fork San Jacinto River (08067548) at FM1791 near Huntsville, TX - Calibration for this gage was included as part of the 2019 West Fork San Jacinto River Flood Protection Planning Study for the August 2017 Harvey storm event.
- USGS Gage: San Jacinto River (08072050) at US90 Business near Sheldon, TX - Because only stage is measured at this gage, no USGS rating curve is published for this gage. Therefore, the focus of calibration was on matching the recorded stage.
- USGS Gage: San Jacinto River (08072000) at Lake Houston - Because only stage is measured at this gage, no USGS rating curve is published for this gage. Therefore, the focus of calibration was on matching the recorded stage.

5.2 Calibration Process

Calibration consisted of the reasonable adjustment and refinement of the hydrologic and hydraulic model parameters developed in the existing conditions flood hazard assessment so that the models reproduce observed data. Models calibrated to an acceptable accuracy provide assurance that the results mimic existing conditions. The calibrated model outputs include stages, hydrograph shape (timing), discharges, and volumes with the primary goal of matching stage peak elevation and shape. A detailed discussion of the calibration process and results is presented in **Appendix D** The general process was as follows:

- **Stage** – Calibrating to the stage ensures the peak elevations from the model match the peak elevations of the historical event. Adjustments were made to Manning's n-values for both the channel and overbank flow regimes to calibration the model to the observed stages for the calibration storms. Channel n-values were increased or decreased in the uncalibrated model to adjust the stage hydrograph for flows within the channel banks. The calibrated channel n-values range from 0.03 to 0.08. Overbank n-values were increased in the uncalibrated model to adjust the stage hydrograph after flows exceed the channel banks. Calibrated overbank n-values range from 0.02 to 0.29. The goal of the model was to have 50% of the modeled gage locations within 0.5-feet of the observed, 75% within 1.0 feet, and 95% within 2.0 feet to be consistent with HCFCD MAAPnext standards.
- **Stage Hydrograph Timing** - Calibrating to the shape of the stage hydrograph includes adjusting appropriate parameters to shift the timing of the watershed as well as change the slope of the rising and falling limbs. A model stage hydrograph shape that follows the shape of the gage stage hydrograph demonstrates that the model is reproducing the timing of the watershed and that the total volume of the stream is distributed appropriately. In general, the timing was calibrated by adjusting the hydrologic transform parameters and the Manning's n-values. BDF values were only increased or decreased on Lake Creek to adjust the Tc+R values and subbasin timing.
- **Discharge** - Gage discharges were reproduced in the models by adjusting the hydrologic and hydraulic parameters such as losses, BDF values, and Manning's n-values. Initial and constant losses were generally increased to lower discharges or decreased to increase discharges. Initial losses were adjusted to calibrate the rising limb of the stage and discharge hydrographs. Constant losses were adjusted to calibrate the abstraction of rainfall from the hyetograph throughout the entire rain event. BDF values were raised to increase the discharges and decreased to lower the overall discharge rate.
- **Volume** - Volume is the total amount of flow that passes through the gage location over a specific time period. Volume is especially important when calibrating reservoirs such as Lake Conroe and Lake Houston. The amount of volume that enters and leaves the reservoir generally impacts the calibration of stage. The model volume results are calibrated by adjusting the initial and constant losses throughout the watershed upstream of the gage. In areas where USGS flow rating curves have high confidence, the volume can be calibrated at the gage. In areas with low confidence, the losses were calibrated to match the stage gage on Lake Houston.

5.3 Calibration Results

Hydrologic and hydraulic parameters for each watershed were reasonably adjusted to produce model results that were within acceptable accuracy of USGS gage data. Hydrologic and hydraulic models were initially calibrated individually for each watershed. Once the initial calibration was complete, the hydrologic models were combined into one comprehensive model and the hydraulic models were also combined into one comprehensive model. The combined models were then calibrated for the August 2017 Hurricane Harvey and May 2016 Memorial Day storm events. The final models were simulated for the October 1994 and the September 2019 Tropical Storm Imelda storm events to validate the ability of the models to reproduce results. The results were checked for general consistency with the results of these storms, but not to the same level as Hurricane Harvey or the Memorial Day 2016 storm.

Table 6 summarizes the calibration results for the Hurricane Harvey storm event. The model was within 0.5 feet of the observed elevation for 65% of the gages. The model was within 1.0 feet of the observed elevation for 88% of the gages. The model was within 2.0 of the observed elevation for 100% of the gages.

Table 6. Hurricane Harvey (2017) Observed vs. Modeled Summary

USGS Gage ID	XS	Description	Modeled Peak Stage (ft)	Modeled Peak Discharge (cfs)	Observed Peak Stage (ft)	Observed Peak Discharge (cfs)
8070500	**110707**	Caney Creek near Splendora	144.7	27762	145.1	21,100
8068740	**190317**	Cypress Creek at House-Hahl	149.4	9,027	149.3	22600
8068800	**133844**	Cypress Creek at Grant Rd.	129.2	20,652	130.0	17,500
8068900	**90551**	Cypress Creek at Stuebner-Airline	112.2	28,373	113.8	23,100
8068780	**50807**	Cypress Creek near Westfield	96.9	32,606	97.1	31500
8070000	**172071**	East Fork San Jacinto River near Cleveland, TX	134.5	88,641	135.2	109,000
8070200	**64422**	East Fork San Jacinto River near New Caney, TX	81.2	90,576	81.2	120,000
8067920	**38367**	Lake Creek at Sendera Ranch Rd.	150.8	151	151.0	55300
8071280	**48696**	Luce Bayou near Huffman, Tx	77.5	30,619	77.8	32,800
8071000	**51995**	Peach Creek near Splendora, Tx	107.4	37,608	107.4	30,800
8068275	**207388**	Spring Creek near Tomball, Tx	165.8	48,432	166.4	-
8068500	**86681.8**	Spring Creek near Spring, Tx	111.3	72,330	111.5	78,400
8067650	**376894**	West Fork San Jacinto River below Lake Conroe	156.7	79,308	156.2	75400
8068000	**311675**	West Fork San Jacinto River near Conroe, Tx	127.0	130,587	126.9	122,000
8068090	**237012**	West Fork San Jacinto River near Porter, Tx	93.3	134,431	94.9	131,000
8069500	**174223**	West Fork San Jacinto River near Humble, Tx	69.6	227,100	69.6	-
8072000	**88621**	Lake Houston near Sheldon, Tx	53.0	413,207	53.1	-

Table 7 summarizes the calibration results for the Memorial Day 2016 storm event. The model was within 0.5 feet of the observed elevation for 56% of the gages. The model was within 1.0 feet of the observed elevation for 81% of the gages. The model was within 2.0 of the observed elevation for 94% of the gages.

Table 7. Memorial Day (2016) Observed vs. Modeled Summary

USGS Gage ID	XS	Description	Modeled Peak Stage (ft)	Modeled Peak Discharge (cfs)	Observed Peak Stage (ft)	Observed Peak Discharge (cfs)
8070500	**110707**	Caney Creek near Splendora	140.7	12748	141.3	10,700
8068740	**190317**	Cypress Creek at House-Hahl	144.7	2,573	145.6	4510
8068800	**133844**	Cypress Creek at Grant Rd.	123.9	8,268	124.0	6,750
8068900	**90551**	Cypress Creek at Stuebner-Airline	105.6	8,196	104.1	6,820
8068780	**50807**	Cypress Creek near Westfield	88.5	9,532	87.9	11600
8070000	**172071**	East Fork San Jacinto River near Cleveland, TX	129.1	19,023	128.8	21,800
8070200	**64422**	East Fork San Jacinto River near New Caney, TX	67.6	17,466	70.6	19,800
8067920	**38367**	Lake Creek at Sendera Ranch Rd.	147.9	37,933	147.8	37400
8071280	**48696**	Luce Bayou near Huffman, Tx	70.2	11,721	68.7	9,990
8071000	**51995**	Peach Creek near Splendora, Tx	103.2	18,292	103.2	13,800
8068275	**207388**	Spring Creek near Tomball, Tx	164.9	47,722	165.2	45400
8068500	**86681.8**	Spring Creek near Spring, Tx	108.3	61,084	108.4	60,000
8067650	**376894**	West Fork San Jacinto River below Lake Conroe	148.2	22,244	148.8	22800
8068000	**311675**	West Fork San Jacinto River near Conroe, Tx	120.9	56,630	121.1	59,000
8068090	**237012**	West Fork San Jacinto River near Porter, Tx	83.5	57,247	-	55,700
8069500	**174223**	West Fork San Jacinto River near Humble, Tx	61.9	120,185	62.0	-
8072000	**88621**	Lake Houston near Sheldon, Tx	48.0	168,547	47.9	-

5.3.1 San Jacinto River at Lake Houston

Appendix D provides a summary of comparisons for all model calibration results and the USGS stage and discharge historical information. The graphs below show the comparisons for the USGS gage at the Lake Houston Dam, located at the downstream end of the watershed and at the location where flow from all watersheds is contributing. The graphs compare the calibration events of Hurricane Harvey and Memorial Day 2016 as well as the validation events of Tropical Storm Imelda and October 1994. The graphs show that the calibrated models match well to historical events and the models validated well with other events.

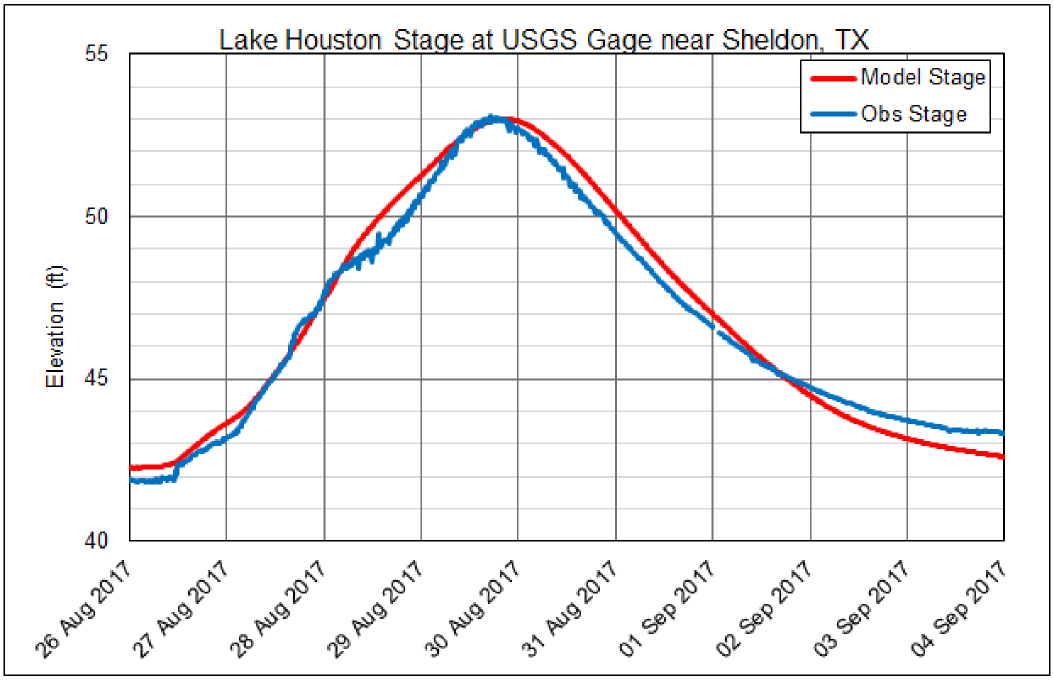


Figure 10: Hurricane Harvey 2017 Lake Houston Calibration

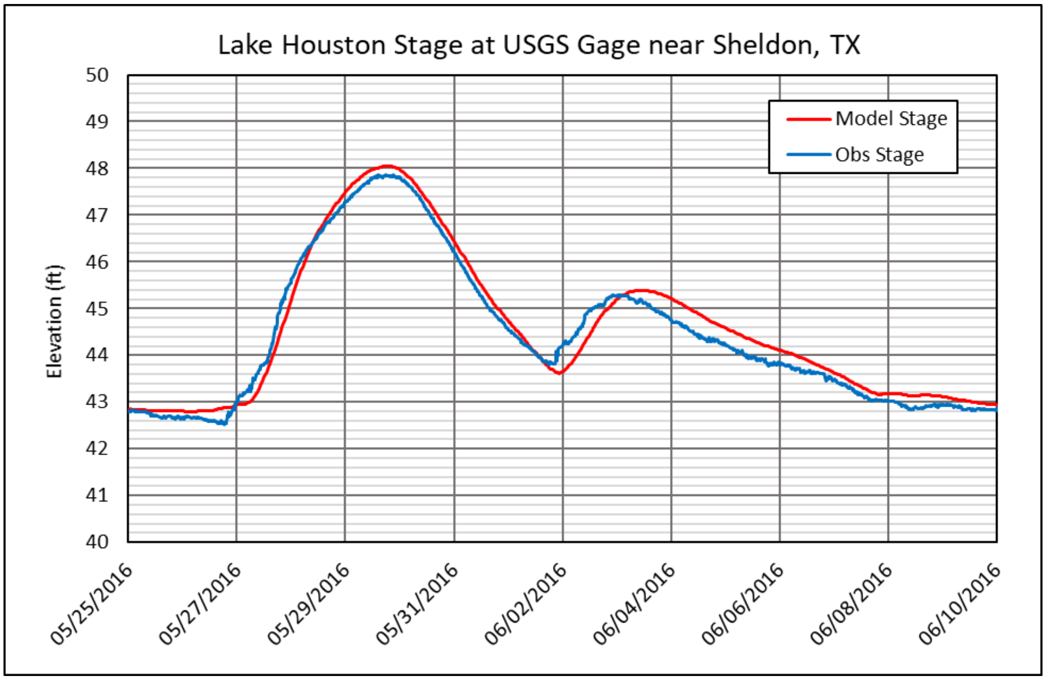


Figure 11: Memorial Day 2016 Lake Houston Calibration

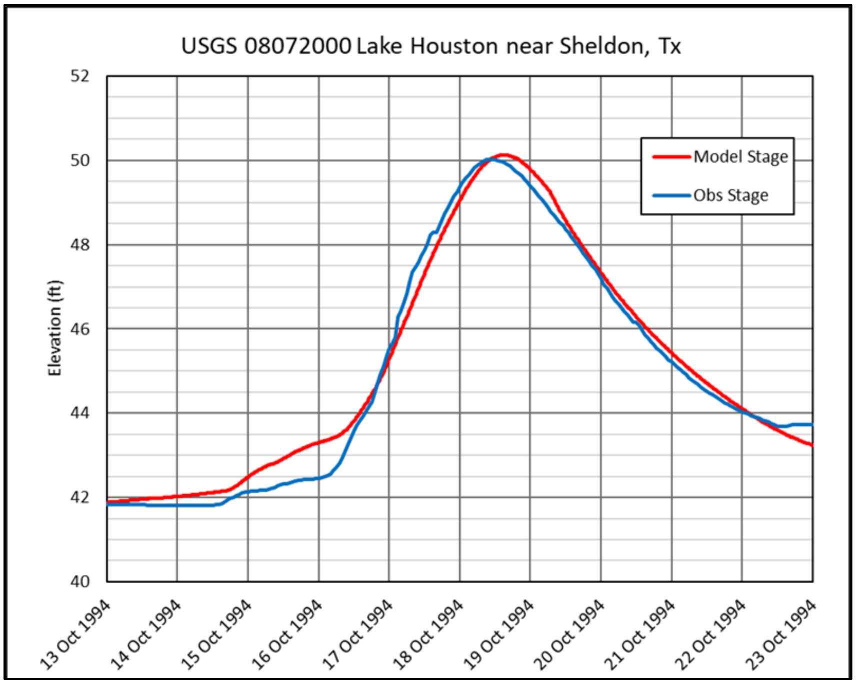


Figure 12: October 1994 Lake Houston Validation

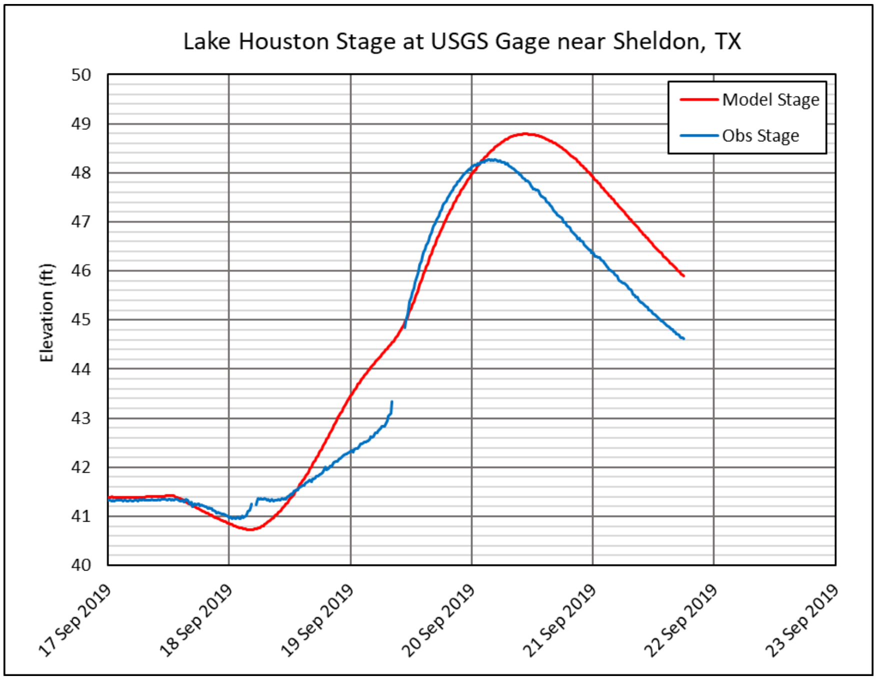


Figure 13: Tropical Storm Imelda 2019 Lake Houston Validation[5]

[5] The models were only validated for this storm event. The stage is slightly higher than observed which can be attributed to loss rates within the model. Adjustments to loss rates during a calibration effort would likely improve the comparisons.

5.4 Existing Conditions Flood Hazard Assessment

The calibrated hydrologic and hydraulic parameters for the Hurricane Harvey 2017 and Memorial Day 2016 storm events were averaged to determine the final parameters for the frequency storm simulations. The final models were then simulated for the Atlas 14 frequency storm events to determine the discharges and water surface elevations throughout the watershed.

Inundation maps were prepared for 1% ACE and 0.2% ACE storm events and compared to the existing floodplains. Inside of Harris and Montgomery Counties, most of the floodplains are studied and are designated as Zone AE (1% ACE studied floodplain). The floodplains in the surrounding counties are primarily approximate or Zone A (1% ACE approximate floodplain). The inundation maps for the frequency storms can be viewed in **Appendix D.2**.

Discharges throughout the watershed increased from the FEMA effective flows with an average increase of 30%. The increase in discharge is mostly due to the Atlas 14 rainfall and updated/calibrated model data.

Table 8: Comparisons to FEMA Effective Flows and WSELs

Watershed	Average Flow Increase (cfs)	Average WSE Increase (ft)
West Fork San Jacinto River	8,400	0.9
East Fork San Jacinto River	19,000	2.6
San Jacinto River	60,500	-0.9
Lake Creek	26,500	4.5
Cypress Creek	900	0.8
Little Cypress Creek	4,400	1.8
Spring Creek	5,600	3.3
Willow Creek	3,500	1.8
Caney Creek	13,500	3.9
Peach Creek	5,400	2.8
Luce Bayou	2,200	1.4
Jackson Bayou	-10	0.8

Water surface profiles were prepared comparing the 1% ACE model results to the effective water surface profiles. Additionally, estimated finished floor elevations for structures within and near to the 0.2% floodplain boundary were also compared to the updated model water surface profiles. This information was used to estimate what homes, businesses, and other structures would be at risk of flooding for the suite of design storm events included in this study. In general, the model water surface elevations calculated for this study are higher than the FEMA effective elevations.

The total acres of floodplain, structural flooding, intersecting parcels, and roadway miles were identified for each modeled storm event. This information is summarized in the tables below.

Table 9. Existing Conditions Flood Hazard Summary

20% ACE Storm Event				
Stream	**# Structures**	**Acreage**	**# Parcels**	**Roadway (mi)**
Caney Creek	76	7,651	2,061	13.3
Cypress Creek	62	13,484	2,363	25.7
East Fork	61	19,860	3,677	20.5
Gum Gully	2	464	147	0.6
Jackson Bayou	1	416	85	0.1
Lake Creek	8	16,085	883	6.4
Little Cypress Creek	41	3,808	801	14.6
Luce Bayou	11	7,032	727	2.0
Peach Creek	108	5,807	2,137	15.3
Spring Creek	50	13,124	3,074	13.7
Tarkington Bayou	88	9,296	724	9.0
West Fork of SJR	54	31,912	6,337	37.7
Willow Creek	60	4,345	1,084	13.8

10% ACE Storm Event				
Stream	**# Structures**	**Acreage**	**# Parcels**	**Roadway (mi)**
Caney Creek	175	9,709	2,446	21.4
Cypress Creek	212	15,700	3,057	38.7
East Fork	186	22,814	4,272	29.3
Gum Gully	3	613	175	0.9
Jackson Bayou	1	524	95	0.1
Lake Creek	26	17,320	971	8.0
Little Cypress Creek	82	4,491	978	23.5
Luce Bayou	24	8,434	821	3.2
Peach Creek	325	6,903	2,395	21.9
Spring Creek	139	15,172	3,616	18.3
Tarkington Bayou	108	10,157	802	11.4
West Fork of SJR	161	36,772	7,656	52.9
Willow Creek	115	4,791	1,232	16.9

4% ACE Storm Event				
Stream	**# Structures**	**Acreage**	**# Parcels**	**Roadway (mi)**
Caney Creek	557	12,179	3,137	32.9
Cypress Creek	708	18,807	4,581	67.6
East Fork	461	26,814	5,109	42.9
Gum Gully	5	794	222	1.1
Jackson Bayou	1	705	108	0.2
Lake Creek	55	18,836	1,113	11.3
Little Cypress Creek	427	5,836	1,185	36.1
Luce Bayou	52	10,543	981	5.3
Peach Creek	581	8,010	2,782	31.6
Spring Creek	470	18,591	5,052	35.9
Tarkington Bayou	140	11,048	870	13.6
West Fork of SJR	732	46,570	9,784	89.1
Willow Creek	241	5,478	1,614	24.0

2% ACE Storm Event				
Stream	**# Structures**	**Acreage**	**# Parcels**	**Roadway (mi)**
Caney Creek	979	13,502	3,611	40.2
Cypress Creek	1,464	21,423	6,217	100.9
East Fork	712	29,670	6,112	60.8
Gum Gully	15	917	252	1.4
Jackson Bayou	1	835	126	0.4
Lake Creek	95	20,017	1,318	15.0
Little Cypress Creek	1,000	6,453	1,268	39.9
Luce Bayou	84	12,863	1,194	7.7
Peach Creek	843	8,868	3,141	40.4
Spring Creek	1,158	21,985	8,448	74.7
Tarkington Bayou	161	11,791	932	14.6
West Fork of SJR	1,659	52,595	12,401	125.4
Willow Creek	388	6,105	2,307	32.0

1% ACE Storm Event				
Stream	**# Structures**	**Acreage**	**# Parcels**	**Roadway (mi)**
Caney Creek	1,384	14,718	4,045	46.6
Cypress Creek	2,920	24,655	7,816	141.7
East Fork	1,073	31,876	6,924	71.1
Gum Gully	62	1,038	289	1.7
Jackson Bayou	20	913	135	1.0
Lake Creek	162	21,010	1,496	17.6
Little Cypress Creek	1,704	6,951	1,357	44.7
Luce Bayou	134	14,790	1,334	10.6
Peach Creek	1,115	9,531	3,351	45.1
Spring Creek	2,909	25,906	13,504	125.3
Tarkington Bayou	179	12,489	988	11.1
West Fork of SJR	3,719	58,003	14,916	174.9
Willow Creek	854	6,623	3,013	36.9

0.2% ACE Storm Event				
Stream	**# Structures**	**Acreage**	**# Parcels**	**Roadway (mi)**
Caney Creek	2,628	17,487	5,178	67.5
Cypress Creek	8,688	30,053	10,872	215.0
East Fork	2,035	35,941	8,569	92.5
Gum Gully	191	1,273	343	5.4
Jackson Bayou	105	1,143	204	2.0
Lake Creek	295	23,043	1,854	24.4
Little Cypress Creek	3,708	7,693	1,510	49.8
Luce Bayou	298	17,928	1,545	17.6
Peach Creek	1,713	11,058	3,813	56.3
Spring Creek	11,125	31,980	19,617	199.0
Tarkington Bayou	238	14,137	1,135	19.7
West Fork of SJR	8,275	67,839	25,355	283.9
Willow Creek	1,854	7,413	4,157	45.5

6.0 Sedimentation and Vegetation

6.1 Introduction

As part of the SJRWMDP, a sediment management strategy was developed for the West Fork San Jacinto River and Spring Creek subwatersheds. The sediment management strategy memorandum in its entirety is provided in **Appendix F**.

The goal of this sediment management strategy as defined by the stakeholders within the watershed is to identify opportunities along the West Fork and Spring Creek mainstems to decrease sediment deposition in the West Fork San Jacinto River channel between its confluence with Spring Creek (just west of West Lake Houston Parkway) and Lake Houston. This sediment problem area is labeled in **Figure 14** below, just south of the master-planned community of Kingwood. The figure also indicates the location of the Spring Creek and West Fork San Jacinto River subwatersheds.

To match the delineation of subwatersheds used in previous sedimentation studies, the West Fork San Jacinto River subwatershed also includes the Lake Creek subwatershed west of Lake Conroe. In the same way, the Spring Creek subwatershed includes the Willow Creek subwatershed, the Cypress Creek subwatershed includes Little Cypress, and the Luce Bayou subwatershed includes Tarkington. As noted previously, this sediment management strategy is focused on the West Fork and Spring Creek mainstems.

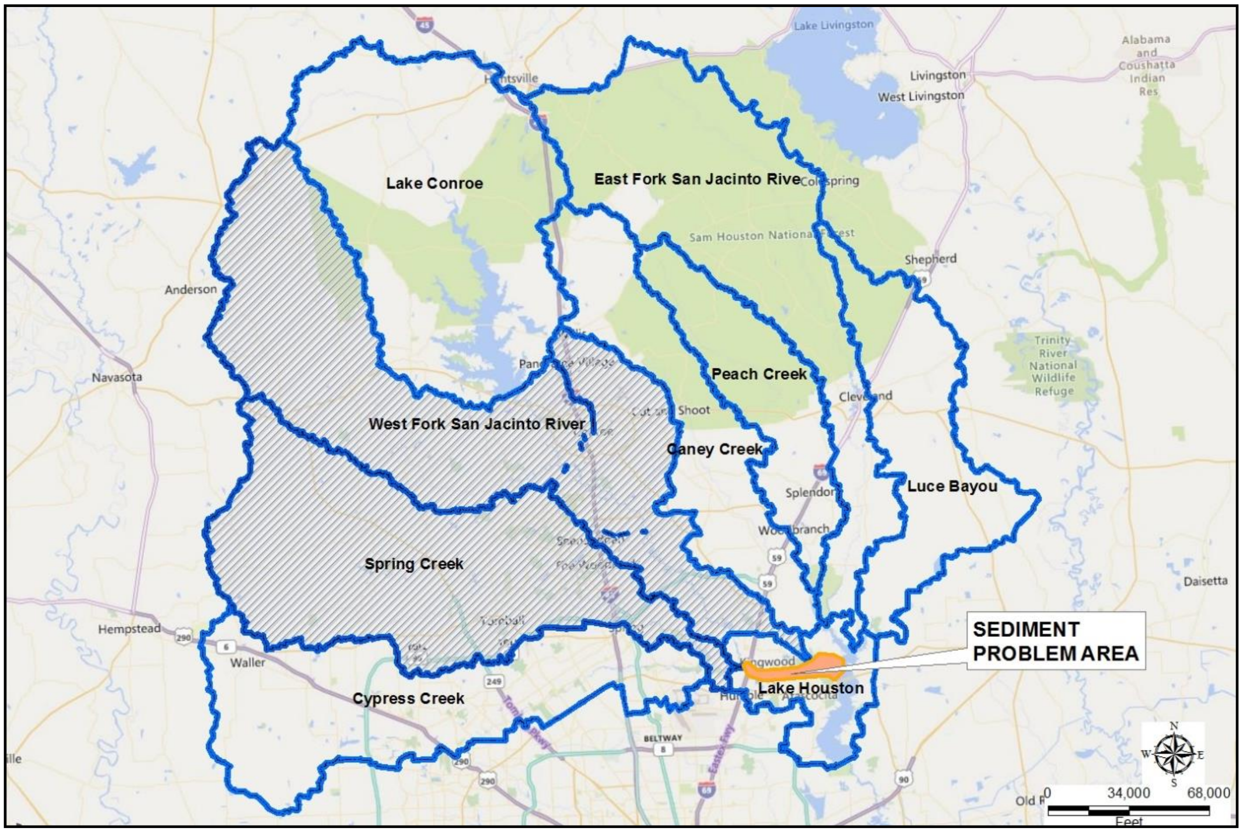


Figure 14: Sediment Management Strategy Study Area

The sediment management strategy included the following objectives:

- Replicate the methods used in previous reports to identify opportunities to prevent sediments from entering the rivers and streams within the watershed, reduce the amount of sediments depositing in the region between the confluence of the West Fork San Jacinto River and Spring Creek and the FM 1960 bridge over Lake Houston, and remove sediment that already deposited in this region.
- Identify locations where sediment management strategies can be implemented in the West Fork San Jacinto River and Spring Creek subwatersheds.
- Provide recommendations for subsequent studies for evaluating additional methodologies that were not used in previous reports. These subsequent studies are needed to understand the relationship between sedimentation and flood water surface elevations in this area, quantify a sediment budget throughout the entire San Jacinto watershed, predict the efficiency of sediment management strategies, and measure the movement of sediments through the watershed.

6.2 Summary of Findings and Sediment Management Strategies

The sediment management strategy analyses and findings were organized by following U.S. Army Corps of Engineers (USACE) guidelines for development of a Regional Sediment Management Plan (RSM). RSMs have been used to develop solutions to complex sediment problems that result in the filling of navigable waters and conveyance channels. This study focuses on sediment from the West Fork San Jacinto River and Spring Creek as an initial phase of work to identify sediment management strategies to reduce sedimentation in Lake Houston. A comprehensive RSM for the watershed is recommended for development as part of a future phase of work.

The main findings of the SJRWMDP sediment management strategy include the following:

- Sedimentation in Lake Houston began as soon as the lake was created with the construction of Lake Houston Dam in 1954. Ongoing deposits of sediment have resulted in reduced water supply storage in the lake. In 2019, the U.S. Army Corps of Engineers (USACE) conducted a dredging project that has removed roughly five percent of the material deposited in Lake Houston since the dam was built. The cost of this project exceeded $90 million. The projected cost to remove the annual sediment load into Lake Houston would exceed $29 million per year. If no additional removal of sediment is conducted between 2020 and 2035, the projected cost to remove all sediment deposited in Lake Houston by 2035 would exceed $2.2 billion.
- Annual sediment rating curves based on USGS stream gage data for each of the seven subwatersheds downstream of Lake Conroe as shown in **Figure 14**, in conjunction with an assessment of historic and current topographic information, indicated that both the West Fork and Spring Creek subwatersheds contribute significant sediment to Lake Houston. The Cypress Creek, Spring Creek, and West Fork subwatersheds are the highest contributors of suspended sediment to Lake Houston, contributing an estimated 38.7 percent, 26.8 percent, and 13.0 percent of the total sediment load, respectively. The majority of this sediment, up to 80 percent, could originate from eroding streambanks and other instabilities along the mainstems.
- A LiDAR volumetric comparison showed that 2,693 acre-feet per year of material is eroded from the San Jacinto watershed landscape. This material may either deposit within the landscape or enter the stream and river network as a mixture of suspended sediment and bedload. The

remaining material deposits in the stream network, deposits in Lake Houston, or is washed over Lake Houston Dam.

- An annual suspended sediment load analysis based on gage data showed that an estimated 433 acre-feet per year of suspended sediment transport may be transported into Lake Houston.
- Sediment is transported to Lake Houston either suspended in water or pushed along river bottoms as bedload. An analysis of geotechnical boring data from Lake Houston indicates that most sediment was suspended. This finding influences the choices of sediment strategies.

Twenty-one sediment management strategies were identified along the West Fork and twenty-eight along Spring Creek. These strategies can be used by watershed community administrators and floodplain managers to identify opportunities to prevent sediment sources from entering the stream network, trap sediment upstream of the lake, or convey sediment through the problem area. The strategies were prioritized based on their potential to reduce sediment deposition in the problem area between the Spring Creek and West Fork confluence and Lake Houston. These strategies include the following:

- Opportunities to trap sediments along the mainstems were identified and organized by predicted reduction of sediments that would otherwise flow into the lake.
- Manipulation of Lake Houston Dam hydraulics or construction of a sediment bypass tunnel can also move sediment deposition further downstream, decreasing sedimentation problem area.
- A stream restoration project upstream of Lake Houston could use dredging spoils from the lake as fill material to restore floodplain geometry and push sediments further out into Lake Houston, away from the Kingwood problem area.
- Aggregate Production Operations (APOs), also known as sand mines, need to be protected to avoid releasing sediments downstream. APOs also present an opportunity to capture sediments. A more detailed evaluation is needed to quantify their level of sediment contribution and the potential for sediment reduction.
- Public-private partnerships and/or an extension of jurisdictional authority may be needed to implement the proposed sediment management strategies. These public-private partnerships, limits of current jurisdictional authority, and an example memorandum of understanding (MOU) to extend jurisdictional authority is provided as an appendix to the sediment management strategy in Appendix F.

6.3 Summary of Recommendations

The following recommendations were also developed from the updated analyses and findings of ways to reduce sedimentation in the region of concern between the Spring Creek and West Fork San Jacinto River confluence and the FM 1960 bridge over Lake Houston.

1. Complete a regional sediment management (RSM) plan and develop an annual sediment budget for the San Jacinto watershed, including individual subwatersheds and notable drainage areas within each subwatershed. The RSM will include a working group consisting of watershed managers and stakeholders who make sediment management decisions or are impacted by sediment related problems. The RSM must include sediment transport analysis and a volumetric analysis of sediment sources and sediment depositional areas using LiDAR comparisons. This

approach will help guide recommendations for sediment management strategies by clarifying their efficacy in removing sediment loads and allowing for cost comparisons.

2. Divide the West Fork and Spring Creek subwatersheds into smaller regions and use existing stream gage data to develop a sediment budget for each of these smaller regions. This will inform where higher suspended sediment is originating within each subwatershed.
3. Identify areas where new stream gages can be installed to measure suspended sediment in Cypress Creek subwatershed and other subwatersheds to improve the understanding of where sediments in the subwatershed originate as noted for the West Fork and Spring Creek above.
4. Complete a GIS exercise similar to the one provided in **Appendix F** of the sediment management strategy in order to quantify potential sediment sources from eroding streambanks and valley walls and determine the percentage of sediments originating from eroding banks versus landscape erosion or anthropogenic activities. Measure topography using LiDAR in a few years to map changes in the landscape and river corridors. The recent LiDAR used in the study was obtained post-Hurricane Harvey and topographic changes are not reflective of an average annual change.
5. Evaluate reasonable manipulations to Lake Houston Dam hydraulics to improve sediment transport in the region of concern and reduce sediment deposition in the water channel. Ensure these improvements do not increase flood risk downstream or affect the lake's water supply.
6. Identify regions where sediment deposition occurs and the resulting obstruction is suspected to result in flooding. Measure the extent of sediment deposition and complete a hydraulic modeling exercise to calculate water surface elevations with and without the sediment obstruction in place. If water surface elevations with sediment in place are unacceptable, complete an annual sediment transport calculation and stable sediment size calculations to understand channel dimension manipulation options to reduce sediment deposition.
7. Complete a feasibility study to implement pilot projects such as:
    a. Sediment trapping to remove sediment from Lake Houston's tributaries.
    b. Channel manipulation to improve sediment transport competency in regions sensitive to channel infilling.
    c. Sediment source protection in sections of Lake Houston tributaries where large potential sediment sources have been measured. Sediment source protection includes activities such as natural channel design and stream bank stabilization.
8. Identify stormwater outfalls that are prone to being blocked by sediment deposition and are suspected to contribute to localized flooding due to the system not being able to convey stormwater. Survey these locations to measure the degree the outfall has been blocked and develop recommendations when the outfall should be cleared.
9. Conduct additional analysis of a sediment tunnel connecting the West Fork San Jacinto River to downstream of Lake Houston Dam. This could allow sediment to bypass the lake by gravity by potentially intercepting and directing the sediments around the area of concern.
10. Conduct reach-level assessments to evaluate in-channel sediments loading rates. In this phase, the streambanks that are contributing the greatest sediment load can be prioritized for any stabilization efforts that become a part of the RSM.

7.0 Future Flood Risk Planning Assessment

7.1 Introduction

To evaluate potential flood risk in the Upper San Jacinto River Watershed related to future conditions, the calibrated existing conditions models were updated based on population growth trends. These future conditions models reflect anticipated changes in population between 2020 and 2070, which are expected to lead to increases in impervious cover and changes in the timing of basin runoff. The future conditions memorandum in its entirety is provided in **Appendix E**.

7.2 Future Conditions Hydrologic Parameter Development

Population estimates for 2070 were based on a combination of Water User Group (WUG) data associated with Texas Water Development Board (TWDB) Regional Water Plans and the Harris-Galveston Subsidence District Regional Groundwater Update Project (RGUP) that was completed in 2013. Census-block-level RGUP data was used in Harris and Montgomery counties, and the coarser WUG data was used in the remaining counties. The current population of the watershed is approximately 1.5 million people and is projected to increase to approximately 3.2 million people by 2070. Population increases are generally concentrated in the lower reaches of the watershed, near Lake Houston.

Table 10 below summarizes the 2018 population and projected 2070 population by subwatershed.

Table 10. Population Projections by Subwatershed

Subwatershed	2018 Population	2070 Population	Change in Population	% Change in Population
Lake Creek	28,078	100,329	72,251	257%
Spring Creek	287,039	797,494	510,455	178%
Willow Creek	71,385	118,212	46,827	66%
Cypress Creek	451,660	590,617	138,957	31%
Little Cypress Creek	47,791	85,353	37,562	79%
West Fork	334,289	785,126	450,837	135%
Lake Conroe	85,907	228,684	142,777	166%
Luce Bayou	8,817	14,609	5,792	66%
Tarkington Bayou	12,228	17,080	4,852	40%
Caney Creek	80,492	263,111	182,619	227%
Peach Creek	29,005	102,300	73,295	253%
East Fork	44,042	67,866	23,824	54%
Jackson Bayou	4,377	6,221	1,844	42%
Gum Gully	11,830	20,982	9,152	77%

These population changes were converted to future land use percentages using two generic development patterns for suburban and rural development types. These two patterns were based on an evaluation of the existing development patterns found within the watershed and allow for denser development in suburban areas. Each subbasin was assigned either the suburban or rural development type based on aerial imagery and proximity to existing development. **Table 11** shows the assumed land use breakdown and population density associated with each type.

Table 11. Future Development Patterns

Future Development Type	Development Pattern (Pct. of Developed Area)					Population Density (Population per Future Developed Acre)
	Transp.	Low Intens.	Med. Intens.	High Intens.	Devel. Open Space	
Suburban	5%	50%	30%	5%	10%	10.05
Rural	5%	65%	15%	5%	10%	6.60

This approach provides a way to convert population growth in each subbasin to an expected change in land use within that subbasin. For example, consider a subbasin with an anticipated population growth of 10,000 people by 2070. If this subbasin is expected to develop according to the suburban development pattern, these 10,000 people, which occupy land at a rate of 10.05 people per acre, will require 995 acres of newly developed land. Of these 995 acres, 5% (49.8 acres) would develop as transportation, 50% (497.5 acres) would develop as low-intensity, and so on.

The additional 2070 populations within each subbasin were converted to areas of future land use, which were then used to calculate new impervious cover and basin development factors (BDFs) for input into HEC-HMS. The calculated BDFs assume a detention rate of 0.55 acre-feet per acre for each acre of future development. The 0.55 detention rate is an estimate of the volume from previous HCFCD detention requirements. Actual detention rates may vary depending on the type of development.

Under existing conditions (2018 land use), the study area of 2,911 square miles includes 779 square miles of developed area and an average of 14.3% impervious cover. Under future conditions (projected 2070 land use), the study area is projected to include 1,074 square miles of developed area and an average of 18.8% impervious cover. In other words, 295 square miles of additional developed area are projected to be added over the next 50 years, representing about 10% of the total study area.

7.3 Future Conditions Hydrologic and Hydraulic Model Results

The HEC-HMS and HEC-RAS models were updated to reflect the 2070 conditions scenario and were executed for the 50% ACE through 0.2% ACE storms. The average 1% ACE water surface elevation along each mainstems increased between 0.0 and 0.2 feet. The maximum 1% ACE increases in water surface elevation remained under 0.75 feet. The 1% ACE increase at Lake Houston Dam was 0.04 feet. The 1% ACE water surface in Lake Conroe increased by approximately 0.3 feet. Lake Conroe was modeled hydrologically using current gate operations for both existing and future conditions. The average 50% ACE increases were generally higher, ranging from 0.0 to 0.5 feet. The maximum 50% ACE increases in each mainstem generally remained under 1 foot, except for a 1.9-foot increase on Cypress Creek between Stuebner Airline Rd and Kuykendahl Rd and a 1.0-foot increase on the West Fork downstream of Lake Creek. The 50% ACE increase at Lake Houston Dam was 0.2 feet.

These increases in water surface elevation are partially a result of the limitations of applying the BDF hydrologic methodology to large subbasins, many of which are expected to see small, incremental increases in developed area between now and 2070. (These limitations are discussed in further detail in

Appendix E.) The increases also reflect the increase in runoff volume resulting from additional impervious cover. Under future conditions (projected 2070 land use), an additional 10% of the total watershed area draining to Lake Houston is expected to develop with an average impervious cover of 44%. Therefore, only 4.4% of the total study area is projected to change from pervious to impervious cover by 2070. Because the soils in the watershed have a limited infiltration capacity, even small storms cause undeveloped areas to contribute a significant amount of runoff. Overlaying these low-infiltration soils with impervious cover will cause only an incremental increase in total runoff volume. This aligns well with the 1% ACE HEC-HMS results, which show an overall 1.3% increase in runoff volume by 2070. Of the 2.45 million acre-feet of 1% ACE rainfall volume, 2.04 million acre-feet becomes runoff under existing conditions. Under future conditions in 2070, this runoff volume increases to 2.07 million acre-feet. Expressed in terms of the average 15.8 inches of 1% ACE rainfall depth, approximately 13.1 inches of this rainfall currently becomes runoff that reaches Lake Houston; by 2070, this runoff increases to approximately 13.3 inches.

7.4 Conclusions

By 2070, anticipated development is expected to produce increases in peak flow, volume, and peak water surface elevations. These increases are based on detailed population projections, development patterns, hydrologic and hydraulic modeling, and assumed onsite detention for local development. These adjustments were performed at the level of existing subbasins, which range in size from 180 to 29,000 acres and have an average area of 4,620 acres. The scale of this study may not fully capture localized differences in the effects of local detention or hydrograph timing. The full future conditions evaluation is provided in **Appendix E.**

The anticipated population increases between today and 2070 are generally concentrated in the lower reaches of the upper San Jacinto watershed, closer to Lake Houston. After 2070, development will continue to extend into the remaining 1,409 square miles of developable land and into the upper reaches of the watershed, not only increasing runoff volume but also potentially resulting in more closely aligned hydrograph peaks at stream confluences.

A detailed assessment of the fully developed hydrologic condition of the watershed is not included in the scope of this study. However, if future development patterns used in this analysis are assumed to eventually fill all currently undeveloped area in the watershed, the impervious percentage of each subbasin will increase to between 35% and 50%. Under these fully developed conditions, the 1% ACE runoff volume of the entire watershed could increase to 2.15 million acre-feet, or 13.9 inches of runoff. This represents a 5.5% increase in runoff volume over existing conditions and a 3.9% increase over 2070 conditions. Detailed fully developed conditions hydraulic model updates were also not conducted as part of this study. However, the increase in runoff volume under fully developed conditions can be expected to cause additional increases to peak 1% ACE water surface elevations, in the range of six inches to a foot above what is projected for 2070. A detailed hydraulic analysis of fully developed conditions may be helpful in determining the mitigation impact of development regulations.

Finally, this analysis only considers the hydrologic effects of anticipated 2070 development that result from increased impervious cover and BDF values. This analysis does not include the potential hydrologic or hydraulic effects of changes in topography such as fill within the 1% ACE floodplain. If future development is allowed to encroach into the floodplain over the next 50 years and beyond, this will cause additional increases in both peak flow rates and peak water surface elevations, if not adequately mitigated.

8.0 Primary Flood Mitigation Planning

8.1 Introduction

The purpose of the primary flood mitigation planning portion of the study is to detail the process, results, and recommendations related to potential flood reduction projects in the San Jacinto River basin. The structural projects and policy discussions included are related to Task 6. Primary Mitigation Planning, which focuses on approaches to either reduce flooding or remove people and property from flood prone areas. This section will provide a general overview of how specific areas were targeted for projects, how the projects were developed, their relative effectiveness at reducing flooding, both locally and regionally, determination of costs and benefits, and potential implementation challenges.

The goals of the primary flood mitigation analysis include the following:

- Identify areas with high concentrations of significant flood damages
- Determine project locations that have the highest potential for local and regional mitigation
- Perform H&H analysis to determine project effectiveness
- Identify estimated project costs, potential flood reduction benefits, and implementation challenges
- Develop a path toward plan implementation for the Master Drainage Plan

8.2 Potential for Regional Detention

Before modeling any proposed projects or evaluating flood risk at individual structures, the project team used the existing conditions hydraulic model to evaluate the relative impact that detention may provide on a regional basis. This evaluation included a sensitivity analysis of the contribution of each major subwatershed on the 1% ACE water surface elevations in Lake Houston and an evaluation of Lake Houston's impact on 1% ACE water surface elevations in the Kingwood area.

8.2.1 Watershed Volume Sensitivity

A high-level volume sensitivity test was conducted on a regional basis to determine how removing runoff from each watershed affects the regionally focused flood risk areas along the West Fork, East Fork, and Lake Houston. The analysis simulated the 1% ACE in the combined hydraulic model, removing discharge hydrographs from entire watersheds. This analysis assumes that during the 1% ACE, runoff from an entire watershed is retained within the watershed and prevented from being conveyed downstream.

Table 12 summarizes the water surface elevation reductions on the West Fork San Jacinto River for the 1% ACE storm. Removal of Spring Creek led to the highest reductions at I-69, FM 1960, and at the Lake Houston Dam as it is the largest subwatershed. Removal of Caney Creek led to the highest reduction at the confluence with the East Fork. The analysis shows that regional detention in the East Fork, Caney Creek, Peach Creek, Lake Creek, and Spring Creek watersheds may have the highest potential for regional benefits downstream.

Table 12: Watershed Volume Sensitivity on West Fork San Jacinto River and Lake Houston

Reduction Location	1% ACE Water Surface Reduction by Basin Hydrograph Removed						
	Luce Bayou	East Fork	Caney Creek	Peach Creek	Lake Creek	Spring & Willow Creek	Cypress & Little Cypress Creek
West Fork at I-69	0.02	0.04	0.03	0.02	3.08	3.83	1.06
East Fork Confluence	0.65	1.49	0.57	0.37	1.13	1.50	0.52
Lake Houston at FM 1960	0.62	1.41	0.54	0.35	1.08	1.44	0.50
Lake Houston Dam	0.48	1.10	0.42	0.27	0.84	1.12	0.39

8.2.2 Kingwood Area Damage Centers

Many of the structures in the watershed that are at risk of flooding are located in the lower portion of the San Jacinto basin, along the West Fork from US-59 to FM 1960 and along the East Fork from the confluence with Caney Creek to FM 1960. This area, which generally includes Kingwood, has experienced significant flood damages. **Figure 15** below shows the terrain elevations along with flood claims made in the area over the last several major storms, which include Memorial Day (2016), Hurricane Harvey (2017), and Tropical Storm Imelda (2019). While many of the flood damages are likely a result of local drainage issues internal to the Kingwood neighborhoods, it is likely that many others are a result of flooding from the West Fork, East Fork, and Lake Houston.

The terrain shown in the figure provides insight into why many of these areas flood, as well as which areas may flood from the West Fork and East Fork San Jacinto Rivers versus internal drainage. There is a distinct drop in the terrain along the banks of the West Fork. The less common but present flood claims in the higher elevations shown below are being analyzed as part of the concurrent Kingwood Area Drainage Analysis project.

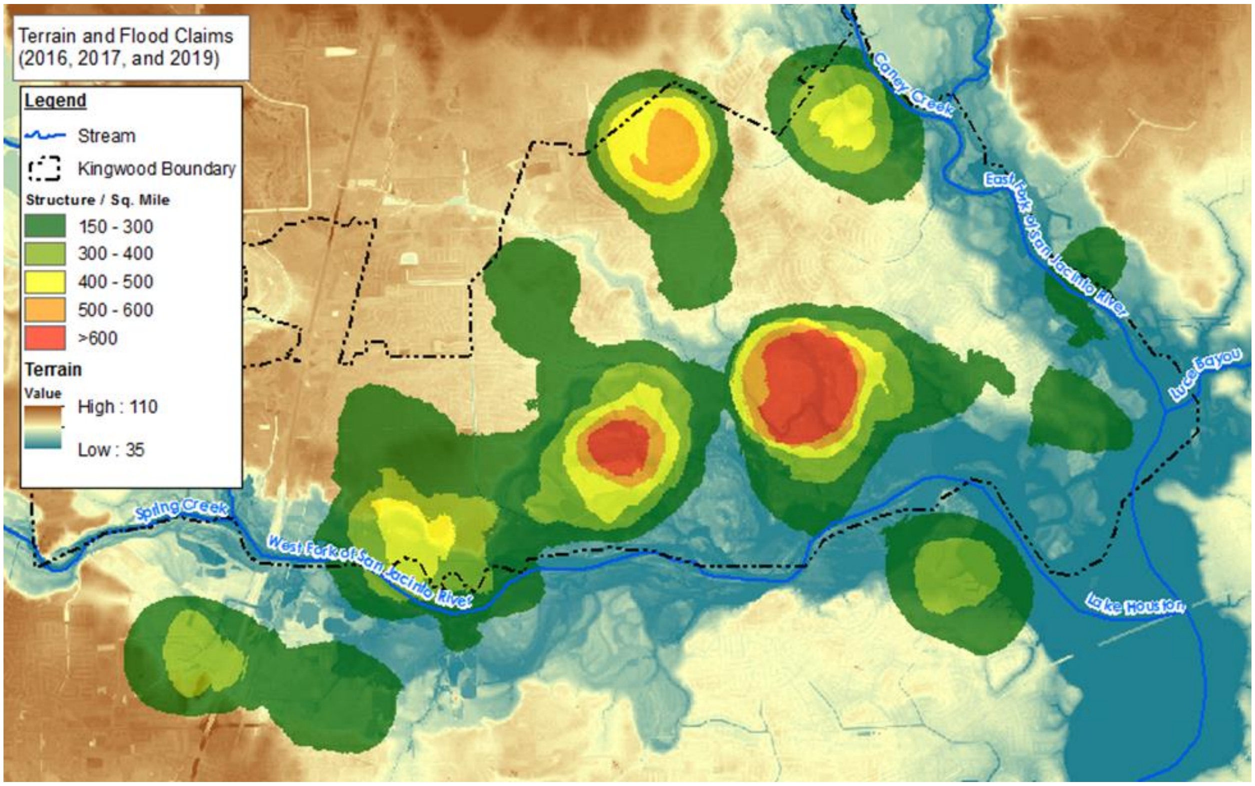


Figure 15: Kingwood Area Flood Claims

Profiles provided in **Appendix D** provide a clear picture of flood risk along the West Fork and East Fork. Along the West Fork, there are relatively few structures that flood from the rivers during storms smaller than the 4% and 2% ACE storms. As flows approach the 1% ACE level there is a significant jump in the number of structures at risk. Between the 1% ACE and 0.2% ACE, the flood risk is even more pronounced. There is a similar pattern along the East Fork. Along the both the East Fork and West Fork, the Memorial Day storm closely approximates the 4% ACE flood elevations. The WSELs for Hurricane Harvey are more representative of between a 1% and 0.2% ACE event, which affected a significant number of structures.

Inundation mapping shown in **Figure 16** below shows the 1% ACE (blue gradation) as well as the 0.2% ACE event (red gradation) based on Atlas 14 hydrology. While the difference in inundation extents appears small, the difference in elevation between the 1% ACE and 0.2% ACE ranges between 3.5 and 5.0 feet. The number of potentially flooded structures jumps significantly between the various flood levels. For example, there are approximately 1,000 at-risk structures for the 1% ACE and more than 2,330 for the 0.2% ACE in this area. As the level of storm diminishes, the number of structures drops off significantly as well. For the 4% ACE event, there are only about 80 structures identified as at-risk. The number of structures identified as at-risk drops to 30 for the 10% ACE.

These findings are consistent with observed flooding in Hurricane Harvey versus the Memorial Day 2016 storm. Reports indicate that there were comparatively few structures flooded by the West Fork and East Fork during the Memorial Day storm, which is the approximate equivalent of a 4% ACE event with about 80 structures at risk. Hurricane Harvey resulted in widespread flooding in the area. The observed flood levels would result in between 1,000 and 2,300 structures potentially flooding along the banks of the rivers.

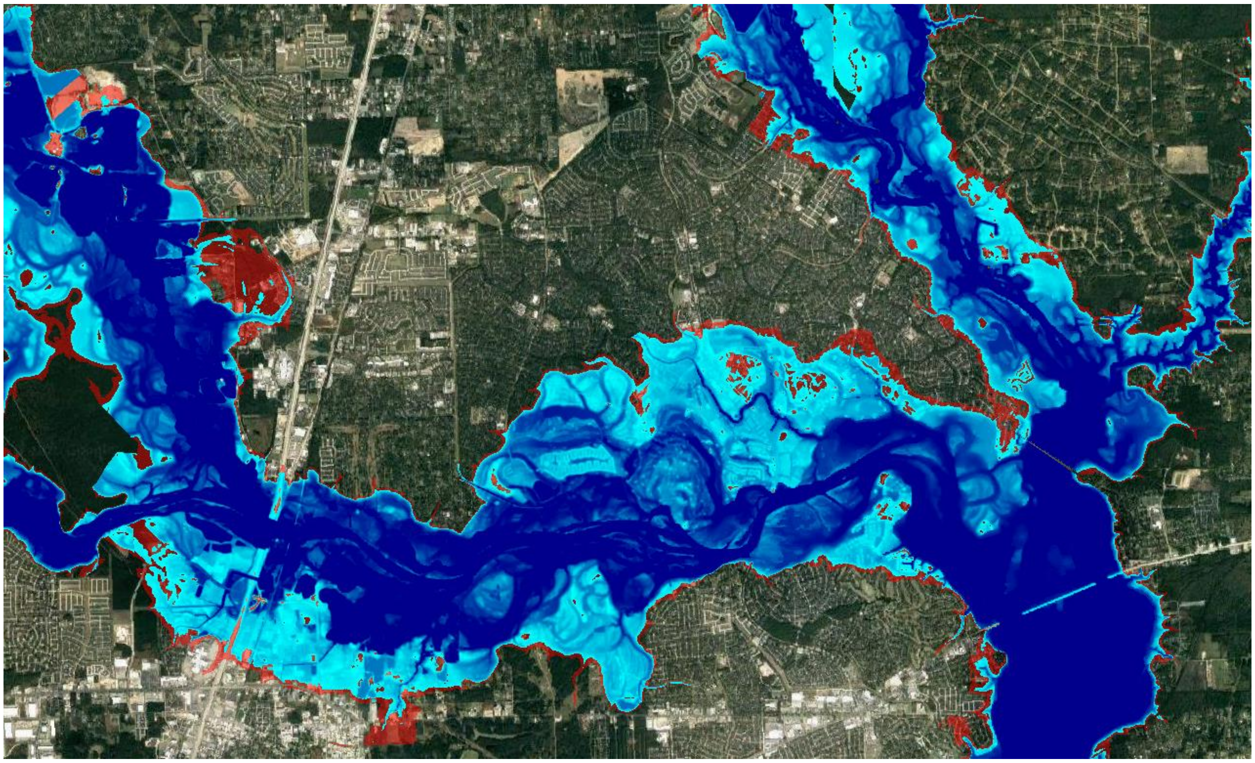


Figure 16. West Fork/East Fork Confluence Inundation Mapping (100- and 500-Year)

As evidenced by the modeling and the resultant water surface profiles, Lake Houston has a significant influence on the WSELs in the lower portions of the both the East and West Forks. As shown in **Figure 17** below, the approximate zone of influence from the Lake Houston Dam is up to W. Lake Houston Parkway on the West Fork and near the Caney Creek confluence on the East Fork. Lake Houston plays a critical part in flood reduction approaches in Kingwood and limits the benefits that can be realized by flood reduction projects on the East and West Forks. The specific results will be discussed in Section 8.0.

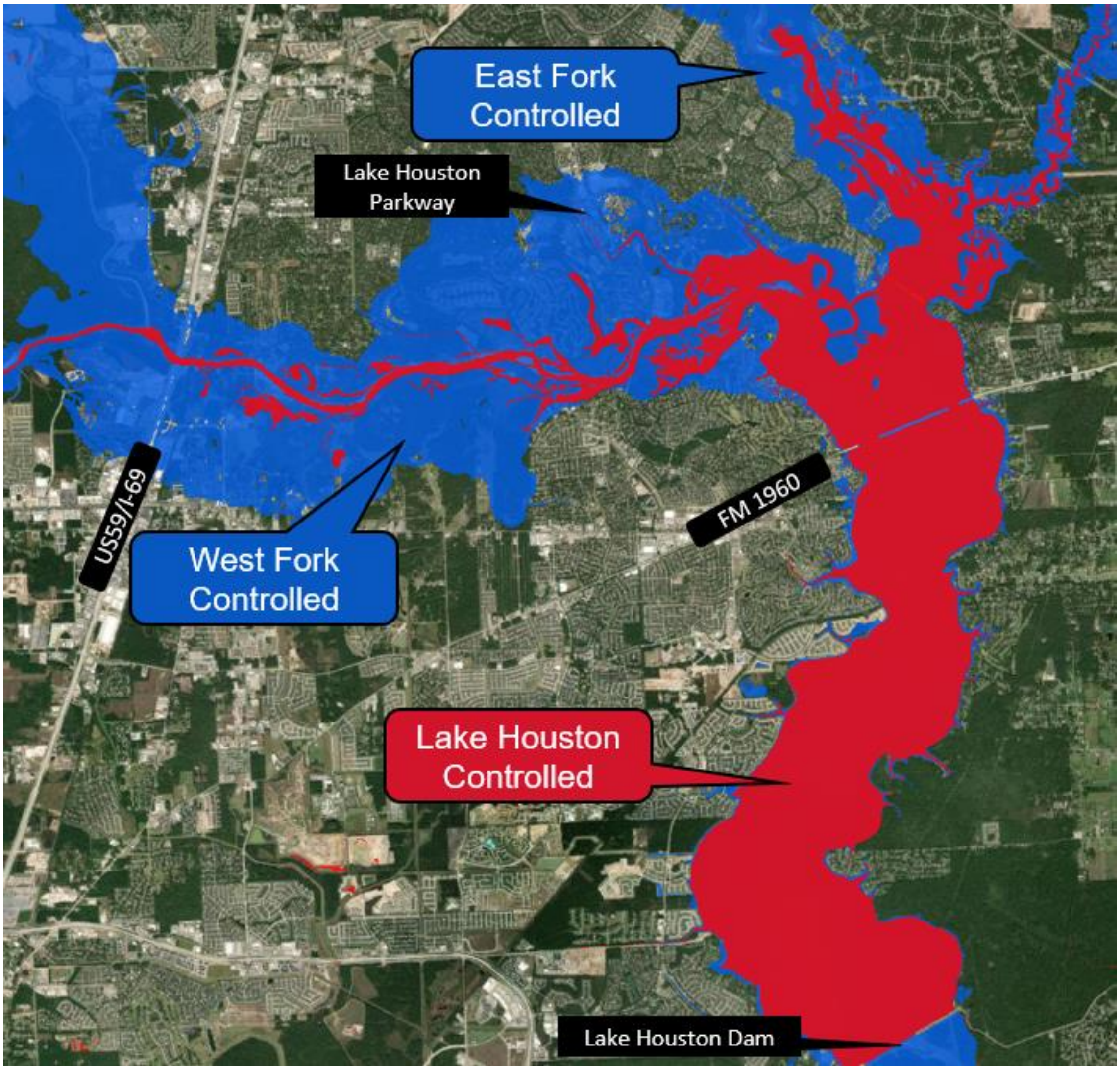


Figure 17: Lake Houston Zone of Influence on the Lower West Fork and East Fork

8.3 Structural Inventory

Developing effective mitigation alternatives required an analysis of existing flood risk in the basin to determine how riverine flooding affects individual structures. The damage center identification process located concentrations of structures within the region that were susceptible to flood risk along the studied streams. The locations of the damage centers informed the process of locating and sizing potential mitigation alternatives.

A structural inventory was developed for the entire basin to identify the structures that are within the existing floodplains developed as part of the SJMDP existing conditions effort. The inventory consisted of HCFCD's structural inventory in Harris County supplemented with structure data from Houston-Galveston Area Council (H-GAC) in areas outside Harris County. In total, the combined inventory includes 108,006 building footprints within a 1,000-foot buffer of the 0.2% ACE floodplain extents along the main stems modeled for this project. Structures along unmodeled tributaries were not included. Each structure was assigned an assumed finished floor elevation of 1 foot above the LiDAR surface; this elevation was manually adjusted using Google Street View or aerial imagery for structures situated near the channel that may be elevated or on piers. The structures were also stationed along each stream centerline using cross sections from the calibrated existing-conditions hydraulic model. Peak water surface elevations were then interpolated from the model results at each individual structure for the 50% ACE through 0.2% ACE storms. The finished floor elevations were subtracted from these water surface elevations to obtain an existing-conditions flooding depth at each structure.

The results of this process were used to estimate the instances of structural flooding over a 50-year period based on the modeling results. This approach collapses data from multiple storm events into a single number and serves as a useful metric for comparing the relative severity of flooding in various locations throughout the watershed. It integrates (a) the number of structures flooding under each frequency storm over (b) the probability of each frequency storm. This information is then used to obtain the annualized "Instances of Structural Flooding." The annualized instances are then multiplied by 50 years to obtain the instances of flooding over a 50-year period.

The initial structural inventory runs indicated several areas with concentrations of structures that flood during relatively frequent events, like the 50% ACE and 20% ACE events. Conversations with the study partners indicated that improvements needed to address flooding for those structures would not be feasible and that buyouts may be considered a better option for those structures. In order to avoid skewing the results, structures flooded during these events (50% and 20% ACE) were dropped from the instances of structural flooding calculation.

As an example, consider the two river miles on Spring Creek shown in the table below. Although river mile 30 has more structures in the 0.2% ACE, 1% ACE, and 2% ACE floodplains than river mile 31, it has a similar number of instances of structural flooding expected over a 50-year period. This is because river mile 31 has 12 structures in the 10% ACE floodplain that are likely to flood multiple times over that 50-year period. If not for those 12 structures, river mile 31 would only have 25 instances of structural flooding expected over a 50-year period. The 12 structures flooded during the 10% ACE storm at river mile 31 contribute significantly to the total estimated instances of structural flooding, bringing the total instances at river mile 31 close to the total instances at river mile 30. This shows that the expected instances of flooding metric increases significantly the more frequently a structure is flooded.

Table 13: Example of Instances of Structural Flooding Calculation

Spring Creek River Mile	Estimated Cumulative Number of Structures Flooded in Each Frequency Event					Estimated Instances of Structural Flooding (50-year Period)
	0.2% ACE	1% ACE	2% ACE	4% ACE	10% ACE	
31	34	27	23	15	12	114
30	178	76	50	11	0	129

A summary of the structural inventory results is broken out by watershed in the table below. The final column lists the total instances of flooding expected over a 50-year period in each watershed; these incorporate the cumulative number of structures flooded by each frequency event and the probability of each frequency event.

Table 14: Structural Inventory Results

Stream	Estimated Cumulative Structures Flooded in Each Frequency Event					Estimated Instances of Structural Flooding (50-yr Period)
	0.2% ACE	1% ACE	2% ACE	4% ACE	10% ACE	
Spring Creek	11,125	2,909	1,158	470	139	5,898
Willow Creek	1,854	854	388	241	115	1,988
Cypress Creek	8,688	2,920	1,464	708	212	6,405
Little Cypress Creek	3,708	1,704	1,000	427	82	3,412
East Fork SJR	2,035	1,073	712	461	186	3,090
West Fork SJR	8,275	3,719	1,659	732	161	6,670
Lake Creek	295	162	95	55	26	417
Peach Creek	1,713	1,115	843	581	325	3,939
Caney Creek	2,628	1,384	979	557	175	3,697
Luce Bayou	298	134	84	52	24	383
Tarkington Bayou	23	179	161	140	108	961
Jackson Bayou	105	20	1	1	1	37
Gum Gully	191	62	15	5	3	99

8.4 Damage Center Identification

The structural inventory results were tabulated and charted along each river mile to identify clusters of high instances of structural flooding and to identify effective locations for flood mitigation projects. These groups were identified as "damage centers" and are documented in detail in **Appendix G**. A total of 48 damage centers were identified based on a series of charts provided as **Appendix G.2**. These are summarized and labeled in **Figure 18** below. The damage centers with the highest instances of structural flooding expected over a 50-year period are generally located along Spring Creek, Cypress Creek, the West Fork of the San Jacinto River near Kingwood, and the confluence of Caney Creek and Peach Creek.

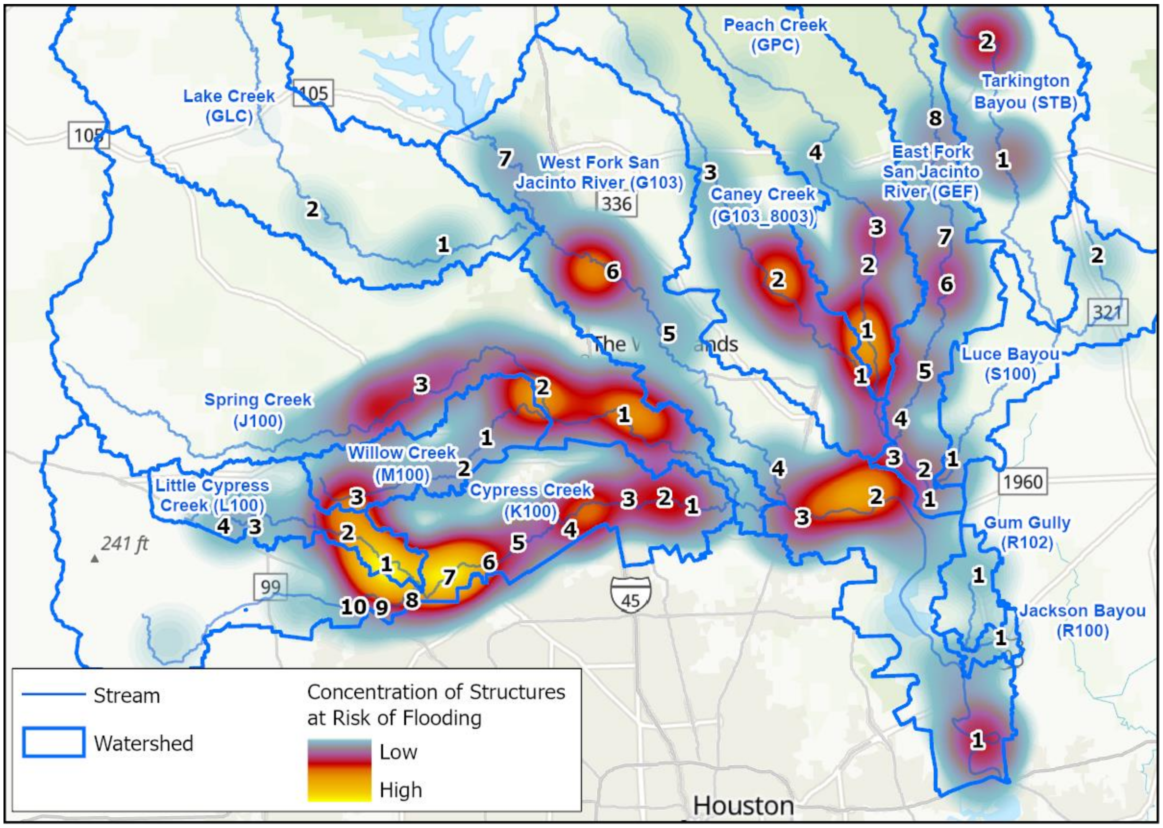


Figure 18. Summary of Damage Centers

Several major damage centers are along the West Fork between I-69 and FM 1960 and along the East Fork from its confluence with Caney Creek to FM 1960. This area, which generally includes structures in Kingwood, has experienced significant historical flood damages as discussed previously in **Section 8.2.2**.

8.4.1 Damage Center Volume Reduction Calculations

Potential detention volumes were calculated at each damage center by comparing volumes and flow rates of the various frequency storm events (10% ACE, 1% ACE, etc.). The conceptual detention volume required to reduce the peak flow of any frequency storm event to the peak flow of a smaller storm event was calculated by calculating the total volume of the larger event that exceeded the peak flow of the smaller event. This provided a range of conceptual detention volumes at each damage center that could reduce a given frequency storm's peak flow to the peak flow of any smaller frequency storm.

8.4.2 Target Volumes, Benefits, and Level-of-Service Improvements by Watershed

Each conceptual detention volume discussed above was used to estimate a corresponding benefit at each damage center. The full alternatives analysis documented below incorporated the value of each structure and standard FEMA/USACE depth-damage curves to estimate benefits as dollars of reduced flood damages; however, at this stage of the analysis, the conceptual range of potential benefits was expressed as an estimated reduction in instances of structural flooding over a 50-year period. At this stage, the detention volumes were not explicitly modeled using HEC-HMS or HEC-RAS. Instead, the benefit of each detention volume was estimated in a spreadsheet based on existing conditions results.

Each conceptual detention volume is expected to lower peak water surface elevations through the damage center for a range of frequency events. For example, a detention volume that reduces the existing 0.2% ACE peak flow through a damage center to the existing 1% ACE peak flow could be designed to also reduce the 1% ACE flow to the 2% ACE flow, the 2% ACE flow to the 4% ACE flow, and so on. Each conceptual detention volume was assumed to reduce the number of structures flooding under each frequency event in this manner. As another example, a smaller detention volume can be designed to reduce the existing 4% ACE flow to the 10% ACE flow, the 10% ACE flow to the 20% ACE flow, and so on. However, because it is a smaller detention facility, it may not be possible to design it to reduce the 0.2% ACE flow to the 1% ACE flow. Therefore, this analysis conservatively assumes that smaller design volumes targeted toward a smaller event (such as the 4% ACE) cannot reduce the number of structures flooding under larger events (such as the 2%, 1%, and 0.2% ACE).

For each conceptual detention volume, the reduced number of structures flooding under each frequency event was then used to calculate the reduced instances of structural flooding occurring over a 50-year period. This reduction in instances of structural flooding is the conceptual benefit realized by that detention volume. A scatterplot was created for each damage center showing all benefit-volume pairs. An example for Damage Center 2 on Spring Creek is provided in **Figure 19**. Volume on the x-axis represents the approximate detention required to reduce the 0.2% ACE peak flow to the 1% ACE peak flow, the 0.2% ACE peak flow to the 2% ACE peak flow, and so on. Benefit on the y-axis represents the expected reduction in instances of structural flooding over a 50-year project life. Refer to **Appendix G.1** for a full set of volume-benefit curves and detailed summary tables.

A given volume may provide a range of benefits depending on the targeted storm events. For example, reducing the 4% ACE peak flow to the 50% ACE peak flow at this location would take a detention volume of approximately 65,000 acre-feet and would provide a benefit of 350 fewer instances of structural flooding over a 50-year period. In comparison, reducing the 1% ACE peak flow to the 4% ACE peak flow at this location would take a lower detention volume of 52,000 acre-feet, but would provide a higher benefit of 670 fewer instances of structural flooding over a 50-year period. This may be because there are many more structures at risk of flooding during the 1% and 2% ACE storms than there are structures at risk of flooding during the 4% ACE storms and lower. The dashed line that follows the outer edge of these points is the Pareto front, which represents the maximum benefit that could be expected for any given detention volume.

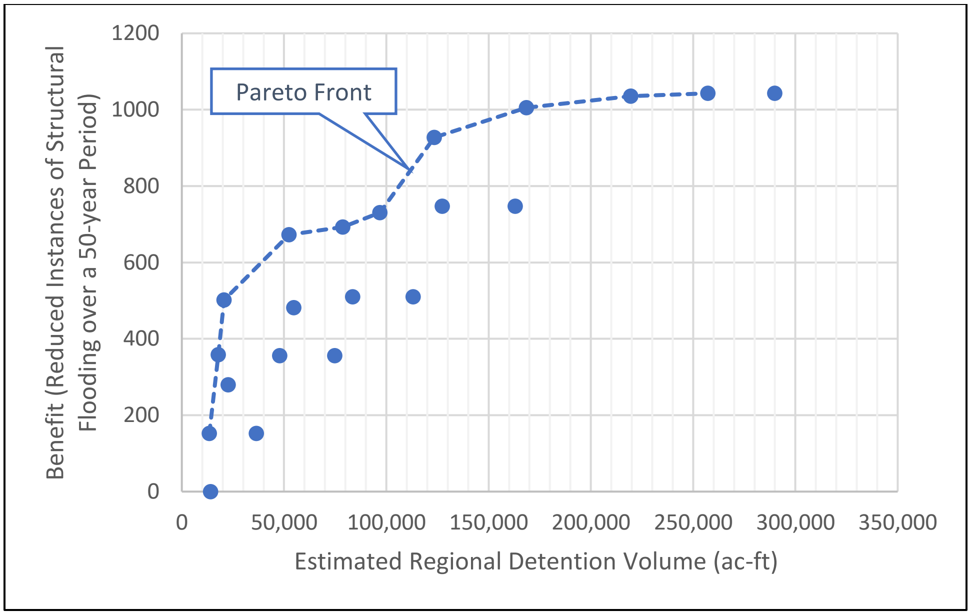


Figure 19. Spring Creek Damage Center 2 Benefit/Volume Scatter Plot

Therefore, each damage center plot illustrates the approximate tradeoff between volume and benefit at that location without identifying a single optimal point. As expected, the smallest volumes generally provide the smallest benefits and the largest volumes generally provide the largest benefits. The Pareto front for each damage center shows diminishing returns with increased volumes, to the point where large increases in volume lead to very small increases in benefit.

On many of these curves, the approximate inflection point is associated with incremental reductions in flow—for example, approximately 52,000 acre-feet of volume would reduce the 1% ACE peak flow to the 4% ACE peak flow and reduce instances of structural flooding over a 50-year period by approximately 670. Increasing volume beyond the inflection point appears to provide diminishing benefits. For damage centers where more structures are flooded in more frequent storms, the inflection point may be associated with higher volumes—for example, reducing the 1% ACE peak flow to the 10% ACE peak flow.

These approximate inflection points were used to select initial detention volumes as a starting point for identifying available land upstream of each damage centers. This screening process was used to select potential detention sites to be verified through detailed hydrologic and hydraulic modeling. Because many damage centers are located near one another, they can each benefit from a common detention volume located upstream. Complete volume-benefit curves for each damage center are provided in **Appendix G.1**.

8.4.3 Watershed Mitigation Potential

Based on the damage center, volume, and regional reduction analysis, the watersheds were divided into three tiers of watershed mitigation potential as shown in the table below. The tiers were based on the availability of open land to construct large reservoirs, potential to provide benefit within the watershed (reduced instances of flooding), and potential to provide regional reduction in flood risk downstream. These tiers were used to guide selection of locations for detailed modeling as described in the section below and is not related to project ranking.

The high-level analysis of the watershed potential shows that Spring Creek, East Fork San Jacinto, Caney Creek, Peach Creek, and Lake Creek were each identified as watersheds that could both benefit locally from regional detention basins (based on the damage center analysis) and provide reductions in water surface elevations in the lower portions of the San Jacinto watershed closer to Lake Houston (based on removing entire stream hydrographs as part of the watershed volume sensitivity analysis). These watersheds were further explored in the detailed modeling phase of this study. **Table 15** summarizes the watershed mitigation potential for projects in each watershed.

Table 15: Watershed Mitigation Potential

	Benefit in Watershed	Open Space	Regional Reductions	Potential
Luce Bayou		✓		Low
East Fork	✓	✓	✓	High
Peach Creek	✓	✓	✓	High
Caney Creek	✓	✓	✓	High
West Fork	✓			Low
Lake Creek		✓	✓	Moderate
Spring Creek	✓	✓	✓	High
Willow Creek	✓			Low
Little Cypress	✓			Low
Cypress Creek	✓			Low
Jackson Bayou				Low

8.5 Flood Mitigation Alternatives Analysis

The goal of the flood mitigation alternative analysis was to develop flood mitigation solutions that would reduce the flood risk throughout the Upper San Jacinto watershed. The analysis considered previous projects that had been recommended to reduce flood risk as well as provide water supply. Flood mitigation projects that had been previously proposed by others in historical reports were considered primary alternatives and were evaluated to see if they were implementable.

8.5.1 Previously Recommended Projects

Other considerations were given in reviewing the previously recommended projects. These considerations included opportunities and challenges to implementing the projects under current conditions as they were originally proposed. The opportunities considered included: the ability to reduce flood damages, the opportunity to improve sediment issues, and the opportunity for ancillary uses. The challenges that were considered included property acquisition, site conflicts (environmental, transportation, utilities, etc.), and operations and maintenance. **Figure 20** shows these previously studied projects.

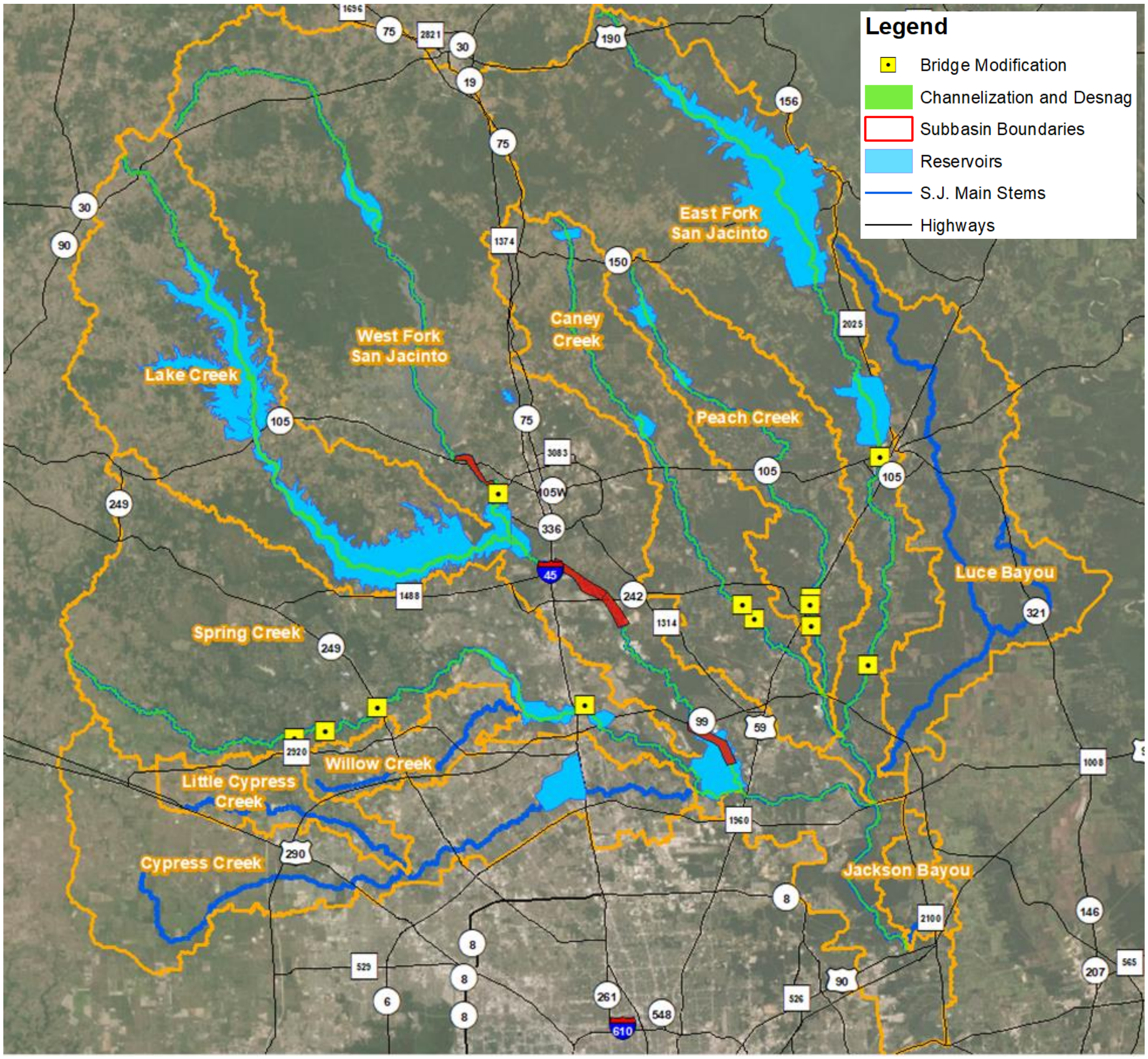


Figure 20. Previously Proposed Projects

After a thorough review, many of the previously recommended projects were found to be infeasible for construction and did not provide the flood mitigation benefits that are needed in the watershed. Only four primary alternatives were found to be feasible for further analysis. These included alternatives on Spring Creek, Lake Creek, Peach Creek, and the East Fork of the San Jacinto River.

8.5.2 Opportunities and Challenges

Beyond the tangible flood reduction, project costs, and structural benefits, there are a variety of considerations for each of the projects that were identified. Among these are ROW acquisition, environmental impacts, utilities and roadways that may be impacted, and potential partnership and funding opportunities.

8.5.2.1 ROW

The right-of-way needs for detention may vary widely depending on the development criteria behind each of the proposed detention basins. Initially, the necessary ROW was identified based on the 1% ACE inundation area behind the dams. After further discussion and consideration, the study team determined that acquiring all property up to the Probable Maximum Flood (PMF) inundation area may be prudent. Ownership of all the property to that level would prevent development in an area that could potentially become inundated during a major rainfall event, such as Hurricane Harvey with the Addicks and Barker Reservoirs in Harris County. Identifying the parcels needed for both levels gives future owners of these facilities a range of costs and levels of protection that can be weighed against the risks of building in these areas.

The process included the intersection of the inundation area with parcel data to identify the total number of parcels that may need to be acquired for the proposed project. The parcel was assumed to be fully acquired if more than 20% of the parcel was inundated by the 1% ACE or PMF event, and partially acquired if less than 20% of the parcel was inundated. This provides a conservative cost assumption without acquiring the entirety of every large parcel that is touched by the flood pool. The estimated cost to acquire the right-of-way was assumed to be 2.5 times the market value. The factor of 2.5 accounts for uncertainty in the current appraisal district estimate, contingency, legal costs, acquisition, relocation, and demolition. The factor was discussed with the study partners, including HCFCD's ROW Department, to confirm that it was reasonable. This assumes an outright land acquisition, but area behind the reservoir could instead be obtained through flooding easements; this was not considered as part of this study.

8.5.2.2 Environmental

A desktop environmental assessment was performed for each proposed project area. The assessment considered potential wetlands and Waters of the United States that may be impacted within the footprint of the proposed embankment or excavation. The National Wetlands Inventory, which is a high-level desktop dataset, was used to identify wetlands and the National Hydrologic Dataset was used to identify Waters of the US. It should be noted that wetlands and stream mitigation will need to be identified in detail through both a detailed desktop analysis using local datasets as well as field observation. Further analysis will need to be conducted in a feasibility phase to evaluate wetland and stream mitigation measures, quality of wetlands and streams, and degrees of aquatic and/or habitat loss. In addition, streams that may be impacted through the channel conveyance improvements or detention embankment will need to be evaluated to determine if the USACE will claim jurisdiction, as well as the quality and extent of the impacts. A permitting and mitigation strategy will need to be developed which will depend on the impacts.

The project team was unable to locate any records of previously observed federally listed endangered species in the area. This does not mean no impact is anticipated, just that no federally listed endangered species have been documented.

Additional investigation of U.S. Fish and Wildlife (USFWS) and TPWD (Texas Parks and Wildlife Department) threatened and endangered species, Texas Historical Commission (THC) cultural resources, and hazardous materials will need to be considered during preliminary and final design. Regarding cultural resources, an initial archeological review of each project site found that archeological surveys have previously been conducted in several proposed project footprints for development or roadway projects. There may be potential to find cultural material along streams and upper terraces. These costs have not been specifically quantified in the cost estimates but may be covered by the contingency.

The USACE may require an Environmental Impact Statement for each detention site identified. This process can take three to five years. Substantial channel improvements may also require an Individual Permit from the USACE; these costs were not specifically included in the estimates because the channel alternatives were designed to be benched above the ordinary high-water mark. Sites in the Sam Houston National Forest will likely also require a NEPA review process, which potentially requires an Environmental Impact Statement. Detention sites on the forest may also yield environmental benefits if coordinated with forest management goals.

8.5.2.3 Utilities/Roadways

Major oil and gas utilities and roadways were identified in the project areas. Major pipeline utilities to be impacted by the project dam embankment or channelization were identified using Texas Railroad Commission data. Roadways to be inundated by more than 1 foot as a result of the detention flood waters were also identified. Detailed utility investigation will be needed during the preliminary engineering and design stages and coordination with TxDOT and the local county will be required to address any roadway changes that may be needed.

8.5.2.4 Potential Partnerships

Potential partners were identified based on the proposed physical location of the project, as well as those jurisdictions that may benefit from the proposed projects. Potential partners consisted of counties, cities, agencies, and districts. They may also include parks and conservation entities which could benefit from a multi-use facility. The identified partners were those who can support the projects either financially or politically. When looking at project funding options, it should be noted that multi-jurisdictional partnerships can improve the likelihood of a successful grant application.

8.5.3 Project Costs

An estimate of costs were developed for each proposed project; however, there is still substantial lack of site-specific technical information and scope clarity in the estimate, resulting in major estimate assumptions. These include technical information and quantities, heavy reliance on cost engineering judgment, and local bid tabs. While certain construction elements can be estimated with a higher degree of confidence, there is still a great deal of uncertainty relative to major construction components. The costs presented provide a reasonable estimate of potential funding needed for the projects but are not necessarily detailed construction costs of a fully defined and developed project. This uncertainty is reflected in the 30% contingency. The most significant cost component of each detention project is the right-of-way acquisition.

The construction costs estimates were derived based on 2020 unit costs from a number of sources including recent bid tabs for HCFCD, Harris County, and TxDOT projects. Quantities were derived from the project extents and include:

- Mobilization – The mobilization of equipment and workers to operate the project site (5% of construction cost).
- Temporary Erosion and Sediment Control – The measures and equipment needed to control erosion and sediment during construction (2% of construction cost).
- Site Preparation and Site Maintenance – The measures needed to prepare the site for construction and to maintain the site during construction.
- Care of Water – The measures that need to be taken to maintain the flow of water and provide any other care of water during construction.
- Clearing and Grubbing – The measures to be taken to remove debris, vegetation, and any other surface elements.
- Utility Conflicts/Relocation – The relocation of any major oil/gas pipeline utility conflicts.
- Site Preparation – The measures needed to prepare the site for construction
- Excavation – The effort to excavate material that needs to be removed from the site for construction purposes. A cost of $10 per cubic yard was assumed for both detention and channel excavation. For detention alternatives, excavation is assumed to remain on-site and used to construct the embankment. For channel alternatives, this quantity of excavation would best be disposed of through an arrangement with developers or other interested buyers rather than disposal in a landfill. If this excavation volume were disposed of in a landfill as is typical for smaller channel projects, the unit cost could increase to at least $20 per cubic yard or as much as $35 per cubic yard depending on the landfill and disposal requirements.
- Embankment – The placement of material including excavation from onsite borrow for the construction of the detention facility.
- Drainage – The construction of internal drainage features of the dam embankment.
- Spillway – The construction of a roller compacted concrete spillway.
- Erosion Control – The placement of rock rip rap at the principal outfall of the structure to provide erosion protection.
- Instrumentation – Placement of information equipment that will assist in the operation and maintenance of the structure.
- Topsoil – Placement of topsoil upon embankment of the detention facility or channel.
- Seeding – The placement of vegetation seeding upon the cleared and grubbed area, embankment, and/or onsite borrow area to stabilize the soil.
- Site Restoration – The measures to restore the site upon completion of construction.
- Access Roadway – The placement of an asphalt road on the dam embankment or along the channel with access to the nearest public roadway.

As previously discussed, there is a degree of uncertainty in the project estimates. This includes construction and utility relocation costs, as well as variations in the potential ROW needs and environmental concerns.

8.5.3.1 Construction Costs

Construction pricing may vary depending on economic conditions, availability of materials, access to the project site, fill import and/or disposal logistics for excavated material, and more. As the industry has seen over the past several years, an increase in roadway or development projects may create a spike in concrete costs, just as the recent uptick in channel repair projects has increased rock rip rap costs. Given that these projects will be built over several decades, there is uncertainly into future material demands, and subsequent cost increases may be. In order to counter these uncertainties, a 30% contingency was included on construction unit costs. In addition, each of the project summaries (**Section 8.6**) include a 20-year escalation to provide some idea of how the costs might change over the next couple decades.

8.5.3.2 ROW Acquisition

The highest cost component of each identified detention project is the right-of-way acquisition. As discussed in **Section 8.5.2.1**, the ROW costs were based on the market value provided by each of the County Appraisal Districts multiplied by a factor of 2.5 to account for uncertainty in the current appraisal district estimate, contingency, legal costs, acquisition, relocation, and demolition. Even though it is appropriate for this level of planning study, there are several areas of uncertainty with this approach. These include the following:

- The market value provided may not be consistent with an actual appraised value
- The amount of property acquired may vary as the projects are further evaluated and refined. The exact limits of property acquisition will also need to be determined by the dam and facility owner.
- Some properties may have willing sellers while others may require the use of eminent domain
- Costs may increase depending on when the project is built and the surrounding development

Because the right-of-way acquisition cost is the highest cost component of each detention project included in this study, and because there is uncertainty regarding the limits of property acquisition, this study presents both the 1% ACE and PMF flood pool acquisition costs for each detention project. In either case, the size and construction limits of the dam itself remains the same; the only difference is in the upstream property acquired. The 1% ACE flood pool area represents the minimum anticipated acquisition area required to construct the project. Beyond the 1% ACE, the dam owner may purchase the entire 0.2% ACE flood pool, the entire PMF flood pool, or potentially designate the 0.2% ACE or PMF flood pool as an inundation easement at a lower cost. The PMF flood pool area represents the maximum anticipated acquisition area required to construct the project.

8.5.3.3 Utility and Roadway Relocations

Utility relocation has been accounted for at a very conceptual level assuming $1 million per utility relocation using readily available data from the Texas Railroad Commission, but more detailed information is required to refine these estimates. The possibility of water, wastewater, and telecommunications utilities is currently not specifically included and is assumed to be covered by the 30% contingency.

Existing roadways cross some of the proposed dam flood pools and may need to be permanently closed, relocated around the flood pool, elevated as a bridge, or relocated and elevated where appropriate. Most existing roads within the proposed dam flood pools are already crossing the current 1% ACE floodplain and thus were designed with a bridge or culvert crossing to provide a certain level of service. Such roads located at the upstream limits of the flood pool could remain in place with minimal to no impact to the level of service, while roads located at the downstream limits of the flood pool in higher-risk areas may need to be relocated or raised to maintain the existing level of service. Other roads may simply be closed provided that they are not the only access to a property, don't create a hardship in increased travel time for users, and are not critical to emergency response. Due to the conceptual nature of this study and the number of potential roadway configurations given these considerations, this study does not include the cost of potential roadway relocations.

8.5.3.4 Environmental Costs

There is also a degree of risk and uncertainty associated with environmental permitting and mitigation. Section 8.5.2.2 discusses the potential stream and wetland impacts associated with these projects. Environmental considerations include, though are not necessarily limited to the following:

- The actual wetlands coverage could be significantly different than the NWI coverage
- The quality of the stream or wetland impacts permitting and is not apparent using NWI data
- There may be impacts to USFWS or TPWD threatened and endangered species, THC cultural resources, or potential hazardous materials.
- The specific mitigation strategy could include mitigation banks or mitigating in place
- Changes to the permitting requirements could create additional challenges

8.5.3.5 Future Development

As the San Jacinto Basin continues to develop, changes to the hydrology of the basin, potentially including the specific sites identified for the projects, could alter the project location, configuration, effectiveness and goals. As these projects move toward feasibility and design, changes to the surrounding area should be considered as they may limit project effectiveness and/or increase project cost.

8.5.3.6 Maintenance

Long-term maintenance costs should also be considered. For each large detention dam, an annual maintenance cost equal to 1% of construction cost can be assumed that would include mowing, monitoring of instrumentation, regular inspections, and occasional minor repairs. This estimate would not include major repairs. For channelization projects, a lower annual maintenance cost of 0.5% can be assumed to include mowing, monitoring, and clearing of debris. These costs are not currently accounted for in the project cost estimates or benefit-cost analyses but are included in the project discussion.

8.5.4 Project Benefits

The primary benefits of these mitigation projects are long-term reduction to structural flood damages. For a straightforward comparison to project costs, project benefits must be measured in dollars of reduced flood damages over the project life. This calculation was performed using spreadsheet calculations that follow the same principles used in FEMA's Benefit-Cost Analysis (BCA) Toolkit. Unlike in the damage center analysis, the 50% ACE and 20% ACE results were included in this calculation of flood damages, as is typical for the FEMA BCA process.

To facilitate calculation of pre-project and post-project flood damages, the structural inventory discussed previously was updated to incorporate appraisal district valuation data for the improvement (structure) value and the parcel's market value for the 2019 tax year. Parcel values for Harris and Montgomery County were obtained from their respective appraisal districts; parcel values for Waller, Walker, Liberty, Grimes, and San Jacinto County were obtained from TNRIS, which obtained the values from each respective county appraisal district.

At each structure, the depth of flooding during each frequency storm was translated to flood damage expressed as a percentage of the structure's value. These depth-damage curves relate flooding depth to multiple types of damage associated with structural flooding, including structural damage, damage to contents, and displacement costs.

This process resulted in a list of expected flood damages for each frequency storm, which has a defined probability of occurring in any given year. This probability versus expected-damages curve was then integrated using the trapezoidal rule to obtain an annualized damages value. The annualized structural damages were then converted to a net present value using a typical 50-year project life for drainage improvement projects and the FEMA-required discount rate of 7 percent. This discount rate for flood damage calculations, which converts future benefits to present dollar values, is mandated by the Office of Management and Budget and is intended to reflect the average rate of return of a typical investment.

This calculation was repeated for the reduced peak water surface elevations under each proposed alternative. The difference between net present value existing and proposed damages represents the project benefit in 2020 dollars. Assigning project benefits in this manner allows for a direct comparison of each alternative's benefit and cost. **Table 16** summarizes the net present value (NPV) of expected structural damages over a 50-year period under existing conditions along each modeled stream. These existing-conditions damages are the basis for the benefit calculations of each individual alternative and the selected combined alternatives.

Table 16: Net Present Value of Structural Damages

Stream	Expected Structural Damages ($M)
Spring Creek	339.3
Willow Creek	119.1
Cypress Creek	373.1
Little Cypress Creek	196.6
East Fork SJR	128.2
West Fork SJR	396.7
Lake Creek	16.5
Peach Creek	163.5
Caney Creek	140.9
Luce Bayou	20.0
Tarkington Bayou	75.1
Jackson Bayou	3.9
Gum Gully	6.3
Total	**1,979.2**

Detailed charts are attached to **Appendix G** depicting the location of existing structural damages per river mile (**Appendix G.2**), along with the reduction in damages anticipated from the combined recommended alternatives (**Appendix G.4**).

8.5.5 Additional Benefits

Secondary benefits to roadway, social impact, and the environment can also be considered as part of the FEMA BCA process but were not calculated as part of this study.

Roadways that are overtopped during rainfall events can lead to increased travel times for commuters and emergency vehicles, and even completely trap certain areas. Evaluating benefits from reduced roadway flooding is not within the current scope of work for this study. However, the Houston-Galveston Area Council (H-GAC) has conducted a preliminary analysis of the economic impact of bridges flooding during the existing conditions 10% ACE storm using the REMI TranSight model and the U.S. Department of Transportation's Vulnerability Assessment Scoring Tool (VAST). The preliminary analysis indicates that the economic impact of roadway flooding is small relative to expected structural flooding damages. For example, if existing roads that are overtopped during the 10% ACE storm are closed for one day, H-GAC's model shows $1.25 million in lost personal income and $990,000 in reduced gross domestic product. These impacts are two orders of magnitude below the expected structural damages during the 10% ACE storm of approximately $189 million. H-GAC's model also shows that roads overtopped during the 0.2% ACE storm lead to 2.2 million in lost personal income and 1.7 million in reduced gross domestic product. These impacts are three orders of magnitude below the expected structural damages during the 0.2% ACE storm of approximately $9.7 billion.

FEMA grants typically allow for social benefits of reduced mental stress, anxiety, and lost productivity to be applied if the project's structural damage evaluation results in a benefit-cost ratio between 0.75 and 1. Assuming a conservative average of 2.5 residents and 1 worker per residential structure would yield a social benefit of $14,843 per residential structure with any level of reduced flood risk according to FEMA methodology. FEMA allows these social benefits to be included if the structural benefits discussed previously result in a structural BCR of between 0.75 and 1. Given that each of the projects being considered as part of this study would benefit several thousand residential structures, any project that qualifies for social benefits should receive hundreds of millions of dollars of social benefits, resulting in a competitive BCR above 1. The BCRs listed for each project in this report are structural BCRs and do not include social benefits in order to allow for a more direct comparison between projects.

For FEMA grants, environmental benefits may be quantified for area that is improved from a developed condition back to a natural condition. Similar to social benefits, FEMA typically allows these environmental benefits to be applied only if the project's structural damage evaluation results in a benefit-cost ratio between 0.75 and 1. The alternatives proposed as part of this study are not expected to have significant environmental benefits. However, some of the alternatives analyzed may be coordinated with separate environmental restoration efforts. For example, a wetlands restoration of wildlife habitat in the Sam Houston National Forest may be paired with an alternative from this study in a manner that achieves both goals, allowing environmental benefits to augment the structural benefits.

Per FEMA methodology, environmental benefits are calculated on a per-acre basis, with benefits ranging from $554 per acre per year for forested area to $39,545 per acre per year for riparian area. These benefits would be difficult to quantify at this stage of study, but these benefits may be able to be added during future project development phases.

8.6 Individual Alternatives

A total of 25 flood mitigation alternatives were explored and conceptually modeled for this study. These generally consist of dry dam construction to provide an inline detention basin along the mainstem or tributary of one of the studied streams, or channelization of the mainstem by providing a wide channel bench set several feet above the channel flowline in an effort to stay above the ordinary high-water mark. Offline detention was considered in the early stages of the project but was not found to be very effective at this regional scale.

Each alternative was modeled individually to determine the benefits on the watershed as a whole. Evaluation of the specific impact of each alternative on the damage centers was not conducted. Instead, the project team assessed benefits throughout the entire watershed. For example, the Spring Creek alternatives primarily benefit structures along Spring Creek but can also benefit structures downstream of its confluence with the West Fork San Jacinto River, or structures at the downstream end of Willow Creek, which drains into Spring Creek.

Each channelization alternative, taken individually, is likely to result in adverse downstream impacts. This is because channelization reduces floodplain storage along the reach and increases peak flow rates downstream. Therefore, compensatory storage must first be constructed upstream of each channelization alternative to avoid adverse downstream impacts. Each detention alternative identified in this study is more than enough to mitigate the adverse downstream impact for the recommended channelization alternatives. This topic is discussed in more detail in **Appendix H**.

The benefit, cost range, and benefit-cost ratio range of each alternative considered in the previous sections are summarized in the table below. The recommended alternatives are highlighted in blue. The benefits shown for each individual alternative includes all benefits from the project in the watershed. For example, the Spring Creek detention alternatives also benefit structures on Willow Creek, and the East Fork detention alternatives also benefit structures on the West Fork.

The table below is followed by a fact sheet for each of the 16 recommended projects of the 25 projects considered. Refer to **Appendix G** for a more extensive discussion of each project.

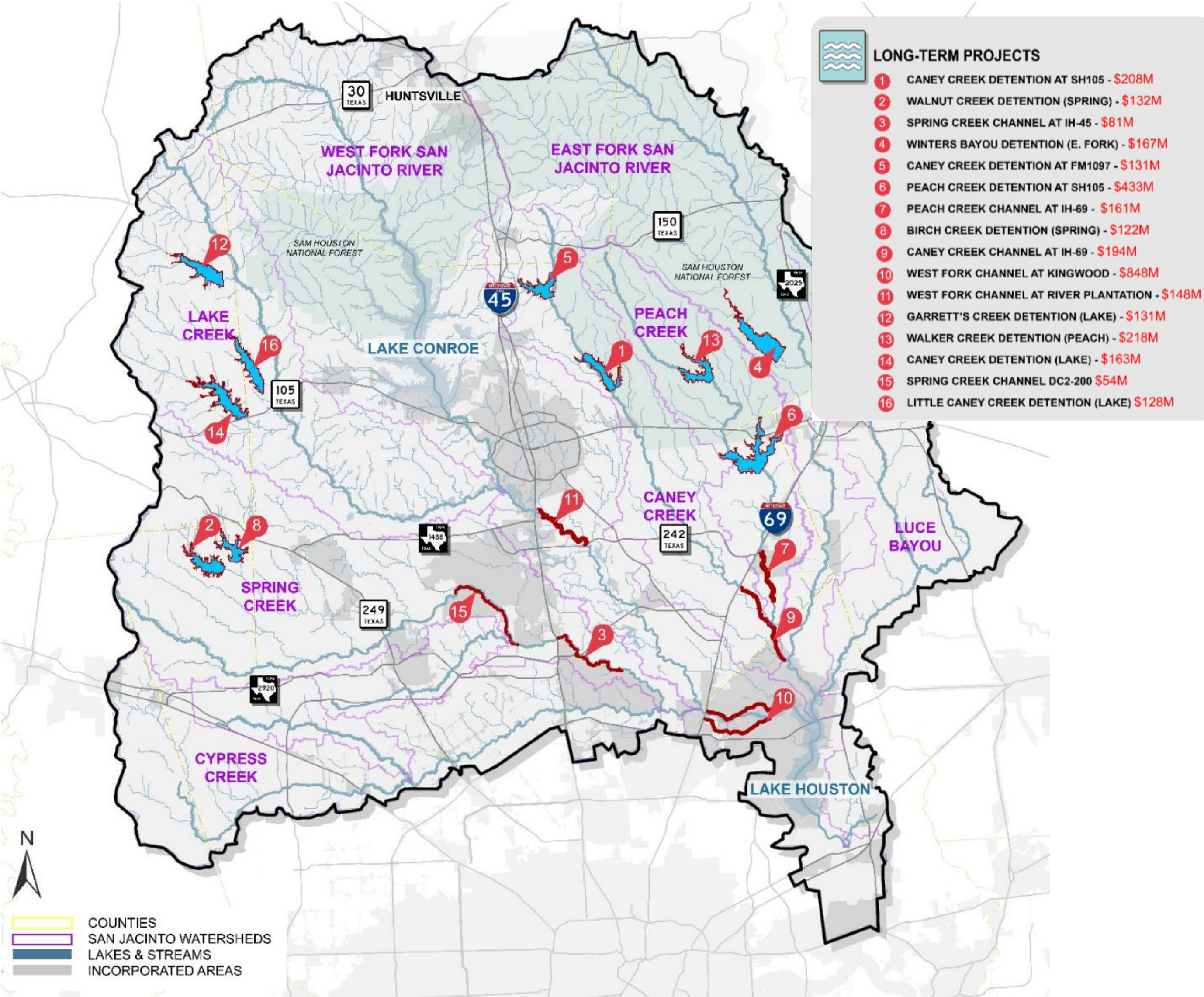


Figure 21. Map of Proposed Long-Term Project Locations

Each channelization alternative, taken individually, is likely to result in adverse downstream impacts. This is because channelization reduces floodplain storage along the reach and increases peak flow rates downstream. Therefore, compensatory storage must first be constructed upstream of each channelization alternative to avoid adverse downstream impacts. Each detention alternative identified in this study is more than enough to mitigate the adverse downstream impact for the recommended channelization alternatives. This topic is discussed in more detail in **Section 11.3** and **Appendices G and H**.

Table 17: Project Summary

Stream	Alternative	Benefit ($M)	Cost Range ($M)	Benefit-Cost Ratio Range
Spring Creek	**Walnut Creek Detention**	**101.2**	**97–132**	**0.77–1.04**
	Mill Creek Detention	65.1	99–131	0.50–0.66
	Birch Creek Detention	**66.0**	**80–120**	**0.55–0.83**
	Woodlands Channel (500-ft)	48.1	149	0.32
	Woodlands Channel (200-ft)	**34.7**	**56**	**0.62**
	I-45 Channelization	**99.4**	**85**	**1.17**
	Gosling Channelization	63.2	132	0.48
Lake Creek	**Caney Creek Detention**	**42.1**	**98–163**	**0.26–0.43**
	Little Caney Creek Detention	**35.0**	**98–128**	**0.27–0.36**
	Garrett's Creek Detention	**39.8**	**107–131**	**0.31–0.37**
	Mainstem Detention	100.4	187–267	0.38–0.54
Peach Creek	**Detention at Walker**	**56.3**	**201–218**	**0.26–0.28**
	Detention at SH 105	**81.5**	**356–433**	**0.19–0.23**
	Channelization at I-69	**73.6**	**159**	**0.46**
Caney Creek	**Detention at FM 1097**	**27.7**	**105–131**	**0.21–0.26**
	Detention at SH 105	**55.2**	**114–149**	**0.37–0.48**
	Channelization at I-69	**57.4**	**189**	**0.30**
East Fork SJR	FM 945 Dam	51.9	146–166	0.31–0.36
	Winters Bayou Dam	**63.5**	**134–167**	**0.38–0.47**
	Winters Bayou-Nebletts Dam	57.3	131–181	0.32–0.44
	FM 1485 Channelization	26.4	340	0.08
West Fork SJR	**River Plantation Channel**	**44.4**	**187**	**0.24**
	Highway 242 Channel	45.4	157	0.29
	Kingwood Channel	72.7	976	0.07
	Kingwood Benching	**60.5**	**837**	**0.07**

SAN JACINTO
REGIONAL WATERSHED
MASTER DRAINAGE PLAN

SPRING CREEK — WALNUT CREEK DETENTION

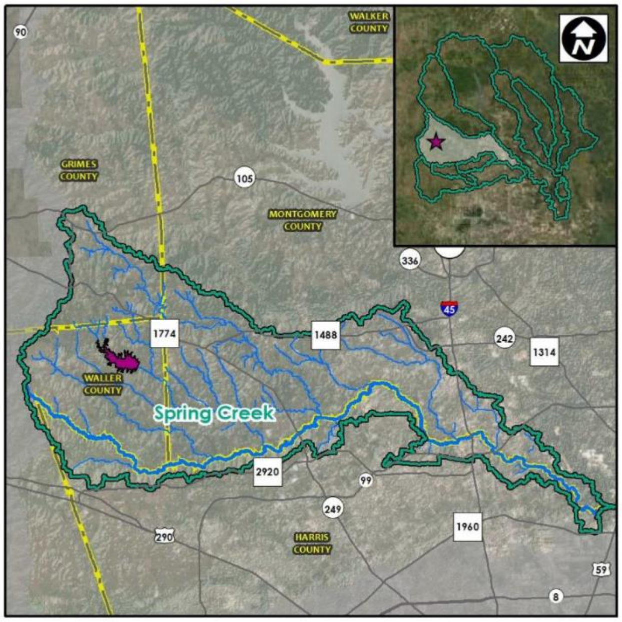
(Recommend Project in SJMDP)

LOCATION: Approximately 12 miles U/S of Spring Creek on Walnut Creek

OBJECTIVE: Reduce flooding along Spring Creek

HOW IT WORKS: Dry dam detention facility impounds stream flow during flood events

IMMEDIATE DOWNSTREAM BENEFIT: Incremental Atlas 14 WSEL reduction – 1% ACE to 2% ACE



IMPROVEMENT SPECIFICATIONS

- Dry dam detention facility
- 1,218 acres (1% ACE)
- 1,279 acres (PMF)
- 12,159 acre-feet (1% ACE)
- Embankment: 670k cubic yards
- Max dam height: 46 ft
- 1.2 miles in length

ESTIMATED BENEFITS

- Structures removed from 1% ACE floodplain: 1,205
- Reduction in instances of flooding over 50-year period: 1,653
- Benefited areas:
  - Tomball, The Woodlands
- Reduces 1% ACE WSEL at least 0.5 feet for 41.2 miles along Spring Creek
- Improves ponding depths on 13 road/rail crossings
- Net Present Value Benefit: $101.2M

OPPORTUNITIES AND CHALLENGES

POTENTIAL PARTNERS

Waller County, Montgomery County, SJRA, USACE, MUD 386, City of Tomball, The Woodlands Township, Woodlands Water Agency, TWDB, GLO, FEMA, HCFCD, Harris County

REQUIRED REAL ESTATE

- 37 parcels within PMF
- 30 parcels within 1% ACE WSEL

DESKTOP ENVIRONMENTAL MITIGATION

- 6 acres of potential wetlands
- 840 linear feet of NHD streams

RELOCATIONS/RECONSTRUCTION

- 1 oil & gas pipeline conflicts
- 1.3 miles of roads (PMF)
- 1.3 miles of roads (1% ACE)

ESTIMATED COSTS

Design Cost	$4M
Construction Cost	$37M
Environmental Cost	$8M
ROW Cost	$49M–$84M
TOTAL COSTS	$97M–$132M
20-Year Escalation Cost	$147M–$200M

BENEFIT-COST RATIO: 0.77–1.04

*Costs for these items are not explicitly included in the project estimate; however, a 30% contingency was added to the project that may cover all or a portion of these relocations. More detailed information should be provided during project development.

SAN JACINTO
REGIONAL WATERSHED
MASTER DRAINAGE PLAN

SPRING CREEK — BIRCH CREEK DETENTION

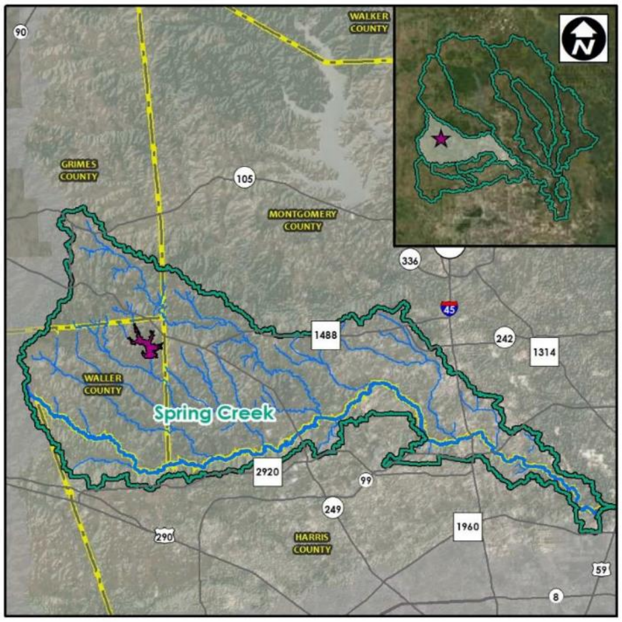
(Recommend Project in SJMDP)

LOCATION: Approximately 12 miles U/S of Spring Creek on Birch Creek

OBJECTIVE: Reduce flooding along Spring Creek

HOW IT WORKS: Dry dam detention facility impounds stream flow during flood events

IMMEDIATE DOWNSTREAM BENEFIT: Incremental Atlas 14 WSEL reduction – 1% ACE to 2% ACE



IMPROVEMENT SPECIFICATIONS

- Dry dam detention facility
- 873 acres (1% ACE)
- 917 acres (PMF)
- 7,731 acre-feet (1% ACE)
- Embankment: 460k cubic yards
- Max dam height: 41 ft
- Dam length: 0.7 miles

ESTIMATED BENEFITS

- Structures removed from 1% ACE floodplain: 815
- Reduction in instances of flooding over 50-year period: 1,084
- Benefited areas:
  - The Woodlands, Tomball, Stagecoach
- Reduces 1% ACE WSEL at least 0.5 feet for 25.9 miles along Spring Creek
- Improves ponding depths on 13 road/rail crossings
- Net Present Value Benefit: $66.0M

OPPORTUNITIES AND CHALLENGES

POTENTIAL PARTNERS

Waller County, Montgomery County, SJRA, USACE, MUD 386, The Woodlands Township, Woodlands Water Agency, City of Tomball, TWDB, GLO, FEMA, HCFCD

REQUIRED REAL ESTATE

- 71 parcels within PMF
- 15 parcels within 1% ACE WSEL

DESKTOP ENVIRONMENTAL MITIGATION

- 2.1 acres of potential wetlands
- 1,370 linear feet of NHD streams

RELOCATIONS/RECONSTRUCTION*

- 1 oil & gas pipeline conflicts
- 0.6 miles of roads (PMF)
- 0.3 miles of roads (1% ACE)

ESTIMATED COSTS

Design Cost... $3M
Construction Cost..................................$23M
Environmental Cost................................ $6M
ROW Cost.................................... $48M–$88M
TOTAL COSTS.........................$80M–$120M
20-Year Escalation Cost .... $121M–$181M

BENEFIT-COST RATIO: 0.55–0.83

*Costs for these items are not explicitly included in the project estimate; however, a 30% contingency was added to the project that may cover all or a portion of these relocations. More detailed information should be provided during project development.

SAN JACINTO
REGIONAL WATERSHED
MASTER DRAINAGE PLAN

SPRING CREEK — WOODLANDS CHANNELIZATION (200-ft)

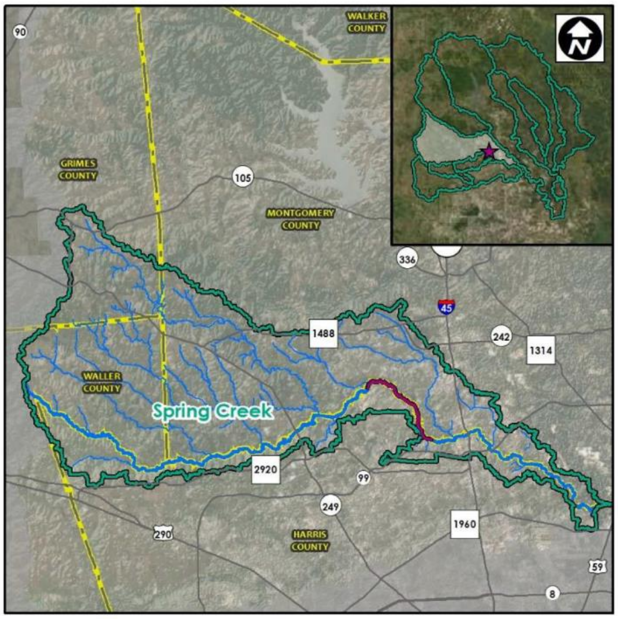
(Recommend Project in SJMDP)

LOCATION: U/S of Kuykendahl Road to D/S of Willow Creek confluence on Spring Creek

OBJECTIVE: Reduce flooding along Spring Creek

HOW IT WORKS: Channelization increases conveyance capacity; a separate upstream detention project in this watershed must be constructed first to mitigate adverse impact

IMMEDIATE AREA BENEFIT: Incremental Atlas 14 WSEL reduction along the channel – 1% ACE to 2% ACE



IMPROVEMENT SPECIFICATIONS

- 8.8 miles of channelization
- 200-foot wide bench
- 155 acres
- 1.9M cubic yards of excavation
- 7,200 acre-feet mitigation required

ESTIMATED BENEFITS

- Structures removed from 1% ACE floodplain: 221
- Reduction in instances of flooding over 50-year period: 477
- Benefited areas:
  - The Woodlands, Timber Lakes
- Reduces 1% ACE WSEL at least 0.5 feet for 11.8 miles along Spring Creek
- Improves ponding depths on 2 road/rail crossings
- Net Present Value Benefit: $34.7M

OPPORTUNITIES AND CHALLENGES

POTENTIAL PARTNERS

Montgomery County, SJRA, USACE, MUD 386, The Woodlands Township, Woodlands Water Agency, TWDB, GLO, HCFCD

REQUIRED REAL ESTATE

- 113 parcels within 1% ACE WSEL

DESKTOP ENVIRONMENTAL MITIGATION

- 11 acres of potential wetlands
- 0 linear feet of NHD streams

RELOCATIONS/RECONSTRUCTION*

- 2 oil & gas pipeline conflicts
- 0.10 miles of roads (1% ACE)

ESTIMATED COSTS

Design Cost.. $6M
Construction Cost................................. $47M
Environmental Cost................................. $1M
ROW Cost.. $2M
TOTAL COSTS.....................................$56M
20-Year Escalation Cost $85M

BENEFIT-COST RATIO: 0.62

*Costs for these items are not explicitly included in the project estimate; however, a 30% contingency was added to the project that may cover all or a portion of these relocations. More detailed information should be provided during project development.

SAN JACINTO
REGIONAL WATERSHED
MASTER DRAINAGE PLAN

SPRING CREEK — I-45 CHANNELIZATION

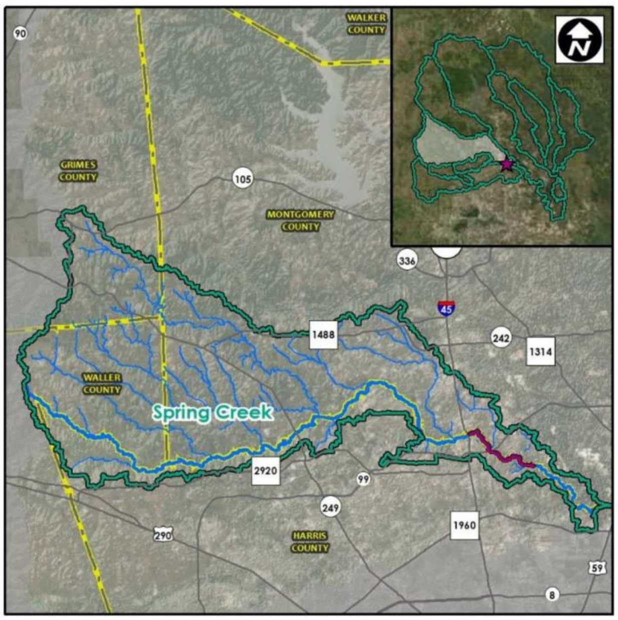
(Recommend Project in SJMDP)

LOCATION: From I-45 to approximately 4 miles D/S of Riley Fuzzel Road on Spring Creek

OBJECTIVE: Reduce flooding along Spring Creek

HOW IT WORKS: Channelization increases conveyance capacity; a separate upstream detention project in this watershed must be constructed first to mitigate adverse impact

IMMEDIATE AREA BENEFIT: Incremental Atlas 14 WSEL reduction along the channel – 1% ACE to 4% ACE



OPPORTUNITIES AND CHALLENGES

POTENTIAL PARTNERS

Montgomery County, TxDOT, SJRA, USACE, TWDB, GLO, FEMA, HCFCD

REQUIRED REAL ESTATE

- 137 parcels within 1% ACE WSEL

DESKTOP ENVIRONMENTAL MITIGATION

- 35 acres of potential wetlands
- 0 linear feet of NHD streams

RELOCATIONS/RECONSTRUCTION*

- 5 oil & gas pipeline conflicts
- 0.05 miles of roads (1% ACE)

IMPROVEMENT SPECIFICATIONS

- 6.9 miles of channelization
- 300-foot wide bench
- 188 acres
- 3.7M cubic yards of embankment
- 8,000 acre-feet mitigation required

ESTIMATED BENEFITS

- Structures removed from 1% ACE floodplain: 1,240
- Reduction in instances of flooding over 50-year period: 1,739
- Benefited areas:
  - Northgate Crossing, Lexington Woods, Spring
- Reduces 1% ACE WSEL at least 0.5 feet for 10.7 miles along Spring Creek
- Improves ponding depths on 4 road/rail crossings
- Net Present Value Benefit: $99.4M

ESTIMATED COSTS

Design Cost $8M
Construction Cost $69M
Environmental Cost.................................$4M
ROW Cost...$4M
<u>TOTAL COSTS.................................... $85M</u>
20-Year Escalation Cost $129M

BENEFIT-COST RATIO: 1.17

*Costs for these items are not explicitly included in the project estimate; however, a 30% contingency was added to the project that may cover all or a portion of these relocations. More detailed information should be provided during project development.

SAN JACINTO
REGIONAL WATERSHED
MASTER DRAINAGE PLAN

LAKE CREEK — CANEY CREEK DETENTION

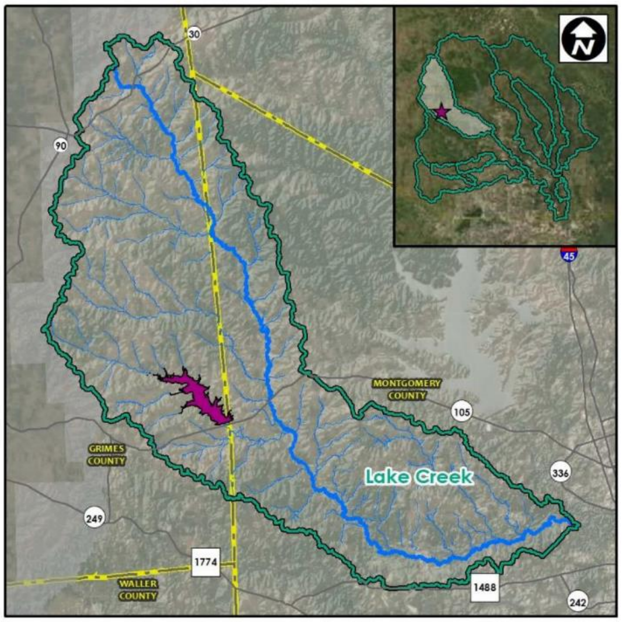
(Recommend Project in SJMDP)

LOCATION: Approximately 0.3 miles U/S of SH 105 on Caney Creek

OBJECTIVE: Reduce flooding along Lake Creek

HOW IT WORKS: Dry dam detention facility impounds stream flow during flood events

IMMEDIATE DOWNSTREAM BENEFIT: Incremental Atlas 14 WSEL reduction – 1% ACE to 2% ACE



IMPROVEMENT SPECIFICATIONS

- Dry dam detention facility
- 1,886 acres (1% ACE)
- 3,272 acres (PMF)
- 19,750 acre-feet (1% ACE)
- Embankment: 825k cubic yards
- Max dam height: 52 ft
- Dam length: 0.8 miles

ESTIMATED BENEFITS

- Structures removed from 1% ACE floodplain: 323
- Reduction in instances of flooding over 50-year period: 686
- Benefited areas:
  - Woodforest, River Plantation, City of Conroe, Woodloch
- Reduces 1% ACE WSEL at least 0.5 feet for 35.1 miles along Lake Creek
- Improves ponding depths on 4 road/rail crossings
- Net Present Value Benefit: $42.1M

OPPORTUNITIES AND CHALLENGES

POTENTIAL PARTNERS

Grimes County, Montgomery County, SJRA, USACE, TWDB, GLO, HCFCD,

REQUIRED REAL ESTATE

- 220 parcels within PMF
- 123 parcels within 1% ACE WSEL

DESKTOP ENVIRONMENTAL MITIGATION

- 10 acres of potential wetlands
- 660 linear feet of NHD streams

RELOCATIONS/RECONSTRUCTION*

- No known gas pipeline conflicts
- 4.9 miles of roads (PMF)
- 1.1 miles of roads (1% ACE)

ESTIMATED COSTS

Design Cost..$4M
Construction Cost $34M
Environmental Cost................................$7M
ROW Cost.................................$54M–$118M
TOTAL COSTS........................ $98M–$163M
20-Year Escalation Cost.......... $149M–$247M

BENEFIT-COST RATIO: 0.26–0.43

*Costs for these items are not explicitly included in the project estimate; however, a 30% contingency was added to the project that may cover all or a portion of these relocations. More detailed information should be provided during project development.

SAN JACINTO
REGIONAL WATERSHED
MASTER DRAINAGE PLAN

LAKE CREEK — LITTLE CANEY CREEK DETENTION

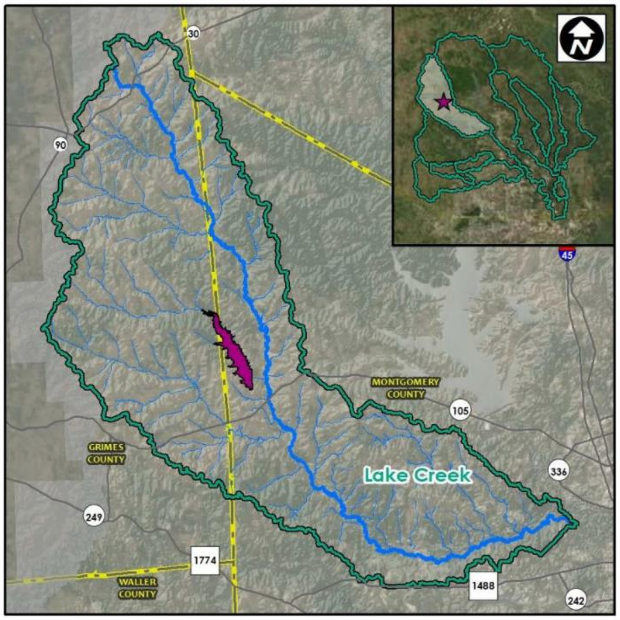
(Recommend Project in SJMDP)

LOCATION: Approximately 1.1 miles U/S of Lake Creek on Little Caney Creek, West of FM 1486

OBJECTIVE: Reduce flooding along Lake Creek

HOW IT WORKS: Dry dam detention facility impounds stream flow during flood events

IMMEDIATE DOWNSTREAM BENEFIT: Incremental Atlas 14 WSEL reduction – 1% ACE to 2% ACE



IMPROVEMENT SPECIFICATIONS

- Dry dam detention facility
- 1,612 acres (1% ACE)
- 2,976 acres (PMF)
- 17,500 acre-feet (1% ACE)
- Embankment: 1.2M cubic yards
- Max dam height: 51 ft
- Dam length: 0.8 miles

ESTIMATED BENEFITS

- Structures removed from 1% ACE floodplain: 248
- Reduction in instances of flooding over 50-year period: 564
- Benefited areas:
  - Woodforest, River Plantation, City of Conroe, Dobbin, Woodloch
- Reduces 1% ACE WSEL at least 0.5 feet for 40.1 miles along Lake Creek
- Improves ponding depths on 6 road/rail crossings
- Net Present Value Benefit: $35.0M

OPPORTUNITIES AND CHALLENGES

POTENTIAL PARTNERS

Montgomery County, Grimes County, SJRA, USACE, TWDB, GLO, HCFCD

REQUIRED REAL ESTATE

- 215 parcels within PMF
- 111 parcels within 1% ACE WSEL

DESKTOP ENVIRONMENTAL MITIGATION

- 8.9 acres of potential wetlands
- 1,105 linear feet of NHD streams

RELOCATIONS/RECONSTRUCTION*

- 6 oil & gas pipeline conflicts
- 3.5 miles of roads (PMF)
- 1.2 miles of roads (1% ACE)

ESTIMATED COSTS

Design Cost.. $6M
Construction Cost $49M
Environmental Cost................................ $10M
ROW Cost.................................... $33M–$63M
TOTAL COSTS......................... $98M–$128M
20-Year Escalation Cost ....$149M–$195M

BENEFIT-COST RATIO: 0.27–0.36

*Costs for these items are not explicitly included in the project estimate; however, a 30% contingency was added to the project that may cover all or a portion of these relocations. More detailed information should be provided during project development.

SAN JACINTO
REGIONAL WATERSHED
MASTER DRAINAGE PLAN

LAKE CREEK — GARRETT'S CREEK DETENTION

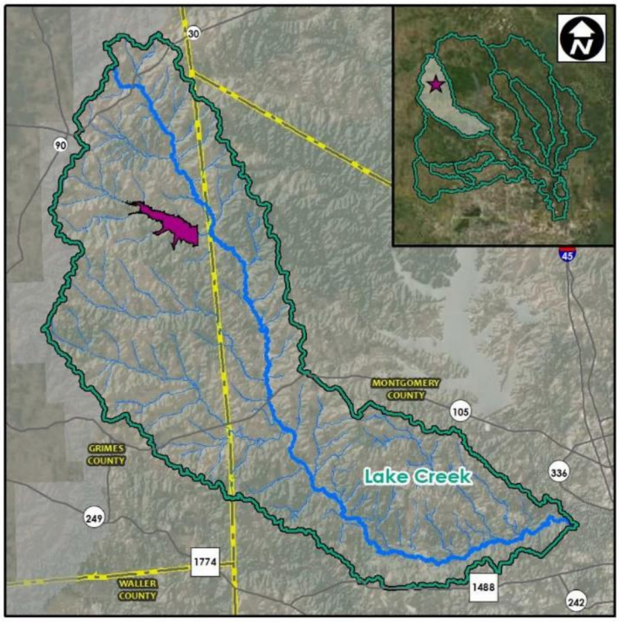
(Recommend Project in SJMDP)

LOCATION: Approximately 0.7 miles U/S of Lake Creek on Garretts Creek

OBJECTIVE: Reduce flooding along Lake Creek

HOW IT WORKS: Dry dam detention facility impounds stream flow during flood events

IMMEDIATE DOWNSTREAM BENEFIT: Incremental Atlas 14 WSEL reduction – 1% ACE to 2% ACE



OPPORTUNITIES AND CHALLENGES

POTENTIAL PARTNERS

Grimes County, Montgomery County, TxDOT, SJRA, USACE, TWDB, GLO, HCFCD

REQUIRED REAL ESTATE

- 74 parcels within PMF
- 36 parcels within 1% ACE WSEL

DESKTOP ENVIRONMENTAL MITIGATION

- 35 acres of potential wetlands
- 2,590 linear feet of NHD streams

RELOCATIONS/RECONSTRUCTION*

- 2 oil & gas pipeline conflicts
- 4.6 miles of roads (PMF)
- 1.5 miles of roads (1% ACE)

IMPROVEMENT SPECIFICATIONS

- Dry dam detention facility
- 1,739 acres (1% ACE)
- 3,009 acres (PMF)
- 16,850 acre-feet (1% ACE)
- Embankment: 1.0M cubic yards
- Max dam height: 43 ft
- Dam length: 1.2 miles

ESTIMATED BENEFITS

- Structures removed from 1% ACE floodplain: 295
- Reduction in instances of flooding over 50-year period: 684
- Benefited areas:
  - Dobbin, River Plantation, City of Conroe, Woodloch, Woodforest
- Reduces 1% ACE WSEL at least 0.5 feet for 53.2 miles along Lake Creek
- Improves ponding depths on 7 road/rail crossings
- Net Present Value Benefit: $39.8M

ESTIMATED COSTS

Design Cost	$6M
Construction Cost	$51M
Environmental Cost	$17M
ROW Cost	$32M–$56M
TOTAL COSTS	$107M–$131M
20-Year Escalation Cost	$162M–$198M

BENEFIT-COST RATIO: 0.31–0.37

*Costs for these items are not explicitly included in the project estimate; however, a 30% contingency was added to the project that may cover all or a portion of these relocations. More detailed information should be provided during project development.

SAN JACINTO
REGIONAL WATERSHED
MASTER DRAINAGE PLAN

PEACH CREEK — WALKER DETENTION

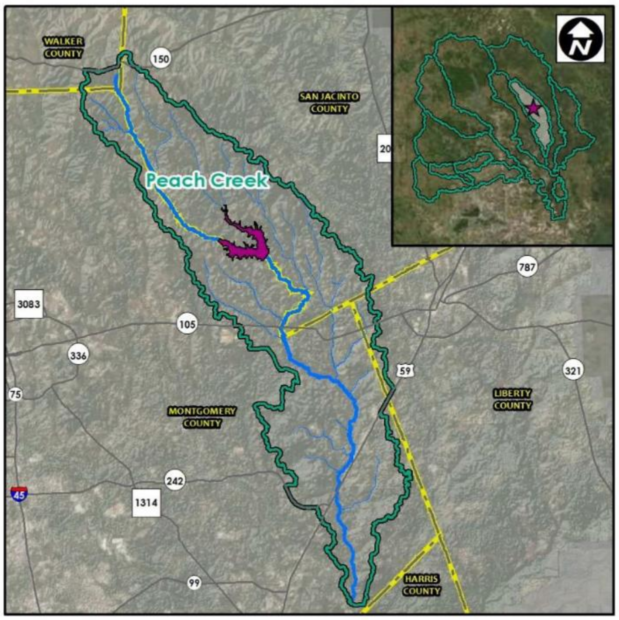
(Recommend Project in SJMDP)

LOCATION: Approximately 19 miles U/S of New Caney on Peach Creek

OBJECTIVE: Reduce flooding along Peach Creek

HOW IT WORKS: Dry dam detention facility impounds stream flow during flood events

IMMEDIATE DOWNSTREAM BENEFIT: Incremental Atlas 14 WSEL reduction – 1% ACE to 10% ACE



IMPROVEMENT SPECIFICATIONS

- Dry dam detention facility
- 1,235 acres (1% ACE)
- 2,191 acres (PMF)
- 36,000 acre-feet (1% ACE)
- Embankment: 4.7M cubic yards
- Max dam height: 51 ft
- Dam length: 3.2 miles

ESTIMATED BENEFITS

- Structures removed from 1% ACE floodplain: 261
- Reduction in instances of flooding over 50-year period: 1,073
- Benefited areas:
  - Woodbranch, Patton Village, Splendora
- Reduces 1% ACE WSEL at least 0.5 feet for 30.5 miles downstream of detention facility
- Improves ponding depths on 9 road/rail crossings
- Net Present Value Benefit: $56.3M

OPPORTUNITIES AND CHALLENGES

POTENTIAL PARTNERS

Montgomery County, San Jacinto County, TxDOT, SJRA, USACE, TWDB, GLO

REQUIRED REAL ESTATE

- 60 parcels within PMF
- 42 parcels within 1% ACE WSEL

DESKTOP ENVIRONMENTAL MITIGATION

- 9 acres of potential wetlands
- 1,365 linear feet of NHD streams

RELOCATIONS/RECONSTRUCTION*

- 1 oil & gas pipeline conflict
- 1.1 miles of roads (PMF)
- 0.4 miles of roads (1% ACE)

ESTIMATED COSTS

Design Cost	$19M
Construction Cost	$160M
Environmental Cost	$9M
ROW Cost	$13M–$30M
TOTAL COSTS	$201M–$218M
20-Year Escalation Cost	$305M–$331M

BENEFIT-COST RATIO: 0.26–0.28

*Costs for these items are not explicitly included in the project estimate; however, a 30% contingency was added to the project that may cover all or a portion of these relocations. More detailed information should be provided during project development.

SAN JACINTO
REGIONAL WATERSHED
MASTER DRAINAGE PLAN

PEACH CREEK — SH 105 DETENTION

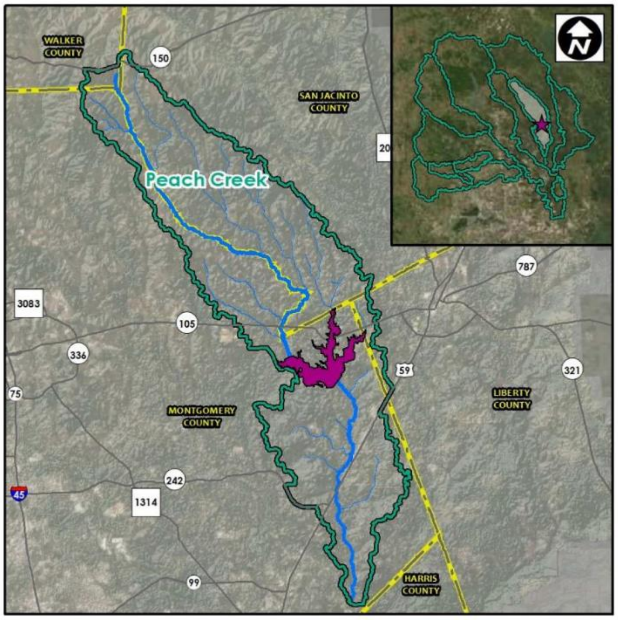
(Recommend Project in SJMDP)

LOCATION: Approximately 12 miles U/S of New Caney on Peach Creek

OBJECTIVE: Reduce flooding along Peach Creek

HOW IT WORKS: Dry dam detention facility impounds stream flow during flood events

IMMEDIATE DOWNSTREAM BENEFIT: Incremental Atlas 14 WSEL reduction – 1% ACE to 4% ACE



IMPROVEMENT SPECIFICATIONS

- Dry dam detention facility
- 3,025 acres (1% ACE)
- 5,195 acres (PMF)
- 36,197 acre-feet (1% ACE)
- Embankment: 6.4M cubic yards
- Max dam height: 46 ft
- Dam length: 4.7 miles

ESTIMATED BENEFITS

- Structures removed from 1% ACE floodplain: 400
- Reduction in instances of flooding over 50-year period: 1,768
- Benefited areas:
  - Woodbranch and Splendora
- Reduces 1% ACE WSEL at least 0.5 feet for 15.4 miles downstream of detention facility
- Improves ponding depths on 6 road/rail crossings
- Net Present Value Benefit: $81.5M

OPPORTUNITIES AND CHALLENGES

POTENTIAL PARTNERS

Montgomery County, SJRA, USACE, TWDB, GLO

REQUIRED REAL ESTATE

- 505 parcels within PMF
- 273 parcels within 1% ACE WSEL

DESKTOP ENVIRONMENTAL MITIGATION

- 7 acres of potential wetlands
- 900 linear feet of NHD streams

RELOCATIONS/RECONSTRUCTION*

- 1 oil & gas pipeline conflict
- 10.7 miles of roads (PMF)
- 4.7 miles of roads (1% ACE)

ESTIMATED COSTS

Design Cost	$26M
Construction Cost	$214M
Environmental Cost	$7M
ROW Cost	$110M–$187M
TOTAL COSTS	$356M–$433M
20-Year Escalation Cost	$540M–$657M

BENEFIT-COST RATIO: 0.19–0.23

*Costs for these items are not explicitly included in the project estimate; however, a 30% contingency was added to the project that may cover all or a portion of these relocations. More detailed information should be provided during project development.

SAN JACINTO
REGIONAL WATERSHED
MASTER DRAINAGE PLAN

PEACH CREEK — I-69 CHANNELIZATION

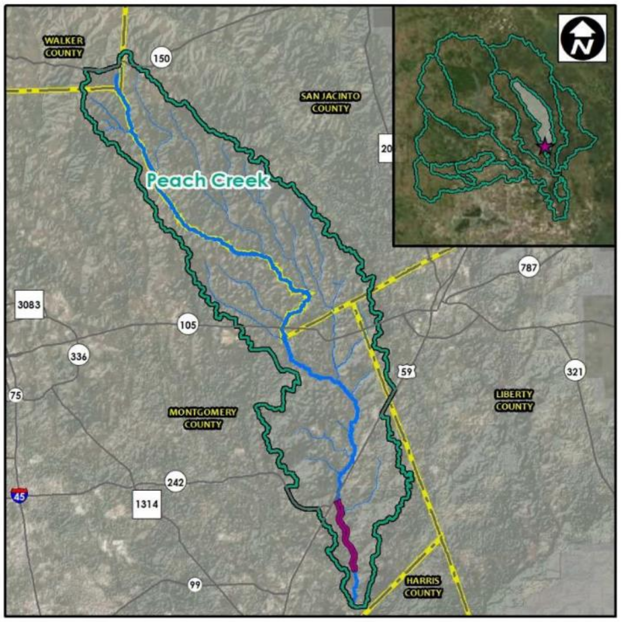
(Recommend Project in SJMDP)

LOCATION: D/S of I-69 to FM 1485 on Peach Creek

OBJECTIVE: Reduce flooding along Peach Creek

HOW IT WORKS: Channelization increases conveyance capacity; a separate upstream detention project in this watershed must be constructed first to mitigate adverse impact

IMMEDIATE AREA BENEFIT: Incremental Atlas 14 WSEL reduction along the channel – 1% ACE to 4% ACE



OPPORTUNITIES AND CHALLENGES

POTENTIAL PARTNERS

Montgomery County, SJRA, USACE, TWDB, GLO

REQUIRED REAL ESTATE

- 286 parcels within 1% ACE WSEL

DESKTOP ENVIRONMENTAL MITIGATION

- 28 acres of potential wetlands
- 0 linear feet of NHD streams

RELOCATIONS/RECONSTRUCTION*

- 3 oil & gas pipeline conflicts
- 1.9 miles of roads

IMPROVEMENT SPECIFICATIONS

- 4.3 miles of channelization
- 800-foot wide bench
- 417 acres
- 7M cubic yards of excavation
- 800 acre-feet mitigation required

ESTIMATED BENEFITS

- Structures removed from 1% ACE floodplain: 383
- Reduction in instances of flooding over 50-year period: 1,880
- Benefited areas:
  - Woodbranch, Patton Village, Roman Forest
- Reduces 1% ACE WSEL at least 0.5 feet for 6.2 miles along Peach Creek
- Improves ponding depths on 4 road/rail crossings
- Net Present Value Benefit: $73.6M

ESTIMATED COSTS

Design Cost..$15M
Construction Cost................................$129M
Environmental Cost................................ $7M
ROW Cost.. $8M
TOTAL COSTS................................. $159M
20-Year Escalation Cost......................$241M

BENEFIT-COST RATIO: 0.46

*Costs for these items are not explicitly included in the project estimate; however, a 30% contingency was added to the project that may cover all or a portion of these relocations. More detailed information should be provided during project development.

SAN JACINTO
REGIONAL WATERSHED
MASTER DRAINAGE PLAN

CANEY CREEK — FM 1097 DETENTION

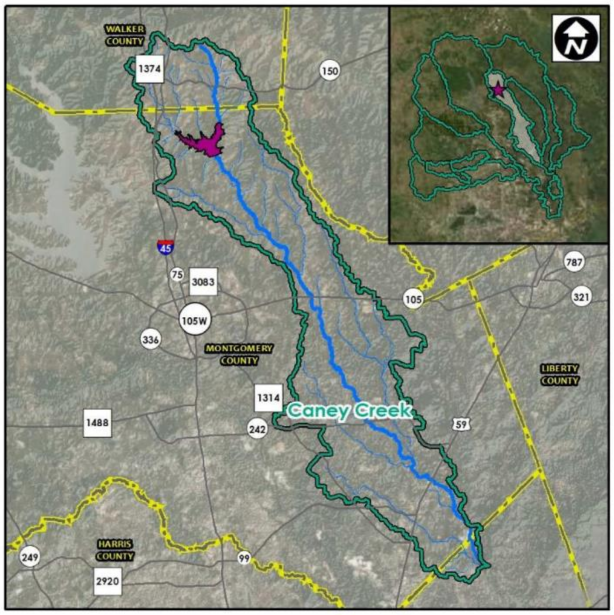
(Recommend Project in SJMDP)

LOCATION: Approximately 1.0 miles U/S of FM 1097 on Caney Creek

OBJECTIVE: Reduce flooding along Caney Creek

HOW IT WORKS: Dry dam detention facility impounds stream flow during flood events

IMMEDIATE DOWNSTREAM BENEFIT: Incremental Atlas 14 WSEL reduction – 1% ACE to 4% ACE



OPPORTUNITIES AND CHALLENGES

POTENTIAL PARTNERS

Montgomery County, TxDOT, SJRA, HCFCD, USACE, TWDB, GLO

REQUIRED REAL ESTATE

- 182 parcels within PMF
- 95 parcels within 1% ACE WSEL

DESKTOP ENVIRONMENTAL MITIGATION

- 1 acre of potential wetlands
- 1,291 linear feet of NHD streams

RELOCATIONS/RECONSTRUCTION*

- No known oil & gas pipeline conflicts
- 4.1 miles of roads (PMF)
- 1.3 miles of roads (1% ACE)

IMPROVEMENT SPECIFICATIONS

- Dry dam detention facility
- 1,514 acres (1% ACE)
- 2,435 acres (PMF)
- 13,900 acre-feet (1% ACE)
- Embankment: 1.5M cubic yards
- Max dam height: 53 ft
- Dam length: 1.2 miles

ESTIMATED BENEFITS

- Structures removed from 1% ACE floodplain: 285
- Reduction in instances of flooding over 50-year period: 783
- Benefited areas:
    - New Caney, The neighborhoods near SH 242 and FM 1484
    - Reduces 1% ACE WSEL at least 0.5 feet for 40.0 miles downstream of detention facility
- Improves ponding depths on 18 road/rail crossings
- Net Present Value Benefit: $27.7M

ESTIMATED COSTS

Design Cost..$8M
Construction Cost $65M
Environmental Cost....................................$8M
ROW Cost.......................................$24M–$50M
TOTAL COSTS...........................$105M–$131M
20-Year Escalation Cost...........$159M–$199M

BENEFIT-COST RATIO: 0.21–0.26

*Costs for these items are not explicitly included in the project estimate; however, a 30% contingency was added to the project that may cover all or a portion of these relocations. More detailed information should be provided during project development.

SAN JACINTO
REGIONAL WATERSHED
MASTER DRAINAGE PLAN

CANEY CREEK — SH 105 DETENTION

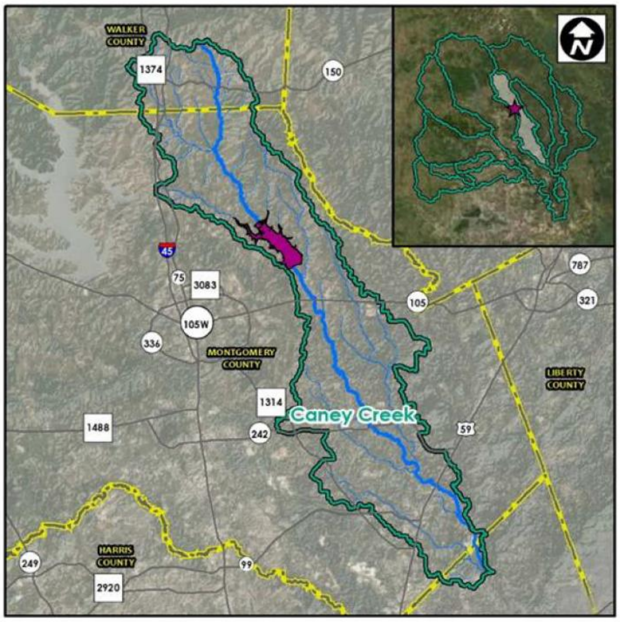
(Recommend Project in SJMDP)

LOCATION: Approximately 1.9 miles U/S of SH 105 on Caney Creek

OBJECTIVE: Reduce flooding along Caney Creek

HOW IT WORKS: Dry dam detention facility impounds stream flow during flood events

IMMEDIATE DOWNSTREAM BENEFIT: Incremental Atlas 14 WSEL reduction – 1% ACE to 4% ACE



IMPROVEMENT SPECIFICATIONS

- Dry dam detention facility
- 1,502 acres (1% ACE)
- 2,310 acres (PMF)
- 28,090 acre-feet (1% ACE)
- Embankment: 1.2M cubic yards
- Max dam height: 62 ft
- Dam length: 0.8 miles

ESTIMATED BENEFITS

- Structures removed from 1% ACE floodplain: 658
- Reduction in instances of flooding over 50-year period: 1,596
- Benefited areas:
  - The neighborhoods near SH 242 and FM 1484
- Reduces 1% ACE WSEL at least 0.5 feet for 31.5 miles downstream of detention facility
- Improves ponding depths on 11 road/rail crossings
- Net Present Value Benefit: $55.2M

OPPORTUNITIES AND CHALLENGES

POTENTIAL PARTNERS

Montgomery County, TxDOT, HCFCD, SJRA, TWDB, GLO, USACE

REQUIRED REAL ESTATE

- 402 parcels within PMF
- 227 parcels within 1% ACE WSEL

DESKTOP ENVIRONMENTAL MITIGATION

- 4 acres of potential wetlands
- 1,058 linear feet of NHD streams

RELOCATIONS/RECONSTRUCTION*

- 1 oil & gas pipeline conflict
- 0.9 miles of roads (PMF)
- 0.5 miles of roads (1% ACE)

ESTIMATED COSTS

Design Cost..$7M
Construction Cost $61M
Environmental Cost.................................$8M
ROW Cost....................................$38M–$74M
<u>TOTAL COSTS........................ $114M–$149M</u>
20-Year Escalation Cost...........$173M–$227M

BENEFIT-COST RATIO: 0.37–0.48

*Costs for these items are not explicitly included in the project estimate; however, a 30% contingency was added to the project that may cover all or a portion of these relocations. More detailed information should be provided during project development.

SAN JACINTO
REGIONAL WATERSHED
MASTER DRAINAGE PLAN

CANEY CREEK — I-69 CHANNELIZATION

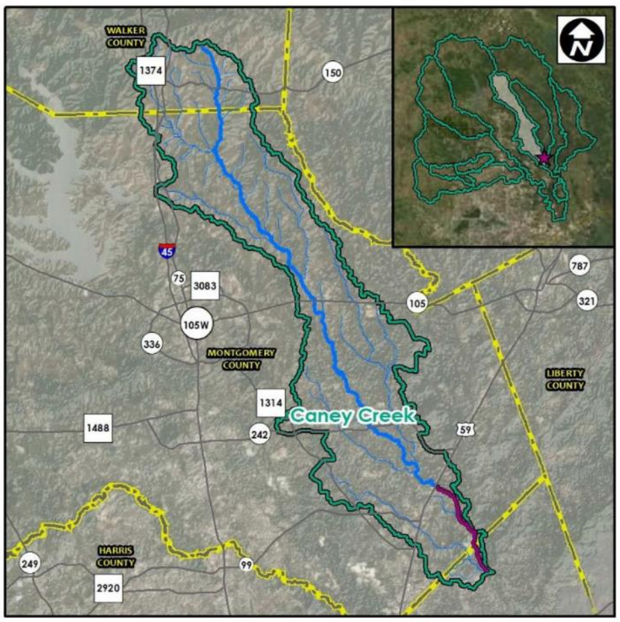
(Recommend Project in SJMDP)

LOCATION: Approximately 0.5 miles D/S of I-69 to confluence of East Fork of San Jacinto River

OBJECTIVE: Reduce flooding along Caney Creek

HOW IT WORKS: Channelization increases conveyance capacity; a separate upstream detention project in this watershed must be constructed first to mitigate adverse impact

IMMEDIATE AREA BENEFIT: Incremental Atlas 14 WSEL reduction along the channel – 1% ACE to 4% ACE



IMPROVEMENT SPECIFICATIONS

- 7.8 miles of channelization
- 700-foot wide bench
- 629 acres
- 4.7M cubic yards of excavation
- 530 acre-feet mitigation required

ESTIMATED BENEFITS

- Structures removed from 1% ACE floodplain: 509
- Reduction in instances of flooding over 50-year period: 1,122
- Benefited areas:
  - Baptist Encampment Road, New Caney
- Reduces 1% ACE WSEL at least 0.5 feet for 9.0 miles along Caney Creek
- Improves ponding depths on 5 road/rail crossings
- Net Present Value Benefit: $57.4 M

OPPORTUNITIES AND CHALLENGES

POTENTIAL PARTNERS

Montgomery County, HCFCD, TxDOT, SJRA, USACE, TWDB, GLO

REQUIRED REAL ESTATE

- 156 parcels within 1% ACE WSEL

DESKTOP ENVIRONMENTAL MITIGATION

- 133 acres of potential wetlands
- 0 linear feet of NHD streams

RELOCATIONS/RECONSTRUCTION*

- 10 oil & gas pipeline conflicts
- 0.6 miles of roads (1% ACE)

ESTIMATED COSTS

Design Cost	$18M
Construction Cost	$146M
Environmental Cost	$20M
ROW Cost	$6M
TOTAL COSTS	$189M
20-Year Escalation Cost	$287M

BENEFIT-COST RATIO: 0.30

*Costs for these items are not explicitly included in the project estimate; however, a 30% contingency was added to the project that may cover all or a portion of these relocations. More detailed information should be provided during project development.

SAN JACINTO
REGIONAL WATERSHED
MASTER DRAINAGE PLAN

EAST FORK SAN JACINTO — WINTERS BAYOU DETENTION

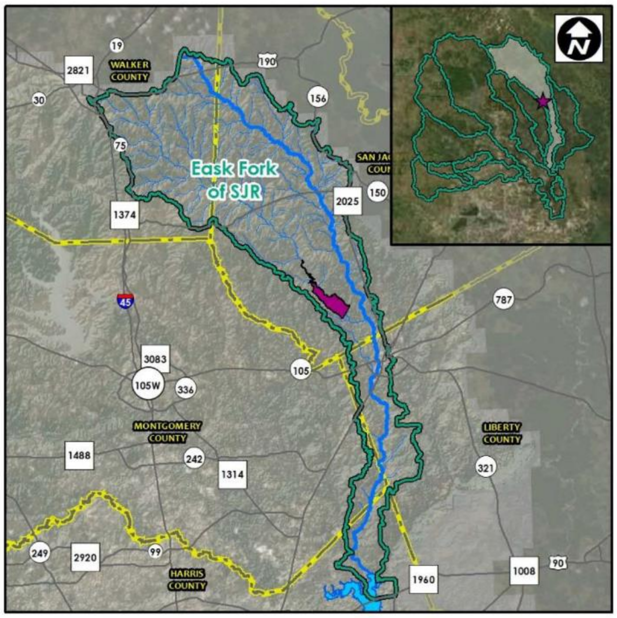
(Recommend Project in SJMDP)

LOCATION: Approximately 3 miles U/S Winters Bayou from East Fork of San Jacinto River

OBJECTIVE: Reduce flooding along East Fork of San Jacinto River

HOW IT WORKS: Dry dam detention facility impounds stream flow during flood events

IMMEDIATE DOWNSTREAM BENEFIT: Incremental Atlas 14 WSEL reduction – 1% ACE to 2% ACE



IMPROVEMENT SPECIFICATIONS

- Dry dam detention facility
- 2,480 acres (1% ACE)
- 2,600 acres (PMF)
- 45,055 acre-feet (1% ACE)
- Embankment: 1.3M cubic yards
- Max dam height: 48 ft
  Dam length: 1.6 miles

ESTIMATED BENEFITS

- Structures removed from 1% ACE floodplain: 615
- Reduction in instances of flooding over 50-year period: 1,334
- Location of benefits:
  - Cleveland, Plum Grove
- Reduces 1% ACE WSEL at least 0.5 feet for 31.6 miles along East Fork
- Improves ponding depths on 10 road/rail crossings
- Net Present Value Benefit: $63.5M

OPPORTUNITIES AND CHALLENGES

POTENTIAL PARTNERS

San Jacinto County, SJRA, TxDOT, USACE, USDA, BNSF Railroad, UPRR, TWDB, GLO, HCFCD

REQUIRED REAL ESTATE

- 181 parcels within PMF
- 88 parcels within 1% ACE

DESKTOP ENVIRONMENTAL MITIGATION

- 18 acres of potential wetlands
- 442 linear feet of NHD streams

RELOCATIONS/RECONSTRUCTION*

- 3 oil & gas pipeline conflicts
- 1.5 miles of roads (PMF)
- 1.1 miles of roads (1% ACE)

ESTIMATED COSTS

Design Cost	$9M
Construction Cost	$74M
Environmental Cost	$7M
ROW Cost	$45M–$77M
TOTAL COSTS	$134M–$167M
20-Year Escalation Cost	$204M–$252M

BENEFIT-COST RATIO: 0.38–0.47

*Costs for these items are not explicitly included in the project estimate; however, a 30% contingency was added to the project that may cover all or a portion of these relocations. More detailed information should be provided during project development.

SAN JACINTO
REGIONAL WATERSHED
MASTER DRAINAGE PLAN

WEST FORK SAN JACINTO RIVER — HIGHWAY 242 CHANNELIZATION

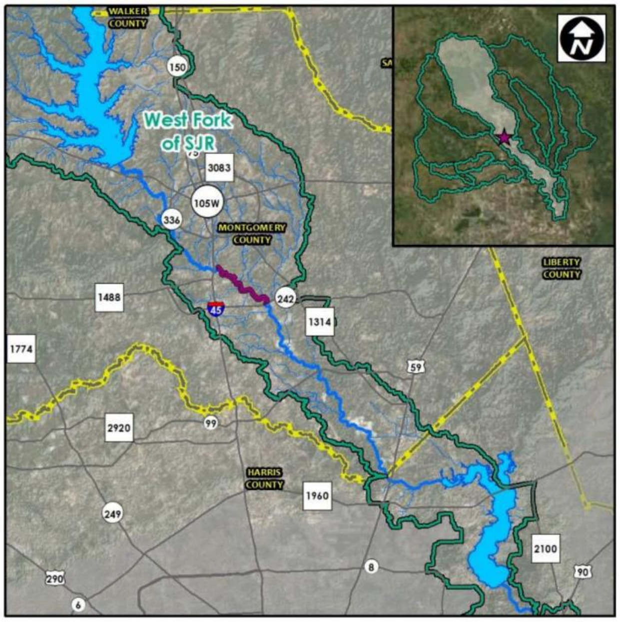
(Recommend Project in SJMDP)

LOCATION: I-45 to SH 242 on West Fork of San Jacinto River

OBJECTIVE: Reduce flooding along West Fork of San Jacinto River

HOW IT WORKS: Channelization increases conveyance capacity; a separate upstream detention project in the Lake Creek watershed must be constructed first to mitigate adverse impact

IMMEDIATE AREA BENEFIT: Incremental Atlas 14 WSEL reduction along the channel – 1% ACE to 2% ACE



IMPROVEMENT SPECIFICATIONS

- 5.7 miles of channelization
- 750-foot wide bench
- 520 acres
- 5.7M cubic yards of excavation
- 12,400 acre-feet mitigation required

ESTIMATED BENEFITS

- Structures removed from 1% ACE floodplain: 383
- Reduction in instances of flooding over 50-year period: 1,004
- Benefited areas:
  - River Plantation, Montgomery Creek Ranch
- Reduces 1% ACE WSEL at least 0.5 feet for 9.1 miles along West Fork
- Improves ponding depths on 2 road/rail crossings
- Net Present Value Benefit: $45.5M

OPPORTUNITIES AND CHALLENGES

POTENTIAL PARTNERS

Montgomery County, SJRA, TWDB, GLO

REQUIRED REAL ESTATE

- 225 parcels within 1% ACE WSEL

DESKTOP ENVIRONMENTAL MITIGATION

- 152 acres of potential wetlands
- 0 linear feet of NHD streams

RELOCATIONS/RECONSTRUCTION

- 6 oil & gas pipeline conflicts
- 0.1 miles of roads

ESTIMATED COSTS

Design Cost	$13M
Construction Cost	$110M
Environmental Cost	$22M
ROW Cost	$11M
TOTAL COSTS	$157M
20-Year Escalation Cost	$238M

BENEFIT-COST RATIO: 0.29

*Costs for these items are not explicitly included in the project estimate; however, a 30% contingency was added to the project that may cover all or a portion of these relocations. More detailed information should be provided during project development.

SAN JACINTO
REGIONAL WATERSHED
MASTER DRAINAGE PLAN

WEST FORK SAN JACINTO RIVER — KINGWOOD BENCHING

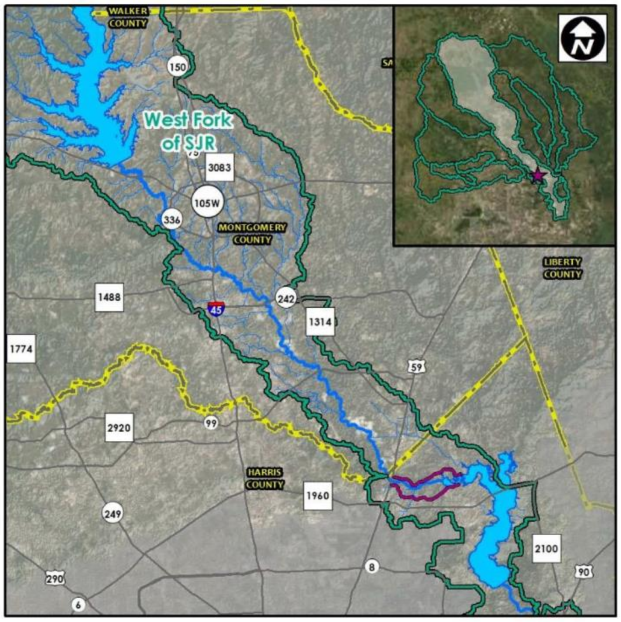
(Recommend Project in SJMDP)

LOCATION: I-69 to West Lake Houston Parkway on West Fork of San Jacinto River

OBJECTIVE: Reduce flooding along West Fork of San Jacinto River

HOW IT WORKS: Channelization increases conveyance capacity; a separate upstream detention project in the Lake Creek or Spring Creek watersheds must be constructed first to mitigate adverse impact

IMMEDIATE AREA BENEFIT: Incremental Atlas 14 WSEL reduction along the channel – 1% ACE to 2% ACE



IMPROVEMENT SPECIFICATIONS

- 5 miles of channel benching
- 3,500-foot wide bench
- 3,527 acres
- 30.5 M cubic yards of excavation
- 923 acre-feet mitigation required

ESTIMATED BENEFITS

- Structures removed from 1% ACE floodplain: 743
- Reduction in instances of flooding over 50-year period: 963
- Benefited areas:
  - Kingwood, Atascocita, Humble
- Reduces 1% ACE WSEL at least 0.5 feet for 9.2 miles along West Fork
- Improves ponding depths on 2 road/rail crossings
- Net Present Value Benefit: $60.5M

OPPORTUNITIES AND CHALLENGES

POTENTIAL PARTNERS

Harris County, HCFCD, Montgomery County, SJRA, USACE, GLO, City of Houston

REQUIRED REAL ESTATE

- 1,301 parcels within 1% ACE WSEL

DESKTOP ENVIRONMENTAL MITIGATION

- 1,416 acres of potential wetlands
- 0 linear feet of NHD streams

RELOCATIONS/RECONSTRUCTION

- 4 oil & gas pipeline conflicts
- 9.9 miles of roads

ESTIMATED COSTS

Design Cost	$64M
Construction Cost	$537M
Environmental Cost	$180M
ROW Cost	$56M
TOTAL COSTS	**$837M**
20-Year Escalation Cost	$1.3B

BENEFIT-COST RATIO: 0.07

*Costs for these items are not explicitly included in the project estimate; however, a 30% contingency was added to the project that may cover all or a portion of these relocations. More detailed information should be provided during project development.

8.7 Summary of Combined Alternatives

The recommended projects were combined into an overall San Jacinto River Master Plan model to determine the total watershed benefit of the master plan implementation. The table below documents the combined structural benefit of implementing all recommended alternatives in the watershed. In this table, the benefits reported are only the benefits located along that particular stream. For example, the individual alternatives table indicates that the individual East Fork Winters Bayou Dam would yield $63.5M in structural benefit, but the combined alternatives table below shows $50.1M in benefits on the East Fork alone. This is because the $63.5M in structural benefit provided by the East Fork Winters Bayou Dam also includes some structural benefit along the West Fork.

In addition, the table below shows that the combined alternatives yield a total structural benefit of $743.2M, which is lower than the sum of the structural benefits of each individual project. As each project is constructed, the incremental benefit of each new project is slightly decreased compared to its individual benefit. This is because, as flood depths continue to decrease at any given structure, the incremental benefit to that structure also decreases. The first few inches of flood reduction yield more benefit than the last few inches.

The combined benefit of these alternatives results in residual benefits to other streams without proposed alternatives, such as Willow Creek, Cypress Creek, Little Cypress Creek, and Luce and Tarkington Bayou. The benefits here accrue because of decreases in tailwater (the water surface elevation at the downstream end of the reach) that propagate upstream.

Figure 22 on the next page maps the distribution of the recommended alternatives' benefits across the watershed.

Table 18: Combined Watershed Benefits

Stream	Existing Structural Damages (50-yr Period) ($M)	Recommended Alternatives Structural Damages (50-yr Period) ($M)	Structural Benefit (50-yr Period) ($M)	Cost Range ($M)
Spring Creek	339.3	117.3	222.0	314–389
Willow Creek	119.1	101.4	17.7	–
Cypress Creek	373.1	372.0	1.1	–
Little Cypress Creek	196.6	196.6	0.0	–
East Fork SJR	128.2	78.1	50.1	134–167
West Fork SJR	396.7	197.2	199.5	966
Lake Creek	16.5	4.5	12.0	303–422
Peach Creek	163.5	32.9	130.6	718–812
Caney Creek	140.9	43.4	97.5	478–533
Luce Bayou	20.0	19.2	0.8	–
Tarkington Bayou	75.1	75.0	0.1	–
Jackson Bayou	3.9	3.9	0.0	–
Gum Gully	6.3	6.3	0.0	–
Total	**1,979.2**	**1,247.9**	**731.3**	**2,913–3,288**

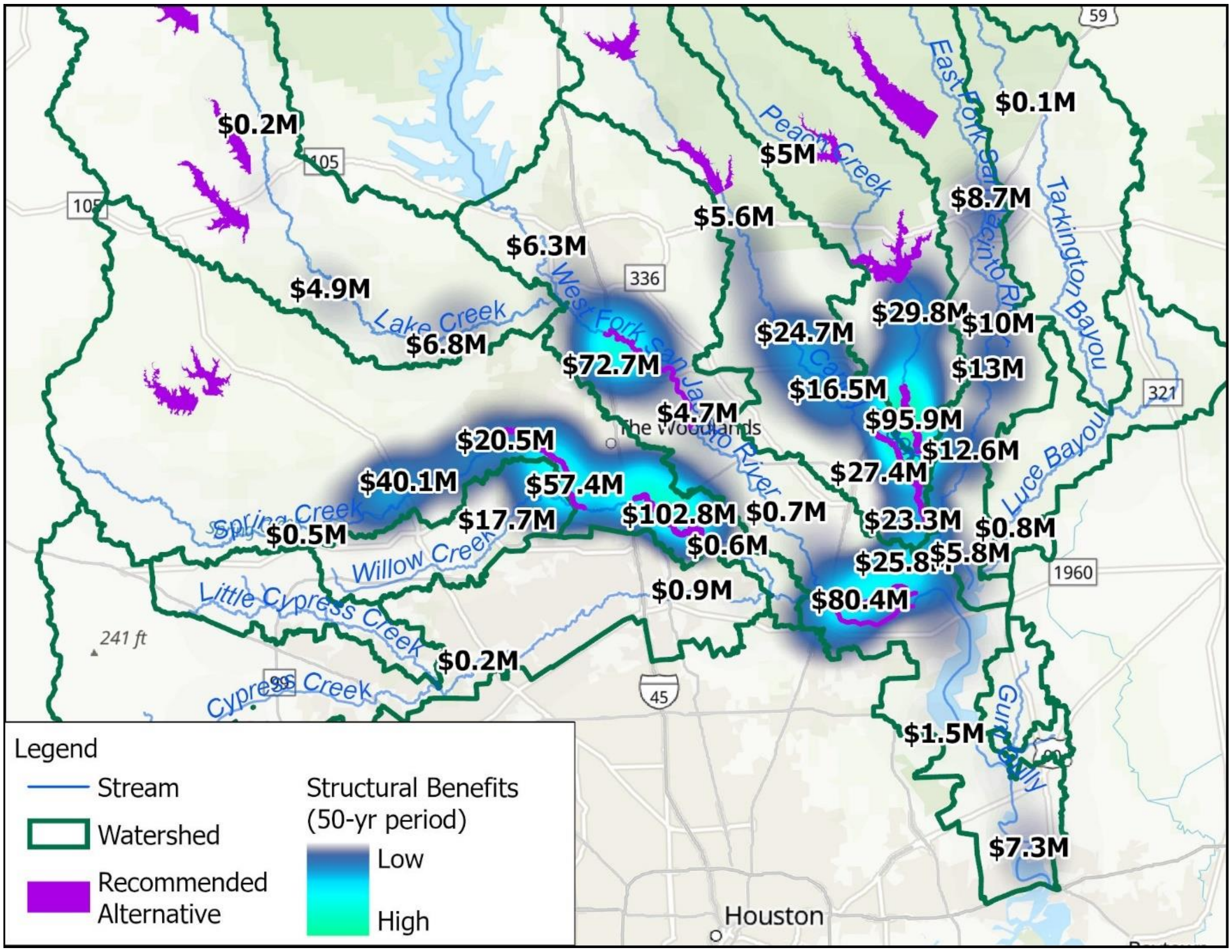


Figure 22: Combined Alternative Benefits (50-Year Period)

8.7.1 Upper San Jacinto River Benefits

The recommended alternatives provide sizeable detention basins in 5 separate watersheds aimed at lowering flows downstream. These are prevalent in the upper portions of the watersheds where higher relative benefits may be achieved with lower storage volumes. In addition, there are also channel improvement areas in most of the watersheds that address specific damage areas. Based on the combined recommended alternatives modeling, there are significant expected WSEL reductions at various points throughout the San Jacinto Basin. Along the West Fork, WSEL reductions range from 1.7’ at SH-99 to 6’ and 5’ at IH-45 and I-69, respectively as shown in the table below. These are significant reductions that will reduce flood risk to a high percentage of structures. Along the East Fork, reductions range from nearly 10’ at the Peach/Caney confluence to nearly 3’ at the East Fork/Caney confluence. However, as previously discussed, the reductions within the Lake Houston zone of influence are somewhat limited since the improvements do not appreciably change the elevations in Lake Houston.

Table 19: Water Surface Elevation Reductions for Recommended Alternatives

Location	1% ACE WSEL Reductions (ft) – Combined Recommendations
Caney Creek at Peach Creek Confluence	9.7
East Fork at Caney Creek Confluence	2.8
West Fork at Lake Creek Confluence	2.4
West Fork at I-45	5.9
West Fork at SH-99	1.7
West Fork at Spring Creek Confluence	4.8
West Fork at I-69	5.1
West Fork at Lake Houston Pkwy*	0.8
West Fork at East Fork Confluence*	0.8
Lake Houston Dam*	0.6

*WSEL at these locations is primarily influenced by Lake Houston Dam

The recommended alternatives provide significant benefits to the remainder of the watershed upstream of Lake Houston, including a 40% reduction in the number of flooded structures over a 50-year period throughout the entire watershed. More specific information includes:

- A 42% reduction in structures at risk of flooding during the 4% ACE storm
- A 41% reduction in structures at risk of flooding during the 2% ACE storm
- A 44% reduction in structures at risk of flooding during the 1% ACE storm
- A 33% reduction in structures at risk of flooding during the 0.2% ACE storm

The data provided above shows a high degree of improved protection up to the 1% ACE storm. The reduction in flood risk during the 0.2% ACE storm is less than the reduction during other storms. For context, the Atlas 14 0.2% ACE storm exceeds Hurricane Harvey levels by a noticeable margin. Given that, decision makers and the public should consider if that level of protection is reasonable.

8.7.2 Lake Houston Flood Reduction

As mentioned in Section 8.2.2, the dam at Lake Houston influences water surface elevations throughout the lake and water surface elevations on the downstream ends of the West Fork, East Fork, and Luce Bayou. Significant storage is needed in the upper basin to achieve target WSEL reductions in Lake Houston that would achieve flood reduction benefits in Kingwood (along the West Fork downstream of W. Lake Houston Pkwy and the East Fork downstream of the Caney Creek confluence). At a conceptual level, these storage volumes would exceed 500,000 acre-feet and would be needed just upstream of the lake, which is not currently feasible to do existing development.

This study does not include the evaluation of specific strategies aimed at significantly lowering Lake Houston flood levels. As such, the modeling does not include any scenarios that analyze gate configuration, spillway options, or lowering of the normal pool elevation. Those strategies may be considered as part of separate study efforts.

Buyouts of flood prone properties are another option for reducing flood risk in the Lake Houston area. This is discussed at a conceptual level in **Section 8.8.2**. This study did not complete a detailed investigation of this option or the implications of those buyouts to overall project benefits.

The projects as proposed in the report for the areas upstream of Lake Houston provide flood reduction benefits in the lower reaches of the West Fork and the East Fork. However, the projects do not completely reduce flood risk at Lake Houston due to the backwater effects of the dam. Modifications to the control structure may be necessary to reduce flood risk associated with Lake Houston. At the time of this report, the City of Houston and Coastal Water Authority were engaged in the *Lake Houston Spillway Improvement Project* to evaluate improvements to the Lake Houston dam spillway.

8.8 Additional Measures

While the Primary Mitigation task primarily focuses on structural flood reduction projects, drainage policy has a significant role to play in mitigating current flood damages and avoiding future damages as the San Jacinto River Basin continues to develop. These policy considerations were not evaluated using detailed analysis and the recommendations are general in nature. Currently, it is up to individual jurisdictions to determine which policies should be applied to development and capital improvements, such that they avoid increasing flood risk in their jurisdictions as well as in neighboring jurisdictions. However, a regional approach to policy would ensure common criteria and regulations are applied throughout the watershed. The modeling prepared as part of this study could be leveraged to perform more in-depth investigations of the implications of policy changes.

8.8.1 Floodplain Preservation

The hydrologic and unsteady hydraulic modeling prepared for the San Jacinto study was based on the most current rainfall and topographic information and accounts for conveyance as well as floodplain storage. As development occurs in the basin, there is the potential for fill in the floodplain to result in a loss of floodplain storage. This storage loss could have an impact on discharge rates and flood elevations. Small, seemingly negligible increases in developed area could result in significant changes to storage throughout the watershed as those increases accumulate.

The San Jacinto study did not evaluate fill scenarios and their resultant impacts because there are an infinite number of potential fill placement combinations. However, the study team has extensive experience with hydraulic modeling and are well versed on the impacts of floodplain storage loss on downstream hydrology. Many jurisdictions within the San Jacinto basin, including HCFCD, Harris County, and the City of Houston, have floodplain fill mitigation and No Adverse Impact policies in place. These policies help ensure that fill placement in the floodplain is not detrimental to other properties within the watershed.

The most effective way to avoid riverine flood damages is to avoid developing in floodplains. As such, implementing a policy of floodplain preservation would protect people and property by 1) avoiding development within the floodplain that increases the public's chance of flood risk and 2) preventing adverse impacts downstream caused by changes to floodplain storage. In addition, avoiding the streams and wetland areas often located in floodplains would protect valuable aquatic resources, improve biodiversity in the region, provide buffer for extreme climate patterns that the region has experienced and is likely to experience in the future, and contribute to the region's overall resiliency.

It cannot be overlooked that most of the property in these floodplains is privately owned and preventing the property owners from developing could result in legal challenges. As such, a floodplain preservation policy through acquisition is recommended where feasible. The Bayou Land Conservancy is another possibly option for landowners interested in granting conservation easements along bayous or streams. As a reference, the market value of the property located within the 1% AEP floodplain as defined in this study is approximately $3 billion based on county appraisal district data obtained from Harris County, Montgomery County, and TNRIS for areas outside Harris and Montgomery counties.

The study team recognizes that a floodplain preservation policy may be infeasible due to property acquisition costs or in areas that are already developed and have a limited amount of area to preserve. At a minimum, floodplain storage should be protected through policies such as the one that HCFCD has for floodplain fill mitigation. Current HCFCD and City of Houston criteria requires that all fill placed below the 0.2% ACE FEMA effective flood elevation be mitigated at a 1:1 ratio. In addition, fill placement should be modeled to ensure that there are no WSEL rises or increases in discharge rates as far downstream as possible. The San Jacinto study H&H models can evaluate changes all the way to IH-10, but smaller tributary models may only be able to be traced to their confluence with the receiving stream.

8.8.2 Buyouts

The flood mitigation projects proposed in this memo are targeted toward reducing the number of structures at risk of flooding under large, infrequent storms. For structures at risk of flooding under smaller, more frequent storms such as the 50% ACE and 20% ACE events, mitigating flood risk with detention or channelization projects is very costly. For these frequently flooded structures, acquiring the property and removing it from the floodplain and from potential flood risk is often the most cost-effective approach. The scope of this project does not include identification of specific buyout projects. A summary of potential buyout candidates in each watershed is provided in **Appendix G**.

The tables below provide a count of structures flood during the 20% ACE event under existing conditions in each watershed and county. The benefit of acquiring a property and removing it from the floodplain is equal to the sum of the net present value of expected flooding damages over a 50-year period per FEMA standards. For this study, the presumed cost of acquiring and removing a structure is 2.5 times the property's market value.

Table 20. Buyout Candidates by Stream—Structures Flooding in 20% ACE Storm

Watershed	Structure Count	Existing Damages (NPV, 50-yr Period) ($M)	2019 Market Value ($M)	Buyout Cost (2.5× Mkt. Value) ($M)	Benefit -Cost Ratio	Reduced Tax Revenue (NPV, 50-yr Period)
Spring Creek	50	46.7	4.4	11.0	4.3	1.2
Willow Creek	60	29.9	9.6	24.5	1.2	2.7
Cypress Creek	62	69.9	16.8	42.1	1.7	4.6
Little Cypress Creek	41	31.0	6.1	15.4	2.0	1.7
East Fork SJR	61	36.5	5.5	13.8	2.6	1.5
West Fork SJR	54	40.3	6.4	16.0	2.5	1.8
Lake Creek	8	4.7	1.0	2.5	1.9	0.3
Peach Creek	108	59.5	8.7	21.7	2.7	2.4
Caney Creek	76	41.8	4.4	11.1	3.8	1.2
Luce Bayou	11	4.8	1.1	2.7	1.8	0.3
Tarkington Bayou	88	57.1	7.3	18.9	3.0	2.0
Jackson Bayou	1	1.5	0.2	0.5	2.9	0.1
Gum Gully	2	1.6	1.0	2.4	0.6	0.3
Totals	**622**	**$425.2**	**$73.1**	**$182.8**	**2.3**	**$20.2**

Table 21. Buyout Candidates by County—Structures Flooding in 20% ACE Storm

County	Structure Count	Existing Damages (NPV, 50-yr Period) ($M)	2019 Market Value ($M)	Buyout Cost (2.5× Mkt. Value) ($M)	Benefit-Cost Ratio	Reduced Tax Revenue (NPV, 50-yr Period)
Harris County	274	211.1	45.7	114.3	1.8	12.6
Liberty County	77	48.5	7.9	19.7	2.5	2.2
Montgomery County	208	124.5	15.1	37.8	3.3	4.2
San Jacinto County	63	41.1	4.4	11.0	3.7	1.2
Totals	**622**	**$425.2**	**$73.1**	**$182.8**	**2.3**	**$20.2**

8.8.3 Detention Policy

This detention policy discussion should distinguish the local impacts of detention from the regional impacts. This study focuses on developing a long-term strategy for flood mitigation on a regional/basin level. The "regional detention basins" evaluated and recommended as part of the alternatives analysis are intended to address existing flooding and the associated damages, whereas detention policy is focused on mitigating local increases due to development. Detention has been demonstrated to be a valuable tool in the flood mitigation toolbox, both at a local and regional level.

As discussed in the future conditions section of this report and the attached future conditions **Appendix E**, the future conditions (2070) modeling indicated that total runoff volume is expected to increase by 1–2% compared to existing conditions and that local detention would maintain existing conditions flow rates at a regional level. If development occurs differently than current population projections indicate, the impact could be more pronounced. Development occurring along tributaries may generally pose a more immediate impact downstream of the development than would be evident on a main stem or at a regional scale; for this reason, local jurisdictions should conduct watershed studies and coordinate regulatory criteria throughout the watershed. The limited regional impact of detention policy does not diminish its substantial positive local impact. Allowing local development to go undetained could potentially exacerbate existing flood problems or create new ones. As the study area continues to develop, counties and municipalities should protect downstream properties by enforcing detention policies that limit post-development runoff rates to pre-development runoff rates.

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

- Local policies that require detention for new development and for capital improvements projects that increase conveyance.
- Requiring drainage analyses for development and capital improvement projects that demonstrate no adverse impact both at the outfall location and throughout the entire Upper San Jacinto River watershed.
- Requiring analyses be performed for multiple storm events ranging from frequent (e.g. 50% ACE) to infrequent (1% ACE or higher) 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.

9.0 Secondary Flood Mitigation Planning

One of the primary goals of the SJMDP was to enhance public information and flood level assessment capabilities during a flood disaster event. The study team assessed the current Harris County Flood Warning System (HCFWS) with the intent of bolstering the existing flood warning capabilities outside of Harris County. The current system has approximately 184 gages, some of which are in Waller, Montgomery, and Liberty Counties.

There are several gages in Montgomery County that are managed by HCFCD, the Woodlands, and the SJRA; however, several of those are rainfall only. There are only a handful of gages in the surrounding counties, mostly around Lake Conroe and in areas in Waller and Liberty Counties that are close to Harris County. The gage concentration in the San Jacinto Basin is approximately 1 gage per 50 square miles, with the concentration much lower outside of Harris County as that density number includes Spring, Willow, Cypress and Little Cypress Creeks which are in Harris County. The average for Harris County is closer to 1 gage per 10 square miles.

For more information, a copy of the Secondary Mitigation Planning memorandum and exhibits is included in **Appendix I**.

9.1 Data Collection

The project team collected existing and proposed gage data from several of the agencies responsible for flood management, flood warning, and emergency operations. Recommendations for additional gages were solicited from the San Jacinto River Authority (SJRA), Woodlands Water Agency (WWA), Harris County Flood Control District (HCFCD), United States Geological Survey (USGS), and Montgomery County (MOCO). A total of 28 additional gages were proposed by the various agencies:

- 21 rain-stage gages (Harris (2), Montgomery (13), Liberty (3), San Jacinto (2), Grimes (1))
- 3 stage gages (USGS)
- 4 stage-flow gages (USGS)

9.2 Recommended Gages

Based on these interviews and internal review, the study team originally recommended 29 additional gages to enhance the Flood Warning System for the SJRWMDP. Further refinement resulted in a recommendation of 26 gages of various types, five (5) which have recently or are currently being installed.

- 19 rain-stage gages
- 3 stage gages
- 3 stage-flow gages
- 1 rain-stage-flow gage (Winter's bayou at SH150)

Figure 23 below provides an overview of the existing and proposed gage locations. More detailed information is provided at the HCFWS website: https://www.harriscountyfws.org/

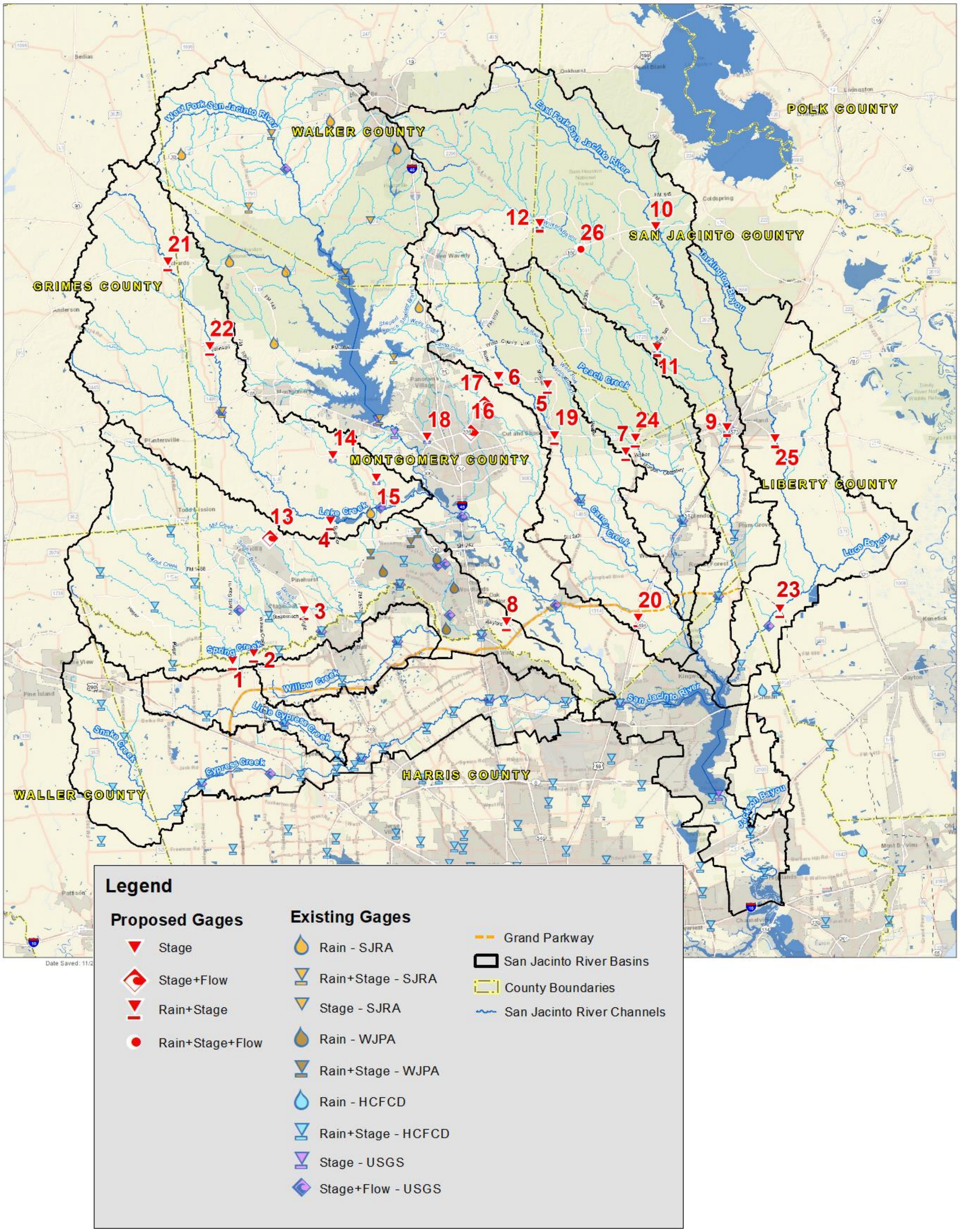


Figure 23: Proposed Flood Warning System Gages

9.2.1 Gage Types

The recommendations include several gage types, some of which may be used together:

- **Rainfall Gages** – The Lake Creek, Luce Bayou, East Fork, Peach Creek, and Caney Creek subbasins have sparse rainfall gage coverage. These subbasins are at the upstream end of the watershed and contribute significant flow to the SJR basin. Additional rainfall gages in the upstream end of these subbasins will provide early indications of rainfall.
- **Stage Gages** – Stage gages are also recommended alongside rainfall gages to ensure adequate water surface elevation information could be obtained for both flood warning and model calibration purposes. Stage gages are recommended along areas where the roads frequently overtopped, majority of which occurred in Montgomery County.
- **Flow Gages** – Flow gages along the mainstems and tributaries are used to predict peak discharges and flow hydrographs. Each gage has a rating curve for predicting discharges based on stage information. The rating curve is developed and updated using measurements (direct and indirect) taken by the USGS. This information can enhance early warning and future model calibration. Gages are recommended on major tributaries to Spring Creek, West Fork, and the East Fork based on input from the USGS. Location and access for field measurements were considered for placement of the proposed gages.

9.2.2 HCFCD Gage Installation

As of July 2020, the gages at East Fork @ SH105 and Tarkington Bayou @ SH105 were active and two others were proposed, including two along Winters Bayou (@ Tony Tap Rd. and @ FM2963).

9.3 Gage Costs

Installation and maintenance of the recommended gages will require funding from a sponsor agency. Installation costs range from $7,000 - $12,000 depending on the parts used in the gage. Additional maintenance is required to ensure the gage is functioning property and to replace parts as needed.

The SJRA is also currently partnering with San Jacinto County to seek grant funding for installation of gages, and could potentially partner with other entities in the future. SJRA can provide gage installation and other in-kind services, but does not have a dedicated funding source for these efforts. Estimated cost for rain and stage gage installation at one site is $10,000, with a yearly maintenance cost of up to $500 if no major repairs or maintenance are required. SJRA would seek grant funds and/or agreements with entities to fund installation and maintenance. Data from any installed gages could potentially be displayed on SJRA's Contrail system, though further coordination with SJRA will be necessary to determine the feasibility and requirements of doing so.

Flow gages owned by the USGS require regular maintenance for updating the stage-flow rating curves. Installation for the gages is approximately $30,000 and yearly maintenance is approximately $15,900 for the full flow and stage gages. The USGS will partner with state, local, non-profit, and private entities for installing and maintaining the gages.

Table 22 summarizes the cost of the proposed gages by watershed, excluding the gages being installed by the HCFCD. Costs will vary depending on agency and gage type and do not include the yearly maintenance and repair required.

Table 22: Approximate Gate Installation Cost

Watershed	Approximate Cost Range
Spring Creek	$58,000 - $78,000
Lake Creek	$35,000 - $60,000
Caney Creek	$35,000- $60,000
West Fork San Jacinto	$67,000 - $72,000
East Fork San Jacinto	$30,000
Peach Creek	$7,000 - $12,000
Luce Bayou	$7,000 - $12,000
Gage Subtotal	**$239,000 - $324,000**
Additional Repeater	$100,000 - $150,000
Improvement Total	**$339,000 – $474,000**

The costs shown only include the gage installation. Maintenance costs will vary depending on the type of gage with rain gage and stage gage maintenance significantly less than the flow gages. In addition, there may be improvements to the data transmission infrastructure needed in order to effectively relay the data via radio frequency.

The HCFWS gages currently transmit data to four primary repeaters, which are in Huffman, Clodine, League City, and Tomball. Given that the location of the proposed gages extends north of Harris County, an additional repeater may be needed to provide adequate coverage for data transmission. The addition of a repeater in the northern San Jacinto watershed could cost between $100,000 and $150,000. Specific locations and numbers of repeaters will need to be determined by HCFCD based on their system needs.

The total estimated cost range of these improvements is between $240,000 and nearly $500,000.

10.0 Other Flood Hazard Mitigation Actions

The focus of the Other Flood Hazard Mitigation Actions task was to evaluate and recommend improvements for flood response in the basin. This included review of emergency management protocols, critical infrastructure, and flooding of roadways throughout the San Jacinto River basin. **Appendix J** includes a summary of communications plans and protocols that are utilized by the various agencies and potential improvements to those protocols, as well as the relative flood risk of critical infrastructure and roadway crossings, specifically defined evacuation routes.

10.1 Other Mitigation Actions Goals

There are several goals that were established for the Other Mitigation Actions task, each of which is addressed in **Appendix J**.

- Coordinate with responsible emergency management personnel
- Review communications plans/protocols and recommend potential improvements
- Locate critical infrastructure and compare to inundation
- Identify evacuation routes and related flood frequency

10.2 Flood Response and Communication

The study team coordinated with several agencies that are responsible or are involved in emergency management. This includes representatives of each of the seven counties that are located, in whole or in part, within the San Jacinto River basin. In addition, the team conducted discussions with the San Jacinto River Authority (SJRA), the Houston-Galveston Area Council (H-GAC), and the cities of Houston and Conroe.

Meetings were conducted with agency leadership and/or personnel familiar with the emergency management practices of that jurisdiction. Each meeting included discussion on a variety of topics, including a general overview of the study, a discussion of each jurisdiction’s communication practices, their knowledge about critical infrastructure in their jurisdiction, known flooding areas and roads, and recommendations for improvements.

In addition, an Emergency Management Workshop was conducted on March 11, 2020, which included participants from several of the agencies listed. The workshop discussed the preliminary findings of the interviews as well as potential gaps in information and some preliminary recommendations for improvement to the communications practices. The notes from each of these meetings and the workshop are included in Appendix J.1.

10.2.1 Communications Summary

The communications discussion included both internal and external communications, which include both the public and neighboring jurisdictions. In general, the various jurisdictions indicated that communication during a disaster was effective. All the various jurisdictions emphasized the positive relationships with EMS, law enforcement, elected representatives, local school districts, and public works personnel, which resulted in good communication internally. They also touched on positive relationships with their neighboring county officials as well as agencies like TXDOT. During storm events, the local officials frequently used phone calls, text messages and emails to keep each other apprised of situations and to share resources. Each of the counties and agencies surveyed use a variety of methods to share information with the public, including social media (Facebook, Twitter, Nextdoor, etc.), agency websites, local media partners, and systems like CodeRed or Nixle to push information to area residents.

10.3 Flood Monitoring and Assessment

There are a variety of ways in which the various jurisdictions monitor flood conditions during a disaster or major rainfall event. These range from electronic monitoring, to staff reconnaissance, to public reporting of flood conditions. The interviews with the counties/agencies included a discussion of the flood monitoring approaches across the basin. Some of the methods include:

- **Remote Monitoring** – Several of the counties and agencies use the Harris County Flood Warning System to quickly view rainfall depth and channel stage information. As discussed in Section 9.2 and **Appendix I**, additional gages are being considered that would bolster the current system, providing more information for the outlying counties.
- **Physical Monitoring by Jurisdiction** – Each of the counties employ in-person monitoring by law enforcement, County Commissioner's and their staff, public works employees, or local school bus drivers. TxDOT can also play an active role in monitoring road crossings.
- **Public Reports** – The public also plays an important part in flood monitoring, including sending emails, texts, calls, and social media posts out and including the responsible emergency management personnel.

The counties and agencies all identified areas potential improvements to existing flood monitoring and assessment protocol. Some of the recommended include:

- In some of the more rural areas, there may be coverage gaps due to limited telecommunications infrastructure
- There was interest in improving internal alerts, specifically alerts about flooding and infrastructure failures.
- Improve linkages from websites and social media accounts across jurisdictions. For example, linking the County sites to law enforcement, Commissioners, NWS, USGS, TxDOT and other sites can provide valuable information to the public without requiring them to search multiple sites or platforms.
- Improve participation in emergency notification systems like Nixle or CodeRed
- Maintain existing and continue to build relationships with local media outlets

10.4 Information Gaps

Based on the interviews, there were a variety of areas where information may be limited or improvement is needed. These gaps include documentation and staffing, floodplain mapping, and the availability of real-time information via gages.

10.4.1 Staff and Documentation

Several of the jurisdictions interviewed have limited staff and resources as it relates to emergency management capabilities. In some instances, one person may be in charge of emergency management with no staff redundancy. This may overextend the individual in an emergency or create a situation where, if that person is absent, there may not be another experienced person available. Written procedures are available in most of the jurisdictions; however, there may not be a consistent effort to update or to review the procedures. Our interviews also revealed that although periodic review of these plans is conducted, regular exercises are not as common due to the difficulty of pulling the various departments together. A lack of practice and familiarity with the planning documents could potentially lead to additional effort or even errors during a disaster.

10.4.2 Floodplain Mapping

One of the concerns expressed by many of the counties interviewed was the lack of coverage and quality of FEMA floodplain mapping information. Floodplain mapping and models are a valuable source of information for emergency responders and accurate and up-to-date information is crucial. The floodplain mapping for most of the counties in the San Jacinto River basin varies by jurisdiction.

Harris County has detailed modeling for all its major bayous and numerous tributaries and sub-tributaries that provide extensive floodplain coverage. Montgomery, Liberty, and Waller Counties have Zone AE with floodway on their major streams; however, due to the age of the modeling, the accuracy may be unclear. Walker, San Jacinto, and Grimes Counties have Zone A (approximate mapping), which indicates that there is no detailed modeling along the streams. Based on our interviews, there was a general concern regarding the existing FEMA mapping and information used to generate the maps. Each of the floodplain administrators were interested in the potential to use the models developed as part of this study for FEMA mapping updates or best available information. Potential options for improved floodplain mapping, specifically outside of Harris County include:

- **Base Level Engineering** – Much of the upper San Jacinto River basin has been recently studied using FEMA Base Level Engineering (BLE) methods. BLE is an automated process to develop riverine hydrology and hydraulic models based on the most recent topographic information. While the level of detail is limited, BLE modeling provides a reasonable approximation of flood elevations and inundation, especially for areas mapped as Zone A or without mapping.
- **San Jacinto Regional WMDP Models** – The modeling developed for the San Jacinto WDMP included 535 miles of detailed hydrologic and hydraulic models for the major rivers and creeks, which uses the most recent LiDAR terrain information and use Atlas 14 rainfall. These models could be made available to each of the jurisdictions to use as best available data or leveraged as a basis for updated mapping.
- **New FEMA Models** – Each of the jurisdictions could conduct studies to develop new FEMA models and mapping for their jurisdictions. Development and approval of the models through FEMA could take several years but constitute an official regulatory map. Harris County is currently in the process of updating the modeling and mapping for all their watersheds through the Mapping, Assessment, and Awareness (MAAPnext) program.

10.4.3 Gage Coverage

There is also a lack of available real-time information in the outlying counties related to rainfall and flooding. The HCFWS includes an extensive network of gages, some of which are in Waller, Montgomery, and Liberty Counties. There are only a handful of gages in the surrounding counties, mostly around Lake Conroe and in areas in Waller and Liberty Counties that are close to Harris County. As discussed in Section 9, approximately 26 additional gages were recommended to augment the existing system. Addressing these gaps in available data could improve the ability of emergency managers to more quickly gather information and respond effectively during a disaster.

10.5 Other Mitigation Actions Recommendation Summary

Overall, the recommendations in this section cover documentation and staffing, communication, flood monitoring and protection, and public education. A summary of the recommendations is provided below.

Documentation and Staffing

- Develop a flood emergency response plan and follow it as much as possible
- Keep contact information up to date
- Perform regular review of the plan and conduct practices exercises and drills
- Implement staffing redundancy for emergency management personnel

Communication

- Work with local service providers to improve radio and cellular coverage
- Link social media accounts so users can see information from a variety of sources
- Add flood stage gages to critical roadways
- Improve internal alerts for infrastructure flooding or failure

Flood Monitoring and Protection

- Identify areas that require monitoring and install gages at those locations
- Work with other agencies to integrate gages into a larger, regional system
- Leverage flood monitoring to provide timely alerts to the public
- Identify all crossings where flood barriers would be appropriate and prioritize the crossings
- Install barriers at frequently flooded crossings

Public Education

- Develop a public education strategy that includes social media, radio, TV, and face-to-face discussion utilizing existing info distribution infrastructure from local schools, libraries and community centers
- Leverage pre-developed resources from agencies like TWDB
- Work with local school districts to provide children with emergency preparedness and disaster readiness information

10.6 Critical Infrastructure

The study team identified critical infrastructure throughout the San Jacinto River basin that may be susceptible to flooding based on the updated modeling and inundation using Atlas 14 rainfall. A database of critical infrastructure was developed throughout the basin to identify the structures that may be susceptible to flooding from the model streams. The database included approximately 1,460 facilities, nearly 240 of which may be at risk of flooding.

Infrastructure categories such as essential government buildings, major healthcare providers, emergency management and response, schools, utility plants, and potential shelters during a storm event were identified and compared to the inundation mapping developed. The database was developed using a mixture of data provided by HCFCD and open source GIS libraries. Following the aggregation of available data, a visual scan was conducted using aerial imagery for quality assurance. **Table 23** summarizes the number of potentially inundated critical structures for each frequency event as well as a total number of facilities.

Table 23: Potentially Inundated Critical Facilities

		Frequency Event							
		50%	20%	10%	4%	2%	1%	0.2%	**Total**
Watershed Critical Infrastructure	Caney Creek	0	0	0	0	0	2	5	**7**
	Cypress Creek	0	0	3	7	11	16	31	**68**
	East Fork San Jacinto	0	1	1	1	4	5	5	**17**
	Jackson Bayou	0	1	1	1	1	1	2	**7**
	Lake Creek	0	0	0	0	0	0	0	**0**
	Little Cypress Creek	0	0	2	5	5	6	6	**24**
	Luce Bayou	0	0	0	0	0	0	0	**0**
	Peach Creek	0	0	0	0	0	2	6	**8**
	Spring Creek	0	0	1	5	7	11	22	**46**
	West Fork San Jacinto	0	0	0	2	2	11	41	**56**
	Willow Creek	0	0	0	1	1	1	3	**6**
	Total	**0**	**2**	**8**	**22**	**31**	**55**	**121**	**239**

10.7 Major Crossing Flood Frequency

Nearly 200 roadway and railway crossings were evaluated along the major streams to determine the potential for flooding. Roadway crossing include bridges, culverts, and low water crossing. Flooded roadways and railways exacerbate risk in the region, causing damage, limiting emergency access during the event, limiting evacuation routes for the public and even causing loss of life. The level of service of each modeled crossing was determined for the roadway crossings at major streams within the San Jacinto River basin. **Table 24** provides a summary.

Table 24: Crossing Levels of Service

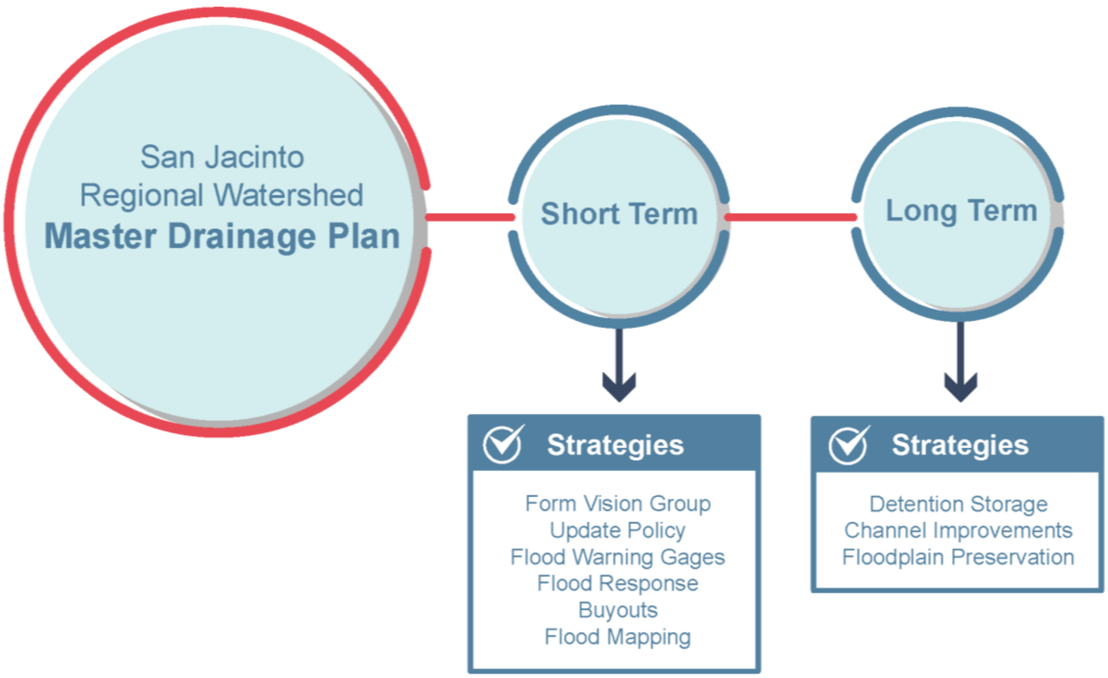
	Level of Service Based on Road Classification								
	< 2-YR	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	500-YR	**Total**
Railroad	0	1	0	2	3	5	5	6	**22**
Interstate	0	0	0	0	2	1	3	1	**7**
State Highway	1	1	0	1	0	4	8	14	**29**
Farm-Market	1	1	2	2	2	6	5	4	**23**
County/City Road	9	11	4	11	8	7	18	29	**97**
Private Road	8	4	1	1	1	2	2	2	**21**
Total	**19**	**18**	**7**	**17**	**16**	**25**	**41**	**56**	**199**
Percent Total	**10%**	**9%**	**4%**	**9%**	**8%**	**13%**	**21%**	**28%**	**100%**

The H-GAC evacuation routes for the Upper San Jacinto River Basin include US 290, IH-45 and IH-69. These routes cross the major streams a total of eight times and are susceptible to flooding in some locations. Four evacuation route crossings are inundated by events lower than the 1% ACE event, which could prevent critical evacuation during a major storm event. The locations include Cypress Creek at IH-45, West Fork San Jacinto at IH-69, Peach Creek at IH-69, and East Fork San Jacinto at IH-69. Raising these roadway profiles to above the 1% or even the 0.2% ACE water surface elevations would provide reliable evacuation routes during storm events. More detailed information about the evacuation routes and their potential flood risk is included in **Appendix J**.

11.0 Implementation

A clear path to project implementation is needed to move the master drainage plan forward through the next several decades as policy and projects are developed and constructed. Planning and construction of the recommended projects is necessary to realize the flood risk reductions needed to protect people and property within the San Jacinto River basin.

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 long-term and short-term solutions. Short-term solutions are those that can be implemented within the next five years and require less funding or have fewer constraints for implementation. Long-term solutions will take more than five years to begin implementation due to funding, construction time, and project constraints.



11.1 Short Term Project Implementation

Short term projects identified in the master plan and can be completed in a 5-year timeframe. These projects include:

- Developing a San Jacinto River Vision Group to foster collaboration among all entities within the watershed with the goal of establishing common drainage criteria, updating floodplain standards, and implementing projects. It is recommended the group be formed in the short term, but discussions through the implementation of the long-term strategies as group visions and goals will change. This group could be the newly created TWDB Regional Flood Planning Group;

- Updating drainage policy within the basin to have minimum detention requirements, standard methodology for developing discharge rates, common criteria for floodplain analysis, and minimum finished floor elevations based on Atlas 14 rainfall;
- Implementing the recommended flood warning enhancements such as the rainfall, flow and discharge gages;
- Continuing storm event flood response among the various emergency managers
- Developing a voluntary buyout program for the watershed for frequently flooded structures
- Re-mapping the main streams and tributaries within the basin based on Atlas 14 rainfall to improve flood risk communication with the public and future development, and;
- Developing watershed protection studies for the tributaries in each of the basins to establish watershed plans for reducing flood risk for the entire basin.

11.2 Long Term Project Prioritization

Recommendations for structural project prioritization include the development of project scoring which includes the identification of evaluation metrics and weighting the metrics for project scoring.

Nine metrics were identified to score and rank the long-term projects. The metrics included:

- **Watershed Historical Damages** – The number of historical damages for the given watershed based on information provided by Montgomery County and Harris County for the 2015, 2016, and 2017 storm events.
- **Watershed Predicted Damages** – The number of predicted instances of flooding over a 50-year period based on the frequency storm analysis and the structural inventory tool for the given basin.
- **Flooding Instance Reduction** – The benefit of the project based on the reduction of predicted instances of flooding over a 50-year period throughout the entire watershed.
- **Structures Removed from the 1% ACE Floodplain** – The second benefit of the project; the number of structures where the 1% ACE water surface elevation is reduced below the structure's finished floor elevation.
- **Benefit Cost Ratio (BCR)** – The benefit-cost ratio based on reduction in structural flood damages. Projects with structural BCRs over 1.0 can be funded by federal agencies such as the FEMA and the USACE. Projects with structural BCRs over 0.75 may also qualify for hundreds of millions of dollars in additional social benefits under FEMA grant requirements.
- **Roadway Benefits** – The total reduction of roadway overtopping depths in feed for each roadway and each frequency event in the basin. Each recommended project provides benefits to transportation crossings throughout the watershed by reducing the discharge and therefore depths of roadway ponding during the frequency events.
- **Social Vulnerability Index (SVI)** – The SVI is assigned by the CDC at the census-block level and measures the resilience of a community confronted by external stresses on human health, including

natural disasters. Each project's SVI score was assigned based on the average SVI of the benefitted structures from the project.

- **Low to Moderate Income (LMI)** – The percent of the population within the census block that qualifies as LMI as identified by the US Census Bureau. The LMI score was assigned based on the average LMI of the benefitted structures from the project.
- **Cost** – The total cost of the project can affect the ability to fund the project whether with local or federal funding.

Projects were scored based on the relation to the other projects for each category. A score was assigned for each metric ranging from 0 to 4 based on the score quartile relative to the other projects. The identified metrics were weighted based on initial discussions with the stakeholders who expressed that the overall goal of the identified projects is to reduce flood risk within the basin. The assigned metric weight was multiplied by the metric score to achieve the overall project score. The weighting assigned is based on an overall weight of 100%. In the project ranking process, the weighting was adjusted to understand the sensitivity of the overall project ranking to the chosen weights. In general, the overall rankings did not change even with drastic changes to the chosen weights.

Table 25: Metric Weighting Summary

Metric	Weight
Historical Damages	10%
Predicted Damages	10%
Instance Reduction	20%
Structures Removed	20%
BCR	10%
Roadway	5%
SVI	10%
LMI	10%
Cost	5%

11.2.1 Project Ranking

The metric score was multiplied by the metric weighting and summed to receive the overall project score. These projects were then ranked based on the overall score with the top score receiving the top ranking. The ranking shown in **Figure 24** and **Table 26** are based on the identified metric weighing. However, many of these projects can be completed individually – not according to the assigned order – based on funding availability and project sponsorship.

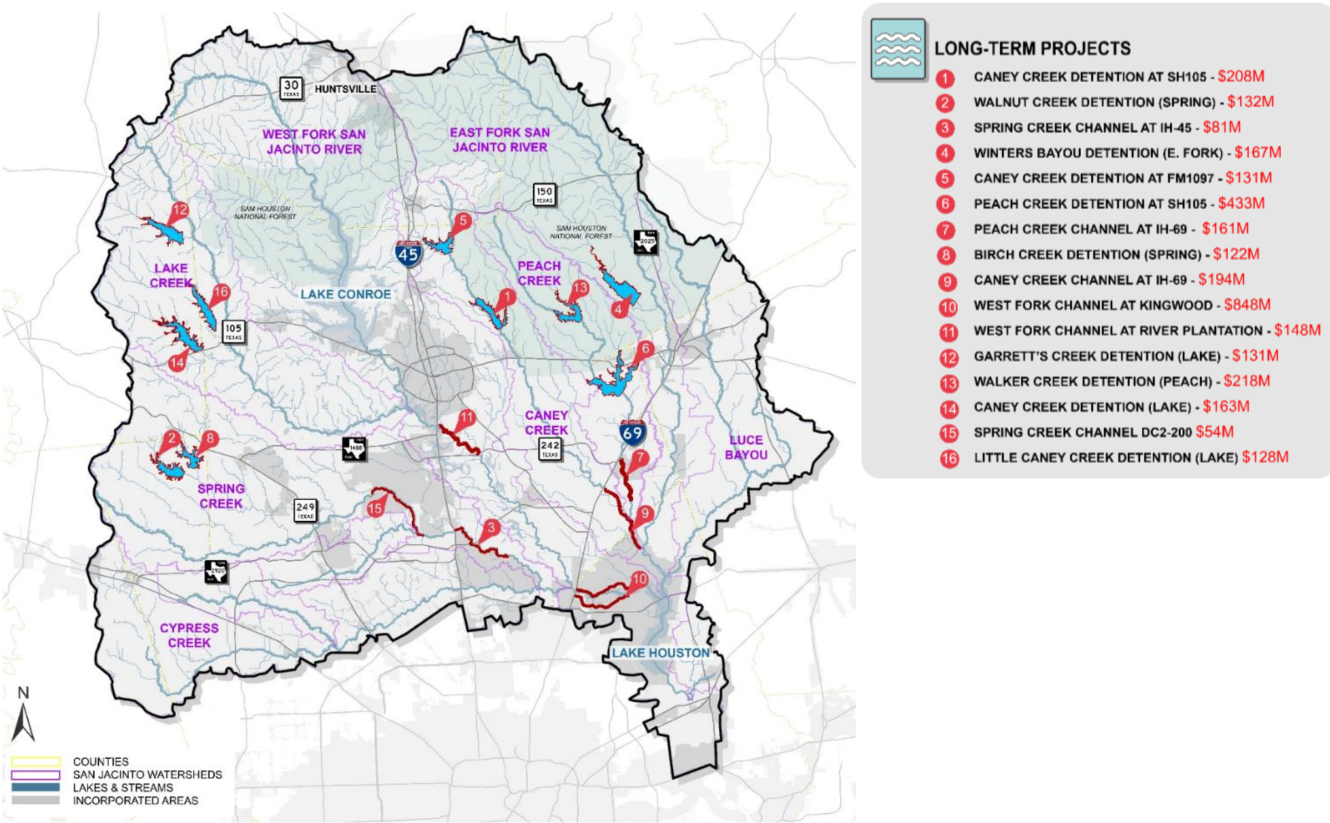


Figure 24. Proposed Long-Term Project Locations

Table 26. List of Proposed Long-Term Project Locations and Ranking

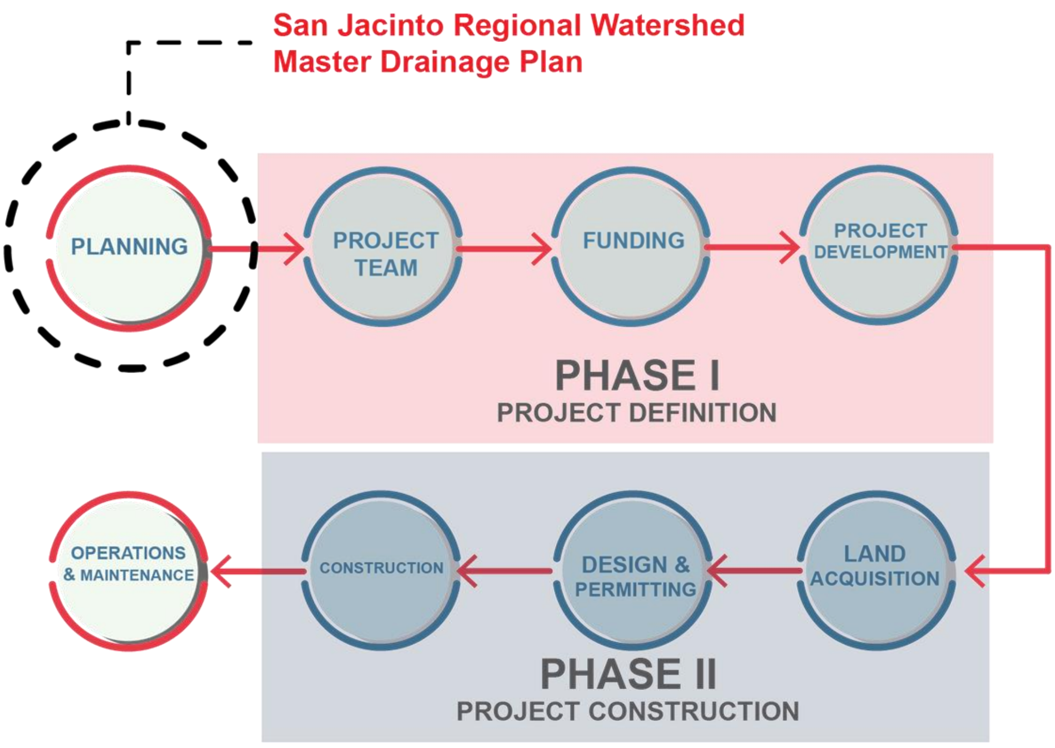
Rank	Project	Score	Cost Range ($M)
1	**Caney - Detention at SH 105**	2.80	114–149
2	**Spring - Walnut Creek Detention**	2.50	97–132
3	**Spring - I-45 Channel ***	2.50	85
4	**East Fork - Winters Bayou Detention**	2.40	134–167
5	**Peach - SH 105 Detention**	2.35	356–433
6	**Peach - I-69 Channel ***	2.35	159
7	**West Fork - Kingwood Benching**	2.05	837
8	**Caney - Detention at FM 1097**	2.00	105–131
9	**Spring - Birch Creek Detention**	1.85	80–120
10	**Caney - I-69 Channelization** *	1.80	189
11	**Peach - Walker Creek Detention**	1.75	201–218
12	**Lake - Garrett's Creek Detention**	1.43	107–131
13	**West Fork - River Plantation Channel** *	1.43	187
14	**Spring - Woodlands Channelization (200-ft)** *	0.90	56
15	**Lake - Caney Creek Detention**	0.85	98–163
16	**Lake - Little Caney Creek Detention**	0.50	98–128

** Each channel project requires upstream detention to be constructed first to prevent downstream impacts caused by increased conveyance. It is recommended to construct upstream detention as identified in the master drainage plan rather than have separate detention only for the channel conveyance. The volume provided by any upstream detention alternative is generally more than enough to offset for the increase in channel conveyance. However, if channel improvements are constructed without upstream detention, a separate detention facility will be required, which may drastically increase channel project costs.*

The rankings of four projects were manually adjusted based on the need for detention prior to channelization. The Peach I-69 Channel project was originally ranked at #2 based on its score of 2.55. However, before this channel can be constructed, either the Peach SH 105 Detention project (score of 2.15) or the Peach Walker Creek Detention project (score of 1.75) must be constructed upstream. Because the Peach SH 105 Detention is the higher-scoring detention alternative in the basin, its score of 2.15 was averaged with the Peach I-69 Channel score of 2.55 to produce an average score of 2.35. This average score was used to move the Peach SH 105 Detention up to rank #5, since it must be constructed first, and to move the Peach I-69 Channel project down to rank #6. The same procedure was used to adjust the ranking of West Fork River Plantation Channel, with an original score of 1.90 and original rank of #9, and the ranking of Lake Garrett's Creek Detention, with an original score of 0.95 and original rank of #13.The relative ranking of other projects was not adjusted because detention alternatives in the remaining basins already score higher than channel alternatives in those basins.

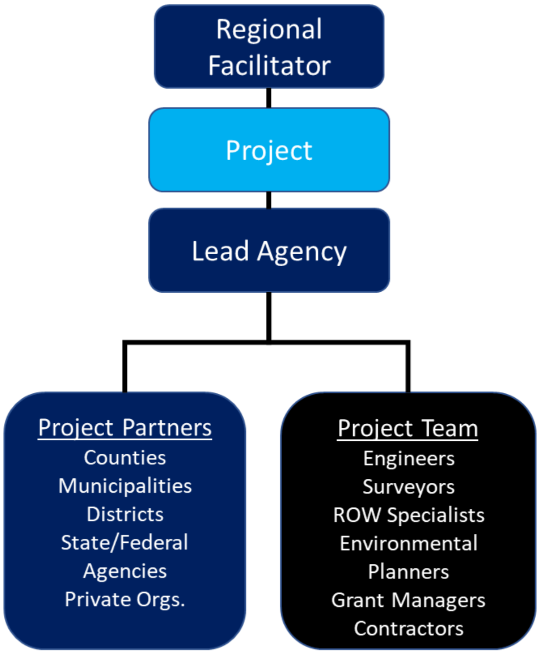
11.3 Long Term Project Implementation

The project ranking provides a potential project list and ranking for moving projects towards design. However, the projects do not necessarily have to be implemented in the recommended order, with the caveat that each channelization project must be preceded by one upstream detention project. Funding opportunities, community goals, and construction constraints may shift the implementation order. The completion of the master drainage plan completes the first step of the implementation process, Planning. The Planning effort has identified the projects needed to reduce flood risk and identified project types, locations, constraints, and costs. The plan provides a basis for seeking funding, performing feasibility studies, and establishing future study requirements. The remaining steps are Project Definition and Project Construction as outlined below::



11.3.1 Develop Project Team

The total project cost for the 16 identified projects can be daunting for communities. However, several communities will likely champion the efforts for each project. Implementation of the identified plan will require many roles and responsibilities for the project partners and key stakeholders. The first step of implementation is identifying the potential project team. This team will be dedicated to finding funding, conducting feasibility studies of the projects, developing design drawings, acquiring the necessary right-of-way, and constructing the projects. A sample project team organization chart is included below.



11.3.2 Identify Funding Sources

Once a project team is established, the group can seek funding opportunities for the project. Some of the watershed partners had already begun to jointly apply for funding to implement projects in Spring Creek, for example, SJRA and the Woodlands MUDs had submitted a TWDB FIF grant application for Walnut and Birch detention facilities. The watershed communities should approach federal agencies to begin feasibility studies and evaluate potential federal funding opportunities. The USACE solicits projects every year for potential study and petition for funding to Congress. Additional project development may demonstrate that other projects have BCR’s that would support FEMA funding.

The other projects do not have a direct potential funding sources identified. Grants, bonds, loans, or other funding mechanisms from state or federal sources may be required for implementation. Some of these are listed in Section 11.4 or **Appendix H**.

11.3.3 Project Development

Project development includes development of an advanced feasibility study or preliminary engineering report (PER), which will gather detailed survey, geotechnical, environmental, utility, and other information and prepare a detailed evaluation of an individual project. From this analysis, the options presented in the feasibility study will be refined and a conceptual design and cost will be prepared. In addition, specific right-of-way needs will be identified. Updates to the benefits and costs may result in more favorable BCRs for federal funding.

11.3.4 Land Acquisition

Land acquisition is required for both the detention and channelization projects. The needs vary widely depending on the development policy behind each of the proposed detention basins. The land identified as part of the detention alternative analysis ranged from the 1% ACE flood pool to the PMF flood pool. The Lead Agency should discuss the land required with the local, state, and federal regulatory agencies to determine which land should be purchased. The agencies should then begin to identify potential tracts within the proposed detention basin area for acquisition. Ownership and availability of the land may change between the project initiation and the actual acquisition. Development may also encroach on the identified areas making acquisition more difficult. The land available for the detention facilities may alter the proposed detention locations presented in this plan. The agencies should consider monitoring the potential sale of property in the vicinity of the proposed projects and consider acquiring it before it is developed.

Land acquisition also includes identifying the owner of the project. While the lead agency may be the main implementor of the project, the agency may not have the ability to purchase the land for the basin. In the case of the Walnut and Birch Creek reservoirs, HCFCD and Montgomery County are the primary beneficiaries of the project, but do not have jurisdiction in Waller County where the project is proposed to be located. Inter-local agreements or separate agencies may be required to purchase the land.

11.3.5 Design and Permitting

During the land acquisition process, the project team can begin designing and permitting the proposed project. Design will include developing the plan drawings for construction as well as operations and maintenance procedures. Permitting will include all utility and environmental permits needed for the construction. The proposed detention projects will require approval from the TCEQ and will require an emergency action plan.

The USACE may require an Environmental Impact Statement for each detention site identified. This process can take three to five years. Sites in the Sam Houston National Forest will likely also require a NEPA review process, which potentially requires an Environmental Impact Statement. Detention sites in the forest may also yield environmental benefits if coordinated with forest management goals.

11.3.6 Construction

Construction of both the dam and channelization projects may likely take several years. Construction will include mobilization of the project, constructing temporary access to the dam locations, and the actual construction of the dam or channel.

11.3.7 Operations and Maintenance

Once constructed, the projects will need to be maintained regularly. For both the detention basins and channel projects, regular mowing, monitoring of instrumentation, regular inspections, and repair will be needed throughout the project life. The constructed dams will require regular certification with the TCEQ. The owning entity of the project would be responsible for the upkeep.

11.4 Funding

The efforts and funding needed to reduce the regions vulnerability to flood hazards is ambitious. Identifying potential funding sources is important for project implementation success. The potential funding sources for each project depend upon the readiness to implement the project as well as the schedule needed to implement the project.

There are many different means to fund the alternatives as proposed in this plan. Funding sources may include HUD/GLO (CDBG-DR and CDBG-MIT), FEMA, NRCS, TWDB and others. Each program may have differing procurement, administrative, and environmental requirements, which may impact the overall cost and schedule of the projects.

There are a variety of potential funding sources; however, many of them are not applicable or may not be feasible due to the types of projects or constraints within the watershed. Given those constraints, the following are recommended:

- **FEMA Pre-Disaster Mitigation (PDM), Building Resilient Infrastructure and Communities (BRIC) and Hazard Mitigation Grant Program (HMGP)** – Grants for buyouts and flood warning systems should be explored.
- **Community Development Block Grant Disaster Relief or Mitigation (CDBG-DR & CDBG-MIT)** – These funding sources do have LMI threshold requirements. Further investigation is required to determine if the projects qualify.
- **Natural Resource Conservation Service Watershed and Flood Prevention Operations (NCRS-WFPO)**– Further investigate is required to determine if projects qualify; this should include face-to-face meeting with NRCS staff.
- **State funding sources including Flood Prevention (FP) and Flood Infrastructure Fund (FIF)** – Several abridged applications were submitted in June 2020 for projects by various agencies. Watershed protection studies could be partially funded by flood protection grants.
- **Local funding** – Local matches may be required by several of the grant sources. Communities and agencies should consider budgeting for drainage studies and projects. Bonds may be considered to implement the projects. Since there is a significant investment in private infrastructure that is at risk of flooding, private partnerships may be explored.

12.0 Community Outreach and Education

The SJMDP team is in the process of scheduling community engagement events in the study area. The purpose of the public open houses was to encourage public participation and input in the SJMDP and provide information about other study efforts in the San Jacinto River watershed. The first round of community engagement took place in December 2019 and the second round in August 2020. The summary of the public meeting is included in **Appendix K**.

Community input from the public meeting included:

- Concerns regarding study budget limiting the size of study area
- Concerns regarding localized flooding issues
- Concerns regarding drainage blockage under FM 2100
- Requests to include communities located in the I-10 & 610 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 sand mining and silting of rivers are making flooding worse
- Concerns that not enough is being done to protect businesses in the Kingwood Town Center area

Community outreach also included a website (https://sanjacstudy.org/) that provides an overview of the study, regular updates, schedule, and a place for comment submission.

13.0 Next Steps

The purpose of the San Jacinto River Regional Watershed Master Drainage Plan is to develop a comprehensive flood mitigation master drainage plan in the basin. The study identified the basin's vulnerability to flood hazard, developed approaches to enhancing public information and flood level assessment capabilities, and recommended flood mitigation strategies for both the near and long-term. 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