CITY OF PEARLAND
BRAZORIA DRAINAGE DISTRICT NO. 4

MASTER DRAINAGE PLAN UPDATE

FINAL REPORT

HALFF ASSOCIATES, INC.
JULY 2019

STATE OF TEXAS
TERRY M. BARR
96540
LICENSED
PROFESSIONAL ENGINEER

07/08/2019
TBPE FIRM NO. 312

HALFF

Executive Summary

Over the last several decades, the City of Pearland (City) and Brazoria Drainage District No. 4 (BDD4) have experienced significant growth. This growth and the accompanying rise in development have resulted in an increased risk of flooding, which can present hazards to the public and property. To more effectively identify flood risks, plan drainage improvements, and consider regulatory measures aimed at minimizing negative development impacts, the City and BDD4 initiated a two-phase effort with Halff Associates, Inc. (Halff) to update and combine the master drainage plans for Pearland and BDD4 into one document, along with updated hydrologic and hydraulic modeling for all major streams within the study area and provide a capacity analysis for more than 90 miles of local drainage ditches.

ES.1 Master Plan Background

The previous Master Drainage Plans were developed in the late 1990's. Within the nearly 20 years since the current plans were completed, the City and BDD4 have successfully implemented numerous projects, including channel improvements, channel diversions, regional detention facilities, and storm sewer improvements. The intent of this master plan update is to leverage the success of these efforts and to modernize the plan based on physical changes to the area, changes in City and BBD4 goals, changes in modeling technologies, and changes in the CIP funding of both the City and BDD4 since the last plan.

The master planning update effort considered these past drainage improvements but focused on how to manage drainage issues along the bayous and major ditches as the area continues to develop. Updating the current hydrologic and hydraulic modeling will facilitate future development growth by better informing citizens of their potential flood risk as well as identifying and prioritizing drainage improvements needed to reduce flooding risk. The evaluation of local drainage infrastructure (roadside ditches or storm sewers) was not included in this master plan, where the emphasis was on channel capacity and detention projects needed to meet the desired level of service (i.e. 100-year or other) for the major streams.

Pearland and BDD4 has long history of flooding, with damages dating back to the 1970s. The region has experienced several significant flooding events, with the most recent event being Hurricane Harvey in 2017. According the City of Pearland's Hurricane Harvey Drainage Assessment Report, the rainfall ranged from 30 to 49 inches for the City and surrounding area over 4 days, which resulted in widespread damage. Approximately 1,080 properties experienced minor damage while 641 properties had major damage based on City of Pearland's Hurricane Harvey Drainage Assessment Report.

ES.2 Study Area Description

The City and BDD4 Master Plan area lies in the northern part of Brazoria County and consists of the shared boundary of the City and BDD4, which encompasses a combined area of nearly 97 square miles. The area is generally bound by Clear Creek to the north and FM 521 to the west. The Galveston County line serves as the primary eastern boundary. A majority of BDD4 is located north of SH6, except for a small area near the Fort Bend County line. Major streams to be included in the study will be Clear Creek, Hickory Slough, Mary's Creek, Cowart Creek, Chigger Creek, West Fork of Chocolate Bayou, and Mustang Bayou. The western half of the study area is generally flat while the eastern half has more elevation change as the ground slopes down to Clear Creek. The dominant flow direction across the study area is west to east, with the exception of Chocolate Bayou, which generally flows from north to south. The majority of the City of Pearland is developed with a majority of residential, commercial development along major roadways, pockets of industrial use, and some institutional and parks/open space. There is significantly less development in the Cowart and Chigger Creek watersheds, with large rural tract predominant in the area. Mustang is similar to Cowart; however, there are some residential areas surrounding SH288. Chocolate Bayou has a mix of newly developed residential areas, mostly north of SH6, and undeveloped open space to the south.

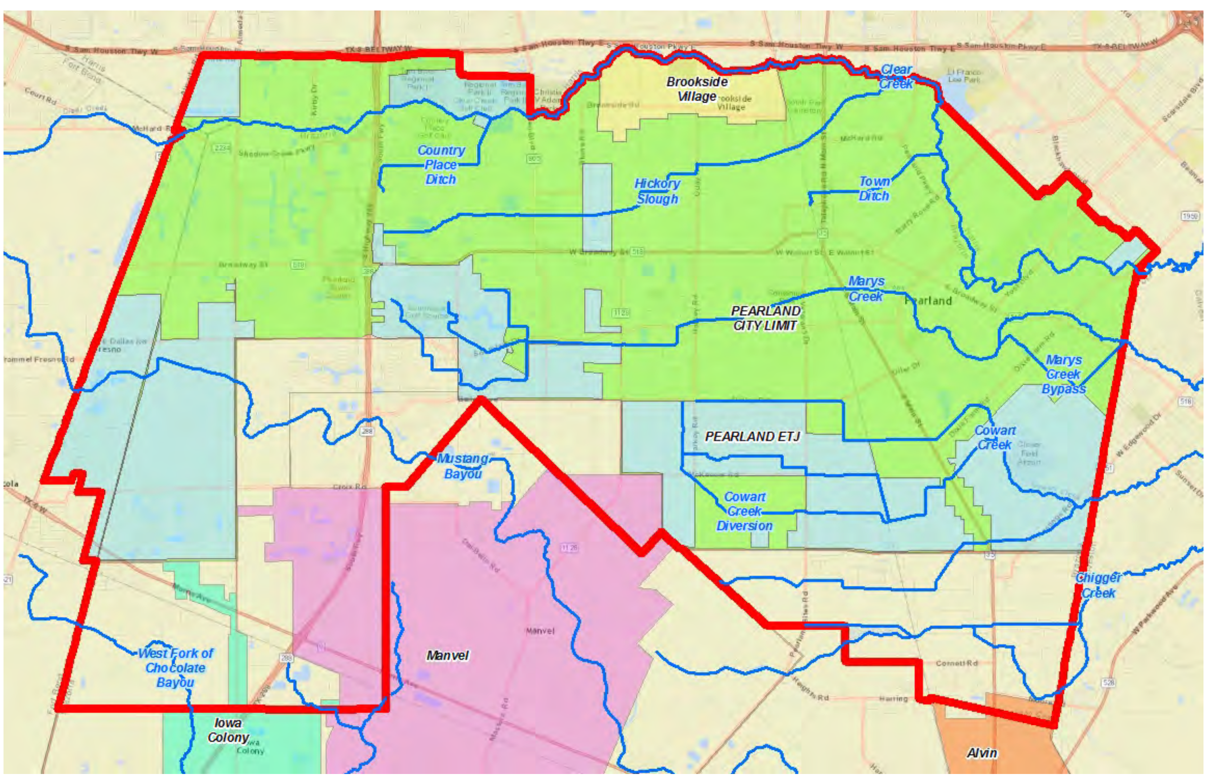


Figure ES1. Master Drainage Plan Area

ES.3 Data Collection

Information relevant to the watershed and beneficial to this study was collected including previous drainage reports, the FEMA hydrologic and hydraulic models (effective modeling), historical rainfall and gage information, and field data. Updated FEMA mapping, developed through Risk Map 6, was included as well as FEMA flood claim and Hurricane Harvey damage data. A significant field investigation effort was conducted to document the existing conditions drainage in the watersheds. The field reconnaissance and collected data were reviewed and used to create a comprehensive database of available drainage information from various sources. The model and field data inventory were utilized during the modeling update process and helped facilitate the City and BDD4 managing their data more effectively.

ES.4 Existing Conditions Model Updates

A major component of this study was updating the existing conditions modeling. Halff, in conjunction with the City and BDD4, updated the hydrologic models to reflect changes in the development and major channel and detention projects. Updates to the hydrology were performed in accordance with HCFCD methodology to maintain consistency with previous HCFCD studies for Clear Creek. Differences in peak flow rates between the revised existing conditions (Halff) and the current FEMA models can be attributed to significant differences in development levels and storage routing.

The FEMA effective hydraulic models for the major streams were converted to the most current version of HEC-RAS and then revised to account for changes in terrain (based on 2008 LiDAR) and new hydraulic structure data. New hydraulic models were developed for the areas where no previous models were available, which included Mustang Bayou, East Fork Chocolate Bayou, and West Fork Chocolate Bayou. Hickory Slough and Mary's Creek were modeled using unsteady HEC-RAS to more effectively capture the impact of multiple regional detention ponds.

The existing modeling results showed that most of the major streams within the study area have less than a 3-year capacity. Mary's Creek provides approximately 5-year capacity and portions of Cowart have upwards of 25- to 5-year capacity. There a few ditches or major bayou segments higher capacity, but the majority of the existing channels provide limited conveyance. The flat terrain and low existing capacity of the major streams result in wide floodplains, resulting in large areas experiencing flooding from relatively frequent storms. In additional, the existing conveyance capacity of local drainage ditches located throughout the study area was evaluated, and the capacity estimations indicated that many of these local ditches do not have the capacity necessary to adequately convey runoff to receiving channels.

ES.5 Flood Reduction Analysis

Two flood reduction alternatives were evaluated for the entire study area based on a desired carrying capacity or level of service (LOS). Alternative 1 was developed to provide the 100-year LOS for each of the major watersheds. Alternative 2 was developed to provide a lower cost improvement, but still show significant flood reduction benefits. The Alternative 2 LOS varied by channel and depended on the existing channel capacity; the goal being to provide an increase of 1-2 levels of service. For example, the goal for a channel with less than 3-year capacity would be to get 5- to 10-year capacity.

The focus of the flood reduction alternative analysis was on structural improvements throughout the study watersheds, specifically channel conveyance improvements and regional detention. Channel improvements consisted of widening the existing channel and providing a uniform, trapezoidal shape. Detention was provided for both reduction of peak discharges as well as for mitigation of flow increases associated with channel conveyance modifications. Bridges and culverts were upsized where necessary to reflect the widened top width of the channels due to proposed channel conveyance improvements and to reduce hydraulic restrictions, which contribute to flooding along the major streams.

While the intent of the flood reduction measures is to address existing flooding concerns within the Pearland BDD4 area, the planning effort considered future development conditions (i.e. ultimate build-out) to ensure that improvements provide the necessary long-term protection. Future conditions hydrology accounted for increases to impervious cover associated with expected development, which result in increased runoff volumes. The future conditions flows were used to size the proposed channel conveyance improvements and detention ponds for the two different flood reduction alternatives.

ES.6 Flood Reduction Project Recommendations

The study resulted in the recommendation of major projects in 29 separate stream segments, which will address flood reduction needs across the entire project area. Each of these projects is comprised of multiple components including detention and channel conveyance improvements. Given the diverse development conditions across the watershed, a variety of metrics were used to prioritize projects. Traditional benefit-cost analyses (BCA) were considered for project prioritization using information from a Flood Damage Assessment; however, the limited number of structures in watersheds like Cowart, Chigger, and Mustang, would result in those projects being pushed way down the priority list. A "Prioritization Based on Need" assessment was developed, which scored projects based on the number of structures at risk for the 10- and 100-year rainfall events, the number of flood insurance claims, and the channel level of service. In addition, an evaluation was performed of the inundation removed from structures, land acreage, and roadway miles. These metrics provided a bit more balanced comparison of the projects in the different watersheds, but those areas with higher levels of development are still heavily favored. Finally, the development potential and projected future buildout timeframes were considered, this measure gave some weight to those watersheds that are still largely undeveloped but may experience growth in the future. The various metrics were weighted to provide a single score for each project, which was used to set the priority. It should be noted that many of the more rural projects would fall under the jurisdiction of BDD4 alone, and as such should be considered separately from projects in the City of Pearland. Recommended projects are listed in the table below.

ES.7 Implementation Planning

An implementation plan was developed to help outline a path forward for the recommended projects provided in the study. The plan includes the development of a project prioritization methodology and identification of the projects to be completed both for major creeks and bayous as well as local ditches. Specific projects are listed in the tables below. Projects were divided into 4 categories:

- **Large CIP Projects:** Top 10 scoring main channel segment projects, will need to be phased
- **Reserve CIP Projects:** Main channel projects that rank from 11-15 and may provide benefits
- **Small CIP:** Local ditch projects from the Top 50 that cost more than $500k
- **Small O&M:** Local ditch projects from the Top 50 that cost less than $500k

The primary challenges to implementation of flood reduction measures include project costs, ROW acquisition, environmental constraints, and utility conflicts. ROW availability was a significant issue in developing proposed alternatives throughout the watershed, particularly within the City of Pearland where high levels of urbanization limit the amount of undeveloped land for drainage improvements. ROW will be needed for both the conveyance improvements and the associated detention to mitigate any potential flow impacts. Another major concern is potential utility conflicts with large oil and gas pipelines that are located throughout the watershed. Environmentally sensitive areas or areas with identified cultural resources need to also be considered and avoided when possible.

The work completed as part of this master drainage plan study represent a major effort in streamlining and modernizing the drainage analysis for the City and BDD4. The updated hydrologic and hydraulic modeling will help facilitate more efficient updates to the master plan in the future as the area continues to develop in order to more accurately identify and manage flooding risks. The development of flood reduction alternatives and supporting analysis and cost estimates will benefit the City and BDD4 as they plan out their short-term and long-term Capital Improvement Planning.

ES.1 - Large Capital Improvement Project (CIP) Recommendations

PROJECT PRIORITY	WATERSHED SEGMENT	PROJECT DESCRIPTION	PROJECT COSTS (M)			
			CHANNEL	DETENTION	ROW	TOTAL
1	Hickory Slough Middle Segment	**100-year LOS**; Channel modifications from Cullen Blvd. to Garden Rd. and 1010 ac-ft mitigation. Max ROW width of 170 ft.	$6.7	$19.2	$17.3	$43.2
2 †	Cowart Creek Segment 16	**10-year LOS**; Channel modifications from Wells Dr. to BNSF Railroad. Max ROW width of 200 ft.	$2.1	-	$5.2	$7.3
3	West Fork Chocolate Cold River Ranch Ditch	**100-year LOS**; Channel modifications from Rio Lindo St. to Hwy 6 and 580 ac-ft mitigation. Max ROW width of 180 ft.	$6.4	$10.4	$4.2	$21.0
4	Cannon Ditch Segment 2	**100-year LOS**; Channel modifications from Pearland Site Rd. to Amoco Industrial St. and 9800 ac-ft mitigation. Max ROW width of 120 ft.	$4.8	$37.5	$4.2	$46.5
5	Mary's Creek Upper Segment	**25-year LOS**; Channel modifications from B129-01-00 to McLean Rd. and 240 ac-ft mitigation. Max ROW width of 250 ft.	$10.5	$4.5	$7.9	$22.9
6 †	Mary's Creek Middle Segment	**25-year LOS**; Channel modifications from Magnolia Dr. to SH35 and 1000 ac-ft mitigation. Max ROW width of 250 ft.	$10.7	$17.6	$3.1	$31.4
7	Mustang Bayou Upper Segment	**25-year LOS**; Channel modifications from CR521 to Airline Rd and 890 ac-ft mitigation. Max ROW width of 240 ft.	$10.7	$44.4	$46.9	$102.0
8	Mary's Creek Lower Segment	**25-year LOS**; Channel modifications from SH35 to downstream of Pearland Pkwy. and 1670 ac-ft mitigation. Max ROW width of 220 ft.	$14.8	$55.2	$51.8	$121.8
9	Mustang Bayou Middle Segment	**25-year LOS**; Channel modifications from Airline Rd. to SH288 and 1070 ac-ft mitigation. Max ROW width of 260 ft.	$5.8	$31.9	$22.8	$60.5
10	Hickory Slough Lower Segment	**10-year LOS**; Channel modifications from Garden Rd. to SH35 and 1310 ac-ft mitigation. Max ROW width of 170 ft.	$12.4	$24.7	$15.2	$52.3

† Detention is included in downstream segment; however, mitigation will be required for conveyance improvements and should be evaluated in the PER Phase

ES.2 - Reserve Capital Improvement Project (CIP) Recommendations

PROJECT PRIORITY	WATERSHED SEGMENT	PROJECT DESCRIPTION	PROJECT COSTS			
			CHANNEL	DETENTION	ROW	TOTAL
11	West Chocolate Bayou CR 383 Ditch	**5-year LOS**; Channel modifications from E101-02-00 to confluence with West Fork Chocolate Bayou and 1260 ac-ft mitigation. Max ROW width of 190 ft.	$8.90	$27.60	$215.70	$252.20
12	West Fork Chocolate Bayou	**5-year LOS**; Channel modifications from county boundary to confluence with E101-00-00 and 3700 ac-ft mitigation. Max ROW width of 260 ft.	$16.10	$69.50	$17.90	$103.50
13	Hickory Slough Upper Segment	**100-year LOS**; Channel modifications from CR 94 to confluence with H126-00-00 and 280 ac-ft mitigation. Max ROW width of 170 ft.	$2.40	$19.60	$34.70	$56.70
14 †	East Chocolate Bayou E103-00-00	**10-year LOS**; Channel modifications from SH288 to confluence with Rodeo Palms Ditch and 2210 ac-ft mitigation. Max ROW width of 220 ft.	$1.70	-	$0.70	$2.40
15 †	West Fork Chocolate Cold River Ranch Ditch	**5-year LOS**; Channel modifications from Hwy 6 to confluence with West Fork Chocolate Bayou and 50 ac-ft mitigation. Max ROW width of 250 ft.	$8.70	-	$1.20	$9.90

† Detention is included in downstream segment; however, mitigation will be required for conveyance improvements and should be evaluated in the PER Phase

ES.3 - Small Capital Improvement Project (CIP) Recommendations

DITCH PRIORITY	WATERSHED	DITCH	3-YR LOS		10-YR LOS	
			TOP WIDTH	COST	TOP WIDTH	COST
1	Cowart Creek	C123-00-00	56	$ 918,000	66	$ 1,161,000
2	Hickory Slough	H123-00-00	311	$ 3,017,000	451	$ 4,356,000
3	Chocolate Bayou	E100-00-00	72	$ 1,490,000	91	$ 1,946,000
4	Cowart Creek	C118-00-00	37	$ 961,000	41	$ 1,199,000
5	Cowart Creek	C122-00-00	71	$ 1,069,000	83	$ 1,332,000
6	West Chocolate	E101-01-06	66	$ 806,000	80	$ 1,029,000
7	Chigger Creek	J101-02-00	146	$ 2,401,000	171	$ 2,920,000
8	Cowart Creek	C128-00-00	34	$ 671,000	40	$ 864,000
9	Chigger Creek	J102-05-01	50	$ 1,492,000	60	$ 1,910,000
10	Cowart Creek	C120-01-00	26	$ 632,000	26	$ 776,000
11	Cowart Creek	C124-01-00	42	$ 551,000	49	$ 701,000
12	Clear Creek	A105-05-00	83	$ 847,000	101	$ 1,074,000
13	Hickory Slough	H125-02-00	158	$ 718,000	159	$ 772,000
14	Cowart Creek	C107-03-01	35	$ 784,000	39	$ 984,000
15	Mary's Creek	B117-00-00	33	$ 1,545,000	37	$ 1,929,000
16	Hickory Slough	H114-00-00	34	$ 1,124,000	38	$ 1,421,000
17	West Chocolate	E101-01-01	52	$ 648,000	60	$ 810,000
18	Clear Creek	A113-00-00	34	$ 665,000	34	$ 799,000
19	Mary's Creek	B102-01-01	56	$ 499,000	66	$ 631,000
20	Chocolate Bayou	E102-00-00	50	$ 1,009,000	67	$ 1,373,000
21	Clear Creek	A115-00-00	39	$ 1,132,000	44	$ 1,420,000
22	Cowart Creek	C124-00-00	34	$ 669,000	35	$ 805,000
23	Cowart Creek	C119-00-00	28	$ 698,000	30	$ 875,000
24	Hickory Slough	H123-01-00	311	$ 3,017,000	451	$ 4,356,000
25	Clear Creek	A116-00-00	25	$ 870,000	33	$ 1,181,000
26	Cowart Creek	C120-00-00	91	$ 1,216,000	110	$ 1,534,000
27	Cowart Creek	C100-00-00	28	$ 532,000	31	$ 676,000
28	Clear Creek	A111-00-00	31	$ 989,000	34	$ 1,241,000
29	Chigger Creek	J101-02-01	94	$ 1,094,000	114	$ 1,382,000
30	Mary's Creek	B114-01-01	37	$ 660,000	43	$ 843,000
31	Cowart Creek	CR 414 Ditch	21	$ 775,000	23	$ 993,000
32	Cowart Creek	C101-00-00	60	$ 2,659,000	79	$ 3,580,000
33	Chigger Creek	J102-00-00	116	$ 3,312,000	160	$ 4,525,000
34	Hickory Slough	H125-01-00	50	$ 1,141,000	50	$ 1,330,000
35	Hickory Slough	C103-03-00	39	$ 535,000	42	$ 657,000
36	Cowart Creek	Cowart's Creek Ditch	35	$ 784,000	39	$ 984,000

ES.4 - Small O&M Project Recommendations

DITCH PRIORITY	WATERSHED	DITCH	3-YR LOS		10-YR LOS	
			TOP WIDTH	COST	TOP WIDTH	COST
1	Chigger Creek	J101-01-01	61	$ 190,000	139	$ 238,000
2	Chigger Creek	J101-01-00	16	$ 233,000	19	$ 298,000
3	Clear Creek	A122-00-00	34	$ 479,000	35	$ 583,000
4	Chigger Creek	J101-01-01	23	$ 239,000	26	$ 309,000
5	Cowart Creek	C105-01-00	34	$ 77,000	41	$ 100,000
6	Cowart Creek	B102-01-03	33	$ 217,000	38	$ 278,000
7	Cowart Creek	C107-10-01	62	$ 429,000	71	$ 546,000
8	Clear Creek	A121-01-00	42	$ 397,000	50	$ 511,000
9	Cowart Creek	C125-00-00	22	$ 193,000	23	$ 241,000
10	Cowart Creek	C107-01-02	24	$ 244,000	28	$ 319,000
11	Cowart Creek	C107-04-01	31	$ 361,000	34	$ 453,000
12	Hickory Slough	H111-00-00	30	$ 85,000	30	$ 103,000
13	Chocolate Bayou	E100-01-01	56	$ 430,000	72	$ 572,000

Table of Contents

Volume 1

Volume 2

Volume 3

Volume 4

1.0 Introduction

Over the last several decades, the City of Pearland (City) and Brazoria Drainage District No. 4 (BDD4) have experienced significant growth and development with the last decade alone seeing a two-fold increase in the area's population. With development comes an increased risk of flooding from streams as well as local sources, which can present hazards to the public and impede growth. To more effectively identify flood risks, plan drainage improvements, and consider regulatory measures aimed at minimizing negative development impacts, the City and BDD4 initiated a two-phase effort with Halff Associates, Inc. (Halff) to update and combine the master drainage plans for Pearland and BDD4 into one document, along with updated hydrologic and hydraulic modeling for all major streams within the study area

The previous Master Drainage Plans, which are currently being used by the City and BDD4 were developed in the late 1990's. The level of growth in the area has changed along with many of the assumptions and modeling parameters that were developed at that time. The plans currently utilized include:

- Flood Protection Plan for Brazoria Drainage District No. 4, Rust Lichliter/Jameson, November 1997
- Master Drainage Plan for the City of Pearland, Rust Lichliter/Jameson, February 1998

Several other planning efforts, including detention master planning and sub-regional plans for drainage improvements have been completed. Within the nearly 20 years since the current plans were completed, the City and BDD4 have successfully implemented numerous projects, including channel improvements, channel diversions, regional detention facilities, and storm sewer improvements. The intent of this master plan update is to leverage the success of these efforts and to modernize the plan based on physical changes to the area, changes in goals on the part of Pearland and BDD4, new technologies, and changes in the CIP funding of both the City and BDD4 since the last plan.

The master planning effort will consider these past successes and the growth that the City and BDD4 have experienced but the focus will now be shifted to how to manage drainage issues along the bayous and ditches as the area continues to develop. The area that encompasses the City and BDD4 is continuing to develop at a healthy rate, with new businesses and residents moving into the area every day. This effort will facilitate that growth by better informing current and future citizens of their potential flood risk, and identifying the current bayous, ditches, and detention needs to accommodate this future growth.

Both the City and BDD4 maintain MS4 permits, follow drainage criteria for development aimed at mitigating negative impacts, identify and address areas of concern, and construct Capital Improvement Projects. Jurisdictions within BDD4 including Pearland, participate in the National Flood Insurance

Program (NFIP); however, since BDD4 is considered a district and not a community, BDD4 is not eligible to directly participate in the NFIP's Community Rating System (CRS) like the jurisdictions within BDD4. The City of Pearland participates in the CRS and has implemented standards that exceed the NFIP minimums, resulting in a CRS rating of 6. The City's rating provides residents within the Special Flood Hazard Area (SFHA) with a 20% discount on their flood insurance premiums and 10% for those not in the SFHA. This is among the highest rated programs in Texas.

1.1 Project Goals

The study focused on identifying and addressing the flood hazards along the main streams within the study area. As part of the study, Pearland, BDD4 and Halff established certain goals and objectives. The goals include:

- Update or develop new hydrologic modeling for all watersheds contributing to the study area using HEC-HMS and updated land use data.
- Update or develop new hydraulic modeling for major bayous within the study area using HEC-RAS and updated terrain information
- Identify high-level comprehensive plan to provide 1% (100-year) level of service as well as a reduced level of service option along the modeled streams.
- Evaluate the capacity of local ditches that flow into the modeled streams and estimate the cost to achieve 3-year and 10-year level of service in the ditches.
- Develop a priority list of projects to reduce flood risks within the watersheds. This includes major channel improvement and detention projects as well as improvements to smaller ditches to improve local drainage.

It is important to note that the focus of this Master Drainage Plan is on channel capacity and detention projects needed to meet the desired level of service (i.e. 100-year or other) for the major streams and larger local ditches. It does not evaluate local drainage infrastructure (roadside ditches or storm sewers) for residential or other developed areas. However, local systems drain to the receiving streams being evaluated and, as such, it is likely that these improvements could result in a reduction in flood levels for these areas. Ultimately, the projects recommended are intended to contain stormwater runoff and protect people and property to the maximum extent practicable. It is likely that there will still be structural and street flooding for low lying areas, even after projects are implemented. These areas should consider elevation or other methods for reducing flood risk.

2.0 Study Area Overview

2.1 General Description of Study Area

The City and BDD4 Master Plan area consists of the shared boundary of the City and BDD4, which encompasses a combined area of nearly 97 sq. mi (**Exhibit 1)**. The area is generally bound by Clear Creek to the north and FM 521 to the west. The eastern and southern boundaries are less clearly demarcated. A portion of the City extends into Harris County on the east side of Clear Creek. The Galveston County line serves as the remainder of the eastern boundary. A majority of BDD4 is located north of SH6, except for a small area near the Fort Bend County line, which includes portions of Iowa Colony and Manvel.

Major streams to be included in the study will be Clear Creek, Hickory Slough, Mary's Creek, Cowart Creek, Chigger Creek, West Fork of Chocolate Bayou, and Mustang Bayou. A map of the master plan area with the major watersheds are included in **Exhibit 2**. Numerous drainage ditches, diversions, and tributaries feeding these streams will be included as well. The study area lies within fourteen (14) FEMA FIRM panels in three counties; Brazoria, Harris, and Fort Bend. The panels include those in Brazoria (48039C-0010I, 0020H, 0030I, 0035I, 0040I, 0045J, 0110H), in Harris (48201C-1010L, 1030L, 1035L, 1055L), and in Fort Bend (48157 0305L, 0315L, 0455L). There have been multiple revisions and amendments for each panel since the effective dates in 1989-1999. Revised FEMA maps were recently released with a preliminary effective date of June 29, 2018, but as of this report, the maps have not been finalized. There are several revisions to the maps throughout the study area. **Exhibit 3** includes the FEMA FIRM panels for the master plan area.

2.2 Historical Flooding

Pearland and BDD4 has long history of flooding, with damages dating back to the 1970s. The region has experienced several significant flooding events including the following: Tropical Storm Claudette, Hurricane Alicia, October 1994 storm, Tropical Storm Francis, Tropical Storm Allison, Hurricane Ike, and in 2017 Hurricane Harvey. Pearland data indicates that 272 flood claims were filed between 2005 and 2011. The largest number of flood claim claims, before Hurricane Harvey, followed Hurricane Ike, which caused 183 additional claims. No loss data was available outside of Pearland.

In 2017 Hurricane Harvey produced widespread flooding in Harris County and the surrounding area. According the City of Pearland's *Hurricane Harvey Drainage Assessment Report*, the rainfall ranged from 30 to 49 inches for the City and surrounding area over 4 days. This storm greatly surpassed the rainfall for all other historical storms in the area. The rainfall for the area exceeds the 0.2% (500-year) annual exceedance probability throughout much of the county. Peak channel water surface elevation frequencies for Clear Creek and its tributaries range from 1% (100-year) to greater than 0.2% (500-year) and record level floods were recorded throughout. Water levels for Hurricane Harvey surpassed the previous record storm (Tropical Storm Claudette) by 2 to 3 feet along Clear Creek and its portions of its major tributaries. However, based on field observations and stream gauge data, portions of the study area may not have experienced a 100-year storm. Based on City of Pearland's Hurricane Harvey Drainage Assessment report, 1080 residencies experienced minor flood damage and 641 major flood damage. While 22 business recorded minor losses and 11 recorded major losses.

2.3 Drainage and Flooding

2.3.1 Regulatory Floodplain

Federal Emergency Management Agency (FEMA) effective floodplains were obtained through various sources and are shown in **Exhibit 3**. FEMA FIRM panels that encompass the watershed are listed above. Chigger Creek, Chocolate Bayou and Clear Creek are all previously studied but do not have detailed studies within the boundaries of Pearland/BDD4. Mary's Creek, Hickory Slough, Mustang Bayou and Cowart Creek all have regulatory floodplain within the study area. During the master planning process, preliminary updated maps were provided. The effective date for the maps is listed as June 29, 2018.

2.3.2 Local Drainage

Local drainage throughout a majority of the watershed consists of roadside ditches and storm sewer. These roadside ditches provide drainage for residential areas and large agricultural tracts and discharge into larger streams. The roadside ditches and culverts are in various states of repair, but generally have capacity that is below the design storm specified in the local criteria (3-year). The capacity for local ditches is shown in **Exhibit 9.** In many instances there is debris present in the culverts, limiting their capacity. Several of the tributaries have ponding upstream of the channel headwaters due to limited access to the channel. These are not intended to be evaluated in detail as part of this Master Drainage Plan.

2.3.3 Flood Claims

The study area has a history of flooding and associated flood damages. Flood loss data provided by Pearland for this study included the flood claim data between 2005 and 2012 as well as data collected in the aftermath of Hurricane Harvey. Approximate locations where flood claims have been filed are shown in **Appendix C.36**.

3.0 Data Collection and Inventory

The initial effort for Phase I of the study consisted of a significant amount of data collection. The City and BDD4 provided all available reports, Geographical Information Systems (GIS) data, hydrologic and hydraulic models, and other data. This data was a critical part of establishing the current benchmark for information required for alternatives modeling conducted in Phase II. Modeling data collected included the current effective models for Mary's Creek, Hickory Slough, Cowart Creek, as well as other modeling data developed as part of smaller master planning efforts and development projects. The current master plans were collected as well as current CIP information. Each of these components will be discussed below.

3.1 Plan Report and Inventory

The first of those mechanisms is the drainage report inventory, which consists of a GIS database of each unique document provided by the City. The City of Pearland and Brazoria Drainage District No. 4 provided a total of 128 documents. In most instances the complete report was provided including narrative, exhibits, and appendices. In some cases, digital data including models were provided. Some of the data provided was in digital format only. Some of the data provided was only small pieces of information or exhibits from reports with no accompanying data. Additional documents may be added once they are received or the City/BDD4 may provide regular updates once they take over management of the database.

3.1.1 Inventory Development Process

All hard copy reports were scanned to Adobe Acrobat (.pdf) format and catalogued. This information was combined with other available information and organized by type of project or study. In order to simplify the inventory, six (6) study/project categories were used, including:

- **CIP Improvements** – Any design report or PER associated with a design project including roadways, channel improvements, detention improvements, storm sewer improvements, etc.
- **Detention Analysis** – Includes planning efforts (Sub-Regional or otherwise) for detention, which may be aimed at specific locations or a larger area and include adjustments to existing ponds.
- **Flood Mitigation Study** – Aimed at flood mitigation efforts for large developments, typically master-planned residential communities
- **Letters of Map Change (LOMC)** – Includes all letters of map change such as LOMR-F (based on fill placement) and CLOMR-F (conditional based on fill placement), LOMR (based on a physical change or updated information) and CLOMR (conditional based on a physical change)
- **Master Plan** – Planning efforts for major watersheds or inclusive of a jurisdiction (City, MUD, etc.)

- **Drainage Report** – Drainage analyses for smaller areas or developments. May include smaller residential areas, commercial areas, etc.

For each of the reports provided, a unique GIS element was generated in polygon format to represent that information. The specific shape was based on the limits of the analysis. For example, a watershed master plan would be identified by watershed drainage area. A drainage report would include the limits of the development or improvement being evaluated. For detention studies, some of the reports may be represented by several polygons where recommendations for detention ponds have been made. Each report was catalogued using several data points as shown in **Figure 1**. These include the following:

- Project or Study Name
- Year of Submittal
- Engineer of Record
- Name of Engineering Firm
- Watershed Name
- Project or Study Type (based on classifications shown above)

Figure 1. Field Verification Data

Project/Study Name	Submittal Year	Engineer of Record	Engineering Firm	Watershed Name	Project/Study Type
2009 Hickory Slough (HI100-00-00) Update	2009	Lawrence Lopez	4Site	Hickory Slough	Flood Mitigation Study
523-Acre Southern Trails Master Drainage Plan Clear Creek Watershed	2004	Lee Clark Lennard	Brown & Gay	Clear Creek	Master Plan
Brazoria County Mapping Update Clear Creek	2005	Brett Sachtleben	Dannenbaum	Clear Creek	Flood Mitigation Study
Brazoria County MUD No 22	2009	Robert Bardin	LJA	Chocolate Bayou	Master Plan
Brazoria County MUD No 23 Master Drainage Plan and Impact Analysis	2005	Robert Bardin	LJA	Clear Creek	Master Plan
Broadway at Woodcreek LOMR	2002	Jennifer J. Walker	Lentz Engineering	Marys Creek	LOMR
City of Manvel Master Drainage Plan	2015	Philip Bullock	Klotz	Chocolate Bayou	Master Plan
City of Pearland Sub-Regional Detention Plan	2010	Dennis Todd Miller	Klotz		Detention Analysis
City of Pearland Tropical Storm Allison Flood Study	2002	Gary Wayne Bezemek	Klotz	Clear Creek	Flood Mitigation Study
Clear Creek From Station 1691+93 to Station 1776+79 Request for	2002	Carolyn Gilligan	LJA	Clear Creek	CLOMR
Clear Creek Watershed Modeling Update	2009		Dannenbaum		CIP Improvement

3.2 Model Inventory

The City and BDD4 provided numerous hydrologic and hydraulic models as part of the data collection process. Because the master plan update focuses specifically on the open channel systems within the study area, those models related to storm sewer analysis were not included in the inventory. The models received included both effective Flood Insurance Study (FIS) models as well as model updates that were not considered effective at the time of the model review, such as those completed for channel improvement projects or updates based on better information or physical changes to the watershed.

There are two sets of FEMA Effective models for the City of Pearland. The effective models for the portions of Pearland in Brazoria County are associated with the Brazoria County FIS conducted in the 1980's. The models for that FIS were created in HEC-1 and HEC-2. Electronic versions of the HEC-1 model of the Clear Creek watershed and the HEC-2 models for Hickory Slough, Mary's Creek, and Cowart Creek were provided by the City/BDD4. No copies of the effective HEC-2 model of Clear Creek or the effective models for Mustang Bayou were obtained. Electronic versions of HEC-1 and HEC-2 models of Mustang Bayou that were created as part of the Brazoria County Master Drainage Plan in 1998 were provided; however, electronic versions of the effective HEC-2 model of Chigger Creek were not available. No hydrologic or hydraulic modeling for the West Fork of Chocolate Bayou was available.

The effective models for the portions of Pearland in Harris County are those associated with the Tropical Storm Allison Recovery Project (TSARP) conducted by Harris County Flood Control District (HCFCD). These models were created in HEC-HMS and HEC-RAS. Digital versions of these models were obtained from the HCFCD Model Management (M3) website and include HEC-HMS and HEC-RAS models for Clear Creek.

In addition to the FEMA Effective models collected, hydraulic models prepared by Dannenbaum Engineering Corporation (DEC) as part of the TSARP hydrologic study for Hickory Slough, Mary's Creek, and Cowart Creek were also obtained. Dannenbaum was the TSARP hydrologic study contractor for the Clear Creek Watershed. Part of their scope was to create tributary hydraulic models to facilitate storage-routing computations in HEC-HMS. This effort provided the base HEC-RAS models for Hickory Slough, Mary's Creek and Cowart Creek.

DEC updated the models for Hickory, Mary's and Cowart in 2006. The models were provided along with a report Clear Creek Watershed Modeling Update for the Clear Creek Watershed Steering Committee and the City of Pearland. The reports provide detailed documentation of the methodology used to create the models as well as modeling results. This effort also produced updated hydrologic modeling of the Hickory, Mary's and Cowart watersheds.

Based on a draft report to the Clear Creek Watershed Steering Committee, there appears to have been another update of the Clear Creek tributary models in 2009. These updates were made by modifying the effective Clear Creek HEC-HMS model. Updates included the addition of some small regional detention ponds on the tributary streams (Hickory, Mary's, Cowart and Chigger) and some channel improvements on Mary's Creek. The DEC models are the basis for the FEMA mapping updates for Brazoria County along the aforementioned streams.

3.2.1 Model Inventory Development

Similar to the report and plan inventory, each of the models provided was organized by classification (i.e. Effective, 2006 Update, 2009 Update, etc.) and then by watershed. The models were then reviewed to determine their applicability for Phase II. The review of these models will be discussed in Section 4 of this report. Information regarding each model was gathered, if available, including effective date (in the case of FEMA Effective models) or date of development, watershed, stream name, etc. During the Phase I effort, it was determined that the GIS Model Inventory would be more effective following the development of the existing conditions models that will be done in Phase II. After the models are developed, they will be compressed in a .zip format and linked to a feature in GIS, as was done with the report and plan inventory. Hydrologic models will be attached to a watershed polygon feature. Hydraulic models will each be attached to a linear stream feature.

As previously mentioned, some of the models were effective, some were updated versions, and others were related to specific projects. Those models that were project specific will not be included in the inventory. The FEMA Effective models will be attached to the associated watershed and stream features as well as the Dannenbaum model updates as best available information. For regulatory purposes, the FEMA effective models should be utilized such that submittals for LOMR's and CLOMR's meet the FEMA requirements.

3.3 Topographic Survey

A limited field survey was performed to collect structure data at selected locations. For each surveyed location photographs of the upstream and downstream face of the structure and channels were provided along with field sketches with culvert and bridge data included. Surveyed cross sections, with centerlines, tops of bank, and at least two other points were provided. The survey was performed to aid in the development of new hydraulic models, which is discussed in later sections. Field survey information is included in **Appendix E**.

4.0 Data and Model Review

A thorough review of the data, including reports and modeling, was needed to identify those projects that have been completed, those that are no longer appropriate, and those that should be considered moving forward. For the latter case, reviewing the specifics such as the project configuration, costs, effectiveness and constraints aided in new model development for the study. As this is a Master Drainage Plan update, the previous master planning efforts were reviewed, as well as the current drainage criteria, the current CIP, and funding sources.

4.1 Previous Master Plans

As mentioned in Section 1, the City and BDD4 both had Master Drainage Plans prepared by Rust Lichliter/Jameson in the late 1990's. Since that time there have been several smaller plans, including watershed plans and a sub-regional detention plan. The plans currently utilized include:

- Flood Protection Plan for Brazoria Drainage District No. 4, Rust Lichliter/Jameson, November 1997
- Master Drainage Plan for the City of Pearland, Rust Lichliter/Jameson, February 1998

Both plans were comprehensive and covered major flood protection projects as well as smaller local storm sewer projects. A brief discussion of each of these plans and recommendations relating to the master plans is provided below.

4.1.1 Flood Protection Plan for Brazoria Drainage District No. 4

The 1997 Flood Protection Plan for BDD4 included a thorough evaluation of the primary system for Mary's Creek, Hickory Slough, Cowart Creek, Chigger Creek, and looked at Clear Creek ditches within the Brazoria County limits. While these streams were updated as part of this master plan, Clear Creek was not modeled. Clear Creek has a shared jurisdiction with Harris County Flood Control District (HCFCD) and is the subject of a significant proposed U.S. Army Corps of Engineers (USACE) project, which is to be funded using federal money allocated in the wake of Hurricane Harvey. In addition, the Mustang Bayou and Chocolate Bayou watersheds within the study boundary were included in the evaluation and planning process.

4.1.2 Master Drainage Plan for the City of Pearland

A heavy focus of the 1998 City of Pearland MDP was the evaluation of roadside ditches and storm sewers. While the intent of this Master Plan Update was to focus on the primary systems, consideration of the flooding history in the area related to local drainage was considered as well. A comparison of the revised flood inundation mapping to those areas outside the "floodplain" that have a record of flooding help determine if flooding in those areas is a function of the local drainage system or due to open channel flooding. In many instances, those areas that have historical flood complaints have been addressed through detention, ditch improvements, storm sewer projects identified in the 1998 master plan and subsequent planning efforts.

In addition to historical flood complaints, public input gathered during the study helped identify areas that continue to flood as a result of local drainage deficiencies. A detailed analysis of neighborhood drainage is not included with Phase II. Recommendations for small area studies are included in subsequent sections.

4.2 Report and Plan Review

Each of the plan sets and reports received and inventoried was subjected to a two-step review process. The first step included a cursory review conducted to determine the document's applicability to the larger master planning effort. Drainage reports for small developments, small projects that were constructed prior to 2008 (date of LiDAR flight), and others were labeled as "Archive" and no detailed review was conducted. For those that were more recent and of a sufficient scale to impact the master planning effort, a detailed review was done. Each of the plans was reviewed for project recommendations, costs, and constraints as well as other information that was helpful during the modeling and planning process.

4.3 Model Review

The models received were reviewed to determine what information could be maintained moving forward and what should be updated to ensure that current conditions are reflected in the models. The review was conducted for both the hydrologic and hydraulic models.

4.3.1 Existing Models and Previous Studies

Past master planning efforts have resulted in several iterations of comprehensive modeling for the Clear Creek watershed and its tributaries. This includes efforts by the USACE, the City, BDD4 and HCFCD. However, these efforts did not include Mustang Bayou or Chocolate Bayou. There are two sets of effective FIS models for the City of Pearland. The effective models for the portions of Pearland in Brazoria County are associated with the Brazoria County FIS conducted in the 1980's. The models for that FIS were created in HEC-1 and HEC-2. Halff has obtained electronic versions of the HEC-1 model of the Clear Creek watershed and the HEC-2 models for Hickory Slough, Mary's Creek, and Cowart Creek. Halff does not have copies of the effective HEC-2 model of Clear Creek or the effective models for Mustang Bayou. Halff does have electronic versions of HEC-1 and HEC-2 models of Mustang Bayou that were created as part of the Brazoria County Master Drainage Plan in 2000. Further, Halff has an electronic version of the HEC-2 model of Chocolate Bayou created in 2003. Halff does not have an electronic version of the effective HEC-2 model of Chigger Creek. The HEC-1 and HEC-2 models were used for informational purposes only.

The effective models for the portions of Pearland in Harris County are those associated with the Tropical Storm Allison Recovery Project (TSARP) conducted by Harris County Flood Control District (HCFCD). These models were created in HEC-HMS and HEC-RAS. Halff has obtained the HEC-HMS and HEC-RAS models for Clear Creek from the HCFCD website. After Tropical Storm Allison in 2001, Dannenbaum Engineering Corporation (DEC) was selected as the TSARP hydrologic study contractor for the Clear Creek Watershed. Part of their scope was to create tributary hydraulic models to facilitate storage-routing computations in HEC-HMS. This effort provided the base HEC-RAS models for Hickory Slough, Mary's Creek and Cowart Creek. These models formed the primary basis in the development of the new hydraulic models. The calculated water surface elevations in the DEC models vary from those in the effective models. The percent difference in elevation ranges from -12% to 0% change.

The existing FEMA effective hydraulic models for the study area were HEC-RAS v. 3.0.1 and the hydrologic models were HEC-HMS v. 3.3. These models were utilized as a starting point for the model update effort, which is discussed below. Per the scope for the Master Drainage Plan, the hydrologic models were converted to HEC-HMS v. 4.2.1 and hydraulic models were updated to HEC-RAS v. 5.0.5, which are the most current versions of the software. In addition to better computational and visual capabilities, the 5 The newer versions of HEC-HMS and HEC-RAS fix errors from previous versions. The most recent version of HEC-RAS has 2D modeling capability, which may be beneficial for Preliminary Engineering analysis of recommended projects, and provides better tools for terrain modification and inundation mapping.

Using the DEC models as a base, new hydraulic modeling was developed for each of the streams that drain to Clear Creek using previous model data wherever possible. Specific modeling information is provided in the sections below. Completely new models were developed for Chocolate Bayou, Mustang Bayou, and several smaller sub-tributaries.

4.4 Drainage Criteria Review

As part of the Phase I reviews, Halff evaluated the current drainage criteria for the City of Pearland and Brazoria Drainage District No. 4. In general, nearly all the needed updates for the City's manual apply to the BDD4 manual since they have nearly identical criteria. At the time of the initial review, there were some updates to the C-value calculations and times of concentration that warranted further investigation. It should be noted that an update to the Engineering Design Criteria Manual (EDCM) was submitted in September 2016, parallel with the Phase I MDP effort. The City requested a subsequent review, which indicated that many of the initial recommendations for changes had been incorporated into the updated criteria. This included the few discrepancies between the City and BDD4 criterion. Future criteria updates may be made as the area grows as long as there is a consistent drainage criteria to clarify acceptable methodologies for developers and engineers working within the jurisdiction.

One concern that was presented during discussions with Pearland and BDD4 staff was the need to ensure that both parties have a way to review or, at a minimum, be aware of submittals along BDD4 channels within the City. It is not uncommon for platting applications to be made to the City where improvements or alterations are proposed along a BDD4 ditch. While both jurisdictions currently sign off on applications where the jurisdictions overlap, a more formal mechanism by which each agency is alerted when a project impacting both jurisdictions may be beneficial.

Another area of concern was how to handle the development of small sites. Requiring detention on very small sites could restrict the desired growth in the area. These requirements were revised as part of the update of the City's Engineering Design Criteria Manual (EDCM) in December 2018. Smaller lots (< 12000 SF) are no longer required to provide detention if they meet the impervious cover maximum requirements. Larger projects are subject to the detention requirement of 0.65 ac-ft per acre plus any floodplain fill mitigation. An evaluation of the cumulative effects of small site development could be considered as part of a future study or implementation phase consideration as well as some guidance on how to handle these types of site projects.

4.5 Current CIP and Funding Review

A review of the current CIP Plan and funding sources was also conducted. Per the City of Pearland's Capital Improvement Program (2018-2022), the five-year program totals $566,193,226. The CIP is funded from several sources including general obligation bonds, water/sewer revenue bonds, impact fees for water and wastewater, and other funding sources. Of the nearly $566.2M in the CIP, only about $12.4M (2%) is planned for drainage projects, with nearly all of that from general obligation bonds. The City has an additional $124.2M in CIP needs; however, to have a manageable program over the next 3-5 years and manage debt, a bond election is planned in 2019 for $70.8M. The four drainage projects listed in the 2018-2022 CIP are:

- Cullen/FM518 Detention Pond - $4.6M
- Southeast Quadrant of Old Townsite Drainage - $1.5M
- PER for Future Bond Referendum - $500k
- D.L. Smith Detention Pond Expansion (Phase I) - $5.8M

The last bond referendum for the City was conducted in 2007 for a total of $162M was scheduled to be completed over a 10-year period; however, it is still ongoing. Several of these projects were completed in cooperation with BDD4. Drainage projects included in the 2007 bond referendum that have been subsequently completed include:

- East Mary's Creek Ditch Improvements – September 2010
- Town Ditch Improvements – February 2011
- Veterans/Walnut Street Storm Sewer – January 2012
- Cowart Creek Diversion – April 2013
- Hickory Slough Detention (Pearland Pkwy) – July 2013

BDD4 is funded from property taxes within its jurisdiction. The tax rate for 2018 is $0.146/$100 appraised valuation. BDD4 does not currently use bonds or other sources of funding. Per discussion with BDD4, there is some capacity for drainage projects that may be recommended as part of this MDP. Specific information is needed on the cost and schedule of the proposed projects before BDD4's CIP capacity can be determined. That information is provided as part of this plan and is included in subsequent sections of the report. Projects that are specific to the City, specific to BDD4, and opportunities to partner will be identified as such in the implementation plan based on jurisdictional boundaries, including the ETJ.

Other mechanisms could potentially be employed to generate additional revenue for drainage projects. Some of these include a Storm Water Utility (SWU), development impact fees, public-private partnerships, TWDB low-interest loans, and FEMA grant programs. The City is currently evaluating the implementation of a SWU. The potential may exist for negotiations with private developers relating to the funding of drainage projects. This approach could be along the lines of an impact fee, where the developer, or group of developers pays a fee in lieu of onsite drainage improvements, and the City and/or BDD4 builds improvements that will benefit the developer as well as the other property owners within the area of influence. Another option could include cost-sharing between the City and private interests to build infrastructure, ostensibly in support of development interests. While these will not be determined by this study, the plan will identify drainage infrastructure needs and, as development interests approach the City, partnership opportunities should be discussed.

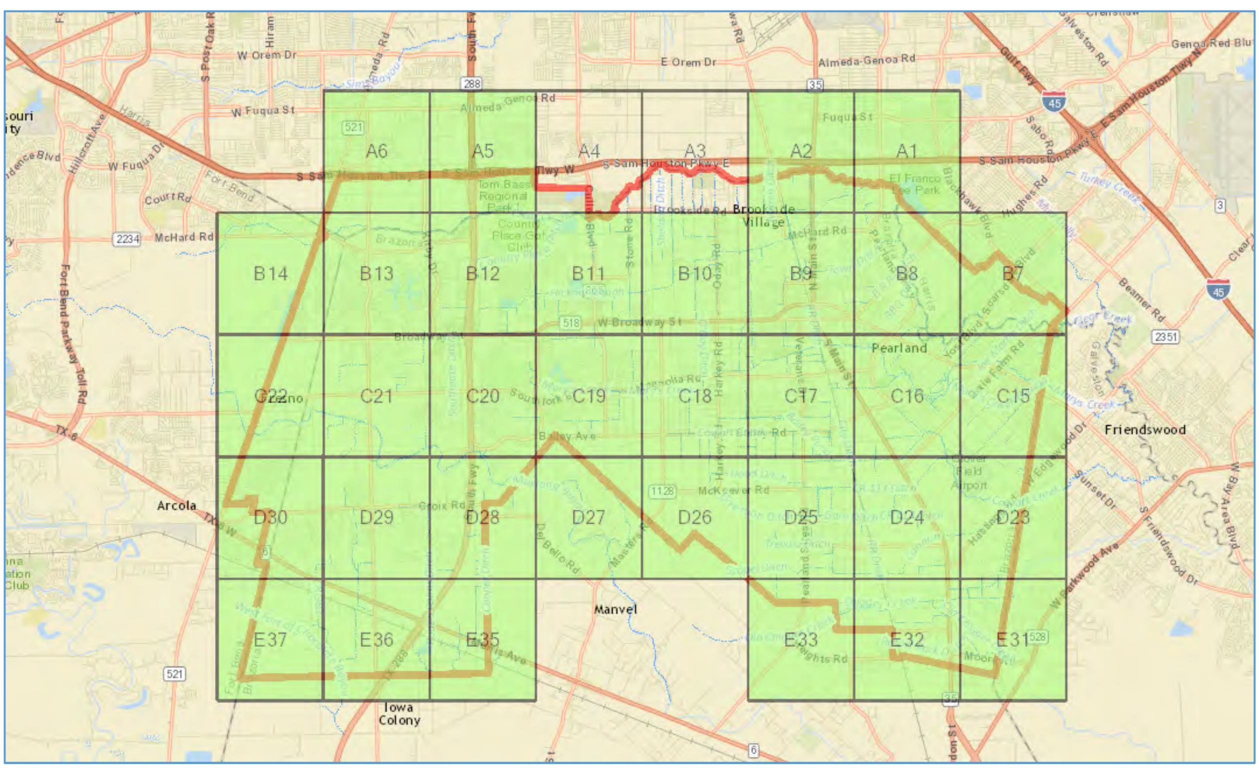
5.0 Field Verification

A significant part of effort for this study was the field verification process. This effort included the development of a systematic approach to the site work and the data collection process. In addition, the data collected was done through the use of mobile GIS applications, enabling Halff to upload data to the database and web map in real-time. A discussion of the field work process and the data collected is provided below.

5.1 Field Reconnaissance Process

During the field data collection process, an effort was made to gather data on as many of the ditches as possible. Specific locations that were targeted included detention ponds, culverts, bridges, storm outfall and channel sections where access was available. It was necessary to develop a systematic method by which the data could be collected and progress tracked. Halff developed a field work grid in order to facilitate that process. Each grid covers an area of approximately 2600 acres (~4.0 sq. mi.) Many of the grids overlap the study area boundary, but very little data was collected outside the boundary. The field work grid was available in the mobile data collection apps as well as the web map. As each grid area was visited and the data collected, the grid cell was marked as complete and colored green, indicating that data collection was finished in that area pending further comments. **(Figure 2)**

Figure 2. Field Reconnaissance Grid



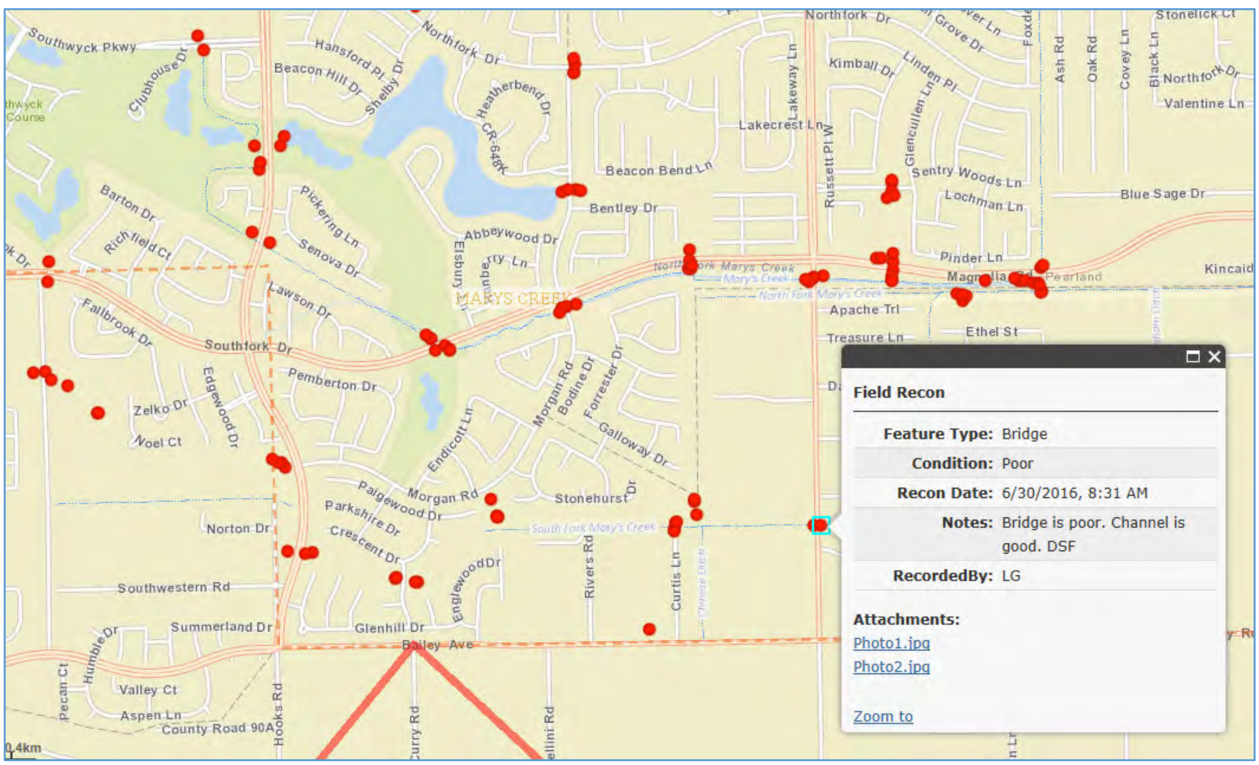
There is a comment feature in the web map available for the City and BDD4 to identify those areas where any additional data is needed.

5.2 Field Data Collected

Most of the focus was on ditches in the Cowart Creek, Mary's Creek, Hickory Slough, Chigger Creek, Mustang Bayou, and Chocolate Bayou watersheds. Less data was collected along Clear Creek because there is an effective HCFCD model for Clear Creek (A100-00-00) and it was not modeled.

Each data point collected included specific information, including the feature type (bridge, culverts, channel, outfall, etc.), a general condition assessment, the date of collection, any specific notes relating to that location, and the person who collected the data. In addition, photos were taken at each location and attached to the data points. The data was placed on the web map for viewing by the City and BDD4. As an example, **Figure 3** shows a zoomed in view of the Mary's Creek data points along Southfork Dr. and the surrounding area. The field verification database was delivered to the City and BDD4 at the completion of Phase I in March of 2017. Some additional data was added as part of this Phase II MDP process.

Figure 3. Field Verification Data



5.3 Findings

In general, the majority of the bayous and ditches in the project are in good condition. They are regularly mowed and are free of debris both along the ditch as well as at most of the structures. The storm sewer outfalls are typically visible and in good condition. There are a few areas along the ditches where light to moderate erosion was observed, often downstream of bridges or culverts where the erosion protection ends. Conversely, there were also some areas of deposition, typically upstream of bridges or culverts; however, these issues were not determined to be pervasive. Based on these observations, it is more likely that any flooding issues are a result of a lack of channel capacity or bridge/culvert capacity than overgrown or blocked ditches or hydraulic structures.

There were several bridges and culvert that could not be approached due to their location. Some of these were on private land and others, particularly the culvert siphons under the canals, could not be measured because they were either completely inundated or surrounded by water. For these, visual estimates were made when possible, but several bridges and culverts have no recorded field (or survey) data. When these areas were encountered, they were marked as ‘No Access’. A query of the points in the database reveals there are numerous such locations with at least one structure that is inaccessible.

6.0 Existing Conditions Modeling

One of the primary tasks of the study was to update and/or develop baseline conditions modeling for the major streams in the study area. Existing models provided by the City of Pearland and Brazoria Drainage District No. 4 are listed below. All the existing hydrologic models listed are included in the Clear Creek hydrologic model available through the HCFCD M3 website. Each individual stream has its own hydraulic models provided by the City of Pearland or BDD4, except Clear Creek, which was downloaded from the M3 website as well. a

Existing Hydrologic Models

- Clear Creek
- Chigger Creek
- Cowart Creek
- Hickory Slough
- Mary's Creek
- Country Place Ditch
- Shadow Creek Ranch Ditch
- Town Ditch

Existing Hydraulic Models

- Clear Creek
- Cowart Creek
- Hickory Slough
- Mary's Creek
- Corrigan Bypass Ditch
- Town Ditch

Several of the tributaries had no effective model available, requiring that new models to be developed. These include the following:

New Hydrologic Models

- Mustang Bayou
- East Chocolate Bayou
- West Chocolate Bayou

New Hydraulic Models

- Mustang Bayou
- East Chocolate Bayou
- West Chocolate Bayou
- Clear Creek
- Country Place Ditch
- Shadow Creek Ranch Ditch
- Chigger Creek
- Mary's Creek (except Corrigan)

The new hydrologic and hydraulic models developed were based on 2008 LiDAR data, along with some survey at bridge or culvert crossings. They are not considered FEMA effective and should be used for planning purposes. While the 2018 LiDAR has very recently been released, it was not available during the model development or alternatives analysis process. The same is true for the NOAA rainfall updated (Atlas 14). Future updates and planning efforts should consider both the terrain and rainfall information. General information relating to the hydrologic and hydraulic modeling process is included in the sections below.

6.1 Hydrologic Model Updates

Several updates were made to the hydrologic models to best reflect current conditions in the study area. Among these changes were updates to the watershed and subbasin boundaries, updates to the loss and hydrograph transform parameters, and the storage routing. All Clear Creek tributaries were previously modeled as part of the HCFCD study and, as such, their existing hydrology is based on HCFCD methods. Updates to the hydrology for Clear Creek tributaries used the same methods as the existing Clear Creek HEC-HMS model. Hydrologic models for Mustang Bayou, East Fork of Chocolate Bayou, and West Fork of Chocolate Bayou used the HCFCD methodology to maintain consistency.

6.1.1 Watershed and Subbasin Delineation

Both the studied stream centerlines and the drainage subbasin delineations were updated using the available 2018 NearMap aerial imagery, 2008 HGAC LiDAR data, and field reconnaissance data. Preliminary boundaries were based upon existing subbasin boundaries provided by the City of Pearland and Brazoria Drainage District No 4. Revisions to the effective model subbasin boundaries were made at locations where the boundaries appeared to vary significantly based on the LiDAR, plans, or discussion with Pearland and BDD4. There are a few locations where the Clear Creek watershed boundary was updated, which added or removed drainage area into Clear Creek. The total decrease in area from the effective model to the revised existing model is 0.06 square miles. The Clear Creek, Mustang Bayou, and Chocolate Bayou drainage areas were subdivided for the purposes of developing new tributary hydraulic models (see **Exhibit 4**).

6.1.2 Watershed Parameter Updates

Percent impervious cover and percent land urbanization (DLU) were determined using 2018 NearMap aerial imagery and City of Pearland and Brazoria Drainage District No 4 land use categories. These categories consist of various land uses including undeveloped, residential, light industrial/commercial, and high-density development. Each category has an associate value for percent imperious cover (IMP) and DLU. To account for future development, Halff assumed the area would improve to near fully-developed conditions. These changes in the watershed were represented by increasing the percent impervious. Major thoroughfares identified in the HGAC data have a 100-foot buffer placed on each side of the major roadway centerline to be reserved for transportation improvement and right-of-way (ROW) development. Roadway and ROW were assumed to have 90% IMP. Another 200-foot buffer was placed on each side of thoroughfares and 1000-foot buffer at major intersections to represent high density development which was assumed to have 85% IMP. Previously vacant areas were classified as small lot resident development with 40% IMP. **Exhibit 5** shows the existing conditions land use, while **Exhibit 7** shows the future conditions land use.

Percent ponding (DPP) and on-site detention (DET) were also determined using 2018 NearMap aerial imagery and 2008 HGAC LiDAR. The remaining 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 methodology. These values were used to update the values for TC and R. The flowpath and DCI lengths for revised existing conditions subbasins are shown in **Exhibit 6.** The flowpath and DCI lengths for the future conditions subbasins are shown in **Exhibit 8**. **Appendix A** includes calculation tables for each of the updated hydrologic parameters.

6.1.3 Modified-Puls Storage Routing

In addition to the loss and unit hydrograph parameters, storage routing parameters were also updated for those watersheds that did not use unsteady HEC-RAS modeling (Hickory, Mary's). A range of flows based on the preliminary 100-year discharges was run through the hydraulic models to iteratively determine storage-discharge relationships for hydrologic routing. In addition, the number of subreaches was determined using the average velocity in the reach calculated from HEC-RAS. The routing was used to determine the hydrograph attenuation due to storage for each stream.

6.1.4 Existing Conditions HEC-HMS Model Updates and Results

The effective HEC-HMS model for Clear Creek was updated from version 3.3 to version 4.2.1. Modifications to the HEC-HMS model included adding drainage subbasin components and connecting subbasins to appropriate junctions, representing the revised subbasins. Several "reservoirs" were added to account for ponding upstream of roadways with limited culvert capacity and were connected to the drainage subbasins draining toward those structures. In addition, diversion relationships were added where overflow potential from one stream to another was identified using the hydraulic models. Modified-Puls routing relationships and subreach values were updated in the model. **Appendix B** provides the tabulated Modified-Puls routing parameters entered into the HEC-HMS model.

Log-linear interpolation was performed for each tributary to develop flow values for use in the hydraulic model. **Table 1** provides a comparison of the effective model (FEMA) peak discharges with that of the Dannenbaum (DEC) modeling (2006-2009), the Risk Map 6 modeling, and the revised existing conditions (Halff) peak discharges at various locations along Clear Creek. The revised existing conditions discharges show a maximum 18% increase from that of the effective model. This large increase is due to significant differences in the watershed parameter determination between the previous FIS study and the revised existing conditions analysis. These differences in watershed parameters consist of: watershed length (L), length to centroid (Lca), channel slope (S), overland slope (So), percent urban development (DLU), percent channel improvement (DCI), percent channel conveyance (DCC), percent ponding (DPP), DLU affected by detention (DET), and percent impervious. DLU and percent impervious values generally increased, but the other values did not have a consistent pattern to the change, they were just updated based on the new terrain. The Green & Ampt soil loss parameters were not changed as it was assumed that the general soil characteristics had not changed. It should be noted that the revised flows shown in **Table 1** are for use as a comparison point for the MDP update. They are not currently being submitted to FEMA for mapping updates or to USACE for use in the Clear Creek Federal Project.

The differences between FEMA Effective, Risk Map 6, and the Halff revised existing conditions varied by reach and cross section (**Table 1**). The lettered cross section is the reference cross section as identified by the FIS and shown on the FIRM panels. Mary's Creek, Mary's Creek Bypass, Hickory Slough, West Chocolate Bayou, Mustang Bayou, Chigger Creek, Chigger Creek Bypass and Cowart Creek all have at least one cross section in a FIS study. The FIS study stationing was compared with defined FIS cross sections to determine the nearest appropriate cross section and junction in Halff's modeling. The changes in peak discharge between the FIS data and the revised existing HMS model ranged from -35% to 177%. The largest change, in Chigger Bayou Bypass, is due to a change in the split flow at the top of the bypass. If the Chigger Bayou and Chigger Bayou Bypass flows are combined, the total difference is 57%. Both Mary's and Hickory Creek exhibit decreases, this is due to improved routing and consideration of inline detention in unsteady HEC-RAS. Some of the increases in flows are due to increased development in the area since the previous version of the model was completed. East Chocolate Bayou did not have any FIS flooding source locations within the study area.

Table 1. FIS Effective Hydrologic Modeling Comparison

Stream	Lettered FIS Cross Section	Peak 100-yr Discharge (cfs)			
		Effective Modeling	DEC Modeling	Risk Map 6	Revised Existing
Chigger Creek	S	640		1060	416
Chigger Creek Bypass	D	490		490	1360
Chocolate Bayou - West Fork	N	1377		1470	1060
Cowart Creek	G	828	1970	977	1281
Hickory Slough	A	1328	1569	1495	1249
Mary's Creek	A	1541	1558	1238	1231
Mustang Bayou	BR	1284		1284	1885
Clear Creek					
Confluence w/Hickory Slough	BS	5376	5166	5376	5956
Confluence w/Beamer Ditch	CP	7901	7921	7901	9357
Confluence w/Mary's Creek	CD	16162	15453		16658
Confluence w/Chigger Creek	BF	22891	21060		22534
Egret Bay Blvd	AA	24535	22997		23941
Confluence w/Cow Bayou	Y	24557	23223		23949
Above Clear Lake	V	24879	23979		24220
Confluence w/Armand Bayou	M	42012	41939		43021
Mouth of Clear Creek	A	46342	46278		47500

Freese and Nichols, Inc. (FNI) completed a study of Cowart Creek, including updates to the hydrologic and hydraulic models and floodplain mapping within the watershed shortly after the completion of the Halff MDP. Several of the subbasins and parameters changed from the DEC models as FNI progressed through their study. Halff used the FNI preliminary existing models for Cowart with only a few minor changes, which were made to facilitate the proposed improvements analysis. These served as the baseline for the proposed conditions to be discussed in subsequent sections. Some minor changes to the models include:

- The flow split at Baker Rd. was modified to reduce artificially high flow through the new box culvert system
- A junction was added at the confluence of Hood and Diversion Ditches so that the flow distribution for Hood Ditch did not account for Diversion Ditch's flows

- The pond owned by Clear Creek Flood Control District (Galveston County) reflected in the LiDAR at the Pearland city limit along Cowart Creek was added to the model

For Chocolate Bayou (East and West) and Mustang Bayou, Halff created a new HEC-HMS model to model the existing conditions. In order to maintain a consistent methodology, these models were also built using the same HCFCD methodology used for the Clear Creek Model updates.

6.2 Hydraulic Model Updates

Information from the effective hydraulic model geometry and parameters was leveraged from the effective models whenever possible to create an updated set of models for those streams that were previously modeled. New hydraulic models were developed for the previously unstudied tributaries. Each of the streams and their status (updated, new) are listed in **Table 2** . For those streams that were updated, the effective HEC-RAS models were converted from v. 3.0.1 to the most recent version, HEC-RAS v. 5.0.5. Clear Creek was not included in the model updates as it is the subject of an ongoing federal project.

The majority of the streams were modeled using steady HEC-RAS modeling. However, Hickory Slough and Mary's Creek were modeled using unsteady HEC-RAS. Unsteady HEC-RAS allowed for a single model to perform the water surface calculations as well as the storage routing. This was useful for these two streams because they both had several existing regional detention ponds which unsteady HEC-RAS can model more effectively than the iterative process between HEC-HMS and steady HEC-RAS.

The 3-year, 5-year, 10-year, 25-year, 50-year, 100-year and 500-year storm events were run for each of the hydraulic models. Resulting flow rates, water surface elevations, and velocities were examined from these models. The resulting inundation maps for the 100-year event, are provided in **Appendix C**. Modeling specifics for each tributary are detailed in subsequent sections.

6.2.1 Hydraulic Modeling Update Process

The modeling updates included extracting the terrain information from the current LiDAR (2008) dataset such that the modeling and mapping terrain is consistent. The newly extracted cross sections were adjusted where necessary to account for features in the terrain which were inadequately represented existing conditions. Many bridges and culverts in the study area were updated based on survey and field observations. Further, ineffective flow areas and blocked obstructions, which were initially based on the effective models, were adjusted where appropriate. Lateral structures were added where needed to calculate diversion relationships or to accommodate offline detention basins where necessary. Flow change locations and values were also updated based on the revised HEC-HMS modeling.

In the unsteady HEC-RAS models for Hickory Slough and Mary's Creek, storage areas were added into the models. After completing the unsteady HEC-RAS modeling for Mary's Creek and Hickory Slough, the models were converted into steady models to maintain consistency with the modeling in other watersheds. The steady state versions are included in the model deliverables; however, the unsteady versions were used for the proposed flood reduction alternatives analysis. A normal depth tailwater condition was used for all models.

6.2.2 Updated Hydraulic Model Sources

All Cowart Creek existing models, except Cannon Ditch, were provided by FNI in November 2018. Cannon Ditch is based on the DEC models from 2006. Hickory Slough, Mary's Creek, and Chigger Creek were based on DEC models from 2006 and 2009. The model for Corrigan Ditch was updated from a study by Halff Associates, Inc. in 2016. The model for Town Ditch was provided by the City of Pearland based on recent updates to the channel.

6.2.3 New Hydraulic Models

New hydraulic models for Mustang Bayou, East Fork Chocolate Bayou, and West Fork Chocolate Bayou, as well as the Clear Creek tributaries were constructed utilizing a methodology similar to the updated models. As with the updated models, cross-section geometries extracted were extracted from the 2008 LiDAR data using HEC-GeoRAS. Cross sections were placed along each tributary to provide sufficient coverage and capture changes in the channel geometry. At the upstream end, the cross sections stopped at the study area boundary. At the downstream end, cross sections were placed downstream of the study area boundary such that the boundary conditions did not interfere with analysis inside the study area.

Table 2. HEC-RAS Models

Watershed	Stream Name	Updated Hydraulic Model	New Hydraulic Model
Chigger Creek	Chigger Creek		x
Chigger Creek	Chigger Creek Bypass		x
Chigger Creek	Moore Road Ditch		x
Chigger Creek	Old Chigger Creek		x
Chigger Creek	Resort Park Ditch		x
Chocolate Bayou (East)	E103-00-00		x
Chocolate Bayou (East)	East Fork of Chocolate Bayou		x
Chocolate Bayou (East)	Rodeo Palms Ditch		x
Chocolate Bayou (West)	Cold River Ranch Ditch		x
Chocolate Bayou (West)	CR 383		x
Chocolate Bayou (West)	McCutchen		x
Chocolate Bayou (West)	Villarreal		x
Chocolate Bayou (West)	West Fork of Chocolate Bayou		x
Country Place Ditch	Country Place Ditch		x
Cowart Creek	C107-03-00	x	
Cowart Creek	Cannon	x	
Cowart Creek	Cowart Creek	x	
Cowart Creek	Cowart Creek (CR 413 Ditch)	x	
Cowart Creek	CR 413 Ditch	x	
Cowart Creek	Dare Ditch	x	
Cowart Creek	Diversion Ditch	x	
Cowart Creek	Hood Ditch	x	
Cowart Creek	LeClair Ditch	x	
Hickory Slough	Hickory Slough	x	
Mary's Creek	Mary's Creek	x	
Mary's Creek	Mary's Creek Bypass	x	
Mary's Creek	New Corrigan Ditch	x	
Mary's Creek	North Fork Mary's		x
Mary's Creek	South Fork Mary's		x
Mary's Creek	Weatherford Ditch		x
Mustang Bayou	Mustang Bayou		x
Mustang Bayou	Mustang Spur		x
Shadow Creek Ranch	Shadow Creek Ranch		x
Town Ditch	Town Ditch	x	

6.2.4 Existing Regional Detention Basins

There are several regional detention ponds in the study area including those in Hickory Slough, Mary's Creek, and Cowart Creek. The following table (**Table 3**) provides water surface elevation and storage volume for existing regional detention during a 100-year storm based on unsteady HEC-RAS modeling or HEC-HMS modeling (Cowart). It should be noted that there are differences between the detention basin volumes provided by the City of Pearland as part of their storage accounting and the volumes calculated using the models. The modeling shows the maximum volume that was actually used for storage during the storm. The amount of water entering the ponds is a function of the water surface elevation and inflow structure configuration. Changes to the WSEL via channel capacity improvements and detention may alter the way that the ponds function. This should be considered as individual projects are evaluated in PER as some changes to the inflow/outflow structures for the ponds may be needed to fully utilize the ponds as intended.

Table 3. Regional Detention Pond Storage Volume

Stream	Basin Name	Water Surface Elevation (ft) 100YR	Modeled Storage Volume (ac-ft) 100YR
Mary's Creek	East Mary's	40.43	191.0
Mary's Creek	Independence	43.86	56.0
Mary's Creek	SWEC	48.52	299.0
Mary's Creek	Veterans	46.47	134.0
Mary's Creek	West Mary's	51.42	544.0
Hickory Slough	Cullen	52.51	81.3
Hickory Slough	SH 35	44.75	9.1
Hickory Slough	SportsPlex	52.11	143.8
Cowart Creek	Bailey Road	42.30	178.1
Cowart Creek	Cowart Diversion	41.90	914.0

6.3 Existing Conditions Hydraulic Model Results

There were noticeable differences in the effective and updated models along Hickory and Mary's Creek, likely due to the change between steady and unsteady modeling. A comparison of the steady vs unsteady differences is included in **Table 4** below. The table shows an average difference of about +0.1 ft or less with variations ranging from -0.15' to +0.41'.

Table 4. Existing Conditions Unsteady vs Steady Modeling WSEL Comparison

Stream	River Station	Existing Conditions WSEL* (ft)		
		Unsteady	Steady	Difference
Hickory Slough	Average			0.06
	34986	54.23	54.08	-0.15
	20256	49.29	49.23	-0.06
	1295	39.47	39.49	0.02
Mary's Creek	Average			0.09
	60725	53.02	53.21	0.19
	13244	30.66	31.07	0.41
	2387	16.88	16.88	0.00

*2018 Field Data and Survey with 2008 LiDAR

These differences were due to a couple of factors, including differences in the computational method. Where steady state modeling only considers conveyance, unsteady modeling includes volume and timing. Storage routing for steady state models uses storage-discharge relationships whereas in the unsteady model, the routing is done with the hydraulic model. Because the unsteady model considers volume, it recognized significant overbank storage along both channels. The water surface elevations change between steady and unsteady likely also included differences at bridges and culverts. As previously discussed, the intent of this analysis is not to submit the modeling to FEMA for map update purposes, but to provide a reasonable basis for comparison during the proposed flood reduction alternatives analysis.

Specific information about the existing conditions findings for each of the modeled streams is provided in the following sections. Each section will include a discussion of the streams included, the original modeling source if there is one, data collected, modeling specifics, and general results. In addition, some general comparisons to the effective FIRM mapping, completed as part of FEMA Risk Map 6 (RM6) is provided for informational purposes. The Revised Preliminary date for the mapping is June 29, 2018. Specific Information regarding the proposed flood reduction alternatives is provided in Section 8.

6.3.1 Chigger Creek

The Chigger Creek system modeling was developed as a system including the following streams: Old Chigger Creek, Chigger Creek Bypass, Resort Park Ditch, Moore Road Ditch, and Old Chigger Creek (**Exhibit 2**). These tributaries were modeled together because they represent a complex network of streams with numerous overflows that can't accurately be modeled with individual models.

Although Chigger Creek and Chigger Creek bypass have an existing FIS model, Halff was unable to obtain the model or model documentation. As such, Halff developed a new HEC-RAS model with survey data collected at several locations, including the three roadway crossings of SH 35 and numerous county roads. Additional field observation data was collected at many of the publicly accessible crossings on the stream network. There was no previous modeling for Resort Park Ditch, Moore Road Ditch and Old Chigger Creek, which were developed as part of this study with geometric information based on 2008 LiDAR data and field observations; no survey was included.

A lateral weir along the right bank of Chigger Creek accounts for the diversion between Chigger Creek and the Chigger Creek Bypass. Two additional lateral weirs account for overflow out of the system into Dickinson Bayou from Old Chigger Creek. The lateral weirs were optimized through several iterations during Modified-Puls routing process.

With the revised modeling approach, the inundation for this area changed as compared to the floodplain shown on the new Revised Preliminary FIRM (RM6). The inundation width at the upper end of the reaches tend to be wider than FEMA RM6 mapping but the lower reaches tend to be the same or smaller. The floodplain along Chigger Creek Bypass maintains a similar inundation shape to the RM6 mapping. The Resort Park and Moore Road Ditches did not have an effective floodplain and so any inundation associated with these streams is new. Other areas experience more ponding than the effective floodplain suggests. Upstream of the BNSF Railway, the floodplain extends further south and west toward the levee associated with the water supply canal than in the effective models. Chigger Creek, Old Chigger Creek and Resort Park Ditch upstream of the railway are significantly inundated in both the 10-year and 100-year storm events. Resort Park Ditch flows into both Moore Ditch Road and Dickinson Bayou, which is out of the system. Significant flooding occurs at the diversion between the two receiving streams. Revised existing inundation mapping for the Chigger Creek system can be found in **Appendix C.1-C.2.**

6.3.2 Chocolate Bayou

The Chocolate Bayou system was modeled as two interconnected stream models divided into the East and the West. The West Chocolate Bayou system includes the following streams: West Fork Chocolate Bayou, E101-00-00, E101-01-00, Villarreal, Cold River Ranch Ditch, McCutchen Ditch and E101-02-00 (CR 383 Ditch) (**Exhibit 2**). The East Chocolate Bayou system includes the following streams: E103-00-00, Rodeo Palms Ditch and East Fork Chocolate Bayou. There is significant overflow between the two systems due to the very flat terrain and significant ponding caused by restrictions along the channel. As a result, these streams experience a 2-dimensional flow problem that is modeled using 1-dimensional flow techniques. As such, the interaction between HMS and RAS models were developed iteratively.

Chocolate Bayou has an existing FIS model developed using HEC-2, but the detailed study is largely downstream of the modeling for this master drainage plan. As such, Chocolate Bayou is a new model, which includes some survey data collected at the stream crossing at County Road (CR) 383 and West Fork Chocolate Bayou. Culvert/bridge data from the existing FIS model was used to supplement field data for several of the bridges in the downstream reach of the models. Halff collected additional field observation data at many of the public crossings on the stream network.

Several lateral weirs aided in balancing the overflows between the two systems and were optimized through several iterations during Modified-Puls routing. Further, the HEC-HMS model has several diversions which represent overflows caused by limited culvert capacity, particularly through the siphons that run under raised raw water canals. Ponding behind the canals is accounted for using “reservoirs” in HEC-HMS, such that the volume was considered.

The revised modeling indicated that the inundation for this area changed as compared to the flooding shown on the FEMA RM6 mapping. The model shows a large increase in inundated area due in large part to the backup created by the canal siphons. The USGS regression curves which were used to determine peak discharges on Chocolate for the previous FIS study do not properly account for the runoff trapped behind the siphons seen in the Halff models, which show extensive ponding throughout the upper Chocolate Bayou watershed. Inundation mapping for the Chocolate Bayou systems can be found in **Appendix C.3-C.6.**

6.3.4 Cowart Creek

Cowart Creek is a modified model with geometry and parameters based on models created by FNI. The models created by FNI were provided in November 2018 as preliminary models to their current study for the City of Pearland. FNI’s work did not include Cannon Ditch. Cowart Creek is modeled from the top of the watershed to the confluence with Clear Creek. Halff changed the flow distribution from FNI’s in several places to better reflect flow conditions and facilitate the proposed flood reduction alternatives analysis. Based on FNI’s hydrology methods, Halff updated the flows and floodplains. Floodplain information for Cowart Creek can be found in **Appendix C.7-C.10**.

6.3.5 Hickory Slough

The Hickory Slough model was based on models created by Dannenbaum Engineering (DEC) and was updated with new terrain data (2008 LiDAR) and hydraulic parameters. Adjustments were made to bridges and culverts where necessary based on engineering judgement, survey data, and field observation. The updated flows were based on the revised hydrology and inundation mapping was performed using the 2008 LiDAR. The model was also extended to begin at CR 94 whereas the current model ends upstream of Cullen Blvd. Hickory Slough was modeled using unsteady HEC-RAS in order to better capture the significant overbank storage and the interaction with several offline regional detention basins. The use of unsteady HEC-RAS allowed for optimization of ponds without iterating in HEC-HMS. Several culvert and bridge crossings were updated or added into the model. The bridge at Old Alvin Road was modeled based on the 2006 DEC model but aerial imagery indicates the bridge has been updated since then. Halff used the 2006 DEC model geometry as neither survey nor plans were obtained.

In addition, all existing offline detention ponds were added into the model using storage areas. In order to capture potential overbank storage on the far side of the detention ponds, cross sections were extended to the limit of the bayou watershed and those areas with ponds were modeled as a blocked obstruction. This was the same approach taken with the Dannenbaum models.

Inundation is prevalent between Cullen Boulevard and Oday Road, where low-lying areas exist in the terrain along the original channel alignment. Aerial imagery shows that by 1944, the channel had been realigned; however, the original channel is still visible. This imagery is consistent with channel remnants detected in the LiDAR. The most downstream portion of the tributary is overlapped by the floodplain from Clear Creek. Inundation Mapping for Hickory Slough can be found in **Appendix C.11-C.13**.

6.3.6 Mary's Creek

Mary's Creek is an updated model with geometry and parameters based on models created by Dannenbaum Engineering. The model was also extended to begin at Southwyk Road and incorporated the online storage area adjacent to Magnolia Rd. near Cullen Pkwy. As with Hickory Slough, unsteady HEC-RAS modeling was used to more effectively capture the stream interaction with offline detention ponds. In order to capture potential overbank storage on the far side of the detention ponds, cross sections were extended to the limit of the bayou watershed and those areas with ponds were modeled as a blocked obstruction. This was the same approach taken with the Dannenbaum models. Adjustments were made to bridges and culverts where necessary based on survey data and field observation. The updated flow rates were based on the revised hydrology. A large percentage of the ineffective flow areas in the model were updated to represent the observed conditions along the stream.

Revised inundation mapping was done using the 2008 LiDAR. It is important to note that the most downstream portion of the Mary's Creek is overlapped by the floodplain from Clear Creek. Floodplain information for Mary's Creek can be found in **Appendix C.14-C.16**.

6.3.3 Country Place Ditch

Country Place Ditch is tributary of Clear Creek. A new model was developed, which incorporates a limited amount of survey data. This tributary is modeled from about 1000 feet upstream of Hughes Ranch Road to the confluence with Clear Creek. Three bridge crossings are included in this model as well as several existing offline detention ponds, which were included in the cross sections as a blocked obstruction, as was done with previous models. The most downstream portion of the tributary is overlapped by the floodplain from Clear Creek. Inundation mapping for the Country Place Ditch can be found in **Appendix C.19.**

6.3.7 Mary's Creek Tributaries

Mary's Creek includes four tributaries: North Fork Mary's Creek, South Fork Mary's Creek, Weatherford Ditch, and Corrigan Ditch (**Exhibit 2**). None of these was previously modeled and are not mapped in the newly effective FIRM panels (June 29, 2018). As such no comparison to the effective mapping is provided.

North Fork and South Fork of Mary's Creek

For the North Fork and South Fork new models were developed and incorporated a limited amount of survey data. These tributaries are modeled from the top of their channel to their confluences with Mary's Creek. The North Fork joins Mary's Creek immediately downstream of Southfork Dr. just west of Versaille Dr. The South Fork joins Mary's Creek near Magnolia Ave, near Charles Ave. Two bridge/culvert crossings on each of the tributaries are included in this model as well as any existing offline detention ponds were included in the cross sections as a blocked obstruction. The most downstream portion of both the tributaries are controlled by the floodplain from Mary's Creek. Floodplain information for these tributaries can be found in **Appendix C.14-C.16.**

Corrigan Bypass Ditch

The model for Corrigan Ditch was updated model based on a previous model developed by Halff. The bypass ditch runs from W. Broadway south to Mary's Creek and confluences between Wagon Trail Rd. and Hatfield Rd. The bypass was built to divert water around the Corrigan Subdivision to reduce flooding. Field observation indicates that the connection between the bypass and Old Corrigan Ditch has been cut off and a wall separates the two ditches. The flows were updated based on the revised hydrology, as discussed in Section 4.2. Three bridge crossings are included in this model as well as any existing offline detention ponds were included in the cross sections as a blocked obstruction, as done with previous models. The entirety of the tributary is overlapped by the 100-year floodplain from Mary's Creek. Floodplain information for Corrigan Ditch can be found in **Appendix C.15.** Corrigan Ditch appears to have a 100-year LOS so no improvements will be recommended.

Weatherford Ditch

The Weatherford ditch model was a new model based on the 2008 terrain. Weatherford Ditch is overlapped by the Mary's Creek cross sections, but the Mary's Creek Floodplain does not appear to inundate the channel during the 100-year. Apart from a few low-lying areas below the bank elevations, Weatherford Ditch appears to have 100-year capacity. As such, no improvement recommendations will be made. Floodplain information for Weatherford Ditch can be found in **Appendix C.15.**

6.3.8 Mustang Bayou

For Mustang Bayou a new model was developed based on the 2008 HGAC LiDAR. This channel is modeled from about 2000 feet downstream of Fort Bend Parkway Toll Road to about 500 feet downstream of Del Bello Rd. (CR90). Eleven culvert/ bridge crossings are included in this model as well as all existing offline detention ponds were included in the cross sections as a blocked obstruction. Two of the bridge geometries were determined based on the HEC-2 model. Similar to other bayous, a lateral weir was added downstream of SH288 to account for overflow from Mustang Bayou into the adjacent watershed (East Fork Chocolate Bayou – Cooper Ditch). The modeling indicates a wide shallow floodplain downstream of FM 521. The floodplain is narrower until the channel approaches SH 288. The downstream portion of this tributary appears to have limited capacity, with the 3-year storm exhibiting significant ponding in low-lying areas all the way from SH288 to the lower limit of the modeling outside the study area. Floodplain information for Mustang Bayou can be found in **Appendix C.17-C.18**.

6.3.9 Shadow Creek Ranch Ditch

The Shadow Creek Ranch ditch, also referred to as the Clear Creek Relief, is a tributary of Clear Creek for which a new model was developed and incorporates a limited amount of survey data. This tributary is modeled from FM 521 to the confluence with Clear Creek. Five bridge/culvert crossings are included in this model as well as any existing offline detention ponds were included in the cross sections as a blocked obstruction. Half of the modeled tributary is overlapped by the floodplain from Clear Creek but, independent of Clear Creek, the ditch appears to have 100-year capacity. Floodplain information for Shadow Creek Ranch can be found in **Appendix C.19**

6.3.10 Town Ditch

Town Ditch is an updated model based on a model from Carter & Burgess. The model was not geo-referenced, so the previous model was used as a guide for cross section locations. Further, the model was extended to begin at Cherry Street and continue to the confluence with Clear Creek. The flows were updated based on the revised hydrology, as discussed in Section 4.2. Revised inundation mapping was done using the 2008 LiDAR. Six bridge crossings are included in this model as well as any existing offline detention ponds were included in the cross sections as a blocked obstruction, as done with previous models. The most downstream portion of the tributary is overlapped by the floodplain from Clear Creek. Town Ditch appears to have 100-year capacity. Any potential improvements to Mykawa Rd. are not included in this analysis as no information was available at the time of this study. Floodplain information for Town Ditch can be found in **Appendix C.19.**

6.4 Local Ditch Capacity Analysis

A channel capacity analysis was performed for roadside ditches located throughout the study area in order to determine the level of service. Flow capacity was determined using the Rational Method; no hydrologic or hydraulic models were prepared for these reaches. A total of 91.8 miles were evaluated in this capacity analysis as shown in **Exhibit(s) 8A-8E**. Several ditch sections showed alignments through recent developments or appear to have recent improvements that include storm sewer sections. These ditches were excluded from the analysis because they are assumed to have adequate capacity because of the recent improvements.

A drainage area was delineated for each ditch in the analysis using 2008 LiDAR and 2018 NearMap imagery. For each drainage area a runoff coefficient, percent impervious, and rainfall intensity was calculated according to BDD4 criteria. If the drainage area was less than 250 acres, Rational Method was used to compute the ditch capacity. If the drainage area was greater than 250 acres, Harris County Flood Control District (HCFCD) Site Runoff Curves were used to compute the capacity. To estimate the existing channel capacity, a typical cross section was identified. The geometry of this cross section was estimated using GIS 3D analyst tools and the LiDAR dataset. Channel slope was estimated between stream points approximately 10% and 85% of the channel length. Manning's equation was used to determine the discharge that would fit in the existing channel geometry. Discharge calculations for each ditch are provided as **Appendix D.2.A**.

The calculate discharge was compared to the discharges for the 3-, 5-, 25-, 50-, and 100-year storm events calculated using the Rational Method or Site Runoff curves. The approximate Level of Service (LOS) for each ditch was estimated based on a comparison to determine for which storm event the ditches had adequate capacity. **Exhibit(s) 8A-8E** provides a graphical estimate of the level of service for the various channels and ditched for the existing conditions. Peak discharge calculations for each of the storms as well as the LOS determination are provided in **Appendix D.2.B.** In general, most of the local ditches provide a level of service below the 3-year storm and require additional capacity. A brief discussion of the improvements is provided in Section 8.5.

7.0 Existing Flooding Issues

The stream modeling and local ditch capacity analysis indicated that a majority (65%) of the streams (both major bayous and local ditches) in the City/BDD4 area have less than a 3-year capacity. The lack of conveyance capacity is widespread with very limited capacity in every watershed, particularly those in the southern portion of the area (Chigger, Cowart, Chocolate, Mustang). Given the limited channel capacity and the generally flat terrain, even frequent storms like the 5-year and 10-year can cause significant out-of-bank flooding. The capacity limitation is particularly evident for the local ditches, 70% of which have less than a 3-year capacity. Of the major creeks and bayous, about 60% have 3-year capacity or less. Clear Creek was not included in the capacity analysis; however, it should be noted that the downstream portions of Hickory Slough, Town Ditch, Country Place Ditch, Shadow Creek Ranch Ditch, and numerous other small ditches are influenced by the Clear Creek floodplain.

At both the main stem and tributary levels, the limited channel capacities are evident by the number of flood claims in the reported area. The locations with reported instances of flooding or flood damage are predominantly within developed areas because the flood data is only provided within the City of Pearland and its Extraterritorial Jurisdiction (ETJ). **Exhibit 9** shows the concentrations of flood claims/damages, which are distributed along the main channel and tributaries and will be discussed in the sections below. These include information from Hurricane Harvey in August 2017. The information provided does not disclose specific flood damaged properties, only the relative concentration in the area. Several clusters throughout the study area showed evidence of repeated losses and losses during Hurricane Harvey. Most of these were within the defined revised preliminary FEMA 100- or 500-year floodplains. There were a few areas where flood claims were found outside of the defined floodplain. These could be the result of either rainfall exceeding the amounts corresponding to those storm events or inadequate capacity in the local ditches, culverts, storm sewers, or inlets.

There are no recorded flood claim locations within Chigger Creek, Chocolate Bayou, and Mustang Bayou because the watersheds are outside of the City of Pearland or its ETJ. Cowart Creek has a few flood FEMA flood claims within the City of Pearland's ETJ. No losses due to Hurricane Harvey were provided for the Cowart Creek, Chigger Creek, Mustang Bayou, or Chocolate Bayou watersheds.

7.1 Country Place Ditch

This section of the study is predominantly residential. There is one recorded FEMA flood claim from Hurricane Ike within the Country Place Ditch drainage area. Country Place Ditch itself has an approximate 100-year capacity; however, the portion to the north of the ditch is inundated by the Clear Creek floodplain per the Halff mapping as well as the Risk Map 6 (RM6) mapping. A majority of the structures that flooded during Harvey were within the floodplain limits. Considering the neighborhood's proximity to Clear Creek, there were relatively few incidents of flooding.

7.2 Hickory Slough

Hickory Slough has a high number FEMA flood claims as well as damages from Hurricane Harvey. More than 500 total claims or damage reports have occurred in the Twin Wood, Twin Creek Woods, and Clear Creek Estates neighborhoods; however, these are entirely within the Clear Creek Floodplain. Flood claims in the Brookland Acres area are also within the Clear Creek floodplain. There are several FEMA Claims and Harvey damages in the Hickory Creek Place subdivision, the majority of which are in the Hickory Slough 100-year floodplain. There are also isolated instances of flood damages upstream of Garden Rd., a majority of which appear to be floodplain related. There is a small pocket of flood damages near Garden Rd. at the watershed boundary between Hickory Slough and Mary's Creek. These are most likely the result of limited local drainage capacity, which is not unexpected given the capacity analysis findings detailed in Section 6.5 and the typically flat terrain found at watershed boundaries. Hickory slough has an estimated capacity of 5-year or less.

7.3 Mary's Creek

Mary's Creek has a significant number of flood claims and Harvey damages throughout the watershed. The section downstream of Pearland Pkwy. has about 250 historical claims, with Harvey damages accounting for about 65% of those. A majority of the flood claims are outside of the delineated floodplain (both Halff and RM6), indicating that internal storm sewers in these neighborhoods may not have adequate capacity.

Upstream of Pearland Pkwy, there are pockets of flood claims located within the floodplain, in particular the Corrigan Subdivision, which has a long history of flooding. Records indicate more than 460 claims in the neighborhood including Harvey and dating back to the 1970's. The Corrigan Bypass ditch was constructed in the mid-2000's, directing flow from the north around the neighborhood to Mary's Creek. There does not appear to be a connection between the bypass and the neighborhood drainage any longer. The Corrigan Bypass has 100-year capacity but is backed up by the Mary's Creek floodplain. The Corrigan Subdivision's internal drainage now goes to a detention pond and is pumped out. The FEMA flood claims appear to cease after the bypass ditch construction, indicating that it helped. However, the magnitude of rainfall during Hurricane Harvey as well as the Mary's Creek floodplain seem to have overwhelmed the system and flooded virtually the entire neighborhood.

Further upstream, the West Lea subdivision has experienced significant flooding, all of which is within the 100- or 500-year floodplain. There are approximately 14 properties who have filed claims, some of them multiple times. After Harvey, that number jumped to nearly 100 flood damage claims. In the upper reaches, there are a few sporadic FEMA flood claims but no Harvey damages. Mary's Creek has an estimated 5- to 10-year channel capacity.

The North Fork and South Fork have very few flood claims between the two of them, all in residential areas. They are likely isolated events due to a temporary blockage in the drainage system given the lack of claims by surrounding property owners. The area surrounding Weatherford Ditch has a handful of Harvey flood claims, all of which are in the River Mist neighborhood to the north of the ditch. These are likely caused by capacity limitations of the local drainage system. Mary's Creek Tributaries have an approximate 50- to 100-year capacity.

7.4 Shadow Creek Ranch Ditch

There is one isolated FEMA repetitive loss claim in Shadow Creek Ranch from Hurricane Ike. There are approximately 40 Harvey flood claims, mostly clustered along a low-lying area south of the ditch and within the Clear Creek backwater area. The Shadow Creek Ranch Ditch itself has approximately 100-year capacity based on the modeling data. The 100-year inundation mapping shows some ponding in the streets but is otherwise contained within the ditch.

7.5 Town Ditch

The lower portion of Town Ditch is within the Clear Creek floodplain; however, there are no Harvey flood claims and only a few FEMA loss claims. The highest concentration of flood claims (mostly Harvey) is upstream of Mykawa Rd in the Willow Crest and Mimosa Acres subdivisions. This area is outside of the delineated floodplain (Halff and RM6) and is likely due to inadequate capacity in the local drainage system. Town Ditch has been improved in the last several years and has an approximately 100-year capacity.

7.6 Cowart Creek

Cowart creek has only a few flood claims within the watershed, making it difficult to assess the flooding extents during Harvey. Cowart is a complex network of ditches with diversions and numerous crossings, both roads and railroads. The revised existing conditions modeling was done by Freese & Nichols with Halff making only minor changes to the existing conditions models. The lower portion (downstream of the RR crossing) of Cowart Creek and Leclair Ditches have 25- to 50-year capacity, as does Dare Ditch, a portion of which is referred to as the Cowart Creek Diversion Ditch (50-year capacity). Beyond that, the majority of the ditches in the system have 3-year capacity or less, with most having less. Inundation

Mapping confirms that Cowart Creek has good capacity downstream of the SH35 crossing, which is similar to the RM6 mapping. The FNI/Halff mapping shows significant flooding along the LeClair ditch all the way up to the railroad crossing, which differs from the RM6 mapping which shows LeClair flooding contained in the ditch up to SH35. The revised existing mapping shows the diversion ditch contains most of the flow for the 100-year; however, the RM6 mapping does not include the diversion ditch.

North of McKeever Rd. (CR100) the revised existing mapping shows flooding for a majority of the area from the railroad west to Berry Rd. (CR879C). There are 3 properties in this area with flood claims between 2000 and 2002. The RM6 mapping does not include the diversion ditch and, as such, shows the area flooded all the way to Manor Rd. There are no flood claims in that area. The area along Bailey Rd. is also flooded as shown in both the revised existing and RM6 mapping. A storm sewer was recently constructed along Bailey Rd. and a majority of the flow directed to the diversion ditch. For larger storms, such as the 100-year, the culvert does not have capacity to contain the flows and there is shallow flooding both north and south of the road from the railroad to west of Manvel Rd.

Cannon ditch shows limited flooding downstream of the railroad, which differs from the RM6 mapping which shows more flooding, including a floodplain for a ditch that does not appear to be there anymore. Upstream of the railroad, there is significant flooding shown in both the revised existing and RM6 mapping, though the revised existing mapping shows greater inundation. The estimated capacity for the upper portion of Cannon Ditch is less than 3-year.

7.7 Chigger Creek

There is no flood claim information for Chigger Creek, including for Hurricane Harvey. The lower reaches of Chigger have a 3- to 5- year estimated capacity, including the Chigger Creek Bypass, which takes the majority of flow off of Old Chigger Creek. Upstream of the Bypass split, the channels have less than a 3-year estimated capacity. The floodplain mapping for Chigger Creek and Old Chigger Creek is similar, except where Old Chigger Creek bends at Moore Rd. The RM6 mapping is much wider at this location, which is potentially the result of modifications to the Chigger Creek Bypass diversion done in order to improve the water surface balance in the modeling. The Resort Park Ditch is not mapped in the RM6 version but shows a wide floodplain. The estimated capacity Resort Park Ditch is less than 3-year.

7.8 Mustang Bayou

There is no flood claim information for Mustang Bayou, including for Hurricane Harvey. All of Mustang Bayou within the study area has less than a 3-year estimated capacity. There are several new developments that have been built right up to channel along the north bank, much of which is shown as inundated based on the 2008 LiDAR. Continued development pressure in the area will make finding detention locations a challenge, but significant detention is needed to reduce the flood risk to the neighboring drainage district caused by improvements in BDD4 jurisdiction. The revised existing and RM6 floodplain mapping are relatively consistent with the RM6 being wider at the lower end and narrower at the upper end. The raw water canal east of Airline Rd. is where the change occurs. The revised existing mapping extends further upstream than the RM6 and shows a large portion of the area between Airline Rd, and FM521 as flooded.

7.9 Chocolate Bayou

Both East and West Chocolate Bayou have similar ditch capacity issues, with both streams having a 3-year capacity or less in all but a few ditch segments. The channel siphons under the raw water canal south of SH6 are a major contributor to flooding in the area. They restrict flow, resulting in significant ponding throughout the area, including over SH6. This results in a majority of the area upstream of the siphons being in the floodplain. In addition, the backup allows water to overflow from one watershed to the other. The most effective solution would be to remove the siphons and have them added to the canal as opposed to the drainage channel; however, significant detention would be required to mitigate the conveyance increases downstream. Most of the RM6 mapping ends before the revised existing inundation starts, so there is no comparison. The mapping along the West Fork of Chocolate Bayou is fairly consistent between the two mapping sources.

8.0 Flood Reduction Alternative Analysis

As discussed in Section 1, there were a few principal goals of the Pearland/BDD4 Master Drainage Plan:

- Identify high-level comprehensive plan to provide 1% (100-year) level of service as well as a lower level of service option along the modeled streams.
- Evaluate the capacity of local ditches that flow into the modeled streams and estimate the cost to achieve 3-year and 10-year level of service in the ditches.
- Develop a priority list of projects to reduce flood risks within the watersheds. This includes major channel improvement and detention projects as well as improvements to smaller ditches to improve local drainage.

Several flood reduction alternatives were considered and evaluated for these streams to accomplish the goals of the study. An Alternative includes the complete solution for all the watersheds within the study area. Each 'Alternative' is comprised of channel conveyance and detention improvements that will be broken into many projects over the implementation lifetime. The alternatives evaluated can be grouped into two major categories as described below.

- **Alternative 1**: 100-year LOS (Contain flow in the channel with some exception for low-lying areas)
- **Alternative 2**: Additional LOS based on Existing Channel Capacity

This section details the types of improvements that were considered as well as the challenges that could potentially be faced during implementation. The alternatives are discussed in detail in the sections below.

For this study, the LOS is defined as the storm event that is contained within the banks of the channel and/or detention basins. If the channel and/or detention basins are designed to contain the 100-year storm event, then the surrounding areas should only flood during storm events greater than the 100-year. However, the surrounding neighborhoods may not experience reduced flooding with channel and/or detention basin improvements until the drainage infrastructure within the neighborhoods is improved as well. Also, structures and property at elevations below the proposed water surface elevation for a given LOS may continue to experience flooding, though it may be reduced. These structures must be raised above the water surface elevation to avoid flooding during the LOS storm event.

8.1 Potential Improvement Options

The focus of the flood reduction alternative analysis was on structural improvements throughout the study watersheds, specifically channel capacity improvements and regional detention. Detention was provided for both reduction of peak discharges where channel conveyance improvements were infeasible as well as for mitigation of flow increases associated with channel conveyance improvements. Trapezoidal sections were modeled for several streams to provide a 1% (100-year) and an alternate LOS. The alternate LOS was selected based on the current channel capacity of each of the modeled streams. Bridges and culverts were assumed to be upsized where necessary to reflect the widened top width of the channels due to proposed channel conveyance improvements. Improvements are addressed specifically for each of the alternatives below.

The proposed channel alignments generally followed the existing channel alignments and additional ROW needs were identified based on the recommended channel configuration. Several of the tributaries and streams in the study are roadside ditches located along public roadways and within their ROW.

Another option to reduce flood damages in the watershed would be to consider buyouts of flood prone properties. While buyouts could remain an option for existing flood damaged properties, it will not address the flooding issues in the watershed or provide adequate drainage infrastructure for future development in the area. Conversely, floodplain preservation of undeveloped property is an option that could prevent future flood damages but will not address existing damages. However, no analysis of buyouts for floodplain preservation was included with the flood reduction alternative analysis. If property buyouts are considered feasible, those properties could potentially be used for detention or conveyance improvements as projects are implemented.

8.1.1 Project Challenges

While the proposed alternatives could significantly reduce the flood potential throughout the watershed, they are not without certain challenges. Among these are utility conflicts, property ownership, environmental constraints, and other factors that could influence project implementation. These challenges have been identified for each project evaluated and were considered during the recommendation process.

One of the primary challenges is property ownership. ROW availability was a significant issue in developing proposed alternatives throughout the watershed, particularly within the City of Pearland. This area is highly urbanized with residential, commercial, and light industrial development. As part of the alternative analysis, ultimate ROW widths were determined for channel improvement projects and required detention volumes were determined to estimate how much property would be needed to accommodate mitigation. The required ultimate ROW locations and widths are included in the individual alternative descriptions within Section 8.4 and shown on the maps in **Exhibits 10-23** for all watersheds. Detention needs are indicated using circles of proportional size, which relates to the approximate total detention footprint needed in that area to achieve the desired Level of Service for the specific alternative being evaluated (i.e. acres of detention ponds needed to provide the 100-year LOS in Alternative 1). The desired level of service alternatives are specified in Section 8.4, which discusses alternatives for flood reduction measures. Specific properties or pond locations were not identified for detention as part of the alternative analysis.

Utility crossings are another constraint that could potentially influence the implementation process. The main utility concern is large oil and gas pipelines that are located throughout the watershed. These crossings were considered during the alternative analysis; however, in many cases they are unavoidable, and relocations must be done if the project is to be constructed. Approximate locations of major pipelines have been included in the ROW maps (**Exhibits 10-23**). In addition, there are other utility crossings including power line easements and several major raw water canal crossings.

Environmentally sensitive areas or areas with identified cultural resources may also pose a challenge to the implementation of flood reduction improvements. Disturbance of these environmental areas could require mitigation in the form of constructing new environmental areas to replace the disturbed areas or purchasing credits. These areas have been identified on the ROW maps and efforts were made during the alternative analysis process to avoid these areas. In those areas where potential impacts to wetlands were unavoidable, mitigation costs have been included in the cost estimates.

8.2 Future Conditions Hydrology

While the intent of the flood reduction measures is to address existing flooding concerns within the Pearland BDD4 area, the planning effort considered in the future development conditions (i.e. ultimate build-out) to ensure that the improvements provide the necessary protection for the long-term. The future conditions hydrology accounted for increases in impervious cover associated with expected development, which would primarily result in increased runoff volumes. Future conditions represent the situation where current undeveloped areas become developed and is based on the ultimate build-out expectation. Per BDD4 policy and City design standards, increases in peak flow due to future development are required to be mitigated onsite and the future conditions hydrology maintained that assumption by not adjusting any of the TC and R parameters. The specific updates to the hydrologic model were discussed with Pearland/BDD4 and are detailed in the sections below. Due to changes in hydrology and channel geometry, the Modified-Puls storage routing was updated for each of the channel improvement alternatives, with the exception of those done for Hickory Slough and Mary's Creek. Both streams were modeled using HEC-RAS Unsteady.

8.2.1 Impervious Cover

The increase in imperviousness due to future development was estimated by updating the land use of the study area to approximate fully-developed (future) conditions. For the City and its incorporated areas, future development was based on the City's future land use classification from the comprehensive plan information. For areas outside the City and its incorporated areas, future development was approximated based on future thoroughfare information, which was provided by HGAC. The approximation based on future thoroughfares added a 200-ft buffer of high-density development (85% impervious) to each side of proposed major thoroughfares and highways, which would consist mainly of commercial development. The remaining area was represented as residential small lot development (40% impervious). **Appendix A.5** provides a map showing the estimated future land use. The updated percent impervious values were added to the HEC-HMS model. The overall composite increase in percent impervious was 24%. While on-site detention would offset any increases for the TC & R parameters, the change in impervious cover slightly increased the peak discharges because of the way that the Green & Ampt Method calculates infiltration losses. This results in a slight increase in peak discharges of around 3% on average with a maximum of 7%.

8.2.2 Future Conditions Hydrologic Results

Appendix D includes a comparison of the existing and future development conditions discharges for each drainage subbasin within the study area. When compared to existing development, the future development subbasin discharges are, on average, about 3% higher than the existing development discharges for the 100-year event. The maximum increase in flow discharge from existing to future conditions discharges is 7% while the minimum increase is 0%. The larger increases occur in subbasins located in the southern portion of the watershed which is currently rural, and this area is assumed to experience the greatest change in levels of development in the future. The smaller increases occur in the northern portion where the watershed is highly developed and would not have much opportunity for significant future development. The future development conditions discharges were used to size the proposed channel conveyance improvements and detention ponds for multiple Levels of Service based on the two different alternatives evaluated.

8.3 Potential Flood Reduction Measures

Using the peak discharges developed from the future development conditions hydrology, hydraulic modeling was developed for several proposed flood reduction projects along the studied streams. These alternatives include channel conveyance improvements and associated mitigation, regional detention basins, and storm sewers in areas where the channel is confined. The following are discussions of the various flood reduction methods.

8.3.1 Trapezoidal Channel Conveyance Improvements

A trapezoidal channel section was evaluated for most of the streams for both Level of Service alternatives. The trapezoidal sections include side slopes of 4:1 or 3:1 depending on the level of development, a 30' maintenance berms on each side, and a minimum longitudinal slope of 0.001 ft/ft. Because of the available space and limited development, a 4:1 was used on Cowart Creek and Cannon Ditch, while others focused on 3:1 because of existing channel encroachments. Channel flowlines were lowered along the streams wherever possible to gain depth. For the starting channel elevation on the proposed stream improvements, the flowline of the receiving stream or higher was used. The channel improvements resulted in a significantly wider channel sections than existing and, in some cases, the width was limited due to property ownership. Detention required to mitigate the LOS storm event was provided on each tributary such that those projects may stand on their own without creating negative impacts along the main stem. Adverse impacts were monitored, and improvements were adjusted to prevent increased water surfaces for all the modeled storms. Hydraulic summary and comparison tables are provided in **Appendix D**.

Currently, there is a significant amount of volume that is stored in the channel overbanks for all of the studied streams; this natural existing storage helps to attenuate peak flows downstream. The channel conveyance improvements result in a more efficient system that can convey more water; however, the loss of floodplain storage increases the peak discharge rates. This increase was mitigated for by using detention. To account for this change, Modified-Puls routing was updated for each channel reach and LOS alternative (Alternative 1, Alternative 2). Alternative specifics will be discussed in subsequent sections. The Modified-Puls routing parameters are tabulated in **Appendix B** and include an update to the storage discharge curves as well as the subreach calculations.

8.3.2 Regional Detention

Beyond just conveyance mitigation needs, regional detention was a significant part of the proposed improvements because, as mentioned in Section 8.1, the existing channel depths could not always be changed, and conveyance improvements were not feasible in all the reaches. Detention was used in a similar fashion to reduce flows where channel conveyance improvements were avoided or minimized. IN some instances, detention pond depths were limited because the receiving channels were shallow with little vertical room to increase depth. This resulted in large detention footprint requirements for a given storage volume. Proposed ponds were modeled as diversions in HMS, which followed the procedure used for the effective Clear Creek models.

As discussed in Section 8.1.1, one the biggest challenges in developing proposed alternatives was limited ROW availability, particularly for improvements along Mary's Creek, Hickory Slough, and Mustang Bayou. These areas are already developed or currently developing, with few undeveloped areas remaining. This limits the potential detention pond locations. To communicate the necessary volume and approximate footprint without identifying specific parcels, the acreage required was estimated using an assumed depth and a general location of the pond(s), or reach along which ponds should be constructed, was determined for a given LOS. Estimated detention ROW acreage was based on a 4:1 side slope, a 30-foot maintenance buffer from top of bank and a square pond. Pipeline and other utility crossings were avoided where possible, and additional costs when utilities or environmentally sensitive areas could not be avoided are included in the project cost estimates.

The detention volume listed in the sections below for each alternative are partly based on the LOS storm event and the volume required to contain the flows from the LOS event within the channel banks. In addition to checking that the WSEL was contained within the banks for that storm, any adverse impacts to the stream were checked and mitigated across a range of storm events from the 3-year to the 500-year. In many situations, this resulted in increased detention requirements. For example, the detention requirement for 10-year LOS may only be 500 ac-ft, but in order to remove impacts from storms above the 10-year, 700 ac-ft was needed

8.4 Alternatives for Flood Reduction Measures

During the existing conditions analysis, several streams were determined to have a capacity to provide approximately a 3-year LOS or less. The second LOS to be evaluated (Alternative 2) was selected based on the existing channel capacity and a reasonable target LOS that could provide flood reduction benefits but at a significantly lower cost than the 100-year LOS (Alternative 1). The modeled alternatives were largely selected based on the existing inundation limits and recorded flooded properties. **Table 5** provides the target LOS for each stream segment for Alternatives 1 and 2. It should be noted that in several instances the channel improvements for both Alternatives 1 and 2 were the same or close in size, but there was a substantial difference in the detention requirement. That is because many of the alternatives rely on detention to bring flows down to a level where the channels can be sized reasonably. However, even with the lower LOS, the detention may still be very large because of the impacts that were considered for all storm events as discussed in Section 8.3.2 above.

Table 5. Existing Conditions Unsteady vs Steady Modeling WSEL Comparison

Modeled Streams				
Watershed	**Streams/Tribs**	**Existing LOS**	**Alternative 1 LOS***	**Alternative 2 LOS***
Chocolate	East Chocolate	3yr - 5yr	100yr	10yr
	Rodeo Palms	3yr - 5yr	100yr	10yr
	E103	< 3yr	100yr	10yr
	West Chocolate	< 3yr	100yr	5yr
	Cold McCutchen	< 3yr	100yr	5yr
	CR 383	< 3yr	100yr	5yr
Mustang	Mustang	< 3yr	100yr	25yr
	Mustang Spur	< 3yr	100yr	25yr
Chigger	Old Chigger	5yr - 10yr	100yr	10yr
	Resort Park	< 3yr	100yr	10yr
	Chigger	< 3yr	100yr	10yr
	Chigger Trib	< 3yr	100yr	10yr
Clear Creek Tribs	Country Place	100yr	N/A	N/A
	Shadow Creek	50yr - 100yr	N/A	N/A
Hickory	Hickory	3yr - 5yr	100yr	10yr
Marys	Marys Main Stem	5yr - 10yr	100yr	25yr
	Marys North Fork	50yr - 100yr	N/A	N/A
	Marys South Fork	50yr - 100yr	N/A	N/A
	Weatherford	50yr - 100yr	N/A	N/A
	Corrigan	100yr	N/A	N/A
Cowart	Cannon	< 3yr	100yr	10yr
	Diversion Ditch	50yr - 100yr	100yr	N/A
	Hood Ditch	< 3yr	100yr	10-yr
	Cowart Tributary	3yr - 5yr	100yr	10-yr
	Dare Ditch	25yr-50yr	100yr	N/A
	Cowart Creek - Upper	< 3yr	100yr	10yr
	Cowart Creek - Lower	25yr-50yr	100yr	N/A

* N/A Indicates that existing capacity was high enough that improvements were not proposed

8.4.1 Chigger Creek

Much of the flooding along Chigger Creek and its tributaries occurs upstream of Highway 35 with a wide area of inundation upstream of the BNSF Railway crossing. The existing channels west of Highway 35 all provide a 3-year LOS or less except for Old Chigger, which provides a 10-year LOS or less. While most of the area west of the BNSF Railway crossing is undeveloped, the area between the railroad and Highway 35 is more urbanized with residential areas to the south and more industrial land use to the north.

Due to the low existing LOS, all studied streams besides Old Chigger required channel conveyance improvements. Channel improvements were not proposed for Old Chigger due to the presence of multiple residential properties adjacent to the stream and limited availability of undeveloped land for channel expansion. There were multiple culvert improvements proposed for Old Chigger aimed at removing hydraulic restrictions along the channel by upsizing culverts and increasing the number of barrels. Several bridges and culverts, which adequately conveyed flows based on existing conditions, will need to be increased to convey the increases in flow due to channel improvements and future conditions.

Detention is provided both in the upstream and downstream portions of the watershed to lower flows in upstream portion and to reduce water surface elevations and mitigate for increase conveyance resulting from the proposed channel improvements.

8.4.1.1 Chigger Creek :100-year LOS

Exhibit 10 A-D shows the project layout, ultimate ROW, and 100-year inundation map for the 100-year LOS scenario. See **Appendix D.6** for details on structure improvements or changes. The total cost for this scenario is $149 million and includes the following:

- Channel Bottom Width: 20-40 feet
- Channel Depth: 3.5 – 15.5 feet
- Channel ROW: 100 – 190 feet
- Bridge/Culvert Replacement: Ramirez Road, Highway 35 (2x), Hastings Road, CR 294, CR 191, Britt Oaks Drive Ware Diary Road, St. Cloud Drive, 5 Private Roads, 6 Driveways, and 8 Private Crossings
- Detention Volume: 4,790 acre-feet

8.4.1.2 Chigger Creek: 10-year LOS

Exhibit 17 A-C shows the project layout, ultimate ROW, and 100-year inundation map for the 10-year LOS scenario. See **Appendix D.6** for details on structure improvements or changes. The total cost for this scenario is $75 million and includes the following:

- Channel Bottom Width: 20-40 feet
- Channel Depth: 3.5 – 15.5 feet
- Channel ROW: 100 – 190 feet
- Bridge/Culvert Replacement: Ramirez Road, Highway 35 (2x), Hastings Road, CR 294, CR 191, Britt Oaks Drive Ware Diary Road, St. Cloud Drive, 5 Private Roads, 6 Driveways, and 8 Private Crossings
- Detention Volume: 1,700 acre-feet

8.4.2 East Chocolate Bayou

Most of East Chocolate Bayou is heavily inundated, particularly upstream of the raw water canals, which force the drainage across via siphons. The channel's upstream portion begins near the Palm Desert Drive and Rodeo Drive intersection and the studied area ends between Mason Road and Burnett Road. There is a shorter channel, E103, that confluences with Rodeo Palms Ditch, and at the most southern position of East Chocolate Bayou, the Rodeo Palms Ditch merges with the main stem. The existing channels in this area all provide a LOS between 3 to 5-years, and the northern portion of Rodeo Palms Ditch is mostly surrounded by residential development which limits the available ROW. Channel conveyance improvements were investigated for all studied streams in the East Chocolate Bayou watershed for the 100 and 10-year LOS. Several bridges and culverts, which adequately conveyed flows based on existing conditions, will need to be increased to convey the increases in flow due to channel improvements and future conditions.

Currently, the drainage siphons along the channel (crossing under the intersecting canals) are the biggest contributor to flooding in the area, due to the flow restriction. Therefore, the removal of these siphons was considered for both levels of service (10- and 100-year). These alternatives would require that the siphons along the channel be removed and the channel widened at the crossings. In order to allow the canals to continue functioning, siphons would need to be built on the canals that cross under the channel. As the canals have a more controlled discharge rate than the drainage, they would function more effectively using siphons than the drainage channels do. To account for the costs of the new siphons, it was assumed from other nearby siphons, that there would be 4-60-inch RCP pipes. Each pipe would also have 2 headwalls. In addition to the removal of the siphons along the drainage channels and channel conveyance improvements, detention was added to reduce the flooding in the East Chocolate Bayou watershed and mitigate impacts due to conveyance increases.

8.4.2.1 East Chocolate Bayou: 100-year LOS

Exhibit 11 A-C shows the project layout, ultimate ROW, and 100-year inundation map for the 100-year LOS scenario. See **Appendix D.6** for details on structure improvements or changes. The total cost for this scenario is $203 million and includes the following:

- Channel Bottom Width: 45 – 75 feet
- Channel Depth: 5 - 11 feet
- Channel ROW: 160 – 260 feet

- Bridge/Culvert Replacement: Oakland Park Drive, Palmero Way, US 288, Highway 6, Railroad, CR 81, CR 418, CR 80, 1 Private Road, 6 Driveways, and 2 Private Crossing Removals
- Remove existing drainage siphons and replace with canal siphons
- Detention Volume: 5,550 acre-feet

8.4.2.2 East Chocolate Bayou: 10-year LOS

Exhibit 18 A-C shows the project layout, ultimate ROW, and 100-year inundation map for the 10-year LOS scenario for East Chocolate. East Chocolate's 10-year LOS maintained the same channel improvements but decreased the detention. The channels maintained the same bottom widths, depths, ROW and bridge replacements as the 100-year LOS. The detention was reduced enough to not allow impacts on the water surface elevation and flow. To not create impacts for all storm events including the 500-year, more detention was needed than for the target level of service, 10-year. See **Appendix D.6** for details on structure improvements or changes. The total cost for this scenario is $161 million and includes the following:

- Channel Bottom Width: 45 – 75 feet
- Channel Depth: 5 - 11 feet
- Channel ROW: 160 – 260 feet
- Bridge/Culvert Replacement: Oakland Park Drive, Palmero Way, US 288, Highway 6, Railroad, CR 81, CR 418, CR 80, 1 Private Road, 6 Driveways, and 2 Private Crossing Removals
- Remove existing drainage siphons and replace with canal siphons
- Detention Volume: 4,220 acre-feet

8.4.3 West Chocolate Bayou

Similar to East Chocolate Bayou, West Chocolate Bayou is also heavily inundated, particularly upstream of the channel siphons used to cross the raw water canals. The channel has three sections: the western section begins near the intersection of Fenn Road and FM 521 Road, the middle section begins near County Road 383, and the eastern section starts by the Old Airline Road and Mars Drive intersection. The western, middle and eastern channels were named West Chocolate, CR383 and Cold McCutchen, respectively. CR383 confluences onto West Chocolate near the southern portion of West Chocolate, and Cold McCutchen and West Chocolate merge at the most downstream potion of the channel. The existing channels in this area all provide a 3-year or less LOS. Channel conveyance improvements for the 100-year and 5-year LOS (Alternative 2) were evaluated for each of the three streams. Several bridges and culverts, which adequately conveyed flows based on existing conditions, will need to be increased to convey the increases in flow due to channel improvements and future conditions.

As with the East Chocolate Bayou alternative, the siphons on the West Chocolate streams were converted to siphons on the raw water canals wherever stream crossings occurred. The removal of the drainage siphons and replacement with canal siphons will allow the streams to flow without the significant restriction that is currently in place. To account for the costs of the new siphons, it was assumed that there would be 4-60-inch RCP pipes. Each pipe would also have 2 headwalls. In addition to the removal of the siphons along the drainage channels and channel conveyance improvements, detention was added to reduce the flooding in the East Chocolate Bayou watershed and mitigate impacts due to conveyance increases.

8.4.3.1 West Chocolate Bayou: 100-year LOS

Exhibit 12 A-C shows the project layout, ultimate ROW, and 100-year inundation map for the 100-year LOS scenario. A detention pond is necessary in the upstream section of CR383 to decrease the flooding from the upstream contributing drainage area. A constraint to the detention pond is that the area nearest to the channel is all residential development. The area north of the residential area is more rural and less developed. Building the pond in the residential area would increase the cost of the pond , whereas building the pond in the rural area would be more economical. While calculating the improvements costs, the detention area was estimated to be one third within the residential area and two thirds in the more rural area. See **Appendix D.6** for details on structure improvements or changes. The total cost for this scenario is $339 million and includes the following:

- Channel Bottom Width: 35 – 80 feet
- Channel Depth: 4 – 18 feet
- Channel ROW: 120 – 280 feet
- Bridge/Culvert Replacement: Rio Lindo Street, Rio Ramos Street, Highway 6 (2x), Oak Street (2x), Railroad (2x), Sanders Street, North Pine Road, Coen Road, South Pine Road, CR 383, 4 Driveways, and 3 Private Crossing Removals
- Remove existing drainage siphons and replace with canal siphons
- Detention Volume: 4,490 acre-feet

8.4.3.2 West Chocolate Bayou: 5-year LOS

Exhibit 19 A-C shows the project layout, ultimate ROW, and 100-year inundation map for the 5-year LOS scenario. The same channel improvements that were created for the 100-year LOS were utilized for this second alternative. To not create impacts for all storm events including the 500-year, more detention was needed than for the target level of service, 5-year. See **Appendix D.6** for details on structure improvements or changes. The total cost for this scenario is $303 million and includes the following:

- Channel Bottom Width: 35 – 80 feet
- Channel Depth: 4 – 18 feet
- Channel ROW: 120 – 280 feet
- Bridge/Culvert Replacement: Rio Lindo Street, Rio Ramos Street, Highway 6 (2x), Oak Street (2x), Railroad (2x), Sanders Street, North Pine Road, Coen Road, South Pine Road, CR 383, 4 Driveways, and 3 Private Crossing Removals
- Remove existing drainage siphons and replace with canal siphons
- Detention Volume: 5,007 acre-feet

8.4.4 Country Place Ditch

Country Place Ditch revised existing conditions modeling shows the ditch having almost a 100-year LOS; however, there is ponding in the streets. In order to remove the street ponding for the future development condition, approximately 156 ac-ft of detention would need to be added upstream of SH 288.

8.4.5 Cowart Creek

Much of the flooding along Cowart Creek and its tributaries occurs upstream BNSF Railway crossings. The existing channels west of the BNSF railway provide a 5-year LOS or less except for the upper portion of Diversion Ditch, which provides a 50-year LOS or less. While most of the area east of the BNSF Railway crossing is industrial land use (oil fields), the area upstream of the railroad is more urbanized with residential areas to the north and more industrial land to the south. The upstream end of Cannon Ditch and in the south-west corner of Diversion Ditch is largely undeveloped. Downstream of the confluence of Cowart Creek and Cannon Ditch, the landuse is predominately residential. Several bridges and culverts, which adequately conveyed flows based on existing conditions, will need to be increased to convey the increases in flow due to channel improvements and future conditions.

Due to the low existing LOS, all studied streams required channel conveyance improvements. There were multiple culvert improvements proposed aimed at removing hydraulic restrictions along the channel by upsizing culverts and increasing the number of barrels. Further, the existing storm sewer along Bailey road requires a significant increase in size and flow line adjustment upstream of Diversion Ditch to provide a 100-year LOS. The storm sewer downstream of Diversion Ditch requires an increase in size in several reaches. Detention is provided throughout the watershed to lower flows in upstream portion and to reduce water surface elevations and mitigate for increase conveyance resulting from the proposed channel improvements.

8.4.5.1 Cowart Creek: 100-year LOS

Exhibit 13 A-D shows the project layout, ultimate ROW, and 100-year inundation map for the 100-year LOS scenario. See **Appendix D.6** for details on structure improvements or changes. The total cost for this scenario is $343 million and includes the following:

- Channel Bottom Width: 20 – 50 feet
- Channel Depth: 5 – 16 feet
- Channel ROW: 70 – 290 feet
- Bridge/Culvert Replacement: CR 143, Amoco St (2x), Railroad (4x), Ramirez Road, CR 128, Main Street, CR 327, CR 143, CR 175C, CR 176C, CR 104, CR829, CR 143, CR 115 (2x), Moore Road, CR 130, CR 129, Baker Road, 6 Private Roads, 4 Driveways, and 5 Private Crossing Removals
- Weir Adjustment: Lower Weir on Diversion Ditch
- Storm Sewer Replacement: 1900 LF of 4’x3.5’ RCBs, 900 LF of 6’x4’ RCBs, 600 LF of 4’x2.5’ LF, 900 LF of 5’x3.5’, 5800 LF of 2 -6’x5’RCBs
- Detention Volume: 6,470 acre-feet

8.4.5.2 Cowart Creek: 10-year LOS

Exhibit 20 A-D shows the project layout, ultimate ROW, and 100-year inundation map for the 10-year LOS scenario. Unlike other streams, the lower LOS does not match the 100-year LOS proposed geometry. The 10-year LOS does not change the existing storm sewer system along Bailey Road nor does it change the diversion channel upstream of CR 143. See **Appendix D.6** for details on structure improvements or changes. The total cost for this scenario is $325 million and includes the following:

- Channel Bottom Width: 20 – 50 feet
- Channel Depth: 5 – 16 feet
- Channel ROW: 70 – 290 feet
- Bridge/Culvert Replacement: CR 143 (2x), Amoco St (2x), Railroad (4x), Ramirez Road, CR 128, Main Street, CR 327, CR 143, CR 175C, CR 176C, CR 104, CR829, CR 115 (2x), Moore Road, CR 130, CR 129, Baker Road, 6 Private Roads, 4 Driveways, and 5 Private Crossing Removals
- Detention Volume: 5,475 acre-feet

8.4.6 Hickory Slough

The majority of flooding along Hickory Slough not related to Clear Creek occurs upstream of Mykawa Road. The entirety of the channel has residential and light industrial development which limits the available ROW. The channel runs from just downstream of CR 94 to the confluence with Clear Creek. Channel conveyance improvements run from CR 94 to 3500 ft upstream of Cullen Road and from Garden Road to the Burlington Northern and Santa Fe railway crossing. Further, two bypass channels were added between Roy Road and Oday Road to add additional capacity to Hickory Slough away from the road-side ditch. The current stream is constrained by the roadway and several structures and cannot be adequately improved within these constraints. The bypass allows flow to follow a path similar to the original Hickory Slough alignment, which is still visible in the terrain. Several bridges and culverts, which adequately conveyed existing conditions flows, will need to be upsized to convey the increases in flow due to channel improvements and future development conditions. Due to uncertain land availability, Halff did not lay out specific detention pond locations for Alternatives 1 and 2, but instead identified required detention as well as the general location in which it would be required.

8.4.5.1 Hickory Slough: 100-year LOS

Exhibit 14 A-D shows the project layout, ultimate ROW, and 100-year inundation map for the 100-year LOS scenario. For the 100-year LOS, two bypass channels in close succession between Roy and Oday roads were required. See **Appendix D.6** for details on structure improvements or changes. The total cost for this scenario is $166 million and includes the following:

- Channel Bottom Width: 5 – 30 feet
- Channel Depth: 7 – 15 feet
- Channel ROW: 130 – 230 feet
- Bridge/Culvert Replacement: Fair Oaks Street, Miller Ranch Road, Garden Road, Oday Road, Hatfield Road, Woody Drive, Mykawa Road, 1 Private Road, 2 Pedestrian Bridges, and 2 Driveways
- New Bridge: Roy Road at proposed channel bypass
- Detention Volume: 3,800 acre-feet

8.4.5.2 Hickory Slough: 10-year LOS

Exhibit 21 A-D shows the project layout, ultimate ROW, and 100-year inundation map for the 10-year LOS scenario. For the 10-year LOS, two bypass channels in close succession between Roy and Oday roads were required. See **Appendix D.6** for details on structure improvements or changes. The total cost for this scenario is $133 million and includes the following:

- Channel Bottom Width: 5 – 30 feet
- Channel Depth: 7 – 15 feet
- Channel ROW: 130 – 230 feet
- Bridge/Culvert Replacement: Fair Oaks Street, Miller Ranch Road, Garden Road, Oday Road, Hatfield Road, Woody Drive, Mykawa Road, 1 Private Road, 2 Pedestrian Bridges, and 2 Driveways
- New Bridge: Roy Road at proposed channel bypass
- Detention Volume: 2,850 acre-feet

8.4.7 Mary's Creek

Most of the flooding along Mary's occurs upstream of the split between Mary's Creek and Mary's Creek Bypass. While much of the channel downstream appears to have near adequate capacity to carry existing 100-year discharges. The entirety of the channel has residential development which limits the available ROW. The channel runs from just downstream of Southwyk Parkway to the confluence with Clear Creek. Channel conveyance improvements run from upstream of Manvel Road to downstream of Pearland Parkway. Several bridges and culverts, which adequately conveyed flows based on existing conditions, will need to be increased to convey the increases in flow due to channel improvements and future conditions. Due to restrictions on land availability, Halff did not lay out specific detention pond locations but instead identified required detention and the approximate location it is needed.

8.4.7.1 Mary's Creek: 100-year LOS

Exhibit 15 A-E shows the project layout, ultimate ROW, and 100-year inundation map for the 100-year LOS scenario. Note that the 500-year flows on Mary's Creek control the required detention so several detention basins were significantly increased to mitigate for the 500-year impacts. See **Appendix D.6** for details on structure improvements or changes. The total cost for this alternative is $294 million and includes the following:

- Channel Bottom Width: 30 – 40 feet
- Channel Depth: 11 – 20 feet
- Channel ROW: 160 –250 feet
- Bridge/Culvert Replacement: Manvel Road, Magnolia Street, Harkey Road, McLean Road, Veterans Drive, Railroad, HWY 35/ Main Street, Old Alvin Road, Pearland Parkway, John Lizer Road, Liberty Drive, Longherridge Drive, and 1 Pedestrian Bridge.
- Detention Volume: 5,770 acre-feet

8.4.7.2 Mary's Creek: 25-year LOS

Exhibit 22 A-E shows the project layout, ultimate ROW, and 100-year inundation map for the 25-year LOS scenario. See **Appendix D.6** for details on structure improvements or changes. The total cost for this scenario is $176 million and includes the following:

- Channel Bottom Width: 30 – 40 feet
- Channel Depth: 11 – 20 feet
- Channel ROW: 160 –250 feet
- Bridge/Culvert Replacement: Manvel Road, Magnolia Street, Harkey Road, McLean Road, Veterans Drive, Railroad, HWY 35/ Main Street, Old Alvin Road, Pearland Parkway, John Lizer Road, Liberty Drive, Longherridge Drive, Dixie Farm Road, and 1 Pedestrian Bridge.
- Detention Volume: 3,480 acre-feet

8.4.8 Mustang Bayou

Significant flooding occurs throughout Mustang Bayou; however, this study only addresses flooding downstream of the Fort Bend – Brazoria County Line to 700 ft downstream of CR 90. Proposed channel conveyance improvements run from FM 521 to CR 90. Several bridges and culverts, which adequately conveyed flows for the existing development conditions, will need to be increased to convey the increases in flow due to channel improvements and future development conditions. Due to restrictions on land availability in much of the Mustang Bayou watershed, Halff did not lay out specific detention pond locations for the two alternatives, but instead identified the detention recommended to achieve the desired LOS as well as the approximate location in which it would be needed.

Upstream of FM521, within Fort Bend County, no improvements were recommended, but potential impacts caused by the proposed improvements were avoided for the future development condition. The area along Mustang Bayou surrounding SH288 has experienced development, which does not appear in the LiDAR dataset; However, those areas were filled above BFE and have been removed from the floodplain. The area downstream of Highway 288, but within Brazoria County has areas adjacent to the channel that are very low as compared to the existing channel. As such, improvements to the level of service desired could not obtained without improvements outside the BDD4 jurisdiction. As such, this area was treated as a "no-impact" area, meaning that the proposed improvements upstream would not negatively impact the drainage, but no significant flood reduction benefits were achieved. Additional benefits could be achieved by considering joint projects with the neighboring jurisdictions.

8.4.8.1 Mustang Bayou: 100-year LOS

Exhibit 16 A-D shows the project layout, ultimate ROW, and 100-year inundation map for the 100-year LOS scenario. See **Appendix D.6** for details on structure improvements or changes. The total cost for this scenario is $303 million and includes the following:

- Channel Bottom Width: 100 feet
- Channel Depth: 5 – 15 feet
- Channel ROW: 200 – 280 feet
- Bridge/Culvert Replacement: CR 564, CR 48, CR 84, SH 288, and 2 Private Crossing Removals
- Detention Volume: 5,380 acre-feet

8.4.8.2 Mustang Bayou: 25-year LOS

Exhibit 23 A-D shows the project layout, ultimate ROW, and 100-year inundation map for the 25-year LOS scenario. See **Appendix D.6** for details on structure improvements or changes. The total cost for this scenario is $160 million and includes the following:

- Channel Bottom Width: 100 feet
- Channel Depth: 5 – 15 feet
- Channel ROW: 200 – 280 feet
- Bridge/Culvert Replacement: CR 564, CR 48, CR 84, SH 288, and 2 Private Crossing Removals
- Detention Volume: 2,950 acre-feet

8.4.8.3 Mustang Bayou Extension

The area between Highway 288 and CR 90 has a shallow, flat channel, which prevents significant flood reduction in the area. One way to address flooding in this vicinity is a bypass channel that would begin downstream of CR 90 and end near Lira Road, which would allow the channel flow line to be lowered. This channel would be outside of the BDD4/Pearland boundaries and would require coordination with Brazoria Drainage District No. 3 as well as acquisition of property along the proposed alignment. Based on preliminary calculations, a bypass channel would allow for a 5-year LOS where currently there is less than a 3-year LOS. The estimate channel would require an approximately 235 ft ROW. A more detailed investigation of the extension is necessary for any cost estimates or detailed explanation of benefits.

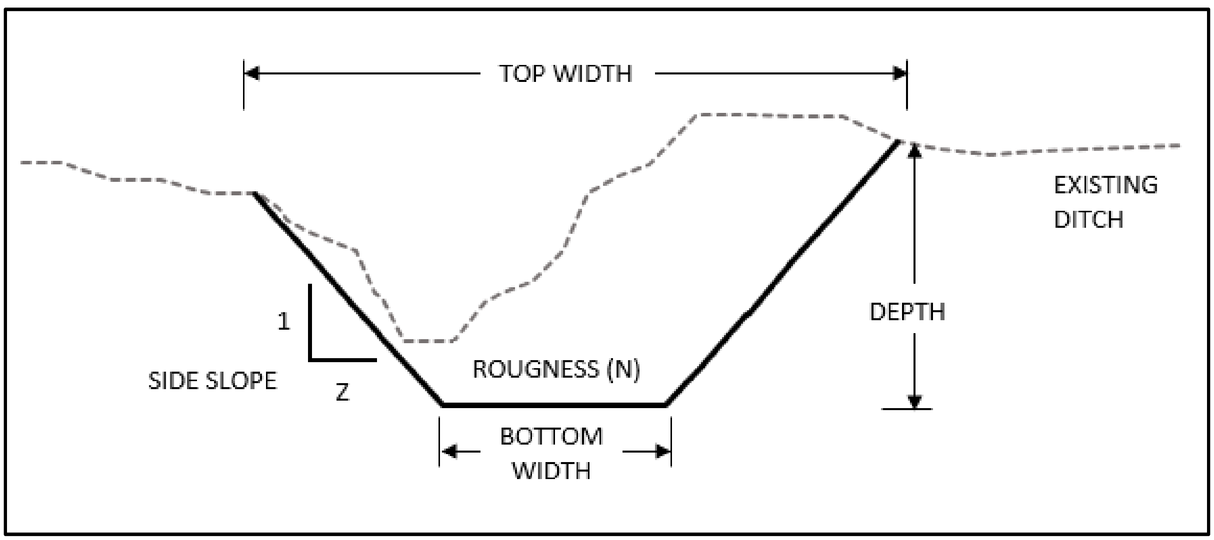
8.4.9 Shadow Creek Ranch

Shadow Creek Ranch has near to a 100-year LOS with the exception of some street ponding in low-lying areas adjacent to the channel. The area is currently fully developed in Pearland, but based on the future development conditions hydrologic analysis, development in Fort Bend County could result in ponding increases along the ditch if it is not mitigated. Coordination with Fort Bend Drainage district on development and drainage projects in their jurisdiction is recommended in order to avoid these increases. Using the same methodology as discussed in Section 8.2, an onsite detention requirement in Fort Bend County could still result in the need for 290 ac-ft upstream of FM 521 and culvert size along the ditch. A demonstration of no impact for projects in Fort Bend County would allay these concerns.

8.5 Local Ditch Capacity Improvements

A procedure similar to what was discussed in Section 6.4 was completed to determine the proposed dimensions for local ditch improvements. Using the Manning's equation and the 3-year and 10-year estimated discharges, the cross-sectional geometry needed to carry the respective flow rate was determined. Proposed cross sections were assumed to have 4:1 side slopes to meet BDD4 design criteria. The ditch bottom width, and depth were updated so that the calculated capacity of ditch matched or exceeded the drainage area discharges. Ditches were sized to contain the 3-year and 10-year discharges within the ditch banks. **Appendix D.3 – D.4** provides tables summarizing the proposed ditch geometries for the 3-year and 10-year levels of service. Conceptual level engineering cost estimates for local ditch improvements are provided in **Appendix F**. Recommendations for local ditch improvements are discussed in Section 10.6 and 11.0 as well as in the Implementation Plan (**Appendix G**).

Figure 4. General Proposed Cross Section Layout



9.0 Costs and Benefits

The recommendation and prioritization of flood risk reduction alternatives was based on a combination of estimated implementation costs and evaluation of general project benefits. A cost/benefit analysis was performed to help prioritize the different proposed flood reduction solutions. The methodology used for estimating costs and performing the cost/benefit analysis is described in the following sections. In addition, other benefits were considered in order to better balance the recommendations for those areas where development is not as dense, or property values are lower due to socio-economic conditions. Each of the alternative benefits are discussed in this section.

9.1 Project Cost Components

Project cost estimates were prepared for each of the proposed alternatives. Cost estimates included several items such as conveyance and detention improvements, utility relocation, ROW acquisition, Wetlands Mitigation, and other costs associated with implementation of the proposed alternatives. Detailed cost estimates for each scenario that was evaluated are provided in **Appendix F.**

9.1.1 Construction Costs

Estimates for channel conveyance improvements and detention included overhead costs for several work items in the spreadsheet such as:

- Mobilization – 5% of Direct Construction Costs
- Planning, Engineering, Design – 12% of Direct Construction Costs
- Construction Management – 10% of Direct Construction Costs
- Contingencies – 20% of Direct Construction Costs

Channel improvement cost estimates included site preparation, earthwork, pipeline and utility conflicts, and installation of structures (such as bridges and culverts/headwalls). Channel excavation volumes were determined using the HEC-RAS Channel Modification tool, which calculated cut/fill quantities by comparing the proposed channel cross-section to the existing channel one.

Structure costs were further broken down into installation and removal costs to account for the cost of both removing the existing structure and constructing the new one. Bridge costs were based on an assumed average cost per square foot of bridge deck, estimated from the existing bridge deck width and the new span length needed for the widened proposed channel. The bridge removal and installation costs were assumed to be $25/SF and $85/SF respectively.

The installation costs for major culverts were based on the modeled configuration required to achieve the specific LOS for each alternative. An average cost per linear foot of RCP or RCB was used to estimate the total cost for each structure based on the culvert size, length, and number of barrels. The removal cost for the major culverts was estimated at $40/LF.

Many small, private bridges and culverts (such as driveway crossings) across various streams were not modeled. A list of structures and the general type of improvement are provided in **Appendix D**. To estimate the installation cost, each crossing was assumed to be 25 feet long and would utilize dual 60" RCPs. This is an estimate and should not be regarded as a recommendation for construction. The removal cost for the small bridges and culverts was $85/SF and $40/LF, respectively.

Detention cost estimates were also prepared, which included similar items. Detention volume was measured up to the estimated peak water surface elevation in the ponds, which was related to the maximum water surface elevation in the adjacent channel. In most cases, this maximum storage elevation was several feet below the existing natural ground. This required additional excavation above the maximum storage elevation, which is why the excavation volumes were based on the necessary mitigation volume plus additional earthwork needed to reach existing grade. Further refinement of the pond designs will be completed during subsequent H&H analyses as part of future individual projects. Detention pond outfall and overflow structure costs are included in the detention estimates. For the purposes of cost estimating, a 48" RCP outfall pipe was assumed. Given the relatively small cost of the pipe and headwall versus other cost items (primarily earthwork and ROW acquisition), the costs associated with variations in actual proposed outfall could reasonably be considered to be within the 20% contingency. Large overflow weir structures were estimated using an assumed depth and estimated peak flow rate from modeling for each alternative. The assumed depth was used to determine the required length and associated surface area required to convey a given peak flow. The surface area was assumed to be concrete paved and used for costing the weir structures.

9.1.2 ROW Acquisition Costs

Ultimate ROW widths were determined for each channel improvement alternative using the proposed top-width and a 30' maintenance easement on either side of the channel. This information was overlaid onto the Harris Galveston Area Council (HGAC) parcel data to determine potential property to be acquired. In order to estimate detention ROW acquisition costs, an average cost/acre was determined using the properties surrounding the potential detention pond location. ROW widths for all the evaluated projects are shown in **Exhibits 10 through 23**. Detention ROW needs were estimated based on the calculated acreage and placement of the proposed detention ponds.

Using the ultimate channel and detention ROW information, the cost of acquisition was determined using the area and estimated value per acre for each property. The estimated cost per acre for each detention basin and channel improvement is provided by segment in **Appendix F**. For each parcel, any publicly-owned land (i.e. existing city, or county) was subtracted from the total area required since land acquisition costs were assumed to be $0 for publicly-owned parcels. Additional closing costs were added, including a 35% value markup and other associated fees to account for potential relocation and demolition costs when structures could not be avoided. Structures being acquired were priced at the "condemned" cost (2X the voluntary cost) for the purpose of these estimates.

9.1.3 Utility Relocation Costs

For the proposed alternatives, pipeline and overhead utility relocation were considered but some public utility information, such as water and sewer lines, was not available. In lieu of available utility data, water and sewer lines quantities to be relocated were estimated by using road lengths within the well-developed areas. Water and sewer relocation costs were determined by identifying the total road length within each specific ROW area and multiplying by the unit prices. Pipeline locations were based on information provided by COP and BDD4. Relocation lengths were estimated based on the length of the pipeline located within the identified project ROW. Cost per linear foot of pipeline relocation were based on the diameter and linear footage to be relocated. Power transmission lines were based on information provided by COP and BDD4. The total number of power lines to be relocated within each specific ROW area was determined and multiplied by the unit price. The unit prices for the pipeline and power line relocations were based on costing information provided from recent bid tabulations.

9.2 Total Flood Reduction Alternative Costs

A detailed breakdown of costs for each scenario is provided in **Appendix F**. These costs are considered a planning level estimate and will need to be refined as projects are implemented.

9.2.1 Chigger Creek

The 100-year LOS scenario has a total cost of $149 million. The 10-year LOS scenario has a total cost of $75 million. **Table 6** provides a breakdown of the total costs by channel conveyance improvements, detention requirements, and ROW acquisition.

Table 6. Chigger Creek Cost Estimate Summary

Scenario	Detention Costs ($M)	Channel Improvement Costs ($M)	ROW Acquisition Costs ($M)		Total Cost ($M)
			Detention	Channel	
Chigger Creek Alternative 1 - 100-yr LOS	$117	$32	$16	$3	$149
Chigger Creek Alternative 2 - 10-yr LOS	$43	$32	$5	$3	$75

9.2.2 East Chocolate Bayou

The 100-year LOS scenario has a total cost of $203 million. The 10-year LOS scenario has a total cost of $161 million. **Table** provides a breakdown of the total costs by channel conveyance improvements, detention requirements, and ROW acquisition.

Table 7. East Chocolate Bayou Cost Estimate Summary

Scenario	Detention Costs ($M)	Channel Improvement Costs ($M)	ROW Acquisition Costs ($M)		Total Cost ($M)
			Detention	Channel	
East Chocolate Bayou Alternative 1 - 100-yr LOS	$172	$31	$52	$14	$203
East Chocolate Bayou Alternative 2 - 10-yr LOS	$130	$31	$36	$14	$161

9.2.3 West Chocolate Bayou

The 100-year LOS scenario has a total cost of $339 million. The 5-year LOS scenario has a total cost of $303 million. **Table** provides a breakdown of the total costs by channel conveyance improvements, detention requirements, and ROW acquisition.

Table 8. West Chocolate Bayou Cost Estimate Summary

Scenario	Detention Costs ($M)	Channel Improvement Costs ($M)	ROW Acquisition Costs ($M)		Total Cost ($M)
			Detention	Channel	
West Chocolate Bayou Alternative 1 - 100-yr LOS	$288	$51	$156	$11	$339
West Chocolate Bayou Alternative 2 - 5-yr LOS	$252	$51	$150	$11	$303

9.2.4 Cowart Creek

The 100-year LOS scenario has a total cost of $343 million. The 10-year LOS scenario has a total cost of $325 million. **Table** provides a breakdown of the total costs by channel conveyance improvements, detention requirements, and ROW acquisition.

Table 9. Cowart Creek Cost Estimate Summary

Scenario	Detention Costs ($M)	Channel Improvement Costs ($M)	ROW Acquisition Costs ($M)		Total Cost ($M)
			Detention	Channel	
Cowart Creek Alternative 1 - 100-yr LOS	$226	$116	$69	$45	$343
Cowart Creek Alternative 2 - 10-yr LOS	$216	$109	$69	$43	$325

9.2.5 Hickory Slough

The 100-year LOS scenario has a total cost of $166 million. The 10-year LOS scenario has a total cost of $133 million. **Table** provides a breakdown of the total costs by channel conveyance improvements, detention requirements, and ROW acquisition.

Table 10. Hickory Slough Cost Estimate Summary

Scenario	Detention Costs ($M)	Channel Improvement Costs ($M)	ROW Acquisition Costs ($M)		Total Cost ($M)
			Detention	Channel	
Hickory Slough Alternative 1 - 100-yr LOS	$131	$35	$59	$13	$166
Hickory Slough Alternative 2 - 10-yr LOS	$98	$35	$43	$13	$133

9.2.6 Mary’s Creek

The 100-year LOS scenario has a total cost of $294 million. The 25-year LOS scenario has a total cost of $176 million. **Table** provides a breakdown of the total costs by channel conveyance improvements, detention requirements, and ROW acquisition.

Table 11. Mary's Creek Cost Estimate Summary

Scenario	Detention Costs ($M)	Channel Improvement Costs ($M)	ROW Acquisition Costs ($M)		Total Cost ($M)
			Detention	Channel	
Mary’s Creek Alternative 1 - 100-yr LOS	$241	$53	$118	$17	$294
Mary’s Creek Alternative 2 - 25-yr LOS	$123	$53	$46	$17	$176

9.2.7 Mustang Bayou

The 100-year LOS scenario has a total cost of $216 million. The 25-year LOS scenario has a total cost of $129 million. **Table** provides a breakdown of the total costs by channel conveyance improvements, detention requirements, and ROW acquisition.

Table 12. Mustang Bayou Cost Estimate Summary

Scenario	Detention Costs ($M)	Channel Improvement Costs ($M)	ROW Acquisition Costs ($M)		Total Cost ($M)
			Detention	Channel	
Mustang Bayou Alternative 1 - 100-yr LOS	$186	$30	$86	$6	$216
Mustang Bayou Alternative 2 - 25-yr LOS	$99	$30	$44	$6	$129

9.2.8 Capacity Analysis Ditches

Ditch improvement costs were estimated based on linear footage of improvement because no modeling was conducted for these ditches. The cost for ditch improvements used for the 3-year LOS is $7.60 per linear foot. This value is an average cost based on TxDOT and Harris County published bid prices. There is no pricing that considers the size of the channel when basing the cost on linear footage alone. To account for the difference in size between the 3-year LOS and 10-year LOS ditch improvements, a ratio of the average channel bottom widths was determined. This ratio along with the 3-year LOS improvement cost was then used to calculate the 10-year LOS improvement cost of $10.60 per linear foot.

The overhead and contingency costs are the same as those for the main streams in the study. The cost of ROW acquisition is estimated to be approximately 33% of the project subtotal. This value is the average percentage of the ROW costs compared to the total project cost for the main streams in the study. This ROW cost was added to the project subtotal to calculate the total cost for each ditch segment. **Appendix F** provides a summary of the cost estimates for these ditch improvements.

9.3 Benefit-Cost Analysis

A benefit-cost analysis (BCA) of the proposed improvements was also conducted to determine the value of the improvements relative to estimated construction and ROW costs. A traditional benefit-cost (BC) ratio was calculated based on project costs vs. benefits. The benefits were determined by subtracting the present value damages for the proposed project scenarios from the existing present value damage estimates. BC ratios were calculated for the main stems of Mary's Creek, Hickory Slough, Cowart Creek, Chigger Creek, Chocolate Bayou, and Mustang Bayou.

9.3.1 Flood Damage Assessment

As part of the study, a damage assessment was conducted using the HEC-FDA. HEC-FDA is a flood damage reduction analysis software developed by the USACE. This program assists in analyzing the economics of flood risk management measures and formulating a flood risk management plan by visualizing data and results and computing the expected and equivalent annual damages.

The main stem of Hickory Slough, Mary's Creek, Cowart Creek, East Chocolate and West Chocolate Bayou, Chigger Creek, and Mustang Bayou were analyzed for damages. Some tributaries were also analyzed, particularly in the Chocolate Bayou watershed. However, for areas where the main stem of a stream and its tributary had areas of overlapping inundation, the main stem took precedence. The streams were divided into damage reaches, which were defined based on major roadway crossings and are used to calculate the annualized damages in HEC-FDA.

The Harris-Galveston Area Council (HGAC) parcel data was used to create a structure module to estimate annualized and present value damages. For every parcel, a data point representing the structure was placed at the centroid of the parcel and a ground elevation extracted from the chosen LiDAR dataset. In several cases this method placed data points far from the actual home location according to the aerial imagery. These data points were edited manually to better represent the true structure location and elevation. Each structure was assigned to the closest cross section from the appropriate hydraulic model. HEC-FDA uses finished-floor elevations for damage calculations which were assumed at 0.5 feet above the ground elevation for slab structures. Because HGAC does not differentiate between slab and pier structures, all structures were assumed slab for the damage assessment. The only exception to this was where mobile home communities were identified. Mobile home finished-floor elevations were assumed at 3 feet above the ground elevation.

No information about specific structure improvements was provided. The same structure module was used for both existing conditions and future conditions damages. Along with the value of the structures, structure contents were also required for HEC-FDA. Damage curves used for the contents were selected from the appropriate category in the depth damage tables developed by USACE New Orleans District. This calculation does not include costs associated with damaged vehicles or lost productivity.

A 50-year project lifetime was assumed for this flood damage analysis. HEC-FDA requires the assignment of a "Most Likely Future Year" which was defined individually and is the estimated year when full buildout is reached for the watershed. Buildout timelines were discussed with the City and BDD4 and were based on the current level of development in the watershed and development pressure. The assumed project durations in **Table** below were used to develop the "Most Likely Future Year" within HEC-FDA.

Table 13. Most Likely Future Year Estimate

Watershed	Most Likely Future (years)
Hickory Slough	20
Mary's Creek	20
Cowart Creek	30
Chocolate Bayou	40
Chigger Creek	30
Mustang Bayou	30

HEC-FDA uses the results from the hydraulic models to calculate the depth of flooding each structure experiences and calculates annualized damages for the stream segment. A "Without-Project" plan was analyzed and uses the existing conditions hydraulic model. "With-Project" plans were analyzed and use the proposed Alternatives 1 and 2 hydraulic models. HEC-FDA results are calculated and provided as annualized damages for the "Base Year" flows (2018) and the "Most Likely Future Year" flows (See **Table**) based on a total analysis period of 50 years. The present values damages were calculated using the annualized values for the period from the Base Year to the End of Analysis (50 years). Present value calculations used the total analysis period (50 years) and a discount rate of 4%. The structures and resulting damages were assigned to the appropriate watershed. Error! Reference source not found.**A-14C** summarizes the expected damage costs for each major watershed for existing as well as improved conditions.

Table 14A Existing Flood Damage Assessment Summary

Without Project			
Stream	Annualized Damages		Present Value Damages
	Current Year (2018)	Most Likely Future Year	
Mary's Creek	$ 2,059,490	$ 2,207,130	$ 45,407,291
Hickory Slough	$ 1,975,560	$ 2,170,590	$ 43,978,306
East Chocolate Bayou	$ 208,280	$ 522,700	$ 5,005,949
West Chocolate Bayou	$ 758,140	$ 954,220	$ 16,618,040
Chigger Creek	$ 35,720	$ 48,120	$ 819,283
Mustang Bayou	$ 1,645,470	$ 1,899,370	$ 36,411,442
Cowart Creek	$ 1,078,040	$ 1,427,280	$ 24,621,481
Total	**$ 7,760,700**	**$ 9,229,410**	**$ 172,861,792**

Note: This table provides the annualized damage costs for the Base Year flows and the Future flows as well at the calculated present value damage costs for the existing conditions.

The current annualized damages Shown in **Table 14A** are the average damages that are expected from flooding based on the current condition, with none of the recommended flood reduction projects in place. The "Most Likely Future Year" values represent the estimated increase in annualized damages that is expected when each watershed reaches its ultimate (full build-out) condition if no flood reduction projects are implemented.

The Present Value Damages represent the current estimated cost of damages over the 50-year period in today's dollars. As expected, the highest expected damages are in those areas where the watershed is more heavily developed, including Hickory Slough, Mary's Creek, and Mustang Bayou. At the other end of the spectrum, Chigger Creek has limited expected damages due to its sparse development.

Similarly, the values shown in **Table 14B** represent the expected damages if Alternative 1 were fully implemented. The improvements would result in expected damages to $24M, a reduction of nearly $150M over the 50-year analysis period, representing an 86% drop in economic costs due to flooding.

14B: Alternative 1 Flood Damage Assessment Summary

With Project - Alternative 1				
Stream	Level of Service	Annualized Damages		Present Value Damages
		Current Year (2018)	Most Likely Future Year	
Mary's Creek	100-year	$ 397,870	$ 445,640	$ 8,924,075
Hickory Slough	100-year	$ 78,590	$ 93,100	$ 1,802,790
East Chocolate Bayou	100-year	$ 20	$ 970	$ 2,035
West Chocolate Bayou	100-year	$ 550	$ 4,670	$ 18,776
Chigger Creek	100-year	$ -	$ -	$ -
Mustang Bayou	100-year	$ 544,530	$ 712,680	$ 12,401,997
Cowart Creek	100-year	$ 37,230	$ 38,670	$ 805,801
Total		**$ 1,058,790**	**$ 1,295,730**	**$ 23,955,473**

Note: This table provides the annualized damage costs for the Base Year flows and the Future flows as well at the calculated present value costs for improvements associated with Alternative 1.

Table 14C shows a similar pattern for Alternative 2; however, because the level of service for Alternative 2 is not as high as for Alternative 1, the expected damages are a little higher. The improvements would result in expected damages to $38M, a reduction of nearly $135M over the 50-year analysis period, representing an 78% drop in economic costs due to flooding.

Table 14C: Alternative 2 Flood Damage Assessment Summary

With Project - Alternative 2				
Stream	LOS	Annualized Damages		Present Value Damages
		Current Year (2018)	Most Likely Future Year	
Mary's Creek	25-year	$ 782,290	$ 852,350	$ 17,358,126
Hickory Slough	10-year	$ 290,070	$ 321,920	$ 6,482,666
East Chocolate Bayou	10-year	$ 780	$ 960	$ 17,060
West Chocolate Bayou	5-year	$ 22,330	$ 26,470	$ 486,699
Chigger Creek	10-year	$ 310	$ 3,480	$ 19,941
Mustang Bayou	25-year	$ 576,960	$ 704,370	$ 12,927,960
Cowart Creek	10-year	$ 49,600	$ 53,680	$ 1,082,592
Total		**$ 1,722,340**	**$ 1,963,230**	**$ 38,375,044**

Note: This table provides the annualized damage costs for the Base Year flows and the Future flows as well at the calculated present value costs for improvements associated with Alternative 2.

These reduced damages do not account for any reduction in vehicle or infrastructure costs or lost productivity. These reductions compared to the project costs were one of several considerations used when prioritizing projects.

9.3.2 Benefit Cost Ratio (BCR)

A benefit-cost analysis (BCA) of the proposed improvements was conducted to determine the value of the flood reduction improvements relative to estimated construction and ROW costs. Benefits were determined by subtracting the present value damages from the existing conditions present value damages for each scenario. The Benefit-Cost Ratios (BCR) were determined by dividing the benefits by the Estimated Project Costs. The BCR aided in determining economic feasibility and project prioritization. Estimated project costs, benefits and BCRs for each watershed are provided in **Tables 15A and 15B** below for Alternatives 1 and 2, respectively.

Table 15A Alternative 1 Benefit Cost Ratios

Stream	Alternative 1		
	Est. Cost ($M)	Benefits ($M)	BC Ratio
Mary's Creek	$ 294.0	$ 36.5	0.124
Hickory Slough	$ 165.9	$ 42.2	0.254
East Chocolate Bayou	$ 203.4	$ 5.0	0.025
West Chocolate Bayou	$ 339.2	$ 16.6	0.049
Chigger Creek	$ 148.7	$ 0.8	0.006
Mustang Bayou	$ 302.6	$ 24.0	0.079
Cowart Creek	$ 342.9	$ 23.8	0.069
Total	**$ 1,796.7**	**$ 148.9**	

Table 15B. Alternative 2 Benefit Cost Ratios

Stream	Alternative 2		
	Est. Cost (M)	Benefits (M)	BC Ratio
Mary's Creek	$ 176.1	$ 28.0	0.159
Hickory Slough	$ 132.6	$ 37.5	0.283
East Chocolate Bayou	$ 161.1	$ 5.0	0.031
West Chocolate Bayou	$ 303.1	$ 16.1	0.053
Chigger Creek	$ 74.8	$ 0.8	0.011
Mustang Bayou	$ 160.1	$ 23.5	0.147
Cowart Creek	$ 324.5	$ 23.5	0.073
Total	**$ 1,332.3**	**$ 134.5**	

It is important to note that the BCR is only one of the metrics used for project prioritization and are a means of comparison. While many federally-funded (FEMA, USACE) projects are required to have a BCR of 1.0 or greater, those are for a specifically defined project with more detailed information about the damage potential, including surveyed finished floor elevations. For this planning study, the BCR considered large segments, often including multiple projects over a diverse area with information about the area based on LiDAR, not detailed survey information. The value of the BCR from a planning standpoint is that the various alternatives can be compared at a watershed level, which can inform prioritization decisions. A project BCR less than 1.0 doesn’t make the project infeasible or of limited value.

9.3.3 Local Ditch BCR

Neither benefits nor damages were calculated for the local ditches because no modeling was conducted. As such there is no BCR available for these projects. A ranking of the projects based on the existing capacity will be discussed in Section 10.6 as well as in the implementation plan in **Appendix G**.

9.4 Non-Monetary Project Benefits

In addition to the monetary value of the of the benefits for each scenario, non-monetary metrics were examined. The non-monetary metrics considered items such as how many structures are expected to no longer flood, how many acres of land are expected to no longer be inundated, and how many miles of roadway are expected to no longer be inundated by the 10- and 100-year storms. These were considered because the projects with lower B/C ratios are skewed to those areas that have less dense development levels and/or are socio-economically disadvantaged. This metric provides a comparison that is independent of assessed property value.

In addition, the development potential for each watershed was considered. If a watershed has a considerable amount of developable property, then the potential exists that significant development may occur in the watershed, which could influence the project priority. Information regarding each metric is discussed below.

9.4.1 Reduction of Inundated Structures

The number of structures from which inundation was removed was calculated using GIS, the resulting inundation mapped from RAS Mapper, and the HEC-FDA information. The number of structures inundated for Alternative 1 (100-year LOS) and the Alternative 2 (LOS varies) were examined to help estimate the benefit of each scenario. The FDA analysis indicates that approximately 3474 of the structures analyzed are inundated by the 100-year storm. The same analysis showed that inundation is removed from all known structures within the study area for Alternative 1. For Alternative 2 a total reduction of 2783 structures (80%) that are expected to be inundated during a 100-year event throughout the entire study area. This is a significant reduction, but not complete removal given the lower levels of service provided. **Table 16** summarizes the reduction number of structures inundated.

Table 16. Summary of Inundated Structures

Stream	Total	Existing	Alternative 1		Alternative 2	
	Structures	100-year	LOS (YR)	100-year	LOS	100-year
Mary's Creek	12385	947	100	0	25	75
Hickory Slough	3950	438	100	0	10	68
East Chocolate Bayou	1008	34	100	0	10	2
West Chocolate Bayou	1344	335	100	0	5	63
Chigger Creek	308	114	100	0	10	6
Mustang Bayou	1471	497	100	0	25	140
Cowart Creek	4788	1154	100	0	10	353
Total	**25254**	**3519**		**0**		**707**

9.4.2 Reduction of Inundated Acreage

Area of inundation was also considered in the benefits. The total acreage was calculated using GIS and the resulting inundation mapped from RAS Mapper. This acreage includes area within the channel. The streams in the study area show 17230 acres (26.9 sq mi) of inundated area, which accounts for more than 25% of the total project area. With the proposed improvements, a reduction of 83% in the area expected to be inundated was shown for Alternative 1 with most of the streams containing flows up to the 100-year event. Alternative 2 provides approximately 64% reduction in the inundated area for the 100-year event. **Table 17** summarizes the reduction inundated area.

Table 17. Inundated Area Estimates (Acreage)

Stream	Existing	Alternative 1		Alternative 2	
	100-year	LOS (YR)	100-year	LOS (YR)	100-year
Mary's Creek	2858	100	666	25	1038
Hickory Slough	1847	100	236	10	683
East Chocolate Bayou	2209	100	132	10	238
West Chocolate Bayou	1778	100	356	5	997
Chigger Creek	2174	100	82	10	549
Mustang Bayou	2457	100	961	25	1663
Cowart Creek	3907	100	586	10	1373
Total	**17230**		**3019**		**6541**

9.4.3 Reduction of Inundated Roadway Miles

The number of roadway miles flooded during the 100-year storms was also considered. Inundation limits for the 100-year storm for both Alternative 1 and Alternative 2 were compared to all roadways within the watershed to determine the extent of flooding impacts to the transportation network. Approximately 150 miles of roadway are estimated to experience flooding during the 100-year storm. Alternative 1 shows a major reduction, with only 14 miles inundated during the 100-year event while Alternative 2 shows 48 miles inundated for the same event, which is still a significant drop**.** **Table** summarizes the reduction of inundated roadway miles.

Table 18. Roadway Inundation Estimates (Miles)

Stream	Existing	Alternative 1		Alternative 2	
	100-year	LOS (YR)	100-year	LOS (YR)	100-year
Mary's Creek	53.7	100	4.4	25	20.1
Hickory Slough	22.5	100	0.9	10	11.8
East Chocolate Bayou	8.3	100	0.3	10	0.7
West Chocolate Bayou	13.6	100	1.2	5	3.1
Chigger Creek	15.3	100	1.3	10	1.3
Mustang Bayou	11.0	100	4.6	25	5.1
Cowart Creek	28.0	100	2.0	10	7.1
Total	**152.4**		**14.7**		**49.2**

Each of these metrics was considered during the prioritization and implementation process that will be discussed in Section 11.0, along with other considerations. Like BCR, the non-monetary benefits are intended to provide an additional basis of comparison for the alternatives.

9.4.4 Watershed Development Potential

The development potential for each watershed was also evaluated and was used as part of the prioritization process. The area of land available for future development as compared to the total area in each watershed was determined and, the percentage was considered the development potential.

9.4.5 Local Ditch Non-Monetary Benefits

None of the non-monetary metrics were calculated for the local ditches because no modeling was conducted. A ranking of the ditch projects based on the existing capacity will be discussed in Section 10.6 as well as in the implementation plan in **Appendix G**.

10.0 Flood Risk Reduction Recommendations

The recommendations provided in this section represent a combination of several factors, which were discussed in Section 9 above. These include the benefit-cost analysis based on damages calculated using HEC-FDA as well as estimated reductions in the number of inundated structures, acreage of inundated area, and the number of roadway miles inundated. Development potential in the watershed is also considered, based on the proportion of undeveloped property to the total watershed area. One of the primary factors influencing the project recommendations is a Priority Based on Need assessment, which considers several factors related to existing flooding. Each of these factors was considered in the selection, order and Level of Service to be provided in these recommendations. The project selection factors are discussed in this section. Information relating to the project selection is included in the Implementation Plan discussed in Section 11.0 and in **Appendix G**.

10.1 Project Prioritization

Project prioritization for the COP/BDD4 implementation plan relied on a number of factors that looked at costs, damages, needs and challenges, and development potential in the watershed. Each of these factors was considered and the project recommendations were determined. Each of the selection factors is discusses in this section.

10.1.1 Priority Based on Need Assessment

The prioritization based on need considered a handful of criteria for project scoring, including the number of structures in the 10- and 100-year inundation areas, channel level of service, and recorded flood losses in the watershed. Records for the structures impacted by the 10% and 1% AEP storms were taken from the HEC-FDA information and were used to set scoring ranges for the prioritization. The 'Current Level of Service' was based on the modeling developed as part of the Pearland/BDD4 MDP. In addition, single FEMA claims as well as FEMA repetitive loss information were utilized in the scoring. **Table 19** shows the scoring matrix for the projects evaluated as part of the MDP.

Table 19. Prioritization Weighting Factors

Studied Stream Weighting	
Criteria	**Weight**
Structure Inventory -10% (10 Year)	0.3
Structure Inventory -1% (100 Year)	0.1
Level of Service	0.3
FEMA Repetitive Loss	0.2
Historical Flooding (FEMA Single)	0.1

Table 20: Priority Based on Need Assessment

Channel Name	Channel Segment	Structures Impacted by 10% AEP Event	Structures Impacted by 1% AEP Event	Current Level of Service	FEMA Repetitive Loss Claims	Historical Flood Claims	Weighted Average	Rounded Score
Cannon Ditch	Segment 2	4	4	4	1	1	3.10	3
	Segment 3	0	1	4	1	0	1.50	2
	Segment 4	0	1	4	0	0	1.30	1
Chigger Creek	Chigger - Bypass C1	2	2	4	0	0	2.00	2
	Chigger - Bypass C2	0	2	4	0	0	1.40	1
	Chigger - Upper	0	0	4	0	0	1.20	1
	Old Chigger - U/S	2	2	3	0	0	1.70	2
	Old Chigger - D/S	0	0	2	0	0	0.60	1
Cowart Creek	Segment 16	4	3	4	2	1	3.20	3
	Segment 17	0	1	4	2	0	1.70	2
	Segment 19	2	3	1	2	0	1.60	2
	Segment 18	0	0	1	0	0	0.30	0
East Chocolate Bayou	E103	3	2	4	0	0	2.30	2
	Rodeo Palms - U/S	2	2	4	0	0	2.00	2
	Rodeo Palms - D/S	2	2	4	0	0	2.00	2
	East Chocolate	0	0	4	0	0	1.20	1
Hickory Slough	Upper	3	3	4	0	2	2.60	3
	Middle	4	4	3	2	3	3.20	3
	Lower	3	3	3	4	4	3.30	3
Mary's Creek	Upper	1	4	2	3	4	2.30	2
	Middle	2	4	2	4	4	2.80	3
	Lower	3	4	2	4	4	3.10	3
Mustang Bayou	Upper	4	4	4	0	0	2.80	3
	Middle	4	3	4	0	0	2.70	3
	Lower	2	2	4	0	0	2.00	2
West Chocolate Bayou	Cold McCutchen - U/S	4	3	4	0	0	2.70	3
	Cold McCutchen - D/S	3	2	4	0	0	2.30	2
	West Chocolate	3	3	4	0	0	2.40	2
	CR 383 Ditch	4	3	4	0	0	2.70	3

Table 20 shows the scoring matrix for the projects evaluated as part of the MDP. Priority Based on need scores ranged from a high of 3.3 on Hickory Slough to a low of 0.3 on Cowart Creek. Different weights were assigned to each of the criteria as shown in Table 5.1.A below. The weighting can be adjusted in the future based on the needs of the City and/or BDD4; however, the weights shown were used for the current prioritization.

10.1.2 Flood Reduction Benefits

In addition to the Priority Based on Need assessment, additional flood mitigation benefits were considered in the prioritization. The reduction of inundated structures, reduction in acreage of inundation, and reduction in miles of roadway inundation were considered. Specific information regarding those reductions is provided below. Alternative 1, which provides 100-year LOS, show the removal of inundation from all structures up to the 100-year. While there are still quite a few structures expected to experience some flooding inundated for the 100-year, Alternative 2 provides a reduction of nearly over 2230 structures (81%) that are expected to be inundated during a 100-year event.

There is a substantial reduction in the area expected to be inundated for both the 10-year and 100-year events. Alternative, which provide 100-year LOS, show the greatest reduction of inundation area, with flow up to the 100-year being contained in the channel. Alternative 2 provides a substantial reduction of inundated area as well, containing the 10-year within the channel and allowing for a 36% reduction in the inundated area for the 100-year event.

Approximately 128 miles of roadway are estimated to experience flooding during the 100-year storm and nearly 33 miles during the 10-year event for the current drainage system. Alternative 1 would remove inundation from more than 28 miles of roadway for the 10-year storm and almost 115 miles for the 100-year event throughout the entire study area. Alternative 2 would result in inundation being removed for more than 27 miles for the 10-year storm and approximately 85 miles for the 100-year storm.

10.1.3 Development Potential

The future development potential of the watersheds were also included in the prioritization. The area of land available for future development as compared to the total area in each watershed was determined and, the percentage was considered the development potential. Watersheds with more currently undeveloped land show a greater potential for future development and get ranked higher than those watersheds that are currently densely developed. The Most Likely Future Year, which was determined by COP/BDD4 and Halff, is the predicted year by which projects would be completed, was also used in the prioritization.

10.1.4 Prioritization Scoring

Each of the factors discussed above were combined and weighted to determine an overall score for the various projects. Each parameter examined was assigned a ranking 0 through 4, and each was weighted according to **Table 21** to determine the overall project ranking. Scoring weights were varied with the greatest emphasis on the priority based on need at 40%. The BC Ratio and other flood reduction metrics made up about 45%, with the development potential accounting for the last 15%. The scoring system is set up to allow for changes to the weighting of each category if needed.

Table 21 – Prioritization Parameter Weights

Parameter	Weight Factor
Priority Based on Need Score	0.40
BC Ratio	0.15
Reduction in Inundated Structures	0.15
Area of Inundation Removed	0.10
Reduction in Inundated Roadway Miles	0.05
Development Potential	0.10
Most Likely Future Year	0.05

Based on the scoring, the projects were divided into priority tiers. The scoring and tier classifications are provided in **Table 22**. More detail is provided in the Implementation Plan in **Appendix G**.

Based on the weighted scores, the Tier 1 (top 6), Tier 2 (Next 4), and Tier 3 (Last 5) ranked projects were identified. The remaining projects are classified as Tier 4. Tier 1 project scores ranged from a 2.8 to 2.6 out of a maximum 4.0. Several of the Tier 1 projects are in the Mary's Creek and Hickory Slough watersheds, likely because the highest concentration of structures is along the main stem of these channels. Tier 2 projects ranged from 2.5 to 2.1. The Tier 3 projects that round out the top 15 have a scoring range between 2.0 and 1.7. Additional projects have been evaluated and a cost determined, but their priority is lower.

HALFF

Table 22 - City of Pearland and BDD4 Project Priority

Channel Name	Channel Segment	Priority Based on Need Score	BC Ratio	Structures Removed	Area of Inundation Removed	Roadway Miles Removed	Development Potential	Most Likely Future Year	Total Weighted Score	Rounded Score
			100-year	100-year	100-year	100-year				
Cannon Ditch	Segment 2	3.10	0.00	4.00	4.00	2.00	2.00	1.00	2.59	3
	Segment 3	1.50	4.00	0.00	0.00	0.00	2.00	1.00	1.45	1
	Segment 4	1.30	0.00	0.00	0.00	0.00	2.00	1.00	0.77	1
Chigger Creek	Chigger - Bypass C1	2.00	0.00	0.00	2.00	1.00	2.00	1.00	1.30	1
	Chigger - Bypass C2	1.40	0.00	1.00	3.00	3.00	2.00	1.00	1.41	1
	Chigger - Upper	1.20	0.00	1.00	1.00	2.00	2.00	1.00	1.08	1
	Old Chigger - U/S	1.70	0.00	1.00	1.00	1.00	2.00	1.00	1.23	1
	Old Chigger - D/S	0.60	0.00	0.00	0.00	1.00	2.00	1.00	0.54	1
Cowart Creek	Segment 16	3.20	4.00	2.00	2.00	1.00	2.00	1.00	2.68	3
	Segment 17	1.70	0.00	0.00	0.00	0.00	2.00	1.00	0.93	1
	Segment 19	1.60	1.00	0.00	0.00	0.00	2.00	1.00	1.04	1
	Segment 18	0.30	0.00	0.00	1.00	1.00	2.00	1.00	0.52	1
East Chocolate Bayou	E103	2.30	0.00	0.00	4.00	2.00	3.00	0.00	1.72	2
	Rodeo Palms - U/S	2.00	0.00	1.00	2.00	2.00	3.00	0.00	1.55	2
	Rodeo Palms - D/S	2.00	0.00	1.00	1.00	0.00	3.00	0.00	1.35	1
	East Chocolate	1.20	0.00	0.00	0.00	0.00	3.00	0.00	0.78	1
Hickory Slough	Upper	2.60	0.00	3.00	1.00	2.00	0.00	2.00	1.79	2
	Middle	3.20	3.00	3.00	4.00	3.00	0.00	2.00	2.83	3
	Lower	3.30	0.00	2.00	2.00	4.00	0.00	2.00	2.12	2
Mary's Creek	Upper	2.30	3.00	4.00	3.00	4.00	0.00	2.00	2.57	3
	Middle	2.80	1.00	4.00	4.00	4.00	0.00	2.00	2.57	3
	Lower	3.10	0.00	3.00	3.00	4.00	0.00	2.00	2.29	2
Mustang Bayou	Upper	2.80	0.00	4.00	4.00	3.00	2.00	1.00	2.52	3
	Middle	2.70	2.00	2.00	3.00	0.00	2.00	1.00	2.23	2
	Lower	2.00	0.00	0.00	1.00	0.00	2.00	1.00	1.15	1
West Chocolate Bayou	Cold McCutchen - U/S	2.70	3.00	3.00	2.00	2.00	4.00	0.00	2.68	3
	Cold McCutchen - D/S	2.30	0.00	1.00	2.00	1.00	4.00	0.00	1.72	2
	West Chocolate	2.40	0.00	2.00	2.00	1.00	4.00	0.00	1.91	2
	CR 383 Ditch	2.70	0.00	1.00	3.00	1.00	4.00	0.00	1.98	2

Tier 1 (Top 6 Priority) Tier 2 (Top 10 Priority) Tier 3 (Top 15 Priority) Teir 4 (Lowest Priority)

10.2 Tier 1 Project Rankings

Tier 1 projects include those that were ranked between 1 and 6 based on the Priority Based on Need assessment score. The projects scored between 2.57 and 2.83 out of a possible maximum score of 4.0 and a minimum score of 0.0. These projects are classified as Large CIP.

10.2.1 Hickory Slough (Cullen Boulevard to Garden Road)

PROJECT RECOMMENDATIONS: Construct channel conveyance improvements that provide 100-year LOS (Alternative 1) along the channel and associated mitigation. **Priority Score: 2.83**

PROJECT DESCRIPTION: The project includes channel conveyance improvements from Roy Road to Garden Road. The channel conveyance improvements and detention will contain the 100-year inundation and remove inundation from all structures for the 10- and 100-year event. Project specifics include:

- Trapezoidal channel with 30 ft bottom width and 4:1 side slope; channel depth 11 ft
- Channel ROW of 170 ft
- Approximately 1010 ac-ft of stormwater detention needed, likely split into multiple basins (~ 130 acres)
- Bridge Replacement: Private Crossing and CR115

PROJECT BENEFITS

- Remove inundation from all the structures for 100-yr and 10-yr
- Contain the 100-year future conditions flows within channel
- Estimated reduction of $36.5 M in present value damages

PROJECT CHALLENGES/CONSIDERATIONS:

- Potential wetlands south of channel that could require permitting and mitigation if they are impacted
- Availability of property; Currently heavily developed and would be difficult to acquire ROW without impacting current development

10.2.2 Cowart Creek (Wells Drive to BNSF Railroad)

PROJECT RECOMMENDATIONS: Construct channel conveyance improvements that provide 10-year LOS (Alternative 2) along the channel and associated mitigation. **Priority Score: 2.68**

PROJECT DESCRIPTION: The project includes channel conveyance improvements from XS 45221 which is ~330 ft south of Bailey Rd and Wells Dr intersection to BNSF railroad. The Alternative 2 (10-year LOS) channel conveyance improvements will provide a significant reduction in the inundated area and remove inundation from all the structures currently estimated to be flooded by the 100-year and 10-year event. Project specifics include:

- Trapezoidal channel with 40 ft bottom width and 4:1 side slope; channel depth 11-16 ft (Alternative 2)
- Channel ROW range from 115 - 185 ft (10-yr LOS).
- Bridge Replacement: Private Crossing and CR115

PROJECT BENEFITS

- Remove inundation from all the structures for 100-yr and 10-yr
- 85+% reduction for 100-year inundation
- Estimated reduction of $10 M in present value damages

PROJECT CHALLENGES/CONSIDERATIONS:

- Railroad bridge replacements will require coordination with railroad authority

10.2.3 West Chocolate Bayou – Cold River Ranch Ditch (Upstream of Hwy 6)

PROJECT RECOMMENDATIONS: Construct regional detention and channel conveyance improvements that provide a 100-year LOS (Alternative 1) along the channel. Acquire approximately 55 acres of property for mitigation. **Priority Score: 2.68**

PROJECT DESCRIPTION: The project includes trapezoidal channel conveyance improvements, from Rio Lindo Street to Hwy 6, and stormwater detention. The Alternative 1 (100-year LOS) channel conveyance improvements will provide a significant reduction in the inundated area and remove inundation from all structures currently estimated to be flooded by the 100-year event and the 10-year event. Project specifics include:

- Trapezoidal channel with 70 ft bottom width and 3:1 side slope; channel depth 6-7 ft
- Approximately 270 ac-ft of stormwater detention needed, likely split into multiple basins (~55 acres)
- Channel ROW range from 170 - 180 ft
- Bridge Replacement – Rio Lindo Street, Rio Bravo Street, Hwy 6, and Private crossings

PROJECT BENEFITS

- Remove inundation from up to 104 structures (10-yr) and 128 structures (100-yr)
- Contain the 100-year future conditions flows within channel
- Estimated reduction of $12.6 M in present value damages

PROJECT CHALLENGES/CONSIDERATIONS:

- Bridge replacement will require coordination with TXDOT
- Natural gas lines cross Cold River Ranch Ditch on downstream of CR 714

10.2.4 Cannon Ditch (Pearland Site Road to Amoco Industrial Street)

PROJECT RECOMMENDATIONS: Construct channel conveyance improvements that provide a 100-year LOS (Alternative 1) along the channel and associated mitigation. Acquire approximately 138 acres of property for mitigation. **Priority Score: 2.59**

PROJECT DESCRIPTION: The project includes trapezoidal channel conveyance improvements from the confluence of Cannon Ditch and C101-12-03 to the railroad crossing near Amoco Industrial Street. The channel conveyance improvements and detention will contain the 100-year inundation and remove inundation from all structures for the 10- and 100-year event. Project specifics include:

- Trapezoidal channel with 20 ft bottom width and 4:1 side slope; channel depth 8-9 ft
- Approximately 980 ac-ft of stormwater detention needed
- Channel ROW range from 105 - 120 ft
- Bridge Replacement: 3 private crossings and Amoco St

PROJECT BENEFITS

- Remove inundation from up to 272 structures (10-yr) and 353 structures (100-yr)
- Contain the 100-year future conditions flows within channel
- Estimated reduction of $2 M in present value damages
- Facilitates improvements to Trevino Ditch (C101-00-00)

PROJECT CHALLENGES/CONSIDERATIONS:

- Railroad bridge replacements will require coordination with railroad authority
- Multiple pipelines cross the channel

10.2.5 Mary's Creek (Confluence with B129-01-00 to McLean Road)

PROJECT RECOMMENDATIONS: Construct regional detention and channel conveyance improvements that provide a 25-year LOS (Alternative 2) along the channel. Acquire approximately 25 acres of property for mitigation. **Priority Score: 2.57**

PROJECT DESCRIPTION: The project includes trapezoidal channel conveyance improvements, from confluence with B129-01-00 to McLean Road, and stormwater detention. The Alternative 2 (25-year LOS) channel conveyance improvements will provide a significant reduction in the inundated area and remove inundation from 249 of 251 structures currently estimated to be flooded by the 100-year event and 2 structures for the 10-year event. Project specifics include:

- Trapezoidal channel with 30 ft bottom width and 3:1 side slope; channel depth 12-15 ft
- Approximately 240 ac-ft of stormwater detention needed (~25 acres)
- Channel ROW range from 160 – 250 ft
- Bridge Replacement – Manvel Road, Magnolia Street, Harkey Road, and McLean Road

PROJECT BENEFITS

- Remove inundation from up to 2 structures (10-yr) and 249 structures (100-yr)
- Significant reduction for 100-year inundation
- Estimated reduction of $18 M in present value damages

PROJECT CHALLENGES/CONSIDERATIONS:

- Availability of property; Currently heavily developed and would be difficult to acquire ROW without impacting current development
- Several natural gas line crossings

10.2.6 Mary's Creek (Magnolia Drive to SH 35)

PROJECT RECOMMENDATIONS: Construct regional detention and channel conveyance improvements that provide a 25-year LOS (Alternative 2) along the channel. Acquire approximately 71 acres of property for mitigation. **Priority Score: 2.57**

PROJECT DESCRIPTION: The project includes channel conveyance improvements from Magnolia Drive to Highway 35 and detention pond. The Alternative 2 (25-year LOS) channel conveyance improvements will provide a significant reduction in the inundated area and remove inundation from 445 of 456 structures currently estimated to be flooded by the 100-year event and all the structures for the 10-year event. Project specifics include:

- Trapezoidal channel with 100ft bottom width and 3:1 side slope; channel depth 13-16 ft
- Approximately 1000 ac-ft of stormwater detention needed, likely split into multiple basins (~70 acres)
- Channel ROW range from 160 - 250 ft
- Bridge Replacement – Harkey Road, McLean Road, Pedestrian Bridge, Veterans Drive, and AT&SF Railroad

PROJECT BENEFITS

- Remove inundation from up to 3 structures (10-yr) and 445 structures (100-yr)
- 75+% reduction for 100-year inundation
- Estimated reduction of $6.1 M in present value damages

PROJECT CHALLENGES/CONSIDERATIONS:

- Potential wetlands along channel that could require permitting and mitigation if they are impacted
- Railroad bridge replacements will require coordination with railroad authority
- Availability of property; Currently heavily developed and would be difficult to acquire ROW without impacting current development

10.3 Tier 2 Project Rankings

Tier 2 projects include those that were ranked between 7 and 10 based on the Priority Based on Need assessment score, which ranges from 2.12 to 2.52. These projects are classified as Large CIP.

10.3.1 Mustang Bayou (CR 521 to Airline Road)

PROJECT RECOMMENDATIONS: Construct regional detention and channel conveyance improvements that provide a 25-year LOS (Alternative 2) along the channel. Acquire approximately 178 acres of property for mitigation. **Priority Score: 2.52**

PROJECT DESCRIPTION: The project includes trapezoidal channel conveyance improvements, from Almeda Road downstream to Airline Road, and stormwater detention. The Alternative 2 (25-year LOS) channel conveyance improvements will provide a significant reduction in the inundated area and remove inundation from 278 of 393 structures currently estimated to be flooded by the 100-year event and 144 structures for the 10-year event. Due to restriction of land availability, improvements are limited along Mustang Bayou. Project specifics include:

- Trapezoidal channel with 100ft bottom width and 3:1 side slope; channel depth 5-8 ft
- Approximately 890 ac-ft of stormwater detention needed, likely split into multiple basins (~180 acres)
- Channel ROW range from 200 - 240 ft
- Bridge Replacement – CR 564, CR 48, and private crossings

PROJECT BENEFITS

- Remove inundation from up to 144 structures (10-yr) and 278 structures (100-yr)
- 55% reduction for 100-year inundation
- Estimated reduction of $4.5 M in present value damages

PROJECT CHALLENGES/CONSIDERATIONS:

- Wetlands along the channel may require permitting and mitigation
- Availability of property; Several large ponds already exist and would be difficult to acquire ROW without impacting current development
- Natural gas line crosses Mustang Bayou downstream of CR 564

10.3.2 *Mary's Creek (Downstream of SH 35)*

PROJECT RECOMMENDATIONS: Construct regional detention and channel conveyance improvements that provide a 25-year LOS (Alternative 2) along the channel. Acquire approximately 140 acres of property for mitigation. **Priority Score: 2.29**

PROJECT DESCRIPTION: The project includes trapezoidal channel conveyance improvements, from SH 35 downstream to approximately 500 feet downstream of Pearland Parkway, and stormwater detention. The Alternative 2 (25-year LOS) channel conveyance improvements will provide a significant reduction in the inundated are and remove inundation from 178 of 240 structures currently estimated to be flooded by the 100-year event and 19 structures for the 10-year event. Project specifics include:

- Trapezoidal channel with 40 ft bottom width and 3:1 side slope; channel depth 15-17 ft
- Approximately 1670 ac-ft of stormwater detention needed, likely split into multiple basins (~140 acres)
- Channel ROW range from 170 - 320 ft
- Bridge Replacement – Highway 35, Old Alvin Road, Pearland Parkway (upstream), Pearland Parkway (downstream), John Lizer Road, Liberty Drive, and Longherridge Drive

PROJECT BENEFITS

- Remove inundation from up 19 structures (10-yr) and 178 structures (100-yr)
- Significant reduction in 100-year inundation
- Estimated reduction of $3.6 M in present value damages

PROJECT CHALLENGES/CONSIDERATIONS:

- Availability of property; Currently heavily developed and would be difficult to acquire ROW without impacting current development
- Several bridge replacements will require coordination with TXDOT
- Natural gas line crosses the Mary's Creek and Mary's Creek Bypass on downstream of Dixie Farm Road

10.3.3 Mustang Bayou (Airline Road to SH 288)

PROJECT RECOMMENDATIONS: Construct regional detention and channel conveyance improvements that provide a 25-year LOS (Alternative 2) along the channel. Acquire approximately 165 acres of property for mitigation. **Priority Score: 2.23**

PROJECT DESCRIPTION: The project includes trapezoidal channel conveyance improvements, from Airline Road downstream to SH 288, and stormwater detention. The Alternative 2 (25-year LOS) channel conveyance improvements will provide a significant reduction in the inundated area and remove inundation from 79 of 96 structures currently estimated to be flooded by the 100-year event and 54 structures for the 10-year event. Project specifics include:

- Trapezoidal channel with 100ft bottom width and 3:1 side slope; channel depth 8-13 ft
- Approximately 1070 ac-ft of stormwater detention needed, likely split into multiple basins (~165 acres)
- Channel ROW range from 240 - 260 ft
- Bridge Replacement – CR 84 and SH 288

PROJECT BENEFITS

- Remove inundation from up to 54 structures (10-yr) and 79 structures (100-yr)
- 55% reduction for 100-year inundation
- Estimated reduction of $19 M in present value damages

PROJECT CHALLENGES/CONSIDERATIONS:

- Wetlands south of the channel may require permitting and mitigation
- Availability of property; Much of the area north of the channel is highly developed

10.3.4 Hickory Slough (Garden Road to SH 35)

PROJECT RECOMMENDATIONS: Construct channel conveyance improvements that provide 10-year LOS (Alternative 2) along the channel and associated mitigation. **Priority Score: 2.12**

PROJECT DESCRIPTION: The project includes channel conveyance improvements from Garden Road to SH 35. The channel conveyance improvements and associated mitigation will provide a significant reduction in the inundated area and remove inundation from 68 of 79 structures currently estimated to be flooded by the 100-year event and 22 structures for the 10-year event. Project specifics include:

- Trapezoidal channel with 30 ft bottom width and 4:1 side slope; channel depth 11-13 ft
- Channel ROW range from 140 - 170 ft
- Approximately 1310 ac-ft of stormwater detention needed, likely split into multiple basins (~ 170 acres)
- Bridge Replacement: Mykawa Rd, Hatfield Rd, Oday Rd, and Garden Rd

PROJECT BENEFITS

- Remove inundation from up 22 structures (10-yr) and 68 structures (100-yr)
- Significant reduction in 100-year inundation
- Estimated reduction of $550 K in present value damages

PROJECT CHALLENGES/CONSIDERATIONS:

- Potential wetlands downstream of SH35 that could require permitting and mitigation if they are impacted
- Availability of property; Currently heavily developed and would be difficult to acquire ROW without impacting current development

10.4 Tier 3 Project Rankings

Tier 3 projects include those that were ranked between 11 and 15 based on the Priority Based on Need assessment score. The projects ranked between 1.70 and 2.00. These projects are classified as Reserve CIP.

10.4.1 West Chocolate Bayou – CR 383 Ditch

PROJECT RECOMMENDATIONS: Construct regional detention and channel conveyance improvements that provide a 5-year LOS (Alternative 2) along the channel. Acquire approximately 268 acres of property for mitigation. **Priority Score: 1.98**

PROJECT DESCRIPTION: The project includes trapezoidal channel conveyance improvements, from upstream end near confluence with E101-02-00 to confluence with West Fork of Chocolate Bayou, and stormwater detention. The Alternative 2 (5-year LOS) channel conveyance improvements will provide a significant reduction in the inundated area and remove inundation from 93 of 94 structures currently estimated to be flooded by the 100-year event and 91 structures for the 10-year event. Project specifics include:

- Trapezoidal channel with 60 ft bottom width and 3:1 side slope; channel depth 8-9 ft
- Approximately 1260 ac-ft of stormwater detention needed, likely split into multiple basins (~270 acres)
- Channel ROW is 190 ft
- Bridge Replacement – Hwy 6, Oak Street, and Railroad at Oak Street
- Remove siphon at CWA canal crossing

PROJECT BENEFITS

- Remove inundation from up to 91 structures (10-yr) and 93 structures (100-yr)
- Significant reduction for 100-year inundation
- Estimated reduction of $955 K in present value damages

PROJECT CHALLENGES/CONSIDERATIONS:

- Bridge replacement will require coordination with TXDOT
- Coordination with CWA for siphon removal
- Natural gas lines crossing at upstream end

10.4.2 West Fork Chocolate Bayou

PROJECT RECOMMENDATIONS: Construct regional detention and channel conveyance improvements that provide a 5-year LOS (Alternative 2) along the channel. Acquire approximately 536 acres of property for mitigation. **Priority Score: 1.91**

PROJECT DESCRIPTION: The project includes trapezoidal channel conveyance improvements, from upstream end near confluence with E101-02-00 to confluence with West Fork of Chocolate Bayou, and stormwater detention. The Alternative 2 (5-year LOS) channel conveyance improvements will provide a significant reduction in the inundated area and remove inundation from 40 of 46 structures currently estimated to be flooded by the 100-year event and 38 structures for the 10-year event. Project specifics include:

- Trapezoidal channel with 80 ft bottom width and 3:1 side slope; channel depth 8-9 ft
- Approximately 3700 ac-ft of stormwater detention needed, likely split into multiple basins (~540 acres)
- Channel ROW range from 190 – 260 ft
- Bridge Replacement –CR 383 (Karsten Road)

PROJECT BENEFITS

- Remove inundation from up to 38 structures (10-yr) and 40 structures (100-yr)
- Significant reduction for 100-year inundation
- Estimated reduction of $1.4 M in present value damages

PROJECT CHALLENGES/CONSIDERATIONS:

- Natural gas lines crossing upstream of CR 383

10.4.3 Hickory Slough (CR 94 to Cullen Boulevard)

PROJECT RECOMMENDATIONS: Construct regional detention and channel conveyance improvements that provide a 100-year LOS (Alternative 1) along the channel. Acquire approximately 42 acres of property for mitigation. **Priority Score: 1.79**

PROJECT DESCRIPTION: The project includes trapezoidal channel conveyance improvements, from upstream end near CR 94 (Smith Ranch Road) to confluence with H126-00-00, and stormwater detention. The Alternative 1 (100-year LOS) channel conveyance improvements will provide a significant reduction in the inundated area and remove inundation from all structures currently estimated to be flooded by the 100-year event and the 10-year event. Project specifics include:

- Trapezoidal channel with 15 ft bottom width and 3:1 side slope; channel depth 12-13 ft
- Approximately 280 ac-ft of stormwater detention needed, likely split into multiple basins (~40 acres)
- Channel ROW range from 130 – 170 ft
- Bridge Replacement – Fair Oaks Street, Miller Ranch Road, and Private crossing

PROJECT BENEFITS

- Remove inundation from up to 12 structures (10-yr) and 147 structures (100-yr)
- Contain the 100-year future conditions flows within channel
- Estimated reduction of $5.1 M in present value damages

PROJECT CHALLENGES/CONSIDERATIONS:

- Availability of property; Currently heavily developed and would be difficult to acquire ROW without impacting current development

10.4.4 East Chocolate Bayou – E103-00-00

PROJECT RECOMMENDATIONS: Construct regional detention and channel conveyance improvements that provide a 10-year LOS (Alternative 2) along the channel. Acquire approximately 347 acres of property for mitigation. **Priority Score: 1.72**

PROJECT DESCRIPTION: The project includes trapezoidal channel conveyance improvements, from upstream end near SH 288 to confluence with Rodeo Palms Ditch, and stormwater detention. The Alternative 2 (10-year LOS) channel conveyance improvements will provide a significant reduction in the inundated area and remove inundation from 17 of 17 structures currently estimated to be flooded by the 100-year event and 13 structures for the 10-year event. Project specifics include:

- Trapezoidal channel with 60 ft bottom width and 3:1 side slope; channel depth 4-6 ft
- Approximately 2210 ac-ft of stormwater detention needed, likely split into multiple basins (~350 acres)
- Channel ROW range from 160 – 220 ft
- Bridge Replacement – CR 418, CR 80, CR 81, and Private crossings

PROJECT BENEFITS

- Remove inundation from up to 13 structures (10-yr) and 17 structures (100-yr)
- Significant reduction for 100-year inundation
- Estimated reduction of $750 K in present value damages

PROJECT CHALLENGES/CONSIDERATIONS:

- Land availability; Much of the available land is outside Brazoria County/BDD4 jurisdiction

10.4.5 West Chocolate Bayou – Cold River Ranch Ditch (Downstream of Hwy 6)

PROJECT RECOMMENDATIONS: Construct regional detention and channel conveyance improvements that provide a 5-year LOS (Alternative 2) along the channel. Acquire approximately 10 acres of property for mitigation. **Priority Score: 1.72**

PROJECT DESCRIPTION: The project includes trapezoidal channel conveyance improvements, from Hwy 6 to confluence with West Fork of Chocolate Bayou, and stormwater detention. The Alternative 2 (5-year LOS) channel conveyance improvements will provide a significant reduction in the inundated area and remove inundation from 16 of 22 structures currently estimated to be flooded by the 100-year event and 16 structures for the 10-year event. Project specifics include:

- Trapezoidal channel with 60 ft bottom width and 3:1 side slope; channel depth 7-10 ft
- Approximately 50 ac-ft of stormwater detention needed, likely split into multiple basins (~10 acres)
- Channel ROW range from 170 – 250 ft
- Bridge Replacement – Oak Street, Railroad at Oak Street, Sanders Street,
- Remove siphon at CWA canal crossing

PROJECT BENEFITS

- Remove inundation from up to 16 structures (10-yr) and 16 structures (100-yr)
- Significant reduction for 100-year inundation
- Estimated reduction of $1.3 M in present value damages

PROJECT CHALLENGES/CONSIDERATIONS:

- Railroad bridge replacements will require coordination with railroad authority
- Coordination with CWA for siphon removal

10.5 Tier 4 Project Rankings

Based on the study, there are several additional projects (Tier 4) that could be completed to provide flood reduction. However, the remaining projects scored a 2.0 or less on the priority and are not among the top 15. In general, they are not included because there are very few structures that are subject to damages or they have a better than average level of service; however, they could potentially be built if a grant or partnership opportunity were to present itself. In most cases, the BC Ratios and benefits were very low, making it difficult to justify allocating resources to those areas. The identified projects not included in the recommendations are:

- Chigger Creek (Amoco Dr. to intersection of SH 35 and Greenhouse Rd.)
- Mustang Bayou (Downstream of SH 288)
- East Chocolate Bayou - Rodeo Palms Ditch (Palm Desert Rd. to Hwy 6)
- East Chocolate Bayou - Rodeo Palms Ditch (Hwy 6 to confluence with East Fork Chocolate Bayou)
- Cowart Creek (Railroad at James St. to SH 35)
- Chigger Creek (Ramirez Rd. to downstream confluence with Chigger Bypass)
- Cowart Creek (Confluence near Pearland Regional Airport to confluence near Hastings Friendswood Rd.)
- Cannon Ditch (Amoco Industrial St. to Hastings Cannon Rd.)
- Chigger Creek (Intersection of SH 35 and Greenhouse Rd. to confluence near Chigger Creek Dr.)
- Cannon Ditch (Hastings Cannon Rd. to confluence by confluence near Hastings Friendswood Rd.)
- Chigger Creek (CR 143 to Amoco Dr.)
- East Chocolate Bayou (Bissell Rd. to confluence with Rodeo Palms Ditch near Mason Rd.)
- Chigger Creek (Confluence with downstream end Chigger Bypass to Windsong Ln.)
- Cowart Creek (Confluence near Hastings Friendswood Rd. to confluence with Clear Creek near Deepwood Dr.)

10.6 Ditch Capacity Analysis Rankings

For the over 190 ditch capacity segments throughout the COP/BDD4 study area, a ranking was determined based on the what percentage the existing ditch was undersized. This was based on the existing ditch capacity and the calculated subbasin discharges. These channels would need the most improvement to reach the desired level of service. The top 50 ditch segments were selected as a point for which the City and BDD4 could assess flooding concerns and needs for improvements. **Appendix G.4** provides a table showing the top 50 ditch sections, the proposed ditch top widths, and estimated costs for both the 3-year and 10-year LOS proposed ditches. More detailed cost estimates are provided in **Appendix F** of the main report for all ditch capacity segments.

As with the main channel segments, the local ditches were divided into 2 categories for implementation; Small CIP projects and Small O&M projects. The distinction is based on cost. Small O&M projects are those local ditch projects that are estimated to cost less than $500k for the 3-year LOS. These may be more likely to be implemented by BDD4 staff. Small CIP projects are those local ditch improvements that are expected to cost mode than $500k, with some of them reaching above $4M. **Appendix G.3** provides a series of maps that show which ditches have a potential project. A complete list of projects, including those that are not ranked in the top 50 are provided in **Appendix D.5**. A summary of the local ditch recommendations for both categories is provided in Section 11.0.

11.0 Implementation Plan

As part of the Pearland and Brazoria Drainage District No. 4 Master Drainage Plan Update, an implementation plan was prepared to help prioritize the projects and provide guidance on the size, scope and order of projects moving forward. The plan is intended to be a stand-alone document and, as such, include some of the same information presented in this report including:

- A discussion of the study background and goals
- Some of the limitations of the plan
- Existing Flood Damages
- Flood Reduction Strategies
- Flood Reduction Metrics and Project Prioritization
- Project Recommendations
- A breakdown of recommended projects into smaller projects
- A general timeline for implementation

The implementation plan is based on current conditions and information and will likely need to be adapted over time. The full implementation plan, including project fact sheets for the recommended Large CIP projects, is provided in **Appendix G**. The tables provided below include recommendations for each of the four project categories discussed:

- **Large CIP Projects:** Top 10 scoring main channel segment projects, will need to be phased
- **Reserve CIP Projects:** Main channel projects that rank from 11-15 and may provide benefits
- **Small CIP:** Local ditch projects from the Top 50 that cost more than $500k
- **Small O&M:** Local ditch projects from the Top 50 that cost less than $500k

Each of these project categories should be considered in the CIP planning proceed for both the City of Pearland and BDD4. It should be noted that the Large CIP and Reserve CIP projects will most likely need to be phased in order to implement within budget. The Large CIP fact sheets have a potential phasing breakdown and cost estimate for each of the Top 10 recommended projects.

Table 23 - Large Capital Improvement Project (CIP) Recommendations

PROJECT PRIORITY	WATERSHED SEGMENT	PROJECT DESCRIPTION	PROJECT COSTS (M)			
			CHANNEL	DETENTION	ROW	TOTAL
1	Hickory Slough Middle Segment	**100-year LOS**; Channel modifications from Cullen Blvd. to Garden Rd. and 1010 ac-ft mitigation. Max ROW width of 170 ft.	$6.7	$19.2	$17.3	$43.2
2 †	Cowart Creek Segment 16	**10-year LOS**; Channel modifications from Wells Dr. to BNSF Railroad. Max ROW width of 200 ft.	$2.1	-	$5.2	$7.3
3	West Fork Chocolate Cold River Ranch Ditch	**100-year LOS**; Channel modifications from Rio Lindo St. to Hwy 6 and 580 ac-ft mitigation. Max ROW width of 180 ft.	$6.4	$10.4	$4.2	$21.0
4	Cannon Ditch Segment 2	**100-year LOS**; Channel modifications from Pearland Site Rd. to Amoco Industrial St. and 9800 ac-ft mitigation. Max ROW width of 120 ft.	$4.8	$37.5	$4.2	$46.5
5	Mary's Creek Upper Segment	**25-year LOS**; Channel modifications from B129-01-00 to McLean Rd. and 240 ac-ft mitigation. Max ROW width of 250 ft.	$10.5	$4.5	$7.9	$22.9
6 †	Mary's Creek Middle Segment	**25-year LOS**; Channel modifications from Magnolia Dr. to SH35 and 1000 ac-ft mitigation. Max ROW width of 250 ft.	$10.7	$17.6	$3.1	$31.4
7	Mustang Bayou Upper Segment	**25-year LOS**; Channel modifications from CR521 to Airline Rd and 890 ac-ft mitigation. Max ROW width of 240 ft.	$10.7	$44.4	$46.9	$102.0
8	Mary's Creek Lower Segment	**25-year LOS**; Channel modifications from SH35 to downstream of Pearland Pkwy. and 1670 ac-ft mitigation. Max ROW width of 220 ft.	$14.8	$55.2	$51.8	$121.8
9	Mustang Bayou Middle Segment	**25-year LOS**; Channel modifications from Airline Rd. to SH288 and 1070 ac-ft mitigation. Max ROW width of 260 ft.	$5.8	$31.9	$22.8	$60.5
10	Hickory Slough Lower Segment	**10-year LOS**; Channel modifications from Garden Rd. to SH35 and 1310 ac-ft mitigation. Max ROW width of 170 ft.	$12.4	$24.7	$15.2	$52.3

† Detention is included in downstream segment; however, mitigation will be required for conveyance improvements and should be evaluated in the PER Phase

Table 24 - Reserve Capital Improvement Project (CIP) Recommendations

PROJECT PRIORITY	WATERSHED SEGMENT	PROJECT DESCRIPTION	PROJECT COSTS			
			CHANNEL	DETENTION	ROW	TOTAL
11	West Chocolate Bayou CR 383 Ditch	**5-year LOS**; Channel modifications from E101-02-00 to confluence with West Fork Chocolate Bayou and 1260 ac-ft mitigation. Max ROW width of 190 ft.	$8.90	$27.60	$215.70	$252.20
12	West Fork Chocolate Bayou	**5-year LOS**; Channel modifications from county boundary to confluence with E101-00-00 and 3700 ac-ft mitigation. Max ROW width of 260 ft.	$16.10	$69.50	$17.90	$103.50
13	Hickory Slough Upper Segment	**100-year LOS**; Channel modifications from CR 94 to confluence with H126-00-00 and 280 ac-ft mitigation. Max ROW width of 170 ft.	$2.40	$19.60	$34.70	$56.70
14 †	East Chocolate Bayou E103-00-00	**10-year LOS**; Channel modifications from SH288 to confluence with Rodeo Palms Ditch and 2210 ac-ft mitigation. Max ROW width of 220 ft.	$1.70	-	$0.70	$2.40
15 †	West Fork Chocolate Cold River Ranch Ditch	**5-year LOS**; Channel modifications from Hwy 6 to confluence with West Fork Chocolate Bayou and 50 ac-ft mitigation. Max ROW width of 250 ft.	$8.70	-	$1.20	$9.90

† Detention is included in downstream segment; however, mitigation will be required for conveyance improvements and should be evaluated in the PER Phase

Table 25 - Small Capital Improvement Project (CIP) Recommendations

DITCH PRIORITY	WATERSHED	DITCH	3-YR LOS		10-YR LOS	
			TOP WIDTH	COST	TOP WIDTH	COST
1	Cowart Creek	C123-00-00	56	$ 918,000	66	$ 1,161,000
2	Hickory Slough	H123-00-00	311	$ 3,017,000	451	$ 4,356,000
3	Chocolate Bayou	E100-00-00	72	$ 1,490,000	91	$ 1,946,000
4	Cowart Creek	C118-00-00	37	$ 961,000	41	$ 1,199,000
5	Cowart Creek	C122-00-00	71	$ 1,069,000	83	$ 1,332,000
6	West Chocolate	E101-01-06	66	$ 806,000	80	$ 1,029,000
7	Chigger Creek	J101-02-00	146	$ 2,401,000	171	$ 2,920,000
8	Cowart Creek	C128-00-00	34	$ 671,000	40	$ 864,000
9	Chigger Creek	J102-05-01	50	$ 1,492,000	60	$ 1,910,000
10	Cowart Creek	C120-01-00	26	$ 632,000	26	$ 776,000
11	Cowart Creek	C124-01-00	42	$ 551,000	49	$ 701,000
12	Clear Creek	A105-05-00	83	$ 847,000	101	$ 1,074,000
13	Hickory Slough	H125-02-00	158	$ 718,000	159	$ 772,000
14	Cowart Creek	C107-03-01	35	$ 784,000	39	$ 984,000
15	Mary's Creek	B117-00-00	33	$ 1,545,000	37	$ 1,929,000
16	Hickory Slough	H114-00-00	34	$ 1,124,000	38	$ 1,421,000
17	West Chocolate	E101-01-01	52	$ 648,000	60	$ 810,000
18	Clear Creek	A113-00-00	34	$ 665,000	34	$ 799,000
19	Mary's Creek	B102-01-01	56	$ 499,000	66	$ 631,000
20	Chocolate Bayou	E102-00-00	50	$ 1,009,000	67	$ 1,373,000
21	Clear Creek	A115-00-00	39	$ 1,132,000	44	$ 1,420,000
22	Cowart Creek	C124-00-00	34	$ 669,000	35	$ 805,000
23	Cowart Creek	C119-00-00	28	$ 698,000	30	$ 875,000
24	Hickory Slough	H123-01-00	311	$ 3,017,000	451	$ 4,356,000
25	Clear Creek	A116-00-00	25	$ 870,000	33	$ 1,181,000
26	Cowart Creek	C120-00-00	91	$ 1,216,000	110	$ 1,534,000
27	Cowart Creek	C100-00-00	28	$ 532,000	31	$ 676,000
28	Clear Creek	A111-00-00	31	$ 989,000	34	$ 1,241,000
29	Chigger Creek	J101-02-01	94	$ 1,094,000	114	$ 1,382,000
30	Mary's Creek	B114-01-01	37	$ 660,000	43	$ 843,000
31	Cowart Creek	CR 414 Ditch	21	$ 775,000	23	$ 993,000
32	Cowart Creek	C101-00-00	60	$ 2,659,000	79	$ 3,580,000
33	Chigger Creek	J102-00-00	116	$ 3,312,000	160	$ 4,525,000
34	Hickory Slough	H125-01-00	50	$ 1,141,000	50	$ 1,330,000
35	Hickory Slough	C103-03-00	39	$ 535,000	42	$ 657,000
36	Cowart Creek	Cowart's Creek Ditch	35	$ 784,000	39	$ 984,000

Table 26 - Small O&M Project Recommendations

DITCH PRIORITY	WATERSHED	DITCH	3-YR LOS		10-YR LOS	
			TOP WIDTH	COST	TOP WIDTH	COST
1	Chigger Creek	J101-01-01	61	$ 190,000	139	$ 238,000
2	Chigger Creek	J101-01-00	16	$ 233,000	19	$ 298,000
3	Clear Creek	A122-00-00	34	$ 479,000	35	$ 583,000
4	Chigger Creek	J101-01-01	23	$ 239,000	26	$ 309,000
5	Cowart Creek	C105-01-00	34	$ 77,000	41	$ 100,000
6	Cowart Creek	B102-01-03	33	$ 217,000	38	$ 278,000
7	Cowart Creek	C107-10-01	62	$ 429,000	71	$ 546,000
8	Clear Creek	A121-01-00	42	$ 397,000	50	$ 511,000
9	Cowart Creek	C125-00-00	22	$ 193,000	23	$ 241,000
10	Cowart Creek	C107-01-02	24	$ 244,000	28	$ 319,000
11	Cowart Creek	C107-04-01	31	$ 361,000	34	$ 453,000
12	Hickory Slough	H111-00-00	30	$ 85,000	30	$ 103,000
13	Chocolate Bayou	E100-01-01	56	$ 430,000	72	$ 572,000