HUFFMAN AREA DRAINAGE ANALYSIS HCFCD BOND PROGRAM PROJECT F-110

Portions of Cedar Bayou, the East Fork of the San Jacinto River, and Luce Bayou Watersheds

EHRA ENGINEERING
October 2019

HCFCD Unit No. S110-00-00 (Shook Gully): Upstream of Fairway Crossing Drive

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Section 1 – Introduction

1.1 Introduction

The purpose of the Huffman Drainage Analysis is to conduct a planning level investigation of multiple flood damage reduction alternatives to reduce structural flooding without causing downstream impacts. The project area overlays portions of three watersheds: San Jacinto River, specifically the East Fork, Luce Bayou, and Cedar Bayou.

The investigation focused specifically on Luce Bayou (HCFCD Unit No. S100-00-00) and four (4) tributaries (see Table 1.1), which were deemed as a high priority due to reported flooding, and the East Fork of the San Jacinto River (HCFCD Unit No. G103-80-00) in two focused areas: from the confluence with S100-00-00 to the area east of G103-80-04 and near the Harris County border and G205-00-00. Two tributaries (S115-00-00 and S102-00-00) were modeled for the first time during this investigation to help evaluate flood reduction alternatives for effectiveness in flood damage reductions. Cedar Bayou had a previous HCFCD study completed in December 2018 and results from this study were incorporated for the portions which overlay the project investigation area. A complete list of waterways investigated is included in Table 1.1.

Table 1.1. Huffman Drainage Analysis Studied Streams

Stream Name	HCFCD Unit No.	Hydraulics Previously Studied	Hydrology Previously Studied
Luce Bayou	S100-00-00	Yes[1]	No[4]
Shook Gully	S110-00-00	Yes	Yes
Mexican Gully	S114-00-00	Yes	Yes
John Young Gully	S115-00-00	No[2]	No[2]
Red Gully	S102-00-00	No[2]	No[2]
East Fork of the San Jacinto River	G103-80-00	Yes	Yes
Cedar Bayou	Q100-00-00	Yes[3]	Yes[3]
Unnamed tributary – Q134-00-00	Q134-00-00	Yes[3]	Yes[3]
Unnamed tributary – Q134-01-00	Q134-01-00	Yes[3]	Yes[3]
Unnamed tributary – Q136-00-00	Q136-00-00	Yes[3]	Yes[3]

Notes:

1. Model updates were performed for this channel within Harris County that has effective models in place. Updates included revised hydrology, which was incorporated into the existing hydraulics model.
2. HEC-HMS and/or HEC-RAS models were developed for streams based on preliminary information, including LiDAR, aerial photographs, field visit measurements, and available HCFCD centerline shapefiles. Drainage areas or stream elevations were not supplemented with survey.
3. Cedar Bayou and its tributaries were studied in a previous HCFCD study titled "Cedar Bayou Flood Risk Reduction Study" completed in December 2018. The data presented within is summarized from the previous study.
4. The previous hydrologic analysis used in the Flood Insurance Study was the Flood Frequency Analysis, which determined the frequency of flows from observed discharges over an acceptable period of time. The flows were determined from USGS Gage 8071280, which is just upstream of the Harris/Liberty County boundary along Luce Bayou.

Key components of the project include development of baseline conditions, investigation of alternatives through traditional structural methods, public input options, and non-structural methods, and recommendations to reach a specified level of service (and maximize, when/where reasonable) for the stormwater conveyance system.

1.2 Project Goals

The analysis focused on identifying and addressing the flood hazards for portions of three watersheds and tributaries located within Harris County. As part of the study, HCFCD and EHRA established primary goals:

1) Identify sources of flooding focusing on the defined areas with groupings of flood complaints or flood claims;
2) Estimate level of service and existing capacity of channels;
3) Formulate recommendations on how flood damages could be reduced; and
4) Identify right-of-way needs for flood damage reduction recommendations.

1.3 Background Information

On August 25, 2018, Harris County voters approved $2.5 billion in bonds to finance flood damage reduction projects in Harris County. In the months before the bond election, HCFCD hosted twenty-three (23) Community Engagement meetings for each of Harris County's watersheds, to gather public input about the proposed projects. A proposed project list was created of 237 projects, which included 38 projects that were added as a result of Community Engagement Meetings held across Harris County in June, July, and August 2018. The Huffman Drainage Analysis project was initiated through comments provided during the Bond Community Engagement process.

1.4 Previous Work Completed

The Cedar Bayou Watershed was recently studied by Halff Associates through a partnership with the Texas Water Development Board. The study titled "Cedar Bayou Flood Risk Reduction Study" examined the main stem of Cedar Bayou (Q100-00-00) and 18 of its tributaries (HCFCD Unit No. Q101-00-00 through Q136-00-00). Their analysis was a planning level investigation of the existing flood hazards and identification of potential future drainage improvements aimed at reducing flood damages. This analysis is not meant to recreate or replace their recently completed study but blend the information into one report.

1.5 Project Schedule for Implementation

The recommendations presented with this investigation are not scheduled for construction. The results presented would need to be further evaluated in a Preliminary Engineering Report (PER) to confirm that no adverse impacts would be created from the recommendations made within this report.

Section 2 – Study Overview

2.1 General Description of Study Area

The area for investigation generally coincides with the Huffman Independent School District boundary in northeastern corner of Harris County and covers portions of three watersheds: San Jacinto River, specifically the East Fork, Luce Bayou, and Cedar Bayou. The major landmarks include Lake Houston, Farm-to-Market road (FM) 1960, FM 2100, FM 1485, the future planned development of Grand Parkway (State Highway 99), and the Luce Bayou Interbasin Canal currently under construction by others. Exhibit 1 is a vicinity map showing the location of Cedar Bayou, Luce Bayou, and East Fork of San Jacinto watersheds. The project area consists of multiple types of development from ranchettes on multiple acres to single-family homes on a quarter of an acre. Exhibit 2 shows the significant neighborhoods within the area of investigation.

The investigation focused of the main stems of these watersheds along with tributaries that were deemed as high priority. Exhibit 3 outlines the main stem and tributaries that were studied with this analysis.

Table 2.1. Huffman Drainage Analysis Studied Streams

Stream Name	HCFCD Unit No.
Luce Bayou	S100-00-00
Shook Gully	S110-00-00
Mexican Gully	S114-00-00
John Young Gully	S115-00-00
Red Gully	S102-00-00
East Fork of the San Jacinto River	G103-80-00
Cedar Bayou	Q100-00-00
Unnamed tributary – Q134-00-00	Q134-00-00
Unnamed tributary – Q134-01-00	Q134-01-00
Unnamed tributary – Q136-00-00	Q136-00-00

2.1.1 Luce Bayou

The Luce Bayou watershed is comprised mostly natural channels with one main stem that flows from north to south as well as smaller tributaries that flow east or west into the main stem. The right-of-way for these streams in owned mostly by private property owners. The City of Houston owns the right-of-way for the main stem near the confluence with the East Fork of the San Jacinto River. Luce Bayou is a tributary to the East Fork of the San Jacinto River. It drains southward for about 35 miles from its headwaters in the Sam Houston National Forest in San Jacinto County to its confluence with the East Fork of the San Jacinto River in the upper portion of Lake Houston. The watershed includes portions of San Jacinto, Liberty, and Harris Counties. The Luce Bayou watershed has approximately 210 square miles of drainage area outside of Harris County, roughly 93% of the total drainage area. Within Harris County, Luce Bayou is approximately 7.5 miles in length before its confluence with Lake Houston. The watershed generally drains from northeast to southwest before draining into Lake Houston. Exhibit 8 shows the Luce Bayou Watershed. There is minimal development in the watershed; most of the land is forest. The project area is located in Precinct 2 and is shown on Key Map pages 258, 259, 298, 299, 338, and 339. The watershed can be divided into roughly three land-use sections with each having unique characteristics as discussed below.

Section 1 – Heavily wooded, undeveloped areas. The characteristics are generally in the northern third of the Huffman boundary upstream of the Luce Bayou confluence with S115-00-00.

Section 2 – Large agricultural plots of land. These are generally located east of Luce Bayou and FM 2100 within the Huffman boundary. Topography in these areas is extremely flat.

Section 3 – Pockets of large-lot residential and commercial development, but most development is spread out. Development is generally in the central portion of the Huffman boundary. Stormwater is mostly directed to tributaries via constructed roadside ditches. The characteristics associated within this section is the predominant land use south of Mexican Gully to Lake Houston.

Although there is anticipated growth within the Huffman area, especially with the addition of Grand Parkway (SH 99) with Segments H and I, this analysis will recommend flood reduction recommendations that are based on existing conditions.

2.1.2 East Fork

The East Fork of San Jacinto flows from its headwaters near Huntsville in Walker County and into Lake Houston. Lake Houston was developed as a water supply reservoir and therefore does not provide significant storage during flood events. The contributing drainage area outside of Harris County is 384 square miles, roughly 96% of its drainage area, and gains another 12 square miles before its confluence with Caney Creek. At Caney Creek, another 370 square miles of drainage area is added of which 99% is located outside of Harris County. Downstream of the confluence with Caney Creek, the East Fork hosts a typical riverine ecosystem and contains reaches that are completely natural, along with areas with development encroaching to the water’s edge. The watershed still has large areas of undeveloped property.

2.1.3 Cedar Bayou

Cedar Bayou forms the eastern boundary of Harris County and serves as the county line for the majority of the boundary between Harris, Liberty, and Chambers Counties. It drains southward for a distance of about 51 miles from its headwaters in Liberty County to its confluence with Galveston Bay. The Cedar Bayou Watershed is approximately 199 square miles in size and is lightly developed. Communities within the watershed include the City of Baytown and unincorporated Harris County.

The Cedar Bayou Watershed was recently studied by Halff Associates through a partnership with the Texas Water Development Board. The study titled “Cedar Bayou Flood Risk Reduction Study” examined the main stem of Cedar Bayou and tributaries HCFCD Unit No. Q101-00-00 through Q136-00-00. The study was prompted by the Halloween 2015 storm event in which an average of 11.5 inches fell over 24 hours. This report will only summarize the information from their report that falls within the project area. These include Q134-00-00 (Unnamed tributary), Q134-01-00 (Unnamed tributary), and Q136-00-00 (Unnamed tributary) in the northern-most portion of Cedar Bayou. The Halff report also focused on flood protection planning, flood warning, and flood response.

The majority of land in the Cedar Bayou Watershed within the project area is currently undeveloped or agricultural, but there are pockets of residential and commercial development. The majority of identified flood insurance claims fall within these pockets of development. The area is projected to grow with an increase in residential, commercial, and educational/governmental land uses.

The tributaries within the project area do not currently meet a 2-year level of service.

2.2 Historical Flooding

There is a history of flooding in Harris County, Texas with many floods resulting in serious flood damages throughout its twenty-three (23) watersheds. Due to the region's climatic, topographic, and soil conditions, stream and overland flooding has persisted ever since the Allen brothers settled Houston. Harris County suffered through 16 major floods from 1836 to 1936. The Harris County Flood Control District is a special purpose district, created by the Texas Legislature in 1937 and governed by Harris County Commissioners Court. HCFCD was created to serve as a local sponsor for USACE projects and to have jurisdictions over open channel drainage systems. The overall mission of HCFCD is to provide flood damage reduction projects that work, with appropriate regard for community and natural values.

2.2.1 Flood Warning System

HCFCD maintains and operates a Flood Warning System (FWS) in Harris County that measures rainfall amounts and monitors water levels in bayous and major streams. The system relies on 163 gage stations strategically placed throughout Harris County. The information received from these gage stations is collected and analyzed to develop post-flood reports, including an approximation of the number of structures inundated from a flood. In addition, the information is used in engineering analyses and modeling efforts for identifying locations of future projects as well as to determine the effectiveness of constructed projects.

The gage stations are utilized to record measurements such as rainfall, water levels, wind speed and direction, barometric pressure, air temperature, road temperature and humidity. The FWS began in 1982 with 13 gage stations and expanded to today's total of 163 which allowed information to be collected on storm events impacting the project area. Gages are typically located on roadway crossings of the streams and bayous. If future roadways are constructed over the streams and bayous, there are possibilities for future gages. However, under current conditions, there are limited opportunities for additional gage locations within the project area.

Currently, there is one gage on each main stem that was utilized for this analysis as a basis for comparison, which include:

1. Farm-to-Market Road 2100 at Luce Bayou (HCFCD #1940)

2. Farm-to-Market Road 1485 at the East Fork of the San Jacinto River (HCFCD #790)
3. US Highway 90 at Cedar Bayou (USGS #08067500 and HCFCD # 1740)

Exhibit 4 shows the location of these gages, and Tables 2.2 – 2.4 show the established flood frequency elevations compared to historic rainfall events. The left side of the gage data shows the stream elevation resulting from the established frequency rainfall events. The right side of the gage data shows the historical storm events and their resulting stream elevation. Gage 1940 is located on Luce Bayou at FM 2100. Gage data for gage 1940 is shown in Table 2.2.

Table 2.2. Harris County Stream Gage 1940 Data

Harris County Stream Gage 1940				
Location: S100 - Luce Bayou @ FM 2100				
-		Historical Storm		
Flood Frequency	Elevation	Date	Elevation	Event
10%	50.30	8/27/2017	60.00	Harvey
2%	56.70	10/18/1994	56.80	-
1%	58.80	5/27/2016	50.90	-
0.20%	64.80	9/13/2008	46.40	Ike

Gage 790 is located on the East Fork of the San Jacinto at FM 1485 and gage data for gage 790 is shown in Table 2.3.

Table 2.3. Harris County Stream Gage 790 Data

Harris County Stream Gage 790				
Location: G103 - EFSJ @ FM 1485				
-		Historical Storm		
Flood Frequency	Elevation	Date	Elevation	Event
10%	63.30	8/27/2017	81.20	Harvey
2%	68.50	10/18/1994	76.20	-
1%	70.60	11/4/1998	71.60	-
0.20%	75.90	5/27/2016	69.70	-
		3/12/2016	67.01	-
		4/18/2016	63.70	-
		10/18/1998	63.50	-
		9/13/2008	56.90	Ike

Gage 1740 is located on Cedar Bayou at US Highway 90 and gage data for gage 1740 is shown in Table 2.4.

Table 2.4. Harris County Stream Gage 1740 Data

Harris County Stream Gage 1740				
Location: Q100 Cedar Bayou @ US 90				
-		Historical Storm		
Flood Frequency	Elevation	Date	Elevation	Event
10%	52.60	8/27/2017	59.00	Harvey
2%	54.30	10/18/1994	56.08	-
1%	54.90	10/31/2015	55.10	-
0.20%	56.80	9/13/2008	53.70	Ike
		6/4/2016	50.40	-
		5/20/2000	50.08	-

2.2.2 Historical Rainfall and Flooding Events

The Luce Bayou watershed has experienced several significant flooding events including the following: October 1994 storm, Hurricane Ike, Memorial Day 2016, and Hurricane Harvey. The East Fork of the San Jacinto watershed experienced notable storm events in October 1994, November 1998, and three storms in 2016. The Cedar Bayou watershed has a long history of flooding dating back to the 1970s. The following sections provide a brief description of the flooding that occurred and during these historic events. Flood reports were provided following the most recent events. These flood reports were used to reference the metrics presented in the sections below and the source flood reports are provided in Appendix P.

2.2.2.1 October 1994

Over a three-day period in October 1994, as much as 29 inches of rainfall flooded 3,400 residences in Harris County. Upstream of Lake Houston along the East Fork of the San Jacinto River, water levels exceeded the FEMA 500-year (0.2% AEP) regulatory flood levels.

2.2.2.2 November 1998

This event dropped as much as 10” over the northeast corner of Harris County; however, dropped significant rainfall in the contributing drainage area outside of Harris County. Estimates show approximately 200 homes flooding during this event in the San Jacinto River watershed.

2.2.2.3 Hurricane Ike

Hurricane Ike made landfall as a category 2 hurricane and tracked north-northwest through eastern Harris County along and east of I-45. The first flood event occurred during the actual landfall of the hurricane as the western and southern eyewall moved across the county. The rainfall frequency ranged from a 20-percent (5-yr) to a 1-percent (100-yr) AEP event across the county. The second heavy rainfall and flood event occurred across the area with rainfall averaging 2 to 4 inches which produced overbank flooding on Luce Bayou and the San Jacinto River. Overall storm totals averaged 10-13 inches and estimates show approximately 7 homes flooded during this event in the San Jacinto River watershed.

2.2.2.4 Tax Day 2016

Water levels along the East Fork of the San Jacinto River averaged between the 10-percent (10-year) and 2-percent (50-yr) elevations and were similar to the October 1998 flood, but over 3.0 feet lower than levels recorded in March of 2016. Estimates show approximately 90 homes flooded during this event in the San Jacinto River watershed.

2.2.2.5 Memorial Day 2016

Memorial Day 2016 occurred only six weeks after the April 2016 "Tax Day" flooding and impacted the north and northwestern parts of Harris County into Waller, Montgomery, and Washington counties. The heaviest rainfall occurred over northern Waller, southern Montgomery and Washington counties with the heaviest rainfall in Harris County generally confined to an area north of FM 1960. Structural flooding was reported across the county from the Memorial Day flood resulting in structural flooding estimates: 190 in the San Jacinto River watershed and 5 in the Luce Bayou watershed.

Rainfall amounts from the San Jacinto River Authority and The Woodlands rain gages indicated widespread rainfall totals of 10.0-12.0 inches over much of southern and southwestern Montgomery County in a 24-hr period. The following rainfall comparison is for the 24-hr time period in inches:

Table 2.5. Historical Rainfall for a 24-hr Time Period

Location	May '16	Apr '16	Oct '98	Nov '98	Oct '94
West Fork San Jacinto at Kingwood	11.3	7.3	N/A	N/A	N/A
East Fork San Jacinto at FM 1485	8.1	6.5	13.3	8.2	10.9

Source: HCFCD Technical Memorandum from HCFCD's Jeff Lindner Dated July 5, 2016

The comparison of the estimated rainfall for the October 1994 flood event and the May 2016 flood event shows similar location of maximum rainfall totals over southwestern and western Montgomery County and into southern Grimes and northern Waller Counties. Both events heavily impacted the West Fork of the San Jacinto River watershed. Water levels along the East Fork of the San Jacinto River averaged between 2-percent and 1-percent AEP storm event levels and were the third highest water levels recorded since the late 1970's.

2.2.2.6 Hurricane Harvey

In 2017, Hurricane Harvey produced widespread flooding in Harris County and the surrounding area. The rainfall ranged from 26 to 47 inches for Harris County over 4 days. Luce Bayou experienced a resulting water surface elevation between a 1-percent and 0.2-percent Annual Exceedance Probability (AEP) storm event. The East Fork of the San Jacinto River experienced a resulting water surface elevation above a 0.2-percent AEP storm event. Cedar Bayou experienced a resulting water surface elevation above a 0.2-percent AEP storm event. Records estimate 2,200 homes were impacted in the Cedar Bayou Watershed during Hurricane Harvey.

2.3 Drainage and Flooding

The results from the existing conditions analysis and proposed alternatives, as presented in the Halff study, are incorporated into this report, but an analysis of the Cedar Bayou watershed was not performed as part of this study. Widespread flooding occurred during Harvey along the East Fork of San Jacinto River. As part of this study, only a planning-level proposed sediment removal/dredging alternative was explored along the East Fork. In the effective FEMA Flood Insurance Study (FIS), the Luce Bayou watershed was not studied within Harris County. As part of this study, the areas draining to Luce Bayou and its tributaries were analyzed. The storage within the reaches of Luce Bayou within Harris County was also analyzed. The Harris County Watershed Master Plan drainage areas were used as a starting point, and then changed where appropriate based on available 2008 LiDAR information. The updated flows for Luce Bayou were added to the existing Luce Bayou hydraulic model to produce inundation boundaries for the studied rainfall events.

2.3.1 Regulatory Floodplain

Federal Emergency Management Agency (FEMA) effective floodplains were obtained and are displayed on Exhibit 5. These were developed as part of the Tropical Storm Allison Recovery Project (TSARP) study and have an effective date of June 18, 2007. FEMA FIRM panels that encompass the Luce Bayou watershed in Harris County include 48201C0140L, C0330L, and C0310L and in Liberty County include 48291C0400C, C0275C, C0300D, and C0175D. Within Harris County, the floodplains (1% and 0.2% AEP) are large, extending up to 3,300 feet in locations and the floodway extends between 540 feet and 1,500 feet. The floodplains extend into portions of the neighborhoods of Pine Way Estates, Fairway Crossing, Lochshire, Plantation Hills, Water Wonderland, and Hidden Echo.

Two of the Luce Bayou tributaries have been studied and have effective mapping. Among these are Shook Gully (S110-00-00) and Mexican Gully (S114-00-00). Mexican Gully has floodway and 1% AEP floodplain mapped up to 1,300 feet from the confluence with Luce Bayou. The 0.2% AEP floodplain extends upstream another 1,300 feet. Once the backwater effects from Luce Bayou impact Shook Gully, the floodway, ranging between 90 feet and 200 feet, extends beyond the limits of the HCFCD easement until it widens outside of the Fairway Crossing residential development. The Shook Gully 0.2% AEP floodplain extends into the Fairway Crossing subdivision.

FEMA FIRM panels that encompass the East Fork of San Jacinto watershed in Harris County include 48201C0310L and C0120L. The floodway is broad in Harris County, extending as much as 2,500 feet. The neighborhoods that have portions impacted by the 0.2% floodplains are Tayme Ranchettes, Northwood Country Estates, River Terrace, Commons Waterway, Magnolia Point, and Paradise Oaks. In Montgomery County, the FIRM panels are 480483C0600G, 48339C0625C, and 48339C0450G. In Liberty County, the FIRM panels are 48291C0275C, C0150C, and C0130C and in Walker County, the FIRM panels are 48471C0425D, C0400D, C0275D, and C0300D.

FEMA FIRM panels that encompass the portion of Cedar Bayou within the project include 48201C0340L and C0345L. The floodplain is broad, in some cases approaching two miles wide and is bounded by FM 2100. The floodplains extend into portions of the Lake Houston Forest, Forest Manor, and Woodland Terrace neighborhoods.

2.3.2 Local Drainage

Local drainage throughout most of the watersheds consists of roadside ditches, storm sewers, and HCFCD channels, and private channels (channels were HCFCD does not hold any property values). The roadside ditches provide drainage for residential areas and large agricultural tracts and discharge into the HCFCD channels. The roadside ditches and culverts are in various states of repair, but generally have limited capacity. Debris and vegetation have been noted from field visits and comments received from the public. Several of the tributaries have ponding upstream of the channel headwaters due to limited access to the channel.

2.3.3 Huffman Reported Flood Losses

The area of investigation has a history of flooding and associated flood damages. Flood loss data provided by HCFCD for this study included the FEMA repetitive loss data, drainage complaint information, and data produced by HCFCD's structural inventory tool. The structural inventory tool was developed by HCFCD and is used to estimate the number of structures, such as residences and businesses that may be at risk of flooding based on certain water surface elevations within the nearby streams. The project area contains 38 repetitive loss structures as determined by flood loss claims. Records maintained by HCFCD from complaints and on-the-ground record keeping show 2 structures impacted from the Memorial Day 2015 rainfall, 1 structure impacted from the Halloween 2015 rainfall, and 6 structures impacted from the Memorial Day 2016 rainfall events. Hurricane Harvey brought heavy rains to the project area with multi-agency reported flood complaint records indicating 828 structures impacted.

Section 3 – Baseline Conditions

3.1 Data Collection

In order to meet our project goals, the primary task was to develop baseline conditions modeling for the main stems and tributaries. EHRA gathered relevant available data to determine characteristics about the study area including historical flooding, current effective models, gage data, regulatory floodplain, local drainage issues from coordination with Precinct staff, and repetitive loss data. Data collection included GIS information such as the Watershed Environmental Baseline Data Summary Tool, repetitive loss data, 2018 aerial photography, HCFCD ROW information, FEMA Floodplain information, and stream location. Additionally, neighborhood drainage reports, construction plans and Preliminary Engineering Reports for projects in the Huffman-Eastgate area were collected.

3.2 Field Reconnaissance

A site visit for field inspection of drainage issues to observe the topographic, hydrologic and hydraulic characteristics of the areas impacted by flooding. The data gathered during the site visits was utilized to confirm or update hydrologic assumptions, inform the development of hydraulic models such as crossing information and channel conditions, identify potential constraints such as utility conflicts or environmentally sensitive areas, and measure baseflow conditions.

The analysis did not include any geotechnical testing, environmental, or fluvial geomorphology analysis. General environmental considerations were documented.

Based on the gathered field reconnaissance information, S100-00-00 and G103-80-00 main stems appear to be a natural (meaning non-constructed or man-made). The static water surface elevation of Luce Bayou is a few feet below the high banks of the channel. The tributaries contain a few feet of base flow due to wastewater plant discharges. Shook Gully, HCFCD Unit No. S110-00-00, appears to be improved exhibiting a grass-lined, benched trapezoidal shape channel in fair condition closer to the confluence with Luce Bayou. Upstream portions are more natural, with light, small tree vegetation. S110-00-00 appears to be a roadside ditch. Red Gully, S102-00-00, appears to be a natural channel with light, small tree vegetation. Access to Mexican Gully, S114-00-00, could not be obtained. John Young Gully, S115-00-00, is a narrow, constructed channel with light vegetation. This channel has a low baseflow of approximately six inches. The only accessible crossing for John Young Gully was Trent Road. A detailed field observation report with photographs is included in **Appendix A**.

3.3 Purpose of Task

In order to meet our project goals, the primary task was to develop baseline conditions modeling for the main stems and tributaries. The FEMA effective hydrologic and hydraulic models were gathered and reviewed for the following streams:

Table 3.1. Streams with Effective FEMA Hydrologic and Hydraulic Models

Stream Name	HCFCD Unit No.
Luce Bayou Main	S100-00-00
Shook Gully	S110-00-00
Mexican Gully	S114-00-00
East Fork of the San Jacinto River	G103-80-00
Cedar Bayou	Q100-00-00

Several tributaries had no effective hydrologic or hydraulic models, requiring new models to be developed as shown in the table below.

Table 3.2. Streams without Effective FEMA Hydrologic and Hydraulic Models

Stream Name	HCFCD Unit No.
John Young Gully	S115-00-00
Red Gully	S102-00-00
Unnamed tributary – Q134-00-00	Q134-00-00
Unnamed tributary – Q134-01-00	Q134-01-00
Unnamed tributary – Q136-00-00	Q136-00-00

The new tributary models were preliminary studies based on 2008 LiDAR data and collected site visit data. Information regarding the model creation process is outlined in the following sections.

3.4 Studied Rainfall Amounts

For this analysis, four storm events were investigated. The rainfall totals for these four storm events are for a 24-hour period and are based on the HCFCD rainfall totals before the 2019 incorporation of the National Oceanic and Atmospheric Administration (NOAA)'s "Atlas 14, Volume 11 Precipitation-Frequency Atlas of the United States, Texas," (hereafter referred to as "Atlas 14") rainfall update. NOAA's Atlas 14 is a publication that serves as the official government source of precipitation frequency values across the United States. Atlas 14 includes location-based estimates for precipitation depth for a storm event based on duration (e.g. time elapsed during the storm event), and frequency (e.g. 1% annual chance or 100-year). Due to the size of Harris County, the rainfall depth-duration amounts vary across the county. Three hydrologic regions have been established to more accurately define rainfall parameters.

3.4.1 Luce and San Jacinto

Luce Bayou and the San Jacinto River upstream of Lake Houston are considered to be in Harris County Hydrologic Region 2. The first rainfall event considered was a 10% annual exceedance probability (AEP) or a 10% chance of this rainfall occurring in a year. The common nomenclature for a 10% AEP event is a 10-year rainfall event. This event drops 7.6" in a 24-hour period.

The second rainfall event is called the 2% AEP or a 2% chance of this rainfall occurring in a year. The common nomenclature is a 50-year rainfall event. This event drops 11.3" in a 24-hour period.

The third rainfall event is called the 1% AEP or a 1% chance of this rainfall occurring in a year. The common nomenclature is a 100-year rainfall event. This event drops 13.2” in a 24-hour period.

The fourth rainfall event is called the 0.2% AEP or a 0.2% chance of the rainfall occurring in a year. The common nomenclature is a 500-year rainfall event. This event drops 18.9” in a 24-hour period. The table below summarizes the rainfall information.

Table 3.3. Summary of Studied Rainfall Amounts

Rainfall Event (AEP)	Common Nomenclature	Rainfall Amount (inches)
10%	10-year	7.6”
2%	50-year	11.3”
1%	100-year	13.2”
0.2%	500-year	18.9”

Commissioned by the National Oceanic and Atmospheric Administration (NOAA) and implemented by the Hydrometeorological Design Studies Center (HDSC) with the Office of Water Prediction (OWP), Atlas 14 is a study used to analyze historical data in order to update statistical hypothetical rainfall events. This data is being utilized in a partnership with the Federal Emergency Management Agency (FEMA) on a flood hazard assessment project to produce new flood hazard maps and information.

Table 3.4. Comparison of Studied Rainfall to Atlas 14

Rainfall Event (AEP)	Before Atlas 14 Incorporation (inches)	With NOAA Atlas 14 Incorporation (inches)
10% AEP	7.6”	8.89”
2% AEP	11.3”	14.4”
1% AEP	13.2”	17.4”
0.2% AEP	18.9”	26.2”

The rainfall totals before Atlas 14 were used in this analysis to determine existing inundation and an analysis of the proposed drainage solutions. The rainfall totals with the NOAA Atlas 14 data will be incorporated with the upcoming MAAPNext effort to update the existing flood hazard maps.

3.4.2 Cedar Bayou

Cedar Bayou is located within Harris County Hydrologic Region 3 and is subject to the rainfall shown below in Table 3.5. However, the Cedar Bayou analysis only examined scenarios for the 10-year and 100-year rainfall events.

Table 3.5. Rainfall for Cedar Bayou before Atlas 14 Incorporation

Rainfall Event (AEP)	Common Nomenclature	Rainfall Amount (inches)
10%	10-year	7.8"
2%	50-year	11.6"
1%	100-year	13.5"
0.2%	500-year	19.3"

3.5 Luce Bayou Methodology

3.5.1 Existing Models and Previous Studies

The Luce Bayou (S100-00-00) watershed is approximately 227 square miles with only about 17 square miles (7.5% of the overall watershed) within Harris County. Luce Bayou does not have an effective hydrologic model. The Luce Bayou watershed hydrology was not studied within Harris County during the last County-wide update, and there are no flow changes within the existing effective hydraulic model for Luce Bayou from the county boundary to the confluence with Lake Houston. In order to evaluate proposed recommendations, a hydrologic model for Luce Bayou was created within Harris County.

The existing FEMA effective hydraulic model for the Luce Bayou (S100-00-00) watershed was HEC-RAS version 3.0.1. This model was utilized as a starting point for the model update effort.

The previously unstudied tributaries required hydrologic and hydraulic models to be developed. Updates were made to the effective hydraulic model for Luce Bayou after a hydrologic model was developed for Luce Bayou. Detailed information relating to hydrologic parameter development is provided in the sections below.

3.5.2 Existing FIS Hydrologic Model – Luce Bayou

The existing FIS hydrologic methodology was based on the Flood Frequency Analysis. Flood Frequency Analysis involves developing a discharge-frequency relationship from observed annual peak discharges over an acceptable period of time at USGS gages. It is listed as the preferred method of developing discharge-frequency relationship assuming minimal physical change in the watershed over time and a suitable period of record. A USGS gaging station (Gage 8071280 – Luce Bayou near the Harris/Liberty County line) was utilized to create the peak discharges for the effective hydraulic model.

No prior detailed hydrologic study was completed for Luce Bayou, and there are no flow changes within the existing effective hydraulic model for Luce Bayou from the Harris/Liberty county boundary to the confluence with Lake Houston.

Table 3.6 shows the current flows from FEMA effective hydraulic model for Luce Bayou (S100-00-00).

Table 3.6. FEMA Effective Hydraulic Model Flows

River Station	HEC-HMS Junction	Flows (cfs)			
		10%	2%	1%	0.20%
39449.5	County line (FEMA Flows)	14,650	33,850	45,700	84,540

For this analysis, it was decided to examine the hydrology within Harris County for Luce Bayou watershed.

3.5.3 Subbasin Delineation

The Harris County Watershed Master Plan drainage subbasins were utilized as a starting point for creating the hydrologic model within Harris County. The Watershed Master Plan drainage subbasins were created as part of the Tropical Storm Allison Recovery Project (TSARP) released in 2007. Each Watershed Master Plan was prepared using 2001 LiDAR and tailored to each watershed's unique characteristics and issues. The LiDAR information was verified with available 2008 LiDAR. The drainage subbasins were combined using engineering judgment, where appropriate, as smaller drainage subbasins can overestimate runoff. The primary purpose of creating the drainage subbasins was to quantify runoff within Harris County entering S100-00-00. The drainage subbasins utilized in this analysis can be found in Exhibit 6.

3.5.4 Hydrologic Methodology

Only the portion of the Luce Bayou watershed within Harris County was examined during the hydrologic analysis. The HEC-HMS program was utilized to determine discharge hydrographs and peak discharges for each drainage area. The hydrologic method used for determining peak discharges was HCFCD's Clark's Unit Hydrograph Method as presented in the HCFCD Guidance Manual (2009). The Green & Ampt loss method was used per HCFCD criteria. The loss parameters were taken from the existing hydrologic models for S110-00-00 and S114-00-00 and are presented below:

- Initial Loss (inches): 0.1
- Moisture Deficit: 0.436
- Suction (inches): 3.5
- Hydraulic Conductivity (inches/hour): 0.024
- Percent Impervious: Between 5-10% (varies by drainage area)

The Time of Concentration and Storage coefficient (R) were determined from watershed parameters. The watershed parameters; percent channel conveyance (DCC), percent channel improvement (DCI), watershed length (L), length to centroid (Lca), channel slope and watershed slope were determined in accordance with the standard HCFCD hydrology and hydraulics manual methodology. The drainage subbasin parameters can be found in **Appendix B**.

In order to evaluate recommendations, the watershed outside of Harris County was broken into three subbasins based on 2008 LiDAR and engineering judgment. For these areas upstream of the Harris/Liberty county line, the TC was estimated based on drainage area characteristics, as described above, and the storage coefficient (R) was adjusted for each rainfall event so that the combined peak discharges in Luce Bayou at the county line matched the peak discharges entering Harris County in the existing Flood Insurance Study (FIS) for each rainfall event. It was evaluated whether a lag time was appropriate; however, it was determined that a lag time would not be needed, because the determined time of concentration for the subbasins upstream of Harris County resulted in an appropriate lag so that the resulting peak discharges upstream of Harris County did not coincide with peak discharges within Harris County. Storage reaches for

Luce Bayou and the studied tributaries were added in the newly created HEC-HMS model to evaluate the storage within the existing channels.

3.5.5 Hydraulic Methodology

The flow file for S100-00-00 was revised to reflect flow changes for areas draining to Luce Bayou and its tributaries within Harris County. Table 3.7 below shows the revised flow file that was used in the baseline (revised existing) condition hydraulic model for Luce Bayou (S100-00-00).

Table 3.7. Revised Flow File for Hydraulic Model for Luce Bayou

Revised Flow File					
River Station	HEC-HMS Junction	Flow (cfs)			
		10%	2%	1%	0.20%
39449.5	County Line (FEMA Flows)	14,650	33,850	45,700	84,540
34375.1	S1000000_0344_J	14,723	33,990	45,888	84,735
26979.1	S1000000_0270_J	14,745	34,043	45,991	84,927
21698.0	S1000000_0217_J	14,805	34,157	46,162	85,223
15136.4	S1000000_0151_J	14,971	34,449	46,564	86,009
8295.3	S1000000_0083_J	14,965	34,450	46,571	86,036
5116.2	S1000000_0051_J	14,953	34,433	46,561	86,027
2930.1	S1000000_0029_J	14,950	34,428	46,568	86,047

There are not effective hydraulic models for S115-00-00 or S102-00-00. Models were created for these streams by using available 2008 LiDAR information. Cross sections were placed along each tributary ending at its confluence with S100-00-00. A steady-state analysis was used to determine the water surface elevations and inundation boundaries. A field visit confirmed any baseflow conditions for these tributaries. The 10%, 2%, 1%, and 0.2% storm events were run for each model. Resulting flow rates, water surface elevations, and velocities were examined from these models. The resulting inundation maps for each storm event modeled, as provided as Exhibits 7-10.

3.5.6 Channel Storage Analysis

The only existing storage-discharge information included in the hydrologic model is for Shook Gully (S110-00-00). Reaches were created in the hydrologic model to account for the storage and attenuation of runoff within the channel for the tributaries and Luce Bayou main stem. Flow change locations were inserted at confluences of tributaries along the main stem indicating separate reaches. Analyzing the existing channel storage within the reaches for Luce Bayou was necessary for two reasons: 1) The channel storage will attenuate the peak discharges; 2) The existing conditions channel storage volume provides a basis for comparing the proposed channel modifications, and shows where detention volume is needed after performing channel modifications. Existing storage-discharge functions were determined from routing percentages of the 100-year flow at the upstream end of the reach. The percentages of the 100-year discharge that were used were 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.5, 1.6, 1.8, and 2.0. The plan in HEC-RAS that was used to determine the storage-discharge functions was titled “Existing SVSQ.” The storage-discharge function was entered in HEC-HMS as a paired data set.

Modified-Puls (level-pool) routing was used to route the discharges in HEC-HMS. A comparison of the assumed 100-year discharge for the HEC-RAS SVSQ run, and the resulting 100-year discharge from the HEC-HMS run was performed. Iterations were made for the assumed 100-year discharge until the assumed 100-year discharge for the HEC-RAS run and the resulting HEC-HMS discharge matched within 5%, per HCFCD methodology. The resulting peak discharges determined with the appropriate storage-discharge functions was used as the flow file for the "Revised Existing" (or "Existing" flow file for newly studied tributaries) hydraulic (HEC-RAS) model for Luce Bayou and its tributaries.

3.6 East Fork Methodology

No channel modifications or detention basins were proposed as recommendations along the East Fork of the San Jacinto River as it is anticipated that a larger, in-depth study will begin on the entire San Jacinto watershed later this year. This analysis established baseline metrics and inundation boundaries for the aforementioned storm events. The baseline metrics included number of structures, parcels, acres of land, and miles of roadway anticipated to be inundated.

3.6.1 Existing Models and Previous Studies

The existing FEMA effective hydraulic models for the East Fork of the San Jacinto Bayou (G103-80-00) watershed was in HEC-RAS version 3.0.1. This model was utilized as a starting point for the sedimentation analysis on the East Fork. There is not an available hydrologic model for the East Fork of San Jacinto Watershed.

3.6.2 Hydrologic Methodology

The existing flow file for the East Fork has flow changes for almost every cross section from the county line down to Lake Houston. These flow change locations account for Caney Creek and additional tributaries that enter the East Fork prior to Lake Houston. Per the scope, the hydrologic methodology was not revised for the East Fork of San Jacinto watershed.

3.6.3 Hydraulic Methodology

The hydraulic methodology was not revised for the East Fork of San Jacinto watershed. This analysis only looked at establishing baseline metrics based on inundation boundaries for different storm events. The baseline metrics included number of structures, parcels, acres of land, and miles of roadway anticipated to be inundated. Dredging was examined as a possible recommendation by performing a limited hydraulic evaluation on the reduced capacity. No channel modifications or detention basins will be proposed as recommendations along the East Fork of the San Jacinto River as it is anticipated that a larger, in-depth study will begin on the entire San Jacinto watershed later this year.

3.7 Cedar Bayou Methodology

3.7.1 Existing Models and Previous Studies

The Cedar Bayou Watershed was recently studied by Halff Associates through a partnership with the Texas Water Development Board. The study titled "Cedar Bayou Flood Risk Reduction Study" examined the main stem of Cedar Bayou and tributaries HCFCD Unit No. Q101-00-00 through Q136-00-00. This report will only summarize the information from their report that falls within the project area. These include a portion of the main stem Q100-00-00 (Cedar Bayou), Q134-00-00 (Unnamed tributary), Q134-01-00 (Unnamed tributary), and Q136-00-00 (Unnamed tributary).

There are existing hydraulic models for Q100-00-00 (Cedar Bayou), Q101-00-00 (Pine Gully), Q112-00-00 (Cary Bayou), Q114-00-00 (McGee Gully), Q122-00-00 (Clawson Ditch), Q128-00-00 (Adlong Ditch), Q130-00-00, and Q200-00-00 (Diversion Channel). There is an existing hydrologic model for the Q100-00-00 (Cedar Bayou) watershed, which encompasses all of these tributaries.

3.7.2 Hydrologic Methodology

In the current effort, there was no revision to the Cedar Bayou watershed models from the January 2019 Final Halff Report. The description here is summarized from the Halff Report.

The hydrologic models were converted to HEC-HMS version 4.2.1. Drainage area subbasin delineations were updated using 2014 aerial imagery, 2008 HGAC LiDAR, and field reconnaissance data. Watershed parameters were determined from 2014 aerial imagery, 2008 LiDAR, and in accordance with the standard HCFCD methodology. However, some irregularities in the hydrologic results were discovered. An alternative hydrologic method was developed to more accurately represent the runoff of the watershed, largely based on the current HCFCD methodology, called the Constant Ratio Method.

Storage routing was also updated for the watershed to determine the hydrograph attenuation due to storage, which is significant, especially in the upper two-thirds of the watershed. Diversion relationships were added where overflow potential from one stream to another was identified particularly between Q134-00-00 and Q136-00-00. The resulting flows were lowered as shown in the table below.

Table 3.8. Resulting Flows for Tributaries

Description	Effective Modeling	Revised Existing
Q136-00-00	4,011 cfs	2,738 cfs
Q134-00-00	3,837 cfs	3,886 cfs

3.7.3 Hydraulic Methodology

In the current effort, there was no revision to the Cedar Bayou watershed models from the January 2019 Final Halff Report. The description here is summarized from the Halff Report.

The effective HEC-RAS models were updated from version 3.0.1 to 5.0.3. Ineffective flow areas were adjusted when necessary, and the hydraulic models were used to update the Modified-Puls routing. Q134-00-00 and Q134-01-00 are new detailed studies. Some survey data was collected, but Q136-00-00 has model geometry solely based on 2008 LiDAR data and field observation. The tributaries were modeled together based on overflow patterns. The floodplain for the system exhibits significant storage downstream of Huffman-Eastgate Road and upstream of FM 1960. This area is inundated from the main stem extending close to the watershed boundary. This area is mostly undeveloped and agricultural land that is almost entirely inundated during both the 10-percent and 1-percent AEP storm events. The entire floodplain for this system is almost entirely caused by overflow from Q100-00-00.

3.8 Inundation Boundaries

An existing terrain was created in HEC-RAS from the existing 2008 LiDAR. The inundation boundaries for each stream were mapped for the 10%, 2%, 1%, and 0.2% AEP rainfall events. The boundaries were exported to ArcGIS as shapefiles. The individual boundaries from each stream were combined as one inundation boundary for each storm event for the comparison of the baseline metrics. When comparing the inundation boundaries from the baseline hydraulic model versus the FIS floodplain mapping, the baseline inundation boundaries are slightly wider than the 2007 effective HEC-RAS model results, which corresponds to the increase in discharges from the hydrologic analysis of the Luce Bayou watershed within Harris County and resulting water surface elevations.

The resulting revised baseline conditions floodplains by watershed are provided in Exhibits 7-10. Inundation was specifically investigated to understand the cause of the flooding and floodplain patterns.

From the modeling effort, it was determined that the streams included in this analysis had less than a 10-year capacity. The inundation boundaries illustrate the relatively wide floodplains with the majority of flooding occurring from the limited capacity to drain the main stem channels. The majority of the flooding that takes place on the tributaries is from the main stem floodplain for Luce and Cedar Bayous.

3.9 Baseline Conditions Metrics

This analysis included establishing baseline metrics based on inundation boundaries for different storm events. The baseline metrics included number of structures, parcels, acres of land, and miles of roadway anticipated to be inundated from the studied rainfall amounts. The depth of inundation was not considered in gathering the metrics. Information regarding each metric is discussed below.

3.9.1 Structure Inventory Database

The structure inventory tool is a geographic information system based inventory of all of the buildings in Harris County with ground elevations, finished floor elevations, Harris County Appraisal District (HCAD) value information, and basic hydraulic model attributes. The latest version of the Structure Inventory tool was developed in May 2018 using 2013 Building Footprints, 2013 HCAD parcels, HCFCD Survey Data, and 2008 LiDAR data.

The geodatabase contains centroids of building footprints and contains an attribute of the 2008 LiDAR elevations incorporated at the point of the centroid. The purpose and methodology regarding its creation is summarized in the technical memorandum outlining the Structure Inventory Update – Workflow Development dated May 25, 2018 prepared by LAN (Memorandum).

The latest version of the Structure Inventory tool contains 1,483,737 records or features across Harris County. The data was clipped to the Z100-00-00-P026 project boundary to only evaluate the structures within the project boundary. There were 12,118 features within the project boundary after the data was clipped.

From the Memorandum, the “finished floor elevation used” (FFE_Used) attribute or from the attribute table was identified as the attribute needed for evaluating the structures impacted at designated water surface elevations. It was determined that not every feature had a value listed within this attribute. A little under half of the features, 6,030 to be exact, were provided with an FFE_Used attribute value.

The same assumptions listed in the Memorandum were utilized to approximate an FFE_Used value. The Memorandum outlined an adjustment factor to the LiDAR value based on the structure class and year built. Of the remaining 6,088 features, 1,282 features had a YearBuilt attribute. These features were assigned an FFE_Used value by adding the LiDAR elevation plus the adjustment factor listed in the Memorandum. The adjustment factor used in the Memorandum for each structure class is shown below as Table 3.9.

Table 3.9: Adjustment Factors for Structure Classes from Memorandum

Structure Class	Code	Adjustment Factor in Feet
Residential on Pier	1	2
Residential on Slab and Year Built < 2008	2	0.85
Residential on Slab and Year Built > 2008	3	1.75
Mobile Home	4	3
Commercial	5	1
Survey – No Adjustment	6	0

For the remaining 4,806 features without an FFE_Used or YearBuilt attribute listed, the Landuse attribute was utilized and the land uses were grouped into the categories listed in Table 3.9. Then the LiDAR elevation plus the adjustment factor listed in the Memorandum were summed and assigned to the FFE_Used attribute.

The FFE_Used attribute was utilized in evaluating the number of structures that would be inundated at a designated water surface elevation. This information was utilized in evaluating the number of structures impacted after modeling the water surface elevations from the scenarios examined in the Alternatives Phase which includes: channel modifications, bypass channel, and regional detention basins. Table 3.10 summarizes how the Structural Inventory tool applicable structures were evaluated.

Table 3.10. Summary of Steps to Evaluate Structure Inventory Geodatabase “FFE_Used” Attribute

Step	Description	Amount of Features
1	Starting Point of Structure Inventory database	1,483,737
2	Data within the project boundary	12,118
3	Data with a FFE_Used attribute value or finished floor elevation used value	6,030
4	Data with a YearBuilt attribute value or year structure built value that were assigned a FFE_Used attribute value by adding the LiDAR elevation plus the adjustment factor listed in the Memorandum	1,282
5	Data with a Landuse attribute value or land use value that were assigned a	4,806

	FFE_Used attribute value by adding the LiDAR elevation plus the adjustment factor listed in the Memorandum	

3.9.2 Roadways

The roadway data was gathered from the Houston-Galveston Area Council (HGAC) and represents relative locations. The Houston-Galveston Area Council is a regional organization through which local governments consider issues and cooperates in solving area wide problems. HGAC provides GIS products and services to the public at no charge.

3.9.3 Parcels

The parcel data was obtained from Harris County Appraisal District (HCAD) and also represents relative locations through polygon parcels. HCAD is a political subdivision of the State of Texas with the purpose of appraising property for ad valorum tax purposes. The best available HCAD data at the time of this study was the 2018 parcel data.

3.9.4 Area

The area data was calculated from the resulting inundation boundaries within the project area determined from each rainfall event.

3.9.5 2D Analysis

A 2D HEC-RAS analysis was performed to determine flow paths within the project boundary and validate the HCFCD Watershed Master Plan drainage areas, which were used for the Luce Bayou watershed. Additionally, the unsteady analysis was used to determine the primary cause of flooding at confluences for Luce Bayou and its tributaries.

A 2D area was created from an existing terrain based on available 2008 LiDAR for the entire Huffman area. The inflow hydrograph for Luce Bayou that was determined from the hydrologic analysis was used as the upstream boundary condition for Luce Bayou in the 2D analysis. A 2D boundary condition was placed on the downstream perimeter of the 2D area, and specified as normal depth, so that the water from the analysis could exit the system. A 2D rain-on-grid analysis was performed for the Huffman area to show flow paths for each rainfall event. The rain-on-grid was entered into the 2D area as a precipitation boundary condition. The incremental rainfall depth was taken from the results of the HEC-HMS model for each rainfall event. As of now, HEC-RAS version 5.0.6 does not have the capability to remove infiltration from the rainfall data, so HEC-HMS (version 4.3) was used to create a rainfall hyetograph. A uniform rainfall and percent impervious were used for the entire watershed during the 2D analysis. A dummy node was created in HEC-HMS with the appropriate Green & Ampt loss parameters from the watershed and an assumed impervious value of the watershed of 5%. The resulting excess runoff (rainfall depth minus losses) depth was used as the inflow hyetograph for the 2D precipitation boundary condition.

3.9.6 Baseline Conditions Metrics Results

The baseline metrics identified in the baseline conditions will be compared against the drainage scenarios to evaluate the reductions as a result of proposed improvements. This information also helps HCFCD and Harris County respond during and after flooding events.

Table 3.11. Baseline Conditions Metrics

Rainfall Event (AEP)	Roads (miles)	Parcels	Structures	Area (acres)
Luce Bayou (All modeled streams as part of this analysis)				
10%	0.84	557	14	1,279
2%	4.10	701	92	1,407
1%	4.65	726	140	1,969
0.2%	7.37	840	225	2,565
San Jacinto (G103-80-00)				
10%	2.24	850	50	2,263
2%	4.51	1,048	115	2,988
1%	5.88	1,284	154	3,317
0.2%	13.45	1,642	414	4,628
Cedar Bayou (Only Q134-00-00 & Q136-00-00)				
10%	5.03[1]	356[1]	37[1]	356[1]
2%	N/A[2]	N/A[2]	N/A[2]	N/A[2]
1%	12.39[1]	514[1]	121[1]	514[1]
0.2%	14.87[1]	562[1]	141[1]	562[1]
Total				
10%	5.08	1,407	65	3683
2%	8.61	1,749	233	4395
1%	11.53	2,010	307	5515
0.2%	20.82	2,482	639	7193

Footnotes:
1 – These metrics were taken from the Cedar Bayou Study (2018).
2 – These metrics were not available from the previous study completed for Cedar Bayou.

From the modeling effort, it was determined that the streams included in this analysis had less than a 10-year capacity. The inundation boundaries illustrate the relatively wide floodplains with the majority of flooding occurring from the limited capacity to drain the main stem channels.

Table 3.12. Baseline Conditions Metrics for Luce Bayou Watershed

Rainfall Event (AEP)	Structures	Area (acres)	Roads (miles)	Parcels
Luce Bayou (S100-00-00)				
10%	11	820	1	370
2%	87	1,223	4	496
1%	133	1,364	5	518
0.2%	217	1,879	7	621
Red Gully (S102-00-00)				
10%	3	24	0	88
2%	5	27	0	95
1%	7	29	0	96
0.2%	8	34	0	100
Shook Gully (S110-00-00)				
10%	0	120	0	67
2%	0	179	0	75
1%	0	211	0	77
0.2%	0	244	0	86
Mexican Gully (S114-00-00)				
10%	0	6	0	5
2%	0	7	0	5

1%	0	7	0	5
0.2%	0	9	0	5
John Young Gully (S115-00-00)				
10%	0	16	0	16
2%	0	21	0	18
1%	0	23	0	20
0.2%	0	29	0	22

The majority of the flooding that takes place on the tributaries is located at the confluence with Luce Bayou.

3.10 Comparison of 2008 versus 2018 LiDAR

While the project was active, the 2018 LiDAR was released for usage in HCFCD projects. In order to evaluate the impact the 2018 LiDAR would have on the project, EHRA completed a comparison of the data. The results of the analysis show that the elevations are generally the same between the two dates within +-0.5'. There are some areas that have been filled and excavated since 2008, but those are shown as outliers. Exhibit 11 shows this comparison between the 2008 and 2018 LiDAR. The positive numbers are where there has been excavation or subsidence; the negative numbers show fill or areas where the elevations have been raised. The large teal section shows that the lake was at a lower water surface elevation in 2018 than in 2008.

Section 4 – Alternatives

4.1 Introduction

Addressing the flooding problem presented several opportunities including:

- Reduce the number of homes affected by flooding
- Decrease the water surface elevations (WSELs)
- Improve local drainage
- Optimize floodplain storage and attenuation
- Protect critical infrastructure, facilities
- Expand the floodplain corridor
- Reducing the number of homes impacted from the 1-percent area of inundation

HCFCD has several structural and non-structural tools for flood damage reduction. These structural tools include stormwater detention basins, channel modifications, bypass channels, bridge modifications, and channel maintenance. Non-structural tools include buyouts and demolition of structures built deep in flood-prone areas, where structural projects to reduce flood levels are impractical.

Stormwater detention basins are areas of land, usually located adjacent to channels that are designed to receive and hold above-normal stormwater volumes. Most stormwater detention basins in Harris County are excavated. The detained stormwater then slowly drains, over time, out of the detention basin as the flow in the channel and associated water surface elevations recede. The Flood Control District uses stormwater detention extensively to reduce the risk of flooding throughout the county.

Channel modifications, or conveyance improvements, are man-made changes to a channel, typically for the purpose of reducing flood damages by increasing the channel's overall capacity. This can be accomplished by widening and/or deepening the channel.

A bypass channel diverts excess stormwater "around" an area with restricted right-of-way or an area with sensitive environmental values. Specifically, a bypass channel involves building a new channel that is attached to the existing channel conveying the excess stormwater runoff around its original path.

Bridge modification involves the replacement, extension or modification of a bridge in order to remove an impediment to flow within a channel and/or accommodate channel modifications.

The Flood Control District also uses non-structural tools to maintain the infrastructure in the County. Floodplain preservation is the acquisition of large areas of land with a high flood risk in an effort to:

1. Preserve the natural and beneficial functions of the floodplain and its ecosystem
2. Prevent future development
3. Provide potential opportunities for recreational use by the public

One of the most effective non-structural tools they use involves acquisition and demolishing of structures that were built deep in flood-prone areas, where structural projects to reduce flood levels are impractical.

Acquisition has multitude of benefits including:

- Relocating families to higher ground out of harm's way.
- Eliminating future flood damages and health and safety risks for owners and rescuers.
- Reducing repetitive subsidized flood insurance payments and federal disaster assistance.
- Restoring the floodplain to its natural and beneficial function for stormwater storage.
- Creating open space with the potential for community amenities (i.e. parks, gardens, playing fields, etc.).

Structures in this situation were typically built years ago before detailed floodplain maps and studies were available and before floodplain management regulations were adopted by the County.

4.2 Scenarios for Analysis

The following scenarios were investigated as part of this analysis:

- Non-Structural Tools
  - Floodplain Preservation
  - Acquisition of Impacted Structures
- Structural Tools
  - Detention for Luce Bayou main stem upstream of County line
  - Trapezoidal channel modifications for Luce Bayou main stem
  - Optimized channel modifications for Luce Bayou main stem
  - Bypass channel for Luce Bayou main stem
  - Combination of optimized channel modifications, bypass channel, and detention upstream of County line
  - Channel modifications and detention analysis for tributary improvements.

4.3 Baseline Conditions

Four metrics were used to quantify the existing flood risk for all of the studied storm events. The fours metrics are number or structures, area (acres), roadway (miles), and number of parcels that are inundated in each storm event. The baseline metrics, which were used to compare to each proposed flood risk alternative, is shown in Table 4.1 below.

Table 4.1. Baseline Conditions Metrics for Luce Bayou

Level of Service	Structures	Area (Acres)	Roadway (Miles)	Parcels
10YR	11	820	1	370
50YR	87	1,223	4	496
100YR	133	1,364	5	518
500YR	217	1,879	7	621

The primary goal of each of the flood risk reduction alternatives is to reduce the risk of structural flooding. For some of the proposed alternatives, especially the upstream detention, all of the metrics may not appropriately quantify the effectiveness of the alternative. This is due to the primary focus of the alternative on the impacts to structures.

4.4 Project Constraints

While the proposed scenarios are slated to reduce flood damages, there are constraints associated with each recommendation. These include utilities, property ownership, and environmental constraints. All of these aspects could impact project implementation of the recommendations and if the alternative is recommended for further study, these constraints will be investigated at that time. Where possible, these aspects were identified and catalogued during the recommendation process.

4.5 Floodplain Preservation

The concept of floodplain preservation is the acquisition of area within the modeled inundation boundary. The modeled inundation boundary was developed under existing conditions and represents areas with a high flood risk. This concept is illustrated in Exhibit 12. The scenario includes the acquisition of structures, land, roads and undeveloped or vacant land.

This scenario does not provide a reduction in flooding; however, it removes structures from flood risk. The table below represents the metrics that would be impacted by this scenario.

Table 4.2. Metrics of Floodplain Preservation

Necessary Acquisition				
Level of Service	Structures	Area (Acres)	Roadway (Miles)	Parcels
10YR	12*	820	1	370
50YR	113*	1,223	4	496
100YR	146*	1,364	5	518
500YR	217	1,879	7	621

* This scenario has additional structures that are acquired due to the structures being located within the inundation boundary. These structures are not considered at risk in existing conditions due to the estimated finished-floor elevations compared to the adjacent WSEs.

4.6 Acquisition of Impacted Structures

The concept of acquisition of impacted structures is the acquisition of structures with a finished floor elevation estimated to be below the adjacent water surface elevation within Luce Bayou for the specified storm event. The modeled water surface elevations were developed under existing conditions for Luce Bayou. This scenario does not provide a reduction in flooding; however, it removes structures from flood risk. This scenario would allow for vacant areas to be developed in the future subject to the latest criteria and is displayed in Exhibit 13. The table below represents the metrics that would be impacted by this scenario.

Table 4.3. Metrics of Acquisition of Impacted Structures

Necessary Acquisition				
Level of Service	**Structures**	**Area (Acres)**	**Roadway (Miles)**	**Parcels**
10YR	11	14	0	11
50YR	87	87	0	87
100YR	133	191	0	133
500YR	217	361	0	217

4.7 Detention for Luce Bayou Main Stem Upstream of County Line

Due to the magnitude of flows from Luce Bayou entering Harris County, this scenario examined the feasibility of placing a detention storage facility near or upstream of the Harris-Liberty County line, which would result in capturing runoff along the Luce Bayou main stem and reduce water surface elevations for Luce Bayou for the reaches within Harris County. This scenario is displayed in Exhibit 14.

Upstream detention in Liberty County or north Harris County was analyzed to reduce the peak discharges entering the Luce Bayou main stem. A detention volume was determined for each of the analyzed storm events to satisfy the target level of service. An iterative process was used to reduce the inflow hydrograph upstream of HEC-HMS Junction S1000000_0394_J, which is the upstream most river station in the hydraulic model. The detention was analyzed as the total volume of runoff diverted away from the main stem into the sink. A time-series diversion was used as the modeling method for diverting flows away from the main stem. Figure 1 below shows the HEC-HMS layout in the detention alternative model.

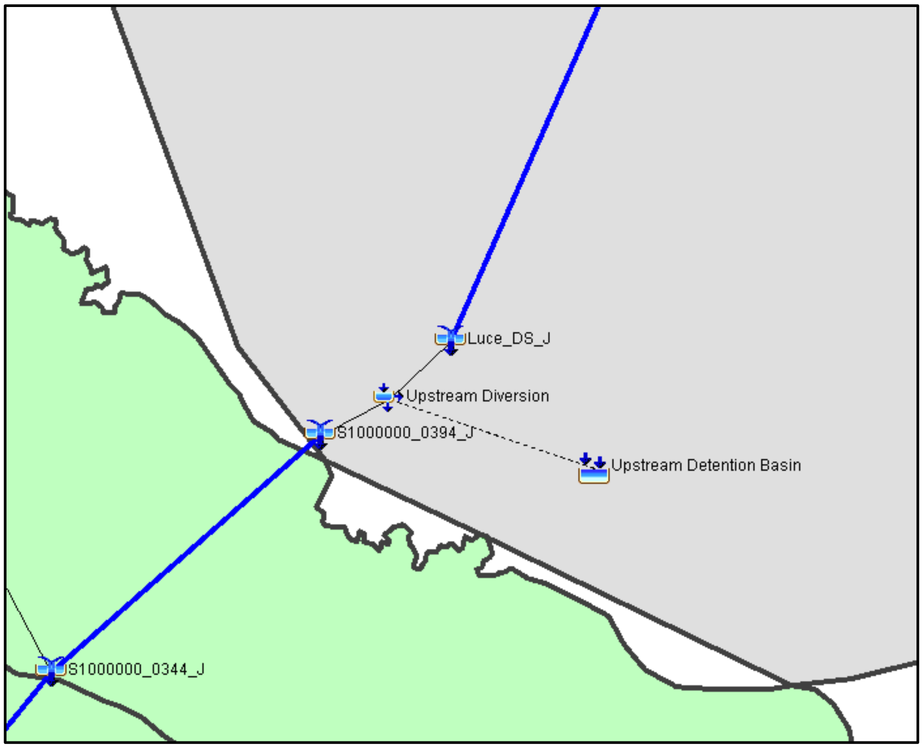


Figure 4.1. Detention Alternative HEC-HMS Layout

Table 4.4 shows the proposed conditions flow file for the upstream detention alternative providing a 10-year level of service along the main stem of Luce Bayou. The proposed flow file for each upstream detention level of service is provided in **Appendix C**.

Table 4.4. Luce Bayou Hydraulic Model Flow File for Proposed Upstream Detention for 10-YR Level of Service

River Station	HEC-HMS Junction	Peak Discharges (cfs)			
		10% (10YR)	2% (50YR)	1% (100YR)	0.2% (500YR)
39449.5	S1000000_0394_J	11,790	30,964	42,808	81,655
34375.1	S1000000_0344_J	11,865	31,103	42,998	81,958
26979.1	S1000000_0270_J	11,892	31,160	43,103	82,171
21698.0	S1000000_0217_J	11,950	31,274	43,275	82,481
15136.4	S1000000_0151_J	12,115	31,572	43,683	83,282
8295.3	S1000000_0083_J	12,114	31,576	43,699	83,309
5116.2	S1000000_0051_J	12,105	31,561	43,686	83,284
2930.1	S1000000_0029_J	12,103	31,557	43,694	83,312

The area required was estimated based on the volume required divided by an allowable depth of 15 feet, which was a conservative estimate of the depth of natural ground to the proposed outfall into Luce Bayou at the Harris/Liberty County line. It should be noted that the surface area associated with this drainage alternative could vary significantly if land near the channel is not available.

Table 4.5. Volume Needs by Level of Service

Level of Service	Volume (Ac-ft)	Surface Area (acres)
10YR	7,015	500
50YR	55,847	3,723
100YR	84,680	5,645
500YR	168,928	11,262

The table below represents the metrics that would be impacted by this scenario.

Table 4.6. Metrics of Upstream Detention

Level of Service	Necessary Acquisition				Helped			
	Structures	Area (Acres)	Roadway (Miles)	Parcels[1]	Structures	Area (Acres)	Roadway (Miles)	Parcels[1]
10YR	0	500	0	-	11	320	1	-
50YR	0	3,723	0	-	87	-2,500	4	-
100YR	0	5,645	0	-	133	-4,281	5	-
500YR	0	11,262	0	-	217	-9,383	7	-

Footnote: 1) Number of parcels comparison is not available due to the uncertain nature of the detention location

4.8 Trapezoidal Channel Modifications for Luce Bayou Main Stem

Channel modification is a man-made change to the existing channel geometry for the purpose of reducing flood damages by increasing its overall conveyance capacity. This can be accomplished by widening and/or deepening the channel. Trapezoidal channel modifications were performed for Luce Bayou using the HEC-RAS channel modification tool. The improvements were performed three feet above the existing flowline of the channel so that the proposed channel modifications will minimize or avoid stream mitigation. The Luce Bayou main stem was broken into reaches for the purpose of evaluating the required ROW width needed so that the resulting water surface elevations within each reach were lower than the lowest FFE of the structures within that reach for each level of service (LOS). The reaches that were established in the baseline conditions hydrologic model were used for the proposed channel modifications. The ROW width was determined from the proposed bank stations of the modified channel plus an additional combined 60 feet of required ROW width (30 on each side) for maintenance. The proposed conditions for the channel modifications were incorporated into the proposed conditions basin in HEC-HMS. Due to the increased conveyance capacity, peak discharges were increased in proposed conditions. The increase in peak discharges will be mitigated in Lake Houston. The flow files associated each level of service for the proposed channel modifications is provided in **Appendix C**. The resulting channel width by level of service is shown below.

Table 4.7. Resulting Right-of-Width Width for Channel Modifications

Level of Service	Avg ROW Width (ft)
10YR LOS	382
50YR LOS	622
100YR LOS	824
500YR LOS	1,599

The table below represents the metrics that would be impacted by this scenario.

Table 4.8. Metrics for Channel Modifications

Level of Service	Necessary Acquisition				Helped			
	Structures	Area (Acres)	Roadway (Miles)	Parcels	Structures	Area (Acres)	Roadway (Miles)	Parcels
10YR	3	270	1	102	8	550	0	268
50YR	13	426	1	134	74	797	3	362
100YR	22	605	1	171	111	759	4	347
500YR	127	1,141	1	398	90	738	6	223

4.9 Optimized Channel Modifications for Luce Bayou Main Stem

After a preliminary analysis of the main stem channel modifications for each level of service, it was determined that the 100-year and 500-year channel modifications would be impractical to implement due to costs and number of impacted property owners compared to the reduction of at-risk structures. It was necessary to first determine a ROW width that was practical to acquire, and then determine the level of service that would result from the channel modifications with that "optimized" ROW width. The optimized ROW width was determined from using judgment to determine the ROW that could be reasonably acquired for channel modifications based on the proximity to adjacent parcels and structures. The optimized ROW width at the most downstream end of the channel was determined to be approximately 570 feet, including the required maintenance berms. This width was used for all of the reaches, and the channel was modified using the channel modification tool in HEC-RAS. The storage-discharge functions were updated for the proposed conditions. The proposed conditions for the channel modifications were incorporated into the proposed conditions basin in HEC-HMS for all four studied rainfall events. Due to the increased conveyance capacity, peak discharges were increased in proposed conditions. The increase in peak discharges will be mitigated in Lake Houston. The results of the channel modifications yielded a level of service (LOS) above the 10-year, but not above the 50-year. Table 4.9 shows the flow file for the proposed channel modifications for Luce Bayou using the optimized ROW width.

Table 4.9. Luce Bayou Hydraulic Model Flow File for Optimized Channel Modifications

River Station	HEC-HMS Junction	Peak Discharges (cfs)			
		10% (10YR)	2% (50YR)	1% (100YR)	0.2% (500YR)
39449.5	S1000000_0394_J	14650	33850	45700	84540
34375.1	S1000000_0344_J	14732	33995	45891	84858
26979.1	S1000000_0270_J	14777	34035	45986	85050
21698.0	S1000000_0217_J	14843	34122	46153	85345
15136.4	S1000000_0151_J	15062	34452	46600	86208
8295.3	S1000000_0083_J	15077	34471	46600	86286
5116.2	S1000000_0051_J	15075	34464	46574	86278
2930.1	S1000000_0029_J	15080	34472	46577	86302

The resulting channel width by level of service is shown below.

Table 4.10. Optimized Right-of-Width Width for Channel Modifications

Level of Service	Avg ROW Width (ft)
10YR+ LOS	570

The table below represents the metrics that would be impacted by this scenario when compared against the 50-year inundation metrics. The scenario produces benefits in other storm events through the reduction in water surface elevations; however, the metrics are based on the direct comparison of storm event rainfall versus level of service. The optimized ROW channel modifications were not designed for a specific level of service and therefore, cannot be directly compared against a specific level of service.

Table 4.11. Metrics of Optimized ROW Width Scenario

Level of Service	Necessary Acquisition				Helped*			
	Structures	Area (Acres)	Roadway (Miles)	Parcels	Structures	Area (Acres)	Roadway (Miles)	Parcels
10YR +	4	398	1	107	83	825	3	387

*Metrics compared with existing 50-year inundation metrics

4.10 Bypass Channel for Luce Bayou Main Stem

A bypass channel was analyzed to divert peak discharges away from the main stem. The target reduction in peak discharges was to provide the 100-year level of service when combined with the optimized channel modifications and 10-year detention alternative, as described above. However, the bypass alternative was analyzed independently of the other improvements in order to quantify the standalone value of the drainage alternative. A bypass location was not feasible east of the Luce Bayou main stem due to the location of Mexican Gully, Shook Gully, and the topography.

Two conceptual bypass routes were analyzed west of Luce Bayou. Both bypass routes start diverting flows just upstream of the confluence of Mexican Gully (S114-00-00) with the main stem. Bypass Route 1 takes flows to Red Gully (S102-00-00). Bypass Route 2 takes flows south directly to downstream of Luce Bayou. The routes were determined based on topography, and with the objective of minimizing the impact to existing structures. Figure 2 shows the bypass routes along with the HEC-HMS junction locations.

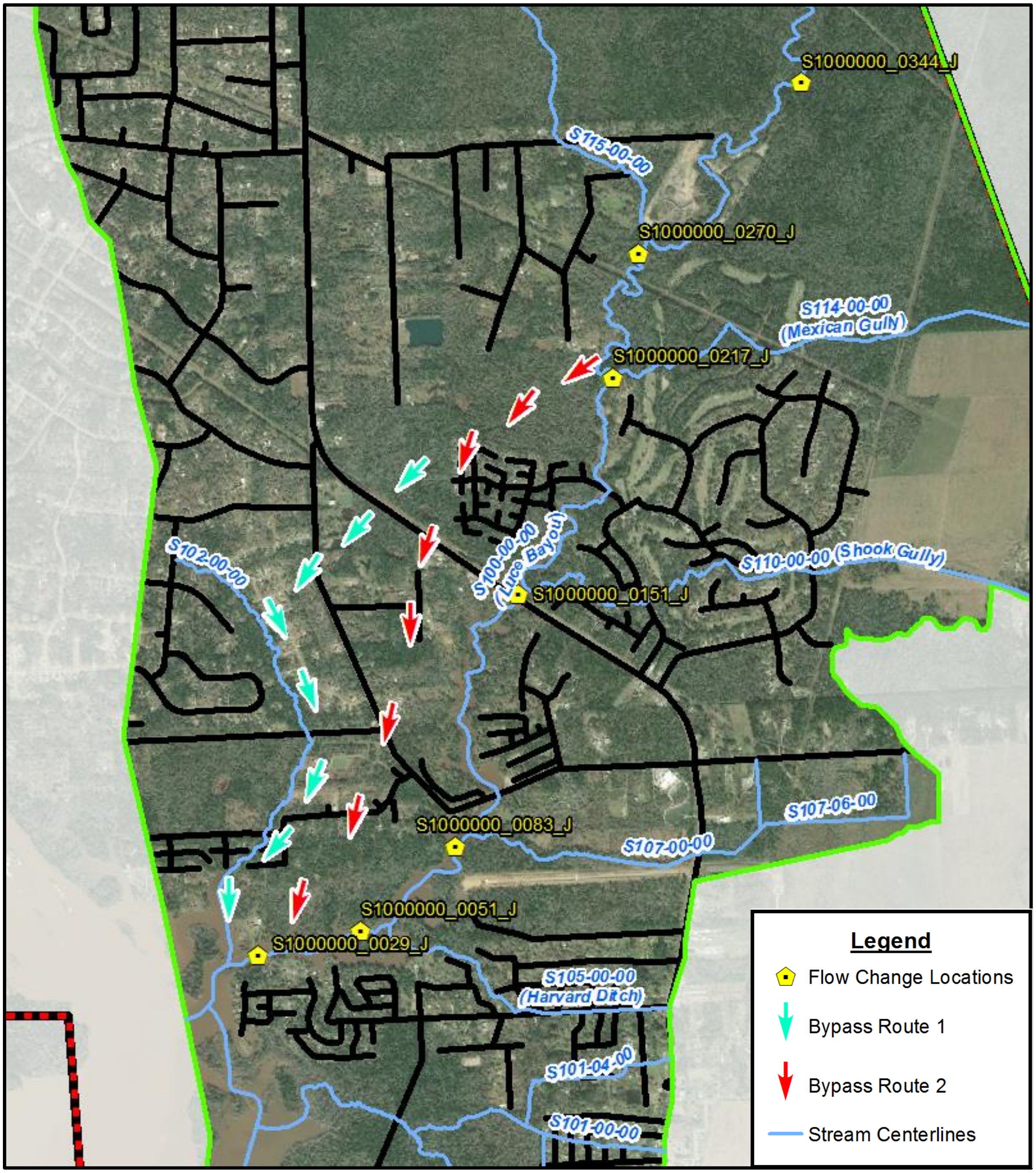


Figure 4.2. Bypass Layout Map

A time-series diversion was created to remove flows from the outflow hydrograph from Reach S1000000_0217_R. Figure 4.3 shows the HEC-HMS layout for the bypass channel alternative.

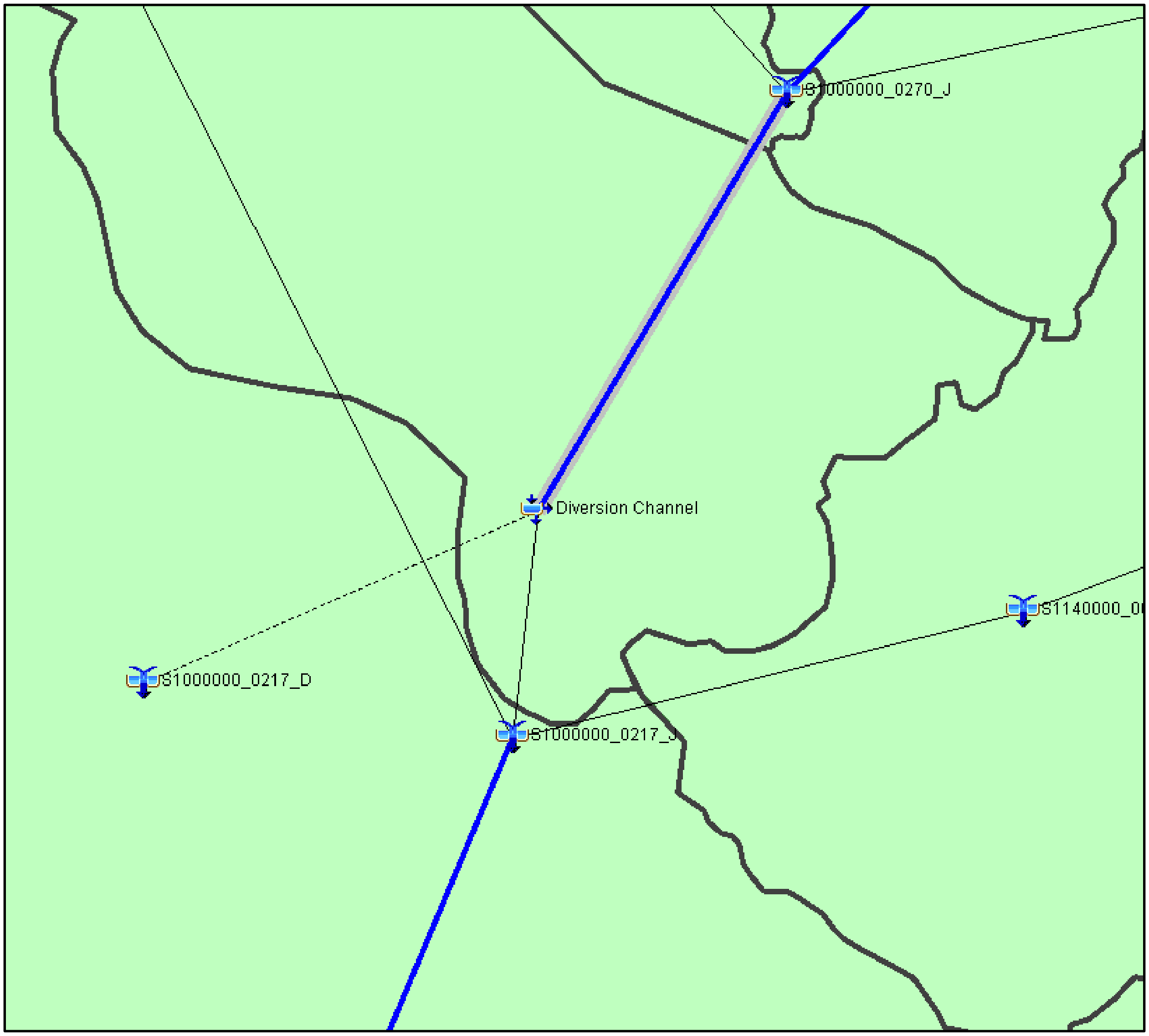


Figure 4.3. HEC-HMS Layout for Bypass Channel Alternative

The bypass channels were analyzed using a simplified method utilizing Manning's Equation and were sized based on the target peak discharge for the diverted flows. The bypass channels were sized for a peak discharge of 12,240 cfs. Table 4.12 shows the proposed conditions flow file for Luce Bayou with the proposed bypass channel alternative.

Table 4.12. Luce Bayou Hydraulic Model Flow File for Proposed Bypass Channel

River Station	HEC-HMS Junction	Peak Discharges (cfs)			
		10% (10YR)	2% (50YR)	1% (100YR)	0.2% (500YR)
39449.5	S1000000_0394_J	14,650	33,850	45,700	84,540
34375.1	S1000000_0344_J	14,723	33,990	45,888	84,735
26979.1	S1000000_0270_J	14,740	34,043	45,991	84,927
21698.0	S1000000_0217_J	4,581	22,059	33,937	72,995
15136.4	S1000000_0151_J	4,578	22,339	34,334	73,790
8295.3	S1000000_0083_J	4,574	22,314	34,352	73,839
5116.2	S1000000_0051_J	4,573	22,299	34,335	73,827
2930.1	S1000000_0029_J	5,457	22,296	34,339	73,842

The bypass channel was not analyzed independently of other drainage features; therefore, there are not metrics to be compared against existing conditions.

4.11 Combination Scenario

The three drainage scenarios, optimized channel modifications, upstream detention for the 10-year LOS, and bypass channel, were combined to achieve the 100-year level of service. Table 4.13 shows the flow file used for the combined alternative proposed conditions hydraulic model.

Table 4.13: Luce Bayou Hydraulic Model Flow File for Proposed Combined Scenario

River Station	HEC-HMS Junction	Peak Discharges (cfs)			
		10% (10YR)	2% (50YR)	1% (100YR)	0.2% (500YR)
39449.5	S1000000_0394_J	11,790	30,964	42,808	81,655
34375.1	S1000000_0344_J	11,872	31,111	43,001	81,981
26979.1	S1000000_0270_J	11,918	31,153	43,099	82,168
21698.0	S1000000_0217_J	3,753	19,126	31,030	70,297
15136.4	S1000000_0151_J	3,753	19,448	31,496	71,146
8295.3	S1000000_0083_J	3,814	19,469	31,538	71,235
5116.2	S1000000_0051_J	4,084	19,466	31,535	71,225
2930.1	S1000000_0029_J	5,496	19,473	31,552	71,262

The resulting water surface elevations from the hydraulic model for each of the drainage alternatives, as well as the revised existing conditions, are provided in the Appendices.

The resulting metrics for the combined scenario is provided in the table below and compared to the 100-year existing metrics. The proposed scenario also produces benefits in other storm events and the full comparison of these metrics are provided in **Appendix D**.

Table 4.14. Metrics for Combination Scenario

	Necessary Acquisition				Helped			
Level of Service	Structures	Area (Acres)	Roadway (Miles)	Parcels	Structures	Area (Acres)	Roadway (Miles)	Parcels
100YR	11	1025	1	159	122	339	4	359

4.12 Tributary Channel Modifications

Channel modifications were examined for three of the Luce Bayou tributaries. Mexican Gully (HCFCD Unit No. S114-00-00) was not examined for channel modifications due to an existing inline detention basin.

4.12.1 General Methodology

The methodology utilized for the tributary channel modifications followed a similar process as the Luce Bayou main stem channel modifications.

- Determine the channel modifications necessary for each tributary for each LOS based on HCFCD trapezoidal channel modifications.
- Create a geometry for each LOS.
- Create proposed storage-discharge functions for the reaches, which represent the streams, for each LOS.
- Incorporate the storage-discharge functions to the reaches in proposed conditions.

All of the channel modifications and resulting water surface elevations and level of service designations are independent of Luce Bayou main stem tailwater conditions.

Table 4.15. Average Right-of-Way Width for Tributary Channel Modifications

	Average ROW Width (ft)			
Stream	**10YR LOS**	**50YR LOS**	**100YR LOS**	**500YR LOS**
S115-00-00	74	79	85	97
S110-00-00	136	150	166	181
S102-00-00	132	165	201	254

The tributary channel modifications were analyzed independently of the main stem of Luce Bayou, so there can be no net increase of runoff from the tributaries into Luce Bayou. For the tributary modifications, the detention volume needed to mitigate for any potential impacts were estimated for each LOS with the below methodology.

- Determine the time-series outflow from each of the reaches under existing conditions. For example, for stream S115-00-00, the time-series outflow data for Reach "S1150000_0007_R" for HEC-HMS basin "S1000000_1%" would be exported.
- Determine the time-series outflow from each of the proposed reaches for each LOS scenario.
- Create a time-series diversion function from the difference between proposed – existing.
- Divert flow from the downstream end of the reach to a sink, which is used to determine the total volume diverted during the simulation.

Based on the analysis described above, Table 4.16 below shows the required detention volume in acre-feet for the proposed tributary channel modifications for each level of service.

Table 4.16. Detention Volume Required for Tributary Channel Modifications

Stream	Detention Volume Required (acre-feet)			
	10YR LOS	50YR LOS	100YR LOS	500YR LOS
S115-00-00	6	6	6	7
S110-00-00	77	91	91	94
S102-00-00	7	11	22	44

The detention locations identified represent a conservative estimate of the required area, but the required area could be smaller with a more detailed study. The amount of volume available in these identified detention locations were identified using three criteria:

- Location or proximity to the channel
- Outfall elevation
- Preliminary design –stage-storage

The locations for potential detention were evaluated using 2018 aerials and effective floodplains to determine available parcels. First, preference was given to parcels that were considered vacant of structures. The outfall elevation was identified from 2008 LiDAR and was assumed to be the standing water surface elevation within the channel. HCFCD criteria calls for an outfall into a HCFCD channel to be 1' above the ordinary high-water mark or 1' above the observed water surface elevation. An approximate required area was then determined from the required volume divided by the allowable depth.

4.12.2 Mexican Gully, S114-00-00

Mexican Gully was not examined for channel modifications due to an existing inline detention basin. The inline detention basin is located in the effective HEC-RAS model and its outlet is included in the model at river station 844. The notes for this structure indicated that "the structure is an outlet for a golf course pond (water feature) thereby explaining the oddity of the outfall inverts." The figure below was taken from the effective HEC-RAS model for Mexican Gully.

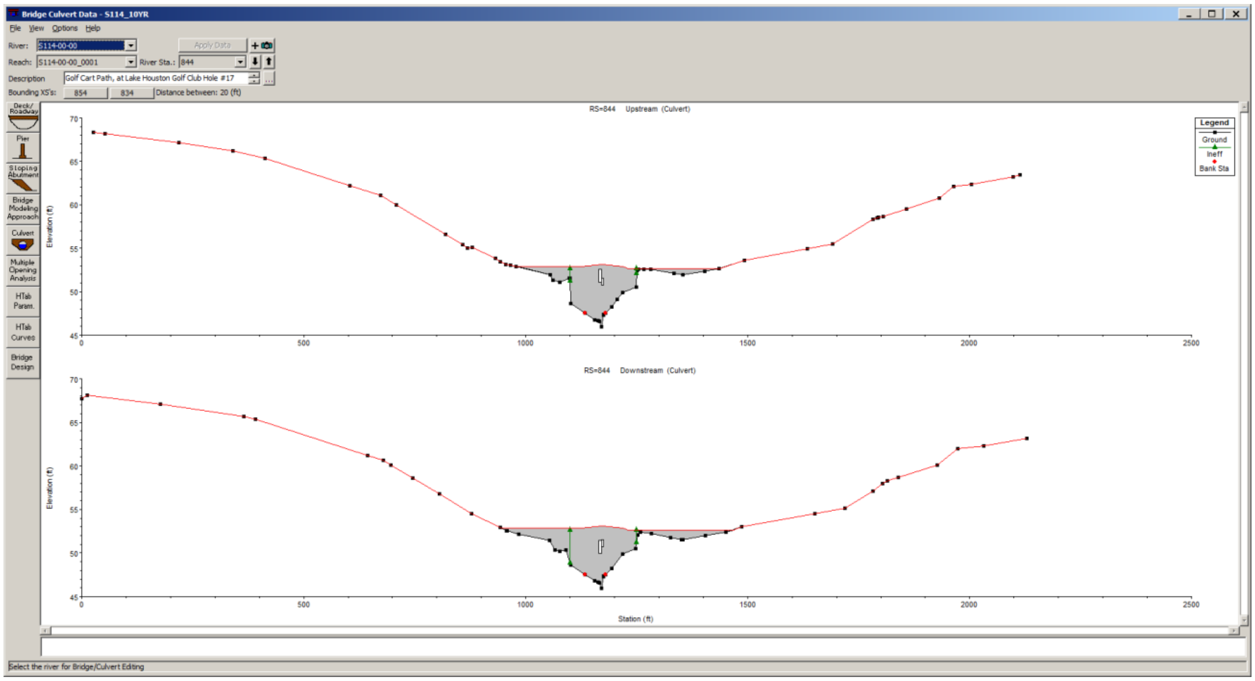


Figure 4.4. Bridge Culvert Data at River Station 844 – Golf Course Pond Outlet

Section 5 – Metrics & Costs

5.1 Introduction

The recommendation and prioritization of flood risk reduction scenarios within the Luce Bayou watershed was based on a combination of estimated implementation costs and evaluation of general project benefits.

5.2 Scenario Cost Components

Cost estimates were prepared for each of the proposed scenarios using a standardization cost estimate format provided by HCFCD. Cost estimates included several items such as right-of-way acquisition, wetlands mitigation, construction, overhead, and other costs. Detailed cost estimates for each scenario are provided in **Appendix E**.

5.2.1 Construction Costs

The construction cost estimates include earthwork, site preparation, landscaping, and demolition and construction of crossings. The costs provided for each alternative are based on the best available data for unit costs per HCFCD based on past bid items.

5.2.2 Environmental Costs

All of the alternatives were designed to reduce environmental impacts and costs, but not all costs could be determined in the feasibility phase. Wetland mitigation was estimated to be 0.1 acres per 1,000 linear feet of channel modifications.

5.2.3 Overhead Costs

Overhead costs are costs associated with the planning, engineering, design, mobilization, and management of the project. Additionally, a contingency was added to the subtotal of costs to account for any variation of costs or design changes between the feasibility phase and the construction phase. Below are the overhead costs as a percentage of the subtotal of costs.

- Mobilization – 5% of direct construction costs
- Planning, Engineering, Design – 12% of direct construction costs
- Construction Management – 10% of direct construction costs
- Contingencies – 30% of subtotal of costs

5.3 Summary of Estimated Costs

The sections below describe the costs associated with each drainage alternative, and provide the total costs including, construction, acquisitions, environmental, and overhead costs for each level of service.

5.4 Floodplain Preservation and Acquisition of Impacted Structures

The costs associated with the floodplain preservation and acquisition alternatives are based on the best available appraisal data from the Harris County Appraisal District (HCAD), which are appraisal values as of January 1, 2019. The floodplain preservation alternative involves acquiring all structures and areas within the inundation boundaries for each of the studied rainfall events. The cost for the land acquisition was evaluated by first determining the cost of the parcel on a per-acre basis, then multiplying that value by the area of that parcel required for acquisition. The acquisition of impacted structures alternative involves comparing the finished flood elevations (FFEs) to the water surface elevations in Luce Bayou for each rainfall event, and only acquiring the structures which are below the water surface elevation for each level of service. The costs associated with these alternatives are based on the 2019 HCAD values and were derived using the following method:

- An additional 30% was added to the HCAD total value (land + improvement) to account for variability in the appraisal value.
- A $750 appraisal fee and an $800 consultant fee were added to the total costs.
- A $10,000 demolition cost was included to the total cost if the acquisition of the parcel included the demolition of an existing structure.
- A $25,000 relocation cost was included to the total cost if the acquisition of the parcel included the removal and relocation of an existing resident.
- If the acquisition of the property will require condemnation, the costs were multiplied by 2. For the acquisition of properties for all drainage alternatives, condemnation was assumed. If the structures were acquired on a voluntary basis, the costs may be less than the costs provided in this section.

Table 5.1 provides the costs associated with the floodplain preservation alternative for each level of service.

Table 5.1. Costs for Floodplain Preservation

Level of Service	Structures	Area (Acres)	Cost ($)
10YR	12	820	$23M
50YR	113	1,223	$84M
100YR	146	1,364	$109M
500YR	217	1,879	$164M

Table 5.2 below provides the costs associated with the acquisition of impacted structures alternative for each level of service.

Table 5.2. Costs for Acquisition of Impacted Structures

Level of Service	Structures	Cost ($)
10YR	11	$4M
50YR	87	$52M
100YR	133	$75M
500YR	217	$122M

5.5 Upstream Detention

The costs associated with the detention option were estimated based on the amount of detention volume required and the associated acquisition and construction costs of this drainage alternative. Of all of the drainage alternatives presented, the costs for this alternative are the most conceptual due to the uncertainty of the specific location or locations for the proposed detention basin. The costs were determined for each level of service based on the required detention volume, which was assumed to be excavated and disposed of offsite, construction costs, and acquisition costs. The area required was estimated based on the volume required divided by an allowable depth of 15 feet, which was a conservative estimate of the depth of natural ground to the proposed outfall into Luce Bayou at the Harris/Liberty County line. The costs per acre of required area was estimated to be approximately $10,000 per acre. It should be noted that the costs associated with this drainage alternative could vary significantly if the assumptions for the costs for these items changed or were evaluated in more detail. Table 5.3 shows the costs associated with the upstream detention alternative for each level of service.

Table 5.3. Costs for Upstream Detention

Level of Service	Volume (acre-feet)	Area (Acres)	Cost ($)
10YR	7,015	500	$152M
50YR	55,847	3,723	$1.3B
100YR	84,860	5,645	$2B
500YR	168,928	11,262	$4B

The impracticality of locating the acreage needed to implement the 50-year through 500-year LOS makes recommendation of this scenario unfeasible.

5.6 Luce Bayou Main Stem Channel Modifications

The costs for the main stem channel modifications were determined from the required right-of-way (ROW) widths for each level of service. The required ROW widths exceed the existing ROW that is owned by HCFCD. Therefore, acquisition costs are a large part of the costs for this drainage alternative. The cost for acquisitions, including structures, was determined in the same way as described above. There are three existing crossing locations over Luce Bayou at: Huffman-Cleveland Road, FM 2100, and Doverbook Drive. The costs for the channel modification alternative for each level of service (with the exception of the 10-year LOS), includes the demolition, expansion, and construction of the crossings. Additionally, the volume of excavation needed for the channel modifications were quantified using the HEC-RAS channel modification tool, and it was assumed the excavation would be disposed of offsite. All of the proposed channel modifications were placed three feet above the flowline of the channel to avoid major environmental costs, but the costs for wetland mitigation was included at a rate of 0.1 acre per 1,000 linear feet of channel modifications. Table 5.4 provides the total costs associated with the main stem channel modifications for each level of service as well as the optimized channel modifications scenario.

Table 5.4. Costs for Channel Modifications

Level of Service	Cost ($)
10YR	$33M
Optimized	$78M
50YR	$103M
100YR	$163M
500YR	$468M

The drastic increase in costs for the 500-yr LOS impacts the practicality of implementation.

5.7 Bypass Channel for Luce Bayou Main Stem

The objective of the proposed bypass channel alternative was to divert runoff away from the main stem of Luce Bayou during extreme rainfall events to reduce flooding downstream of the confluence. The bypass channel was sized in combination with other drainage alternatives and was not sized as a standalone alternative for the specific levels of services. The costs for the diversion include acquisitions, volume of excavation, environmental, and site preparation. Two alignments were explored for the bypass channel. The costs for the two alignments are presented in Table 5.5 below.

Table 5.5. Costs for Bypass Channel

Alignment	Description	Cost ($)
Alignment 1	Luce Bayou to Red Gully	$110M
Alignment 2	Luce Bayou to Downstream Along Luce Bayou	$39M

Alignment 2 is the preferred alignment due to significant difference in costs based on the available depth available in Luce Bayou and its impact on needed right-of-way width.

5.8 Tributary Channel Modifications

The tributaries for Luce Bayou were evaluated for channel modifications to meet the desired level of service (LOS). The modifications were performed with the HEC-RAS channel modification tool for a trapezoidal channel improvement. Modifications were performed to meet the effective 10-year, 50-year, 100-year, and 500-year level of service. The three tributaries analyzed were S102-00-00 (Red Gully), S110-00-00 (Shook Gully), and S115-00-00 (John Young Gully).

The costs for the tributary channel modifications include detention, acquisitions, and construction costs. The acquisition costs for the tributaries was not analyzed in the same level of detail as the main stem ROW acquisitions, and was instead estimated on a per acre basis of $25k/acre (recommendation based from land values in the area). The costs for the tributary channel modifications for S102-00-00, S110-00-00, and S115-00-00 for each level of service are presented below.

Table 5.6. Costs for Tributary Channel Modifications

Description	Cost by Target LOS			
	10YR	50YR	100YR	500YR
S115-00-00 (John Young Gully)	$756K	$868k	$946K	$1.1M
S110-00-00 (Shook Gully)	$4.7M	$6.1M	$6.4M	$7.1M
S102-00-00 (Red Gully)	$1.3M	$2.0M	$2.8M	$4.3M

S114-00-00 (Mexican Gully) is a tributary to Luce Bayou that was studied. No recommendations were proposed for S114-00-00, because there are not any existing structures adjacent to S114-00-00 that are at risk. Additionally, there is an inline detention basin that provides controlled discharge downstream of the basin.

Section 6 – Dredging of the East Fork

6.1 Background of Flooding/Causes of Flooding

Harris County consists of portions of two larger watershed systems, the San Jacinto River and Buffalo Bayou, along with a number of smaller watershed systems. Each of these ultimately drains into Galveston Bay on the southeast side of the county. The channels and corresponding watersheds that make up portions of the San Jacinto River system are the West Fork of the San Jacinto River, East Fork of the San Jacinto River, Spring Creek, Cypress Creek, Little Cypress Creek, Willow Creek, Peach Creek-Caney Creek, Lake Creek, Luce Bayou, Jackson Bayou, and Goose Creek as shown in Exhibit 20. Cypress Creek, Spring Creek, Peach Creek-Caney Creek, Lake Creek, and Luce Bayou watersheds have large portions of their contributing drainage area outside of Harris County.

The East Fork of the San Jacinto River (HCFCD Unit No. G103-80-00) has a watershed that covers approximately 396 square miles upstream of Caney Creek with 384 square miles upstream of the Harris County border. This means that the 384 square miles outside of Harris County are not subject to the same drainage criteria for detention and mitigation as Harris County or HCFCD. Downstream of Caney Creek, 766 square miles are draining through the East Fork into Lake Houston. Lake Houston is a water supply reservoir located in northeast Harris County along the San Jacinto River, which includes the confluence of the East and West Forks. Exhibit 21 shows the contributing drainage area upstream of the project area. **Appendix F** contains documentation on the San Jacinto River and Lake Houston.

The San Jacinto River Authority (SJRA) is a public entity created by the Texas Legislature in 1937 whose jurisdiction covers all or part of seven counties, excluding Harris County. Its primary purpose is to implement long-term, regional project related to water supply and wastewater treatment. However, its secondary purpose is to coordinate regional flood planning. Constructed by SJRA beginning in 1969, Lake Conroe was completed in 1973 as a water supply reservoir through a joint venture with the City of Houston, which owns two-thirds of the water rights in the reservoir. Lake Conroe outfalls into the West Fork of the San Jacinto River.

Hurricane Harvey dropped an unprecedented amount of rain in the San Jacinto River watershed. The East Fork of the San Jacinto River experienced a resulting water surface elevation above a 0.20-percent AEP storm event. Lake Conroe reached a peak level of 206.2 feet above sea level during the morning of August 28th, with normal levels of the lake near 201 feet. Lake Conroe has a 6-foot flowage easement around the perimeter of the lake. Exhibit 22 shows the estimated peak flows in the San Jacinto River Basin from August 25th through August 29th. At that time, SJRA did not pre-release water from Lake Conroe. **Appendix G** contains documentation on Lake Conroe.

Another question SJRA frequently received is whether releases from the Lake Conroe dam are the cause of downstream flooding. The operational guidelines for Lake Conroe are such that the peak rate of flow released from the dam is lower than what would have occurred if the dam had not been built.

Since June 2018, a temporary flood mitigation strategy was approved by the Texas Commission on Environmental Quality (TCEQ). The strategy includes lowering Lake Conroe's water level by 1 foot in April and May, and by 2 feet in August and September. TCEQ approval was necessary on account of its regulation of water rights. The strategy is intended to provide flood mitigation while the USACE emergency dredging project is being completed.

There are no minimum detention requirements for Montgomery County; however, developments must cause no adverse impact and release flows according to pre-development conditions.

6.2 Effective Hydrologic & Hydraulic Conditions

The East Fork and West Fork are contained within separate models. The models described here are applicable to the East Fork. The existing FIS hydrologic methodology was updated with Tropical Storm Allison Recovery Project (TSARP). There is one HCFCD gaging station (Gage 790: G103_790 – East Fork San Jacinto at FM 1485 near the Harris/Montgomery County line) was used to determine the peak discharges for the hydraulic model. The current effective hydraulic model for the East Fork begins upstream of FM 1485 by over 10,500 feet. From this point, the model spans over 67,000 feet to Lake Houston past the confluence with Luce Bayou.

The existing flow file for East Fork has flow changes for almost every cross section from the county line down to Lake Houston. The flows by cross section are listed below.

Table 6.1. Flows by Storm Event from Effective HEC-RAS Hydraulic Model

River	RS	10PCT_10yr	2PCT_50yr	1PCT_100yr	0.2PCT_500yr
G103-80-00	118228.4	10,500	24,500	34,200	66,100
G103-80-00	FM 1485 (Huffman-Cleveland Road)				
G103-80-00	104043.6	10,527	24,553	34,253	66,127
G103-80-00	102148.9	10,578	24,657	34,357	66,178
G103-80-00	98845.11	10,611	24,731	34,431	66,215
G103-80-00	96828.22	10,638	24,776	34,476	66,238
G103-80-00	95509.5	10,652	24,804	34,504	66,252
G103-80-00	94407.89	10,665	24,829	34,529	66,265
G103-80-00	92882.15	10,685	24,870	34,570	66,285
G103-80-00	91343.42	10,727	24,955	34,655	66,327
G103-80-00	88594.25	10,764	25,028	34,728	66,364
G103-80-00	87213.89	10,793	25,086	34,786	66,393
G103-80-00	85298.22	10,839	25,177	34,877	66,439
G103-80-00	81851.79	10,860	25,219	34,919	66,460
G103-80-00	80668.04	10,890	25,281	34,981	66,490
G103-80-00	78754.21	10,902	25,304	35,004	66,502
G103-80-00	77767.82	10,948	25,397	35,097	66,548
G103-80-00	74263.07	10,969	25,437	35,137	66,569
G103-80-00	73434.88	11,000	25,500	35,200	66,600
G103-80-00	71410.85	41,300	84,400	108,500	182,800
G103-80-00	70314.34	41,308	84,467	108,584	182,984
G103-80-00	68799.84	41,313	84,507	108,634	183,094
G103-80-00	67491.99	41,315	84,520	108,651	183,131
G103-80-00	66268.62	41,323	84,582	108,727	183,300
G103-80-00	65134.8	41,358	84,860	109,075	184,066
G103-80-00	60012.01	41,369	84,946	109,182	184,301
G103-80-00	56652.75	41,400	85,200	109,500	185,000
G103-80-00	53751.67	42,700	94,300	121,700	211,500
G103-80-00	51110.17	42,935	94,300	121,724	211,500

Besides the FM1485 crossing, there are no other bridge /culvert crossings of the East Fork in Harris County. The regulatory floodplain is based on the aforementioned rainfall totals before the implementation of Atlas 14 as described in Section 3.

FEMA FIRM panels that encompass the East Fork of San Jacinto watershed in Harris County include 48201C0310L and C0120L. The floodway is broad in Harris County, extending as much as 2,500 feet. The neighborhoods that have portions impacted by the 0.2% floodplains are Tayme Ranchettes, Northwood Country Estates, River Terrace, Commons Waterway, Magnolia Point, and Paradise Oaks. In Montgomery County, the FIRM panels are 480483C0600G, 48339C0625C, and 48339C0450G. In Liberty County, the FIRM panels are 48291C0275C, C0150C, and C0130C and in Walker County, the FIRM panels are 48471C0425D, C0400D, C0275D, and C0300D.

6.3 Requirements for Dredging

From conversations with HCFCD Environmental staff and review of environmental documentation, the following sections outline the considerations when moving forward with a dredging project.

6.3.1 Agency Participation

A dredging project could require coordination with multiple agencies depending on the scope and location for a dredging project. These agencies include the United States Army Corps of Engineers (USACE), Texas Commission on Environmental Quality (TCEQ), United States Fish and Wildlife Services (USFWS), and Texas Parks and Wildlife (TPWS). A typical dredging project has several phases, and data is collected during each: Project planning, advertising, bidding, contract award, contractor, dredge equipment, dredging, placement, inspection, timekeeping, project completion, and payment.

6.3.2 Environmental Concerns

Federal jurisdiction extends to different features of a dredging project including, but not limited to: waters of the U.S. (WOTUS), threatened and endangered species, and adjacent wetlands. Total avoidance of all jurisdictional features is not practicable.

Under the Clean Water Act, six categories of waters are considered “waters of the United States:”

- Traditional navigable waters
- Tributaries
- Certain ditches
- Certain lakes and ponds
- Impoundments
- Adjacent wetlands

The ordinary high-water mark (OHWM) defines the lateral limits of federal jurisdiction for non-tidal waters. Disturbance of the OHWM is typically the feature that triggers USACE permitting requirements. The OHWM is delineated by an environmental specialist and its boundaries are stated within a delineation report that is sent to the USACE for a WOTUS Jurisdictional Determination.

If the area of dredging provides habit for any species of animal and vegetation listed on the threatened and endangered species/plant list for the United States or Texas, coordination would be required with TPWD and USFWS. The main threatened and endangered class encountered in dredging projects in our region is freshwater mussels. There are seventeen different species of mollusk listed on the Federal and State Listed Invertebrates on the TPWS website. HCFCD is not currently aware if Federal or State-listed mussels are present in the East Fork of the San Jacinto River.

Three types of non-tidal regulatory wetlands are forested (PFO), scrub/shrub (PSS), and emergent (PEM). A detailed wetland delineation would be required to confirm the areas of wetland and upland features. Impacts to wetlands require compensatory mitigation through either: mitigation banks; in-lieu fee programs; or permittee-responsible mitigation.

6.3.3 Environmental Permits

A pivotal feature of completing a dredging project is having a location to place the dredged material. Ideally, locations are along the banks of the waterway being dredged. In past projects, sand pits have been utilized for the material. The location where the dredged material is placed is subject to multiple restrictions. An ideal location for dredged material placement would be on an area delineated as uplands and therefore not subject to Clean Water Act jurisdiction. Uplands areas are areas lacking any of the three indicators from the wetland delineation criteria. The three indicators of a wetland set forth in the guidance documents are hydrophytic vegetation, hydric soils, and hydrology.

Placement on an uplands area would still require coordination with TCEQ regarding water discharges from the dredged material to ensure that stormwater quality regulations are met under Section 404 of the Clean Water Act permits.

The TCEQ and the USACE have developed a tiered system of review for all standard individual Section 404 permit applications based on project size and the area of waters in the state affected. Generally, for small projects (Tier I) that affect less than three acres of waters in the state, or less than 1,500 linear-feet of streams, TCEQ allows for best management practices to address the likelihood that water quality will remain at the desired level. Best management practices would be required to ensure runoff from the placement area meet certain thresholds, such as turbidity and total suspended solids concentration, before releasing flows into the receiving stream. Tier II projects are subject to a certification review by TCEQ. The applicant must complete and submit the 401-certification questionnaire and the alternatives analysis checklist to TCEQ for Tier II.

If the dredged material is placed entirely within an uplands area and the dredging activity is for maintenance purposes, the work could be completed under a nationwide permit issued by the USACE. Under Section 404(e) of the Clean Water Act, the USACE can issue general permits to authorize activities that have only minimal individual and cumulative adverse environmental impacts. A nationwide permit is a general permit that authorizes activities across the county. There are currently 54 nationwide permits available that authorize a wide variety of activities.

If the dredged material is placed within a wetland or if the impact to the dredged area exceeds previously authorized depths, the impacted wetland and water of the U.S. would require mitigation and an individual permit would be required from the USACE. Activities that do not qualify for authorization under the nationwide permit program have to apply for a Standard Individual Permit (IP). An IP involves evaluation of individual, project specification applications in what can be considered four steps: pre-application consultant, formal permit application review, public notice comment period, and decision-making. Applying for an IP requires a more thorough review of the potential environmental and socioeconomic effects of the proposed activity.

The process requires consideration of potentially less environmentally damaging alternatives available to accomplish the project purpose, to discuss measures for reducing the impacts of the project, and to inform the applicant of the factors the USACE considers in its decision-making process. Once a complete application is received, the formal review process begins. A public notice is prepared, evaluates the impacts of the project and considers all comments received, addresses potential modifications to the project if appropriate, and drafts or oversees drafting of appropriate documentation to support a recommended permit decision. The permit decision document includes a discussion of the environmental impacts of the project, the findings of the public interest review process, and any special evaluation required by the type of activity such as determinations of compliance with the Section 404(b)(1) Guidelines.

It has been well established that the timeline for approval of a individual permit application take two years from the pre-application consultant meeting through the permit issuance.

It is cost prohibitive to place dredged material at a location that is not along or adjacent to the banks of the waterway being dredged. The amount of on-road capable vehicles needed is the main reason it is cost prohibitive.

On previous projects completed by HCFCD, Section 10 of the Rivers and Harbors Act of 1899 (Section 10) might also be considered. Section 10 is applicable for any structures in or over any navigable water of the United States and if the structure or work affects the course, location, or condition of the water body. Section 10, navigable waters are designated by Congress and are identified as those waters that are currently, historically and could in the future be used for interstate commerce. In the past, the USACE has not required that Section 10 be applied to areas upstream of the Lake Houston dam and spillway due to the structure of the dam preventing a vessel from navigating from the Port of Houston upstream.

A letter of permission is a type of permit issued through an abbreviated processing procedure that includes coordination with Federal and state fish and wildlife agencies, and a public interest evaluation, but without the requirements of publishing a public notice. It can be used on projects subject to Section 10 when the USACE has concluded that the proposed work would be 1) minor; 2) would not have significant individual or cumulative impacts on environmental values; 3) should encounter no appreciable opposition.

6.3.4 Definition of Dredging

First, there is a difference between a dredging and desilt project. Desilting refers to the removal of earthy materials, fine sand, etc. carried by running water and deposited as sediment. Desilt projects consist of sediment and debris removal on man-made channels where HCFCD has available right-of-way. Man-made channels offer the benefit of construction plans indicating how the channel was built. The construction plans would be employed as a guide to the desilt project. HCFCD has performed desiltation or desilt projects throughout Harris County. These projects occur under HCFCD's maintenance program and are covered by a USACE Nationwide Permit #43. These projects typically range between 1,000 and 2,000 feet, but can be as long as

10,000 feet as shown in the current projects for tributaries discharging to Addicks and Barker Reservoir. The East Fork of the San Jacinto River and Luce Bayou are both natural channels and HCFCD does not currently have right-of-way along Luce Bayou or the East Fork of the San Jacinto River.

There are multiple interpretations in what dredging consists of in regard to the geometry of a channel. The following figures have been prepared to explain the difference and how it impacts permitting requirements.

Figure 6.1 presents the physical representation of a channel geometry and one interpretation of dredging activities. In this figure, the carrying capacity is changed through alterations to the channel geometry by widening of the channel width and channel depth. Sometimes, this interpretation of dredging is utilized when the soil strength is not sufficient to maintain the current side slope causing future erosion issues. The ordinary high-water mark (OHWM) is impacted in this interpretation triggering more intensive documentation and permitting requirements with the USACE. The ordinary high water mark is a "line of the shore established by the fluctuations of water and indicated by physical characteristics such as clear, natural line impressed on the bank, shelving, changes in the character of soil, destruction of terrestrial vegetation, the presence of litter and debris, or other appropriate means that consider the characteristics of the surrounding areas." (33 CFR 328.3) OHWM are often as various elevations through a channel and can vary between left and right banks. Under the Clean Water Act, the OHWM defines the lateral limits of federal jurisdiction for non-tidal waters of the U.S. in the absence of adjacent wetlands. More surface area is also impacted in this interpretation and therefore mitigation is needed for the trees, possible wetlands, and other vegetation along the banks of the channel. In total, the types of mitigation required for this interpretation of dredging is channel, stream, and riparian vegetation mitigation.

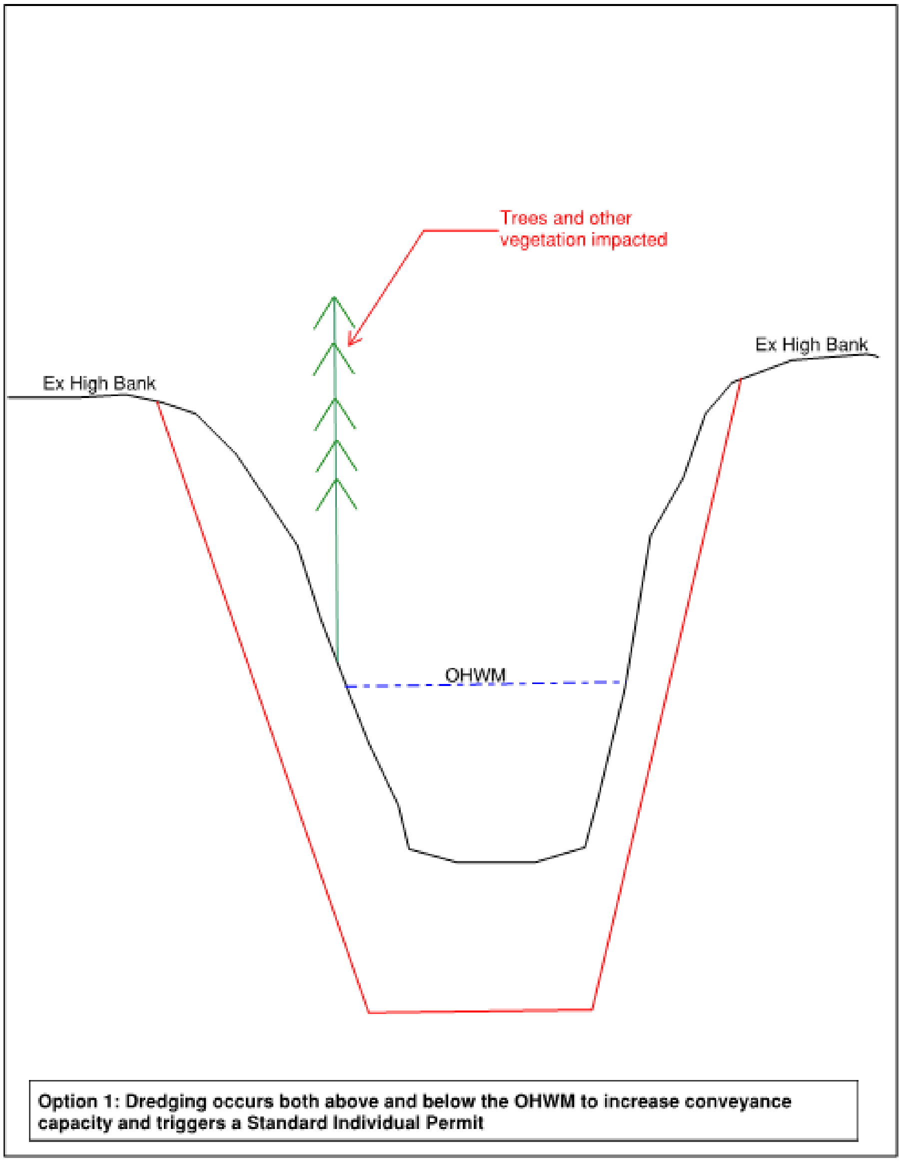


Figure 6.1. Area near Harris-Montgomery County Line

Figure 6.2 is the second interpretation of the physical representation of a channel geometry and interpretation of dredging activities. In this figure, the carrying capacity is changed through alterations to the channel geometry by deepening the channel depth. As the dredging activities are occurring below the OHWM, the soil strength is not critical. Soils below the static water surface elevation are typically stable due to lack of shrink/swell applications on the soils. If impacts below the OHWM are limited to restoring previous channel capacity, then mitigation requirements and federal requirements are significantly lessened. Figure 6.2 is more amenable to HCFCD due to the minimization of regulations, timing, and costs.

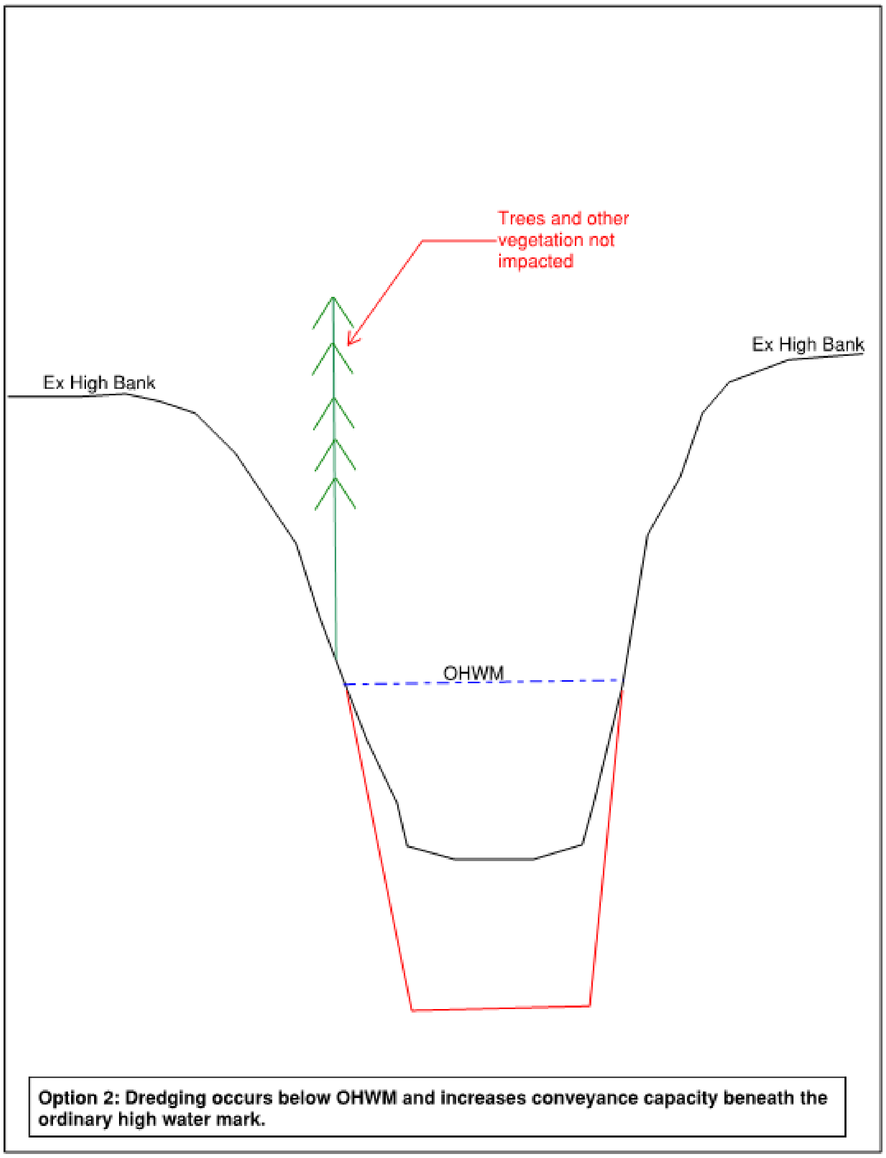


Figure 6.2. Area near Lake Houston

6.4 Preliminary Investigation of Environmental Concerns

Luce Bayou, upstream of the developed residential areas, appears to be a forested wetland area. The National Wetland Inventory shows all of the Luce Bayou banks from the confluence to the CenterPoint Easement north of FM 2100 as open water. North of the CenterPoint easement a mixture of open water and Freshwater Forested/Shrub Wetland is shown. A detailed wetland delineation would be required to confirm the areas of wetland and upland features.

The National Wetland Inventory shows all of the East Fork of the San Jacinto River banks as a mixture of open water and Freshwater Forested/Shrub Wetland with Riverine Wetlands north of Northwood Country Road. A detailed wetland delineation would be required to confirm the areas of wetland and upland features.

There does appear to be a sand pit operation at the border of Harris County and Caney Creek. This location would need additional investigation as a dredge placement area for the East Fork. The current West Fork dredging project has a dredge placement area located 10 miles upriver that is conveying the dredged material through a pipeline in the river supported by multiple booster pumps.

As part of the recommended environmental due diligence, sediment to be dredged must be tested for known contaminants and pollutants. There does not appear to be any large industrial facilities along the East Fork that could pose a high potential for this step.

6.5 Preliminary Investigation of Sediment Deposition

Fifteen cross sections were examined for comparison purposes in two locations shown in the following two figures. Table 6.2 lists the cross sections examined.

Table 6.2. Cross Sections Analyzed for Sediment Deposition

XS Name	Description from Effective Model
62736.58	411v48 Bank Station offset = 768
65134.8	411v47 Bank Station offset = 1056 No block necessary for ROB. Flow will be conveyed.
66268.62	411v41 Bank Station offset = 1707 LOB block due to a parallel stream causing no conveyance No block necessary for ROB. Flow will be conveyed.
68799.84	411v40 Bank Station offset = 1342 Extended XS on LOB to elev. 64 No block necessary for ROB. Flow will be conveyed.
70314.34	411v39 Bank Station offset = 1282 Extended XS on LOB to elev. 64 No block necessary for ROB. Flow will be conveyed.
71410.85	411v38 Bank Station offset = 1412 Extended XS on LOB to elev. 64
73434.88	411v37 Bank Station offset = 2069 ROB block and low Manning's in place to model Caney Creek, a study stream.
81851.79	411v29 Bank Station offset = 3821 ROB block at edge of watershed
82583.35	411v28 Bank Station offset = 3862 ROB block at edge of watershed
83946.74	411v27 Bank Station offset = 3614
87213.89	411v25 Bank Station offset = 2281
90087.30	411v23 Bank Station offset = 3127 block on ROB to close cross section
94407.89	411v20 Bank Station offset = 1632 ROB flow will be conveyed for 500yr flood
98845.11	411v16 Bank Station offset = 2152
107249.7	Copy of 411s1u: XS 1/4 Bank Station offset = 504

Figure 6.3 shows the general area and cross sections examined at the upstream portion of the East Fork near the Harris County line with Montgomery County.

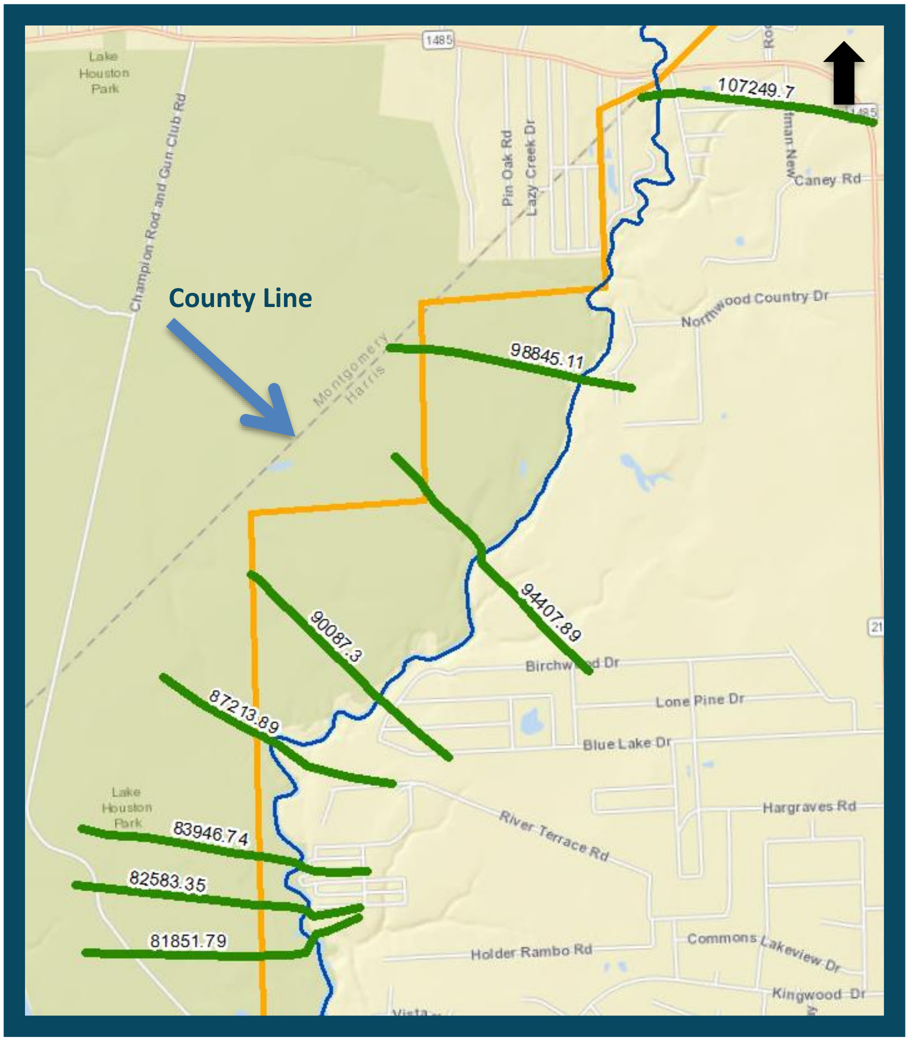


Figure 6.3. Area near Harris-Montgomery County Line

Figure 6.4 shows the general area and cross sections examined downstream of the confluence with Caney Creek, but upstream of Lake Houston. Exhibit 23 shows illustrates all of the cross sections in relation to the project boundary.

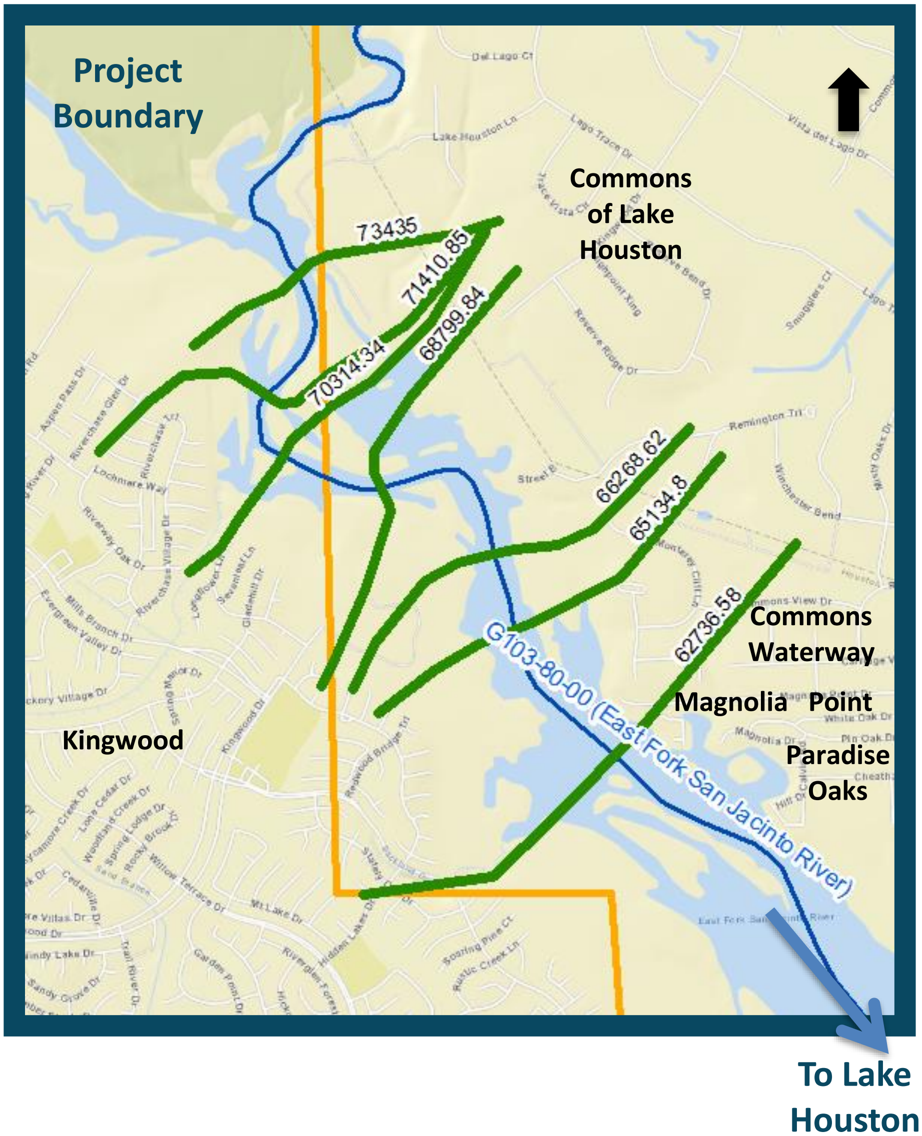


Figure 6.4. Area near Lake Houston

Conditions regarding sediment deposition on the East Fork of the San Jacinto River were examined in three ways. The purpose was to quantify if sediment deposition was occurring using available data.

1. Changes in geometry above the water surface
    - Aerial photography
    - LiDAR
2. Changes in geometry below the water surface
    - Bathymetry
3. Carrying capacity

6.5.1 Changes in Geometry above the Water Surface

Aerial Photography

Aerial photography was downloaded from the National Oceanic and Atmospheric Administration (NOAA) Data Access Viewer (DAV). The DAV hosts elevation, imagery, and land cover data for download of the coastal U.S. and its territories. Aerial imagery for 2006 and 2016 was available for download from this site. Aerial imagery for 2018 was provided by HCFCD.

Aerial images were examined at the locations of the cross sections to estimate the width of the channel. The width of the channel was subjective based on engineering judgment.

Table 6.3. Results of Aerial Imagery

	Aerials			Difference in Aerial Lengths		
	2006	2016	2018	2006-2016	2006-2018	2016-2018
XS	Length (ft)	Length (ft)	Length (ft)	Diff (ft)	Diff (ft)	Diff (ft)
62736.58	1,778.28	1,764.14	1,769.89	14.14	8.39	-5.75
65134.8	871.28	877.25	886.11	-5.97	-14.82	-8.85
66268.62	627.43	655.30	652.86	-27.87	-25.43	2.44
68799.84	338.71	339.41	355.13	-0.70	-16.42	-15.72
70314.34	217.58	278.31	233.60	-60.72	-16.01	44.71
71410.85	458.51	462.73	678.60	-4.22	-220.09	-215.87
73434.88	380.58	380.58	368.00	0.00	12.58	12.58
81851.79	154.56	147.99	168.18	6.57	-13.62	-20.19
82583.35	122.45	119.65	125.41	2.80	-2.96	-5.76
83946.74	143.84	136.20	125.89	7.64	17.94	10.30
87213.89	161.95	132.80	111.31	29.15	50.64	21.49
90087.3	110.96	102.18	103.72	8.78	7.23	-1.55
94407.89	122.32	114.06	149.81	8.26	-27.49	-35.75
98845.11	84.27	68.26	87.65	16.02	-3.38	-19.39
107249.7	62.95	57.92	89.24	5.03	-26.29	-31.32

Footnotes:

1. Negative values mean that the channel widened.
2. Positive values mean that the channel width reduced.

The differences show that between 2006 and 2016 that the East Fork channel width appeared to reduce closer to the Harris-Montgomery County line while closer to Lake Houston, the channel width expanded. The trend of the channel widened was more prevalent in the comparison from 2006 to 2018 and 2016 to 2018.

Then, the distance between the bank stations for current effective HEC-RAS model cross sections was calculated and compared with the lengths estimated from the aerial imagery as shown in Table 6.4. Bank stations are points set in the HEC-RAS model that affect where the channel is defined into three distinct conveyance zones. By segregating out the different conveyance zones, the Manning's equation can more appropriately determine the energy loss through the system and therefore, the resulting water surface elevations. Ultimately, HEC-RAS compresses everything into a single Manning's "n" roughness value for each cross section as a one-dimensional model, but it computes the channel and the overbanks separately.

Table 6.4. Comparison of Aerial Imagery to Effective HEC-RAS Model

		Difference from HEC-RAS to Aerial Length		
		XS-2006	XS-2016	XS-2018
XS	Cross Section Width Btw BS	Diff (ft)	Diff (ft)	Diff (ft)
107249.7	88.66	25.71	30.74	-0.58
98845.11	178.59	94.32	110.33	90.94
94407.89	185	62.68	70.94	35.19
90087.3	144	33.04	41.82	40.28
87213.89	145	-16.95	12.20	33.69
83946.74	160	16.16	23.80	34.11
82583.35	153	30.55	33.35	27.59
81851.79	258	103.44	110.01	89.82
73434.88	399.6	19.02	19.02	31.60
71410.85	480.39	21.88	17.66	-198.21
70314.34	368.43	150.85	90.12	134.83
68799.84	398.61	59.90	59.20	43.48
66268.62	633.23	5.80	-22.07	-19.63
65134.8	808.3	-62.98	-68.95	-77.81
62736.58	1749.83	-28.45	-14.31	-20.06

Footnotes:

1. Negative values mean that the distance between the bank stations of the modeled cross section is smaller than what was approximated from the aerial imagery.
2. Positive values mean that the distance between the bank stations of the modeled cross section is wider than what was approximated from the aerial imagery.

The overall trend prevalent from the comparison of aerial imagery to the distance between the modeled bank stations was that the bank station distance is wider than what was approximated from the aerial imagery. A sensitivity analysis was not completed on how much shifting the bank stations would have on water surface elevation and ultimately on the comparison between the aerial imagery and the distance in the HEC-RAS model. It may be necessary in a future study to determine the long-term effects of how the shifting stream banks impact the carrying capacity of the East Fork.

Light Detection and Ranging (LiDAR)

Light Detection and Ranging (LiDAR) data was provided by HCFCD through their partnership with by the Houston-Galveston Area Council (HGAC) whose mission is to serve as the instrument of local government cooperation for the 13 counties in their service region. H-GAC periodically collects LiDAR data for the region. It is ground elevation data above a static water surface elevation as it is unable to penetrate the region's muddy waters since it is collected by reflecting light.

The analysis was performed using HEC-RAS and Excel to examine the 2001, 2008, and 2018 LiDAR data. **Appendix H** contains the results of this comparison. The LiDAR data was compared at these cross sections to view the channel width and overbank changes over time. The flat line across the channel shows the water surface elevation on the day the LiDAR was collected. Since LiDAR cannot penetrate water, information below the static water surface elevation cannot be determined with LiDAR. The 2001 LiDAR data was utilized in the creation of the effective model for the East Fork, the 2008 LiDAR data was collected in response to Hurricane Ike, and the 2018 LiDAR was collected in response to Hurricane Harvey. In general, the LiDAR data shows that erosion has occurred above the static water surface elevation on the East Fork side slopes and areas where the channel is widening.

6.5.2 Geometry below the Water Surface

To analyze the geometry below the water surface, bathymetry data was obtained from the Texas Water Development Board (TWDB) from their recent studies of volumetric and sedimentation studies of Lake Houston and portions of five contributing tributaries. Periodically, the TWDB, authorized by the Texas Water Code Section 15.804, performs surveys to determine reservoir storage capacity, sedimentation levels, rates of sedimentation, and projected water supply availability. Bathymetry is defined as the measurement of depth of water in oceans, seas, or lakes.

The TWBD collected bathymetric data using a single-beam, multi-frequency sub-bottom profiling depth sounder integrated with differential global positioning system equipment. Data as collected along pre-planned survey line oriented perpendicular to the assumed location of the original river channels and spaced approximately 500 feet apart. The point file resulting from spatial interpolation is used to create volumetric and sediment Triangulated Irregular Network (TIN) models and contours.

To perform these calculations, data was provided from the 1994, 2011, and 2018 volumetric surveys. The 2011 data was collected between December 13, 2011, and December 19, 2011 and the 2018 data was collected between March 19, 2018, and June 13, 2018. Table 6.5 shows the previous capacity estimates from these volumetric surveys.

Table 6.5. Data from TWDB Volumetric Surveys of Lake Houston

Year of Report	Total Reservoir Capacity (acre-feet)	Estimated Capacity Loss Rate (acre-feet/year)
Original Design	158,553	-
1965	146,769	1,071.3
1994	136,381	585.5
2011	126,900	344 – 689
2018	128,775	384

Each TDWB study recommends repeating the survey with the same calculation methodology every 10 years or after major flood events.

The analysis of their bathymetry data was performed in ArcGIS by examining the 1994, 2011, and 2018 surfaces beneath the water. The extent of the 2018 bathymetric data available through TWDB ended on the East Fork of the San Jacinto upstream of cross section 90087.3, on Caney Creek upstream of cross section 11020.73, Luce Bayou upstream of cross section 20416.72, and multiple streams to the west of the project area. The volumetric survey reports completed on Lake Houston, including the 2018 study from which the data was provided, are located in **Appendix F**. There was not bathymetry data available from all three analyses upstream of cross section 68799.84. **Appendix I** contains the results of the comparison of geometry below the surface by cross section. Overall, the data shows inconsistent trends with a few cross sections showing sediment deposition between 2011 and 2018 and other showing erosion between 2011 and 2018. The 1994 data was consistently at an elevation above the 2011 and 2018 surfaces indicating erosion. In conclusion, the data shows that erosion and sedimentation has occurred beneath the static water surface level. As Lake Houston's primary purpose is to provide storage for drinking water supplies, sedimentation below the static water surface elevation would impact the volume of water supplies which concurs with the TWDB report.

6.6 Carrying Capacity

The level of service within the existing East Fork of the San Jacinto River was calculated at providing less than a 10-year level of service during the establishment of the baseline conditions.

For this analysis, a theoretically based calculation was performed illustrating the carrying capacity of the channel and was based on the following assumptions:

1. A trapezoidal channel.
2. 2 feet horizontal: 1-foot vertical side slope for banks.
3. Overall channel slope of 0.0017 ft/ft.
4. Manning's "n" value of 0.04.

5. Normal depth calculated by taking the difference between the average bank station vertical elevation and the flowline from the HEC-RAS model.

6. No static water surface elevation was applied.

7. The width of the channel utilized was estimated from the accompanying aerial imagery. Shown in Table 6.4.

Table 6.6. Carrying Capacity for Existing Channel Cross Section

				Flow (cfs)			
XS	**Avg BS El**	**Flowline**	**Normal Depth (ft)**	**HEC-RAS**	**2006**	**2016**	**2018**
107249.7	53.75	43.7	10.05	10,500	2,300	1,900	4,100
98845.11	51.695	40.42	11.275	10,611	3,900	2,600	4,200
94407.89	51.66	39.61	12.05	10,665	7,500	6,700	10,100
90087.3	51.2	37.7	13.5	10,727	6,800	5,900	6,100
87213.89	49.88	30.88	19	10,793	16,000	10,600	6,900
83946.74	47.46	26.91	20.55	10,839	12,700	11,200	9,100
82583.35	47.28	27.13	20.15	10,839	8,600	8,100	9,100
81851.79	45.885	32.86	13.025	10,860	11,300	10,600	12,800
73434.88	47.155	31.17	15.985	11,000	47,700	47,700	45,800
71410.85	45.635	27.81	17.825	41,300	69,500	70,200	110,300
70314.34	47.805	25.83	21.975	41,308	30,000	45,200	33,900
68799.84	46.9	29.15	17.75	41,313	47,100	47,300	50,120
66268.62	43.63	25.44	18.19	41,323	103,800	109,200	108,701
65134.8	44.41	28.95	15.46	41,358	117,600	118,500	119,827
62736.58	45	31.66	13.34	41,358	198,100	196,500	197,150

The data from the analysis, shown in Table 6.6, supports the notion that the existing channel is not capable of carrying the flows within the main channel (between the bank stations).

The second theoretically based calculation was performed illustrating the width of channel needed to carry the flows of the East Fork of the San Jacinto River and was based on the following assumptions:

1. A trapezoidal channel.

2. 2 feet horizontal: 1-foot vertical side slope for banks.

3. Overall channel slope of 0.0017 ft/ft.

4. Manning's "n" value of 0.04.

5. Water surface elevations from effective HEC-RAS Model subtracted from the flowline elevation from the effective HEC-RAS model. This assumption assumes no increase in the existing water surface elevations and no static water surface elevation is applied.

6. Using goal seek, calculate a width to carry flows within +-0.8% of the effective flows with no rise in water surface elevation

Once a channel width was calculated to carry the effective flows, then the water surface depth, calculated by subtracting the water surface elevations from the flowline elevation, was lessened by 2'. This would create the assumption of 2 feet of sediment deposition while evaluating its impact on channel width. This analysis was also performed assuming 4 feet of sediment depth.

Table 6.7. Results of Sediment Deposition Theoretical Calculation 10-year and 50-year Rainfall Event

					Channel Width in Feet Needed to Carry Flows					
	Effective Flows				Eff Q	2'	4'	Eff Q	2'	4'
XS	10-yr	50-yr	100-yr	500-yr	10-yr	10-yr	10-yr	50-yr	50-yr	50-yr
62736.58	41,358	84,860	109,075	184,066	325	387	481	463	535	636
65134.8	41,358	84,860	109,075	184,066	262	296	345	378	421	478
66268.62	41,323	84,582	108,727	183,300	220	239	264	317	343	376
68799.84	41,313	84,507	108,634	183,094	247	275	314	346	380	424
70314.34	41,308	84,467	108,584	182,984	211	226	246	297	317	342
71410.85	41,300	84,400	108,500	182,800	222	241	266	312	336	367
73434.88	11,000	25,500	35,200	66,600	109	114	122	156	163	174
81851.79	10,860	25,219	34,919	66,460	110	116	125	157	165	176
82583.35	10,839	25,177	34,877	66,439	105	105	107	146	148	152
83946.74	10,839	25,177	34,877	66,439	105	105	107	145	147	151
87213.89	10,793	25,086	34,786	66,393	106	108	113	149	154	160
90087.30	10,727	24,955	34,655	66,327	120	132	151	168	181	199
94407.89	10,665	24,829	34,529	66,265	117	128	145	165	177	194
98845.11	10,611	24,731	34,431	66,215	110	116	126	154	162	172
107249.7	10,500	24,500	34,200	66,100	108	113	122	153	160	170

Table 6.8. Results of Sediment Deposition Theoretical Calculation 100-year and 500-year Rainfall Event

					Channel Width in Feet Needed to Carry Flows					
	Effective Flows				Eff Q	2'	4'	Eff Q	2'	4'
XS	10-yr	50-yr	100-yr	500-yr	100-yr	100-yr	100-yr	500-yr	500-yr	500-yr
62736.58	41,358	84,860	109,075	184,066	520	594	695	643	719	816
65134.8	41,358	84,860	109,075	184,066	427	473	533	543	590	652
66268.62	41,323	84,582	108,727	183,300	360	388	423	462	494	534
68799.84	41,313	84,507	108,634	183,094	388	423	468	487	525	571
70314.34	41,308	84,467	108,584	182,984	335	356	384	428	453	484
71410.85	41,300	84,400	108,500	182,800	352	378	410	447	475	511
73434.88	11,000	25,500	35,200	66,600	180	189	200	239	250	263
81851.79	10,860	25,219	34,919	66,460	181	190	202	240	251	265
82583.35	10,839	25,177	34,877	66,439	166	170	175	219	225	232
83946.74	10,839	25,177	34,877	66,439	166	169	174	218	223	230
87213.89	10,793	25,086	34,786	66,393	171	177	184	227	234	244
90087.30	10,727	24,955	34,655	66,327	194	207	226	255	270	290
94407.89	10,665	24,829	34,529	66,265	191	204	221	252	267	286
98845.11	10,611	24,731	34,431	66,215	179	187	198	237	247	261
107249.7	10,500	24,500	34,200	66,100	177	185	196	236	246	259

The information shown in Tables 6.7 and 6.8 illustrate how the channel width would need to widen as sediment is deposited and no longer able to be used to carry flows. However, these calculations do not take into account the impact velocity has to sediment deposit. The impact of velocity can be seen through the bathymetry data which shows that in some locations the channel was deepened between 2008 and 2018.

6.7 Other Ongoing Efforts

The Upper San Jacinto Regional Watershed Master Drainage Plan, HCFCD Bond Project No. C-17, is a comprehensive regional study funded by a federal grant and local partnerships. The study effort is led by HCFCD and joined by three other local agencies: The San Jacinto River Authority (SJRA), Montgomery County, and the City of Houston. This integrated effort kicked off in April 2019 and will identify future flood mitigation projects that can be implemented in the near- and long-term to reduce flood risks. This regional study will not provide an in-depth analysis of the effects of sediment removal.

6.8 Recommendation for Dredging

Based on the analysis of available data, there is evidence to assert that the storage capacity within Lake Houston has generally decreased over time. There was not enough available information to determine the effects of sediment on the conveyance capacity in the East Fork of the San Jacinto River or the provided benefit of dredging along the stream. There was not bathymetry data available from all three analyses upstream of cross section 68799.84. It is recommended that a thorough bathymetric survey of the East Fork of the San Jacinto River is performed to understand the existing sediment and how it has increased or decreased over time. It is also recommended that a hydraulic analysis is performed after the bathymetric survey to quantify the conveyance benefits of dredging the East Fork versus the storage water level in Lake Houston. A sediment transport analysis for the entire watershed could be performed to determine areas where more sediment is entering the channel and addressing best management practices with area stakeholders to reduce sediment in the channel.

Section 7 – Recommendations

7.1 Flood Risk Reduction Recommendation

The recommendations provided in this section are for the Luce Bayou Watershed and Cedar Bayou Watershed and represent a combination of several factors. These include costs, acquisition, and structures removed from inundation.

7.1.1 Luce Bayou Watershed

The Combination Scenario employs a combination of strategies including optimized channel modifications, upstream detention, and a bypass channel to achieve a 100-year level of service.

The channel modifications are for the main stem of Luce Bayou and were optimized to best fit within the existing development. The Luce Bayou main stem was broken into reaches for evaluating the maximum right-of-way (ROW) width that could be placed within the limits established by existing residential structures. The reaches that were established in the baseline conditions hydrologic model were used for the proposed channel modifications. The ROW width was determined from the proposed bank stations of the modified channel plus an additional combined 60 feet of required ROW for a 30-foot maintenance berm on each side. The most limiting reach ROW width was utilized for the "optimized" channel modifications, which was evaluated for the resulting level of service. The optimized ROW width is 570 feet, including the required maintenance berms and yields a level of service above the 10-year, but not above the 50-year. The estimated preliminary cost for this drainage feature is $78 million.

Upstream detention will temporarily store floodwaters in Liberty County or north Harris to reduce the peak discharges on Luce Bayou's main stem. The detention volume used to raise the level of service, with the aforementioned optimized channel modifications, to a 50-year level of service is 7,015 acre-feet, and based on the estimated available depth of 15 feet, the needed surface area is approximately 500 acres. The preliminary cost for this drainage feature is estimated at $152 million.

The parallel bypass channel to divert peak discharges away from the main stem route 2 provides approximately a 10-year level of service independently, and when combined with the optimized channel modifications and upstream detention features, provides a 100-year level of service for the Luce Bayou watershed. Route 2 diverts flows just upstream of the confluence of Mexican Gully (S114-00-00) with the main stem of Luce Bayou and travels south directly to the downstream end of Luce Bayou. The route was based on topography and with the objective of minimizing the impact to existing structures. Route 2 was preferred due to its smaller width of 320 feet, available depth of 14-feet, and accompanying cost. The exact location of the route for the proposed bypass channel has not been finalized and would be evaluated in more detail in a Preliminary Engineering Report phase. The cost for the bypass channel is approximately $39M.

In summary, this scenario includes the following:

- Luce Bayou Channel ROW: 570 feet
- Detention Volume: 7,015 acre-feet
- Bypass Channel ROW: 320 feet

- Bypass Channel Depth: 14 feet

The channel modification and parallel bypass channel features were not evaluated with mitigation as it was assumed that increased flows would be mitigated within Lake Houston. The total estimated project cost for all three drainage features is $269 million.

7.1.2 Cedar Bayou Watershed

In the previous study, the projects were prioritized for all of Cedar Bayou based on need including structures in the 10- and 100-year inundation areas, channel level of service, and flood losses in the watershed. The projects were placed into four tiers based on their prioritization.

- Tier 1 includes the top 5 projects based on priority score
- Tier 2 includes the projects ranking between 6 and 11 based on the priority score (top 10)
- Tier 3 includes the projects ranking between 12 and 15 based on priority score (top 15)
- Tier 4 includes the remaining projects that scored the lowest on the prioritization

Improvements to Q134-00-00 and Q134-01-00 were given a Tier 2 rank.

The Q134-00-00 channel conveyance improvements scenario calls for the construction of channel conveyance improvements along Q134-00-00 from FM 2100 to the confluence with Q100-00-00 downstream of Ramsey Road to provide a 10-year LOS. The associated mitigation consists of approximately 155 acres of property to provide Q134 conveyance mitigation of 789 acre-feet and 135 acres to provide Q134-01 mitigation of 301 acre-feet. The existing culvert at 3rd Street along Q134-01 would also be replaced. Improvements to Q134 would provide better capacity for the channel, which serves as the Forest Manor subdivision's outfall. The cost for this scenario is $29.5 million and includes the following:

- Channel Bottom Width: 15 – 80 feet
- Channel Depth: 6 – 13 feet
- Channel ROW: 130 – 180 feet
- Detention Volume: 788.6 acre-feet

The Q134-01-00 channel conveyance improvements scenario run from Huffman-Eastgate Road to FM 1960 and include mitigation for conveyance increases. It is important to note that the improvements to the upstream end of the Cedar Bayou main stem are recommended to provide 100-year LOS which will remove the overflow from Cedar Bayou into Q136 and Q134-01. The cost for this scenario is $12.1M and includes the following:

- Channel Bottom Width: 50 feet
- Channel Depth: 3 – 5 feet
- Channel ROW: 140 – 160 feet
- Bridge Replacement: 3rd Street
- Detention Volume: 150.7 acre-feet

The projects were included on the 2018 HCFCD Bond Program as Bond Projects F-45 and F-68. Bond Project F-45 is a "Local Only" project, which means there is no funding partner identified at this time, and the project will be funded entirely from the 2018 Bond Program. The Bond Project List includes a total allocation of $11 million for implementation. HCFCD has moved into the next phase for this scenario. The planned improvements are currently undergoing detailed alternatives analysis as part of the feasibility investigation stage. The effort will result in more detailed recommendations for flood damage reduction projects and an implementation strategy. The project was funded with $850,000.00 in November 2018.

7.2 Project Constraints & Benefits

The recommendations are based on a combination of project constraints and benefits.

7.2.1 Luce Bayou Watershed

While the proposed recommendations are slated to reduce flood damages, there are benefits and constraints associated with the recommendation that will need to be further examined in a Preliminary Engineering Report phase.

With a total estimated project cost of $269 million, the funding required to construct exceeds the current available funds for the watershed. On account that the recommendation is comprised of multiple features, it is possible to fund each feature individually thereby constructing each feature one at a time. This would allow for flood damage reduction benefits to be seen immediately after one feature is built. This scenario is highly recommended due to its ability to be phased or funded and constructed in pieces. Each feature individually meets or exceeds the 10-year level of service. When two features are combined, the system is able to meet the 50-year level of service. With all three features in place, the system is able to meet the 100-year level of service. However, until all the components are in place, structures will be subjected to flood damage risk.

The optimized channel modifications were the most preferred channel modification option on account that the least number of structures would be required to construct the feature. However, it has been documented that along Luce Bayou, upstream of the developed residential areas, forested wetland areas exist. Any wetlands impacted would need compensating mitigation most likely through the purchase of wetland credits. The costs account for 0.1 acres of wetlands per 1,000 feet of channel modification; however, the costs associated with wetland mitigation credits can vary based on available credits within the hydrologic unit.

The upstream detention for a lower level of service was preferred as being seen as more attainable based on the magnitude of land needed.

There are known flooding issues near FM 2100 and the Huffman Cleveland Road. The bypass channel feature can provide additional drainage relief for the roadside ditches along Huffman Cleveland Road and FM 2100. HCFCD has begun coordination with TxDOT on their planned improvements of FM 2100. The channel modification and parallel bypass channel features were not evaluated with mitigation as it was assumed that increased flows would be mitigated within Lake Houston. If mitigation is needed for each drainage feature, the cost and feasibility would need to be re-evaluated. HCFCD has begun coordination with the City of Houston and the Coastal Water Authority on the mitigation aspects for these drainage features. The 2019 State Legislature authorized the creation of Liberty County Drainage District (LCDD). There is the opportunity for HCFCD to partner with LCDD on providing detention in undeveloped locations. Table 7.1 is a summary of the benefits and disadvantages associated with the recommended scenario.

Table 7.1. Benefits and Disadvantages of Recommended Scenario for Luce Bayou

Benefits		
Channel Modifications	**Upstream Detention**	**Bypass Channel**
Imagined/evaluated to minimize environmental impacts	Available undeveloped land	Could provide additional relief to residents in and around FM 2100
Increase conveyance capacity	Require little or no acquisition of existing structures	Could provide additional outfall capabilities to future development
Would provide benefit to future development upstream draining into Luce Bayou	Could potentially partner with Precinct for regional park	Ability to partner with TxDOT and/or local developer
Disadvantages		
Channel Modifications	**Upstream Detention**	**Bypass Channel**
Requires significant number of residents affected through acquisition	Require significant portion of land upstream	Potential acquisition of structures not currently at risk
Potentially unknown environmental impacts	Least cost effective alternative	Unknown whether flows can be mitigated in Lake Houston
Unknown whether flows can be mitigated in Lake Houston	-	Would require coordination with TxDOT on current roadway improvement of FM 2100

The scenario was evaluated based on the rainfall criteria effective prior to implementation of the Atlas 14 data on July 9, 2019. The scenario does not take into account to future development upstream of Harris County, which does not currently have detention/impervious area requirements. The authorization (HB 1820) in the State Legislature gives the Liberty County Drainage District authority to: issue bonds; impose assessments, fees, or taxes; and exercise limited powers of eminent domain. A temporary board of directors was established, but a confirmation election must occur before September 2022. There could be significant changes in development prior to regulations being put in place.

7.2.2 Cedar Bayou Tributaries (Q134-00-00 and Q134-01-00)

The project has many benefits including containing the 10-year future conditions flows and reduction in the 100-year inundation. It should also be noted that Q134-00-00 drains the Forest Manor subdivision, which has a significant number of flood claims. Improvements have already been completed to address local drainage in response to resident concerns. Improvements to Q134-00-00 would provide better capacity for the channel and the combination of local drainage improvements and Q134-00-00 should provide a reduction in flooding in the area.

The proposed improvements to Q134-00-00 will have to be designed with consideration for the Gin City Mitigation Bank. In the area adjacent to the Gin City conservation easement, the left bank will have to remain unaltered, shifting the channel conveyance modification. While efforts were made to avoid removing structures, the presence of the conservation easement on the left bank limited the available space for improvements, which resulted in the need for structural buyouts to meet the desired level of service. Current development interest may limit detention sites and a potential wetland along Q134-00-00 downstream section may require permitting and mitigation, if impacted.

7.3 Metrics

The project metrics for each drainage alternative was one measure utilized in the formation of the recommendation. The four metrics analyzed for the Luce Bayou Watershed were: the number of structures, area, roadway, and parcels that were inundation during each of the studied rainfall events.

7.3.1 Luce Bayou Watershed

Below are the existing metrics for each of the studied rainfall events as well as the metrics that would be acquired with the recommended alternative. These metrics are for the implementation of the full recommended alternative with all three individual components.

Table 7.2. Comparison of Metrics for the Combined Scenario

	Existing				Necessary Acquisition			
Rainfall	Structures	Area (Acres)	Roadway (Miles)	Parcels	Structures	Area (Acres)	Roadway (Miles)	Parcels
10-year (10%) Current Rainfall	11	820	1	370	11	1,025	1	159
50-year (2%) Current Rainfall	87	1,223	4	496	11	1,025	1	159
100-year (1%) Current Rainfall	133	1,364	5	518	11	1,025	1	159
500-year (0.2%) Current Rainfall	217	1,879	7	621	11	1,025	1	159

Table 7.3 provides the metrics for the benefits for the recommended alternative for each of the studied rainfall events.

Table 7.3. Metrics of Benefits from Implementation of the Combined Scenario

	Inundated After Improvement	Benefits			
Rainfall Event	Structures	Structures	Area (Acres)	Roadway (Miles)	Parcels
10-year (10%) Current Rainfall	0	0	-205	0	211
50-year (2%) Current Rainfall	0	76	198	3	337
100-year (1%) Current Rainfall	0	135	339	4	359
500-year (0.2%) Current Rainfall	102	104	854	6	462

7.3.2 Cedar Bayou Tributaries (Q134-00-00 and Q134-01-00)

For the previous study for the Cedar Bayou Watershed, the comparison of the metrics and costs were incorporated into the benefit/cost analysis, which resulted in projects being categorized into tier rankings. A tier two ranking was given for the recommended alternatives for Q134-00-00 and Q134-01-00.

7.4 Costs

Project costs for each recommended scenario was another measure utilized in formulation of the recommended scenarios.

7.4.1 Luce Bayou Watershed

The costs associated with the recommended combination scenario, which achieves a 100-year LOS, are $269 million. For a more detailed explanation on the breakdown of costs, see **Appendix E**. These costs are considered a planning level estimate and will need to be refined as projects are implemented. Table 7.4 provides a breakdown of the total costs by upstream detention, channel modifications, and bypass channel.

Table 7.4. Breakdown of Recommended Combination Scenario

Level of Service	Description	Cost
10YR	Upstream Detention	$152M
10YR+ (Optimized)	Channel Modifications	$78M
10YR	Bypass Channel	$39M
	Total Cost	$269M

7.4.2 Cedar Bayou Tributaries (Q134-00-00 and Q134-01-00)

In the previous study, the recommended projects included the channel modifications of Q134-00-00 and Q134-01-00 to meet the 10-year level of service. Below are the costs associated with these recommendations.

Table 7.5. Q134-00-00 and Q134-01-00 Cost Estimate Summary

Scenario	Detention Costs	Channel Modifications Costs	ROW Acquisition Costs	Total Cost
Q134-00-00 SCEN 2 – 10-yr LOS	$19.5	$6.7M	$3.3M	$29.5M
Q134-01-00 SCEN 2 – 10-yr LOS	$8.1	$1.8M	$2.2M	$12.1M

7.5 HCFCD Life Cycle

This study serves as the first task in the HCFCD Project Lifecycle; identify the problem and solutions through a feasibility study.

- Project Development – This includes development of a 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 ROW needs will be identified.

- ROW Acquisition/Utility Relocation – ROW acquisition and utility relocation that need to be done in order to facilitate the project. • Project Design – Specific projects determined to be feasible during the project development phase will move to design. This includes development of construction documents, specifications, and cost estimates as well as an evaluation of the constructability of the project.
- Construction – Includes construction of the improvements.
- Operation and Maintenance – Includes regular maintenance of the facility including mowing, repairs, etc.

Figure 0.1. HCFCD Project Lifecycle

7.6 Project Implementation Timeline

There is currently no specific timeframe for implementation. However, HCFCD intends to implement projects within the 2018 bond program in systematic and efficient manner. In the immediate future, HCFCD has indicated that a PER will commence on the bypass channel. In the PER, a more detailed evaluation of the site conditions, environmental, geotechnical, and design configuration will be conducted. This will result in a more refined solution and associated costs.

Project design and construction will be conducted in the longer term after the PER is completed and funding is available.

7.7 Conclusion and Summary of Recommendations

It is important to note that the complete solutions recommended in this analysis will likely take decades to implement fully. During that time, the area will experience any number of changes that may require adjustment to the plan. Given the scale, H&H modeling, future conditions, land availability, utilities and other factors are based on current information and assumptions using available resources, all of which were discussed with HCFCD. Throughout the life of the plan, conditions will change, and additional information will be required. The planned projects were not based on the future development conditions. New development would be required to provide its own on-site detention. As the area changes, these assumptions will likely be updated. Hydraulic analyses for these projects will be based on detailed survey information, geotechnical, field location of utilities, field delineation of environmentally sensitive areas and other factors.

The current level of service (LOS) for streams in the Luce Bayou is a 10-year LOS or less. While the funding to increase the LOS is expensive, the recommended scenario allows for the project to be completed in phases. The Luce Bayou watershed has large portions that are undeveloped and, in many cases, agricultural. While structures may be limited, economic damages may still occur on those properties. The Luce Bayou watershed is not as heavily populated as other watersheds; however, the planned roadway construction of Grand Parkway in Liberty County will increase the accessibility and development in the watershed.

Changes to the design criteria and drainage policies within Harris County are probable during the lifetime of the plan. The flood damage reduction scenarios were based on current HCFCD criteria, which requires mitigation for any development or conveyance improvements. Liberty County does not appear to have the same requirements; however, the creation of the Liberty County Drainage District in the Texas Legislature, criteria could be developed. Changes to the rainfall data and associated return period for a given rainfall depth could change the Level of Service anticipated for a given project. This will need to be evaluated for individual projects or updated for the entire watershed as those changes occur.

In addition, the concentration of roadways in the watershed is significantly less than other, more urbanized watershed in Harris County. As such, reducing the number of roadway miles that are inundated can have a marked impact on access, both for the public and emergency services during a major rainfall event.

There are other challenges that may be faced during the project development and implementation phases. These will need to be considered during the PER and/or ROW acquisition tasks associated with recommended projects. Challenges include the following:

- Acquisition Challenges
- Environmental Permitting and Mitigation
- Project Phasing to Ensure No Adverse Impacts
- Outside Agency Coordination
- Development of Parcels needed for Detention

During the study process, every effort was made to avoid acquisition of existing structures; however, due to the channel and detention needs, there are some areas where acquisitions are necessary. There could potentially be resistance to acquisitions, leaving a couple options such as altering the detention locations, reducing the level of service, or condemnation. For the purposes of cost estimating the projects, it was assumed that all properties will need to go through condemnation, which is likely a conservative estimate. One important aspect of the property acquisition is to have a plan in place to relocated individuals whose property is purchased. HCFCD will need to develop a plan to relocate people to a comparable residence and community. Environmental permitting and mitigation will also need to be addressed on many of the projects that are recommended. General environmental knowledge of the area yields a high likelihood of finding wetlands throughout the watershed. Placement of potential detention ponds should consider these wetland areas and avoid them where possible. Estimates of wetlands mitigation were included in the construction cost estimates for each of the projects. As aspects of the recommended scenario are selected for further development, the Preliminary Engineering Report will need to evaluate potential adverse impacts of each project and provide the requisite mitigation to avoid these impacts. This analysis has sought to offer an approximate channel size and ROW estimates as well as detention volume and approximate acreage needed to accommodate any improvements made; however, a detailed evaluation will be necessary to ensure that no negative impacts occur from individual projects.

Several of the drainage features of the recommended scenario identified include adjustments that will require coordination with outside agencies. These agencies may include, but are not limited to, Texas Department of Transportation (TXDOT), Coastal Water Authority (CWA), local governments, and private companies. Identification of these entities will be necessary early in the project development phase such that coordination can begin. This could include replacement of bridges and culverts at road crossings, utility relocation, property acquisition and other needs.

In addition, it is understood that land availability will change as the area develops. The analysis sought to identify the scale of channel conveyance improvements and detention volumes needed to address existing flooding in the watershed as well as to accommodate improvements in the overall system. Volumes and estimated acreage of property needed to meet those targets have been provided; however, specific parcels recommended for acquisition are not included and will depend on availability as projects are considered. Upstream or regional detention would reduce flooding, in addition to providing an opportunity to create multi-use facilities that can be used for recreation, environmental benefits, or both. Regional detention will require coordination with and the possible acquisition of property within Liberty County. Detention in this area could also be done in partnership with TxDOT on the Grand Parkway (SH99) project.

Available ROW for improvement may be a challenge to improvements over time as many of the currently undeveloped properties could be attractive to developers. It is recommended that HCFCD start the process of acquiring property in that area that can be used for the bypass channel, detention, and channel modifications. It may be beneficial to partner with the local community as well as private interests to develop a solution in those areas where land availability could become scarce. This is particularly likely to be encountered as segments of the Grand Parkway (SH99) increase accessibility to the area.

The recommended scenario has the potential to significantly reduce flooding and reduce the damages and disruption associated with a storm event. While the recommended scenario is comprehensive, there are several factors that will determine how the plan is implemented. As the watershed developed or funding availability changes, it will be necessary to make adjustments to ensure the most effective flood reduction approach is followed.

Section 8 – Community Engagement

8.1 The Bond Program

Harris County Commissioners Court called a Harris County Flood Control District bond election for August 25, 2018, to provide funding for projects across Harris County to reduce the risk of flooding. Voters approved the $2.5 billion bond proposal for flood risk reduction projects located throughout the county. The funding will allow the Harris County Flood Control District to leverage local funding dollars to take advantage of federal funding opportunities. The bond proposal included a preliminary list of projects that would meet the goals of the bond election, which are to assist with recovery after previous flooding events and to make Harris County more resilient for the future.

In the summer of 2018, the Flood Control District held twenty-three large-scale community information and engagement meetings to provide Harris County residents the opportunity to review and provide input on the preliminary list of flood damage reduction projects. These meetings were held in each of Harris County's twenty-three major watersheds. From the community input comments received, an additional thirty-eight capital projects were added to the preliminary project listing.

8.2 Prior to Bond Passage Comments

Thirty-one (31) public comments were submitted regarding the project area during the Bond Community Engagement process which allowed the public to provide first-hand knowledge of areas with flooding issues and express interest in certain types of flood damage reduction projects. The comments received were recorded by watershed and summarized into categories. The percentages for each category by watershed do not add up to 100% since some comments were classified into multiple categories. The description for each category can be found in the table below.

Table 8.1. Comment Categories

Comment Category	Comment Description
Other Jurisdiction	Outside the jurisdiction of HCFCD (i.e., street drainage, the Addicks and Barker reservoirs, home elevations, dredging the ship channel, trails, and Lake Houston)
Channel Modification	Widening, straightening, or deepening any channel, bayou, stream, creek, or tributary (including the north canal bypass channel)
Channel Maintenance	Mowing, removal of illegally dumped rubbish, and/or clearing of overgrown vegetation
Stormwater Detention	Large regional water basins, detention or retention, modification, or creation of new detention, including the "third reservoir"
Storm Repair	Repair or damage to the riverine system from Hurricane Harvey, Tax Day, or Memorial Day floods Phrasing in the comment suggesting the need for repairs from erosion, bank failure, silting, sinkholes, and/or outfall pipe exposure
Home Buyouts	Purchasing of private property or properties for the use of flood control measures
Engineering Study	Requests for flood damage risk reduction studies or studies to determine channel modifications or storm detention
Environmental Impacts	Preservation of the natural state of the channel, the protection for trees and natural habitat, or opposition to concrete channel lining
Bridge Modification	Bridge as a reason for flooding or a bridge needing to be removed or modified (type of bridge does not matter, i.e., roadway, pedestrian, or rail)
Transparency	How projects are selected, accounting for where money is spent or for more community engagement

Similar comment themes were expressed across the watersheds and the following sections summarize the bond comments by watershed received at community meetings or submitted online through the 2018 Bond Program website. The official summaries from the Bond Community Engagement process can be found in **Appendix K**.

8.2.1 Luce Bayou

A Community Engagement meeting took place on July 23, 2018 for the Bond Community Engagement process. Sixteen comments were received, and comments were categorized into ideas, concerns requests, and information presented.

Common themes expressed include channel modifications and concerns that fall outside of HCFCD's jurisdiction as illustrated in Table 8.2.

Table 8.2. Luce Bayou Public Input Themes

Public Input Themes	
Other Jurisdiction	42.86%
Channel Maintenance	42.86%
Channel Modification	21.43%
Engineering Study	7.14%

Requests for channel maintenance or modification pertained to Luce Bayou's confluence with the East Fork of the San Jacinto River. Community members expressed concerns related to a potential obstruction possibly restricting flow of Luce Bayou into the San Jacinto River. An additional comment requested flood damage reduction projects along Luce Bayou north of FM 2100.

Community input that fell outside of HCFCD's jurisdiction included street drainage improvements in various areas, dredging, and water supply. Multiple comments expressed concern over the street drainage in the Water Wonderland and Cypress Point neighborhoods. There was also concern that the water supply channel (Luce Bayou Interbasin Transfer) currently under construction near Wolf Road will increase the flooding in the Luce Bayou watershed.

8.2.2 East Fork of San Jacinto River

There was one meeting held for the San Jacinto Watershed as part of Bond Community Engagement process. Therefore, the comments were not subdivided between the different branches, East Fork or West Fork. The Community Engagement meeting took place on July 10, 2018 at Kingwood Park High School. Eight hundred forty comments were received. A total of four new "Community Input" projects were incorporated into the proposed bond program as a result of community input.

The major public input themes expressed were engineering study and concerns that fall outside of HCFCD's jurisdiction per Table 8.3 below.

Table 8.3. San Jacinto Public Input Themes

Public Input Themes	
Other Jurisdiction	88.14%
Engineering Study	74.01%
Channel Modification	3.59%
Stormwater Detention	3.23%
Channel Maintenance	1.92%
Bridge Modification	1.44%
Home Buyouts	1.20%
Transparency	0.60%
Storm Repair	0.12%
Environmental Impacts	0.12%

Many comments received addressed flooding experienced within the Kingwood area, as well as concerns about the water supply infrastructure on the San Jacinto River. Hundreds of comments were regarding dredging the San Jacinto River and Lake Houston, installation of gates on Lake Houston Dam, and the addition of more stormwater detention facilities within the watershed. Community input that fell outside of HCFCD's jurisdiction included neighborhood and street flooding and dredging. The concerns that fall outside of HCFCD's jurisdiction require coordination with other municipalities and/or agencies to address these comments.

One of the "Community Input" projects created from this meeting is titled "East Fork, West Fork and Lake Houston Dredging" budgeted with a local cost of $10,000,000.

8.2.3 Cedar Bayou

A Community Engagement meeting took place on July 19, 2018 for the Bond Community Engagement process. Twenty-five comments were received, and comments were categorized into ideas, concerns requests, and information presented.

Common themes expressed include channel maintenance and concerns that fall outside of HCFCD's jurisdiction. The Cedar Bayou Public Input themes are outlined in Table 8.4.

Table 8.4. Cedar Bayou Public Input Themes

Public Input Themes	
Other Jurisdiction	44.44%
Channel Maintenance	25.93%
Channel Modification	14.81%
Engineering Study	7.41%
Bridge Modification	3.70%
Transparency	3.70%

Requests for channel maintenance or modification pertained to the clearing of the channels between I-10 and FM 1960, including as U.S. Highway 90. Many comments requested that the U.S. Highway 90 bridge and the nearby rail bridge be modified to allow additional stormwater to flow without restriction. The FM 1960 bridge over Cedar Bayou was also a common concern, and requests for changes to the bridge were made. Requests for channel maintenance downstream of I-10 focused on removal of large trees and other debris in the waterway.

Community input that fell outside of HCFCD's jurisdiction focused on working with Harris County Engineering Department to improve roadside drainage ditches in the area.

8.3 Bond Program Requirements

In compliance with the 2018 Harris County Flood Control Bond Program, the Harris County Flood Control District requires that consultants deliver comprehensive community engagement for each bond project. The purpose of these community engagement efforts is to provide transparent and accessible public information about each bond project and solicit meaningful public comments per the "Order Calling the Election," approved by Harris County Commissioners Court on June 12, 2018. This includes the stated intention to have at least one meeting for each bond project: It is the Flood Control District's intention to be consistent in the type of information presented; the manner in which it is presented; the way in which comments are requested, gathered and documented; and the response to public comments received. Therefore, a uniform process has been developed by the Flood Control District to ensure community engagement consistency and equity across all bond projects.

8.4 Community Engagement Goals

Community engagement focuses on giving the public who live or work in the study area an opportunity to participate in the process. Involvement of the general public through a series of key public input meetings was guided by a public outreach plan that had the following goals:

- Effectively communicate HCFCD's strategy for flood damage reduction;
- Implement an engaging, community-driven process that will inform the final plan; and
- Provide a forum for flood-impacted constituents to express their input and demonstrate how that input will be part of the overall strategy.

8.5 Community Engagement Meeting #1: Baseline Conditions

On March 26, 2019, a community engagement meeting was held at the May Community Center in Huffman from 6:00 pm to 8:00 pm. The purpose of the meeting was to review the baseline conditions and collect feedback on both areas of concern not identified in the analysis as well as the types of alternatives the public supports. The level of service for the streams studied and baseline metrics were presented. A total of 51 people attended the meeting and four comments were submitted either at the meeting or during the two-week comment period following the meeting. The comment themes from the March 26, 2019 are expressed in Table 8.5.

Table 8.5. Public Input Themes from March 26th Community Engagement Meeting

Public Input Themes	
Other Jurisdiction	50% - 3 comments
Channel Maintenance	33% - 2 comments
Channel Modification	0%
Engineering Study	0%
Bridge Modification	0%
Transparency	0%
Other	17% - 1 comment

Comments that fell into multiple themes are counted in each theme so the table above may give the impression of more comments being recorded. The responses to these overall themes are captured in a subsequent section or responses to specific comments are included in **Appendix L**.

8.6 Community Engagement Meeting #2: Recommendations

On July 11, 2019, a second community engagement meeting was held at the May Community Center in Huffman. The purpose of the meeting was to review the recommendations determined from the alternatives evaluated. A total of 97 people attended the meeting and 23 comments were submitted either at the meeting or during the two-week comment period following the meeting. Table 8.6 illustrates the comment themes that were expressed.

Table 8.6. Public Input Themes from July 11th Community Engagement Meeting

Public Input Themes	
Other Jurisdiction	9% - 3 comments
Channel Maintenance	6% - 2 comments
Channel Modification	13% - 4 comments
Storm Repair	3% - 1 comment
Home Buyouts	6% - 2 comments
Engineering Study	0%
Bridge Modification	0%
Transparency	13% - 4 comments
Other	50% - 16 comments

Comments that fell into multiple themes are counted in each theme so the table above may give the impression of more comments being recorded. The responses to these overall themes are captured in a subsequent section or responses to specific comments are included in **Appendix M**.

8.7 General Responses to Comment Themes

From the comments received from either the Summer 2018, March 2019, or July 2019 community engagement meetings, themes were expressed in which a general explanation or response is summarized below.

8.7.1 Street Drainage

Streets and roads have their own drainage features to convey stormwater. The District doesn't have authority over road drainage, which could be under the jurisdiction of TxDOT, Harris

County, or the City of Houston. Farm-to-market (FM) roads 2100 and 1485 fall under the jurisdiction of the Texas Department of Transportation (TxDOT) and have their own drainage criteria for their improvement projects.

From time to time, local storm drains become clogged with debris or are in need of maintenance. The District does not have jurisdiction over these other aspects of our drainage network, such as roadside ditches, storm sewers, or streets.

8.7.1.1 FM 2100

TxDOT has planned improvements for FM 2100 underway from FM 1960 to Huffman Cleveland Road to widen from a two-lane road to a 4-lane road with a 6' shoulder. The FM 2100 improvements project is also located in the preliminary path of the bypass channel scenario. HCFCD has started coordinating with TxDOT on their planned improvements.

8.7.2 Development

Harris County is a zero-rise community, meaning any new development is required to provide stormwater detention. For areas outside of the District's jurisdiction, detention cannot be mandated. The City of Houston, for example, has its own criteria for design of its drainage systems – primarily the design of storm sewers and street drainage, but also stormwater detention for these systems. Other incorporated areas, which include the many cities located in Harris County, are also floodplain administrators and have their own drainage design criteria for their road systems and development.

Villages of Pine Ridge

There is a planned development, Villages of Pine Ridge, located off of FM 2100, in which many residents had concerns or questions over the existing drainage problems west of FM 2100 near Huffman Cleveland Road. Overland sheet flow utilizes Lazy Pine Drive. When flows overwhelm the roadside ditches on FM 2100, flows travel east to the roadside ditches along Huffman Cleveland Road and enter into a swale behind the Commons of Lake Houston residential development. The swale discharges into Red Gully. Residents brought up concerns over maintenance responsibility and a cursory search of documentation revealed that two of the plats (Commons of Lake Houston Section 2 & 14) state that "[d]rainage easements are dedicated to the Public and are to be maintained by the Commons of Lake Houston Property Owners Association." The Villages of Pine Ridge is also located in the preliminary path of the bypass channel scenario. HCFCD has started coordinating with Academy Development on their planned development.

8.7.3 Bypass Channel Scenario

At this stage in the planning process, it was determined that a bypass channel would be more preferable (due to the associated costs and reduction in flood risk) than widening of the existing channel. As part of the recommended scenario, a bypass channel would provide a 10-yr level of service by diverting flows from the main stem of Luce Bayou in a parallel channel located adjacent to Huffman Cleveland Road. The goal of the proposed bypass channel is to provide relief for Luce Bayou in major rainfall events. The bypass channel would have the added benefit of providing relief for localized drainage issues reported at the intersection of FM 2100 and

Huffman Cleveland Road. The analysis examined two possible routes: 1) Discharging back into the main stem of Luce Bayou downstream using the Huffman Cleveland Road; 2) Discharging into Red Gully. The recommended option was Option 1, which provides an available depth of 14 feet, greatly reducing the needed width for the right-of-way versus Option 2. Residents along Huffman Cleveland Road expressed concerns over Option 2 bypass channel's route, the timeframe, exposing properties to flooding, and why the analysis did not widen and/or deepen Luce Bayou.

The route of the bypass channel was examined as a high-level concept in this analysis and would be further studied in a Preliminary Engineering Report. A Preliminary Engineering Report would examine the ground conditions, explore existing constraints, and analyze the routes in more detail. During the next phase, the inflow structure from Luce Bayou into the proposed bypass channel would be studied as well as how flows would be prevented from Luce after the bypass reaches its capacity so that we would not adversely affect areas adjacent to the bypass that are not currently at flood risk. The preliminary design stage would determine exact bypass route and would have another public meeting likely in the next 6-8 months. As with any HCFCD project, the proposed bypass channel would not increase the existing flood risk for any of the surrounding areas.

8.7.4 Luce Bayou Interbasin Transfer

In 2011, AECOM prepared a Preliminary Engineering Report (PER) on the Luce Bayou Interbasin Transfer (LBIT) Project for the Coastal Water Authority. The LBIT project is a regional water supply project to transfer raw water from the Trinity River to Lake Houston, which is in the San Jacinto River Basin. The City of Houston holds permits to divert raw water at a maximum rate of 775 cubic feet per second (approximately 500 million gallons per day).

The project consists of a raw water pump station, approximately three miles of pipeline, a sedimentation basin, and approximately twenty-four miles of open canal. The pump station will be located on the Trinity River and travel by pipeline in a west-southwest direction before discharging into a sedimentation basin at the start of the canal. The canal continues in a west-southwest direction through Liberty County and into the northeast portion of Harris County. The canal will outfall into the lower reaches of Luce Bayou.

Additional surface water supplies are needed to meet the Harris-Galveston Subsidence District (HGSD) conversion deadline of 70 percent surface water in HGSD Area 3 by January 1, 2020. The HGSD is a special purpose district responsible for regulating groundwater withdrawals in Harris and Galveston counties to reduce subsidence and prevent flooding.

8.7.5 Conveyance Capacity

A resident questioned whether the analysis addressed the conveyance capacity of the East Fork of the San Jacinto River. The storage capacity of Lake Houston and five contributing tributaries was presented based on three Texas Water Development Board (TWDB) volumetric studies for Lake Houston and five contributing tributaries. The capacity referenced in the presentation relates only to the storage capacity in the Lake and five contributing tributaries, not the conveyance capacity of the East Fork.

The LiDAR data shows that erosion has occurred above the static water surface level on the East Fork side slopes and areas where the channel is widening. Theoretically, as the channel side slopes erode, the channel would widen, which would enable it to carry more flows above the static water surface elevation. However, this analysis did not include an evaluation of the conveyance capacity of the East Fork between pre- and post-Harvey channel conditions.

In the San Jacinto watershed, there is a separate project underway called the Upper San Jacinto Regional Watershed Drainage Plan. In its tasks, detailed modeling and analysis of sedimentation on a watershed level will be examined and regional recommendations to manage sediment will be provided.

8.7.6 Dredging

Many comments requesting dredging were made for different locations: Lake Houston; East Fork; Luce Bayou confluence; and Red Gully. As part of this study, only a planning level proposed sediment removal/dredging alternative was explored along the East Fork in select locations. Most of the District-owned easements or right-of-way are outside of the lake areas or the contributing streams. When a request is received to desilt or improve conveyance capacity of channels in areas where the District has jurisdiction, they are normally evaluated on a case-by-case basis to determine appropriate maintenance activities.

More details regarding dredging can be found in the dredging chapter.

Lake Houston

Lake Houston lies on the San Jacinto River in northeast Harris County (centered at 29°55' N, 95°08' W). The man-made lake is owned by the City of Houston and operated by the Coastal Water Authority for municipal, industrial, recreational, mining, and irrigation purposes. The Coastal Water Authority is a conservation and reclamation district that delivers untreated surface water to the cities of Houston, Baytown, and Deer Park. The City of Houston supplies water to Harris County and portions of the seven surrounding counties. The drainage area for Lake Houston is 2,828 square miles. Surface water supplies from Lake Livingston, Lake Houston, and Lake Conroe account for 71 percent of Houston's water supply with groundwater supplying the remaining 29 percent.

Dam construction began in January 1952 and was completed in December 1953. The deliberate impoundment of water began April 9, 1954. Lake Houston's dam consists of a conventional Ambursen type reinforced concrete slab and buttress spillway section that is 3,160 feet in length.

The conservation pool elevation of Lake Houston is 41.73 feet (NAVD88). Previous capacity estimates include the original design estimate of 158,553 acre-feet at the time of impoundment, a 1965 survey estimate of 146,769 acre-feet, and 1994 and 2011 volumetric surveys estimate of 136,381 acre-feet and 126,900 acre-feet, respectively. The latest 2018 TWDB volumetric survey estimated a total reservoir capacity of 128,775 acre-feet, or an estimated capacity loss rate of 384 acre-feet/year.

The lake is crossed by the Missouri Pacific railroad line adjacent to FM 1960.

West Fork

The current West Fork dredging project is being performed by the USACE directed by FEMA. Under the Stafford Act, FEMA can assign emergency response work to designated agencies. Under the National Response Framework, the Corps responds to FEMA requests as part of the Emergency Support Function #3. This enables FEMA to accomplish disaster response requirements quickly. It is strictly a federal level implementation, in partnership with the owner of the lake, which is the City of Houston. The District is not aware of the specifics of the USACE's or the City of Houston's determination of current dredging areas. The 2000 Brown and Root report for Lake Houston looked specifically into the sediment issues at the upstream portion of Lake Houston. It concluded that 75% of the sediment came from the west side (Cypress Creek, Spring Creek, West Fork) and the remaining 25% came from the East Fork and other sources. The current draft USACE dredging report repeats the same data as the 2000 report. When examining the history of flooding claims, a greater density and number of flooding complaints came from the West Fork.

Section 9 – Financing Options

9.1 HCFCD Current Funding

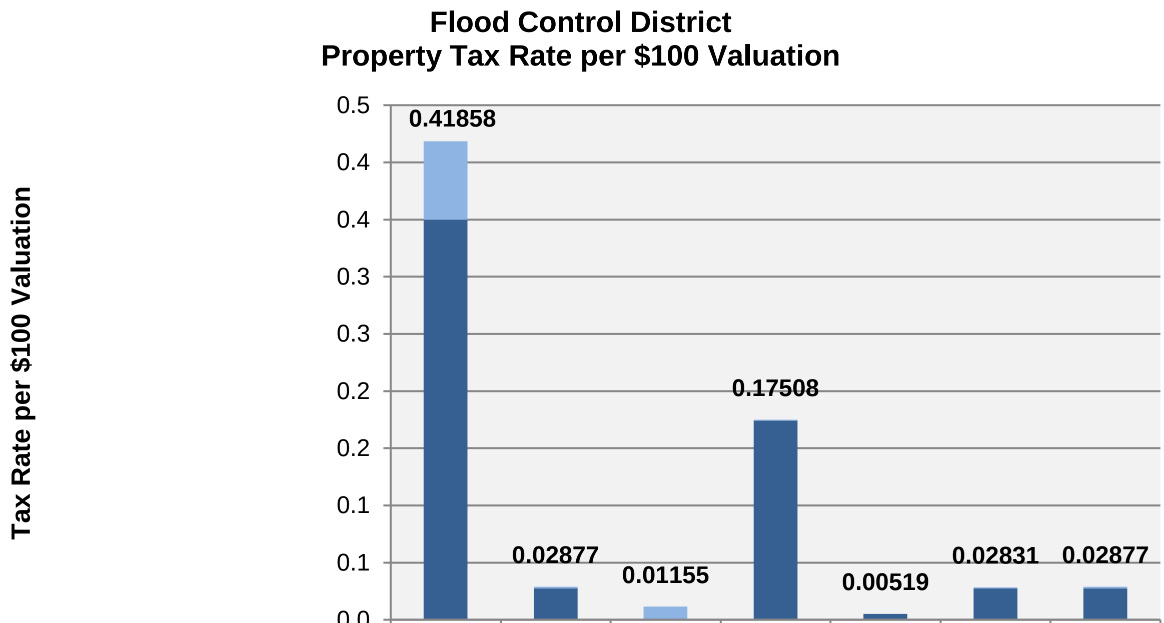
The mission of the Harris County Flood Control District is to provide flood damage reduction projects that work, with appropriate regard for community and natural values. The District reduces the risk of flood damage by devising stormwater management plans, implementing the plans and maintaining the infrastructure. The Flood Control District is headed by an Executive Director, a Chief Engineer, a Director of Operations, and is organized into eight primary divisions to carry out its mission: Construction, Engineering, Planning, Human Resources, Infrastructure, Community Services, Hydrologic Operations, and Support Services.

In accordance with Chapter 111 of the Local Government Code, the County prepares and adopts an annual operating budget which serves as a financial plan for the District for the new fiscal year beginning March 1. The Commissioners Court, as the elected governing body of the County, is also the statutory governing body of the District.

The County is responsible for setting the tax rates for the District. Tax rates are levied for maintenance and operations and debt service requirements relative to General Obligation Bonds. Tax rates for the District are usually adopted in September or October. The respective tax rates which were adopted in 2018 for the District per $100 of taxable value are: $0.02738 for maintenance and operations and $0.00139 for debt service, for a total of $0.02877. The District issued debt to finance the ongoing capital improvement program.

Property taxes for the District are levied each year based on tax rates adopted within 60 days of receiving the certified roll or September 30, whichever is later. Taxes are levied on the assessed value of all taxable real and personal property as of the preceding January 1. Appraised values are determined by the Harris County Appraisal District equal to 100% of the appraised market value as required by the State Property Tax Code. Real property must be appraised at least every three years. Taxpayers and taxing units may challenge appraisals of the Appraisal District through various appeals, and if necessary, legal action. Table 9.1 shows the history of the District's Property Tax Rate per $100 valuation for the past six years.

Table 9.1. Flood Control District Property Tax Rate per $100 Valuation



	2012	2013	2014	2015	2016	2017	2018
Debt Rate	0.06858	0.00139	0.01155	0.00108	0.00000	0.00095	0.00139
Maintenance & Operations Rate	0.35000	0.02738	0.00000	0.17400	0.00519	0.02736	0.02738
Adopted Tax Rate	0.41858	0.02877	0.01155	0.17508	0.00519	0.02831	0.02877

Footnotes:

1) The Debt Rate is the component of the adopted tax rate of a taxing unit that will impose the amount of taxes needed to fund the unit's debt service for the following year.
2) The Maintenance and Operations Rate is the component of the adopted tax rate of a taxing unit that will impose the amount of taxes needed to fund maintenance and operation expenditures of the unit for the following year.
3) The Adopted Tax Rate is the tax rate adopted by the governing body of a taxing unit.

The District has operated on a $120 million dollar program for several years split evenly between capital projects and operating and maintenance expenditures. At this funding level, the District was limited to providing flood risk reduction projects in a piecemeal approach. At a special election on August 25, 2018, voters approved issuance up to $2.5 billion in bonds to fund capital projects related to Hurricane Harvey and other projects aimed at reducing the impact of future flood events. The $2.5 billion bond program offered residents an opportunity to accelerate the delivery of flood damage reduction projects. By investing in the county infrastructure in this way, the District will be better positioned to leverage local funding dollars to take advantage of federal funding opportunities and deliver large-scale regional projects. The bond proposal included a preliminary list of projects that would meet the goals of the bond election. Broad categories of projects include:

- Channel modification projects
- Regional stormwater detention basins
- Major repairs to flood-damaged drainage infrastructure

- Voluntary home buyouts of flood-prone properties
- Wetland mitigation banks
- Property acquisition for preserving the natural floodplains
- Drainage improvements made in partnership with other cities, utility district, or other local government agencies
- Upgrading the Harris County Flood Warning System

With the passage of the 2018 HCFCD Bond Program, the $120 million dollar budget is dedicated to operating and maintenance expenditures. HCFCD implements the bond program programs through a $250 million dollar line of commercial paper that is currently being anticipated at obtaining a new line each year up to the total of $2.5 billion. Commercial paper is a general obligation of the County secured by ad valorem taxes for the purposes of financing various short-term assets and providing temporary construction financing for certain long-term fixed assets.

9.2 Frontier Programs

In the 1980's, Harris County Commissioners Court authorized HCFCD to take the lead and coordinate efforts of various groups interested in pursuing Regional Stormwater Control Program that could be accomplished through joint funding by the public and private sectors of the community.

This was accomplished by completing Master Drainage Studies in conformance with the criteria established by the District's drainage policies. The studies presented a reasonable approach to stormwater management to reduce floodplains while still allowing development of the watershed and included different flood damage reduction tools such as regional detention and channel modifications. One of the key tasks associated with a Master Drainage Plan (MDP) is the creation of master models to incorporate all major proposed drainage features in the watershed and to prove the proposed drainage features will holistically provide a 100-year level of service. The MDP serves as the technical framework to communicate the benefits of the Frontier Program to land developers.

Programs of this nature differed from HCFCD's normal operations budget and established funding assistance for implementation by establishing a system of user fees. The fees were intended to be generated in connection with drainage capacity created by regional detention and channel modifications.

HCFCD recommends a user fee, later called an impact fee, based on construction cost estimates for the flood damage reduction features in the Master Drainage Study to Commissioners Court. Adjustments to the amount may be necessary to take into account inflation and actual project costs.

9.2.1 Impact Fee

An impact fee is a one-time tax that is imposed by a local government on a new or proposed development to pay for all or a portion of the costs providing public services to the new development. These fees are designed to reduce the economic burden on local jurisdictions that are dealing with population growth. In Texas, impact fees are authorized under Chapter 395 of the Texas Local Government Code.

HCFCD collects impact fees for new development or construction on existing properties/structures that affect the following Harris County watersheds:

- White Oak Bayou
- Brays Bayou
- Sims Bayou
- Langham Creek
- Greens Bayou
- Cypress Creek

Impact fees for these watersheds were approved by Commissioners Court in the late 1980's. Impact fees are calculated based upon Commissioners Court approved fee rates, the amount of acreage impacted by the new development or construction, and other varying factors. Impact fees must be collected before the new development or construction plans can be approved by HCFCD. HCFCD may use the impact fees collected to plan, design, or construct any aspect of the Master Drainage Plan that it deems to be of benefit to the Service Area, to the limit it is legally permitted to do so. This includes the acquisition of right-of-way, environmental permitting or mitigation, bridge or utility adjustments for conveyance, and other costs.

Chapter 395 of the Texas Local Government Code has been amended multiple times and requires the political subdivision to prepare a Capital Improvements Plan that must contain specific enumeration of the following items:

- A description of the existing capital improvements within the service area and the costs to upgrade, update, improve, expand, or replace the improvements to meet existing needs and usage and stricter safety, efficiency, environmental, or regulatory standards, which shall be prepared by a qualified professional engineer licensed to perform the professional engineering services in this state;
- an analysis of the total capacity, the level of current usage, and commitments for usage of capacity of the existing capital improvements, which shall be prepared by a qualified professional engineer licensed to perform the professional engineering services in this state;
- a description of all or the parts of the capital improvements or facility expansions and their costs necessitated by and attributable to new development in the service area based on the approved land use assumptions, which shall be prepared by a qualified professional engineer licensed to perform the professional engineering services in this state;
- a definitive table establishing the specific level or quantity of use, consumption, generation, or discharge of a service unit for each category of capital improvements or facility expansions and an equivalency or conversion table establishing the ratio of a service unit to various types of land uses, including residential, commercial, and industrial;

- the total number of projected service units necessitated by and attributable to new development within the service area based on the approved land use assumptions and calculated in accordance with generally accepted engineering or planning criteria; and
- the projected demand for capital improvements or facility expansions required by new service units projected over a reasonable period of time, not to exceed 10 years.

Furthermore, the political subdivision must adopt an order, ordinance, or resolution establishing a public hearing date to consider the land use assumptions and capital improvements plan for the designated service area.

The biggest challenge is the stipulation that after collecting the impact fee, the political subdivision, HCFCD, must commence construction no later than 5 years from the date of payment.

9.2.2 Little Cypress Creek Frontier Program

The Little Cypress Creek Frontier Program is one example of a Frontier Program and is an organized effort to plan for regional drainage infrastructure in advance of future land development in the Little Cypress Creek watershed. The Little Cypress Creek Frontier Program focuses on the 52 square mile watershed in northwest Harris County. The area is experiencing rapid development with construction of the Grand Parkway, lacks sufficient natural drainage to accommodate expected growth. The program also calls for stricter stormwater detention requirements to mitigate runoff from new developments.

This innovative approach is in contrast to typical efforts in which individual landowners and developers install drainage infrastructure that serves their site resulting in smaller, isolated stormwater detention basins and minimum width channels for stormwater management. By collaborating, the program identifies large-scale mutually beneficial plan for drainage that cost-effectively maximizes stormwater mitigation and water quality, as well as opportunities for public recreation amenities and open space.

The impact fee structure allows developers the option to negotiate for/acquire ROW in advance, absent of funding. Developers participate in the Frontier Program by paying a $4,000 per acre fee to develop in the watershed service area. Developers also participate by excavating a portion of regional drainage facilities and by dedicating property for right-of-way. The Little Cypress Creek Frontier Program will use impact fees primarily to acquire right-of-way along the channel and for stormwater detention basins.

The Little Cypress Creek program has been under construction for more than 10 years limited by funding. The goal is to have the bulk of the program in place by 2024.

Little Cypress Creek also has a Stormwater Quality Master Plan in place to help provide additional options for developers to meet HCFCD stormwater quality requirements.

9.3 Community Development Block Grant

The Community Development Block Grant (CDBG) Program is authorized under Title 1 of the Housing and Community Development Act of 1974, as amended. The primary objective of the

CDBG program is the development of viable urban communities, principally for low-income persons through the provision of the following:

- Decent housing
- A suitable living environment
- Economic opportunity

CDBG grantees are responsible for assuring that eligible activities meet one of the following three national objectives:

1. Directly benefit low-income persons: The project must be located in a Harris County target area or serve an area with Harris County's service area where at least 51% of the residents are low income persons (Area Benefit), or must provide a direct benefit to Harris county individuals or families, the majority of whom are considered low income based on the median area income figures (Limited Clientele Benefit.)
2. Aid in the prevention of slum or blight: The applicant must supply proof that the area meets the State or local government's definition of slums and blight.
3. Meet an urgent need: The activity provides a remedy to a serious and immediate health or welfare problem, such as a natural disaster; and there are no other funds available; and the problem is or a recent origin.

Examples of projects constructed with a portion of funding from this program include Zube Detention Basin Phase 1 and 2 in the Little Cypress Creek Frontier Program.

9.4 Hazard Mitigation Grant Program

The purpose of Hazard Mitigation Grant Program (HMGP) is to help communities implement hazard mitigation measures following a Presidential Major Disaster Declaration in the areas of the state requested by the Governor. The key purpose of this grant program is to enact mitigation measures that reduce the risk of loss of life and property from future disasters. HMGP is authorized under Section 404 of the Robert T. Stafford Disaster Relief and Emergency Assistance Act. FEMA provides up to 75 percent of the funds for mitigation projects. The remaining 25 percent can come from a variety of sources.

Examples of projects constructed with a portion of funding from this program include home buyouts.

9.5 Flood Mitigation Assistance Program

The Flood Mitigation Assistance Program (FMA) grant uses funds allocated by the National Flood Insurance Program from the proceeds of flood insurance. The FMA program is authorized by Section 1366 of the National Flood Insurance Act of 1968, as amended with the goal of reducing or eliminating claims under the National Flood Insurance Program (NFIP). FMA grants are awarded annually, and the Flood Control District must compete with all other communities nationwide for these grants. Examples of projects that have utilized this type of funding include home buyouts.

9.6 Future Possibilities

The Bond Program projects which are projected to utilize only local funds that are within the watersheds in the project area are shown below in Table 9.2.

Table 9.2. Local Funds Only Bond Program Projects

Bond ID	Project Name	Total Bond Allocation	Funded
Luce Bayou Watershed			
F-51	Luce Bayou Acquisition and Floodplain Preservation	$10M	$0
F-85	Watershed Feasibility Study	$500,000	$0
F-108	General Drainage Improvements	$10M	$0
F-110	Huffman to San Jacinto, Luce and Cedar Bayou	$10M	$400K
Cedar Bayou Watershed			
F-41	Clawson Ditch and Q124-00-00	$19M	$0
F-42	Magee Gully	$33M	$0
F-43	Adlong Ditch	$23M	$0
F-44	Cedar Bayou Tributary Analysis	$18M	$700K
F-45 & F-68	Cedar Bayou Tributary Analysis	$11M	$850K
F-46	Q500-01 Stormwater Detention Basin	$26M	
F-47	Stormwater Detention Basin near Coastal Water Authority Canals and IH10	$23M	$0
F-48	Design and Construction of Crosby Eastgate Environmental Mitigation Bank	$1M	$0
F-69	Q136-00-00	$10.5M	$0
F-70	Upstream Cedar Bayou Project	$74M	$0
F-110	Huffman to San Jacinto, Luce and Cedar Bayou	$10M	$400K
F-123	Watershed-Wide Implementation Program for Cedar Bayou		
San Jacinto River Watershed			
F-14	General Drainage Improvements Near Kingwood	$10M	$350K
F-15	General Drainage Improvements Near Atascocita	$10M	$0
F-110	Huffman to San Jacinto, Luce and Cedar Bayou	$10M	$400K
F-111	General Drainage Improvements East of Lake Houston	$10M	$0
CI-60	Panther Creek	$10M	$0

Possible next steps include creation of a Watershed Master Plan to provide guidance for future development and a version of the frontier program to implement within Luce Bayou. Cedar Bayou has a Master Drainage Plan and Implementation Plan. HCFCD is working on implementation of the Master Drainage Plan. The San Jacinto Master Drainage Plan will provide recommendations and guidance for political entities within the watershed for development.