Texas Water Development Board

VOLUME 2

2023 REGIONAL FLOOD PLAN
REGION 6
SAN JACINTO

July 2023

PREPARED FOR THE **SAN JACINTO REGIONAL FLOOD PLANNING GROUP**

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Friendswood – Inline and Offline Detention

Results Report for City of Friendswood - Clear Creek Inline & Offline Detention - Bay Area Blvd. Phase I– 063000424

TO: San Jacinto Regional Flood Planning Group

CC: Harris County

Texas Water Development Board

FROM: Ericka Reyes EIT**,** Brian Edmondson, PE, CFM, Maggie Puckett, PE, CFM

SUBJECT: City of Friendswood - Clear Creek Inline & Offline Detention - Bay Area Blvd. Phase I Benefit-Cost Analysis

DATE: 02/23/2023

PROJECT: San Jacinto Regional Flood Plan

The City of Friendswood set out to evaluate flood mitigation projects, including channel improvements and detention basins, to reduce damage from increasingly frequent and heavy rainfall events. Clear Creek is the flooding source the flood mitigation project is set to protect against.

The Texas Water Development Board (TWDB) requires each Flood Mitigation Project (FMP) included in a regional flood plan to have a benefit/cost analysis (BCA) performed. This memorandum documents to benefit cost analysis performed by Freese and Nichols within the regional flood planning process.

Benefit Cost Analysis

TWDB developed the Benefit-Cost Analysis (BCA) Input Tool to facilitate the calculation of flood mitigation benefits from a Flood Mitigation Project (FMP). This tool receives input of existing and proposed conditions to determine expected benefits related to the construction of the FMP in question. The benefits considered in the analysis include, but are not limited to, the reduction of damages to residential structures, commercial structures, and flooded street impacts. The BCA Input Tool was modified to handle larger structural datasets included in the analysis. The BCA Input Tool was used in conjunction with the Federal Emergency Management Agency (FEMA) BCA Toolkit v6.0.0, and an adapted BCA Input tool.

Project Costs

According to the opinion of probable cost of the project, the total construction cost of the project is estimated to be $65.8 million. The annual operations & maintenance cost was assumed to be $10,000. The project was assumed to have a useful life of 30 years. The project cost used in the BCA includes the FM 1959 detention basin ($30 million), Whitcomb Terracing ($7.4 million), Whitcomb detention basin ($17.2 million), Blackhawk Terracing ($1.4 million), and Blackhawk detention basin ($9.8 million). **Figure 1** shows the breakdown of the project and each respective estimated cost. This detailed reference can be found in greater detail in **Appendix A- Friendswood Detention Map.**

Proposed Flood Mitigation Projects:

FM 1959 Detention Basin: 1,700 ac.ft of new storage capacity
ROM Capital Cost: $30M

Whitcomb Terracing: Up to 400 ft
wide, along 5,300 LF of the left bank of Clear Creek
ROM Capital Cost: $7.4M

Whitcomb Detention Basin: 340 ac.ft of new storage capacity
ROM Capital Cost: $17.2M

Blackhawk Terracing: Up to 250 ft wide, along 3,000 LF of the
left bank of Clear Creek
ROM Capital Cost: $1.4M

Blackhawk Detention Basin: Expansion of existing 5 ac
detention pond to include approximately 200 ac.ft of additional
storage capacity
ROM Capital Cost: $9.8M

Figure 1: Proposed Flood Mitigation Projects and their associated costs

Expected Flood Damages without FMP

Building Information

The "Texas Buildings with SVI and Estimated Population (November 2021)" dataset provided by TWDB for Regional Flood Planning was used to determine building sizes and building types. The FMP project team also provided a structural inventory dataset with ability to extract building sizes, but not immediate information on building types. The FMP project team provided structural inventory provided more extensive building data, there was 1,429 more structures in the FMP team provided dataset than in the TWDB provided dataset. The TWDB was still ultimately chosen to determine building sizes and building types due to the detailed data on individual structures. The Finished Floor Elevations (FFE) for all structures was assumed to be 0.5 feet above ground level and number of stories has been factored into group sizing of structures. Based on the provided building types, structures were reclassified as either residential, commercial, industrial, or agricultural. Public buildings were reclassified as commercial structures. Buildings marked as "Vacant or Unknown" in the TWDB dataset were reclassified as agricultural buildings.

There were 9 structures that were identified as being within the detention basins being proposed in the project and included severe increases in flood depth. For these 9 structures the with project depth was assumed to be zero, as it was assumed these structures would also be bought out in the event the detention basin was constructed. **Table 1** calls out the building IDs, for reference, of the structures removed from consideration in structural damages calculated due to being within the proposed detention basins.

Table 1: Buildings within Detention Basins

Building ID	Detention Basin
10930660	FM 1959
10827383	FM 1959
10930662	FM 1959
10930658	FM 1959
10930666	FM 1959
10930664	FM 1959
8888517	Whitcomb
8812440	Whitcomb
8804582	Whitcomb

Green Infrastructure

The detention basins proposed in this project convert forested lands to open green space, this change of habitat was included in the expected benefits of the proposed project. The FM 1959 Detention basin is contained within about 69 acres.

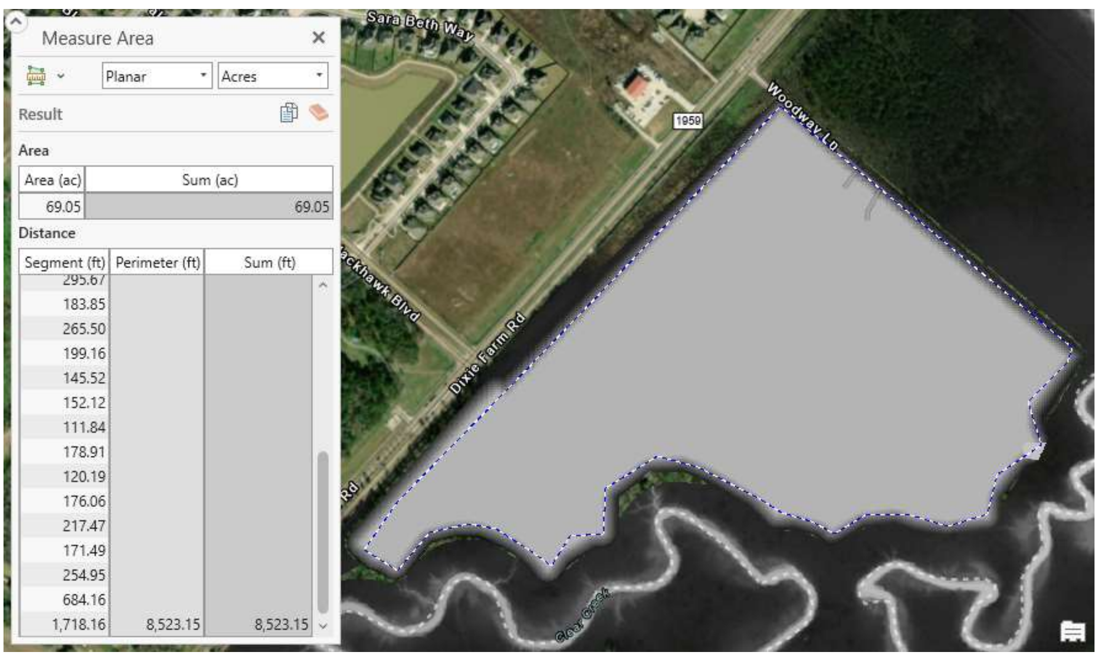

Figure 2: FM 1959 Detention Basin Area

The Whitcomb Detention basin is contained within about 31.7 acres.

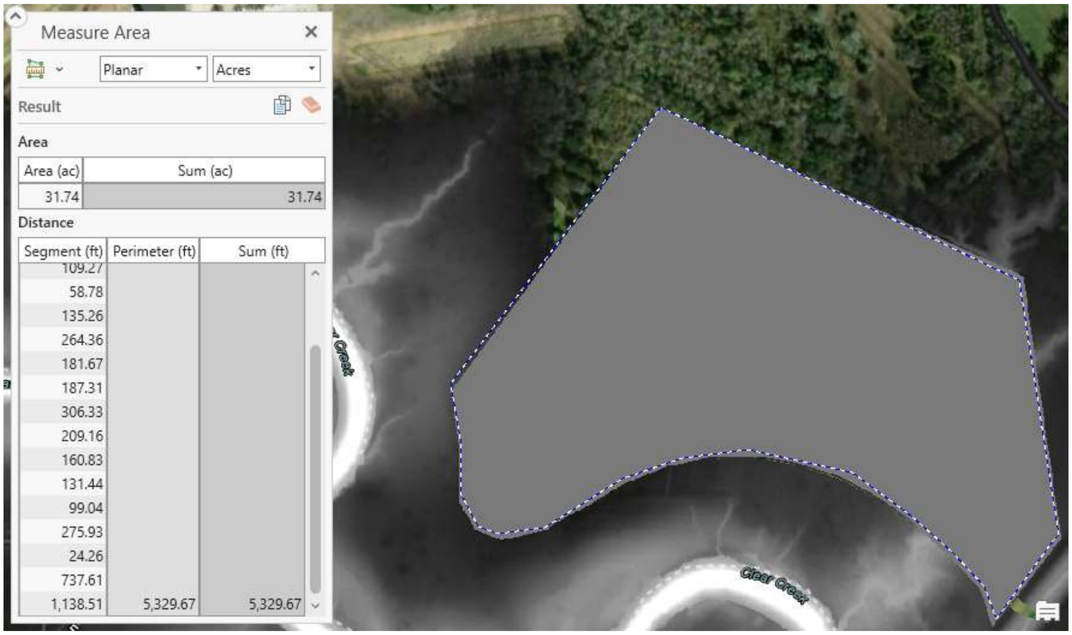

Figure 3: Whitcomb Detention Basin Area

The Blackhawk Detention basin is an extension of an existing 5 acre detention basin. The expansion alone of the detention basin results in 23.9 additional acres of storage area, neglecting the existing 5 acres of storage area.

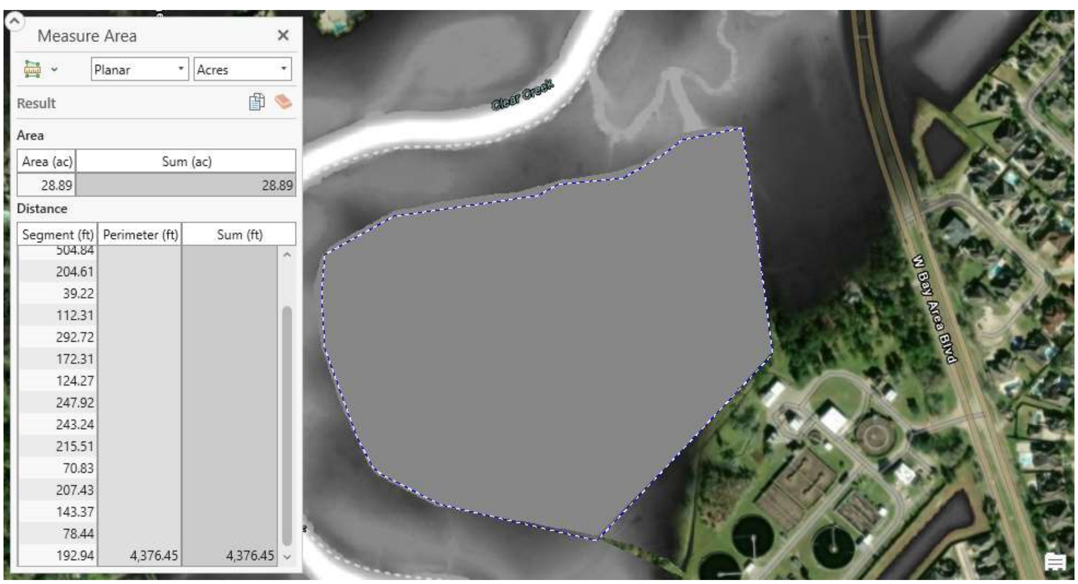

Figure 4: Blackhawk Detention Basin Area

The table below, shows the total detention area created with the addition of the FM 1959, Whitcomb, and Blackhawk Basins.

Table 2: Area in acres per detention basin

Detention	**Acres**
FM 1959 Basin	69.1
Whitcomb Basin	31.7
Blackhawk Basin	23.9
Total	124.7

This creation of green open space for the detention basins was considered as a green infrastructure element for this project. The combined 124.7 acres of detention area removes that land area from a forest habitat and reestablishes the land as green open space. To provide an accurate determination of the benefit, the removal of the forested lands was included in the determination. **Table 3** and **Table 4** show the comparison in determined benefits when the removal of the forests was included.

Table 3: Environmental Benefits- with Forested lands removed included.

Type of Habitat	Acres
Green Open Space	124.7
Riparian	-
Wetlands	-
Forests	-124.7
Marine & Estuary	-
Total Benefits: $1,848,010	

Table 4: Environmental Benefits- without forested lands removed included.

Type of Habitat	Acres
Green Open Space	124.7
Riparian	-
Wetlands	-
Forests	-
Marine & Estuary	-
Total Benefits: $1,980,044	

Flood Hazard Data

The flood depths for each structure within the study areas was determined only for the 1% annual chance event. The baseline and with project damages are included in **Table 5**.

Table 5: Project Impacts by Recurrence Interval

	100 – Year Storm	
	Baseline	With Project
Residential Flood Damage	$3,030,652	$2,662,828
Commercial Flood Damage	$346,863	$348,155
Total Structural Damage	$3,377,515	$3,010,983

Expected Flood Damages After FMP Implementation

For the structures analyzed, the Friendswood Inline & Offline detention FMP results in $45,479 in standard mitigation benefits and $1,848,010 in total net benefits.

Benefit-Cost Summary

The benefit-cost analysis for this project was completed using the FEMA BCA Tool Version 6.0, TWDB BCA tool-kit, and FNI adapted BCA. The final benefit-cost ratio (BCR) with standard benefits is 0.00 and 0.03 with recreation. **Figure 5**, on the following page, shows the breakdown of the final BCR.

Input Into BCA Toolkit		
Project Useful Life	**30 years**	
Event Damages	**Baseline**	**Project**
100 - year storm	**$3,377,515**	**$3,010,983**
500 - year storm	**$0**	**$0**
Results from BCA Toolkit:		
Total Standard Mitigation Benefits	$45,479	
Other Benefits (Not Recreation)	$1,848,010	
Recreation Benefits	$0	
Discounted Total Costs	$65,924,090	
Net Benefits	$1,893,489	
Net Benefits with Recreation	$1,893,489	
Final BCR	**0.00**	
Final BCR with Recreation	**0.03**	

Figure 5: BCA for City of Friendswood - Clear Creek Inline & Offline Detention

BCA Appendices

Appendix A- Friendswood Detention Map

FREESE NICHOLS
801 Cherry Street, Suite 2800
Fort Worth, TX 76102
(P) 817-735-7300 (F) 817-735-7491

100-year Water Surface Elevation Changes

FM 1959, Whitcomb, and Blackhawk Inline and Offline Detention

FN JOB NO	FSW21628
FILE	Exb1_FSWDetention
DATE	8/9/2022
SCALE	1:12,000
DRAFTED	90206

EXHIBIT 1

Appendix 5-4K:
Keegans Bayou Flood Risk Reduction Project

TORRES & ASSOCIATES, LLC
ENGINEERS | SCIENTISTS | PROFESSIONALS

MEMORANDUM

DATE: February 28th, 2023

TO: San Jacinto Regional Flood Planning Group

CC: Harris County Flood Control District; Texas Water Development Board

FROM: Evan Adrian, PE, CFM, ENV SP; Jacob Torres, PhD, PE, CFM, D.WRE; Cristian Ayala, EIT

PROJECT NO.: 10-220120-00

PROJECT: TWDB San Jacinto Regional Flood Plan

SUBJECT: Keegans Bayou Flood Risk Reduction Project Benefit-Cost Analysis

The Flood Risk Reduction Project for the Keegans Bayou (HCFCD Unit ID. D118-00-00) was developed by Huitt-Zollars, Inc. on behalf of the Harris County Flood Control District (HCFCD). Keegans Bayou is a tributary of Brays Bayou, encompassing about 19 square miles, and is primarily a residential area with some commercial and industrial development. The proposed project improvements include widening sections of the Keegans Bayou main channel with a total detention volume of 2,257 acre-feet. The project could significantly increase the conveyance capacity of Keegans Bayou and provide the required detention to offset impacts from peak flow increases due to the improved conveyance capacity. The Feasibility Study Plan is included as **Appendix 1** and includes a more detailed breakdown of the proposed project.

The Texas Water Development Board (TWDB) requires each Flood Mitigation Project (FMP) included in a regional flood plan to have a benefit/cost analysis (BCA) performed. The final engineering report prepared by Huitt-Zollars did not include a BCA. This memorandum documents a benefit cost analysis performed for the Keegans Bayou Flood Risk Reduction Project by Torres and Associates within the regional flood planning process.

Benefit Cost Analysis Methodology

TWDB developed the Benefit-Cost Analysis (BCA) Input Tool to facilitate the calculation of flood mitigation benefits due to FMP. The TWDB BCA Input Tool is provided as **Appendix 2**. This tool receives input of existing and proposed conditions to determine expected benefits related to the construction of the FMP in question. The benefits considered in the analysis include the reduction in damages to residential structures, commercial structures, and social benefits. The BCA Input Tool was modified to handle the nearly 20,000 structures included in the analysis. The modified BCA Input Tool is provided as **Appendix 3**. The BCA Input Tool was used in conjunction with the Federal Emergency Management Agency (FEMA) BCA Toolkit v6.0.0. The FEMA BCA Toolkit is provided as **Appendix 4.** Social benefits used in the analysis were developed within the FMEA Benefit-Cost Calculator.

Project Costs

According to the report, the overall cost to design and construct the proposed project is approximately $190,218,000. The conveyance improvements were assumed to have a useful life of 30 years. The project cost used in the BCA includes construction costs, contingency (15%), engineering and permits (10%), and right-of-way acquisition costs. The annual maintenance cost is estimated at $0. Harris County Flood Control District will be responsible for long-term maintenance of the Keegans Bayou Flood Risk Reduction Project.

Benefit Cost Analysis

1.1 Building Information

The "Texas Buildings with SVI and Estimated Population (November 2021)" dataset provided by TWDB for Regional Flood Planning was used to determine building sizes and building types. The Finished Floor Elevations (FFE) for all structures were assumed to be 6 inches above ground level and all structures were assumed to be 1 story. The FFE assumption was gathered from the approximate median FFE from HCFCD's structural inventory dataset for the project area. Based on the provided building types, structures were reclassified as either residential, commercial, industrial, or agricultural. Public buildings were reclassified as commercial structures. Buildings marked as "Vacant or Unknown" in the TWDB dataset were reclassified as agricultural buildings.

1.2 Flood Hazard Data

The flood depths for each structure within the study area was determined for the 1 percent, 2 percent, and 10 percent annual chance events. The flood hazard data was obtained from the hydraulic models developed as part of the Feasibility Study Plan. All hydrological and hydraulic analyses were completed by Huitt-Zollars. The baseline structural flood damages are included in **Table 1**.

Table 1. Summary of Damages by Recurrence Interval for Without and With Project Conditions

	1% AEP Storm		2% AEP Storm		10% AEP Storm	
	Without Project	With Project	Without Project	With Project	Without Project	With Project
Residential Flood Damage	$415,759,525	$177,545,297	$207,336,985	$49,103,124	$9,884,848	$0
Commercial Flood Damage	$59,355,949	$19,333,586	$33,301,173	$11,295,906	$13,795,471	$0
Total Structural Damage	**$475,115,473**	**$196,878,883**	**$240,638,157**	**$60,399,031**	**$23,680,320**	**$0**

1.3 Expected Flood Damages After FMP Implementation

For the structures analyzed, the Keegans Bayou Flood Risk Reduction FMP results in $142,728,129 in standard mitigation benefits and $4,836,816 in other non-recreational benefits.

1.4 Benefit-Cost Analysis Summary

The benefit-cost analysis for this project was completed using the FEMA BCA Tool Version 6.0. The final benefit-cost ratio (BCR) with standard benefits was determined to be 0.94. Other benefits from the residual value of investments on right-of-way acquisition were utilized in the analysis.

Table 2. Benefit-Cost Analysis Summary

Input Into BCA Toolkit		
Project Useful Life	**30 years**	
Event Damages	**Baseline**	**Project**
1% AEP storm event	**$475,115,473**	**$196,878,883**
0.2% AEP storm event	**$240,638,157**	**$60,399,031**
10% AEP storm event	**$23,680,320**	**$0**
Results from BCA Toolkit:		
Total Benefits from BCA Toolkit	$137,891,313	
Other Benefits (Not Recreation)	$4,836,816	
Discounted Total Costs from TWDB Spreadsheet	$151,919,731	
Net Benefits	$142,728,129	
Final BCR	**0.94**	

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Drainage report submitted with model files.

Appendix 5-4L:
Goose Creek Flood Risk reduction Project

TORRES & ASSOCIATES, LLC
ENGINEERS | SCIENTISTS | PROFESSIONALS

MEMORANDUM

DATE: February 28th, 2023

TO: San Jacinto Regional Flood Planning Group

CC: Harris County Flood Control District; Texas Water Development Board

FROM: Evan Adrian, PE, CFM, ENV SP; Jacob Torres, PhD, PE, CFM, D.WRE; Cristian Ayala, EIT

PROJECT NO.: 10-220120-00

PROJECT: TWDB San Jacinto Regional Flood Plan

SUBJECT: Goose Creek Flood Risk Reduction Project Benefit-Cost Analysis

The initial evaluation for the Goose Creek Flood Risk Reduction Project was conducted in 2021 as part of the Final Engineering Report for the Goose Creek Watershed Planning Project by AECOM prepared for Harris County Flood Control District (HCFCD). The final engineering report is included as **Appendix 1**. The project includes three phases of development. Phase 1 includes a regional detention basin and channel improvements along two segments of Goose Creek for a total length of 1.65 miles. Phase 2 includes a regional detention basin and channel improvements along a one-mile segment of Goose Creek. Phase 3 includes local channel and crossing improvements along two Goose Creek tributaries (HCFCD Unit ID. O117-00-00 and O126-00-00). This analysis was conducted for the ultimate condition project inclusive of all three development phases.

The Texas Water Development Board (TWDB) requires each Flood Mitigation Project (FMP) included in a regional flood plan to have a benefit/cost analysis (BCA) performed. The final engineering report prepared by AECOM did not include a BCA. This memorandum documents a benefit cost analysis performed for the Goose Creek Flood Risk Reduction Project by Torres and Associates within the regional flood planning process.

Benefit Cost Analysis Methodology

TWDB developed the Benefit-Cost Analysis (BCA) Input Tool to facilitate the calculation of flood mitigation benefits due to FMP. The TWDB BCA Input Tool is provided as **Appendix 2**. This tool receives input of existing and proposed conditions to determine expected benefits related to the construction of the FMP in question. The benefits considered in the analysis include the reduction in damages to residential structures, commercial structures, and social benefits. The BCA Input Tool was modified to handle the nearly 20,000 structures included in the analysis. The modified BCA Input Tool is provided as **Appendix 3**. The BCA Input Tool was used in conjunction with the Federal Emergency Management Agency (FEMA) BCA Toolkit v6.0.0. The FEMA BCA Toolkit is provided as **Appendix 4.** Social benefits used in the analysis were developed within the FMEA Benefit-Cost Calculator.

Project Costs

According to the report, the overall cost to design and construct the Ultimate Project (Phase 1 through Phase 3) is estimated at $46,493,360 based on 2021 construction costs. The conveyance improvements were assumed to have a useful life of 30 years. The project cost used in the BCA includes Construction and Construction Phase Services (45%) and Contingency (55%). The annual maintenance cost is estimated at $0. Harris County Flood Control District will be responsible for long-term maintenance of Goose Creek.

Benefit Cost Analysis

1.1 Building Information

The "Texas Buildings with SVI and Estimated Population (November 2021)" dataset provided by TWDB for Regional Flood Planning was used to determine building sizes and building types. The Finished Floor Elevations (FFE) for all structures were assumed to be 8 inches above ground level and all structures were assumed to be 1 story. The FFE assumption was gathered from the approximate median FFE from HCFCD's structural inventory dataset for the project area. Based on the provided building types, structures were reclassified as either residential, commercial, industrial, or agricultural. Public buildings were reclassified as commercial structures. Buildings marked as "Vacant or Unknown" in the TWDB dataset were reclassified as agricultural buildings.

1.2 Flood Hazard Data

The flood depths for each structure within the study area was determined for the 1 percent, 0.2 percent, and 10 percent annual chance events. The flood hazard data was obtained from the hydraulic models developed as part of the Final Engineering Report, all hydrological and hydraulic analyses were completed by AECOM. The baseline structural flood damages are included in **Table 1**.

Table 1. Summary of Damages by Recurrence Interval for Without and With Project Conditions

	1% AEP Storm Event		0.2% AEP Storm Event		10% AEP Storm Event	
	Without Project	With Project	Without Project	With Project	Without Project	With Project
Residential Flood Damage	$58,577,254	$38,769,002	$160,927,202	$126,449,927	$5,543,995	$1,710,200
Commercial Flood Damage	$14,567,492	$10,732,865	$32,613,101	$29,043,440	$497,897	$7,670
Total Structural Damage	**$73,144,746**	**$49,501,867**	**$193,540,304**	**$155,493,367**	**$6,041,891**	**$1,717,869**

1.3 Expected Flood Damages After FMP Implementation

For the structures analyzed, the Goose Creek Flood Risk Reduction FMP results in $17,781,465 in standard mitigation benefits.

1.4 Benefit-Cost Analysis Summary

The benefit-cost analysis for this project was completed using the FEMA BCA Tool Version 6.0. The final benefit-cost ratio (BCR) with standard benefits was determined to be 0.48. No other benefits (i.e., recreation, roadway, etc.) were analyzed during this analysis.

Table 2. Benefit-Cost Analysis Summary

Input Into BCA Toolkit		
Project Useful Life	**30 years**	
Event Damages	**Baseline**	**Project**
1% AEP storm event	**$73,144,746**	**$49,501,867**
0.2 % AEP storm event	**$193,540,304**	**$155,493,367**
10% AEP storm event	**$6,041,891**	**$1,717,869**
Results from BCA Toolkit:		
Total Benefits from BCA Toolkit	$17,225,251	
Other Benefits (Not Recreation)	$556,214	
Discounted Total Costs from TWDB Spreadsheet	$37,132,442	
Net Benefits	$17,781,465	
Final BCR	**0.48**	

List of Appendices

Appendix 01 – Final Engineering Report for the Goose Creek Watershed Planning Project

Appendix 02 – TWDB BCA Input Workbook (included as an excel document)

Appendix 03 – Modified Benefit Cost Analysis Spreadsheet (Included as an excel document)

Appendix 04 – FEMA BCA Toolkit 6.0 (included as an excel document)

Final Engineering Report for the Goose Creek Watershed Planning Project

March 1, 2021

Prepared by:

Pol Bouratsis, Elizabeth Levitz, Isabella Gandara

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AECOM TBPE Reg No. F-3580

STATE OF TEXAS
POLYDEFKIS BOURATSIS
134403
LICENSED
PROFESSIONAL ENGINEER

Final Engineering Report for the Goose Creek Watershed Planning Project

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Acknowledgments

This project is funded by Harris County, the Texas General Land Office of the State of Texas, and the United States Department of Housing and Urban Development through the Community Development Block Grant Program to provide for disaster recovery and restoration of infrastructure for communities impacted by Hurricane Harvey.

1. Introduction

1.1. Study Overview

AECOM is under contract to Harris County Flood Control District (HCFCD or District) to perform a planning study of Goose Creek watershed to identify projects to reduce riverine flood risk. The study area includes all of Goose Creek watershed, excluding Spring Gully. The study is substantially funded under the 2017 Hurricane Harvey Texas Community Development Block Grant Disaster Recovery (CDBG-DR) program. The primary goal of this project is to create a high-level Watershed Plan to identify strategies for mitigation of existing flooding problems and to address improved drainage infrastructure required for future development. The detailed goals and objectives for this effort, as described by HCFCD, are listed below:

1. Define existing baseline conditions for the drainage infrastructure and identify existing and potential future flooding problems in the watershed.
2. Evaluate the location and severity of the problems and the potential solutions using criteria provided by District.
3. Identify opportunities and constraints for the considered solutions and develop a strategy for the watershed that provides appropriate improvements for future drainage infrastructure.
4. Create a comprehensive Watershed Plan to document recommendations for required improvement projects.
5. Develop more detailed cost and implementation information for identified immediate improvement projects.

During the course of the current study, AECOM has developed three technical memos and has presented two technical workshops. In those memos and workshops, AECOM presented important information about the watershed, delineated the areas with the greatest flooding problems (referred to as problem areas, or PAs), quantified the magnitude of historic and predicted flooding, identified the main sources of flooding in every problem area, and presented various potential improvements that can be developed to mitigate flooding. Furthermore, AECOM has developed a Preliminary Project Plan that includes detailed information about the short-term recommended improvements that can be partially funded by available 2018 Bond funds and are expected to provide significant benefits to the watershed.

The current Final Engineering Report is addressed to HCFCD personnel and administrators from stakeholder groups involved in partnering for flood mitigation projects. The purpose of the report is to provide an extensive summary of the information that was presented in the previous reports and workshops. For items that are not covered in full detail here, the reader is referred to the attached technical memos and technical presentations for additional information and useful exhibits and tables. However, it should be noted that several recommendations included in the attachments are now outdated, due to more recently received input from various stakeholders. Notes and comments have been added to the attachments to highlight any outdated information.

1.2. Watershed Overview

Goose Creek watershed encompasses 27 square miles in eastern Harris County. Its population is approximately 49,000, and it lies entirely within Harris Country Precinct 2, with the southern half of the watershed within the City of Baytown. Unincorporated Harris County accounts for less than one half of the watershed. An overview of the watershed is provided in **Exhibit 1**. The watershed is approximately 7% undeveloped and consists primarily of rural areas with scattered large plot subdivisions that were built in the 1970s and 1980s. In addition, there are numerous pipelines and canals crossing the watershed, due to the large petrochemical industry in the area, including the ExxonMobil Baytown refinery. Goose Creek consists of one main stem channel (Goose Creek- O100-00-00), two major tributaries (East Fork Goose Creek- O105-00-00 and West Fork Goose Creek- O119-00-00), and over 30 other minor tributaries. The headwaters of Goose Creek channel start near the Highlands Reservoir and flow southward to Goose Lake/Tabbs Bay, near the Houston Ship Channel. **Technical Memo 1 (TM 1)** and the presentation for **Technical Workshop 1** include additional maps for the watershed, along with descriptions of other important features.

Historical Flooding

The Goose Creek watershed has experienced numerous significant flood events. From information obtained from the Goose Creek Watershed Workbook, supplied by HCFCD, since 1979, 17 of the 46 largest storms in Harris County have impacted residents of the watershed. The most severe was Hurricane Harvey in August 2017, when record flooding was documented along Goose Creek, upstream of US 146. South of US 146, surge levels were higher during Hurricane Ike (2008) and Tropical Storm Allison (2001). During Hurricane Harvey, some areas of Baytown experienced up to 60 inches of precipitation. Along Goose Creek, downstream of US 146, Hurricane Harvey's water surface levels averaged nearly 50% of Hurricane Ike's storm surge values (Source: Goose Creek Watershed Workbook, HCFCD).

Table 1 summarizes FEMA All Claims data from recent storm events, and **Exhibit 2** illustrates the approximate location of FEMA claims and reported flooding complaints. There were no claims reported for the Memorial Day 2015 and 2016 storms. Of the 490 total claims since 1979, 219 were made prior to 2000, and 432 were located north of Interstate 10 (I-10).

Table 1. FEMA All Claims per Storm Event

Storm Event	Number of Claims
Allison	1
Ike	25
April 2009	17
Tax Day 2015	1
Halloween 2015	21
Harvey	189
Total Claims (since 1979)	490

Previous Studies and Ongoing Projects

A detailed review of recent relevant projects and studies in the Goose Creek watershed was performed for the preparation of **Technical Memo 2 (TM 2)**. As part of this effort, documentation of previous studies was provided by HCFCD and evaluated by AECOM. **TM 2** provides a summary of previously recommended projects and active studies that may impact the overall improvement plan. Out of all the projects reviewed in **TM 2**, the projects that could have the greatest impact to the current watershed planning study are described below.

Highland Estates - Cedar Bayou Phase 1 and Phase 2 Studies, by HCFCD and Halff Associates. Phase 1 of the Cedar Bayou Flood Risk Study was completed in 2017 and Phase 2 was completed in 2020. Both phases of the project evaluate flooding within the Highland Estates neighborhood, located north of the Highlands Reservoir. For Phase 2 of the study, the latest recommended improvements (reviewed in April 2020) focus on channel widening along O119-00-00 and O200-00-00, along Barbers Hill Road, and structure improvements along the Highlands Reservoir access road. The channel widening would be accomplished by relocating the berm of the reservoir. Given that this study thoroughly examines flood mitigation solutions in the Highlands Estates neighborhood, it was decided that the current study by AECOM would not further evaluate that area. A preliminary review of this study's proposed conditions hydraulic models indicates that there will be small benefits outside the vicinity of Highlands Estates. Additionally, at the time the current report was prepared, it was not certain that the proposed improvements recommended in the Highlands Estates study would be constructed; therefore, it was decided that AECOM's watershed-wide hydraulic models would not include the proposed improvements for the Highlands Estates. This project is expected to proceed to the preliminary engineering phase soon, and it will be funded by the 2018 HCFCD Bond funds.

Meadow Lake Drainage Study, by Harris County Engineering Department and R.G. Miller Engineering. The Meadow Lake Drainage Study, completed in 2018, focuses on HCFCD stream unit O126-00-00. The Meadow Lake subdivision is located within one of the most flood-prone problem areas within the watershed. The key finding from the study is that the tailwater of Goose Creek channel (O100-00-00) at this location is higher than the structure elevations of the subdivision. This condition results in backflow flooding impacts. According to the report, the high tailwater is a major concern as it "impedes the possibility of any solutions for Meadow Lake until Goose Creek is improved to lower the tailwaters." Stream O126-00-00 was modeled for this Watershed Planning Study, and it was concluded that the flooding along O126-00-00 is largely due to high tailwater in O100-00-00. The current study by AECOM proposes solutions to lower the tailwater of Goose Creek channel at this location, as well as additional improvements along O126-00-00 to further reduce flooding within the Meadow Lake subdivision.

Proposed Residential Development in Harris County Municipal Utility District (HCMUD) No. 567; plans by R.G. Miller Engineering and drainage report by Preston Hydrologic. The undeveloped, 193-acre area west of Goose Creek and south of I-10 is expected to be developed in the near future. The new development will include four detention basins that are expected to mitigate any adverse hydraulic impacts under proposed conditions. This development will occupy a large piece of land that would otherwise be an ideal location for the development of new detention basins that would provide regional flooding relief. The proposed improvements in the current study by AECOM are not in conflict with the proposed development in the HCMUD report.

Channel Conveyance Improvements in O100-00-00 from Baker Road to O128-00-00, by HCFCD and TCB. In 2010, HCFCD performed channel improvements to an approximately one-mile long segment of Goose Creek from Baker Road to south of W. Cedar Bayou Lynchburg Road. The improvements included a combination of channel widening, deepening, concrete lining, and bank reinforcement. The current project that is recommended by AECOM does not include any modifications to the concrete-lined segment of this recent project.

2. Hydraulic Modeling

Existing conditions modeling has been carried out to evaluate the flooding susceptibility of the various areas within the watershed and to identify flooding sources. The modeling included a combination of 2D Rain-on-Grid and 1D Unsteady HEC-RAS models. The models included FEMA-studied streams O100-00-00 and O105-00-00, along with 8 additional unstudied tributaries, as shown in **Table 2** and **Exhibit 1**. Several proposed conditions scenarios were simulated in the models to assess the benefits and impacts of different combinations of improvements. Detailed descriptions of the model configurations, along with the existing conditions results, are provided in **TM 1**. The proposed conditions modeling results for various scenarios are presented in **TM 2** and **Technical Memo 3 (TM 3)**. The current report includes a brief description of the modeling approach and a summary of the modeling results under existing and proposed conditions corresponding to the recommended project.

Table 2. Studied Streams

HCFCD Stream Unit	Name	Length of Study
O100-00-00	Goose Creek	11.69
O105-00-00	East Fork Goose Creek	2.86
O105-04-00	Unnamed Tributary	1.79
O107-00-00	Unnamed Tributary	1.38
O111-00-00	Unnamed Tributary	1.47
O111-01-00	Ditch No. 6	1.84
O117-00-00	Unnamed Tributary	0.97
O119-00-00	West Fork Goose Creek	4.18
O121-00-00	Unnamed Tributary	0.32
O126-00-00	Unnamed Tributary	2.04

2.1. Rain on Grid Results Summary

The purpose of the 2D Rain-on-Grid model was to assist in identifying sheet flow patterns within the study limits, areas of overflow between sub-watersheds within the Goose Creek watershed, and areas of overflow between the Goose Creek watershed and adjacent watersheds. The model was built in HEC-RAS Version 5.0.7, and it utilized the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 100-year, 24-hour storm rainfall (total cumulative rainfall depth = 18.2 inches). Based on the 2D modeling results, the boundaries of several sub-watersheds were adjusted. Additionally, the results were used to provide an initial understanding of the surface runoff patterns and verify findings of the detailed 1D modeling, which is described in the next section.

2.2. Detailed Existing Conditions Modeling

The primary modeling effort included the development of multiple 1D unsteady hydraulic models for the 10-year, 50-year, 100-year, and 500-year events for Goose Creek and the tributaries shown in **Exhibits 3** to **6**. Predicted structural flooded for existing conditions is shown in **Exhibit 7**. The hydrology for the 1D models included a combination of updated Model and Map Management (M3) System HEC-HMS models and the development of new hydrologic outputs using the Basin Development Factor (BDF) method. Rainfall intensities were based on the NOAA Atlas 14 precipitation data, and the hydraulic models were built in HEC-RAS Version 5.0.7.

The only FEMA-studied streams within the watershed are O100-00-00 and O105-00-00. The effective M3 models for these streams were combined into a single model, which was updated using 2018 LiDAR data, making several corrections to the overall geometry. New 1D HEC-RAS models were built for tributaries O121-00-00, O119-00-00, O117-00-00, O126-00-00, and O105-04-00. The geometry for these tributaries was based on the 2018 LiDAR and HCFCD outfield data. Tributaries O111-00-00 and O111-01-00 were modeled with a 2D model, as deemed appropriate due to the complex local surface runoff patterns.

A comparison between the current existing conditions model results and the FEMA model results indicates that the current 100-year water surface elevation (WSE) profiles for O100-00-00 and O105-00-00 are, in general, higher than the 100-year FEMA WSE profiles and lower than the 500-year FEMA WSE profiles. This is primarily attributed to the implementation of the NOAA Atlas-14 rainfall. Additionally, the floodplain areas for all events were significantly larger than the FEMA floodplains, due to the inclusion of several tributaries that have not been studied by FEMA.

The reader is referred to **TM 1** for a more detailed description of the modeling configurations and results. The existing conditions models were reviewed by Freese and Nichols, on behalf of HCFCD. Review comments and responses are included as an Attachment.

2.3. Proposed Conditions Modeling

In order to evaluate the various considered improvements, several proposed conditions models were built, as described in **TM 2**. Some of these models included individual improvements, such as the development of a detention basin or the upsizing of a culvert, while other models included combinations of multiple improvements, such as the widening of a stream segment and the development of a detention basin. The results were carefully examined to understand which improvements provide the maximum benefit, and what the mitigation requirements would be for different scenarios. In **TM 2** and **TM 3**, the hydraulic results for selected scenarios were further processed to calculate numbers of flooded structures and other useful metrics.

It should be noted that the final proposed project includes a combination of improvements that is different from the scenarios described in **TM 2** and **TM 3**. The current report includes the latest modeling results and metrics, as explained in **Section 4**. Finally, an independent technical review of the proposed conditions model was carried out by Kenall Inc., subcontracted to AECOM. The review documentation is included as an Attachment. All existing and proposed conditions HEC-RAS and HEC-HMS files are included here as an electronic attachment.

3. Existing Conditions Flooding

3.1. Problem Area Delineation

Existing conditions modeling results were examined to identify the factors that contribute to flooding in various locations within the watershed. In addition to the modeling described in **Section 2**, a series of smaller models were built to estimate the level of service for segments of Goose Creek and its tributaries. The results of this analysis are shown in **Exhibit 8** and they are used extensively in the identification of flooding sources and potential solutions.

It was found that the majority of the flooding problems within the watershed are attributed to a combination of the following factors:

1. High tailwater depth at the outfalls of the tributaries.

2. Insufficient stream capacity.

3. Hydraulic structures with low level of service.

4. Insufficient capacity of the secondary drainage system within subdivisions.

5. Structures built at very low elevations.

Common sources of flooding, along with inundation extents for all storm events, subdivision boundaries, and sub-watershed boundaries, were taken into consideration to delineate problem areas within the watershed. In total, 13 problem areas were delineated for Goose Creek watershed (**Exhibit 9**). A detailed description of the PA features, along with several useful exhibits, are included in **TM 1**. In the current report, only the three PAs with the greatest historical and predicted structural flooding are described in detail (PA1, PA2, and PA4).

Problem Area 1

Problem Area 1 (PA1) is located north of I-10 and it includes subdivisions east and west of O-100-00-00, Stream O117-00-00, and Stream O126-00-00. The area is partially residential and partially undeveloped. It includes segments of the following neighborhoods: Meadow Lake Village, Kings Colony, Terrell Village, and Harlem. Meadow Lake Village, north of O126-00-00, is estimated to have been built in the 1980s. Subdivisions to the west of Goose Creek in this area are estimated to primarily be constructed prior to 1970. The approximate population is 2,400; the area is not classified as Low to Moderate Income (LMI), and the Social Vulnerability Index (SVI) is 7. This problem area has the highest number of FEMA historic claims (191) and Repetitive Loss claims (21) within the watershed. Additionally, this area has the highest predicted flooding within the watershed.

This area is experiencing significant flooding along tributaries O117-00-00 and O126-00-00. A careful examination of the modeling results indicates that flooding is caused primarily by the high tailwater elevation at the confluence of the two tributaries with O100-00-00. A sensitivity modeling test was carried out by eliminating all lateral inflows from the two tributaries, and it was found that there is still substantial flooding in the area. The modeling results indicate that there are considerable energy losses at the I-10 crossing (main lanes and frontage roads). Additionally, the low hydraulic conveyance of O100-00-00 contributes to the high stage elevations that are causing flooding.

In order to lower the stage along Goose Creek, the solution would have to include a combination of improving the I-10 crossing, increasing the hydraulic conveyance of Goose Creek downstream of I-10, and providing detention. It is likely that improvements at the local, secondary drainage systems would also need to be part of the solution. However, the current analysis indicates that a lower stage along Goose Creek would benefit the majority of the structures in the developed areas of PA1.

Problem Area 2

Problem Area 2 (PA2) is located mostly east of SH-330 and mostly south of W. Cedar Bayou Lynchburg Road. It includes a segment of O100-00-00 and tributaries O111-00-00 and O111-01-00. The area is primarily residential, with pockets of commercial, industrial, and park space. Subdivisions in this area are estimated to have primarily been built in the 1970s and 1980s. It is the most populated problem area within the watershed, with approximate population of 8,400. The area is classified as LMI and the SVI is 8. In this problem area, there are 28 FEMA historic claims and 4 Repetitive Loss claims. Most of the claims are attributed to Hurricane Harvey. Additionally, this area has the third highest predicted structural flooding in the watershed. The hydraulic conveyance of O111-01-00 is lower than 10-year conditions, and the hydraulic conveyance of O111-00-00 and O100-00-00 in this PA is between 10-year and 100-year.

There are several factors that contribute to flooding in this area, as listed below:

- Low hydraulic conveyance at O111-01-00;
- Undersized culverts at O111-00-00 and O111-01-00;

- Several subdivisions built at relatively low elevations; and
- Insufficiencies in the secondary drainage system (small number/size of outfalls draining from the subdivisions to Goose Creek).

Solutions could include local measures, such as improvements of hydraulic structures with high head loss and accompanying mitigation measures, and regional measures, such as channel improvements and detention that would focus on lowering the stage at Goose Creek.

Problem Area 4

Problem Area 4 (PA4) is located south of the Highlands Reservoir, at the confluence of Goose Creek with O119-00-00. The area consists primarily of residential and undeveloped land. The major neighborhood is County Terrace, with subdivisions estimated to be built in the 1970s and 1980s. The approximate population is 750; the area is not classified as LMI and the SVI is 8. In PA4, there are 89 FEMA claims and 2 repetitive claims. Most of the claims are attributed to Hurricane Harvey. Additionally, this area has the second highest predicted structural flooding in the watershed. The hydraulic conveyance of Goose Creek and O119-00-00, in this area, is between 10-year and 100-year.

The factors contributing to flooding in this area are:

- Local problems in O119-00-00. Most of the stream includes a berm that protects the developed areas from flooding, but in some segments, there is no berm and there is spillage;
- Some of the subdivisions in the northern subdivision are built at very low elevations; and
- A high-level evaluation of the secondary drainage system indicates that flooding may be caused by the low hydraulic conveyance of the culvert outfalls from the subdivisions to O119-00-00.

Given that solutions like building levees or buying-out houses could be cost-prohibitive, the solution would need to include lowering the WSE of O119-00-00 and O100-00-00. This would require detention at or upstream of PA4 and channelization downstream of it. In PA4, there are limited undeveloped areas that could be used for detention. Additionally, local channel improvements and upgrades of the secondary drainage system would need to be part of the solution.

3.2. Flooding Metrics and Scores

Detailed metrics were calculated for each of the thirteen PAs, and based on these metrics, the areas were categorized into three tiers. Tier 1 PAs have the greatest amount of flooding damages based on the metrics established for these watershed plans. Tier 2 PAs generally have lesser flooding problems and/or greater challenges in the development of effective flood reduction projects than Tier 1 problem areas, but still need near-term solutions and efforts to address the flood problems for these areas. Finally, Tier 3 PAs generally have limited flood damages to homes and businesses, are usually scattered over a large area that makes solutions difficult and more expensive, and are expected to require a longer horizon to address.

The metrics were calculated following the methodology provided by HCFCD and included: historical flooding, predicted structural flooding for the 100-year event, total probable annual structural flooding, and predicted roadway flooding. The results of this analysis, along with notes and definitions for the metrics, are included in **Appendix 1**.

Although all metrics were taken into careful consideration, emphasis was given to the predicted structural flooding, the historical structural flooding, and the length of roadway that is predicted to flood by more than 1 foot of water in the 100-year event. Using these metrics, a flooding category score was calculated, as described at the end of this section, to categorize the problem areas. Additional aspects were taken into consideration, including environmental constraints, expected cost, land availability, and potential for partnership with other entities.

PA1, PA2, and PA4 experience the most substantial flooding issues and are grouped as Tier 1 problem areas. According to the primary metrics in **Appendix 1**, PA3 and PA5 also appear to be Tier 1 problem areas, primarily due to the historical structural flooding; however, discussions between HCFCD and the City of Baytown have led to the conclusion that the reported historical structural flooding may not be accurate in these locations, and these areas might be less susceptible to flooding.

4. Proposed Project

4.1. Plan Description

One of the main goals of this watershed planning study is to propose a project that is expected to provide significant flood relief to the most vulnerable areas within the watershed that can be developed in the short- to mid- term. The development of this project is at a feasibility level of analysis. The key features of this project are discussed in this section, and an overall layout is provided in **Exhibit 10**. More detailed descriptions and dimensions of the various project components are included in the Preliminary Project Plan, which is a separate submittal addressed primarily to the HCFCD Engineering and Property departments.

<u>Channel Improvements Along Goose Creek (HCFCD Unit O100-00-00):</u>

This component includes channel improvements along two segments of Goose Creek. The southern segment extends from just north of O107-00-00 to just south of Rollingbrook Drive. The northern segment extends from Battlebell Road to 0.3 miles north of W Cedar Bayou Lynchburg Rd. The total length of the proposed channel improvements is 2.7 miles, the proposed side slopes are set to 4:1 (horizontal:vertical), and the longitudinal slope is set to approximately 0.08%. According to preliminary estimates, these channel improvements would require the acquisition of at least 26.7 acres of land. The proposed channel improvements do not include any modifications to the segment of Goose Creek that was concrete-lined in 2010.

As shown in **Exhibit 8**, the channel capacity of Goose Creek is moderate to low in the wider area adjacent to the Tier 1 PAs, and this is the primary factor of flooding in these areas. The channel improvements will increase the capacity of Goose Creek and will significantly reduce the water surface elevations at the Tier 1 PAs.

Regional Detention Basins:

This component includes two new detention basins that will be developed adjacent to Goose Creek, Basin I and Basin J. The purpose of the detention basins is to provide flooding relief and to mitigate the negative impacts of the channel and structure improvements. Several undeveloped pieces of land were considered as candidate locations for detention basins and were included in modeling scenarios. Basins I and J, shown in **Exhibit 10**, were found to provide the optimum benefit, in combination with the channel and structure improvements of this proposed plan.

Basin I is located north of W. Cedar Bayou Lynchburg Road, west of Goose Creek, and it extends within three parcels that belong to the City of Baytown. These parcels are mostly undeveloped, except for an area where there is a shooting range facility for the local police department. The preliminary basin layout avoids conflicts with the developed area within the three parcels. The preliminary volume, area, and depth for Basin I are 561 ac-ft, 42 ac, and 15 ft, respectively. These values correspond to a feasibility-level analysis and are expected to be refined during the preliminary engineering phase.

Basin J is located north of Rollingbrook Drive, east of Goose Creek. The area is undeveloped and is currently for sale by a real estate company, Claire Sinclair Properties. The preliminary volume, area, and depth for Basin I are 659 ac-ft, 39 ac, and 19 ft, respectively.

Local Channel and Structure Improvements:

Local impact improvements are proposed along the O126 and O117 tributaries, as shown in **Exhibit 10**. These tributaries are located north of I-10, in the area that has the highest predicted structural flooding within the watershed (PA1).

The O117 improvements involve channel widening along a 1-mile segment of O117 and structural improvements in two culvert crossings located near O100. These crossings are privately owned and could be potentially removed. The current recommendation is the complete removal of these crossings. However, if a complete removal is not possible, then the culverts should be upsized as much as possible, as the existing conditions models show major hydraulic losses at the crossings.

The O126 improvements involve channel widening along a 0.5-mile segment of O126 and structural improvements at three culvert crossings. One of these crossings is located at John Martin Road and is proposed to be upsized from a 2 – 6’x6’ reinforced concrete box to a bridge with an approximately 100-foot top-width opening. The two other crossings are located very close to O100, are privately owned and could be potentially removed. The current recommendation is the complete removal of these two crossings. However, if a complete removal is not possible, then the culverts should be upsized as much as possible, as the existing conditions models show major hydraulic losses at the crossings. The proposed conditions hydraulic models indicate that the adverse impacts of the O117 and O126 improvements can be mitigated by the O100 channel improvements and the regional detention basins, described above.

4.2. Proposed Project Sequence

The recommended project can be developed in three phases, as follows:

Phase 1: Regional detention basin J and channel improvements along two segments of Goose Creek, with total length equal to 1.65 miles, as shown on **Exhibit 11**.

Phase 2: Regional detention Basin I and channel improvements along a 1-mile-long segment of Goose Creek, as shown on **Exhibit 12**.

Phase 3: Local channel and crossing improvements along tributaries O117 and O126, as shown on **Exhibit 13**.

Given that the most common flooding source in the watershed is the insufficient capacity of Goose Creek, the current project is aiming to improve conveyance along this stream. The hydraulically optimum sequence of improvements prioritizes modifications at the downstream-most segment of Goose Creek. Additionally, Basin J is included in Phase 1 to mitigate any adverse impacts caused by the increased channel conveyance. As mentioned above, the local improvements along O117 and O126 do not include any local detention basins. Instead, the adverse impacts of these components are being mitigated by the combined effects of the regional detention basins and the channel improvements along O100. Therefore, channel improvements along O100 should precede the local tributary improvements. Additionally, the proposed conditions hydraulic models indicate that the local improvements will have considerable benefits only if they are combined with the lowering of the tailwater at O100. For these reasons, Phase 2 includes improvements along the northern part of Goose Creek and the development of Basin I to mitigate any adverse impacts. Finally, the local improvements to O117 and O126 in Phase 3 are expected to further improve the hydraulic conditions to the most vulnerable area of the watershed (PA1).

It should be noted that the detention basins will provide some flooding relief to certain areas of the watershed even without the development of any other component. As the Goose Creek watershed is being developed, it is important for HCFCD to acquire the land that can be used for detention as quickly as possible, as the viability of any future projects depends on these detention basins.

4.3. Special Considerations and Constraints

In the current feasibility-level analysis, several assumptions were made to build the proposed conditions hydraulic models and develop the proposed plan guidelines. Many of these assumptions will need to be evaluated during the preliminary engineering phase when additional information is available. The following list summarizes the aspects of the proposed project that are potential constraints and as such are expected to be re-evaluated in the next phase.

<u>Right-of-Way (ROW):</u>

The acquisition of right-of-way (ROW) for channel improvements may be complicated. According to the maps provided by HCFCD, the existing ROW is narrower than the existing channel in some areas. The currently proposed channel extents do not span within any developed areas, but they do extend within privately owned parcels. A ROW survey should be carried out to determine the exact ROW extents, and then the acquisition of additional ROW will have to be investigated. The results of this investigation should guide the final channel design. A preliminary examination of impacted Harris County Appraisal District (HCAD) parcels for the proposed ROW extents is shown in **Appendix 2**.

Additionally, the preliminary engineering study should verify the availability of the required parcels for the development of the proposed detention basins. For the current feasibility study, an effort was made to identify parcels that are available and provide the maximum hydraulic benefit. If these parcels are not available or cannot be acquired at a reasonable price, then the proposed plan will need to be adjusted, as discussed in **Section 4.4**. **Exhibit 14** shows the extents of the additional ROW that will need to be acquired, based on the available data.

<u>Topography and Bridges:</u>

The proposed channel design is based on dated bathymetric data obtained from the effective M3 model. A bathymetric survey of the extents identified for channel improvement and a topographic survey at the crossings will be required before the channel design is finalized. One of the most important aspects that will need to be examined is the channel and bridge geometry at the crossings. The channel improvements extents include two main crossings: I-10 and Rollingbrook Drive. The currently proposed design requires deepening of the channel by about 2 to 3 feet at the I-10 bridge. This deepening may be able to be accommodated with a deep, low-flow channel between the piers, without any other major modifications; however, this will need to be re-evaluated when the topographic survey is available.

Apart from the channel deepening considerations, coordination with the Texas Department of Transportation (TxDOT) and the City of Baytown will determine whether the existing bridge abutments can be replaced by steeper-slope abutments to increase conveyance at the crossings with I-10 and Rollingbrook Drive. The channel design can be adjusted to accommodate constraints at the bridge crossings.

<u>Environmental Analysis:</u>

The environmental investigation that was completed for this study (see **TM 2**, **TM 3**, and **Section 6** in the current report) did not identify any major constraints with the proposed improvements. One potential constraint is a number of oil and gas pipelines that cross Goose Creek between I-10 and W. Cedar Bayou Lynchburg Road. The proposed channel deepening in this area is only about 2 feet. While it is expected that the pipelines are deeper than that, a utility survey is recommended to verify that there are no conflicts. Another potential constraint is related to the shooting range facilities adjacent to Basin I. It is expected that the presence of lead in the ground will trigger additional environmental investigation and efforts.

Regarding the permitting efforts, it is expected that United States Army Corps of Engineers (USACE) permits will be required due to channel improvements being proposed within the wet sections of Goose Creek, which will most likely be considered the ordinary high-water limits.

Hydraulic Modeling:

Additional details will need to be added to the existing and proposed conditions hydraulic models. Examples of updates include refinement of Manning's n roughness values and inclusion of new survey for the channel and bridges.

That being said, it is likely that the 1D/2D watershed-wide Modeling, Assessment, and Awareness Project (MAAPnext) model will be available for use during the preliminary engineering analysis. In this case, the MAAPnext model could be used as a starting basis for the final analysis and design, as it includes more recent and detailed inputs, and its 2D areas provide a better representation of the benefits/impacts of the proposed improvements.

Channel Design:

The current channel design has adopted a 4:1 side slope to avoid concrete lining requirements along almost the entire modified section. However, according to the available bathymetry, in several areas the existing side slopes are steeper than 3:1, and the channel is not concrete-lined. It is recommended that a geotechnical investigation is performed to identify the stable slope for the channel and verify whether it can be steeper than 4:1. This will provide flexibility to overcome many of the aforementioned constraints, by reducing ROW requirements or allowing for reduced channel deepening.

4.4. Recommendations for Constraint Resolution

One of the most probable constraints is that the land where the proposed basins are to be built is not available or is very hard to acquire. In this case, HCFCD could pursue the acquisition of different basins as described in **TM 3** and as shown in **Exhibit 15**. Details about the cost, size and expected detention volume for these basins are presented in **TM 3**. It should be noted that the proposed channel improvements that are presented here will need to be redefined if one or both of Basins I and J are not available, and two other basins are developed instead. Given that all the alternative basins are located in the mid-to-northern part of the watershed, it is expected that the proposed channel improvements will not be able to be extended as far south. During the preliminary engineering phase, when the location of the basins has been determined and bathymetric survey data is available, additional modeling will need to be performed to determine the exact channel improvement extents. It is expected that the reduced segment of the proposed channel improvements would start from Battlebell Road and extend at least up to I-10 (or farther south, if there are no adverse impacts anywhere within the watershed). This would benefit the Tier 1 problem areas north of I-10.

If the updated cost estimates during the preliminary engineering phase are higher than expected, and/or if partnership efforts are unsuccessful, the first step to reduce the cost should be the reduction of the channel improvement extent. If additional reductions are required, the second step should be acquisition of less expensive land for detention. Finally, cost could be significantly reduced by developing a single detention basin and adjusting the channel improvement extents accordingly. In this scenario, it is likely that the local improvements would have to be omitted, as well, depending on the location of the basin and the channel improvements.

4.5. Opportunities

As discussed in the previous memos, HCFCD may be able to partner with other entities to support the proposed project. The regional detention basins and the O100 improvements are expected to significantly benefit areas within the City of Baytown, and it would be in the City's interest to see these projects realized. The City could help by facilitating the acquisition of the Basin I parcel by HCFCD and by co-sponsoring any of the regional improvements. Additionally, the local improvements north of I-10 will benefit areas that are expected to be incorporated by the City soon.

The area south of I-10 and east of O100 has been acquired by a land developer and is expected to be developed soon. This proposed HCFCD project is expected to reduce the floodplain extents in that area, thus providing more flexibility to the land developer and reducing flood risks to the future development. Therefore, the land developer could be another potential sponsoring partner. Also, it is noted that the combination of local and regional improvements would benefit the subdivisions north of I-10 more than any other area within the watershed. These local subdivisions (such as Meadowlake Village) could potentially provide further support. Furthermore, partnership with TxDOT should be sought to improve hydraulic conditions at the I-10 main lanes and frontage roads.

Finally, the City of Baytown and the land developers could support any multi-purpose use opportunities for the detention basins or the O100 ROW. Specifically, these areas could serve as green/recreational areas and benefit the area.

4.6. Preliminary Cost Estimates

Preliminary cost estimates were developed for each phase of the recommended project using the methodology provided by HCFCD. A detailed breakdown of the various costs is provided in **Appendix 3**, and a summary is provided in **Table 3**. The HCFCD 2018 Bond funds that are expected to be immediately available for the Goose Creek watershed are on the order of $25 million. It should be noted that this budget is allocated for projects recommended by the current watershed planning study, and for other HCFCD projects within the Goose Creek watershed. Given that at least one other HCFCD project within the watershed (Highland Estates, see **Section 1.2)** will be soon at the preliminary engineering phase, the funds available for the project proposed by the current study will be less than $25 million. The overall cost for the recommended project is approximately $46 million. The proposal of a project with a higher cost was deliberate in order to take into account potential partnerships and additional funding mechanisms. Additionally, it is possible that some of the current contingencies can be reduced as the design is further refined in the preliminary engineering phase.

Table 3. Cost Estimate Summary

Phase	Estimated Cost
Phase 1	$23,450,510
Phase 2	$18,338,302
Phase 3	$4,704,548
Total	$46,493,360

4.7. Project Performance

The expected performance of the proposed project has been quantified by following the HCFCD methodology as described in **TM 2**. The Probable Structural Flooding predicted to occur over a 50-year period (PSF50) is the most important metric that has been used to evaluate existing and proposed conditions consistently throughout this study. **Table 4** lists the existing and proposed PSF50 values for individual PAs. The total numbers of structures removed from the floodplain for various flooding events are listed in **Table 5**. The location of predicted flooded and benefitted structures per flooding event is shown in **Exhibits 16** to **19**. It is shown that the three Tier 1 PAs have considerable benefits under proposed conditions, especially in the 10-, 50- and 100- year events. Also, it is shown that flooding problems persist in several areas under proposed conditions. The current combination of proposed improvements has been found to provide the maximum benefits within the watershed.

Since the initially available funding is expected to be less than $25 million, it is likely that the Phase 1 improvements will have to be revised to take into account the funding that will be applied to other HCFCD projects within the watershed, such as the Highland Estates project. Also, due to funding constraints, Phase 2 and Phase 3 improvements will be developed at a later time. **Table 4** and **Table 5** include expected metrics for Phase 1 only, to illustrate the benefits that can be expected in the interim phase after the development of Phase 1 and before the development of Phase 2. Although the interim benefits are relatively small compared to the overall benefits, the improvements of Phase 1 are considered an essential step for any further improvements.

Table 4. Existing and Proposed PSF50 Comparison for Individual PAs

Problem Area	PSF50 Comparison				
	Existing	Complete Project		Phase 1	
	TPASF50	PSF50	Reduction	PSF50	Reduction
1	**460.9**	**205.4**	255.5	**440.5**	20.4
2	**112.2**	**85**	27.2	**90.7**	21.5
3	**0**	**0**	0	**0**	0
4	**125.6**	**53.9**	71.7	**124.9**	0.7
5	**0**	**0**	0	**0**	0
6	**32.1**	**27.7**	4.4	**30.2**	1.9
7	**12.6**	**12.6**	0	**12.6**	0
8	**9.9**	**7.9**	2	**7.5**	2.4
9	**0**	**0**	0	**0**	0
10	**1.7**	**1.7**	0	**1.7**	0
11	**0.1**	**0**	0.1	**0.1**	0
12	**1.1**	**1.1**	0	**1.1**	0
13	**1.5**	**1.5**	0	**1.5**	0
Watershed Wide	**773.4**	**406.5**	366.9	**722.5**	50.9

Table 5. Total Number of Structures Removed from the Floodplain for each Flooding Event.

Total Number of Benefited Structures		
Event	**Complete Project**	**Phase 1**
10-yr	55	4
50-yr	111	13
100-yr	152	14
500-yr	334	228

The score for the entire project was calculated using the methodology provided by HCFCD and was found to be 5.28. Detail project scoring assumptions are included in **Appendix 4**.

5. Long-Term Projects

5.1. Other Considered Improvements

As part of **Technical Memos 2** and **3**, several improvements were considered, but did not end up being part of the recommended project for various reasons. Some of these improvements were examined in detail via hydraulic modeling, and others were only discussed qualitatively between HCFCD and AECOM. The considered improvements included solutions that could mitigate fluvial flooding. On the contrary, solutions that would improve urban flooding, such as improvements on the secondary drainage systems, were not considered. Additionally, solutions including individual structure buy-outs were not considered. A summary of the considered improvements is provided here, and an overview is provided in **Exhibit 20**. As discussed, some of these improvements can be implemented when additional funding is available, while others were deemed to be unfeasible or inefficient.

Expansion of Detention Basin HCFCD - O500-02-00

HCFCD Basin O500-02-00 is located south of W. Cedar Bayou Lynchburg Road. A preliminary review of the as-builts and the LiDAR data for this detention basin indicates that the footprint and depth of the basin could be increased to provide additional detention storage. However, high-level discussions with HCFCD Engineering Department have revealed that there are significant conflicts, such as wetlands and major utility conflicts, which would prohibit the considered improvements.

Alternative Detention Sites along O100-00-00 (map and areas north of Basin I)

Detention Basins A, B, C and D were included in earlier versions of the proposed conditions models and were found to provide flood mitigation benefits. Basins I and J were preferred instead of Basins A, B, C and D, due to their location with respect to the recommended channel improvements and due to other site-specific factors, as described below. However, these basins can be part of future projects if additional funds become available. On the contrary Basins E, F, G, and H, which were also modeled earlier in this study, are no longer under consideration for future projects. Additional details about Basins A to H are provided here.

<u>Basin A</u>: This considered, 51-acre regional detention basin is located along O100, east of the Highlands Reservoir, and would add 250 ac-ft of storage. It primarily benefits PA4. Preliminary environmental examination of the site using the Hazardous Materials (HAZMAT) database shows oil and gas wells near the area; however, further investigation is needed.

<u>Basin B</u>: This considered, 35-acre regional detention basin is located along O100, east of the Highlands Reservoir, and would add 270 ac-ft of storage. PA4 and PA1 would be benefitted from this basin, and the site is privately owned.

Basin C: This considered, 24-acre regional detention basin is located 1,000 ft north of I-10 along O100 and would add 180 ac-ft of storage. PA1 and PA2 would be benefited from Basin C. The site is privately owned, making it a viable candidate for acquisition.

Basin D: This considered, 33-acre regional detention basin is located 1,000 ft north of I-10 along O100 and would add 310 ac-ft of storage. PA1 and PA2 would be benefited from Basin D. This site is primarily owned by the Missouri Pacific Railroad company, making it potentially difficult for acquisition.

Basins E, F, G, H: Four sites adjacent to O100-00-00 with total area of 169 acres and maximum available detention volume of approximately 2,000 ac-ft were considered earlier in this project. However, HCFCD and AECOM recently became aware that the entire area encompassing these basins is expected to be developed, as discussed in **Section 1**. Preliminary discussions with H.R. Green and Preston Inc. confirmed that property acquisitions for the development of detention basins in this area would be very challenging.

O111-00-00 and O111-01-00 Improvements

Streams O-111-00 and O111-01 are located in the middle portion of the watershed within PA2. Considered improvements that were modeled included structure upsizing and two local detention basins (24- and 13.5-acres). The basins would add approximately 183 ac-ft of storage. Modeling showed that significantly greater detention volumes would be required to mitigate flooding problems in these tributaries. However, the local parcels are almost fully developed and the costs for ROW acquisition could be prohibitive under the currently available funds. If additional funds become available in the future, it is recommended that similar improvements are examined. The City of Baytown and local subdivisions could be considered for project partnerships.

O119 Detention Basin

O119 is a major tributary of Goose Creek located near the Highlands Reservoir. The study by Halff Associates recommended solutions for the upstream segment of the channel, north of the reservoir. For this watershed planning study, only the downstream portion of the channel was considered for improvements. A 37-acre detention basin was modeled, located south of the reservoir and north of E. Wallisville Rd. The considered basin would add 220 ac-ft of storage and benefit PA4. Local subdivisions are potential partners for this improvement. The development of this basin would provide significant benefits to PA4 and should be considered if additional funding becomes available in the future.

O105-04-00 Improvements

O105-04 is a tributary located near the southeastern part of the watershed. This tributary was found to have low capacity, which is causing moderate street flooding and limited structural flooding (three structures in the 100-year event). One potential solution would include channel improvements and a detention basin, and another solution could include redirecting flow away from this tributary by extending and upsizing the storm sewer that runs along Rollingbrook Drive. These solutions were not modeled in this study, as they would serve an area with significantly fewer flooding problems than the Tier 1 areas in the watershed.

6. Auxiliary Reports

High-level environmental and geomorphological condition assessments were performed as part of the existing conditions study. Key takeaways from baseline conditions, which may affect planning and improvement efforts in the watershed, are summarized below.

6.1. Environmental

The environmental assessment was conducted based on a desktop review of available digital data from state, federal, and local agencies, as well as additional data provided by HCFCD. Constraints that were evaluated include: floodplain data, wetlands and waterbodies, protected species and their habitat, utilities, potential hazardous materials sites, and cultural resources. Constraints are discussed and shown in exhibits of **TM 1** and **TM 2**; an overview of the environmental constraints is also provided in **Exhibit 21** of the current report. Of these constraints, utilities and hazardous materials sites appear to be of the most concern for future flood management projects.

Data from the HCFCD web-based database indicates that approximately 2,800 potential hazardous materials sites are located within the watershed, primarily concentrated along major transportation routes. Further investigation of the mapped sites would be needed prior to any project design and engineering activities to determine the potential risks posed by these sites to proposed projects in the watershed.

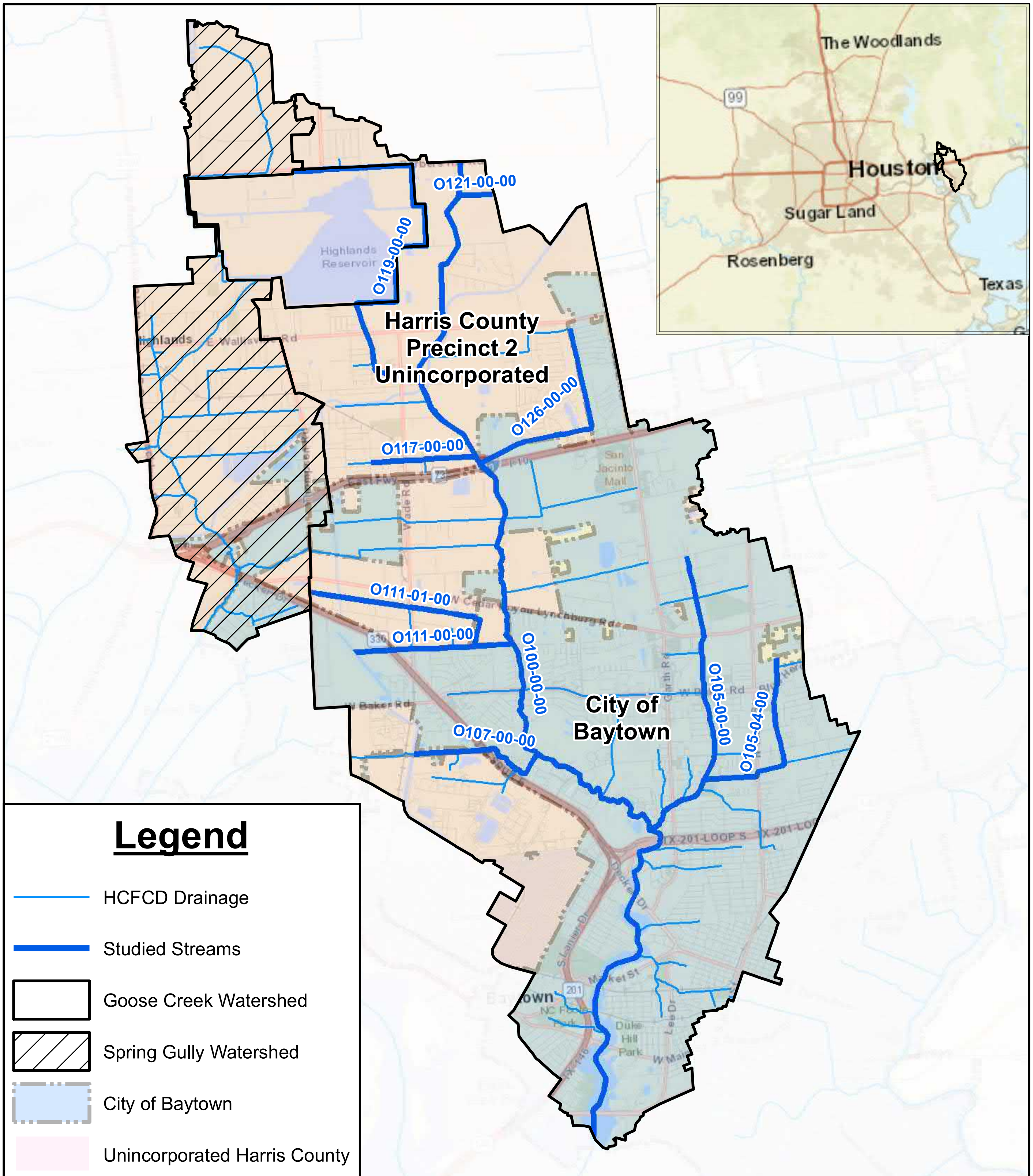
Pipeline data from the Texas Railroad Commission, the National Pipeline Mapping System, and the HCFCD web-based database were reviewed to determine the presence of pipelines. Numerous oil and gas pipelines are present, due to significant oil and gas infrastructure within and surrounding Goose Creek watershed. Publicly available data from the Texas Water Development Board and data from the HCFCD web-based database were accessed to review the presence of wells in the area. There are 59 documented water wells and 638 oil and gas wells located within the watershed. These data do not indicate the activity status of the wells; therefore, further investigation to determine if the wells are categorized as active, inactive, abandoned, or plugged would be needed during planning and design. A review of private utility providers would furnish additional information, as data regarding electrical lines, substations, water lines, wastewater lines, and other private utility resources is not accessible through publicly available data sources.

6.2. Geomorphological

A Level 1 Stream Condition Assessment (SCA) was conducted for Goose Creek watershed to evaluate the relative potential of a stream to support and maintain a diverse community of organisms. This assessment results in a Reach Condition Index (RCI) score of 1-5 for each stream, with 5 being optimal stream conditions and 1 being poor conditions. The intent of this assessment is that projects should be avoided for streams that receive high RCI scores of 4-5, as projects at these locations would result in the greatest negative environmental impact. Within Goose Creek watershed, a majority of streams have poor conditions (RCI=2). The East Fork Goose Creek tributary and the section of Goose Creek main stream south of SH 146 were rated as marginal (RCI=3). Only one stream reference unit (O104-00-00) was determined to be suboptimal (RCI=4). No streams were rated to have severe conditions (RCI=1) or optimal conditions (RCI=5). For additional details and exhibits, refer to **TM 1**.

7. Exhibits

1. Goose Creek Vicinity Map
2. Historical Losses
3. 10-Yr Flooding Inundation
4. 50-Yr Flooding Inundation
5. 100-Yr Flooding Inundation
6. 500-Yr Flooding Inundation
7. Predicted Structural Flooding
8. Level of Service
9. Problem Area Groupings
10. Project Layout
11. Phase 1
12. Phase 2
13. Phase 3
14. Existing & Proposed Right-of-Way (ROW)
15. Detention Basin Alternatives
16. Proposed Project 10-Year Benefits
17. Proposed Project 50-Year Benefits
18. Proposed Project 100-Year Benefits
19. Proposed Project 500-Year Benefits
20. All Considered Improvements
21. Environmental Constraints



Final Engineering Report

Exhibit 01
Goose Creek Vicinity Map

Miles
0 0.3750.75 1.5

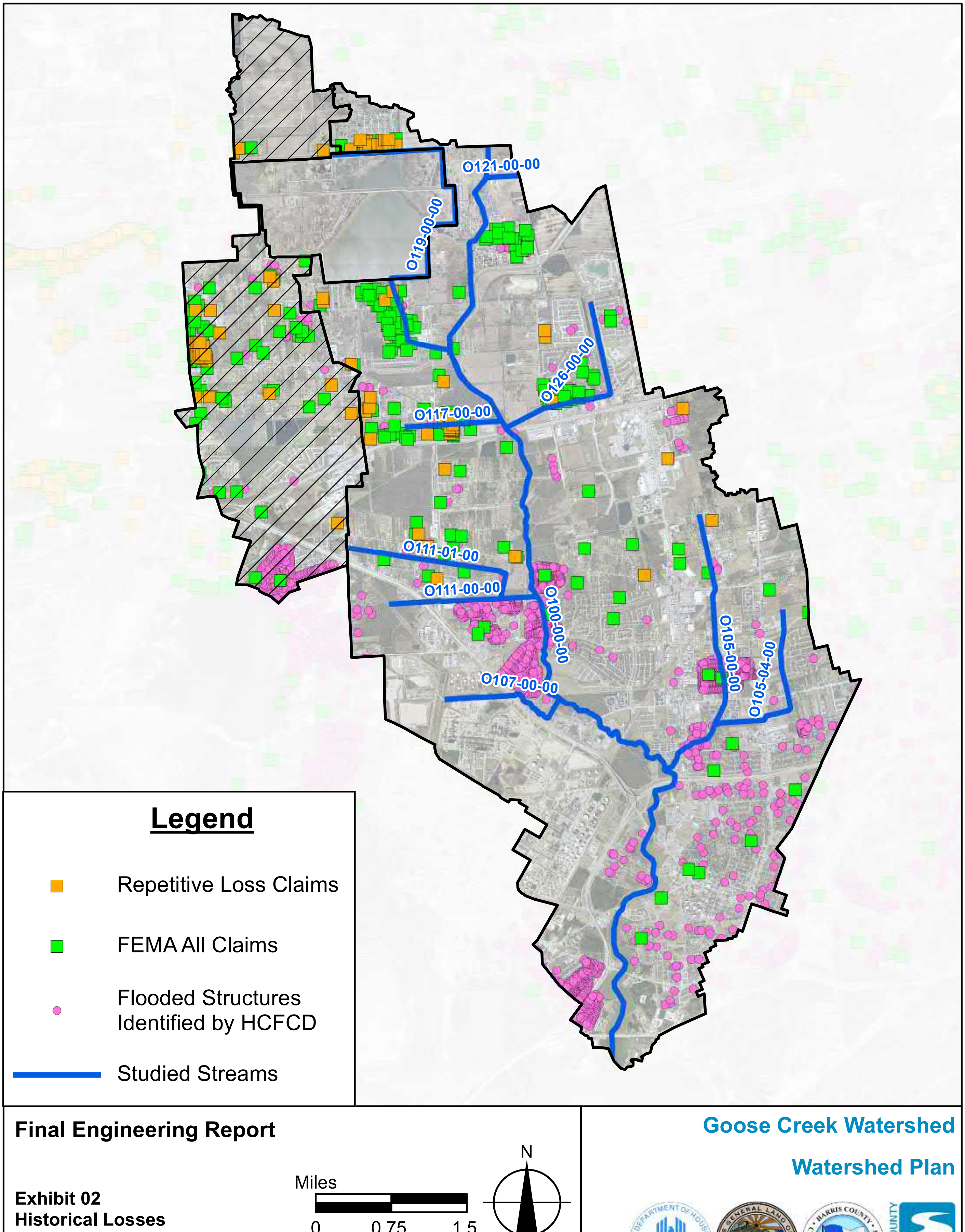
N

Created: 10/27/2020

Goose Creek Watershed

Watershed Plan

HARRIS COUNTY FLOOD CONTROL DISTRICT



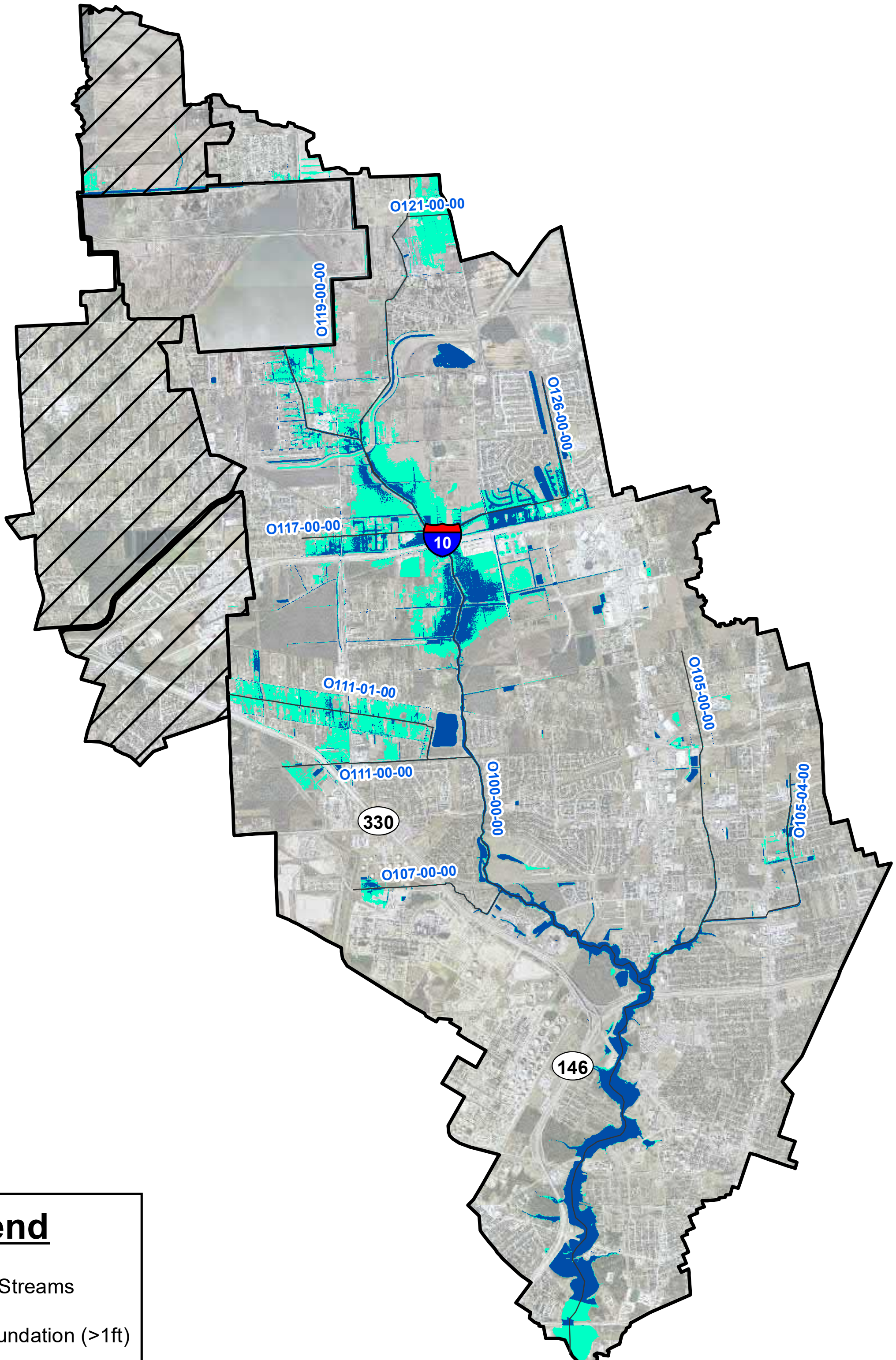
Final Engineering Report

Exhibit 02
Historical Losses

Created: 10/27/2020

Goose Creek Watershed

Watershed Plan



Legend

Studied Streams
10-Yr Inundation (>1ft)
10-Yr Inundation

Final Engineering Report

Exhibit 03
10-Yr Flooding Inundation

Miles
0 0.45 0.9 1.8

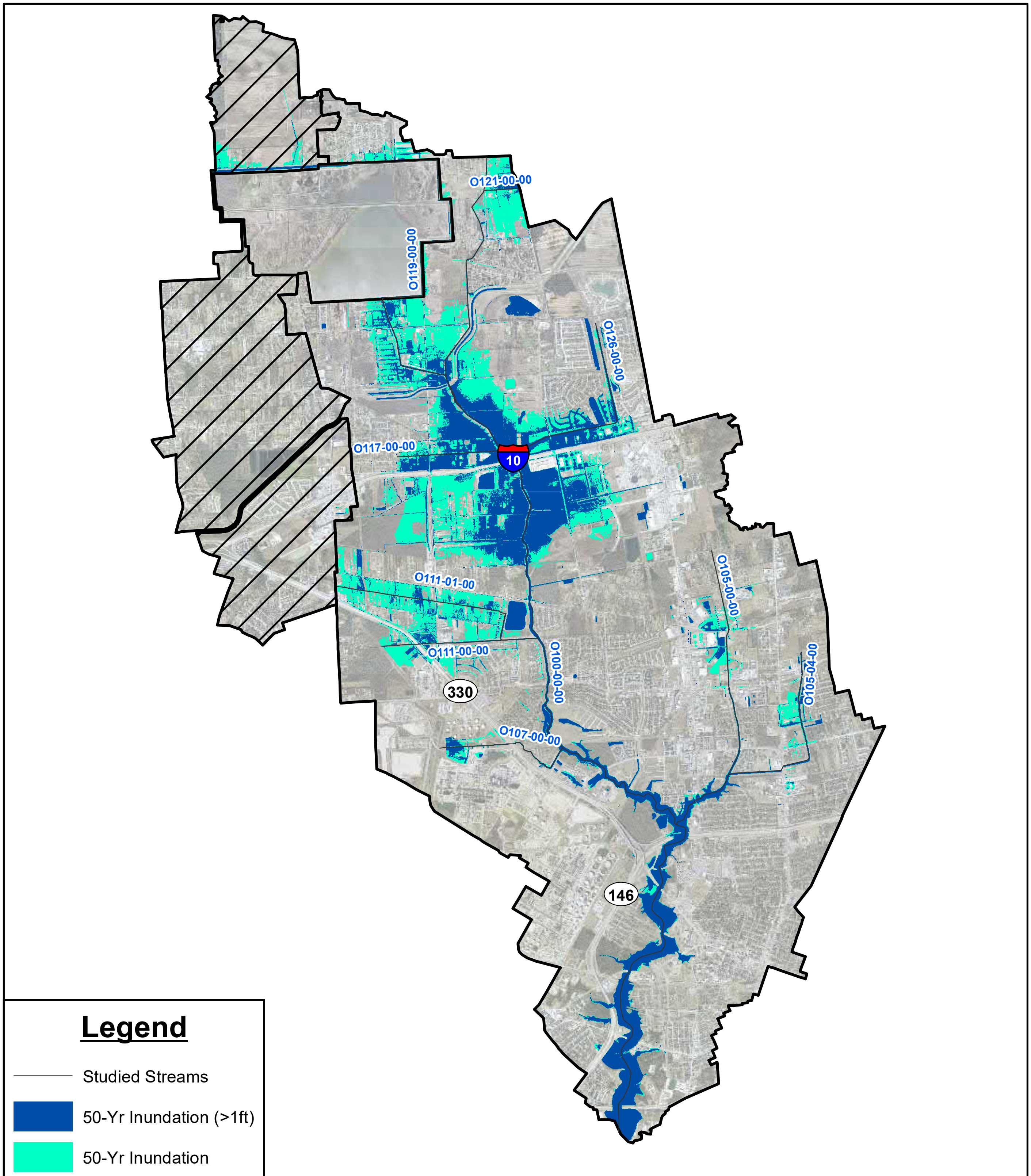
N

Created: 10/27/2020

Goose Creek Watershed

Watershed Plan

HARRIS COUNTY FLOOD CONTROL DISTRICT



Final Engineering Report

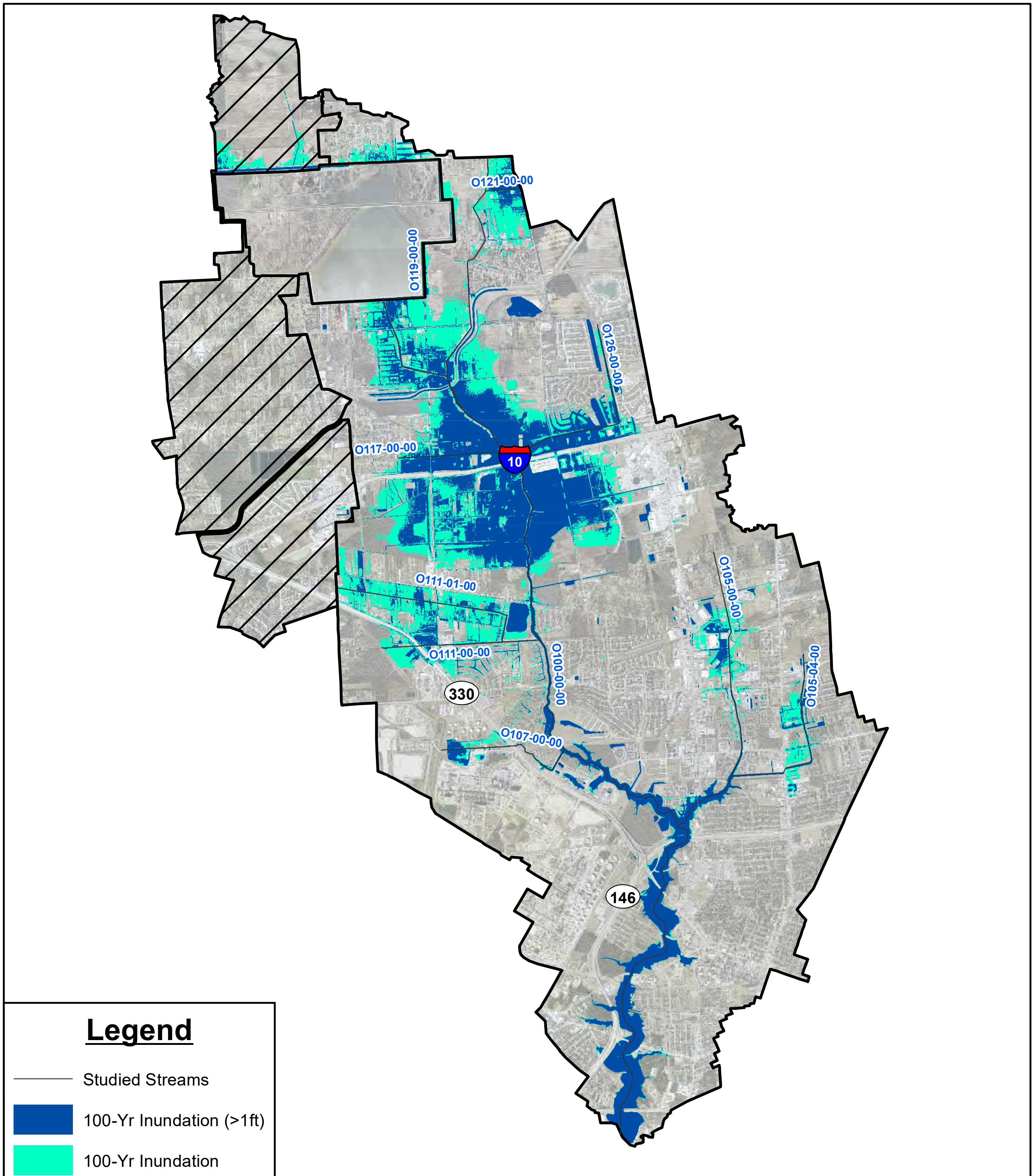
Exhibit 04
50-Yr Flooding Inundation

Created: 10/27/2020

Goose Creek Watershed

Watershed Plan

HARRIS COUNTY FLOOD CONTROL DISTRICT



Final Engineering Report

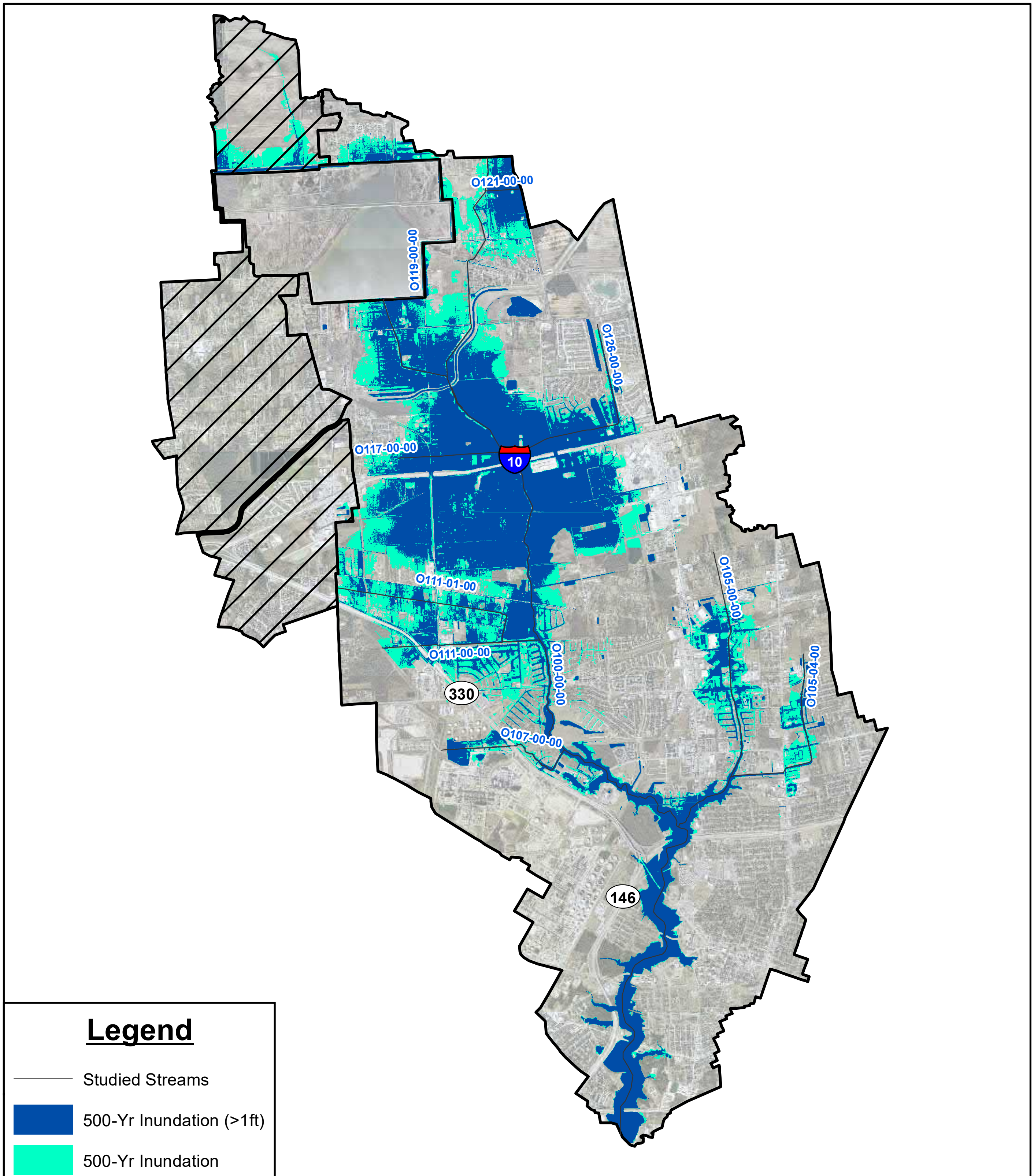
Exhibit 05
100-Yr Flooding Inundation

Created: 10/27/2020

Goose Creek Watershed

Watershed Plan

HARRIS COUNTY FLOOD CONTROL DISTRICT



Final Engineering Report

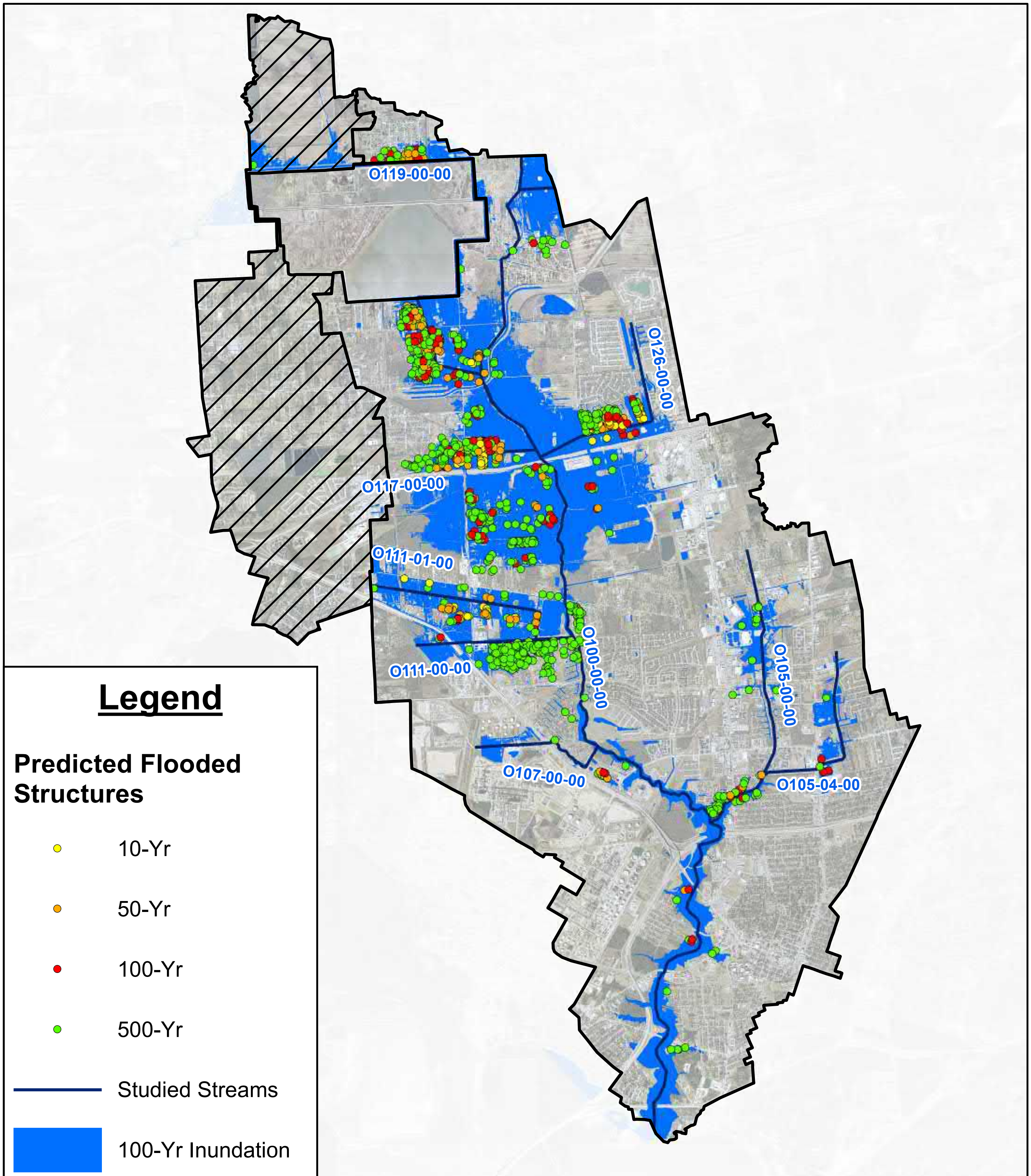
Exhibit 06
500-Yr Flooding Inundation

Created: 10/27/2020

Goose Creek Watershed

Watershed Plan

HARRIS COUNTY FLOOD CONTROL DISTRICT



Final Engineering Report

Exhibit 07
Predicted Structural Flooding

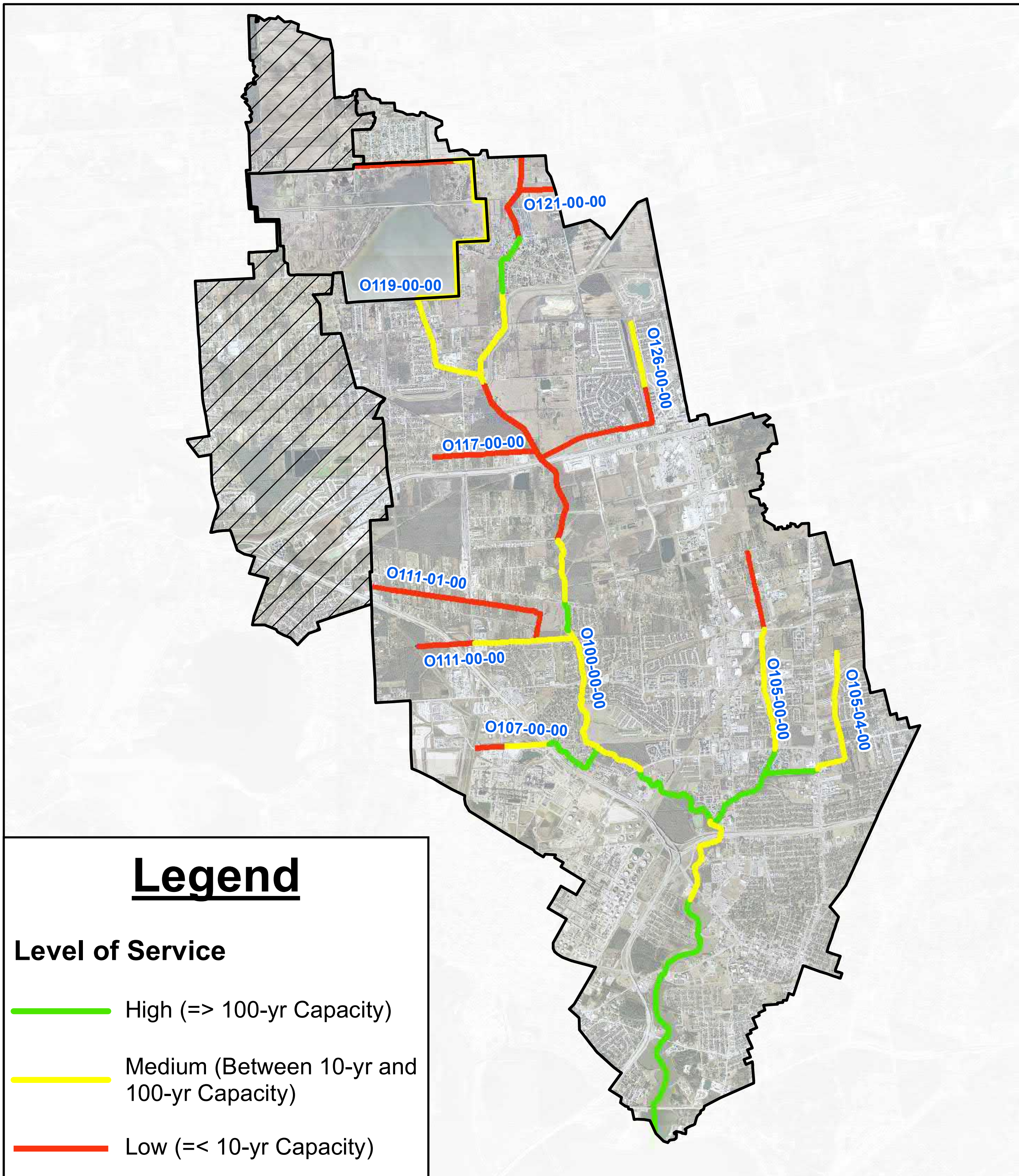
Miles
0 0.75 1.5

N

Created: 10/27/2020

Goose Creek Watershed

Watershed Plan



Legend

Level of Service

High (=> 100-yr Capacity)

Medium (Between 10-yr and 100-yr Capacity)

Low (=< 10-yr Capacity)

Final Engineering Report

Exhibit 08
Level of Service

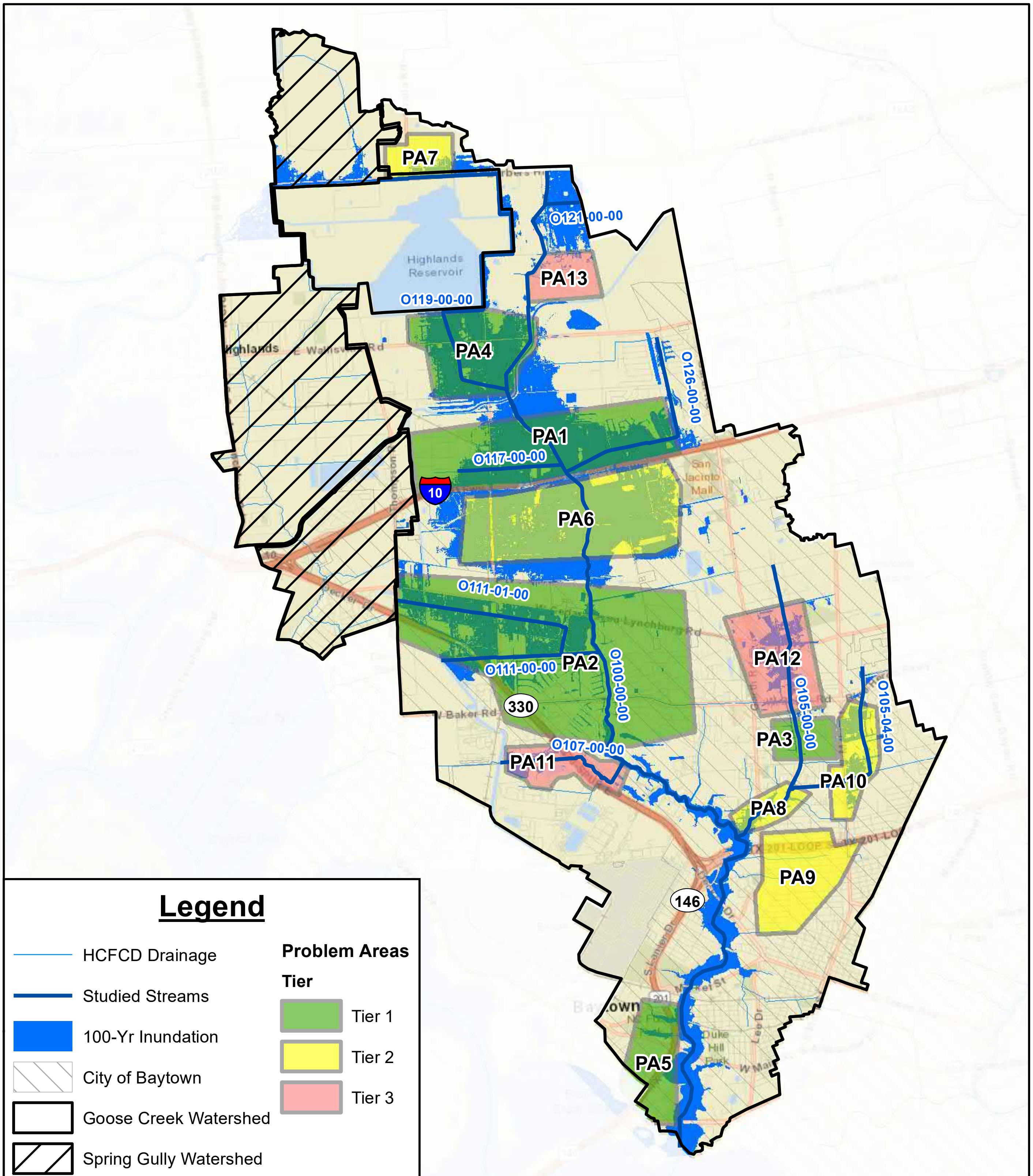
Miles
0 0.75 1.5

N

Created: 10/27/2020

Goose Creek Watershed

Watershed Plan



Final Engineering Report

Exhibit 09
Problem Area Groupings

Miles

0 0.45 0.9 1.8

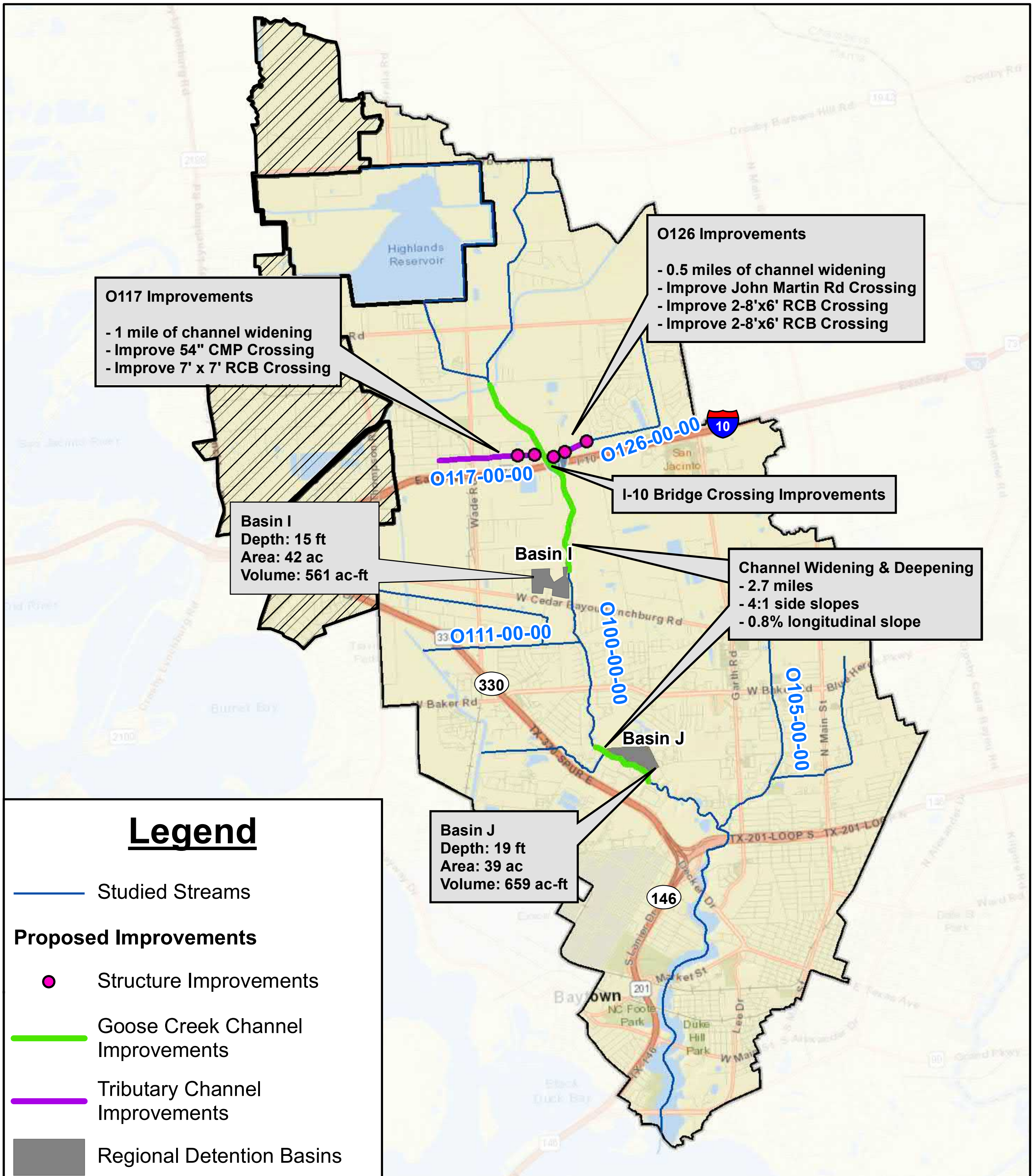
N

Created: 10/27/2020

Goose Creek Watershed

Watershed Plan

HARRIS COUNTY FLOOD CONTROL DISTRICT



Final Engineering Report

Exhibit 10
Project Layout

Miles
0 0.45 0.9 1.8

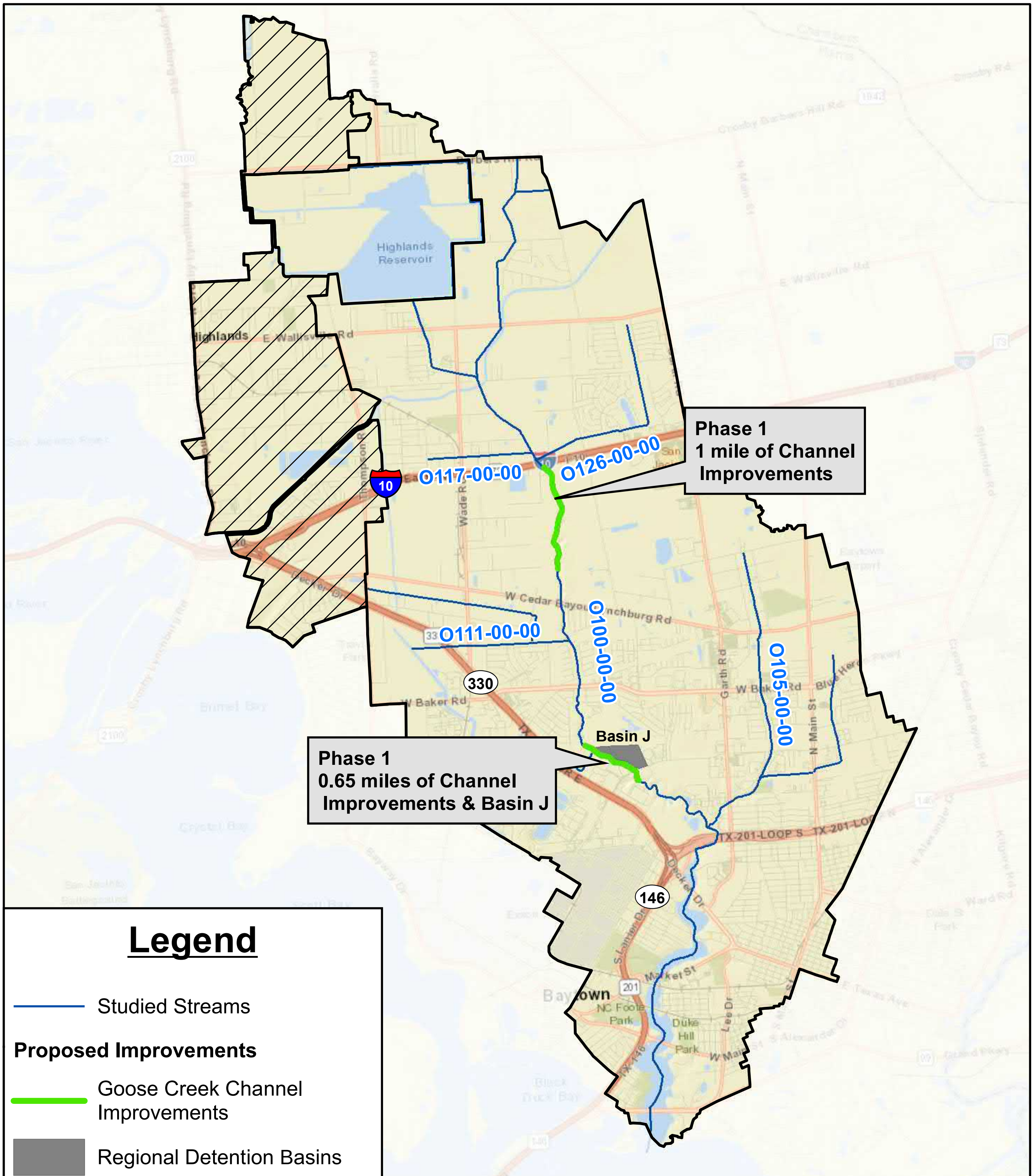
N

Created: 11/17/2020

Goose Creek Watershed

Watershed Plan

HARRIS COUNTY FLOOD CONTROL DISTRICT



Legend

Studied Streams

Proposed Improvements

Goose Creek Channel Improvements

Regional Detention Basins

Final Engineering Report

Exhibit 11
Phase 1

Miles
0 0.45 0.9 1.8

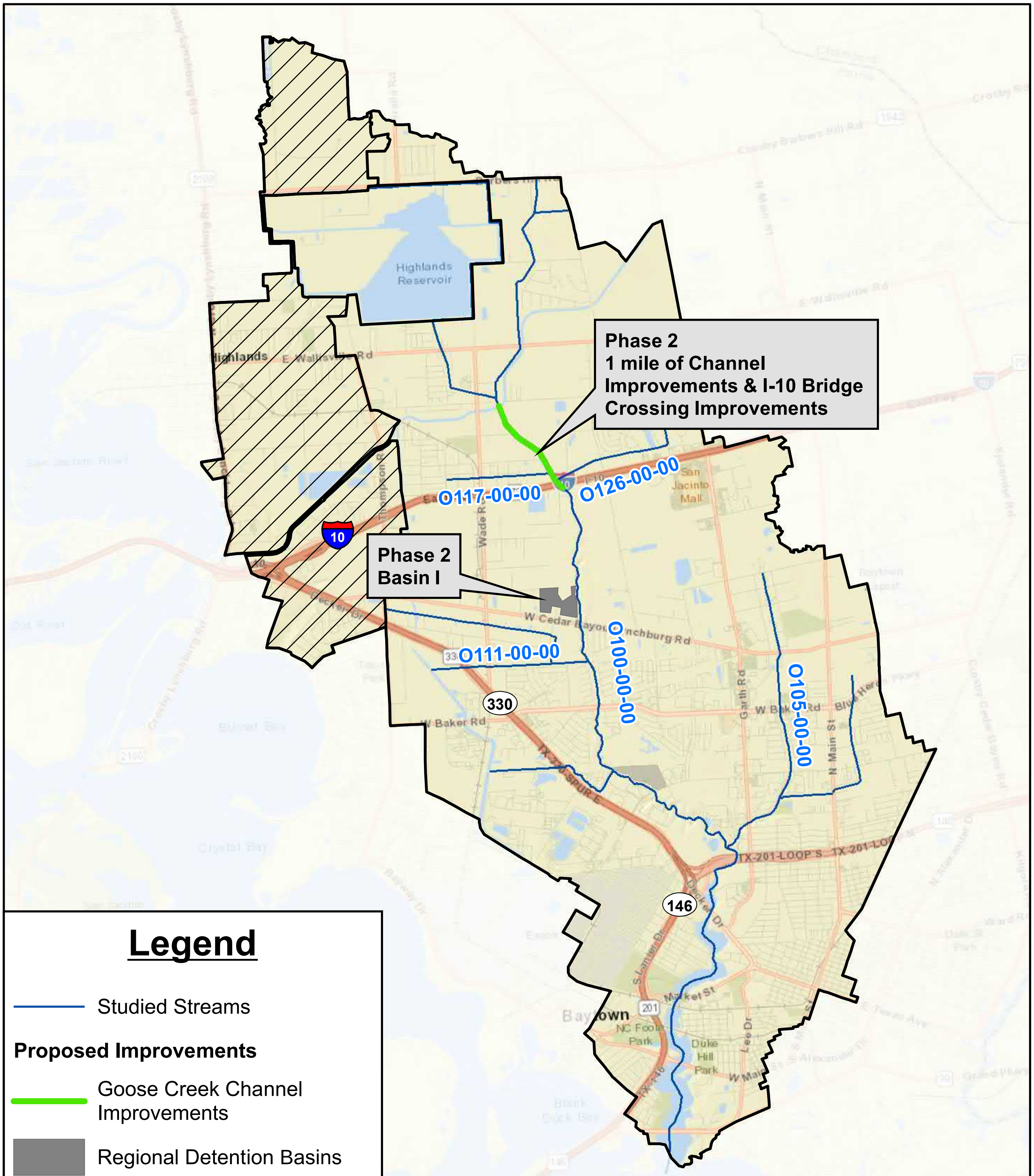
N

Created: 10/27/2020

Goose Creek Watershed

Watershed Plan

HARRIS COUNTY FLOOD CONTROL DISTRICT



Final Engineering Report

Exhibit 12
Phase 2

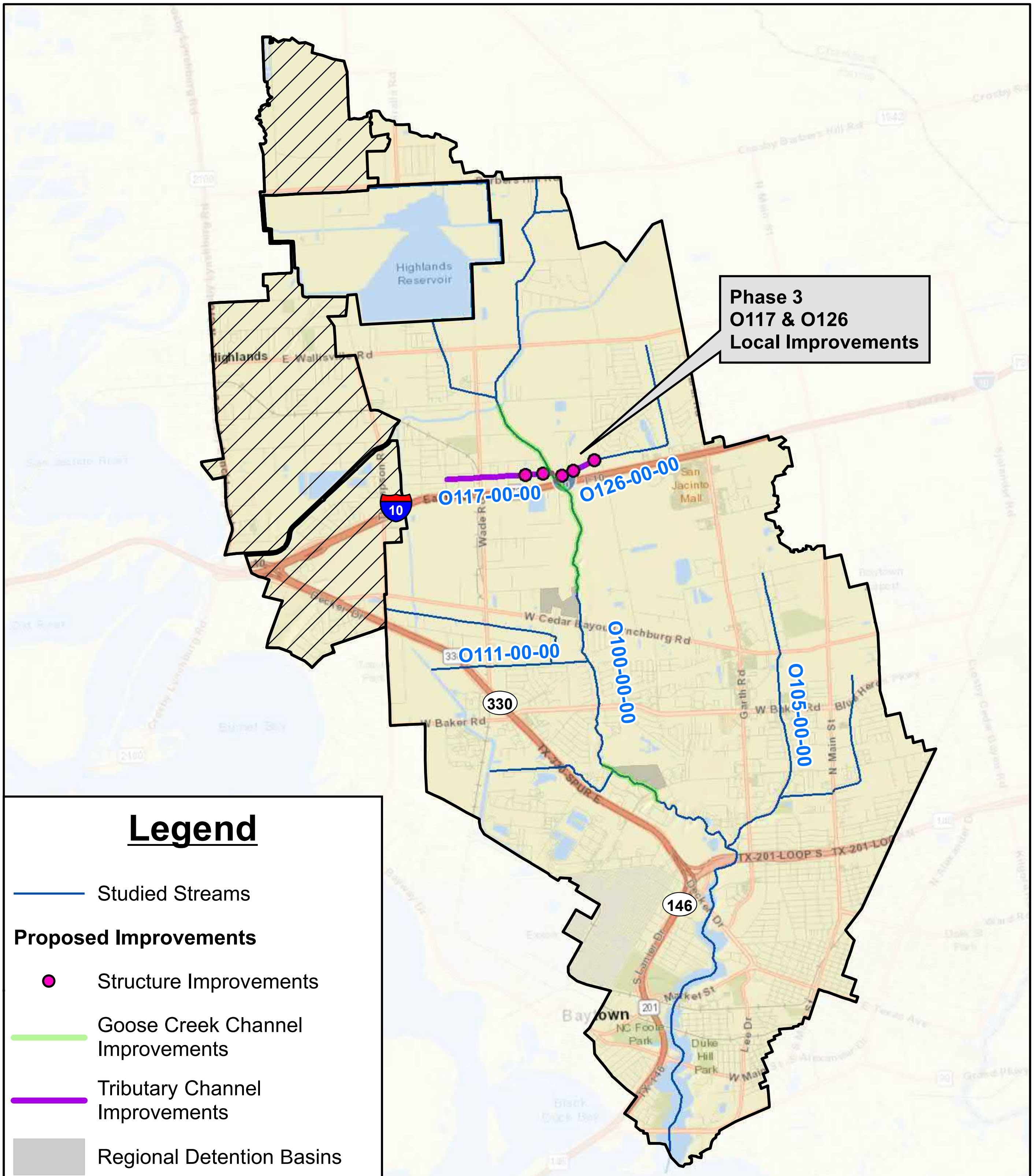
Miles
0 0.45 0.9 1.8

N

Created: 10/27/2020

Goose Creek Watershed

Watershed Plan



Final Engineering Report

Exhibit 13
Phase 3

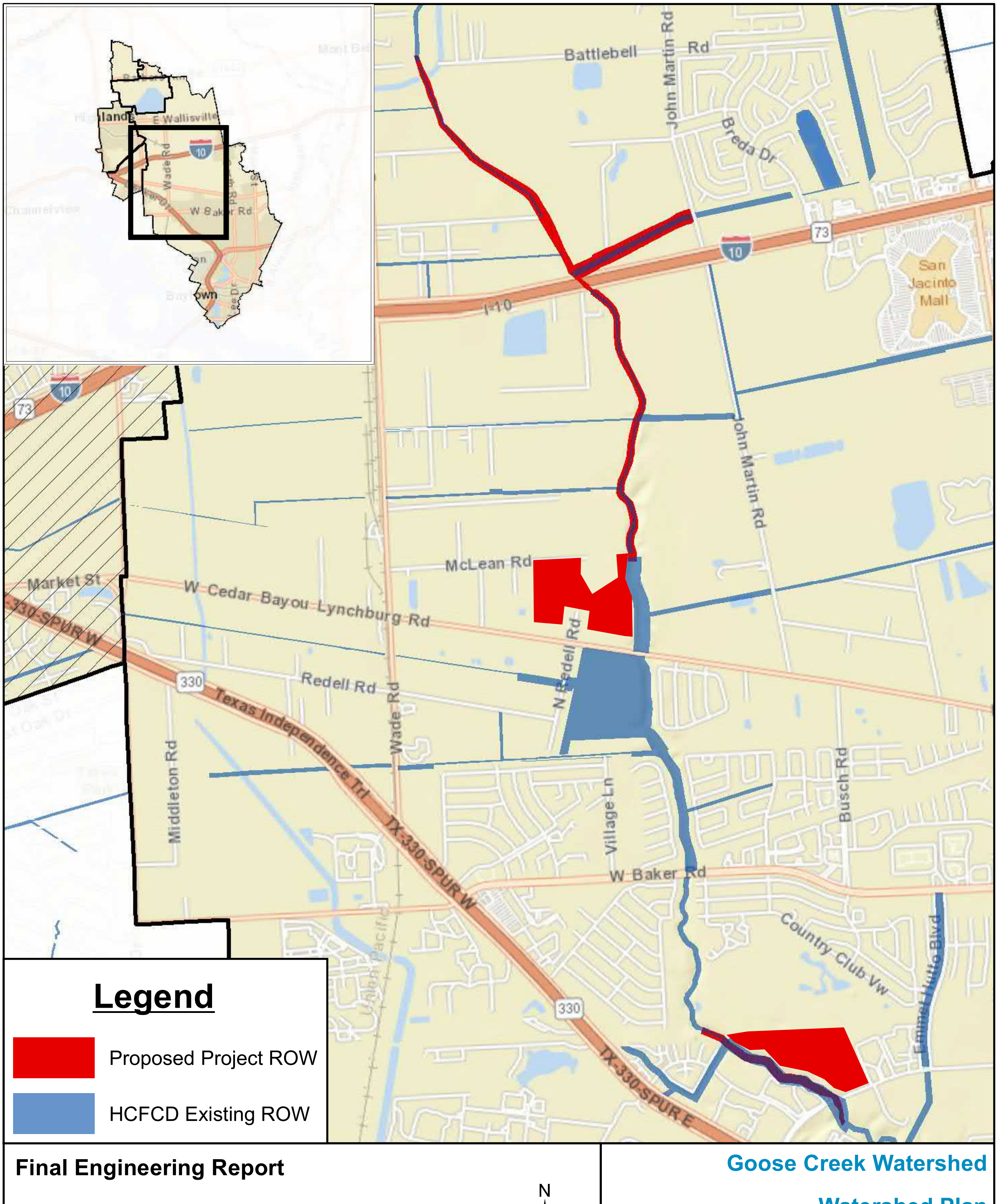
Miles
0 0.45 0.9 1.8

N

Created: 10/27/2020

Goose Creek Watershed

Watershed Plan



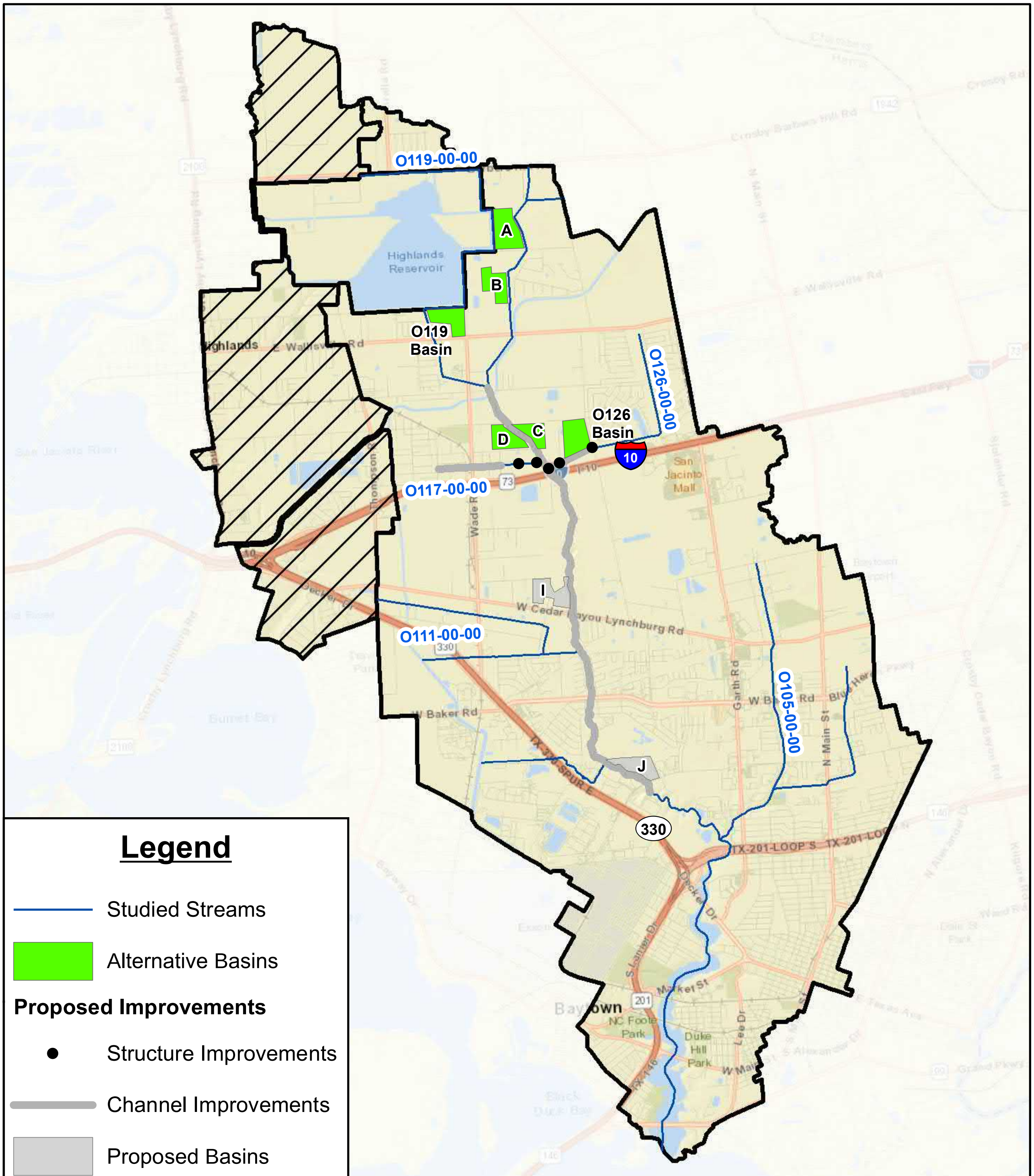
Final Engineering Report

Exhibit 14
Existing & Proposed
Right-of-Way (ROW)

Created: 10/27/2020

Goose Creek Watershed

Watershed Plan



Final Engineering Report

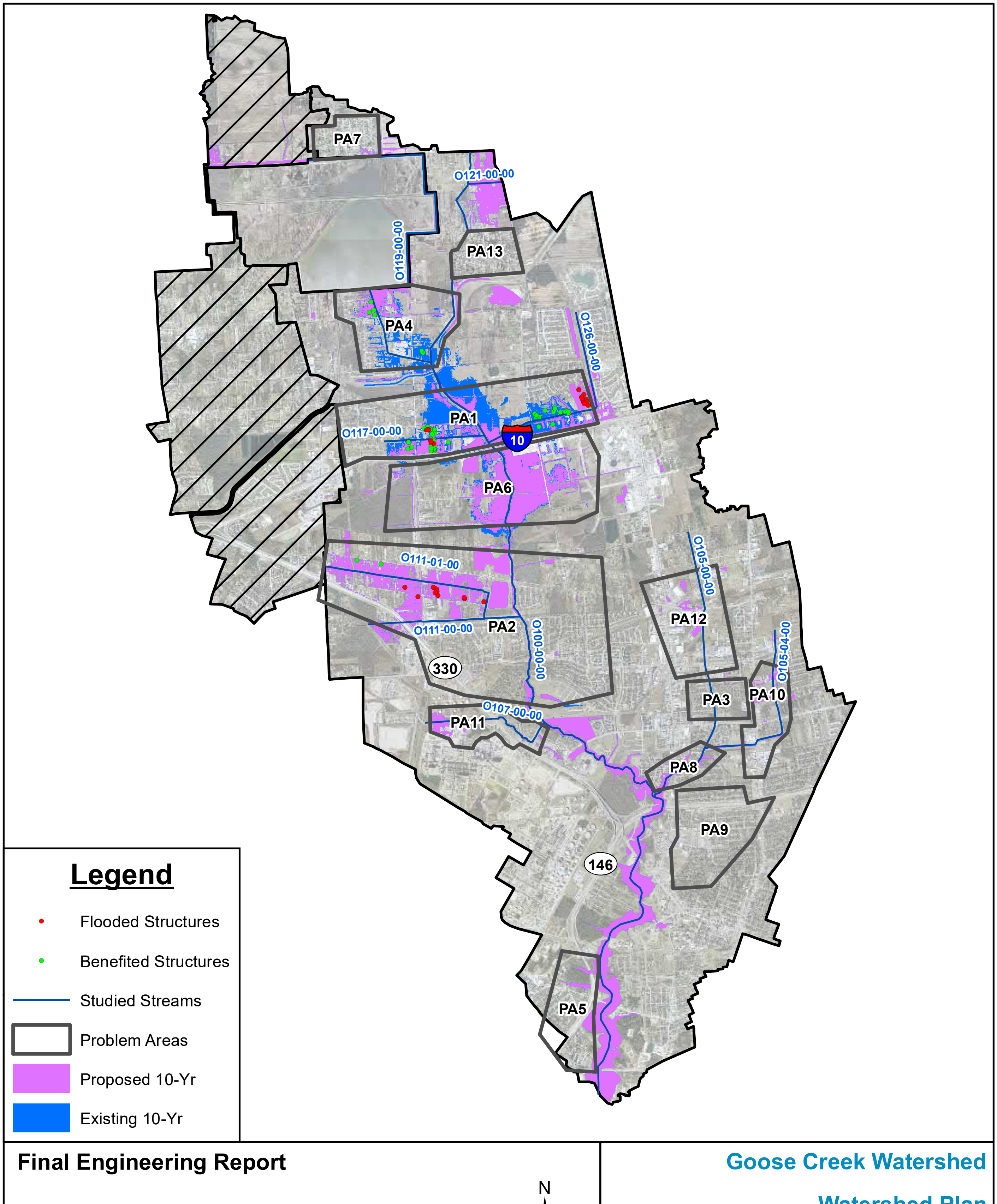
Exhibit 15
Detention Basin Alternatives

Miles
0 0.425 0.85 1.7

N

Created: 8/26/2020

Goose Creek Watershed



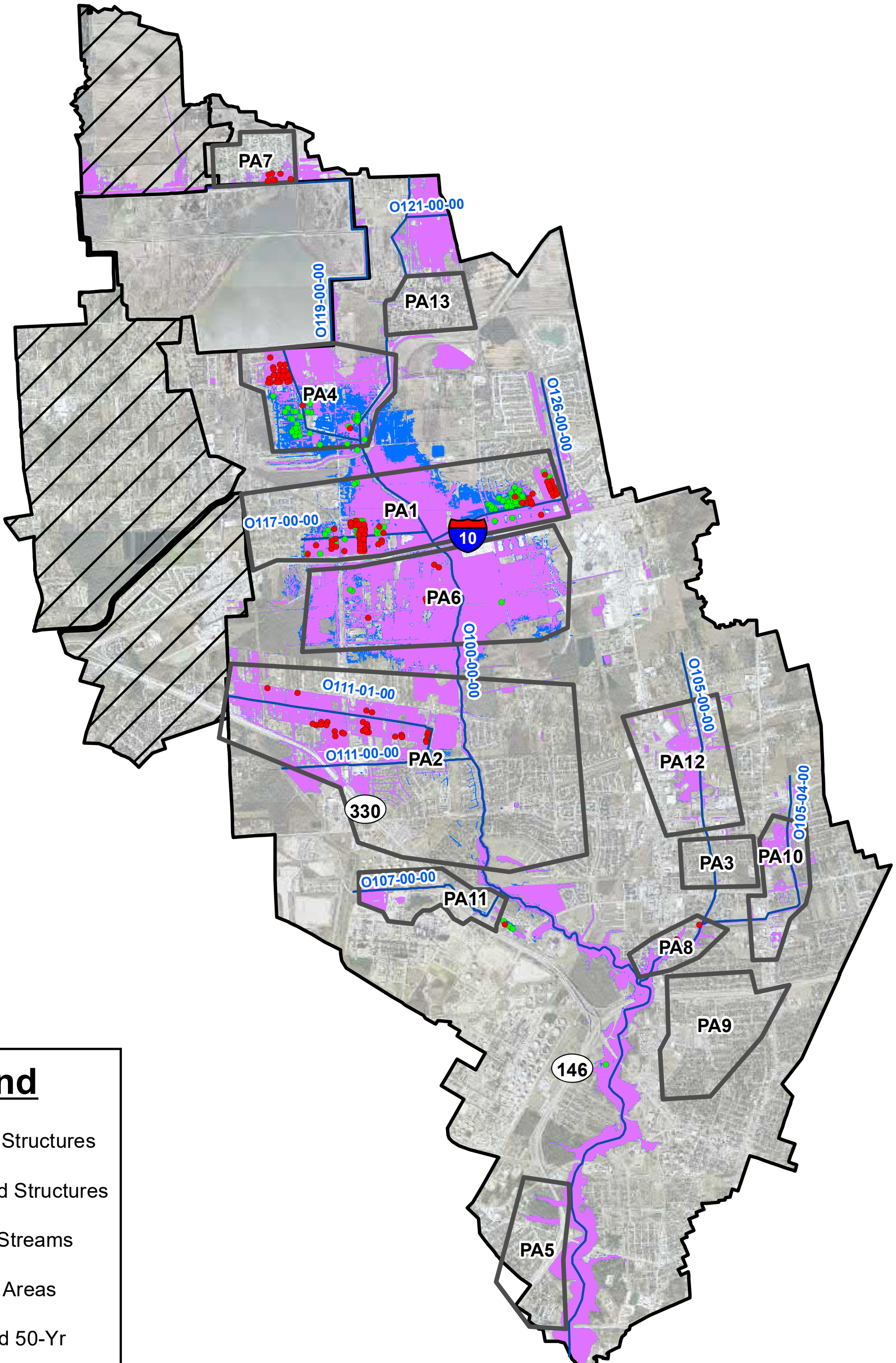
Final Engineering Report

Exhibit 16
Proposed Project 10-Year Benefits

Created: 10/27/2020

Goose Creek Watershed

Watershed Plan



Legend

- Flooded Structures
- Benefited Structures
- Studied Streams
- Problem Areas
- Proposed 50-Yr
- Existing 50-Yr

Final Engineering Report

Exhibit 17
Proposed Project 50-Year Benefits

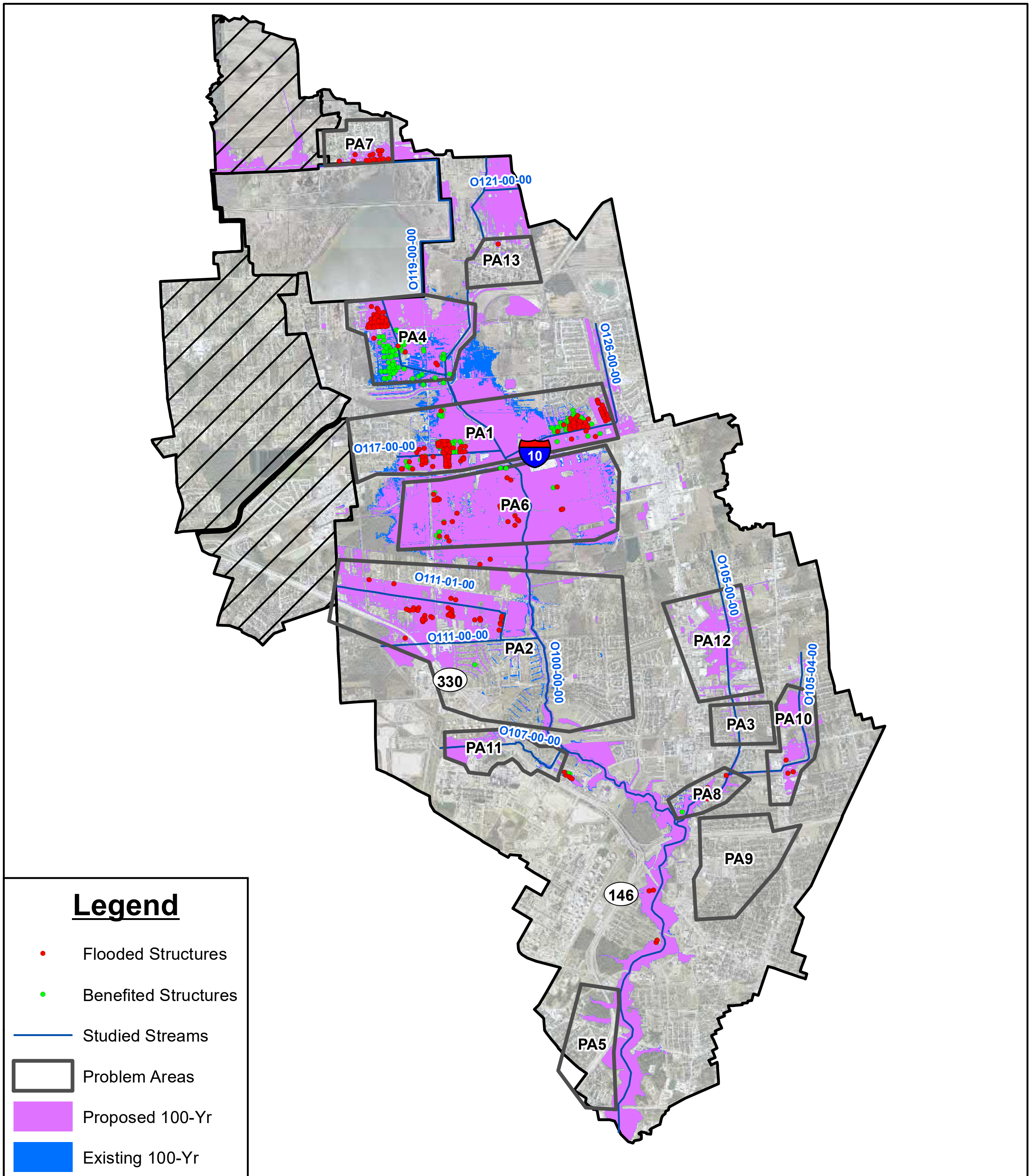
Miles
0 0.45 0.9 1.8

N

Created: 10/27/2020

Goose Creek Watershed

Watershed Plan



Final Engineering Report

Exhibit 18
Proposed Project 100-Year Benefits

Miles
0 0.45 0.9 1.8

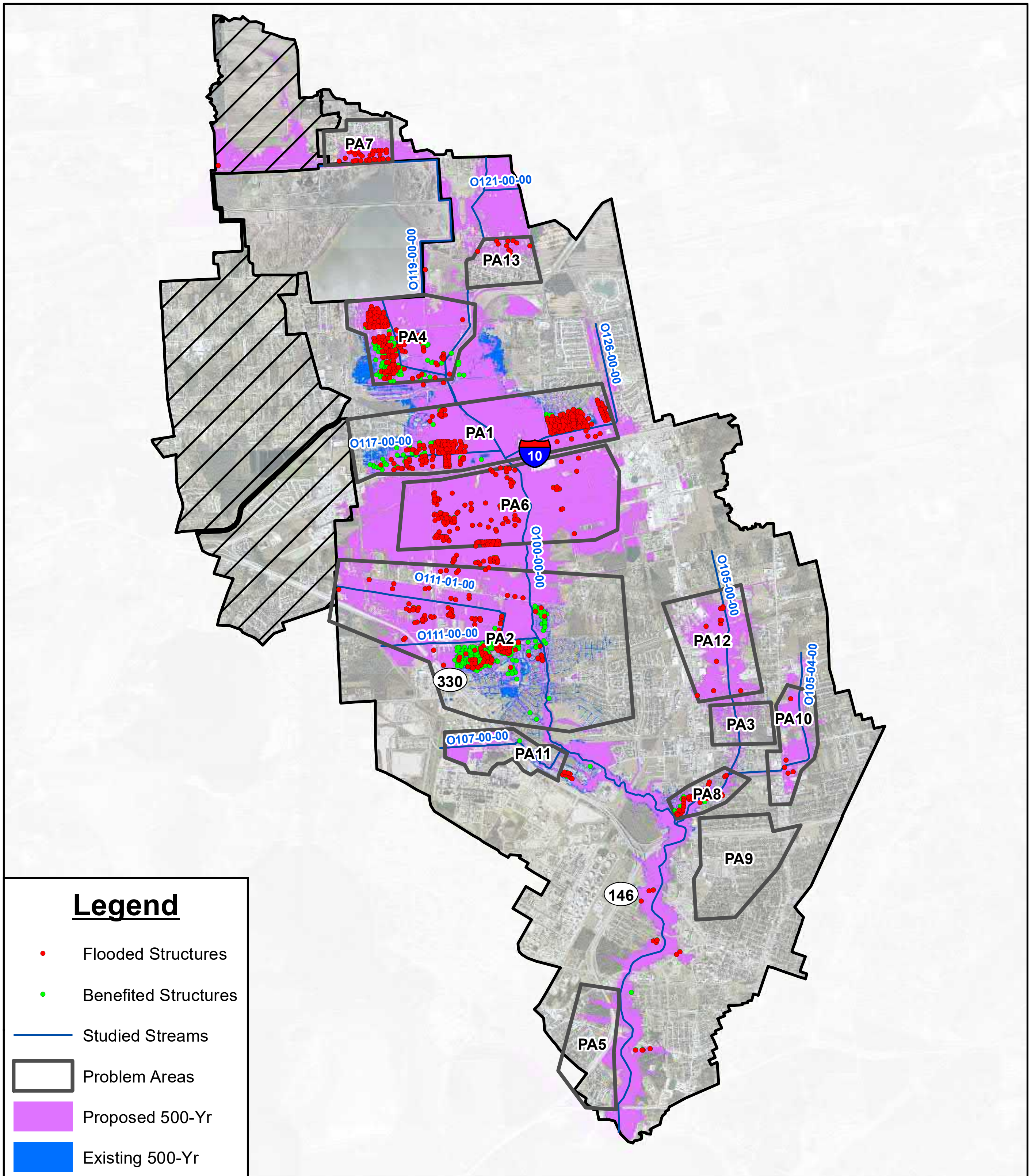
N

Created: 10/27/2020

Goose Creek Watershed

Watershed Plan

HARRIS COUNTY FLOOD CONTROL DISTRICT



Final Engineering Report

Exhibit 19

Proposed Project 500-Year Benefits

Miles

0 0.45 0.9 1.8

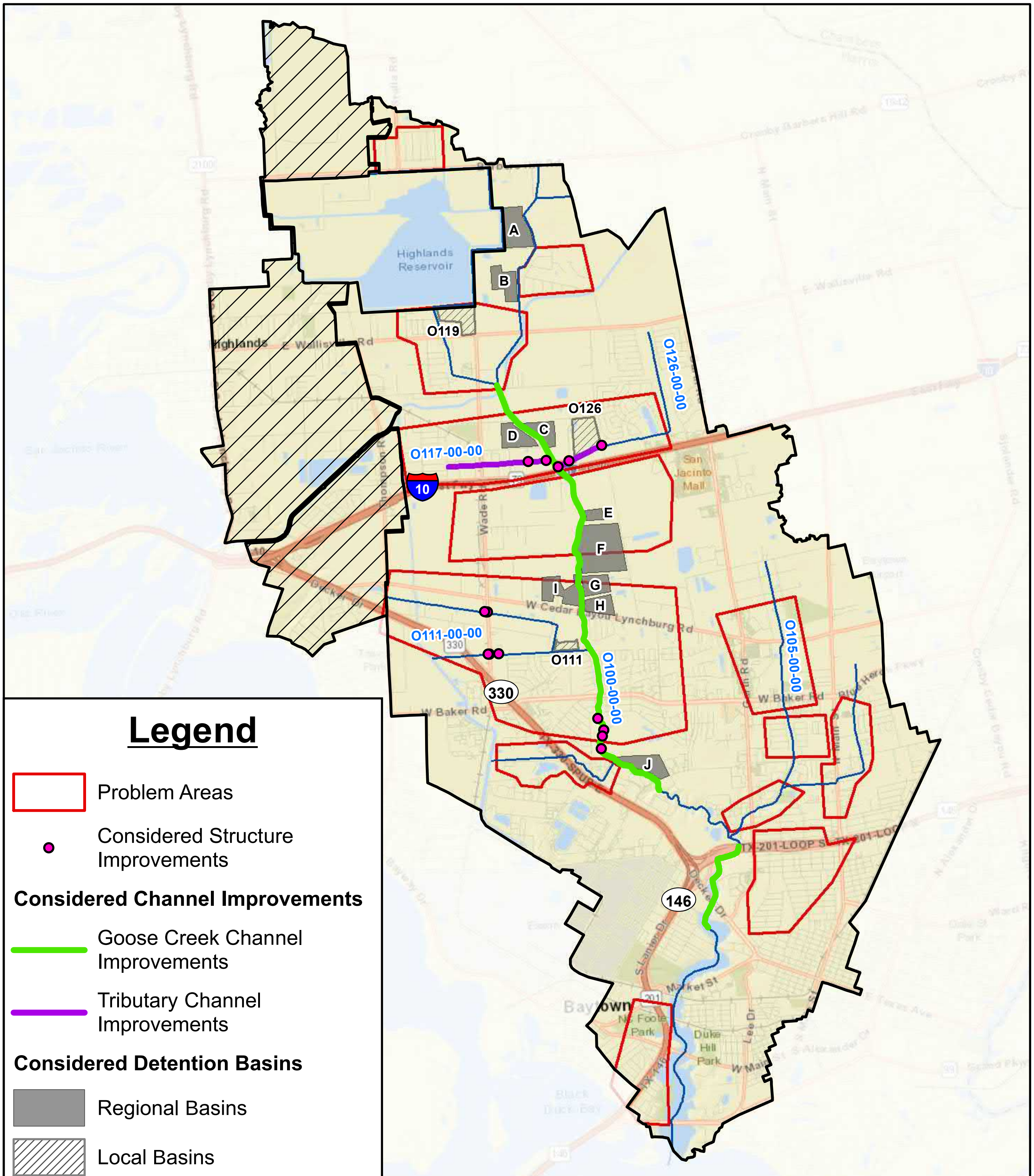
N

Created: 10/27/2020

Goose Creek Watershed

Watershed Plan

HARRIS COUNTY FLOOD CONTROL DISTRICT



Final Engineering Report

Exhibit 20
All Considered Improvements

Miles
0 0.85 1.7

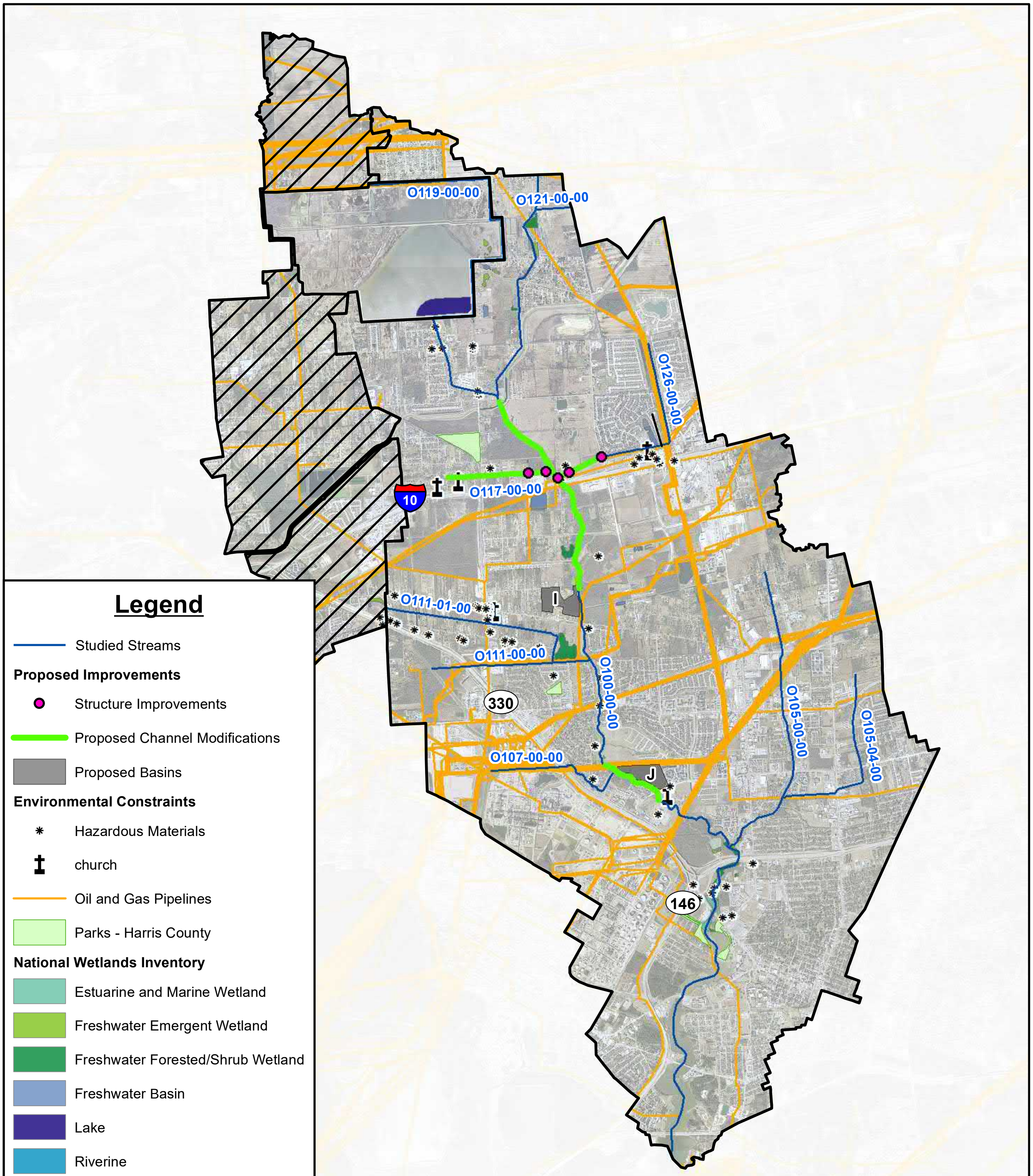
N

Created: 10/27/2020

Goose Creek Watershed

Watershed Plan

HARRIS COUNTY FLOOD CONTROL DISTRICT



Final Engineering Report

Exhibit 21
Environmental Constraints

Miles
0 0.85 1.7

N

Created: 10/27/2020

Goose Creek Watershed

Watershed Plan

HARRIS COUNTY FLOOD CONTROL DISTRICT

8. Appendices

Appendix 1 - Problem Area Summary Table

Appendix 2 - HCAD Parcels

Appendix 3 - Cost Estimates

Appendix 1

Problem Area Summary Table

AECOM

Problem Area Summary Table

				0.45			*0.45*		*0.1*				
				Historical Actual Flooding (45%)		***Predicted Structural Flooding (45%)***			***Non-Structural Flooding (10%)***				
[1] Problem Area Name	**[1a] Watershed/Subwatershed**	**[2] Primary Jurisdiction**	**[3] Flooding Source**	**[4] Historical Flooding Data**	***[5] Historical Flooding***	**[6] Total Predicted Structural Flooding (1% AEP)***	**[7] Predicted Structural Flooding (PSF50)**	***[8] Predicted Structural Flooding***	**[9] Predicted Roadway Flooding (Total Length >1-foot during 1% AEP)**	***[10] Predicted Roadway Flooding***	***[11] Total Weighted Score***	**[12] Tier Classification**	**[13] Comments**
				(number of homes)	***(propotional value)***	**(number of structures)**	**(structures per year)**	***(proportional value)***	**(miles)**	***(proportional value)***			
PA01	O100-00-00/O117-00-00/O126-00-00	Unincorporated	Overbank flow and high TW from Goose Creek main stem	240	*38*	214	460.9	*100*	5.3	*100*	*72*	Tier 1	
PA02	O100-00-00/O111-00-00	City of Baytown	Overbank flow and high TW from Goose Creek main stem	635	*100*	38	112.1	*24*	2.7	*51*	*61*	Tier 1	
PA03	O100-00-00/O105-00-00	City of Baytown	Local stormwater drainage limitation	328	*52*	0	0	*0*	0.0	*0*	*23*	Tier 1	This problem area is classified as Tier 1 primarily due to the Historical Structural Flooding count; however, discussions between HCFCD and the City of Baytown have led to the conclusion that the reported Historical Structural Flooding may not be accurate in this locations, and this areas might be less susceptible to flooding.
PA04	O100-00-00/O119-00-00	Unincorporated	Overbank flow and local stormwater drainage limitation	60	*9*	114	125.6	*27*	2.0	*37*	*20*	Tier 1	
PA05	O100-00-00/O100-00-00	City of Baytown	Local stormwater drainage limitation; possible coastal influence or overflow from San Jacinto watershed	233	*37*	0	0	*0*	0.2	*4*	*17*	Tier 1	This problem area is classified as Tier 1 primarily due to the Historical Structural Flooding count; however, discussions between HCFCD and the City of Baytown
PA06	O100-00-00/O100-00-00	City of Baytown	Overbank flow and high TW from Goose Creek main stem	12	*2*	32	32.1	*7*	1.0	*19*	*6*	Tier 2	
PA07	O100-00-00/O119-00-00	Unincorporated	Overbank flow and local stormwater drainage limitation	43	*7*	15	12.6	*3*	0.3	*6*	*5*	Tier 2	This problem area is being currently studied in an ongoing project by Harris County Flood Control District and Halff Associates. This study will yield detailed flood mitigation alternatives that will be incorporated in the Watershed Plan.
PA08	O100-00-00/O105-00-00	City of Baytown	Overbank flow	24	*4*	10	9.9	*2*	0.5	*9*	*4*	Tier 2	
PA09	Not Applicable	City of Baytown	Local stormwater drainage limitation	35	*6*	0	0	*0*	0.0	*0*	*2*	Tier 2	
PA10	O100-00-00/O105-04-00	City of Baytown	Overbank flow	1	*0*	3	1.7	*0*	0.8	*14*	*2*	Tier 2	
PA11	O100-00-00/O107-00-00	City of Baytown	Overbank flow	14	*2*	0	0.1	*0*	0.2	*4*	*1*	Tier 3	
PA12	O100-00-00/O105-00-00	City of Baytown	Local stormwater drainage limitation	5	*1*	0	1.1	*0*	0.3	*5*	*1*	Tier 3	
PA13	O100-00-00/O100-00-00	Unincorporated	Local stormwater drainage limitation	12	*2*	1	1.5	*0*	0.0	*0*	*1*	Tier 3	
Max				635		214	460.9		5.3				*The maximum value of each metric category*

AECOM

Notes and Definitions

[4] Historical Flooding (data value) - Total historical flooding from the multiple events recorded in the HCFCD database – (Events include Imelda 2019, Harvey 2017, Memorial Day 2015, Tax Day, and others).

[5] Historical Flooding (proportional value) - This column in red italic font provides a formula for numerical scoring of the factor in the preceding column for ranking the problem area. The numerical factor is normalized against the highest number of all values in the preceding column. For example, the maximum historical flooding value for all problem areas considered is 635 which provides a score of 100 for this particular factor. All other historical values are normalized against this maximum value.

[6] Predicted Structural Flooding (1% AEP) - Number of homes predicted to flood during storm event with a 1% annual exceedance probability. This value is not used in the scoring and ranking of problem areas.

[7] Predicted Structural Flooding (PSF50) = Probable Structural Flooding (all structures) predicted to occur in the problem area over a 50-year period. This statistic is based on four predicted frequency events, i.e. [(N10yr x 5) + ((N50yr-N10yr) x 1) + ((N100yr-N50yr) x 0.5) + ((N500yr-N100yr) x 0.1)] = theoretical total cumulative flooding over a 50-year period

[**8] Predicted Structural Flooding (proportional value) -** This column in red italic font provides a formula for numerical scoring of the factor in the preceding column for ranking the problem area. The numerical factor is normalized against the highest number of all values in the preceding column. For example, the maximum predicted structural flooding value for all problem areas considered is 457.2 which provides a score of 100 for this particular factor. All other predicted values are normalized against this maximum value.

[9] Predicted Roadway Flooding (Total Length >1-foot in 1% AEP) - Total length of all roadways in miles flooded by more than 1 foot during 1% AEP storm event for all classifications of roadways within the problem area.

[10] Predicted Roadway Flooding (proportional value) - This column in red italic font provides a formula for numerical scoring of the factor in the preceding column for ranking the problem area. The numerical factor is normalized against the highest number of all values in the preceding column. For example, the maximum predicted roadway flooding value for all problem areas considered is 8.5 miles which provides a score of 100 for this particular factor. All other predicted values are normalized against this maximum value.

[11] Total Weighted Score - A weighting factor that is calculated using the predicted structural flooding (PASF-50), the historical structural flooding count, and the length of roadway flooded by more than 1 foot. This score is uniformly applied across all watersheds and is used to determine the Tier Classification

Appendix 2

HCAD Parcels

AECOM

Appendix 2. HCAD Information

Phase	Project Component	HCAD Number(s)	Current Owner	Market Value
1	Basin J	410220020352	ATHARI REAL ESTATE LTD	$ 1,083,011
1	O100 Channel Improvement	591440010056	GREENE KENNETH	$ 1,213
1	O100 Channel Improvement	591440010039	BAPTISTE HENRY	$ 1,228
1	O100 Channel Improvement	591440010032	SWINDLE JIM	$ 1,549
1	O100 Channel Improvement	451440010136	CENTERPOINT ENERGY HOU ELE	$ 2,962
1	O100 Channel Improvement	591440010074	LOPEZ PRIMITIVO	$ 12,937
1	O100 Channel Improvement	410220000019	EQUISTAR CHEMICALS LP	$ 17,325
1	O100 Channel Improvement	591440010069	GONZALEZ CELESTINO	$ 24,437
1	O100 Channel Improvement	591440010078	BAPTISTE ERNESTINE J	$ 26,096
1	O100 Channel Improvement	591440010063	RABLOT ELTON	$ 32,579
1	O100 Channel Improvement	591440010079	DELAGARZA EDUARDO C	$ 39,810
1	O100 Channel Improvement	591510010154	MORALES ALFREDO & SYLVIA	$ 51,540
1	O100 Channel Improvement	410220000105	EXXON PIPELINE 00795	$ 69,478
1	O100 Channel Improvement	410220020033	EXXON PIPELINE 00665	$ 73,224
1	O100 Channel Improvement	591440010068	HERNANDEZ ALFREDO JR	$ 77,797
1	O100 Channel Improvement	591510010005	HUA DAVE V	$ 94,419
1	O100 Channel Improvement	591440010037	RABLOT ELTON	$ 96,919
1	O100 Channel Improvement	591440010073	TORRES SAUL & OLGA	$ 98,689
1	O100 Channel Improvement	591440000256	JONES KELVIN &	$ 135,801
1	O100 Channel Improvement	591440000130	HANNOVER ESTATES LTD	$ 203,834

Phase	Project Component	HCAD Number(s)	Current Owner	Market Value
1	O100 Channel Improvement*	1155680000002	KJEX PROPERTIES LLC	$ 439,063
1	O100 Channel Improvement	591440000309	DIETSMAN REALTY	$ 759,610
1	O100 Channel Improvement	591440000131	HANNOVER ESTATES LTD	$ 1,225,909
1	O100 Channel Improvement	591440000025	WEST LITTLE YORK 62 AC LTD	$ 2,304,060
1	O100 Channel Improvement*	1155680000001	RT BAYTOWN PARTNERS LLC	$ 14,097,741
1	O100 Channel Improvement*	410220000024	EXXON CORP 03042	$ 14,185,597
1	O100 Channel Improvement	591440000325	HARRIS COUNTY FLOOD CONTROL DISTRICT	$ -
2	Basin I	591440000210	CITY OF BAYTOWN	$ 1,000,000 (Estimate) HCAD Value = $0
2	Basin I	591440000326	CITY OF BAYTOWN	
2	Basin I	861660000041	CITY OF BAYTOWN	
2	O100 Channel Improvement	591420000030	CASTILLO DANIEL	$ 119,499
2	O100 Channel Improvement	591470060083	MISSOURI PACIFIC RAILROAD COMPANY	$ 168,142
2	O100 Channel Improvement	591470060029	MISSOURI PACIFIC RAILROAD COMPANY	$ 259,060
2	O100 Channel Improvement	591490150035	COX CHARLES H	$ 340,679
2	O100 Channel Improvement	591420000037	VELEZ NICKIE M	$ 425,734
2	O100 Channel Improvement*	591490150040	MISSOURI PACIFIC RAILROAD COMPANY	$ 583,756
2	O100 Channel Improvement	591420000045	COX CHARLES H & PHYLLIS	$ 2,314,125
2	O100 Channel Improvement	591490160020	COUNTY OF HARRIS	$ -
2	O100 Channel Improvement	591490160074	TEXAS DEPARTMENT OF TRANSPORTATION	$ -

** Property can be avoided with optimized channel configuration*

Appendix 3

Cost Estimates

Summary

Phase 1	Pond J	$ 19,377,783.2
	Channel Phase 1	$ 4,072,727.2
Phase 2	Pond I	$ 14,448,525.0
	Channel Phase 2	$ 1,127,277.2
	I-10 Bridge Improvements	$ 2,762,500.0
Phase 3	O126 Improvements	$ 4,120,266.5
	O117 Improvements	$ 584,281.3
Total		$ 46,493,360.3

Basin J

SUMMARY OF QUANTITIES				
Item	**Unit**	**Quantity**	**Unit Price**	**Item Total**
Clearing, Grubbing, and Disposal	**AC**	39.00	$ 6,200.00	$ 241,800
Excavation (Off-Site Haul)	**CY**	788,920	$ 12.00	$ 9,467,040
Concrete Pilot Channels	**SY**	10,373	$ 55.00	$ 570,516
Turf Establishment (Sodding / Seeding)	**AC**	35.49	$ 3,600.00	$ 127,771
Backslope Swale	**FT**	5,174	$ 5.00	$ 25,868
Backslope Drain Structure	**EA**	16	$ 3,500.00	$ 56,000
Backslope Interceptor Rip-rap	**SY**	160	$ 80.00	$ 12,800
Land Acquisition	**1 Parcel owned by a Real Estate Company**			$ 3,100,000

Contingency	**55%**	
	TOTAL	$ 19,377,783.16

Channel Improvements - Phase 1

SUMMARY OF QUANTITIES				
Item	**Unit**	**Quantity**	**Unit Price**	**Item Total**
Clearing, Grubbing, and Disposal	**AC**	**25**	$ 6,200.00	$ 155,000
Excavation (Off-Site Haul)	**CY**	**162,000**	$ 12.00	$ 1,944,000
Rock Rip-Rap	**SY**	**500**	$ 80.00	$ 40,000
Backslope Swale	**LF**	8,765	$ 5.00	$ 43,824
Backslope Drain Structure	**EA**	22	$ 3,500.00	$ 77,000
Land Aqcuisition	**AC**	12.7	$ 44,921.25	$ 570,500
			Subtotal =	$ 2,259,824.00
		Contingency =	**55%**	$ 1,242,903.20
			TOTAL	$ 4,072,727.20

Basin I

SUMMARY OF QUANTITIES				
Item	**Unit**	**Quantity**	**Unit Price**	**Item Total**
Clearing, Grubbing, and Disposal	**AC**	42.00	$ 6,200.00	$ 260,400
Excavation (Off-Site Haul)	**CY**	543,693	$ 12.00	$ 6,524,320
Concrete Pilot Channels	**SY**	12,550	$ 55.00	$ 690,271
Turf Establishment (Sodding / Seeding)	**AC**	38.36	$ 3,600.00	$ 138,083
Backslope Swale	**FT**	5,370	$ 5.00	$ 26,852
Backslope Drain Structure	**EA**	16	$ 3,500.00	$ 56,000
Backslope Interceptor Rip-rap	**SY**	160	$ 80.00	$ 12,800
Land Acquisition	**3 Parcels owned by HCFCD**			$ 2,500,000

Contingency	**55%**	
	TOTAL	$ 14,448,525.01

Channel Improvements – Phase 2

SUMMARY OF QUANTITIES				
Item	**Unit**	**Quantity**	**Unit Price**	**Item Total**
Clearing, Grubbing, and Disposal	**AC**	**20**	$ 6,200.00	$ 124,000
Excavation (Off-Site Haul)	**CY**	**3,000**	$ 12.00	$ 36,000
Rock Rip-Rap	**SY**	**500**	$ 80.00	$ 40,000
Backslope Swale	**LF**	8,765	$ 5.00	$ 43,824
Backslope Drain Structure	**EA**	22	$ 3,500.00	$ 77,000
Land Aqcuisition	**AC**	14	$ 44,921.25	$ 628,448
			Subtotal =	$ 320,824.00
		Contingency =	**55%**	$ 176,453.20
			TOTAL	$ 1,127,277.20

Bridge Improvements

Bridges Improvements				
Work Item		**Unit Cost**		**Total**
O117 Removals	SF	$170	1000	$170,000
O126 Removals	SF	$170	5500	$935,000
I-10 Improvements	SF	$170	16250	$2,762,500
			Subtotal	$3,867,500

O126 - Channel Improvements

SUMMARY OF QUANTITIES				
Item	**Unit**	**Quantity**	**Unit Price**	**Item Total**
Clearing, Grubbing, and Disposal	**AC**	**11.4784**	$6,200.00	$ 71,166
Excavation (Off-Site Haul)	**CY**	**156,570**	$ 12.00	$ 1,878,844
Rock Rip-Rap	**SY**	**500**	$ 80.00	$ 40,000
Backslope Swale	**LF**	4,600	$ 5.00	$ 23,000
Backslope Drain Structure	**EA**	12	$3,500.00	$ 42,000
			Subtotal =	$ 2,055,010.65
		Contingency =	**55%**	$ 1,130,255.86
			TOTAL	$ 3,185,266.51

O117 Channel Improvements

SUMMARY OF QUANTITIES				
Item	**Unit**	**Quantity**	**Unit Price**	**Item Total**
Clearing, Grubbing, and Disposal	**AC**	**2.41047**	$6,200.00	$ 14,945
Excavation (Off-Site Haul)	**CY**	**7,778**	$ 12.00	$ 93,333
Rock Rip-Rap	**SY**	**500**	$ 80.00	$ 40,000
Backslope Swale	**LF**	8,400	$ 5.00	$ 42,000
Backslope Drain Structure	**EA**	22	$3,500.00	$ 77,000
Backslope Interceptor Structure Rip-rap	**SY**	0	#N/A	#N/A
			Subtotal =	$ 267,278.24
		Contingency =	**55%**	$ 147,003.03
			TOTAL	$ 414,281.27

Appendix 4

Project Score

Harris County Flood Control District Project Scoring Form

Scenario #1 (100-Year Event) SUMMARY

		SCORING CRITERIA:	1	2	3	4	5	6	7	8	
		Weight:	25%	20%	20%	10%	10%	5%	5%	5%	
Problem Area:	**Project ID:**	Tier:	Flood Risk (100-Year Event) Reduction	Existing Conditions Drainage LOS	Social Vulnerability Index (SVI)	Project Efficiency	Partnership Funding	Long Term Maintenance Costs	Minimize Environmental Impacts	Potential for Multiple Benefits	**TOTAL SCORE**
Goose Creek Watershed	Project 1	1	1.50	0.80	1.88	0.20	0.20	0.30	0.20	0.20	5.28

Harris County Flood Control District Project Scoring Form

Scenario #1 (100-Year Event)

USERS: Only type in cells that are ORANGE shaded. GREY cells are automatic calculations (Do not type in these cells). * YELLOW cells have dropdown for easy data input. Click on cell, then use drop down just outside the cell, to the right.	NOTES :

TOTAL PROJECT SCORE:	5.28	Problem Area:	Goose Creek Watershed
		Project ID:	Project 1
		Project Name:	Recommended Project
		Project Manager:	HCFCD - Kent Wu | AECOM - Elizabeth Levitz
		Project Watershed:	(O) Goose Creek *

1. What is the project cost?	$ 46,493,360.30	USD.		
2.How many structures are subject to flooding in the 100-yr event baseline (existing) condition? 2a. How many roadway miles are subject to inundation greater than a foot in the 100-yr (existing) condition?	427	Structures (100-yr)	21	Non-Structures (Miles) * Reference Only
3. How many structures and non-structures are subject to flooding in the alternative (proposed) condition?	275	Structures (100-yr)	15	Non-Structures (Miles) * Reference Only
3.a. Total number of structures and roadway miles removed from flood risk (benefitted)?	152		6	
3.b. Percent of structures and roadway miles removed from flood risk?	36%		29%	
4. What is the baseline (existing) condition Level of Service (L.O.S.) of the observed channel reach / flooding source?	<=25-Yr *			
4.a. What is the source of potential flooding in the Project Area (Pick all that apply)?	Riverine (Out of Bank)	Uncontrolled Sheetflow	Multiple Causes	N/A *
4.b. Upper bounding Annual Exceedance Probability for the channel reach Level of Service (L.O.S.) capacity.	25		-Year	
5. What is the CDC Social Vulnerability Index (SVI) of the observed Project Area?	Area (Ac)	Percentage (%)		Project Area: Goose Creek Watershed
5.a. Amount of Project Area with an SVI indicated as low level of vulnerability (SVI = 1)?		0%		4800 acres
5.b. Amount of Project Area with an SVI indicated as low to moderate level of vulnerability (SVI = 4)?	500	10%		
5.c. Amount of Project Area with an SVI indicated as moderate to high level of vulnerability (SVI = 7)?		0%		
5.d. Amount of Project Area with an SVI indicated as high level of vulnerability (SVI = 10)?	4300	90%		
6. Does the project have potential for partnership (Percentage of Potential Cost of sharing by others)?	Potential for partnership, but unknown participation (No prior coordination yet). *			
6.a. If estimated partner share is known, what is the estimated partner share responsibility of project cost?	0%	If unknown, enter "0%"		
7. What is the projects potential to offer multiple benefits? (e.g., additional Recreational and/or Environmental improvements in conjunction with drainage improvements.)?	Project has recreational benefits. *			
8. What is the qualitative expectation of the projects need for long term maintenance? (Typical / Frequent or Additional / Specialized)	Project will require maintenance outside of HCFCD's regular maintenance cycles. *			used new instructions to assign a score of 4 (see next tab)
9. What is/are the project's potential environmental impacts?	Project is able to significantly avoid environmental impacts. *			
10. What is the estimated project efficiency? 10.a. Project Efficiency = Total Project Cost (USD.) / total number of structures removed from flood risk.	$305,877.37		USD. / Benefitted Structure Count	

Appendix 5-4M: Kingwood Diversion Ditch

TORRES & ASSOCIATES, LLC
ENGINEERS | SCIENTISTS | PROFESSIONALS

MEMORANDUM

DATE: February 28th, 2023

TO: San Jacinto Regional Flood Planning Group

CC: Harris County Flood Control District; Texas Water Development Board

FROM: Evan Adrian, PE, CFM, ENV SP; Jacob Torres, PhD, PE, CFM, D.WRE; Cristian Ayala, EIT

PROJECT NO.: 10-220120-00

PROJECT: TWDB San Jacinto Regional Flood Plan

SUBJECT: Kingwood Diversion Ditch Project Benefit-Cost Analysis

The Conceptual Watershed Planning Study for the Kingwood Area was conducted by Neel-Schaffer, Inc. for the Harris County Flood Control District (HCFCD), Lake Houston Redevelopment Authority TIRZ Number 10, and the City of Houston. The Kingwood Diversion Ditch (HCFCD Unit G103-38-00) is a previously constructed man-made ditch designed to alleviate Bens Branch (HCFCD Unit G103-33-00) through a diversion of excess flow around Kingwood to the West Fort San Jacinto River. The proposed improvements include the construction of a concrete control structure, channel modifications, bridge improvements, and detention. The Watershed Planning Study report is included as **Appendix 1**.

The Texas Water Development Board (TWDB) requires each Flood Mitigation Project (FMP) included in a regional flood plan to have a benefit/cost analysis (BCA) performed. The final engineering report prepared by Neel-Schaffer, Inc. did not include a BCA. This memorandum documents a benefit cost analysis performed for the Kingwood Diversion Ditch Project by Torres and Associates within the regional flood planning process.

Benefit Cost Analysis Methodology

TWDB developed the Benefit-Cost Analysis (BCA) Input Tool to facilitate the calculation of flood mitigation benefits due to FMP. The TWDB BCA Input Tool is provided as **Appendix 2**. This tool receives input of existing and proposed conditions to determine expected benefits related to the construction of the FMP in question. The benefits considered in the analysis include the reduction in damages to residential structures, commercial structures, and social benefits. The BCA Input Tool was modified to handle the nearly 20,000 structures included in the analysis. The modified BCA Input Tool is provided as **Appendix 3**.

The BCA Input Tool was used in conjunction with the Federal Emergency Management Agency (FEMA) BCA Toolkit v6.0.0. The FEMA BCA Toolkit is provided as **Appendix 4.** Social benefits used in the analysis were developed within the FMEA Benefit-Cost Calculator.

Project Costs

According to the report, the preliminary cost estimate for the proposed improvements to the Kingwood Diversion Ditch is approximately $62,938,000. The conveyance improvements were assumed to have a useful life of 30 years. The project cost used in the BCA includes Channel Construction Costs ($25,428,000), Detention Costs ($33,928,000), and Right-of-Way Acquisition Costs ($3,582,000). The annual maintenance cost is estimated at $0.

Benefit Cost Analysis

1.1 Building Information

The “Texas Buildings with SVI and Estimated Population (November 2021)” dataset provided by TWDB for Regional Flood Planning was used to determine building sizes and building types. The Finished Floor Elevations (FFE) for all structures were assumed to be 6 inches above ground level and all structures were assumed to be 1 story. Based on the provided building types, structures were reclassified as either residential, commercial, industrial, or agricultural. Public buildings were reclassified as commercial structures. Buildings marked as “Vacant or Unknown” in the TWDB dataset were reclassified as agricultural buildings.

1.2 Flood Hazard Data

The flood depths for each structure within the study area was determined for the 1 percent annual chance event. The flood hazard data was obtained from the hydraulic models developed as part of the Watershed Plan Report, all hydrological and hydraulic analyses were completed by Neel-Schaffer, Inc. The baseline structural flood damages are included in **Table 1**.

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Table 1. Summary of Damages for 1% AEP for Without and With Project Conditions

	1% AEP Storm	
	Without Project	With Project
Residential Flood Damage	$3,528,647	$544,113
Commercial Flood Damage	$6,839,057	$1,744,209
Total Structural Damage	**$10,367,704**	**$2,288,321**

1.3 Expected Flood Damages After FMP Implementation

For the structures analyzed, the Goose Creek Flood Risk Reduction FMP results in $1,002,564 in standard mitigation benefits and $293,039 in other mitigation benefits from the residual value of investment.

1.4 Benefit-Cost Analysis Summary

The benefit-cost analysis for this project was completed using the FEMA BCA Tool Version 6.0. The final benefit-cost ratio (BCR) with standard benefits was determined to be 0.03.

Table 2. Benefit-Cost Analysis Summary

Input Into BCA Toolkit		
Project Useful Life	**30 years**	
Event Damages	**Baseline**	**Project**
1% AEP storm event	**$10,367,704**	**$2,288,321**
Results from BCA Toolkit:		
Total Benefits from BCA Toolkit	$1,002,564	
Other Benefits (Not Recreation)	$293,039	
Discounted Total Costs from TWDB Spreadsheet	$50,266,137	
Net Benefits	$1,295,603	
Final BCR	**0.03**	

List of Appendices

Appendix 01 – Kingwood Drainage Study (Conceptual Watershed Plan for Flood Damage Reduction in Kingwood)

Appendix 02 – TWDB BCA Input Workbook (included as an excel document)

Appendix 03 – Modified Benefit Cost Analysis Spreadsheet (Included as an excel document)

Appendix 04 – FEMA BCA Toolkit 6.0 (included as an excel document)

Drainage report submitted with model files.

Appendix 5-4N:
B509-03 Technical Memorandum

11200 Westheimer Rd. #353, Houston TX 77042 | 832-800-3483 | **B509-03 Technical Memorandum.docx**

February 24, 2023

To: **Gary Bezemek, PE, HCFCD** **From:** **5engineering, LLC**

Project: **BCA** **Job No.:** **007A-002**

Subject: **BCA for B509-03**

Introduction

Project Description & Location

The information presented is based on the report titled *Preliminary Engineering Report Phase 2 Genoa Red Bluff Stormwater Detention Basins,* prepared by iGet Services, dated December 2nd, 2022. This report recommended alternative 3. Three separate dry bottom basins are proposed along Spring Gully (B109-00-00). The project is located in Pasadena, Texas between West Fairmont Parkway and Red Bluff Road. The objective of this project is to reduce flood damage along Spring Gully. The report indicates this alternative has no adverse impacts (pg. 36). This corresponds to the following HEC-RAS model files:

HEC-RAS Project File Name: B509-03-00-E001.prj

Frequency	**Existing Plan**	**Existing Geometry and Flow**
10 - year	B509-04-00-E001.p02 (Revised_existing_B509_10yr)	B509-04-00-E001.g01 (Revised_Existing)
		B509-04-00-E001.u01 (Atlas14_10yr)
100 - year	B509-04-00-E001.p01 (Revised_existing_B509_100yr)	B509-04-00-E001.g01 (Revised_Existing)
		B509-04-00-E001.u03 (Atlas14_100yr)
500 - year	Revised_existing_B509_500yr.p04 (Revised_existing_B509_500yr)	B509-04-00-E001.g01 (Revised_Existing)
		B509-04-00-E001.u04 (Atlas14_500yr)
	Proposed Plan	**Proposed Geometry and Flow**
10 - year	B509-04-00-E001.p11 (Prop_Alt3_B509_10yr)	B509-04-00-E001.g11 (Prop_Alt3_509_dry_200_200_200_100_1)
		B509-04-00-E001.u01 (Atlas14_10yr)
100 - year	B509-04-00-E001.p07 (Prop_Alt3_B509_100yr)	B509-04-00-E001.g11 (Prop_Alt3_509_dry_200_200_200_100_1)
		B509-04-00-E001.u03 (Atlas14_100yr)

500 - year	B509-04-00-E001.p17 (Prop_Alt3_B509_500yr)	B509-04-00-E001.g11 (Prop_Alt3_509_dry_200_200_200_100_1)
		B509-04-00-E001.u04 (Atlas14_500yr)

Structural Inventory

Structural Inventory datasets were created using three data sets:

- Houston-Galveston Area Council (HGAC) Land use
- Harris County Flood Control District (HCFCD) building footprints
- 2018 LiDAR

These data sets were joined using ArcGIS and used to estimate ground elevation at each structure. The FNI provided BCA Pilot v5 spreadsheet assumes the finished floor elevation (FFE) to be 6" above LiDAR. Aerial imagery and the HGAC Land use was used to categorize building types.

Project Schedule

Information on project schedule wasn't available within the provided PER. The project was assumed to be designed and delivered over a 10-year period beginning in 2026.

Project Costs

The total construction cost for alternative 3 is expected to be $34,846,263.40. This cost does not include engineering.

Project costs estimated in December 2021 were adjusted to September 2020 dollars using a factor of 0.92 taken from the construction cost index from Engineering News-Record. The adjusted cost is $32,058,562.

Operation and maintenance costs were not available within the provided PER. A conservative value of $100 per acre was assumed for the acquired 23.3 acres.

The adjusted project costs were input into the TWDB BCA Input Workbook v1.2PILOT to calculate the project cost discounted by 7 percent over the 10-year construction period. The discounted cost of $19,097,382 is used in the benefit cost ratio calculation.

BCA Assumptions

Project benefits are considered to be the reduction of flooding damages to residential, commercial, and industrial structures. These benefits were quantified by comparing without the project and with the project conditions in the 10, 100, and 500-year frequencies. Benefits were quantified using the BCA Pilot v5 spreadsheet.

Benefit Summary

Benefits (Non-Discounted)

	10 - year storm		100 - year storm		500 - year storm	
Project Impacts by Recurrence Interval	Baseline	Project	Baseline	Project	Baseline	Project
Residential Flood Damage	$81,537	$75,112	$19,582,848	$18,781,897	$63,689,672	$63,525,697
Commercial Flood Damage	$0	$0	$5,550,250	$5,476,321	$11,278,632	$11,187,339
Total Damages	$81,537	$75,112	$25,133,098	$24,258,218	$74,968,303	$74,713,035
Net Benefit by Storm		**$6,425**		**$874,880**		**$255,268**

Discounted Benefits

The damage estimates from the BCA Pilot v5 spreadsheet were entered into the FEMA BCA Calculator. Total benefits discounted at 7 percent over the project's assumed lifetime of 30 years are $180,440.

Benefit Cost Ratio

Discounted Project Benefits (FEMA BCA Toolkit)	$180,440
Total Benefits	$181,569
Discounted Project Cost	$19,097,382
Final BCR	**0.01**

Appendix 5-4O:
Cypress Creek Program Detention Basin Implementation Plan

TECHNICAL MEMORANDUM

To: Gary Bezemek, PE
Harris County Flood Control District – Planning Department

From: Mujahid Chandoo, PE

Date: February 22, 2023

Subject: Cypress Creek Program Implementation Plan (K100-00-00-P007)
Benefit Cost Analysis (BCA)

Project Description

The Cypress Creek flood control project proposes to construct a series of 22 detention basins along Cypress Creek in Harris County. The Cypress Creek watershed (K100-00-00) extends across northwest Harris County and into Waller County. There are 250 miles of open waterways in the watershed, including the main Cypress Creek channel and its major tributaries.

The Cypress Creek Program Implementation Plan report (Implementation Plan) is based on the Jones|Carter study, dated November 2021. The Regional Drainage Plan found that flooding along tributaries of Cypress Creek is predominately caused by stormwater from a rising Cypress Creek backing up into tributaries, rather than a lack of sufficient stormwater conveyance or drainage capacity on the tributaries themselves. Therefore, stormwater detention basins along the Cypress Creek channel are expected to be more effective than other types of structural approaches to flood risk reduction in the watershed.

Structure Inventory

Two (2) datasets were used to obtain the information for Finished Floor Elevation (FFE), building footprint and building category.

- **Structure Inventory Dataset**: This information was obtained from Harris County Flood Control District (HCFCD). The FFE was obtained from this dataset.
- **National Structure Inventory (NSI):** The building (structure type) category (i.e. residential commercial and industrial) and building footprint (sq. ft) was obtained with this dataset.

Using ArcGIS these datasets were joined together using the parcel information.

Project Schedule

The schedule is based on optimal delivery and includes anticipated activity durations with the following assumptions:

- Planning Phase I in 2023 with Delivery Phase II (ROW, Engineering, Construction Plan) starting 2024 and Phase III (Excavation and removal) beginning in 2026.
- For the purposes of project cost discounting, Phase II and Phase III for each basin or basin groupings are assumed to spread evenly over a 10-year period from 2026 to 2036.

2002 W Grand Pkwy N Suite 325 | Katy, TX 77449
Office: 713-954-5300 | mbakerintl.com

- Environmental permitting was assumed for a minimum of 12 months
- Duration for construction (Phase III) was assumed a minimum of 12 months per basin and extended for spending an average of approximately $55 million per year.

The Program schedule requires more than ten (10) years to deliver and execute all basins if funding were available in an ideal scenario.

BCA Assumptions

For purposes of the BCA, project benefits are elimination of flooding damages to residential, commercial, and industrial structures. Benefits were quantified by comparing the baseline situation without the project to the project conditions in the 10-, 50- and 100-year storm scenarios. Project costs estimated in November 2021 were adjusted to September 2020 dollars using a factor 0.92. The adjusted project costs were input to the TWDB BCA Input Workbook v1.2PILOT to calculate the discounted by 7 percent over the 10-year constriction period, the discounted cost is $337.4 million.

Tiers 1-2: Groups 1-11 (22 Sites)

- The scheduled duration to deliver 22 projects will be more than ten years from 2026 to 2036.
- The peak annual cost is estimated approximately $91 million in 2029.
- Total cumulative costs for Tiers 1 and 2 are approximately $549 million with estimated program costs and no cost escalation

Project Costs

Cost Categories	2020 Dollars*
Environmental Permitting and Mitigation*	$5.16 million
Engineering and Design	$63.19 million
Right of Way	$59.74 million
Construction (including Excavation & Removal)	$421.29 million
Total Project Cost	**$549.38 million**

* - Updated from November 2021 cost estimate (Jones|Carter)

* - Environmental and cultural reviews were conducted for the 22 sites during the second prioritization analysis. An overall environmental and cultural inventory and desktop review were conducted for each proposed Cypress Creek watershed project site to determine the potential magnitude of impacts on existing natural resources as well as the impacts and concerns of stakeholders. The findings will determine the permits required and define the scope for permitting as projects progress in later phases.

The cost estimate for construction was based on the conceptual design quantities for detention excavation volumes and outfall facilities. For utilities that require relocation, costs were estimated with the construction costs.

Unit costs were based on average HCFCD pricing and bid prices from 2018-21 HCFCD databases and Jones|Carter data. The unit costs were pro-rated for proposed projects based on the detention mitigation volumes. The base unit costs for excavation and off-site removal were estimated assuming lower unit cost for higher basin volumes for the following ranges:

Excavation and Off-Site Disposal

	Quantity Ranges (Cu. Yds.)	Unit Cost per Cu. Yd.
High	> 2,500,000	$12.00
Medium	900,000 to 2,500,000	$13.00
Low	92,000 to 900,000	$14.00

Project benefits from the elimination of flooding damages to residential, commercial, and industrial structures were quantified by inputting structure FFE's and flood depths to the BCA_Pilot_v5, provided by FNI. The output compares the baseline structure damages without the project to the project conditions in the 10-, 50- and 100-year storm scenarios:

Benefits Summary (non-discounted)

	100 - year storm		50 - year storm		10 - year storm	
	Baseline	w/Project	Baseline	w/Project	Baseline	w/Project
Residential Flood Damage	$897,708,132	$778,535,008	$490,830,151	$286,929,224	$27,319,343	$16,102,990
Commercial Flood Damage	$70,041,298	$74,343,826	$40,270,077	$40,077,626	$1,788,100	$1,396,476
Industrial Damages	$87,701,109	$82,037,755	$45,584,939	$36,370,163	$6,062,307	$4,257,466
Total Damages	$1,055,450,539	$934,916,589	$576,685,166	$363,377,013	$35,169,750	$21,756,931
Net Benefit by Storm		**$120,533,950**		**$213,308,154**		**$13,412,819**

Total Benefit: $347,254,922

Discounted Benefits

Total benefits discounted at 7 percent over the project's 30-year duration are $95,807,114 including $3,256,588 in residual value from right-of-way acquisition. These benefits only include the mitigated damages to residential, commercial. and industrial structures identified and no other additional mitigation.

Benefit Cost Ratio

Discounted Project Benefits (damages calculated in FEMA BCA toolkit)	$92,550,526
Discount Residual Value (ROW)	$3,256,588
Total Benefits	$95,807,114
Discounted Project Cost	$337,411,090
Final BCR	**0.284**

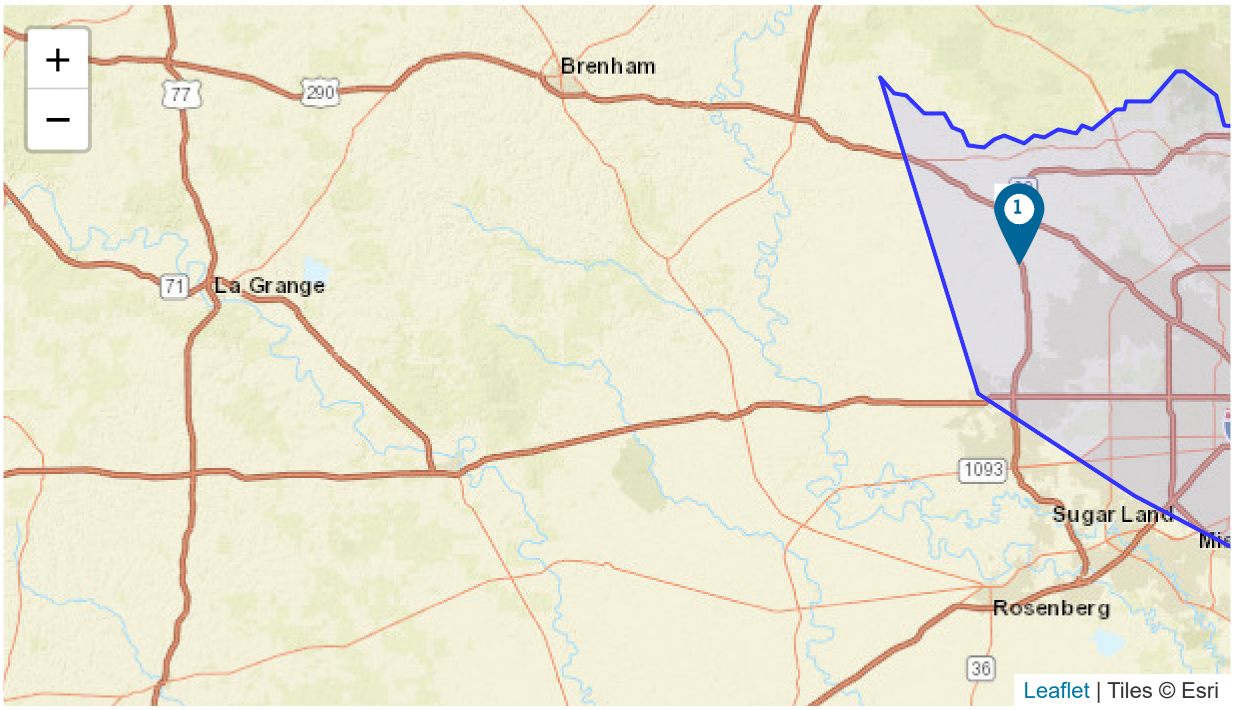
FEMA

Benefit-Cost Calculator

V.6.0 (Build 20230103.1822 | Release Notes)

Benefit-Cost Analysis

Project Name: Cypress Creek Implementation Plan



				Using 7% Discount Rate			Using 3% Discount Rate (For FY22 BRIC and FMA only)		
Map Marker ▲	Mitigation Title	Property Type	Hazard	Benefits (B)	Costs (C)	BCR (B/C)	Benefits (B)	Costs (C)	BCR (B/C)
1	Drainage Improvement @ 29.9395450; -95.7680950		DFA - Riverine Flood	$ 92,550,526	$ 13	7,119,271.23	$ 146,186,246	$ 21	6,961,249.81
TOTAL (SELECTED)				**$ 92,550,526**	**$ 13**	**7,119,271.23**	**$ 146,186,246**	**$ 21**	**6,961,249.81**
TOTAL				**$ 92,550,526**	**$ 13**	**7,119,271.23**	**$ 146,186,246**	**$ 21**	**6,961,249.81**

Property Configuration

Property Title:	Drainage Improvement @ 29.9395450; -95.7680950
Property Location:	77433, Harris, Texas
Property Coordinates:	29.9395450064631, -95.76809501544018
Hazard Type:	Riverine Flood
Mitigation Action Type:	Drainage Improvement
Property Type:	Residential Building
Analysis Method Type:	Professional Expected Damages

Cost Estimation

Drainage Improvement @ 29.9395450; -95.7680950

Project Useful Life (years):	30
Project Cost:	$1
Number of Maintenance Years:	30 Use Default: *No*
Annual Maintenance Cost:	$1

Damage Analysis Parameters - Damage Frequency Assessment

Drainage Improvement @ 29.9395450; -95.7680950

Year of Analysis was Conducted:	2023
Year Property was Built:	0
Analysis Duration:	30 Use Default: *No*

Professional Expected Damages Before Mitigation

Drainage Improvement @ 29.9395450; -95.7680950

	OTHER	OPTIONAL DAMAGES			VOLUNTEER COSTS		TOTAL
Recurrence Interval (years)	Damages ($)	Category 1 ($)	Category 2 ($)	Category 3 ($)	Number of Volunteers	Number of Days	Damages ($)
100	1,055,450,539	0	0	0	0	0	1,055,450,539
50	576,685,166	0	0	0	0	0	576,685,166
10	35,169,750	0	0	0	0	0	35,169,750

Annualized Damages Before Mitigation

Drainage Improvement @ 29.9395450; -95.7680950

Annualized Recurrence Interval (years)	Damages and Losses ($)	Annualized Damages and Losses ($)
10	35,169,750	11,393,155
50	576,685,166	7,801,684
100	1,055,450,539	10,554,400
	Sum Damages and Losses ($)	Sum Annualized Damages and Losses ($)
	1,667,305,455	29,749,239

Professional Expected Damages After Mitigation

Drainage Improvement @ 29.9395450; -95.7680950

	OTHER	OPTIONAL DAMAGES			VOLUNTEER COSTS		TOTAL
Recurrence Interval (years)	Damages ($)	Category 1 ($)	Category 2 ($)	Category 3 ($)	Number of Volunteers	Number of Days	Damages ($)
100	934,916,589	0	0	0	0	0	934,916,589
50	363,377,013	0	0	0	0	0	363,377,013
10	21,756,931	0	0	0	0	0	21,756,931

Annualized Damages After Mitigation

Drainage Improvement @ 29.9395450; -95.7680950

Annualized Recurrence Interval (years)	Damages and Losses ($)	Annualized Damages and Losses ($)
10	21,756,931	7,113,241
50	363,377,013	5,828,612
100	934,916,589	9,349,072
	Sum Damages and Losses ($)	Sum Annualized Damages and Losses ($)
	1,320,050,533	22,290,925

Standard Benefits - Ecosystem Services

Drainage Improvement @ 29.9395450; -95.7680950

Total Project Area (acres):	0
Percentage of Urban Green Open Space:	0.00%
Percentage of Rural Green Open Space:	0.00%
Percentage of Riparian:	0.00%
Percentage of Coastal Wetlands:	0.00%
Percentage of Inland Wetlands:	0.00%
Percentage of Forests:	0.00%
Percentage of Coral Reefs:	0.00%
Percentage of Shellfish Reefs:	0.00%
Percentage of Beaches and Dunes:	0.00%
Expected Annual Ecosystem Services Benefits:	$0

Additional Benefits - Social

Drainage Improvement @ 29.9395450; -95.7680950

Number of Workers:	0
Expected Annual Social Benefits:	$0

Benefits-Costs Summary

Drainage Improvement @ 29.9395450; -95.7680950

Total Standard Mitigation Benefits:	$92,550,526
Total Social Benefits:	$0
Total Mitigation Project Benefits:	$92,550,526
Total Mitigation Project Cost:	$13
Benefit Cost Ratio - Standard:	7,119,271.23
Benefit Cost Ratio - Standard + Social:	7,119,271.23

Appendix 5-4P:
P518-11-E002 Aldine Westfield N Detention BCA Memorandum

PLANNING

ENGINEERING

PROGRAM MANAGEMENT

memo

TEXAS
AUSTIN
COLLEGE STATION
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DALLAS
FORT WORTH
FRISCO
HOUSTON
LAREDO
MONTGOMERY COUNTY
SAN ANTONIO
SAN MARCOS
WACO

CALIFORNIA
LOS ANGELES
ORANGE
SAN JOSE

FLORIDA
MIAMI

ILLINOIS
CHICAGO

MICHIGAN
FLINT
LANSING

OKLAHOMA
NORMAN

To: Gary Bezemek, P.E.

From: Tak Makino, CFM

Date: March 1, 2023

Subject: P518-11-00 Phase 2 Basin
State Flood Plan BCA

Project Description

This BCA is for the P518-11-00 Phase 2 Basin described as "Aldine Westfield North Detention Basin" in the Halls Bayou Watershed Flood Risk Reduction Phasing Study (Phasing Study) prepared for Harris County Flood Control District by LAN. The Phasing Study completed in 2021 updated the 2013 Halls Ahead Study Vision Plan and developed a phasing strategy for identified bond projects. The concept for the P518-11-00 Basin was studied prior to the Phasing Study in the 2019 Preliminary Engineering Report performed by LAN in coordination with Harris County Flood Control District. This BCA is based on the models and cost estimates from the PER.

Aldine Westfield North is a proposed wet bottom detention pond roughly bound to the west by P118-21-00, to the east by Aldine Westfield Road, to the north by Isom Street, and to the south by Halls Bayou. The basin was planned to be constructed in two phases. Phase 1 is currently under construction while Phase 2 is the object of this analysis. The total proposed usable area for both phases is approximately 52 acres and would require 23 acres of ROW acquisition for Phase 2. The complete basin provides approximately 610 acre-feet of storage. Proposed channel improvements along P118-21-00 are currently under construction as well. The 100-year event shows a maximum WSE reduction of 3.0 feet and 0.3 feet within P118-21-00 and Halls Bayou, respectively compared to baseline conditions.

The Texas Water Development Board (TWDB) requires each Flood Mitigation Project (FMP) included in a regional flood plan to have a benefit/cost analysis (BCA) performed. This memorandum documents to benefit cost analysis performed by LAN within the regional flood planning process.

Benefit Cost Analysis

TWDB developed the Benefit-Cost Analysis (BCA) Input Tool to facilitate the calculation of flood mitigation benefits due to FMP. This tool receives input of existing and proposed conditions to determine expected benefits related to the construction of the FMP in question. The benefits considered in the analysis include the reduction in damages to residential structures, commercial structures, and social benefits. The BCA Input Tool was modified to handle the nearly 20,000 structures included in the analysis. The BCA Input Tool was used in

Lockwood, Andrews
& Newnam, Inc.

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conjunction with the Federal Emergency Management Agency (FEMA) BCA Toolkit v6.0.0. Social benefits used in the analysis were developed within the FMEA Benefit-Cost Calculator.

Structure Inventory

Two (2) datasets were used to obtain the information for Finished Floor Elevation (FFE), building footprint and building category.

- **Structure Inventory Dataset:** This information was obtained from Harris County Flood Control District (HCFCD). The FFE was obtained from this dataset.
- **Texas Buildings with SVI and Estimated Population (November 2021) –** This information was provided by TWDB for Regional Flood Planning. Building sizes and types were obtained from this dataset.

Project Schedule

The project is currently being planned and designed. Construction of Phase 1 is underway. Construction of Phase 2 is scheduled to commence between 2025-2026.

BCA Assumptions

For purposes of the BCA, project benefits are elimination of flooding damages to residential, commercial, and industrial structures. Based on the provided building types, structures were reclassified as either residential, commercial, industrial, or agricultural. Public buildings were reclassified as commercial structures. Buildings marked as “Vacant or Unknown” in the TWDB dataset were reclassified as agricultural buildings. Benefits were quantified by inputting structure FFE’s and flood depths to the BCA_Pilot_v5 spreadsheet, provided by FNI.

Flood Damages

The flood depths for each structure within the study area was determined for the 50 percent, 10 percent, 4 percent, 2 percent, 1 percent, and 0.2 percent annual chance events. The flood hazard data was obtained from the PER, all hydrological and hydraulic analyses were completed by LAN. The structural flood damages are included in **Tables 1-2**.

TABLE 1: PROJECT IMPACTS BY RECURRENCE INTERVAL 2YR, 10YR, 25YR STORM EVENTS

Flood Damages	2 - year storm		10 - year storm		25 - year storm	
	Baseline	Project	Baseline	Project	Baseline	Project
Residential	$10,107,156	$10,325,235	$52,869,503	$52,407,765	$92,137,844	$90,176,722
Commercial	$6,280,149	$5,933,522	$18,385,958	$18,639,807	$24,236,941	$24,135,194
Total	$16,387,305	$16,258,756	$71,255,461	$71,047,572	$116,374,786	$114,311,916

TABLE 2: PROJECT IMPACTS BY RECURRENCE INTERVAL 50YR, 100YR, 500YR STORM EVENTS

Flood Damages	50 - year storm		100 - year storm		500 - year storm	
	Baseline	Project	Baseline	Project	Baseline	Project
Residential	$159,004,791	$156,634,865	$194,293,404	$190,744,256	$331,083,874	$329,306,009
Commercial	$35,702,950	$35,695,497	$45,433,677	$44,468,369	$97,834,429	$96,383,281
Total	$194,707,741	$192,330,362	$239,727,081	$235,212,624	$428,918,303	$425,689,290

Benefits

The damage estimates from the BCA_PILOT_v5 model were inputted to the FEMA BCA Calculator. The total benefit, discounted at 7 percent over the assumed 30-year project duration, is **$6,544,028** including **$3,453,333** in environmental benefits from converting land to green space within the basin. These benefits include only include the mitigated damages to residential and commercial structures identified and no other additional mitigation.

Discounted Total Benefits: $6,544,028

Project Costs

The features were assumed to have a useful life of 30 years. The total construction cost is **$10,370,600** with no ROW costs required. The project construction cost used in the BCA includes Design Report ($400 thousand), Design ($650 thousand), Vegetation ($325 thousand) and Contingency (25% of construction and vegetation total). The annual maintenance cost is estimated at 4% of the construction cost: **$414,824**. Harris County Flood Control District will be responsible for long-term maintenance of Halls Bayou.

The adjusted project costs were input to the TWDB BCA Input Workbook v1.2 to calculate the project cost discounted by 7 percent over the construction period.

Discounted Total Costs: $12,963,740

Benefit Cost Ratio

Results from BCA Toolkit:	
Total Benefits from **FEMA** BCA Toolkit	$3,090,695
Other Benefits (Not Recreation)	$3,453,333
Recreation Benefits	$0
Discounted Total Costs from **TWDB** Spreadsheet	$12,963,740
Total Benefits	$6,544,028
Net Benefits	-$6,419,712
Final BCR	**0.24**
Final BCR with Other Benefits	**0.50**

Appendix 5-4Q:
P118-23-00 Drainage Improvements BCA Memorandum

Benefit Cost Analysis (BCA)

The benefit cost ratio (BCR) for the proposed project is 0.482.

An Initial BCA was performed April 2020. A pair of memoranda dated 5/8/2020 detailing the methods and results of this analysis are attached. In June 2020, a revised opinion of probable costs was produced. An updated BCA using the revised opinion of probable costs was performed shortly thereafter.

This benefit cost analysis was performed in anticipation of submission to the HUD CDBG-MIT grant program. While the FIF program and the CDBG-MIT program are two different grant programs administered by two separate entities, the principles used in the BCA apply to both.

The Halls Bayou watershed is a low-to-moderate income area. The property values in the area reflect this. The damage calculations in this BCA are based on depth-damage functions that estimate percentage of property value damaged based on depth of flooding in a storm event. As the property values are generally modest, even high percentages of property damage do not create high property damage values. The standard benefits of the proposed project take the form of mitigated damages. The damages mitigated are not very high because the initial baseline damage values are not very high.

The low property damage values when compared to higher income areas reflect market factors and should not be taken to indicate that flood damage in the Halls Bayou watershed is any less impactful or disruptive than in other areas. The proposed project will have positive effects on the health, safety, and quality of life of the population in the project benefit area.

The hydraulic and hydrologic analyses used in this BCA featured a 100-year storm as the smallest recurrence interval. In the absence of higher-frequency events, there is likely damage from high frequency storm events that is not being captured in this BCA. Consequently, this BCA may under-report damages and the BCR should be considered a conservative estimate.

Preliminary Halls Bayou Benefit Cost Analysis
June 12, 2020

Project Bond ID	C-26 / C-27
Project Unit ID	P118-23-**
Previous Analysis	
Date	4/16/2020
Total Project Cost (excluding O&M)	$36,900,000
Source of Cost	Halls Bayou Bundling Project List with construction Years and CDBG App… "LAN Estimate of Total Cost" (footnote to cost - based on maximized project scopes)
Standard BCR	0.005
Comprehensive BCR	0.332
Updated Analysis (for FIF)	
Date	6/12/2020
Total Project Cost (excluding O&M)	$31,316,863
Source of Cost	20200605 Halls Bayou Preliminary Cost Comparison with Callouts "Total Cost"
Standard BCR	0.006
Comprehensive BCR	0.482
Approach to overlap with Halls Bayou mainstem floodplain	No exclusions for mainstem FP, and project service area is within mainstem FP, so BCR is likely overestimated.
Factors contributing to BCR	Benefits include environmental and social benefits. Structural benefits are primarily limited to 500-yr conditions, and only a small number of structures are benefitted overall.
BCR underestimation due to missing storm frequencies	Current BCA limited to models of 100-yr and 500-yr storms.
Other comments	ROW parcels have been adjusted since development of BCA inputs. Number of structures in purchased parcels that would no longer be subject to any damage post-mitigation may have changed.
Other comments	Acreage being converted from developed land use to green space may have changed (impacts environmental benefits).
Other comments	Additional acreage requiring maintenance after project implementation may have changed, impacting O&M costs.
Other comments	*BCR incorporates estimated annual O&M cost in addition to the total project costs shown in this table.

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TO:	Dena Green, Alan Black, Xin He (Harris County Flood Control District)
CC:	Lars Zetterstrom, Chris Edwards, Michael Liga, Nick Barnett, Tak Makino, Laura Casset (LAN)
FROM:	Cory Stull, Courtney Corso, Shannon Mack, and Jordan Skipwith (FNI)
SUBJECT:	Draft for Coordination: Preliminary Benefit-Cost Analysis Methodology and Discussion
DATE:	May 8, 2020
PROJECT:	SCG17357 – Disaster Recovery Services: CDBG-MIT Grant Application for Halls Bayou

Freese & Nichols, Inc. (FNI) is performing benefit-cost analyses (BCA) of proposed mitigation activities in the Halls Bayou Watershed as part of the preparation of grant applications for the CDBG-MIT funding through the Texas General Land Office (GLO). Two stages of BCA are being performed:

(1) Preliminary for individual mitigation projects (each considered an "activity" in CDBG). These BCAs will consider only traditional benefits – avoided losses due to reduced damages to structures and contents. Benefits and costs will be assessed for individual activities. This phase is intended to inform the grouping of activities into two Covered Projects.

(2) Complete BCA for each Covered Project. Once activity groupings have been finalized, combined hydraulic models for each Covered Project will be used to assess the composite impact on water surface elevations (WSE). Subsequent benefits will be derived in multiple categories with the intention of demonstrating as much benefit as can be reasonably and reliably quantified.

This memorandum describes the benefit-cost analysis methodology applied in Stage 1 (individual project preliminary analysis), as well as a review of benefit categories which were considered but not included. All benefit categories discussed here are equivalent to avoided costs resulting from project implementation, unless explicitly stated otherwise.

Benefit-Cost Requirements for CDBG-MIT Projects

Although a benefit-cost ratio (BCR) is not a factor in the competition score as set forth by GLO, applicants are required to demonstrate that the benefits of the Covered Project outweigh the costs. As described in the Federal Register,[1] this requirement may be met in two ways:

1. Benefit-cost ratio developed during a benefit-cost analysis (BCA) is greater than 1.0.
    a. Calculations should be prepared in accordance with OMB Circular A-94[2].
    b. BCA methodology should follow FEMA standardized methodologies unless
        i. A BCA for the project has already been completed or is in progress under guidelines of other Federal agencies, or
        ii. The BCA addresses a non-correctable flaw in the FEMA methodology, or

[1] Allocations, Common Application, Waivers, and Alternative Requirements for Community Development Block Grant Mitigation Grantees, 84 FR 169 (August 30, 2019).

[2] *Circular A-94*, Office of Management and Budget, last revised October 29, 1992.

iii. A new approach is proposed that is unavailable using the FEMA Toolkit.

2. Alternately, projects may have a benefit-cost ratio of less than 1.0 under these conditions:
   a. A BCA is still completed following the methodologies described above.
   b. The project "serves low- and moderate- income persons or other persons that are less able to mitigate risks or respond to and recover from disaster."
   c. A qualitative description is provided for "benefits that cannot be quantified but sufficiently demonstrate unique and concrete benefits of the Covered Project for low- and moderate- income persons or other persons that are less able to mitigate risks, or respond to and recover from disasters."

In accordance with these requirements, a quantitative BCA has been performed for each proposed project in Halls Bayou. Additionally, numerous metrics have been compiled to demonstrate that the proposed projects not only benefit low- and moderate- income persons but also a population that is generally vulnerable to disasters. Data has also been compiled to demonstrate potential benefits of the projects that could not be reliably monetized in the BCA.

General Description of Methodology

Where possible, the Halls Bayou BCA was based on the methodologies applied in the FEMA BCA Toolkit, version 6.0[3] ("FEMA Toolkit"). However, input data and assumptions, as well as some calculation methods, deviated from the FEMA Toolkit in some ways:

- The FEMA Toolkit allows for certain default values and tables to be replaced with user input values when documentation is provided. (These are described in more detail in sections on specific benefit categories.)
- Project Useful Life – In the FEMA Toolkit, project lifetime is specified for each structure individually, allowing a different discount factor to be applied to structures subject to buyouts. (See section on Present Value Analysis for more detail.)
- The greatest deviation is the method of determining Expected Annual Benefits from data for specific storm frequencies. (See section on Annualization for more detail.)

Due to the differing methodologies, the Expected Annual Benefit (EAB) values calculated in the Halls Bayou BCA could not be duplicated within the FEMA Toolkit. Pending further guidance on the technical requirements of the BCA for CDBG-MIT applications, this methodology may be revised. The current methodology was deemed to be fully sufficient for performing a preliminary analysis to inform grouping of activities under Covered Projects.

Input Data and Assumptions

The Halls Bayou BCAs primarily used Halls Bayou Structure Inventory (SI)[4] and project data provided by LAN, in conjunction with reference values from the FEMA Toolkit and Hazus (another FEMA BCA tool). Project information from LAN included estimated capital and maintenance costs, project spatial extents, and parcels to be acquired for right-of-way. ArcGIS was used to associate updated parcel and census tract data with the SI, as well as to relate project information to structure locations. A separate analysis was performed to estimate the number of residents and residential units per structure, as well as the number

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[3] *Benefit Cost Toolkit Version 6.0.* FEMA. October 2019. Available at https://www.fema.gov/media-library/assets/documents/179903.

[4] "Structure Inventory Update – Workflow Development," Technical Memorandum dated May 25, 2018, and associated dataset for Halls Bayou subwatershed. Performed by LAN for HCFCD.

of residents who are full-time workers. The datasets used in the Halls Bayou BCA are summarized in *Table 1*, and *Table 2* lists the various standard values and lookup tables referenced in the calculations.

Table 1 – Input Datasets to Benefit-Cost Analysis

Dataset	Description
Halls Bayou Structure Inventory	attributes of individual structures in the study area, including use, size, and look-up codes for various reference tables
American Community Survey Data[5]	data from US Census Bureau at the census tract level related to population, average household size, number of full-time workers, median household income
Regional Groundwater Update Project Population Projections[6]	population projections at the census tract level from a prior regional population study
Project Extents	project locations
Parcel ROW Acquisition	parcels to be partly or fully acquired
Capital Costs	project capital costs provided by LAN
Maintenance Costs	estimated annual maintenance costs provided by HCFCD
Texas Tracts	boundaries and attributes of 2010 Census tracts

[5] U.S. Census Bureau. American Community Survey, 2014-2018. Detailed Tables, Subject Tables, and Data Profile Tables; generated by Freese & Nichols, Inc.; using the U.S. Census Bureau Application Programming Interface.
[6] Regional Groundwater Update Project. 2013. Population Projection Datasets. Freese & Nichols, Inc., Metrostudy, and U. Houston Hobby Center for Public Policy. Prepared for Harris-Galveston Subsidence District, Fort Bend Subsidence District, and Lone Star Groundwater Conservation District.

Table 2 – Sources of Standard Values and Reference Tables

Name	Purpose	Source
Discount Rate	calculate discount factors for converting between annual and present value equivalent costs/benefits	FEMA BCA Toolkit v6.0
Demolition Threshold	threshold above which building is assumed to be fully lost and contents maximally lost	
Useful Life	project lifetime used in discounting	
Depth-Days Curve	table of days displaced for depth flooded	
Disruption Cost Factor	one-time cost per square foot for non-residential structures	
Monthly Cost Factor	recurring cost per square foot per month for non-residential structures	
Hotel per Diem Cost	daily cost per household, up to 5 people, for lodging	
Meal per Diem Cost	daily cost per person of eating out, less average cost of eating at home	
Mental Stress and Anxiety Unit Cost	mental stress and anxiety cost per resident	
Productivity Loss Unit Cost	productivity loss per full-time worker	
Land Use Conversion Unit Benefit	value of ecosystem services ($/acre/year) provided by land use conversion	
Replacement Cost Models	building replacement values ($/sq. ft.)	Hazus-MH MR3 Technical Manual[7]
Depth-Damage Functions	tables of percent damage for depth flooded given the building type	Halls Bayou Structure Inventory
SFR Content-to-Structure Value Ratios	ratio for single-family residences for 1 story, 2 stories, or mobile home	
Other Content-to-Structure Value Ratios	ratio for structures other than single-family residences	

Project Costs

Estimated capital costs of each mitigation project were provided by LAN. The FEMA Toolkit specifies that costs considered in the BCA should include all costs required for completing the project, including but not limited to land acquisition, design, permitting, construction, reporting, and more. Based on this, the full costs provided by LAN were used.

Additionally, guidance in the FEMA Toolkit requires the inclusion of incremental increases in annual maintenance costs associated with the project (limited to maintenance activities which are necessary to maintain project effectiveness). HCFCD provided costs to LAN which were associated with mowing, tree upkeep, and similar costs. Costs provided by HCFCD did not include estimates for Bond ID C-01 (project P518-26-00) nor for Phase 1 projects (Downstream of Bertrand and Hardy West Detention). Annual costs were estimated for these projects based on the unit costs provided by HCFCD.

[7] Hazus-MH MR3 Technical Manual. FEMA. Tables 14.1 through 14.5.

Present Value Analysis

As benefits were determined on an annualized basis (AB), present value projects costs were converted to an annualized cost (AC) to determine the Benefit-Cost Ratio (BCR) as shown in *Equation 1.* Discount factors were determined using the FEMA standard annual rate[8] of 7% and an assumed project useful life of 50 years. The 50-year life was based on a table of project lifetimes within the FEMA Toolkit (*Table 3*).

$$BCR = \frac{(Project\ Capital\ Cost) * \left(\frac{A}{P} Discount\ Factor\right) + Annual\ Maintenance\ Costs}{Expected\ Annual\ Benefits} \qquad \text{Equation 1}$$

Note that the FEMA Toolkit typically shows total cost and benefits of a project as Present Value Cost (PVC) and Present Value Benefit (PVB). However, since the discount factor is the same for both cost and benefit, PVB/PVC is equivalent to AB/AC.

A 100-yr life is typically applied to acquisitions. However, for simplicity in the preliminary BCAs, a single discount factor based on a 50-year life was applied across the entire project. As benefits were calculated on an annual basis, this does not affect the BCR, with the exception of a slight underestimation of social benefits, which must be calculated on a present-value basis and then converted. (Annualized social benefits for structures to be bought out are underestimated by approximately 3%.)

Table 3 – Standard Values for Project Useful Life in FEMA BCA Toolkit v6.0

Flood Hazard Mitigation Project Type	Useful Life (years)
Acquisition / Relocation	
Acquisition / Relocation	100
Building Elevation	
Residential Building	30
Non-Residential Building	25
Public Building	50
Historic Buildings	50
Mitigation Reconstruction	
Mitigation Reconstruction	50
Infrastructure Projects	
Major Infrastructure (dams, levees)	50
Concrete infrastructure, flood walls, roads, bridges, major drainage system	50
Culverts (concrete, PVC, CMP, HDPE, etc.) with end treatment	30
Culverts without end treatment	10
Major pump stations, substations, wastewater systems, or equipment such as generators	50
Minor pump stations, substations, wastewater systems, or equipment such as generators	5

A benefit-cost analysis performed for a project in New York[9] included an alternate analysis that used a 3% discount rate, in addition to the primary analysis with a 7% rate. The final results reported for the project BCR were based on the 7% rate as mandated by OMB Circular A-94[8]. However, reanalyzing the project

[8] Standard discount rate for benefit-cost analyses prescribed by *Circular A-94*, Office of Management and Budget, as last revised October 29, 1992.
[9] *East Side Coastal Resiliency Updated Benefit-Cost Analysis.* New York City Department of Design and Construction. 2019.

with a 3% rate indicated the sensitivity of the BCR to the discount rate used, as a lower rate produces a larger BCR. Using a different discount rate is not recommended for the CDBG-MIT applications.

Annualization

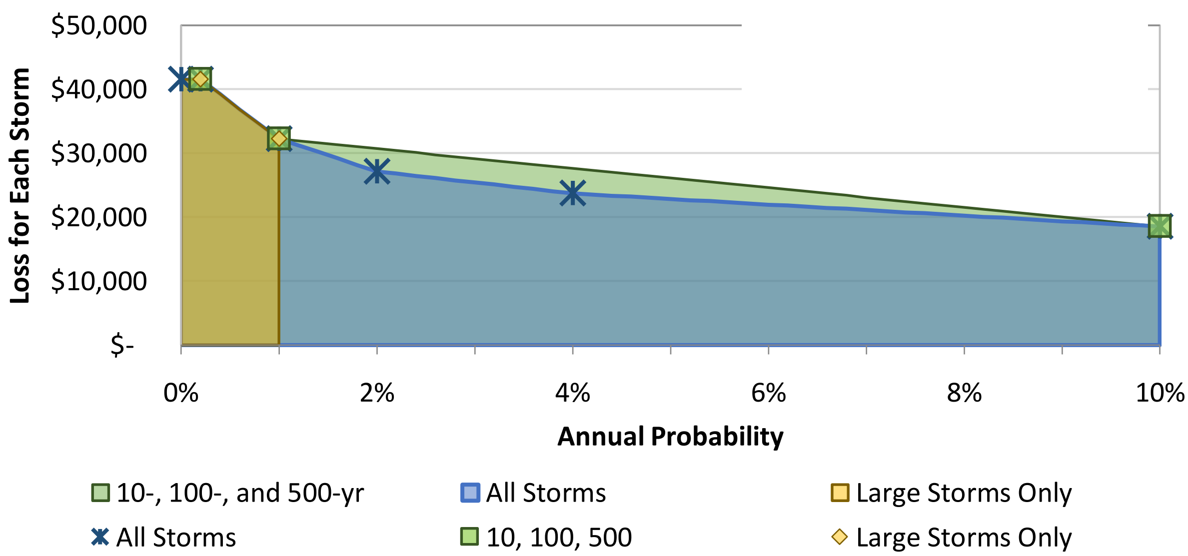
For benefit categories based on avoided losses, impacts are assessed for multiple storm recurrence intervals, and an Expected Annual Loss value is estimated from the damage or loss caused by each storm and the associated probability of such a storm in a single year. This annualized value is estimated as the area under the Damage vs Probability curve. In the BCA for Halls Bayou, a simple trapezoidal area method was applied based on FEMA Guidance[10] associated with the loss estimation software Hazus. *Equation 2* demonstrates how this method is applied if impacts are modeled for 10-, 25-, 50-, 100-, and 500-year storms.

$$\begin{aligned} Annualized\ Loss = & \left(\frac{1}{500} * Loss_{500yr}\right) \\ & + \left(\frac{1}{100} - \frac{1}{500}\right)(Loss_{100yr} + Loss_{500yr}) \\ & + \left(\frac{1}{50} - \frac{1}{100}\right)(Loss_{50yr} + Loss_{100yr}) \\ & + \left(\frac{1}{25} - \frac{1}{50}\right)(Loss_{25yr} + Loss_{50yr}) \\ & + (\frac{1}{10} - \frac{1}{25})(Loss_{10yr} + Loss_{25yr}) \end{aligned} \qquad \textit{Equation 2}$$

The EAB is the difference in Expected Annual Loss under existing and post-mitigation conditions.

The BCA tool developed by FNI is flexible and adjusts this equation if one or more of these storms are not available, but loss values are not extrapolated to storm recurrence intervals smaller than those modeled in HEC-RAS. As a result, monetary benefits for some projects are underestimated (Figure 1).

Figure 1 – Impact of Number of Storms Modeled on Annualized Loss Calculation



In the preliminary BCA, storms with annual probabilities greater than 1% (events smaller than 100-year storms) were not modeled for three projects. However, FNI did not deem it necessary to request additional modeling by LAN for the preliminary BCAs for these projects for reasons described below.

[10] "Guidance for Flood Risk Analysis and Mapping," p. 18. FEMA. February 2018.

- C-26 and C-27 (projects on P118-23-00 and P118-23-02) were modeled for 100-year and 500-year storms only. Benefits from these projects are mostly limited to the 500-year storm. The number of structures and average benefit/structure for the 100-year storm are both low, so it is unlikely that overall benefits would increase by much with the addition of modeling results for more frequent storms.
- C-24 (project on P118-09-00) was modeled for various storm frequencies. However, due to discrepancies in the results for the 50-year storm, LAN advised against using that and smaller storm results, so the final BCA was based only on 100-year and 500-year storms. Preliminary results that included the additional storm frequencies suggested that the overall BCA was not significantly affected by this exclusion due to the small magnitude of standard benefits from this project.
- Phase 1 Hardy West – Impacts were modeled for the 100-year storm only, which could cause an underestimation of benefits. However, this project as proposed in March 2020 also produced negative impacts on numerous structures; these impacts preclude inclusion in the CDBG-MIT application and also negatively affect the project's BCR. Should revised bundles include this project with the negative impacts mitigated, it is recommended that additional storms be modeled for this project.

The FEMA Toolkit does not use the trapezoidal area method. Instead, the FEMA Toolkit estimates a curve of loss values for all storm frequencies based on the relationship between flow depth and flow rate at each location along the stream. As a result, the FEMA Toolkit estimates losses for events more frequent than the smallest storm modeled. However, it should be noted that a benefit-cost analysis performed for a project seeking CDBG-DR funds through HUD's Rebuild by Design[11] competition used the trapezoidal method to calculate expected annual losses[12], as FNI has done for Halls Bayou.

Standard Benefits – Avoided Losses Based on Depth of Inundation of Individual Structures

Overview of Standard Benefits

A traditional BCA for flood mitigation projects assesses the difference in probable damages to a structure and its contents under existing (baseline) conditions and post-mitigation (proposed) conditions. Baseline and post-mitigation impacts to a structure and its contents are assessed for multiple storm recurrence intervals based on the depth to which the structure is inundated in each scenario. Flooding depth is calculated as the difference in water surface elevation (WSE) as modeled in HEC-RAS and Finished Floor Elevation (FFE) as provided in the SI. Where FFE was not available in the SI, FFE was estimated at 6 inches above ground elevation[13].

Within the FEMA Toolkit, standard benefit categories include traditional benefits as well as others that can be related to the depth of flooding in a given storm frequency:

- Building Damages – Depth related to % of value lost.
- Content Damages – Depth related to % of value lost.

[11] Hurricane Sandy Rebuilding Task Force: Rebuild by Design Competition. *https://www.hud.gov/sandyrebuilding/rebuildbydesign*
[12] *East Side Coastal Resiliency Updated Benefit-Cost Analysis.* New York City Department of Design and Construction. 2019.
[13] *Bare Earth LiDAR, HGAC 2008 Datum Adjusted*. Houston-Galveston Area Council. 2008.

- Displacement – Depth related to number of days displaced.
- Loss of Function / Loss of Income– Depth related to number of days rent payment income or commercial function is lost.

The following sections explain how these categories were treated in the Halls Bayou BCA.

Building and Content Losses

Assumptions maintained from the FEMA Toolkit:

- Value of structure damages are based on the Building Replacement Value (BRV), not the appraised or market value.
  - BRV = Area (sq ft) x Unit BRV
- A demolition threshold was set to 50% (default value in FEMA Toolkit). When percent damage based on depth and the depth-damage curve exceeded this threshold:
  - Structure was assumed to need replacement rather than repair. Expected Damage = 100% * BRV.
  - Content losses were assumed to be maximized (not a total loss, but the maximum value on the depth-damage curve).

Several changes to FEMA Toolkit default assumptions were incorporated. All of these have the option to be changed within the FEMA Toolkit as well.

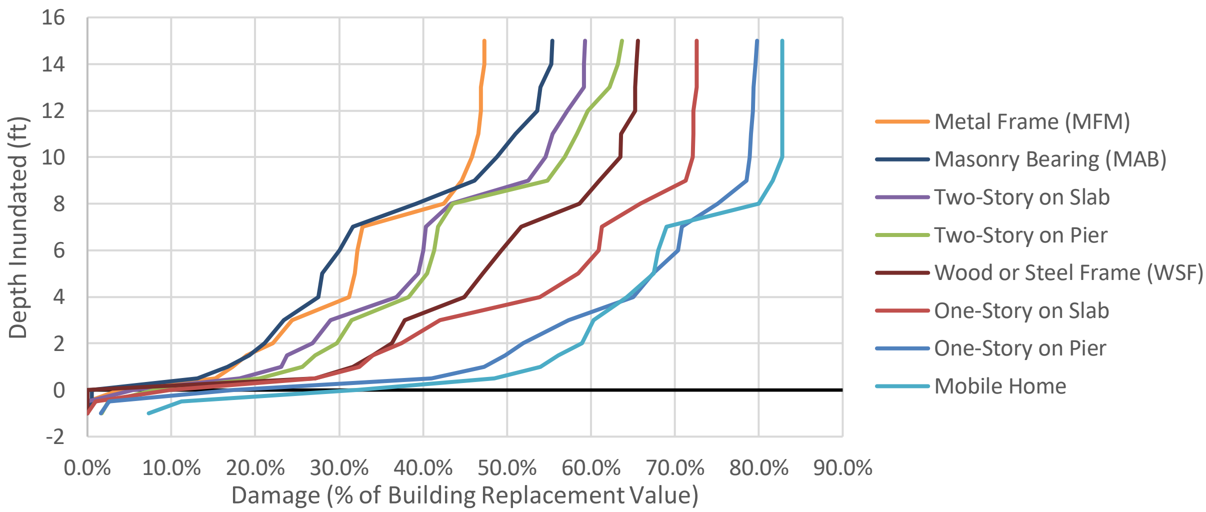
- Default depth-damage functions (DDFs) were replaced with DDFs provided in the Halls Bayou SI (*Figure 2*), which were developed by the USACE New Orleans District[14].
  - As indicated by the technical memorandum provided with the SI, the DDF for each structure was applied both to the building value and the contents value. (FEMA Toolkit has option but not requirement for separate curves.)
  - It should be noted that some structures are expected to experience damage even when WSE is below FFE by up to 2 feet, depending on structure type.
- Building Replacement Values (cost / square foot) have a default value of $100/sf in the FEMA Toolkit. BRVs from Hazus (another FEMA loss estimation software package) were used instead.
  - Hazus values account for building type, number of stories, and for residential structures, household income. This allowed for inclusion of local data to appropriately reflect structure values.
  - Residential unit BRVs are based on construction class (economy, average, custom, or luxury). Using Hazus methodology, these classes were determined based on median household income in each census tract.
  - Values documented in the Hazus Technical Manual[15] are based on standard cost-estimation models published in *Means Square Foot Costs*[16] and were reported in 2006

[14] *Final Report: Depth-Damage Relationships for Structures, Contents, and Vehicles and Content-to-Structure Value Ratios (CSVR) in Support of the Donaldsonville to the Gulf, Louisiana, Feasibility Study*. U.S. Army Corps of Engineers, New Orleans District. New Orleans, Louisiana. 2006.
[15] Hazus-MH MR3 Technical Manual. FEMA.
[16] R.S. Means, 2005.

dollars. For the Halls Bayou BCA, these values were scaled up using RSMeans Historical Cost Indices from 2006 to January 2020 to be consistent with project cost estimates.

- Total value of contents in each structure was estimated from content-to-structure value ratios included in the SI, which specify a percentage of the building value, in place of the default of percentages.

Figure 2 – Depth-Damage Functions from Halls Bayou Structure Inventory



Displacement Losses (Residential)

Avoided cost of residential displacement is considered a "standard" benefit in the FEMA Toolkit. Residential displacement losses based on the FEMA Toolkit include:

- Temporary lodging for each displaced household (assumes up to 5 household members per hotel room)
- Increase in meal cost (above average cost of eating at home) for each displaced resident

Expected annual benefits depend on a Depth-Days curve to determine number of days displaced for depth of inundation. Standard values for lodging and meals, as well as the Depth-Days curve, were taken from the FEMA Toolkit. The FEMA Depth-Days curve estimates 45 days of displacement for each foot of flooding above FFE.

Displacement Losses (Non-Residential)

Avoided cost of non-residential displacement is considered a "standard" benefit in the FEMA Toolkit and depends on the same Depth-Days curve as residential displacement costs. Non-residential displacement losses based on the FEMA Toolkit include:

- One-time cost of relocating business equipment
- Monthly rental costs of new space
  - Can overlap with Loss of Income by property owner. Loss should be applied as Displacement *or* Loss of Income, but not both.

Cost factors are provided in the FEMA Toolkit as $/sq. ft. values to estimate both components of non-residential displacement.

Loss of Function / Loss of Income Benefits

Considered a "standard" benefit in the FEMA Toolkit. Loss of function or income represents the cost to the property owner due to lack of tenants paying rent or inability to operate a business. Loss of function also applies to critical facilities.

- Loss of Income – monthly rental income for owners of rental properties
    - Can overlap with Non-residential Displacement costs by renter. Loss should be applied as Displacement *or* Loss of Income, but not both.
- Loss of Function – based on portion of annual operating budget pertaining to location of interest

Loss of Function or Income benefits were not included in the Halls Bayou BCA for these reasons:

- Residential Displacement costs have been included instead of Loss of Income, which represent the additional cost to the renter and are calculated based on standard values from FEMA. These calculations were considered to be more reliable than estimating monthly rent prices in the area.
- Non-residential Loss of Function costs require knowledge of the operating budget for each non-residential structure. This data was not available, but as the majority of mitigation benefits in Halls Bayou are to residential structures, the exclusion of this category is not expected to have a substantial impact on the total quantified benefit of a project.

Ancillary Benefit Categories included in Comprehensive Benefit-Cost Analysis for Halls Bayou

Social Benefits

Social benefits based on the FEMA Toolkit are based on the expected mental health impacts of experiencing a disaster, regardless of size. These benefits include avoided costs of:

- Health treatment for mental stress and anxiety of impacted residents
- Productivity losses by impacted residents who work full-time due to impacts on mental health

The Halls Bayou BCA replicated the method used in the FEMA Toolkit, which does not estimate an expected annual benefit from storm frequencies. Instead, a present value amount per benefitted person is applied to estimate the avoided costs of mental health treatment and of lost productivity *(Table 4*). These values are based on studied prevalence, severity, and course of mental effects following a disaster[17].

Table 4 – Unit Values for Avoided Costs of Mental Health Impacts

Category	Unit Cost (Present Value)	Unit
Treatment for mental stress and anxiety	$2,443	Resident of flooded home
Lost productivity	$8,736	Resident of flooded home who works full-time

[17] *Final Sustainability Benefits Methodology Report.* FEMA. Task order HSFEHQ-11-J-1408. August 2012.

Environmental Benefits

Environmental benefits based on the FEMA Toolkit include:

- Value of ecosystem services provided by enhancement of a parcel's land use to a use type which provides a higher level of natural environmental benefits

Rather than an avoided cost, environmental benefits represent an added service. *Table 5* indicates the value of each land use type (assuming conversion from developed land).

Table 5 – Unit Benefit Values for Conversion of Developed Land to Land Use of Higher Ecosystem Value

Documented Benefit/acre/year *				
Green Open Space	**Riparian**	**Wetlands**	**Forests**	**Marine /Estuary**
$8,308	$39,545	$6,010	$554	$1,799

**Documented in help section of B/C Analysis Toolkit v6.0, as of 01/28/2020.*

Several of the Halls Bayou mitigation projects require acquisition and conversion of developed land to undeveloped floodplain or detention. For the preliminary BCA, converted acreage was approximated and was assumed to be converted to green open space. As the proposed projects are not yet in final phases of design, a conservative approach will be taken to estimate total acreage converted in the final BCA for Covered Projects to avoid overstating environmental benefits.

Other Ancillary Benefit Categories

Numerous other potential benefits were researched; however, a lack of reliable input data, valid methodology, or other factors made these infeasible for inclusion in the Halls Bayou BCA. Descriptions of these benefit categories are provided below, along with references and explanations of the roadblocks preventing their inclusion in the comprehensive BCA.

Property Value Losses – Lost Tax Revenue

Recommendation: Per HCFCD guidance, do not consider lost tax revenues as part of the benefit-cost analysis, as this can be considered both a positive factor for residents as much as a negative factor for governmental entities. See next section for an alternate way to address reduced property values.

Property Value Losses – Impacts on Owners

As discussed at a previous meeting with HCFCD, falling property values can have a negative effect on the financial flexibility of housing cost-burdened homeowners and even renters. Data on housing cost-burdened residents (those paying above a percentage threshold of income for housing costs) is available from the US Census Bureau American Community Survey and has been compiled for the Halls Bayou watershed and Harris County as a whole.

This category is not found in the FEMA toolkit. Avoided losses in property values were included as a quantified benefit in another project analysis[18], which calculated low, medium, and high potential losses in value based on percentages (3%, 7%, and 12%, respectively) from a previous study. The referenced study[19] was based on trends following Hurricanes Fran and Floyd in Carteret County, North Carolina and

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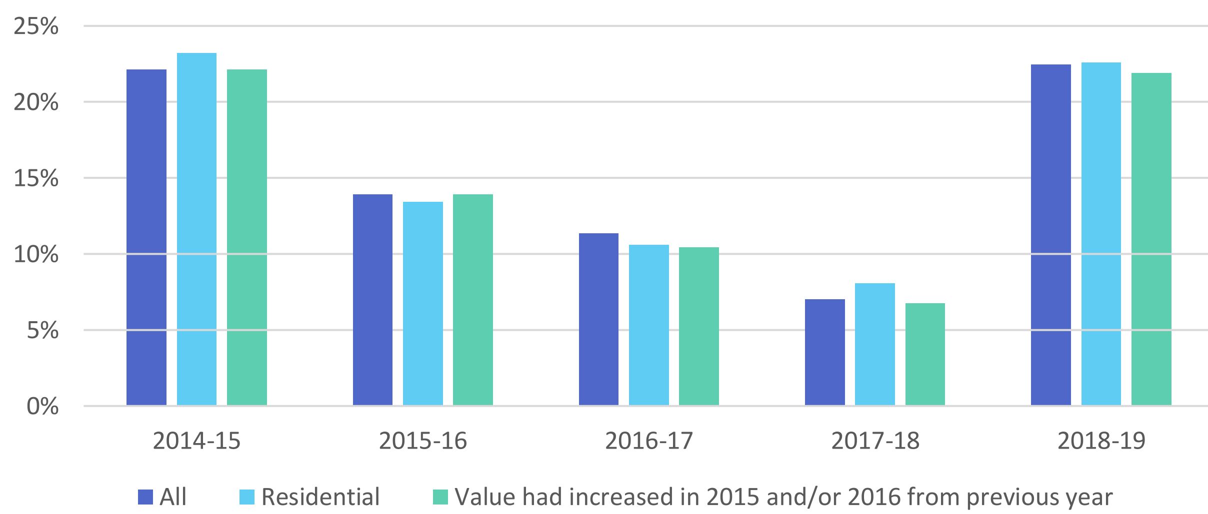
[18] *East Side Coastal Resiliency Updated Benefit-Cost Analysis.* New York City Department of Design and Construction. 2019.

[19] Bin, O., Brown Kruse, J., and C.E. Landry. 2008. "Flood Hazards, Insurance Rates, and Amenities: Evidence from Coastal Housing Market." *Journal of Risk and Insurance*, *75-1*, p. 63-82.

may not be directly applicable to property value trends in Harris County. Additionally, this study implied that property values are reduced following a significant flood event. Based on parcel value data from the Harris County Appraisal District (CAD), properties in the Halls Bayou watershed did not experience such a universal loss in value following recent flood events. However, the CAD data does suggest that annual growth in property values, at least for residential properties, generally slowed after Hurricane Harvey in the watershed.

CAD parcel values were assessed from 2014 to 2019. A comparison of parcels within and outside the approximate inundation extents of Harvey flooding mapped by HCFCD did not reveal any significant difference in trends in property values. Although growth in property values did slow from 2017 to 2018, growth had been slowing over the previous two years as well.

Figure 3 – Median Year-to-Year Percent Change in Assessed Values of Individual Parcels in Halls Bayou
**Parcels included in assessment were limited to those which had values available for all years 2014 – 2019. Percent change values of 0% were excluded to avoid errors from repeated entries across years.*



These trends could be caused or influenced by floods in 2015, 2016, and 2017, but the degree to which local flooding impacted the value growth rates cannot be ascertained. General economic conditions in Harris County following Hurricane Harvey, as well as other external economic factors, could also contribute to changes in property values. Because the exact impact on property values of local flooding in the Halls Bayou watershed cannot be quantified, this category has not been included in the BCA.

Recommendation: Describe flood impacts on property values in the CDBG-MIT application, alongside profiles of % housing cost-burdened and LMI residents in the project areas. Discuss the financial impact of disaster-induced property value reductions on owners for whom the home is a large percentage of their overall assets.

Productivity Losses Not Included in the FEMA BCA Toolkit

The FEMA Toolkit estimates productivity losses only for full-time workers, and these losses are limited to estimates based on the mental health impacts to workers. As part of the BCA literature review, FNI searched for methods to quantify other productivity losses, including those for part-time workers and for working parents impacted by school closures after a flood. However, no methods were found. (Standard unit values for full-time worker productivity loss in the FEMA Toolkit should not be linearly scaled to develop unit losses for part-time workers, who may work varying numbers of hours/week and weeks/year.)

Recommendation: Include estimates of the number of part-time workers benefitted by mitigation activities in the CDBG-MIT applications as part of the project impact description. (no monetary value)

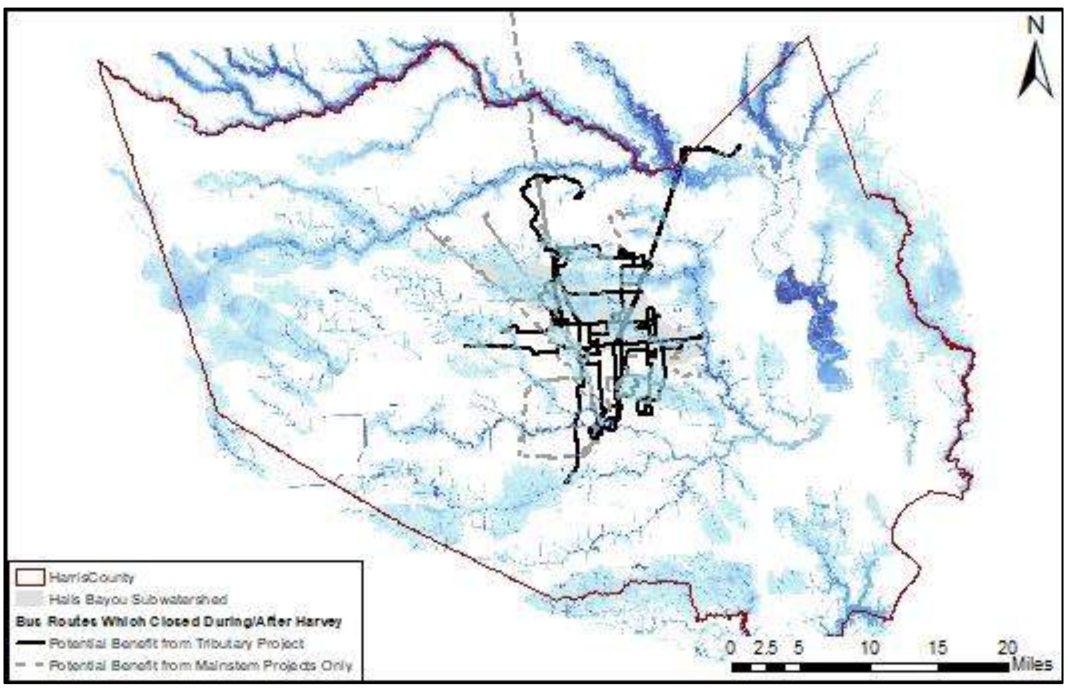
Public Transportation – Impacts of Roadway Flooding on Bus Riders and Bus Fare

Street closures due to flooding in the Halls Bayou Watershed likely impacted a large number of commuters who do not live in the watershed. Data from the Metropolitan Transit Authority of Harris County (Metro) indicates that several bus routes through the Halls Bayou watershed were closed for 4 to 9 days during and after Hurricane Harvey.

FNI did not find any references for a method to monetize the productivity losses of workers impacted by road closures. A separate study[20] assessed economic impacts as the value of lost time by bus riders and lost bus fare revenue. The study found that the annual value of expected benefits (avoided impacts) related to bus service for that project would be only $158, less than 0.2% of total project benefits.

All Metro bus routes passing through the service areas of the proposed Halls Bayou projects also extend across multiple floodplains in Harris County (*Figure 4*). It was determined that even if a substantial section of a route is removed from the floodplain due to a Halls Bayou mitigation project, inundation elsewhere could still cause route closure. Because of this, assigning economic benefits to these routes from reduced flooding along Halls Bayou is not considered to be a valid approach, so this category was not included in the BCA.

Figure 4 – Harvey-Impacted Bus Routes Intersecting Halls Bayou Watershed



FNI has compiled average ridership data for the impacted bus routes in Halls Bayou and has analyzed the number of days these routes were each closed after Hurricane Harvey.

[20] *East Side Coastal Resiliency Updated Benefit-Cost Analysis.* New York City Department of Design and Construction. 2019.

Recommendation: In CDBG-MIT grant application, describe the bus routes potentially benefitted by the proposed mitigation activities and include the number of days these routes were closed during and after Hurricane Harvey. Include information on the average number of riders to demonstrate the number of persons potentially benefitted by reduced flooding in Halls Bayou, but clarify that reduced flooding in the Halls Bayou watershed does not guarantee the routes would not be closed due to potential flooding elsewhere.

Transportation – Other Impacts of Roadway Flooding

The FEMA Toolkit includes a module to calculate avoided economic loss of service costs for roads and bridges. Determining the benefit from mitigated roadway flooding requires prescribing a likely detour route for each flooded road segment and estimating the travel time and mileage of both the original and detour routes. Traffic counts and speed limits are necessary inputs to this analysis. Avoided loss of service considers both the value of lost time and the standard federal rate for mileage, both of which are based on the additional time and mileage beyond the normal trip that a detour would require.

The most recently documented value in FEMA guidance documents[21] was $29.63. However, the value of lost time currently applied in the FEMA Toolkit is estimated at $33.44 per hour per vehicle, based on back-calculations from test inputs in a 2020 build of the Toolkit. Presumably, the $33.44 per hour rate accounts for inflation since the determination of the $29.63 value in 2011.

For many of the roads impacted by the proposed Halls Bayou projects, flooded roadways are residential streets in neighborhoods, where the main problem is a loss of access rather than impeding thru traffic. Based on this, the loss of service cannot be monetized as the additional time and mileage required for a detour. An approach to this issue was presented in another BCA report[22], which used a delay time of 12 hours per one-way trip for roads or bridges without detours as recommended in FEMA supplemental guidance[23]. However, applying a 12-hour delay time to each daily trip on a one-way residential street may be inappropriate, as the average daily traffic counts on these streets represent multiple trips by individual households, which in practice would not be losing more than 24 hours per day of roadway service time if the street is flooded all day. No mileage benefits can be counted when a detour is not available.

This benefit category has not been included in the preliminary BCA performed for each individual Halls Bayou project. However, roadway benefits could potentially be developed for each of the two Covered Projects once hydraulic modeling results are available for the grouped activities.

Recommendation: Determine avoided losses in terms of the economic value of lost time for each residential structure with no available road access due to flooding which would gain full roadway access after implementation of the proposed projects. Assume 12 hours of lost time as prescribed by FEMA guidance and use the standard value in the FEMA Toolkit. This analysis will require significant spatial analysis and may require discussion with GLO to assess the viability of the proposed method.

Avoided Physical Injuries and Fatalities

Avoided injuries and fatalities were researched for inclusion as a benefit. The number of injuries due to a flood event can be estimated as shown in *Equation 3*.

$$\#\,Physical\ Injuries = (Impacted\ Population) * (\%\,reported\ injuries) \qquad \text{Equation 3}$$

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[21] *FEMA Benefit-Cost Analysis Re-engineering (BCAR), Development of Standard Economic Values.* Version 6.0. FEMA. December 2011.

[22] *HUD National Disaster Resilience Competition (NDRC) Phase 2 Application, Attachment F Benefit Cost Analysis.* Commonwealth of Virginia. 2015.

[23] *Supplement to the Benefit-Cost Analysis Reference Guide*. FEMA. June 2011. Page 5-14.

The cost of these injuries can be monetized by applying the Abbreviated Injury Scale (AIS), which estimates economic injury values by severity to obtain the cost of injury as shown in *Equation 4*[24].

$$Cost\ of\ Injuries = (AIS\ \$\ value\ of\ average\ injury) * (\#\ Physical\ Injuries) \qquad \text{Equation 4}$$

The AIS is a comprehensive system for rating the severity of accident-related injuries and includes six levels of injury severity. It classifies nonfatal injuries into five categories depending on the short-term severity of the injury. The sixth category corresponds to injuries that result in death 30 days or more after the injury. A summary of the classification of different injuries by AIS level and their threat to life is included in *Table 6*.

Table 6 – AIS Classifications[25]

AIS	Injury Severity	Selected Injuries
1	Minor	Superficial abrasion or laceration of skin; digit sprain; first-degree burn; head trauma with headache or dizziness (no other neurological signs).
2	Moderate	Major abrasion or laceration of skin; cerebral concussion (unconscious less than 15 minutes); finger or toe crush/amputation; closed pelvic fracture with or without dislocation).
3	Serious	Major nerve laceration; multiple rib fracture (but without flail chest); abdominal organ contusion; hand; foot, or arm crush/amputation.
4	Severe	Spleen rupture; leg crush; chest-wall perforation; cerebral concussion with other neurological signs (unconscious less than 24 hours)
5	Critical	Spinal cord injury (with cord transection); extensive second- or third-degree burns; cerebral concussion with severe neurological signs (unconscious more than 24 hours)
6	Fatal	Injuries, which although not fatal within the first 30 days after an accident, ultimately result in death.

Federal agencies such as the Federal Aviation Administration (FAA), US Department of Transportation (USDOT), and National Highway Traffic Safety Administration (NHTSA) calculate an economic value for avoiding different AIS scale injuries by using the relative value coefficients as a fraction of the VSL. By following this methodology, FEMA is able to establish an economic value for the various injury levels that could be avoided and therefore counted as benefits from a hazard mitigation project[26].

A valuation for each AIS injury severity level is established by relating each level to the loss of life and quantity of life resulting from an injury typical of that level. This loss is expressed as a fraction of the value placed on an avoided fatality. For analysis with a base year of 2012, guidance suggests that $6.6 million be used as the current estimate for the value of a statistical life (VSL), measured in 2012 dollars. The fraction shown in column 3 of *Table 7* should be multiplied by the suggested VSL to obtain the values of preventing the injuries being analyzed. For example, to obtain the value of a “serious” injury (AIS 3), the Fraction of VSL for a serious injury (0.0575) should be multiplied by the VSL ($6.6 million) to calculate the

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[24] *HUD National Disaster Resilience Competition (NDRC) Phase 2 Application, Attachment F Benefit Cost Analysis.* State of New York. October 25, 2015.

[25] *Treatment of the Values of Life and Injury in Economic Analysis.* Federal Aviation Administration. September 2016. Available at https://www.faa.gov/regulations_policies/policy_guidance/benefit_cost/media/econ-value-section-2-tx-values.pdf.

[26] *FEMA Benefit-Cost Analysis Re-engineering (BCAR), Development of Standard Economic Values.* Version 6.0. FEMA. December 2011.

value of the serious injury ($379,000). Values for injuries in the future would be calculated by multiplying the Fractions of VSL below by the future VSL.

Where specific information is available on separate injuries for the same individual by AIS level, only the value of the most severe injury should be used.

*Table 7 – AIS Valuation (2012 Dollars)**Error! Bookmark not defined.***

AIS Code	Description of Injury	Fraction of VSL	Economic Value
AIS 1	Minor	0.0020	$13,000
AIS 2	Moderate	0.0155	$102,000
AIS 3	Serious	0.0575	$379,000
AIS 4	Severe	0.1875	$1,237,000
AIS 5	Critical	0.7625	$5,032,000
AIS 6	Fatal	1.0000	$6,600,000

It has been estimated that there will be an expected 1.07 percent annual growth rate in median real wages. These estimates imply that VSL in future years should be estimated to grow by 1.07 percent per year[27]. This guidance can be used to convert the table above based on 2012 dollars to 2017 dollars for Hurricane Harvey.

*Table 8 – AIS Valuation (2017 Dollars)**

AIS Code	Description of Injury	Fraction of VSL	Dollar Value*
AIS 1	Minor	0.0020	$13,900
AIS 2	Moderate	0.0155	$107,900
AIS 3	Serious	0.0575	$400,200
AIS 4	Severe	0.1875	$1,305,100
AIS 5	Critical	0.7625	$5,307,500
AIS 6	Fatal	1.0000	$6,960,700

**Rounded to the nearest hundred dollars*

Because the number and severity of injuries related to a particular storm is not a predictable quantity, determining a probable annual value of avoided costs of injuries due to a mitigation project is not considered feasible. As such, this factor will not be included in the quantitative benefit-cost comparative analysis. However, an approximate valuation of the injuries and fatalities during Hurricane Harvey within the Halls Bayou project areas can still be presented as part of the CDBG-MIT application to demonstrate additional benefits from the project. The 2017 AIS dollar values can be distributed among those impacted during Hurricane Harvey to obtain the cost of injuries associated with Hurricane Harvey based on the equations provided above.

The following information related to the injury data for Hurricane Harvey is still required in order to include this benefit in the BCA.

- Data providing an indication of injury severity
- Percentage of reported injuries during Hurricane Harvey

[27]*Guidance on Treatment of the Economic Value of a Statistical Life (VSL) in U.S. Department of Transportation Analyses.* U.S. Department of Transportation Memorandum. February 28, 2018.

One paper[28] reviewed by FNI included the percentage of reported injuries after Hurricane Sandy as cited in a Centers for Disease Control and Prevention (CDC) report[29]. A similar report for Hurricane Harvey was searched for on the CDC website, but it was determined that such a report has not been published.

Recommendation: Identify a source in Harris County to provide the injury data required to include Cost of Physical Injuries due to Hurricane Harvey as part of the qualitative discussion of benefits in the CDBG-MIT application.

Loss of Utility Services – Electricity

Loss of electricity was explored as a possible benefit to include in the BCA. Two methods were identified:

1. An Interruption Cost Estimate (ICE) Calculator was located to determine cost associated with loss of electricity - https://icecalculator.com/interruption-cost. Input data required includes:
    a. Number of non-residential customers
    b. Number of residential customers
    c. Reliability Index Results (explained here - https://www.centerpointenergy.com/en-us/Services/Pages/reliability-indexes.aspx?sa=HO&au=bus)

Table 9 – Reliability Indexes

Name	Definition
System Average Interruption Duration Index	$SAIDI = \frac{\text{sum of all outage durations}}{\text{\# of customers}}$
System Average Interruption Frequency Index	$SAIFI = \frac{\text{count of all extended outages}}{\text{\# of customers}}$
Customer Average Interruption Duration Index	$CAIDI = \frac{SAIDI}{SAIFI}$

Values for SAIDI, SAIFI, and CAIDI could not be determined. Therefore, this method was not explored further.

2. The FEMA Toolkit[30] applies a standard value of $148 per capita per day for the economic impact of power loss. Approximately 19% of this is the impact to residential customers[31].

A paper**Error! Bookmark not defined.** reviewed by FNI assumed the probability for power loss to be equal to the probability of displacement, which was calculated by the FEMA BCA Tool. However, this category was included in the reviewed paper as a benefit to implement mitigation measures for electricity that would increase efficiency and improve reliability rather than for flood mitigation measures.

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[28] *HUD National Disaster Resilience Competition (NDRC) Phase 2 Application, Attachment F Benefit Cost Analysis.* State of New York. October 25, 2015.
[29] *Centers for Disease Control and Prevention, Morbidity and Mortality Weekly Report (MMWR) Nonfatal Injuries 1 Week After Hurricane Sandy — New York City Metropolitan Area, October 2012 Weekly, October 24, 2014 / 63(42): 950-954, Robert M. Brackbill, PhD et al.*
[30] *Benefit Cost Toolkit Version 6.0.* FEMA. October 2019. Available at https://www.fema.gov/media-library/assets/documents/179903.
[31] *FEMA Benefit-Cost Analysis Re-engineering (BCAR), Development of Standard Economic Values.* Version 6.0. FEMA. December 2011.

Electrical substations were located based on the Halls Bayou Structure Inventory. No substations are at risk of flooding in the service areas of the proposed mitigation projects, so this benefit was not assessed further.

Recommendation: Do not include in the BCA; proposed projects would not mitigate any potential loss of electricity as no substations are at risk of flooding in the project service areas.

Loss of Utility Services – Water

In addition to the City of Houston, several small public water systems (PWS) operate in the Halls Bayou watershed. Many of these utilize groundwater from wells operated independently by each PWS. FNI mapped the locations of such wells and determined that only two such wells might benefit from the proposed tributary projects. Additional wells could have benefits if one of the mainstem projects was selected. Most of these water systems serve small populations, which limits the value of the potential benefit.

To determine the cost of loss of water service, the FEMA Toolkit requires an estimate for the number of people and length of time that water service would be lost. It is not clear if this applies only to complete system interruptions in which no running water is available. Several PWS in the Halls Bayou watershed issued Boil Water Notices after Hurricane Harvey based on information from TCEQ[32], as shown in *Table 10*. However, data on service interruptions by individual utility was not available.

Table 10 – Public Water Systems in Halls Bayou Watershed Which Implemented Boil Water Notices After Hurricane Harvey

Facility Name	Population Served	Number of Days with Boil Water Notice in Place
GREENWOOD VILLAGE	2250	3
BERGVILLE ADDITION	27	5
MARY FRANCIS SUBDIVISION	1659	3
COLONIAL HILLS	930	12
STETNER ADDITION	135	5
MOBILE HOME ESTATES	543	10
LONE WILLOW MHP WEST	90	18
LONE WILLOW MOBILE HOME PARK	80	14
FATIMA FAMILY VILLAGE MHP	100	11
SELLERS ESTATES MOBILE HOME COMM	85	32
TASFIELD	219	5
ROSEWOOD MOBILE HOME PARK	234	11
MCFARLAND VILLAGE APARTMENTS	120	5
HEAVENS MOBILE HOME PARK	25	16

Recommendation: If projects are selected with service areas overlapping the well locations of any PWS, FNI recommends submitting a data request (fee required) to TCEQ for specific information on any service interruptions following Hurricane Harvey and the duration of such interruptions in those PWS. Follow-ups with the operators of such PWS may also be required to determine whether the cause of such

[32] "Public Drinking Water: Community Water Systems (CWSs) Impacted by Hurricane Harvey with Rescinded Boil Water Notices." TCEQ Dataset. December 28, 2017. Available at https://www.tceq.texas.gov/assets/public/response/hurricanes/bwn-rescinded.pdf.

interruptions would be mitigated by reduced flooding depths. If so, the standard FEMA value ($105/person/day) for the loss of water service per person per day may be applied in the final BCA.

Loss of Utility Services – Wastewater

FNI determined that multiple public water systems (PWS) operate wastewater treatment facilities (WWTF) within the Halls Bayou watershed. These WWTFs treat wastewater from their respective PWS subdivision(s) and discharge treated effluent into nearby streams, such as Halls Bayou. FNI mapped the locations of these WWTFs and found that none would benefit from the proposed tributary projects. Three WWTFs might benefit if one of the mainstem projects was selected. The WWTFs that could benefit from the mainstem projects serve relatively small populations, so potential benefits are likely limited.

In order to determine the cost from loss of wastewater utility services, the FEMA Toolkit requires an estimate for the number of customers served and length of time that wastewater services are impacted. It is not clear if this applies only to complete utility interruptions where the WWTF is not operable. At one point during Hurricane Harvey, 40 WWTFs were rendered inoperable or even destroyed[33], including many within Harris County. However, data on the specific facilities impacted to this extent and the duration of impact were not available. News reports indicate that none of the WWTFs rendered inoperable or destroyed one month after Hurricane Harvey were located in Halls Bayou[34].

Recommendation: If projects are selected that could mitigate flooding at any WWTFs serving PWS within the Halls Bayou watershed, FNI recommends submitting a data request (fee required) to TCEQ for specific information on any WWTFs that were damaged, rendered inoperable, or destroyed following Hurricane Harvey and the duration of potential sewer service or treatment interruptions in those PWS. Follow-ups with the operators of the WWTFs may also be required to determine whether the cause of such interruptions would be mitigated by reduced flooding depths. If so, the standard value from the FEMA toolkit for the loss of water service per person per day ($49/person/day) may be applied in the final BCA.

Energy Savings

Energy savings were explored as a possible benefit type to include in the BCA. Energy consumption in the west south central region in 2015 was determined to be 38.1 Btu/SF

(https://www.eia.gov/consumption/residential/data/2015/c&e/pdf/ce1.4.pdf). This data for energy consumption includes natural gas, electricity, fuel oil/kerosene, and propane. A method to monetize is needed in order to include this benefit.

Recommendation: Do not include in the BCA as a benefit of flood mitigation projects. This benefit category was included in the paper[35] reviewed by FNI based on energy-efficient improvements through the installation of retrofits to improve building efficiency and produce energy cost savings.

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[33] *Hurricane Harvey Response 2017, After Action Review Report.* Texas Commission on Environmental Quality. April 3, 2018. Available at:
https://www.tceq.texas.gov/assets/public/response/hurricanes/hurricane-harvey-after-action-review-report.pdf

[34] *"Raw sewage spilled in Houston after wastewater plants damaged by Harvey",* Stuckey, Alex. Houston Chronicle. September 19, 2017. Available at:
https://www.chron.com/news/houston-texas/article/Nearly-a-dozen-wastewater-treatment-facilities-12209605.php

[35] *HUD National Disaster Resilience Competition (NDRC) Phase 2 Application, Attachment F Benefit Cost Analysis.* State of New York. October 25, 2015.

Damage Related to Potential Pollution Sources

NOAA's Coastal Flood Exposure Mapper includes potential pollution sources as a contributing factor to overall risk for areas subject to flood hazards. During FNI's research (including review of benefits quantified in HAZUS), no references were located for methods of monetizing risks associated with hazardous materials or other pollutants.

Recommendation: Describe the number and type of potential pollution sources in the project impact areas as part of the CDBG-MIT application, and include a qualitative discussion of the benefit of reducing flood risk to these facilities.

Elderly Care Centers

One reference included avoided costs of evacuating elderly residents of care facilities[35]. However, no elderly care centers were identified within Halls Bayou.

Recommendation: Do not include. This benefit category is not applicable to the Halls Bayou projects due to the lack of elderly care facilities in the project impact area.

Emergency Response and Recovery Efforts

After Hurricane Harvey, flooded roadways and non-functioning transportation services impeded travel. Flooded roads could (in the future) prevent emergency response vehicles—such as police cars, ambulances, or firefighting equipment—from reaching flood victims in time. The protection of these areas from flooding will serve to reduce emergency response times and give adequate access to crews that typically deal with fallen trees, downed power lines, or other disaster incidents. Flood risk reduction will also favorably impact post-disaster recovery efforts, allowing residents and property owners to return from evacuation safely in order to address possible damages. No method or associated data was found to quantify the reduction in need for and cost of emergency services, but this has been included as a qualitative benefit in other studies[36].

Recommendation: Discuss benefit to emergency response and recovery efforts as part of a qualitative benefits discussion in the CDBG-MIT application.

Economic Revitalization

Losses to economic output due to flooding have been estimated by other entities[36,37] using the IMPLAN economic impact assessment software. However, this approach requires significant detailed input data, and the use of this software is outside FNI's expertise.

Additionally, the flood mitigation projects within Halls Bayou will support local construction jobs. Although number of jobs could be estimated, this is a short-term benefit and thus cannot be included in the benefit-cost analysis as it will not last through the lifetime of the project.

Recommendation: Do not include in the Halls Bayou BCA.

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[36] *HUD National Disaster Resilience Competition (NDRC) Phase 2 Application, Attachment F Benefit Cost Analysis.* Commonwealth of Virginia. 2015.

[37] *East Side Coastal Resiliency Updated Benefit-Cost Analysis.* New York City Department of Design and Construction. 2019.

Excerpt from Federal Register

"Allocations, Common Application, Waivers, and Alternative Requirements for Community Development Block Grant Mitigation Grantees", 84 FR 169 (August 30, 2019).

Agency: Office of the Assistant Secretary for Community Planning and Development, Department of Housing and Urban Development.

Action: Notice

Section V.A.2.h(2) Covered Project action plan or substantial amendment requirements

The following must be provided for each Covered Project proposed in an action plan or a substantial amendment:

(a) Project description and eligibility
[…]

(b) Consistency with the Mitigation Needs Assessment

(c) National Objective, including additional criteria. The action plan must describe how the Covered Project will meet a national objective, including additional criteria for mitigation activities and Covered Projects. The national objectives for CDBG-MIT projects are described in section V.A.13 HUD has established additional criteria for Covered Projects that require a plan for long-term efficacy and fiscal sustainability, a demonstration that the benefits outweigh the costs, and a demonstration that the Covered Project is consistent with other mitigation activities in the same MID area, as described below in (i) through (iii):

(i)Long-term efficacy and fiscal sustainability
[…]

(ii)Demonstration of benefits

(ii.a.) Demonstration of benefits through benefit cost analysis.

The action plan or substantial amendment must describe how the benefits of the Covered Project outweigh the costs of the Covered Project. Benefits outweigh costs if the Benefit Cost Analysis (BCA) results in a benefit-to-cost ratio greater than 1.0 (which aligns with FEMA's BCA ratio). The action plan or substantial amendment must include a description of the methodology and the results of the BCA that has been conducted for the Covered Project. The grantee must indicate whether another Federal agency has rejected a BCA for the Covered Project (including any BCA for an earlier version of the current proposed Covered Project). Grantees and subrecipients may use FEMA-approved methodologies and tools to demonstrate the cost- effectiveness of their projects. FEMA has developed the BCA Toolkit to facilitate the process of preparing a BCA. Using the BCA Toolkit will ensure that the calculations are prepared in accordance with OMB Circular A–94 and FEMA's standardized methodologies. It is imperative to conduct a BCA early in the project development process to ensure the likelihood of meeting the cost- effectiveness eligibility requirement. A non-FEMA BCA methodology may be used when: (1) A BCA has already been completed or is in progress pursuant to BCA guidelines issued by other Federal agencies such as the Army Corps or the Department of Transportation; (2) it addresses a non- correctable flaw in the FEMA-approved BCA methodology; or (3) it proposes a new approach that is unavailable using the FEMA BCA Toolkit. In order for HUD to accept any BCA completed or in progress pursuant to another Federal agency's requirements, that BCA must account for economic development, community development and other social/community benefits or costs and the CDBG–MIT project must be substantially the same as the project analyzed in the other agency's BCA.

(ii.b.) Alternate demonstration of benefits.

Alternatively, for a Covered Project that serves low- and moderate- income persons or other persons that are less able to mitigate risks or respond to and recover from disasters, the grantee may demonstrate that benefits outweigh costs if the grantee completes a BCA as described above and provides HUD with a benefit-to-cost ratio (which may be less than one) and a qualitative description of benefits that cannot be quantified but sufficiently demonstrate unique and concrete benefits of the Covered Project for low- and moderate-income persons or other persons that are less able to mitigate risks, or respond to and recover from disasters. This qualitative description may include a description of how the Covered Project will provide benefits such as enhancing a community's economic development potential, improving public health and or expanding recreational opportunities. The grantee shall include the BCA for a Covered Project, together with any qualitative description of benefits for projects benefitting low- and moderate- income persons and other persons that are less able to mitigate risks, or respond to and recover from disasters, as an appendix to the action plan or substantial amendment that proposes the project.

(iii)Consistency with other mitigation activities
[…]

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TO:	Dena Green, Alan Black, Xin He (Harris County Flood Control District)
CC:	Lars Zetterstrom, Chris Edwards, Michael Liga, Nick Barnett, Tak Makino, Laura Casset (LAN)
FROM:	Cory Stull, Courtney Corso, Shannon Mack, and Jordan Skipwith (FNI)
SUBJECT:	Draft for Coordination: Summary of Preliminary Scoring and Benefit-Cost Analyses
DATE:	May 8, 2020
PROJECT:	SCG17357 – Disaster Recovery Services: CDBG-MIT Grant Application for Halls Bayou

Introduction

HCFCD intends to submit two applications for grant funding to the Hurricane Harvey State Mitigation Competition for CDBG-MIT funds allocated to Texas and distributed by the Texas General Land Office (GLO). In coordination with LAN, FNI has assessed flood mitigation projects in the Halls Bayou sub-watershed to inform decisions on which projects should be grouped together as "Covered Projects" to be most competitive for grant funding.

This memorandum presents results of a preliminary benefit-cost analysis (BCA) performed on each of the individual mitigation projects. Additionally, individual projects and potential project groupings were scored based on available guidance from the GLO in the State of Texas CDBG Mitigation (CDBG-MIT) Action Plan (hereafter "Action Plan"), and scores are presented here. The intent of these analyses was to identify individual projects ("activities") which, when grouped together as "Covered Project" would be most competitive in the CDBG-MIT grant competition.

The Action Plan was approved by HUD on March 31, 2020, and additional guidance on requirements for the CDBG-MIT grant applications is expected to be available in early May from GLO. Methods of scoring and benefit-cost analysis will be revised per GLO guidance before performing final analyses on the selected Covered Projects.

Halls Bayou Mitigation Projects Considered for CDBG-MIT Funding

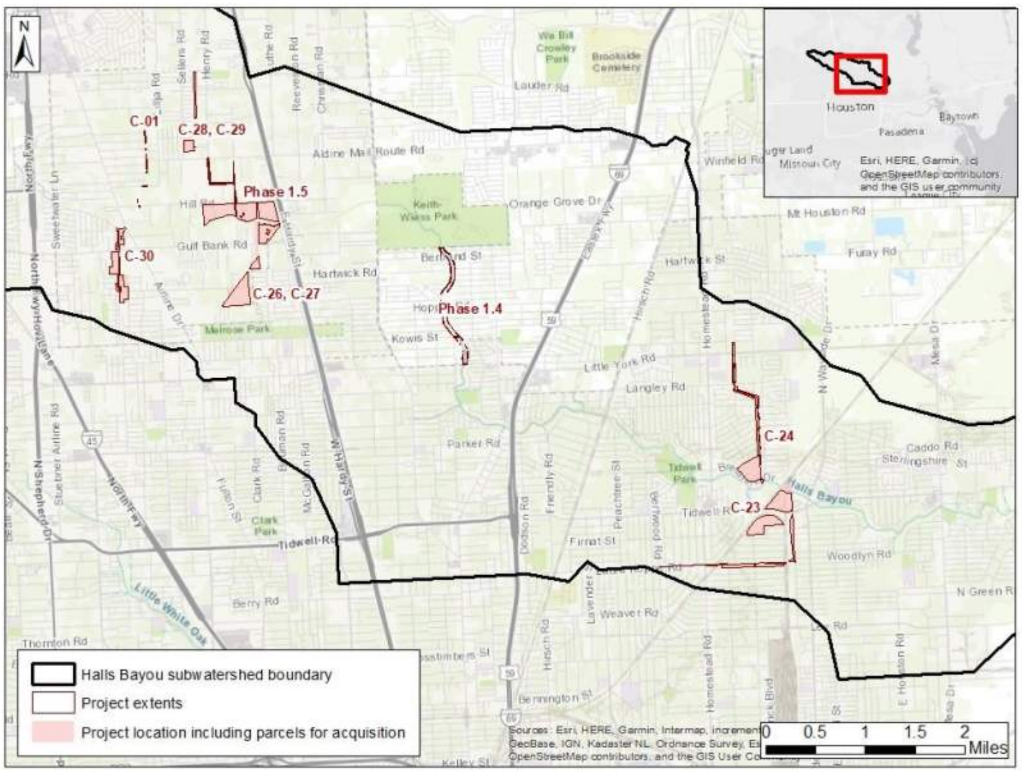
Table 1 lists the Halls Bayou mitigation projects which were considered, as provided by LAN. Project locations are shown in *Figure 1*.

Table 1 – Halls Bayou Flood Mitigation Projects Considered for CDBG-MIT Grant Applications

Bond ID	Unit ID / Description	Assessed?	Comments
C-01	P518-26-00-FP	Yes	
C-26	P118-23-00-FP	Yes	Assessed together (interdependent projects)
C-27	P118-23-02-FP		
C-28	P118-25-00-FP	Yes	Assessed together (interdependent projects)
C-29	P118-25-01-FP		
C-23	P118-08-00	Yes	
C-24	P118-09-00	Yes	
C-30	P118-27-00	Yes	

Bond ID	Unit ID / Description	Assessed?	Comments
Phase 1 DS of Bertrand	P118-00-00	Yes	
Phase 1 Hardy West	n/a	Yes	
C-35	P518-10-00-FP001; P118-14-00	No	Already Funded
C-02	P518-Aldine-CDBG	No	Already Funded
C-25	P118-21-00-FP	No	Already Funded
CI-006	P118-Brock	No	Estimated cost less bond funding exceeds CDBG-MIT funding maximum grant

Figure 1 – Halls Bayou Flood Mitigation Project Locations



Preliminary Scoring Assessment Results

Preliminary scoring assessments were performed to estimate localized scores and other metrics for Social Vulnerability, Poverty Rate, and Project Impact. Considering the size and population of Harris County, social vulnerability and poverty rates are highly variable at the local scale. This localized approach illustrates that projects in the Halls Bayou watershed score much higher in these categories than what was shown at the county level in the Action Plan. Other scoring criteria were constant across all projects, as they rely either on county-level data or on information at the sub-applicant level (HCFCD). Localized scores considered the approximate project impact area to be the 500-year floodplain of the associated channel under existing conditions. It should be noted that the Action Plan did not define how points are assigned in the scoring categories “Project Impact” and “Mitigation/Resiliency Measures.” As such, the associated metrics have been estimated, but the scores in this preliminary analysis only indicate the minimum score before addition of points associated with Project Impact. Up to 25 additional points are available from this category. For now, it has been assumed that HCFCD will qualify for the 5 points related to Mitigation/Resiliency Measures. *Table 2* ranks individual projects by minimum expected score.

Table 2 – Projects Ranked by Individual Score and Number of Benefitted Persons

Rank	Bond ID	Expected Minimum Score[1]	Number of Beneficiaries[2]
1	C-24	78	2,109
2	C-23	78	1,551
3	C-28, C-29	76	3,600
4	C-30	76	2,422
5	C-26, C-27	76	938
6	Ph I DS of Bertrand	71	43,011
7	Ph I Hardy West	71	26,789
8	C-01	71	1,618

[1]Does not include points for Project Impact (up to 25 points).
[2]Related to Project Impact score.

Preliminary Benefit-Cost Analysis

Although a benefit-cost ratio (BCR) is not a factor in the competition score as set forth by GLO, applicants are required to demonstrate that the benefits of the Covered Project outweigh the costs. As described in the Federal Register,[1] this requirement may be met in two ways:

1. Benefit-cost ratio developed during a benefit-cost analysis (BCA) is greater than 1.0.
   a. Calculations should be prepared in accordance with OMB Circular A-94[2].
   b. BCA methodology should follow FEMA standardized methodologies unless
      i. A BCA for the project has already been completed or is in progress under guidelines of other Federal agencies, or
      ii. The BCA addresses a non-correctable flaw in the FEMA methodology, or
      iii. A new approach is proposed that is unavailable using the FEMA Toolkit.
2. Alternately, projects may have a benefit-cost ratio of less than 1.0 under these conditions:
   a. A BCA is still completed following the methodologies described above.
   b. The project "serves low- and moderate- income persons or other persons that are less able to mitigate risks or respond to and recover from disaster."
   c. A qualitative description is provided for "benefits that cannot be quantified but sufficiently demonstrate unique and concrete benefits of the Covered Project for low- and moderate- income persons or other persons that are less able to mitigate risks, or respond to and recover from disasters."

[1] Allocations, Common Application, Waivers, and Alternative Requirements for Community Development Block Grant Mitigation Grantees, 84 FR 169 (August 30, 2019).
[2] *Circular A-94*, Office of Management and Budget, last revised October 29, 1992.

In accordance with these requirements, a quantitative BCA has been performed for each proposed project in Halls Bayou. Additionally, numerous metrics have been compiled to demonstrate that the proposed projects not only benefit low- and moderate- income persons but also a population that is generally vulnerable to disasters. Data has also been compiled to demonstrate potential benefits of the projects that could not be reliably monetized in the BCA. The text of the relevant section of 84 FR 169 is attached to this memorandum.

Quantitative Benefit-Cost Analysis Results

The Halls Bayou quantitative BCA was based on methodologies in the FEMA BCA Toolkit (v6.0). However, the Toolkit itself was not used, as it is best suited to limited-area analyses. A separate tool was developed that uses many of the standard values and concepts in the FEMA BCA Toolkit with some exceptions. More detail on the benefit-cost analysis methodology is provided in a separate memorandum[3]. The BCA included the following benefit categories:

- Building damages (avoided losses)
- Content damages (avoided losses)
- Residential displacement (avoided costs)
- Non-residential displacement (avoided costs)
- Mental health treatment (avoided costs)
- Worker productivity (avoided losses)
- Ecosystem services (benefit of conversion of developed land)

Table 3 ranks projects by BCR.

Table 3 – Projects Ranked by Benefit-Cost Ratio

Rank	Bond ID	Comprehensive BCR
1	Ph I DS of Bertrand	2.66
2	C-30	2.08
3	Ph I Hardy west	0.48
4	C-01	0.37
5	C-23	0.34
6	C-26, C-27	0.33
7	C-24	0.32
n/a*	C-28, C-29	0.30 - 3.24

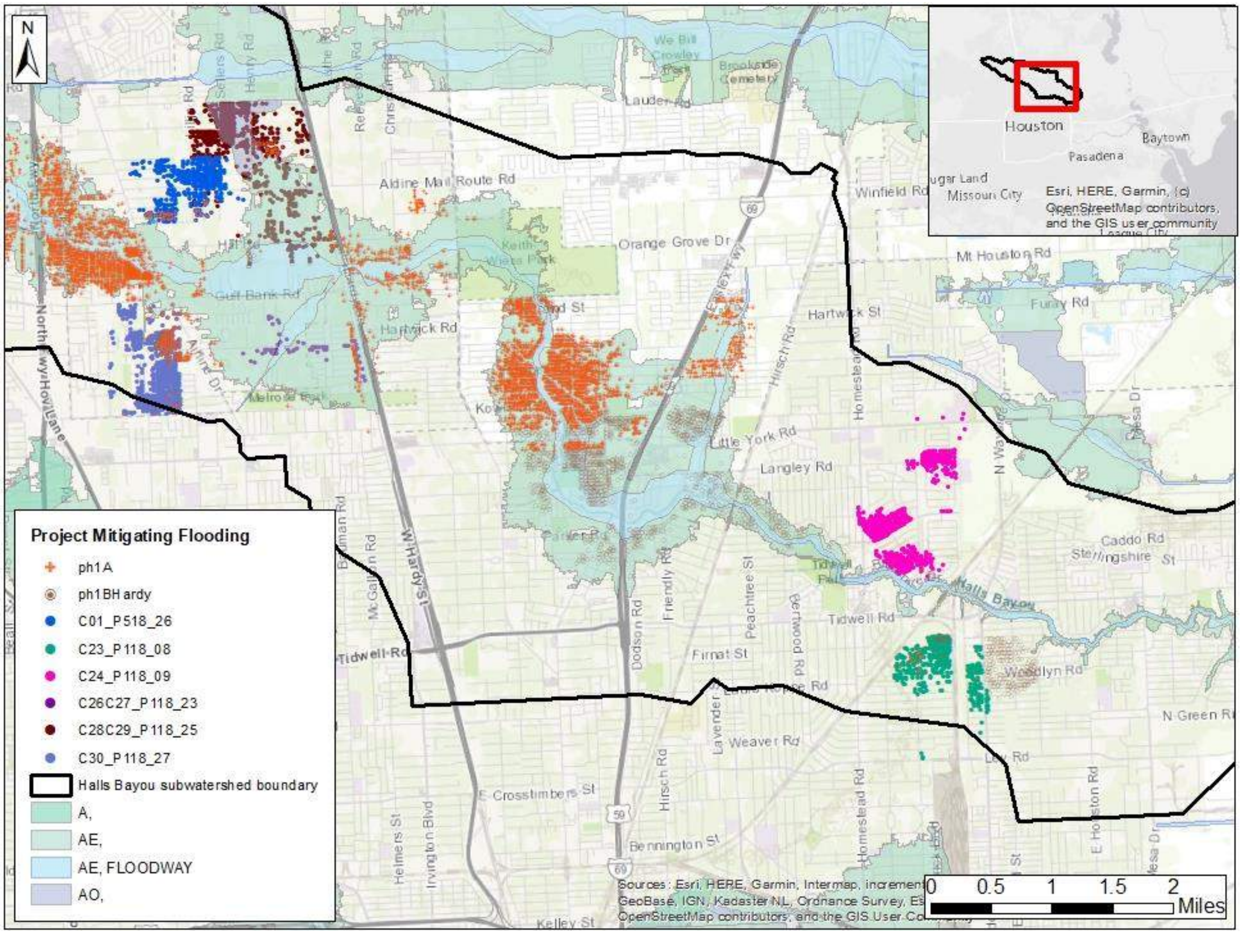
**BCR varies depending on inclusion of structures which are also at risk of flooding from the main stem of Halls Bayou and from P118-26.*

The benefit-cost analysis considered water surface elevations as modeled for existing and post-mitigation conditions in HEC-RAS. Most benefits were calculated for individual structures and totaled for the project area, with the exception of environmental benefits. *Figure 2* indicates structure locations at which the modeled 100-year storm water surface elevation was removed or reduced by implementation of the mitigation projects. Note that this preliminary assessment did not account for mainstem-tributary interactions. Subsequently, some of the structures shown to be benefitted by the tributary mitigation

[3] "Draft for Coordination: Preliminary Benefit-Cost Analysis Methodology and Discussion." Prepared by Freese & Nichols, Inc. for Harris County Flood Control District. April 2020.

projects may still be at risk of flooding from Halls Bayou. For reference, *Figure 2* also indicates the FEMA Special Flood Hazard Area.

Figure 2 – Structures Benefitted at 100-yr Level of Service



More details on BCA results for individual projects can be found in ***Attachment A***. Factors that had substantial effects on BCRs included:

- Detention
  - Conversion of developed area to green space provides environmental benefits.
- Non-residential buildings
  - Building damage values are based on building type and size. Large footprints of commercial buildings can result in high pre-mitigation damage values.
  - Contents in certain non-residential building types are valued at a greater amount than the structure itself.
- Baseline conditions
  - Benefits are greater in areas where existing flooding conditions are worse.
- Size of project service area

- In addition to reducing damage for more structures, the social benefits to residents of those structures are substantial and are not dependent on the magnitude of the structural benefit.

Recommendations for Qualitative Benefit Discussion in CDBG-MIT Application

1. Project Area Profiles – For each Covered Project, describe the population to indicate how the project would serve "LMI persons and other persons that are less able to mitigate risks or respond to and recover from disasters." The following metrics, when analyzed in the study area, indicate that the Halls Bayou watershed is home to a particularly vulnerable population (*Table 4*).

    a. LMI Percentage (required to meet LMI National Objective and attain 20 points from scoring matrix)

    b. Social Vulnerability Index (required to attain up to 10 points from scoring matrix)

    c. Percentage housing cost-burdened (households spending more than 30% of monthly income on housing-related costs)

    d. Percentage of population with poor or no internet access, which could impact their ability to benefit from early warning systems in case of flooding events

Table 4 – Metrics Indicating the Vulnerability of the Population to be Served by Proposed Projects

Analysis Area	Number of Census Tracts	Percent Low- and Moderate-Income	Percentage of Households			Percentage of Working-Age Population (16+)	
			Housing Cost-Burdened (30%+)	Severely Housing Cost-Burdened (50%+)	No Internet Access	Working Full-Time	Working, but less than Full-Time
Halls Bayou Project Areas	19	66%	33%	17%	38%	44%	22%
Halls Bayou	36	71%	38%	19%	35%	45%	23%
Harris County	786	47%	33%	15%	16%	53%	23%

2. Qualitative Discussion of Non-monetized Benefits

    a. Describe trends in property values following Hurricane Harvey and discuss the potential impacts to property owners of disaster-induced property value reductions.

    b. Estimate the number of part-time workers benefitted by the projects. (Methods to monetize avoided productivity losses are limited to full-time workers.)

    c. Other benefit categories as discussed in a separate memo[3], contingent on data availability.

3. Quantile-mapped BCA Comparison – Still needs Proof-of-Concept. If BCR of either Covered Project is ultimately less than 1.0, perform a quantile-mapping analysis that replaces Halls Bayou building replacement values (BRV) with values from a higher-income area (such as Buffalo Bayou watershed) in the same project analysis to demonstrate that LMI areas will by nature have lower

BCR scores. Thus, relying on a high BCR counteracts the intention of serving LMI populations. Replacement is performed by matching quantiles of the Halls Bayou BRV distribution to equal quantiles of the alternate area BRV distribution.

Potential Project Groupings: Assessment and Recommendations

Potential groupings of projects were considered to determine performance against the scoring matrix; these groupings comprised two sets of mutually exclusive project options (*Table 5),* representing options for two Covered Project applications. Additional proposed groupings can be assessed as requested by LAN or HCFCD.

The initial groupings considered inclusion of all assessed projects except for Phase 1 Hardy West Detention.

Table 5 – Project Groupings Assessed

Covered Project	1		2		
Group	**1**	**1a**	**2**	**2a**	**2b**
Included Projects	C-01	C-01			
	C-26, C-27	C-26, C-27			
	C-28, C-29	C-28, C-29			
			C-23		C-23
			C-24	C-24	
				C-30	C-30
	Ph I DS of Bertrand				

Results for assessments of these project groups are shown in *Table 6,* which also includes the total cost of included projects and the total available bond funding.

Table 6 – Performance of Project Groupings

Group	Total Cost ($ millions)	Bond Funding ($ millions)	Expected Minimum Score[1]	Number of Beneficiaries[2]	Average Poverty Rate	Comprehensive Benefit-Cost Ratio[3]
1	$110.2	$5.2	76	23,877	27%	1.06
1a	$95.2	$5.2	76	6,120	27%	0.80
2	$125.3	$3.7	78	3,261	26%	0.33
2a	$95.0	$2.4	76	4,239	28%	0.86
2b	$87.9	$3.7	76	3,686	24%	0.91

[1]*Does not include points for Project Impact (up to 25 points).*

[2]*Related to Project Impact score. Sum of beneficiaries of individual projects. Total for combined project may be lower.*

[3]*BCR for groups equal to ratio of the sum of individual project benefits to sum of individual project costs. Total benefits for grouping may be lower when projects are modeled together.*

A detailed record of BCA and scoring results for individual projects and potential project groupings can be found in ***Attachment A***.

Covered Project 1

Options 1 and 1a perform similarly in most scoring categories and tiebreaker. However, the inclusion of Phase 1 Downstream of Bertrand in Group 1 substantially increases the potential number of beneficiaries, which should increase the points available in the Project Impact criteria. Group 1 is also anticipated to have a higher BCR. However, the selection of this option is contingent upon the development of mitigation measures to prevent negative impacts resulting from the implementation of Phase 1 Downstream of Bertrand. Additionally, Option 1 would require $5 million in additional funding from another source due to the $100 million cap on CDBG-MIT funding per Covered Project.

Considerations for grouping:

- Option 1 may perform better in the CDBG-MIT competition due to a greater number of beneficiaries. However, application for funds for this option are contingent on
    - Mitigation of negative impacts associated with Phase 1 Downstream of Bertrand
    - Additional funding for the remaining $5,000,000.
- Interaction between the main channel of Halls Bayou and the tributaries may have significant effects on the anticipated scores and BCR once projects are modeled together.

Covered Project 2

For Covered Project 2, Option 2 has a slightly higher minimum score due to the Social Vulnerability Index of the project service areas. However, the projects included had some of the lowest individual BCRs. The inclusion of C-30 substantially increases the group BCR.

Recommendation:
Based on the groupings analyzed, Option 2a may be the best option for the second CDBG-MIT application for these reasons:

- Relatively high BCR.
- Tie-break score (poverty rate) is highest among 2, 2a, and 2b.
- Option 2a will be able to take advantage of $92.6 million in CDBG-MIT funds, whereas Option 2b would only be able to request $84.2 million.
- No additional funding sources would be required for C-24 and C-30 if CDBG-MIT funds are awarded.

It should be noted that mainstem interactions with the tributary projects considered for Covered Project 2 have not been modeled. Such interactions could impact the final project score and BCR. However, the service areas for the projects in options 2, 2a, and 2b have minimal overlap with the 100-year floodplain of Halls Bayou, so final scores are expected to be affected minimally.

Summary and General Recommendations

- Demonstration that project benefits outweigh costs is a requirement of any CDBG-MIT project. However, a quantitative analysis of monetized benefits does <u>not</u> have to demonstrate a benefit-cost ratio of greater than 1.0. Instead, a BCR less than 1.0 can be supplemented with a qualitative description of how the project benefits low- and moderate- income persons and other vulnerable populations.

- BCR is not a criterion used for awarding points in the Hurricane Harvey State Mitigation Competition. A project needs to demonstrate benefits to be eligible, but there is not a requirement to demonstrate that the benefit-cost ratio exceeds that of other competing projects.
- Project Impact scores cannot be determined until the application guides are available. Maximizing the number of project beneficiaries is the best way to increase this score.
- Bundles should be selected based on the ability to maximize Project Impact and Leverage scores, as well as maximizing the total requested grant amount.

Attachment A

Detailed Tables of Results from the Preliminary Benefit-Cost Analysis and Scoring Assessment for Halls Bayou CDBG-MIT Project Candidates

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Table 1 – Benefit-Cost Analysis: Costs, Benefits, and Benefit-Cost Ratios

Project Bond ID(s)	Unit ID(s)	Smallest Storm Included in BCA	Total Annualized Cost ($ millions)	Standard Expected Annual Benefits* ($ millions)	Ancillary Expected Annual Benefits* ($ millions)	Total Expected Annual Benefits* ($ millions)	BCR (Standard)	BCR (Comprehensive)	Comment
C-01	P518-26-00-FP	10-yr (10%)	$3.16	$0.16	$1.02	$1.18	0.05	0.37	Baseline damage amount is lower, making total standard benefit lower.
C-26, C-27	P118-23-00-FP, P118-23-02-FP	100-yr (1%)	$2.71	$0.01	$0.89	$0.90	0.00	0.33	Standard benefits are underestimated due to lack of data for smaller storms, but low BCR is still probably reasonable. Benefit is primarily in 500-yr, and average 100-yr benefit is low, as is the total count of structures benefitted.
C-28, C-29	P118-25-00-FP, P118-25-01-FP	10-yr (10%)	$1.08	$1.19	$2.33	$3.52	1.10	3.24	High BCR due to high baseline damage, non-residential structures along Aldine Mail Route, and high social benefit due to # residents impacted. However, service area significantly overlaps floodplain of the main channel of Halls Bayou and also receives overflow from P118-26.
C-23	P118-08-00	10-yr (10%)	$4.32	$0.41	$1.07	$1.48	0.10	0.34	Baseline damage amount is lower, making total standard benefit lower.
C-24	P118-09-00	100-yr (1%)	$4.82	$0.24	$1.32	$1.56	0.05	0.32	Standard benefits are underestimated due to removal of smaller storms from analysis. However, standard BCR is low regardless. Project includes negative impacts and associated negative benefits in the 500-year storm only.
C-30	P118-27-00	10-yr (10%)	$2.11	$2.62	$1.77	$4.39	1.24	2.08	Non-residential structures with large footprints contribute significantly to standard benefit amount. Benefit values shown here reflect exclusion of 5 commercial structures that were assumed to be overvalued.
Ph I DS of Bertrand	P118-00-00	10-yr (10%)	$1.09	(-$0.10)	$2.99	$2.89	-0.09	2.66	Significant social benefits due to number of residents impacted. Project includes negative impacts and associated negative benefits.
Ph I Hardy west	-	100-yr (1%)	$5.43	(-$0.01)	$2.61	$2.61	0.00	0.48	Significant social benefits due to number of residents impacted. Expected annual standard benefits may be underestimated due to the lack of storms other than 100-yr. Project includes negative impacts and associated negative benefits.

**Both standard and ancillary benefits include NET social benefits (positive – negative).*

Table 2 – Benefit-Cost Analysis: Additional Metrics

Project Bond ID(s)	Overlap with Mainstem FP	Baseline Structure + Content Damage	# Structures No Longer Damaged in 100yr Storm	Average EAB per Benefitted Structure	Average 100-yr Benefit per Benefitted Structure	BCR (Comprehensive)	Comment
C-01	yes	$155,777	327	$386	$5,994	0.37	Baseline damage amount is lower, making total standard benefit lower.
C-26, C-27	yes	$13,849	47	$51	$952	0.33	Standard benefits are underestimated due to lack of data for smaller storms, but low BCR is still probably reasonable. Benefit is primarily in 500-yr, and average 100-yr benefit is low, as is the total count of structures benefitted.
C-28, C-29	yes	$1,157,030	714	$1,257	$26,089	3.24	High BCR due to high baseline damage, non-residential structures along Aldine Mail Route, and high social benefit due to # residents impacted. However, service area significantly overlaps floodplain of the main channel of Halls Bayou and also receives overflow from P118-26.
C-23		$399,868	324	$769	$14,370	0.34	Baseline damage amount is lower, making total standard benefit lower.
C-24		$508,622	201	$337	$21,678	0.32	Standard benefits are underestimated due to removal of smaller storms from analysis. However, standard BCR is low regardless. Project includes negative impacts and associated negative benefits in the 500-year storm only.
C-30		$2,599,638	397	$3,867	$54,305	2.08	Non-residential structures with large footprints contribute significantly to standard benefit amount. Benefit values shown here reflect exclusion of 5 commercial structures that were assumed to be overvalued.
Ph I DS of Bertrand		#N/A	1,329	$238	$3,025	2.66	Significant social benefits due to number of residents impacted. Project includes negative impacts and associated negative benefits.
Ph I Hardy west		#N/A	501	$69	$5,648	0.48	Significant social benefits due to number of residents impacted. Expected annual standard benefits may be underestimated due to the lack of storms other than 100-yr. Project includes negative impacts and associated negative benefits.

Table 3 – Project Scoring Assessment Results

Project Bond ID(s)		**C-01**	**C-26, C-27**	**C-28, C-29**	**C-23**	**C-24**	**C-30**	**Ph I DS of Bertrand**	**Ph I Hardy west**	**Comments**
Unit ID(s)		*P518-26-00*	*P118-23-00 P118-23-02*	*P118-25-00, P118-25-01*	*P118-08-00*	*P118-09-00*	*P118-27-00*	*P118-00-00*	*-*	
Project Cost (Present Value Capital Cost, $ millions)		$43.6	$36.9	$14.7	$59.1	$66.2	$28.8	$15.0	$74.3	As provided in Halls Bayou Bundling Project List
# Persons Benefitted		1,618	938	3,600	1,551	2,109	2,422	43,011	26,789	Limited to residents of benefitted structures for now
Project Impact Scoring Category	**Max Points**									
Application Amount ($) per Person Benefitted	15	$26,947	$39,339	$4,083	$38,104	$31,389	$11,891	$349	$2,774	Using present value capital cost / # impacted persons
% of Jurisdiction Pop	10	0.04%	0.02%	0.08%	0.03%	0.05%	0.05%	0.93%	0.58%	HCFCD jurisdiction population represented as Harris County population (ACS, 2018).
Scoring Category	**Max Points**									
CCDI	10	10	10	10	10	10	10	10	10	County Composite Disaster Index (GLO-defined)
SoVI	10	8	8	8	10	10	8	8	8	Social Vulnerability Index
PCMV	10	8	8	8	8	8	8	8	8	Per Capita Market Value
LMI	20	20	20	20	20	20	20	20	20	Does / does not meet LMI National Objective
Local Plan	5	5	5	5	5	5	5	5	5	Assuming adoption by HCCC
Management Capacity	15	15	15	15	15	15	15	15	15	Assuming HCFCD in good standing on any existing CDBG contracts
Leverage	5	0	5	5	5	5	5	0	0	2018 Bond Table HCFCD Cost Share is at least 1% of Project Cost
Mitigation / Resiliency Measures	5	5	5	5	5	5	5	5	5	Assumed that this yes/no criterion will be met by HCFCD, but not yet defined in Action Plan. Pending application guides.
Total* (excluding Project Impact)	**105 (80)**	71	76	76	78	78	76	71	71	Not yet known how Project Impact metrics will be converted to scoring points.
Average Poverty Rate	**tiebreaker**	27.9%	24.6%	28.6%	20.6%	29.8%	26.3%	26.6%	26.6%	Average poverty rate in CDBG-eligible counties = 16.08%. (2017) Higher poverty rates given precedence as a tiebreaker.

**Applications that do not score a minimum of 65 points will only be considered after all applications scoring greater than this amount have been funded.*

Appendix 5-4R:
P118-25-00 & P118-25-01 Drainage Improvements BCA Memorandum

Benefit Cost Analysis (BCA)

The benefit cost ratio (BCR) for the proposed project is 0.958.

An Initial BCA was performed April 2020. A pair of memoranda dated 5/8/2020 detailing the methods and results of this analysis are attached. In June 2020, a revised opinion of probable costs was produced. An updated BCA using the revised opinion of probable costs was performed shortly thereafter.

This benefit cost analysis was performed in anticipation of submission to the HUD CDBG-MIT grant program. While the FIF program and the CDBG-MIT program are two different grant programs administered by two separate entities, the principles used in the BCA apply to both.

The Halls Bayou watershed is a low-to-moderate income area. The property values in the area reflect this. The damage calculations in this BCA are based on depth-damage functions that estimate percentage of property value damaged based on depth of flooding in a storm event. As the property values are generally modest, even high percentages of property damage do not create high property damage values. The standard benefits of the proposed project take the form of mitigated damages. The damages mitigated are not very high because the initial baseline damage values are not very high.

The low property damage values when compared to higher income areas reflect market factors and should not be taken to indicate that flood damage in the Halls Bayou watershed is any less impactful or disruptive than in other areas. The proposed project will have positive effects on the health, safety, and quality of life of the population in the project benefit area.

Preliminary Halls Bayou Benefit Cost Analysis
June 12, 2020

Project Bond ID	C-28 / C-29	
Project Unit ID	P118-25-**	
Previous Analysis		
Date	4/23/2020	
Total Project Cost (excluding O&M)	$14,700,000	
Source of Cost	Halls Bayou Bundling Project List with construction Years and CDBG App... "LAN Estimate of Total Cost" (footnote to cost - based on maximized project scopes)	
Standard BCR	0.253	*0.022*
Comprehensive BCR	0.905	*0.296*
Updated Analysis (for FIF)		
Date	6/12/2020	
Total Project Cost (excluding O&M)	$14,938,614	
Source of Cost	20200605 Halls Bayou Preliminary Cost Comparison with Callouts "Total Cost"	
Standard BCR	0.249	*0.022**
Comprehensive BCR	0.958	*0.315**
Approach to overlap with Halls Bayou mainstem floodplain	Results shown are for exclusion of structures in C-01 500-yr floodplain and mainstem 100-yr floodplain in the BCA.	Results shown are for exclusion of structures in C-01 500-yr floodplain and mainstem ***500-yr*** floodplain in the BCA.
Factors contributing to BCR	Benefits include environmental and social benefits. Pre-mitigation (baseline) damages are high, partly due to non-residential structures along Aldine Mail Route.	
BCR underestimation due to missing storm frequencies	Current BCA does not include model of 25-yr storm. However, because 10-yr and 50-yr storms are included, impact of missing 25-yr storm is expected to be minimal.	
Other comments	ROW parcels have been adjusted since development of BCA inputs. Number of structures in purchased parcels that would no longer be subject to any damage post-mitigation may have changed.	
Other comments	Acreage being converted from developed land use to green space may have changed (impacts environmental benefits).	
Other comments	Additional acreage requiring maintenance after project implementation may have changed, impacting O&M costs.	
Other comments	*BCR incorporates estimated annual O&M cost in addition to the total project costs shown in this table.	

**Sweeping exclusions in this scenario likely represent a substantial underestimation of BCR, as structures in the mainstem 500-yr floodplain are excluded from benefitting under 50-yr and 100-yr storms by the project.*

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TO:	Dena Green, Alan Black, Xin He (Harris County Flood Control District)
CC:	Lars Zetterstrom, Chris Edwards, Michael Liga, Nick Barnett, Tak Makino, Laura Casset (LAN)
FROM:	Cory Stull, Courtney Corso, Shannon Mack, and Jordan Skipwith (FNI)
SUBJECT:	Draft for Coordination: Preliminary Benefit-Cost Analysis Methodology and Discussion
DATE:	May 8, 2020
PROJECT:	SCG17357 – Disaster Recovery Services: CDBG-MIT Grant Application for Halls Bayou

Freese & Nichols, Inc. (FNI) is performing benefit-cost analyses (BCA) of proposed mitigation activities in the Halls Bayou Watershed as part of the preparation of grant applications for the CDBG-MIT funding through the Texas General Land Office (GLO). Two stages of BCA are being performed:

(1) Preliminary for individual mitigation projects (each considered an "activity" in CDBG). These BCAs will consider only traditional benefits – avoided losses due to reduced damages to structures and contents. Benefits and costs will be assessed for individual activities. This phase is intended to inform the grouping of activities into two Covered Projects.

(2) Complete BCA for each Covered Project. Once activity groupings have been finalized, combined hydraulic models for each Covered Project will be used to assess the composite impact on water surface elevations (WSE). Subsequent benefits will be derived in multiple categories with the intention of demonstrating as much benefit as can be reasonably and reliably quantified.

This memorandum describes the benefit-cost analysis methodology applied in Stage 1 (individual project preliminary analysis), as well as a review of benefit categories which were considered but not included. All benefit categories discussed here are equivalent to avoided costs resulting from project implementation, unless explicitly stated otherwise.

Benefit-Cost Requirements for CDBG-MIT Projects

Although a benefit-cost ratio (BCR) is not a factor in the competition score as set forth by GLO, applicants are required to demonstrate that the benefits of the Covered Project outweigh the costs. As described in the Federal Register,[1] this requirement may be met in two ways:

1. Benefit-cost ratio developed during a benefit-cost analysis (BCA) is greater than 1.0.
    a. Calculations should be prepared in accordance with OMB Circular A-94[2].
    b. BCA methodology should follow FEMA standardized methodologies unless
        i. A BCA for the project has already been completed or is in progress under guidelines of other Federal agencies, or
        ii. The BCA addresses a non-correctable flaw in the FEMA methodology, or

[1] Allocations, Common Application, Waivers, and Alternative Requirements for Community Development Block Grant Mitigation Grantees, 84 FR 169 (August 30, 2019).
[2] *Circular A-94*, Office of Management and Budget, last revised October 29, 1992.

iii. A new approach is proposed that is unavailable using the FEMA Toolkit.

2. Alternately, projects may have a benefit-cost ratio of less than 1.0 under these conditions:
    a. A BCA is still completed following the methodologies described above.
    b. The project "serves low- and moderate- income persons or other persons that are less able to mitigate risks or respond to and recover from disaster."
    c. A qualitative description is provided for "benefits that cannot be quantified but sufficiently demonstrate unique and concrete benefits of the Covered Project for low- and moderate- income persons or other persons that are less able to mitigate risks, or respond to and recover from disasters."

In accordance with these requirements, a quantitative BCA has been performed for each proposed project in Halls Bayou. Additionally, numerous metrics have been compiled to demonstrate that the proposed projects not only benefit low- and moderate- income persons but also a population that is generally vulnerable to disasters. Data has also been compiled to demonstrate potential benefits of the projects that could not be reliably monetized in the BCA.

General Description of Methodology

Where possible, the Halls Bayou BCA was based on the methodologies applied in the FEMA BCA Toolkit, version 6.0[3] ("FEMA Toolkit"). However, input data and assumptions, as well as some calculation methods, deviated from the FEMA Toolkit in some ways:

- The FEMA Toolkit allows for certain default values and tables to be replaced with user input values when documentation is provided. (These are described in more detail in sections on specific benefit categories.)
- Project Useful Life – In the FEMA Toolkit, project lifetime is specified for each structure individually, allowing a different discount factor to be applied to structures subject to buyouts. (See section on Present Value Analysis for more detail.)
- The greatest deviation is the method of determining Expected Annual Benefits from data for specific storm frequencies. (See section on Annualization for more detail.)

Due to the differing methodologies, the Expected Annual Benefit (EAB) values calculated in the Halls Bayou BCA could not be duplicated within the FEMA Toolkit. Pending further guidance on the technical requirements of the BCA for CDBG-MIT applications, this methodology may be revised. The current methodology was deemed to be fully sufficient for performing a preliminary analysis to inform grouping of activities under Covered Projects.

Input Data and Assumptions

The Halls Bayou BCAs primarily used Halls Bayou Structure Inventory (SI)[4] and project data provided by LAN, in conjunction with reference values from the FEMA Toolkit and Hazus (another FEMA BCA tool). Project information from LAN included estimated capital and maintenance costs, project spatial extents, and parcels to be acquired for right-of-way. ArcGIS was used to associate updated parcel and census tract data with the SI, as well as to relate project information to structure locations. A separate analysis was performed to estimate the number of residents and residential units per structure, as well as the number

[3] *Benefit Cost Toolkit Version 6.0.* FEMA. October 2019. Available at https://www.fema.gov/media-library/assets/documents/179903.

[4] "Structure Inventory Update – Workflow Development," Technical Memorandum dated May 25, 2018, and associated dataset for Halls Bayou subwatershed. Performed by LAN for HCFCD.

of residents who are full-time workers. The datasets used in the Halls Bayou BCA are summarized in *Table 1*, and *Table 2* lists the various standard values and lookup tables referenced in the calculations.

Table 1 – Input Datasets to Benefit-Cost Analysis

Dataset	Description
Halls Bayou Structure Inventory	attributes of individual structures in the study area, including use, size, and look-up codes for various reference tables
American Community Survey Data[5]	data from US Census Bureau at the census tract level related to population, average household size, number of full-time workers, median household income
Regional Groundwater Update Project Population Projections[6]	population projections at the census tract level from a prior regional population study
Project Extents	project locations
Parcel ROW Acquisition	parcels to be partly or fully acquired
Capital Costs	project capital costs provided by LAN
Maintenance Costs	estimated annual maintenance costs provided by HCFCD
Texas Tracts	boundaries and attributes of 2010 Census tracts

[5] U.S. Census Bureau. American Community Survey, 2014-2018. Detailed Tables, Subject Tables, and Data Profile Tables; generated by Freese & Nichols, Inc.; using the U.S. Census Bureau Application Programming Interface.
[6] Regional Groundwater Update Project. 2013. Population Projection Datasets. Freese & Nichols, Inc., Metrostudy, and U. Houston Hobby Center for Public Policy. Prepared for Harris-Galveston Subsidence District, Fort Bend Subsidence District, and Lone Star Groundwater Conservation District.

Table 2 – Sources of Standard Values and Reference Tables

Name	Purpose	Source
Discount Rate	calculate discount factors for converting between annual and present value equivalent costs/benefits	FEMA BCA Toolkit v6.0
Demolition Threshold	threshold above which building is assumed to be fully lost and contents maximally lost	
Useful Life	project lifetime used in discounting	
Depth-Days Curve	table of days displaced for depth flooded	
Disruption Cost Factor	one-time cost per square foot for non-residential structures	
Monthly Cost Factor	recurring cost per square foot per month for non-residential structures	
Hotel per Diem Cost	daily cost per household, up to 5 people, for lodging	
Meal per Diem Cost	daily cost per person of eating out, less average cost of eating at home	
Mental Stress and Anxiety Unit Cost	mental stress and anxiety cost per resident	
Productivity Loss Unit Cost	productivity loss per full-time worker	
Land Use Conversion Unit Benefit	value of ecosystem services ($/acre/year) provided by land use conversion	
Replacement Cost Models	building replacement values ($/sq. ft.)	Hazus-MH MR3 Technical Manual[7]
Depth-Damage Functions	tables of percent damage for depth flooded given the building type	Halls Bayou Structure Inventory
SFR Content-to-Structure Value Ratios	ratio for single-family residences for 1 story, 2 stories, or mobile home	
Other Content-to-Structure Value Ratios	ratio for structures other than single-family residences	

Project Costs

Estimated capital costs of each mitigation project were provided by LAN. The FEMA Toolkit specifies that costs considered in the BCA should include all costs required for completing the project, including but not limited to land acquisition, design, permitting, construction, reporting, and more. Based on this, the full costs provided by LAN were used.

Additionally, guidance in the FEMA Toolkit requires the inclusion of incremental increases in annual maintenance costs associated with the project (limited to maintenance activities which are necessary to maintain project effectiveness). HCFCD provided costs to LAN which were associated with mowing, tree upkeep, and similar costs. Costs provided by HCFCD did not include estimates for Bond ID C-01 (project P518-26-00) nor for Phase 1 projects (Downstream of Bertrand and Hardy West Detention). Annual costs were estimated for these projects based on the unit costs provided by HCFCD.

[7] Hazus-MH MR3 Technical Manual. FEMA. Tables 14.1 through 14.5.

Present Value Analysis

As benefits were determined on an annualized basis (AB), present value projects costs were converted to an annualized cost (AC) to determine the Benefit-Cost Ratio (BCR) as shown in *Equation 1.* Discount factors were determined using the FEMA standard annual rate[8] of 7% and an assumed project useful life of 50 years. The 50-year life was based on a table of project lifetimes within the FEMA Toolkit (*Table 3*).

$$BCR = \frac{(Project\ Capital\ Cost) * \left(\frac{A}{P} Discount\ Factor\right) + Annual\ Maintenance\ Costs}{Expected\ Annual\ Benefits} \qquad \text{Equation 1}$$

Note that the FEMA Toolkit typically shows total cost and benefits of a project as Present Value Cost (PVC) and Present Value Benefit (PVB). However, since the discount factor is the same for both cost and benefit, PVB/PVC is equivalent to AB/AC.

A 100-yr life is typically applied to acquisitions. However, for simplicity in the preliminary BCAs, a single discount factor based on a 50-year life was applied across the entire project. As benefits were calculated on an annual basis, this does not affect the BCR, with the exception of a slight underestimation of social benefits, which must be calculated on a present-value basis and then converted. (Annualized social benefits for structures to be bought out are underestimated by approximately 3%.)

Table 3 – Standard Values for Project Useful Life in FEMA BCA Toolkit v6.0

Flood Hazard Mitigation Project Type	Useful Life (years)
Acquisition / Relocation	
Acquisition / Relocation	100
Building Elevation	
Residential Building	30
Non-Residential Building	25
Public Building	50
Historic Buildings	50
Mitigation Reconstruction	
Mitigation Reconstruction	50
Infrastructure Projects	
Major Infrastructure (dams, levees)	50
Concrete infrastructure, flood walls, roads, bridges, major drainage system	50
Culverts (concrete, PVC, CMP, HDPE, etc.) with end treatment	30
Culverts without end treatment	10
Major pump stations, substations, wastewater systems, or equipment such as generators	50
Minor pump stations, substations, wastewater systems, or equipment such as generators	5

A benefit-cost analysis performed for a project in New York[9] included an alternate analysis that used a 3% discount rate, in addition to the primary analysis with a 7% rate. The final results reported for the project BCR were based on the 7% rate as mandated by OMB Circular A-94[8]. However, reanalyzing the project

[8] Standard discount rate for benefit-cost analyses prescribed by *Circular A-94*, Office of Management and Budget, as last revised October 29, 1992.

[9] *East Side Coastal Resiliency Updated Benefit-Cost Analysis.* New York City Department of Design and Construction. 2019.

with a 3% rate indicated the sensitivity of the BCR to the discount rate used, as a lower rate produces a larger BCR. Using a different discount rate is not recommended for the CDBG-MIT applications.

Annualization

For benefit categories based on avoided losses, impacts are assessed for multiple storm recurrence intervals, and an Expected Annual Loss value is estimated from the damage or loss caused by each storm and the associated probability of such a storm in a single year. This annualized value is estimated as the area under the Damage vs Probability curve. In the BCA for Halls Bayou, a simple trapezoidal area method was applied based on FEMA Guidance[10] associated with the loss estimation software Hazus. *Equation 2* demonstrates how this method is applied if impacts are modeled for 10-, 25-, 50-, 100-, and 500-year storms.

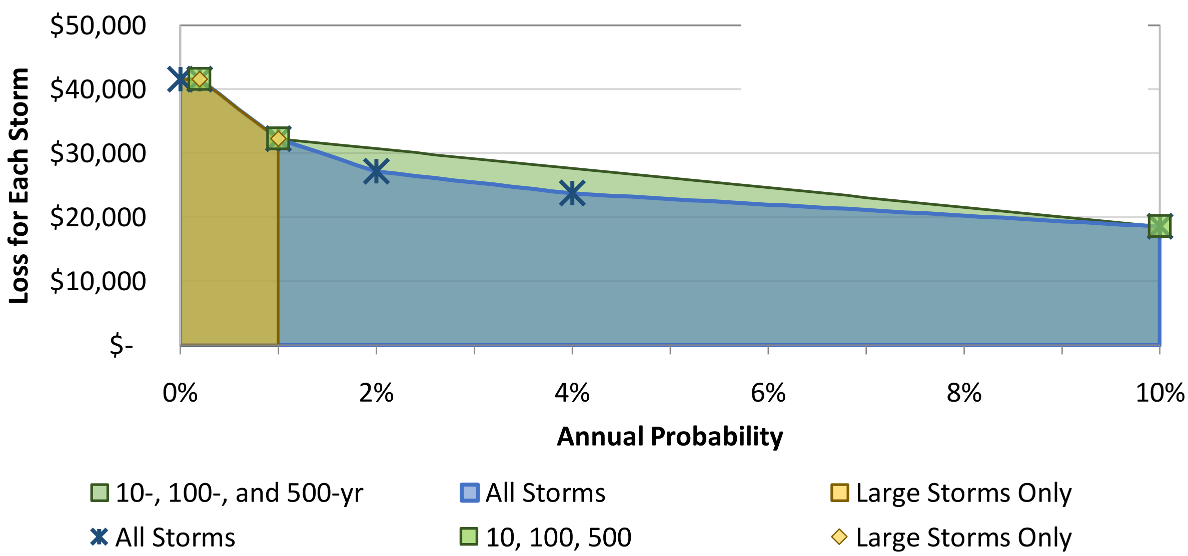
$$\begin{aligned} Annualized\ Loss = & \left(\frac{1}{500} * Loss_{500yr}\right) \\ & + \left(\frac{1}{100} - \frac{1}{500}\right)\left(Loss_{100yr} + Loss_{500yr}\right) \\ & + \left(\frac{1}{50} - \frac{1}{100}\right)\left(Loss_{50yr} + Loss_{100yr}\right) \\ & + \left(\frac{1}{25} - \frac{1}{50}\right)\left(Loss_{25yr} + Loss_{50yr}\right) \\ & + (\frac{1}{10} - \frac{1}{25})(Loss_{10yr} + Loss_{25yr}) \end{aligned}$$

Equation 2

The EAB is the difference in Expected Annual Loss under existing and post-mitigation conditions.

The BCA tool developed by FNI is flexible and adjusts this equation if one or more of these storms are not available, but loss values are not extrapolated to storm recurrence intervals smaller than those modeled in HEC-RAS. As a result, monetary benefits for some projects are underestimated (Figure 1).

Figure 1 – Impact of Number of Storms Modeled on Annualized Loss Calculation



In the preliminary BCA, storms with annual probabilities greater than 1% (events smaller than 100-year storms) were not modeled for three projects. However, FNI did not deem it necessary to request additional modeling by LAN for the preliminary BCAs for these projects for reasons described below.

[10] "Guidance for Flood Risk Analysis and Mapping," p. 18. FEMA. February 2018.

- C-26 and C-27 (projects on P118-23-00 and P118-23-02) were modeled for 100-year and 500-year storms only. Benefits from these projects are mostly limited to the 500-year storm. The number of structures and average benefit/structure for the 100-year storm are both low, so it is unlikely that overall benefits would increase by much with the addition of modeling results for more frequent storms.
- C-24 (project on P118-09-00) was modeled for various storm frequencies. However, due to discrepancies in the results for the 50-year storm, LAN advised against using that and smaller storm results, so the final BCA was based only on 100-year and 500-year storms. Preliminary results that included the additional storm frequencies suggested that the overall BCA was not significantly affected by this exclusion due to the small magnitude of standard benefits from this project.
- Phase 1 Hardy West – Impacts were modeled for the 100-year storm only, which could cause an underestimation of benefits. However, this project as proposed in March 2020 also produced negative impacts on numerous structures; these impacts preclude inclusion in the CDBG-MIT application and also negatively affect the project's BCR. Should revised bundles include this project with the negative impacts mitigated, it is recommended that additional storms be modeled for this project.

The FEMA Toolkit does not use the trapezoidal area method. Instead, the FEMA Toolkit estimates a curve of loss values for all storm frequencies based on the relationship between flow depth and flow rate at each location along the stream. As a result, the FEMA Toolkit estimates losses for events more frequent than the smallest storm modeled. However, it should be noted that a benefit-cost analysis performed for a project seeking CDBG-DR funds through HUD's Rebuild by Design[11] competition used the trapezoidal method to calculate expected annual losses[12], as FNI has done for Halls Bayou.

Standard Benefits – Avoided Losses Based on Depth of Inundation of Individual Structures

Overview of Standard Benefits

A traditional BCA for flood mitigation projects assesses the difference in probable damages to a structure and its contents under existing (baseline) conditions and post-mitigation (proposed) conditions. Baseline and post-mitigation impacts to a structure and its contents are assessed for multiple storm recurrence intervals based on the depth to which the structure is inundated in each scenario. Flooding depth is calculated as the difference in water surface elevation (WSE) as modeled in HEC-RAS and Finished Floor Elevation (FFE) as provided in the SI. Where FFE was not available in the SI, FFE was estimated at 6 inches above ground elevation[13].

Within the FEMA Toolkit, standard benefit categories include traditional benefits as well as others that can be related to the depth of flooding in a given storm frequency:

- Building Damages – Depth related to % of value lost.
- Content Damages – Depth related to % of value lost.

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[11] Hurricane Sandy Rebuilding Task Force: Rebuild by Design Competition. *https://www.hud.gov/sandyrebuilding/rebuildbydesign*
[12] *East Side Coastal Resiliency Updated Benefit-Cost Analysis.* New York City Department of Design and Construction. 2019.
[13] *Bare Earth LiDAR, HGAC 2008 Datum Adjusted*. Houston-Galveston Area Council. 2008.

- Displacement – Depth related to number of days displaced.
- Loss of Function / Loss of Income– Depth related to number of days rent payment income or commercial function is lost.

The following sections explain how these categories were treated in the Halls Bayou BCA.

Building and Content Losses

Assumptions maintained from the FEMA Toolkit:

- Value of structure damages are based on the Building Replacement Value (BRV), not the appraised or market value.
  - BRV = Area (sq ft) x Unit BRV
- A demolition threshold was set to 50% (default value in FEMA Toolkit). When percent damage based on depth and the depth-damage curve exceeded this threshold:
  - Structure was assumed to need replacement rather than repair. Expected Damage = 100% * BRV.
  - Content losses were assumed to be maximized (not a total loss, but the maximum value on the depth-damage curve).

Several changes to FEMA Toolkit default assumptions were incorporated. All of these have the option to be changed within the FEMA Toolkit as well.

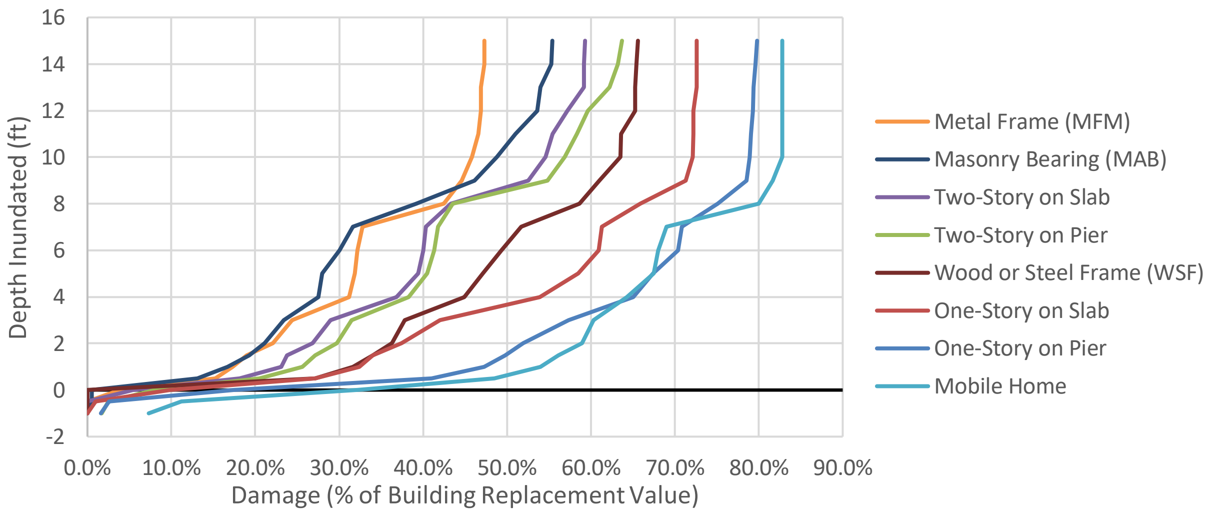
- Default depth-damage functions (DDFs) were replaced with DDFs provided in the Halls Bayou SI (*Figure 2*), which were developed by the USACE New Orleans District[14].
  - As indicated by the technical memorandum provided with the SI, the DDF for each structure was applied both to the building value and the contents value. (FEMA Toolkit has option but not requirement for separate curves.)
  - It should be noted that some structures are expected to experience damage even when WSE is below FFE by up to 2 feet, depending on structure type.
- Building Replacement Values (cost / square foot) have a default value of $100/sf in the FEMA Toolkit. BRVs from Hazus (another FEMA loss estimation software package) were used instead.
  - Hazus values account for building type, number of stories, and for residential structures, household income. This allowed for inclusion of local data to appropriately reflect structure values.
  - Residential unit BRVs are based on construction class (economy, average, custom, or luxury). Using Hazus methodology, these classes were determined based on median household income in each census tract.
  - Values documented in the Hazus Technical Manual[15] are based on standard cost-estimation models published in *Means Square Foot Costs*[16] and were reported in 2006

[14] *Final Report: Depth-Damage Relationships for Structures, Contents, and Vehicles and Content-to-Structure Value Ratios (CSVR) in Support of the Donaldsonville to the Gulf, Louisiana, Feasibility Study*. U.S. Army Corps of Engineers, New Orleans District. New Orleans, Louisiana. 2006.
[15] Hazus-MH MR3 Technical Manual. FEMA.
[16] R.S. Means, 2005.

dollars. For the Halls Bayou BCA, these values were scaled up using RSMeans Historical Cost Indices from 2006 to January 2020 to be consistent with project cost estimates.

- Total value of contents in each structure was estimated from content-to-structure value ratios included in the SI, which specify a percentage of the building value, in place of the default of percentages.

Figure 2 – Depth-Damage Functions from Halls Bayou Structure Inventory



Displacement Losses (Residential)

Avoided cost of residential displacement is considered a "standard" benefit in the FEMA Toolkit. Residential displacement losses based on the FEMA Toolkit include:

- Temporary lodging for each displaced household (assumes up to 5 household members per hotel room)
- Increase in meal cost (above average cost of eating at home) for each displaced resident

Expected annual benefits depend on a Depth-Days curve to determine number of days displaced for depth of inundation. Standard values for lodging and meals, as well as the Depth-Days curve, were taken from the FEMA Toolkit. The FEMA Depth-Days curve estimates 45 days of displacement for each foot of flooding above FFE.

Displacement Losses (Non-Residential)

Avoided cost of non-residential displacement is considered a "standard" benefit in the FEMA Toolkit and depends on the same Depth-Days curve as residential displacement costs. Non-residential displacement losses based on the FEMA Toolkit include:

- One-time cost of relocating business equipment
- Monthly rental costs of new space
    - Can overlap with Loss of Income by property owner. Loss should be applied as Displacement *or* Loss of Income, but not both.

Cost factors are provided in the FEMA Toolkit as $/sq. ft. values to estimate both components of non-residential displacement.

Loss of Function / Loss of Income Benefits

Considered a "standard" benefit in the FEMA Toolkit. Loss of function or income represents the cost to the property owner due to lack of tenants paying rent or inability to operate a business. Loss of function also applies to critical facilities.

- Loss of Income – monthly rental income for owners of rental properties
    - Can overlap with Non-residential Displacement costs by renter. Loss should be applied as Displacement *or* Loss of Income, but not both.
- Loss of Function – based on portion of annual operating budget pertaining to location of interest

Loss of Function or Income benefits were not included in the Halls Bayou BCA for these reasons:

- Residential Displacement costs have been included instead of Loss of Income, which represent the additional cost to the renter and are calculated based on standard values from FEMA. These calculations were considered to be more reliable than estimating monthly rent prices in the area.
- Non-residential Loss of Function costs require knowledge of the operating budget for each non-residential structure. This data was not available, but as the majority of mitigation benefits in Halls Bayou are to residential structures, the exclusion of this category is not expected to have a substantial impact on the total quantified benefit of a project.

Ancillary Benefit Categories included in Comprehensive Benefit-Cost Analysis for Halls Bayou

Social Benefits

Social benefits based on the FEMA Toolkit are based on the expected mental health impacts of experiencing a disaster, regardless of size. These benefits include avoided costs of:

- Health treatment for mental stress and anxiety of impacted residents
- Productivity losses by impacted residents who work full-time due to impacts on mental health

The Halls Bayou BCA replicated the method used in the FEMA Toolkit, which does not estimate an expected annual benefit from storm frequencies. Instead, a present value amount per benefitted person is applied to estimate the avoided costs of mental health treatment and of lost productivity *(Table 4*). These values are based on studied prevalence, severity, and course of mental effects following a disaster[17].

Table 4 – Unit Values for Avoided Costs of Mental Health Impacts

Category	Unit Cost (Present Value)	Unit
Treatment for mental stress and anxiety	\$2,443	Resident of flooded home
Lost productivity	\$8,736	Resident of flooded home who works full-time

[17] *Final Sustainability Benefits Methodology Report.* FEMA. Task order HSFEHQ-11-J-1408. August 2012.

Environmental Benefits

Environmental benefits based on the FEMA Toolkit include:

- Value of ecosystem services provided by enhancement of a parcel's land use to a use type which provides a higher level of natural environmental benefits

Rather than an avoided cost, environmental benefits represent an added service. *Table 5* indicates the value of each land use type (assuming conversion from developed land).

Table 5 – Unit Benefit Values for Conversion of Developed Land to Land Use of Higher Ecosystem Value

Documented Benefit/acre/year *				
Green Open Space	Riparian	Wetlands	Forests	Marine /Estuary
$8,308	$39,545	$6,010	$554	$1,799

**Documented in help section of B/C Analysis Toolkit v6.0, as of 01/28/2020.*

Several of the Halls Bayou mitigation projects require acquisition and conversion of developed land to undeveloped floodplain or detention. For the preliminary BCA, converted acreage was approximated and was assumed to be converted to green open space. As the proposed projects are not yet in final phases of design, a conservative approach will be taken to estimate total acreage converted in the final BCA for Covered Projects to avoid overstating environmental benefits.

Other Ancillary Benefit Categories

Numerous other potential benefits were researched; however, a lack of reliable input data, valid methodology, or other factors made these infeasible for inclusion in the Halls Bayou BCA. Descriptions of these benefit categories are provided below, along with references and explanations of the roadblocks preventing their inclusion in the comprehensive BCA.

Property Value Losses – Lost Tax Revenue

Recommendation: Per HCFCD guidance, do not consider lost tax revenues as part of the benefit-cost analysis, as this can be considered both a positive factor for residents as much as a negative factor for governmental entities. See next section for an alternate way to address reduced property values.

Property Value Losses – Impacts on Owners

As discussed at a previous meeting with HCFCD, falling property values can have a negative effect on the financial flexibility of housing cost-burdened homeowners and even renters. Data on housing cost-burdened residents (those paying above a percentage threshold of income for housing costs) is available from the US Census Bureau American Community Survey and has been compiled for the Halls Bayou watershed and Harris County as a whole.

This category is not found in the FEMA toolkit. Avoided losses in property values were included as a quantified benefit in another project analysis[18], which calculated low, medium, and high potential losses in value based on percentages (3%, 7%, and 12%, respectively) from a previous study. The referenced study[19] was based on trends following Hurricanes Fran and Floyd in Carteret County, North Carolina and

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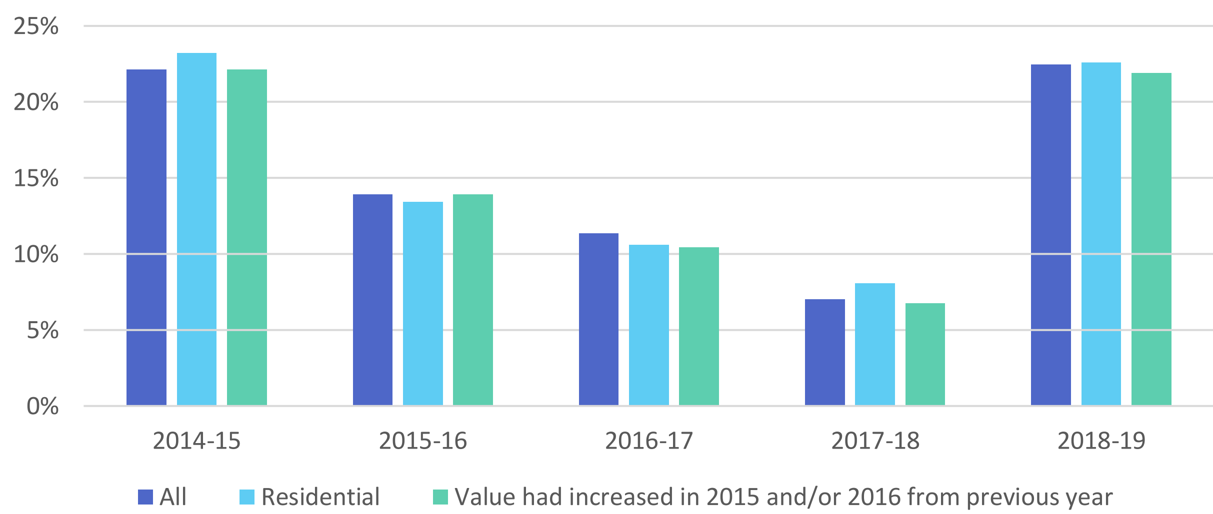
[18] *East Side Coastal Resiliency Updated Benefit-Cost Analysis.* New York City Department of Design and Construction. 2019.

[19] Bin, O., Brown Kruse, J., and C.E. Landry. 2008. "Flood Hazards, Insurance Rates, and Amenities: Evidence from Coastal Housing Market." *Journal of Risk and Insurance*, *75-1*, p. 63-82.

may not be directly applicable to property value trends in Harris County. Additionally, this study implied that property values are reduced following a significant flood event. Based on parcel value data from the Harris County Appraisal District (CAD), properties in the Halls Bayou watershed did not experience such a universal loss in value following recent flood events. However, the CAD data does suggest that annual growth in property values, at least for residential properties, generally slowed after Hurricane Harvey in the watershed.

CAD parcel values were assessed from 2014 to 2019. A comparison of parcels within and outside the approximate inundation extents of Harvey flooding mapped by HCFCD did not reveal any significant difference in trends in property values. Although growth in property values did slow from 2017 to 2018, growth had been slowing over the previous two years as well.

Figure 3 – Median Year-to-Year Percent Change in Assessed Values of Individual Parcels in Halls Bayou
**Parcels included in assessment were limited to those which had values available for all years 2014 – 2019. Percent change values of 0% were excluded to avoid errors from repeated entries across years.*



These trends could be caused or influenced by floods in 2015, 2016, and 2017, but the degree to which local flooding impacted the value growth rates cannot be ascertained. General economic conditions in Harris County following Hurricane Harvey, as well as other external economic factors, could also contribute to changes in property values. Because the exact impact on property values of local flooding in the Halls Bayou watershed cannot be quantified, this category has not been included in the BCA.

Recommendation: Describe flood impacts on property values in the CDBG-MIT application, alongside profiles of % housing cost-burdened and LMI residents in the project areas. Discuss the financial impact of disaster-induced property value reductions on owners for whom the home is a large percentage of their overall assets.

Productivity Losses Not Included in the FEMA BCA Toolkit

The FEMA Toolkit estimates productivity losses only for full-time workers, and these losses are limited to estimates based on the mental health impacts to workers. As part of the BCA literature review, FNI searched for methods to quantify other productivity losses, including those for part-time workers and for working parents impacted by school closures after a flood. However, no methods were found. (Standard unit values for full-time worker productivity loss in the FEMA Toolkit should not be linearly scaled to develop unit losses for part-time workers, who may work varying numbers of hours/week and weeks/year.)

Recommendation: Include estimates of the number of part-time workers benefitted by mitigation activities in the CDBG-MIT applications as part of the project impact description. (no monetary value)

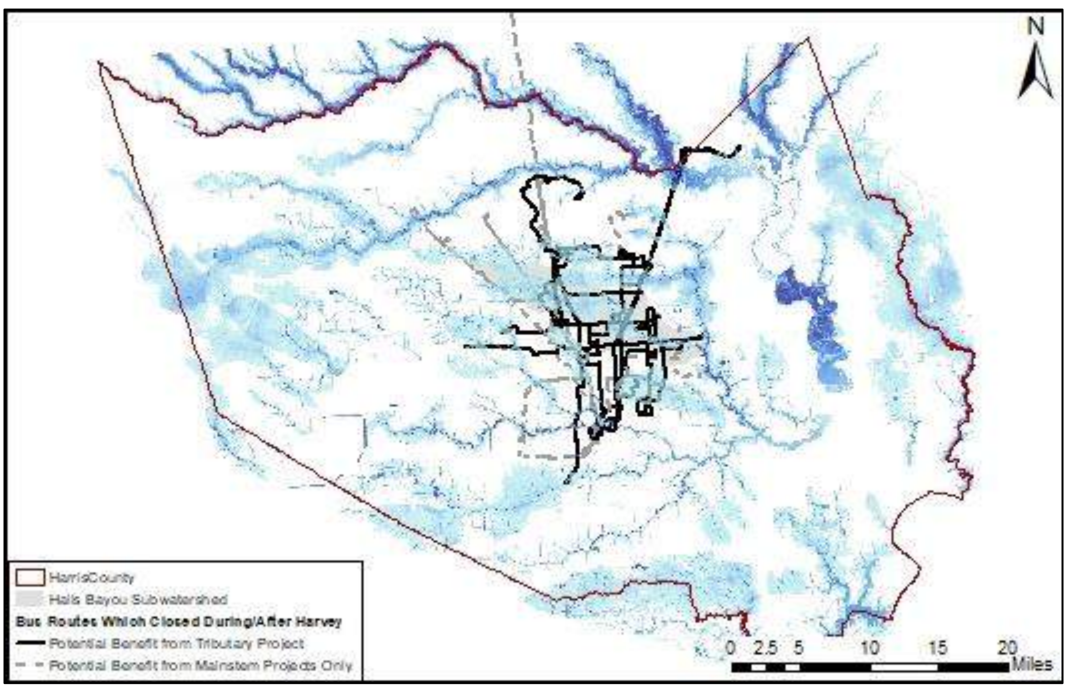
Public Transportation – Impacts of Roadway Flooding on Bus Riders and Bus Fare

Street closures due to flooding in the Halls Bayou Watershed likely impacted a large number of commuters who do not live in the watershed. Data from the Metropolitan Transit Authority of Harris County (Metro) indicates that several bus routes through the Halls Bayou watershed were closed for 4 to 9 days during and after Hurricane Harvey.

FNI did not find any references for a method to monetize the productivity losses of workers impacted by road closures. A separate study[20] assessed economic impacts as the value of lost time by bus riders and lost bus fare revenue. The study found that the annual value of expected benefits (avoided impacts) related to bus service for that project would be only $158, less than 0.2% of total project benefits.

All Metro bus routes passing through the service areas of the proposed Halls Bayou projects also extend across multiple floodplains in Harris County (*Figure 4*). It was determined that even if a substantial section of a route is removed from the floodplain due to a Halls Bayou mitigation project, inundation elsewhere could still cause route closure. Because of this, assigning economic benefits to these routes from reduced flooding along Halls Bayou is not considered to be a valid approach, so this category was not included in the BCA.

Figure 4 – Harvey-Impacted Bus Routes Intersecting Halls Bayou Watershed



FNI has compiled average ridership data for the impacted bus routes in Halls Bayou and has analyzed the number of days these routes were each closed after Hurricane Harvey.

[20] *East Side Coastal Resiliency Updated Benefit-Cost Analysis.* New York City Department of Design and Construction. 2019.

Recommendation: In CDBG-MIT grant application, describe the bus routes potentially benefitted by the proposed mitigation activities and include the number of days these routes were closed during and after Hurricane Harvey. Include information on the average number of riders to demonstrate the number of persons potentially benefitted by reduced flooding in Halls Bayou, but clarify that reduced flooding in the Halls Bayou watershed does not guarantee the routes would not be closed due to potential flooding elsewhere.

Transportation – Other Impacts of Roadway Flooding

The FEMA Toolkit includes a module to calculate avoided economic loss of service costs for roads and bridges. Determining the benefit from mitigated roadway flooding requires prescribing a likely detour route for each flooded road segment and estimating the travel time and mileage of both the original and detour routes. Traffic counts and speed limits are necessary inputs to this analysis. Avoided loss of service considers both the value of lost time and the standard federal rate for mileage, both of which are based on the additional time and mileage beyond the normal trip that a detour would require.

The most recently documented value in FEMA guidance documents[21] was $29.63. However, the value of lost time currently applied in the FEMA Toolkit is estimated at $33.44 per hour per vehicle, based on back-calculations from test inputs in a 2020 build of the Toolkit. Presumably, the $33.44 per hour rate accounts for inflation since the determination of the $29.63 value in 2011.

For many of the roads impacted by the proposed Halls Bayou projects, flooded roadways are residential streets in neighborhoods, where the main problem is a loss of access rather than impeding thru traffic. Based on this, the loss of service cannot be monetized as the additional time and mileage required for a detour. An approach to this issue was presented in another BCA report[22], which used a delay time of 12 hours per one-way trip for roads or bridges without detours as recommended in FEMA supplemental guidance[23]. However, applying a 12-hour delay time to each daily trip on a one-way residential street may be inappropriate, as the average daily traffic counts on these streets represent multiple trips by individual households, which in practice would not be losing more than 24 hours per day of roadway service time if the street is flooded all day. No mileage benefits can be counted when a detour is not available.

This benefit category has not been included in the preliminary BCA performed for each individual Halls Bayou project. However, roadway benefits could potentially be developed for each of the two Covered Projects once hydraulic modeling results are available for the grouped activities.

Recommendation: Determine avoided losses in terms of the economic value of lost time for each residential structure with no available road access due to flooding which would gain full roadway access after implementation of the proposed projects. Assume 12 hours of lost time as prescribed by FEMA guidance and use the standard value in the FEMA Toolkit. This analysis will require significant spatial analysis and may require discussion with GLO to assess the viability of the proposed method.

Avoided Physical Injuries and Fatalities

Avoided injuries and fatalities were researched for inclusion as a benefit. The number of injuries due to a flood event can be estimated as shown in *Equation 3*.

$$\#\, Physical\ Injuries\ =\ (Impacted\ Population)\ *\ (\%\, reported\ injuries) \quad \text{Equation 3}$$

[21] *FEMA Benefit-Cost Analysis Re-engineering (BCAR), Development of Standard Economic Values.* Version 6.0. FEMA. December 2011.
[22] *HUD National Disaster Resilience Competition (NDRC) Phase 2 Application, Attachment F Benefit Cost Analysis.* Commonwealth of Virginia. 2015.
[23] *Supplement to the Benefit-Cost Analysis Reference Guide*. FEMA. June 2011. Page 5-14.

The cost of these injuries can be monetized by applying the Abbreviated Injury Scale (AIS), which estimates economic injury values by severity to obtain the cost of injury as shown in *Equation 4*[24].

$$Cost\ of\ Injuries = (AIS\ \$\ value\ of\ average\ injury) * (\#\ Physical\ Injuries) \qquad \text{Equation 4}$$

The AIS is a comprehensive system for rating the severity of accident-related injuries and includes six levels of injury severity. It classifies nonfatal injuries into five categories depending on the short-term severity of the injury. The sixth category corresponds to injuries that result in death 30 days or more after the injury. A summary of the classification of different injuries by AIS level and their threat to life is included in *Table 6*.

Table 6 – AIS Classifications[25]

AIS	Injury Severity	Selected Injuries
1	Minor	Superficial abrasion or laceration of skin; digit sprain; first-degree burn; head trauma with headache or dizziness (no other neurological signs).
2	Moderate	Major abrasion or laceration of skin; cerebral concussion (unconscious less than 15 minutes); finger or toe crush/amputation; closed pelvic fracture with or without dislocation).
3	Serious	Major nerve laceration; multiple rib fracture (but without flail chest); abdominal organ contusion; hand; foot, or arm crush/amputation.
4	Severe	Spleen rupture; leg crush; chest-wall perforation; cerebral concussion with other neurological signs (unconscious less than 24 hours)
5	Critical	Spinal cord injury (with cord transection); extensive second- or third-degree burns; cerebral concussion with severe neurological signs (unconscious more than 24 hours)
6	Fatal	Injuries, which although not fatal within the first 30 days after an accident, ultimately result in death.

Federal agencies such as the Federal Aviation Administration (FAA), US Department of Transportation (USDOT), and National Highway Traffic Safety Administration (NHTSA) calculate an economic value for avoiding different AIS scale injuries by using the relative value coefficients as a fraction of the VSL. By following this methodology, FEMA is able to establish an economic value for the various injury levels that could be avoided and therefore counted as benefits from a hazard mitigation project[26].

A valuation for each AIS injury severity level is established by relating each level to the loss of life and quantity of life resulting from an injury typical of that level. This loss is expressed as a fraction of the value placed on an avoided fatality. For analysis with a base year of 2012, guidance suggests that $6.6 million be used as the current estimate for the value of a statistical life (VSL), measured in 2012 dollars. The fraction shown in column 3 of *Table 7* should be multiplied by the suggested VSL to obtain the values of preventing the injuries being analyzed. For example, to obtain the value of a "serious" injury (AIS 3), the Fraction of VSL for a serious injury (0.0575) should be multiplied by the VSL ($6.6 million) to calculate the

[24] *HUD National Disaster Resilience Competition (NDRC) Phase 2 Application, Attachment F Benefit Cost Analysis.* State of New York. October 25, 2015.
[25] *Treatment of the Values of Life and Injury in Economic Analysis.* Federal Aviation Administration. September 2016. Available at https://www.faa.gov/regulations_policies/policy_guidance/benefit_cost/media/econ-value-section-2-tx-values.pdf.
[26] *FEMA Benefit-Cost Analysis Re-engineering (BCAR), Development of Standard Economic Values.* Version 6.0. FEMA. December 2011.

value of the serious injury ($379,000). Values for injuries in the future would be calculated by multiplying the Fractions of VSL below by the future VSL.

Where specific information is available on separate injuries for the same individual by AIS level, only the value of the most severe injury should be used.

*Table 7 – AIS Valuation (2012 Dollars)**Error! Bookmark not defined.***

AIS Code	Description of Injury	Fraction of VSL	Economic Value
AIS 1	Minor	0.0020	$13,000
AIS 2	Moderate	0.0155	$102,000
AIS 3	Serious	0.0575	$379,000
AIS 4	Severe	0.1875	$1,237,000
AIS 5	Critical	0.7625	$5,032,000
AIS 6	Fatal	1.0000	$6,600,000

It has been estimated that there will be an expected 1.07 percent annual growth rate in median real wages. These estimates imply that VSL in future years should be estimated to grow by 1.07 percent per year[27]. This guidance can be used to convert the table above based on 2012 dollars to 2017 dollars for Hurricane Harvey.

*Table 8 – AIS Valuation (2017 Dollars)**

AIS Code	Description of Injury	Fraction of VSL	Dollar Value*
AIS 1	Minor	0.0020	$13,900
AIS 2	Moderate	0.0155	$107,900
AIS 3	Serious	0.0575	$400,200
AIS 4	Severe	0.1875	$1,305,100
AIS 5	Critical	0.7625	$5,307,500
AIS 6	Fatal	1.0000	$6,960,700

**Rounded to the nearest hundred dollars*

Because the number and severity of injuries related to a particular storm is not a predictable quantity, determining a probable annual value of avoided costs of injuries due to a mitigation project is not considered feasible. As such, this factor will not be included in the quantitative benefit-cost comparative analysis. However, an approximate valuation of the injuries and fatalities during Hurricane Harvey within the Halls Bayou project areas can still be presented as part of the CDBG-MIT application to demonstrate additional benefits from the project. The 2017 AIS dollar values can be distributed among those impacted during Hurricane Harvey to obtain the cost of injuries associated with Hurricane Harvey based on the equations provided above.

The following information related to the injury data for Hurricane Harvey is still required in order to include this benefit in the BCA.

- Data providing an indication of injury severity
- Percentage of reported injuries during Hurricane Harvey

[27]*Guidance on Treatment of the Economic Value of a Statistical Life (VSL) in U.S. Department of Transportation Analyses.* U.S. Department of Transportation Memorandum. February 28, 2018.

One paper[28] reviewed by FNI included the percentage of reported injuries after Hurricane Sandy as cited in a Centers for Disease Control and Prevention (CDC) report[29]. A similar report for Hurricane Harvey was searched for on the CDC website, but it was determined that such a report has not been published.

Recommendation: Identify a source in Harris County to provide the injury data required to include Cost of Physical Injuries due to Hurricane Harvey as part of the qualitative discussion of benefits in the CDBG-MIT application.

Loss of Utility Services – Electricity

Loss of electricity was explored as a possible benefit to include in the BCA. Two methods were identified:

1. An Interruption Cost Estimate (ICE) Calculator was located to determine cost associated with loss of electricity - https://icecalculator.com/interruption-cost. Input data required includes:
    a. Number of non-residential customers
    b. Number of residential customers
    c. Reliability Index Results (explained here - https://www.centerpointenergy.com/en-us/Services/Pages/reliability-indexes.aspx?sa=HO&au=bus)

Table 9 – Reliability Indexes

Name	Definition
System Average Interruption Duration Index	$SAIDI = \frac{\text{sum of all outage durations}}{\text{\# of customers}}$
System Average Interruption Frequency Index	$SAIFI = \frac{\text{count of all extended outages}}{\text{\# of customers}}$
Customer Average Interruption Duration Index	$CAIDI = \frac{SAIDI}{SAIFI}$

Values for SAIDI, SAIFI, and CAIDI could not be determined. Therefore, this method was not explored further.

2. The FEMA Toolkit[30] applies a standard value of $148 per capita per day for the economic impact of power loss. Approximately 19% of this is the impact to residential customers[31].

A paper[Error! Bookmark not defined.] reviewed by FNI assumed the probability for power loss to be equal to the probability of displacement, which was calculated by the FEMA BCA Tool. However, this category was included in the reviewed paper as a benefit to implement mitigation measures for electricity that would increase efficiency and improve reliability rather than for flood mitigation measures.

[28] *HUD National Disaster Resilience Competition (NDRC) Phase 2 Application, Attachment F Benefit Cost Analysis.* State of New York. October 25, 2015.
[29] *Centers for Disease Control and Prevention, Morbidity and Mortality Weekly Report (MMWR) Nonfatal Injuries 1 Week After Hurricane Sandy — New York City Metropolitan Area, October 2012 Weekly, October 24, 2014 / 63(42): 950-954, Robert M. Brackbill, PhD et al.*
[30] *Benefit Cost Toolkit Version 6.0.* FEMA. October 2019. Available at https://www.fema.gov/media-library/assets/documents/179903.
[31] *FEMA Benefit-Cost Analysis Re-engineering (BCAR), Development of Standard Economic Values.* Version 6.0. FEMA. December 2011.

Electrical substations were located based on the Halls Bayou Structure Inventory. No substations are at risk of flooding in the service areas of the proposed mitigation projects, so this benefit was not assessed further.

Recommendation: Do not include in the BCA; proposed projects would not mitigate any potential loss of electricity as no substations are at risk of flooding in the project service areas.

Loss of Utility Services – Water

In addition to the City of Houston, several small public water systems (PWS) operate in the Halls Bayou watershed. Many of these utilize groundwater from wells operated independently by each PWS. FNI mapped the locations of such wells and determined that only two such wells might benefit from the proposed tributary projects. Additional wells could have benefits if one of the mainstem projects was selected. Most of these water systems serve small populations, which limits the value of the potential benefit.

To determine the cost of loss of water service, the FEMA Toolkit requires an estimate for the number of people and length of time that water service would be lost. It is not clear if this applies only to complete system interruptions in which no running water is available. Several PWS in the Halls Bayou watershed issued Boil Water Notices after Hurricane Harvey based on information from TCEQ[32], as shown in *Table 10*. However, data on service interruptions by individual utility was not available.

Table 10 – Public Water Systems in Halls Bayou Watershed Which Implemented Boil Water Notices After Hurricane Harvey

Facility Name	Population Served	Number of Days with Boil Water Notice in Place
GREENWOOD VILLAGE	2250	3
BERGVILLE ADDITION	27	5
MARY FRANCIS SUBDIVISION	1659	3
COLONIAL HILLS	930	12
STETNER ADDITION	135	5
MOBILE HOME ESTATES	543	10
LONE WILLOW MHP WEST	90	18
LONE WILLOW MOBILE HOME PARK	80	14
FATIMA FAMILY VILLAGE MHP	100	11
SELLERS ESTATES MOBILE HOME COMM	85	32
TASFIELD	219	5
ROSEWOOD MOBILE HOME PARK	234	11
MCFARLAND VILLAGE APARTMENTS	120	5
HEAVENS MOBILE HOME PARK	25	16

Recommendation: If projects are selected with service areas overlapping the well locations of any PWS, FNI recommends submitting a data request (fee required) to TCEQ for specific information on any service interruptions following Hurricane Harvey and the duration of such interruptions in those PWS. Follow-ups with the operators of such PWS may also be required to determine whether the cause of such

[32] "Public Drinking Water: Community Water Systems (CWSs) Impacted by Hurricane Harvey with Rescinded Boil Water Notices." TCEQ Dataset. December 28, 2017. Available at https://www.tceq.texas.gov/assets/public/response/hurricanes/bwn-rescinded.pdf.

interruptions would be mitigated by reduced flooding depths. If so, the standard FEMA value ($105/person/day) for the loss of water service per person per day may be applied in the final BCA.

Loss of Utility Services – Wastewater

FNI determined that multiple public water systems (PWS) operate wastewater treatment facilities (WWTF) within the Halls Bayou watershed. These WWTFs treat wastewater from their respective PWS subdivision(s) and discharge treated effluent into nearby streams, such as Halls Bayou. FNI mapped the locations of these WWTFs and found that none would benefit from the proposed tributary projects. Three WWTFs might benefit if one of the mainstem projects was selected. The WWTFs that could benefit from the mainstem projects serve relatively small populations, so potential benefits are likely limited.

In order to determine the cost from loss of wastewater utility services, the FEMA Toolkit requires an estimate for the number of customers served and length of time that wastewater services are impacted. It is not clear if this applies only to complete utility interruptions where the WWTF is not operable. At one point during Hurricane Harvey, 40 WWTFs were rendered inoperable or even destroyed[33], including many within Harris County. However, data on the specific facilities impacted to this extent and the duration of impact were not available. News reports indicate that none of the WWTFs rendered inoperable or destroyed one month after Hurricane Harvey were located in Halls Bayou[34].

Recommendation: If projects are selected that could mitigate flooding at any WWTFs serving PWS within the Halls Bayou watershed, FNI recommends submitting a data request (fee required) to TCEQ for specific information on any WWTFs that were damaged, rendered inoperable, or destroyed following Hurricane Harvey and the duration of potential sewer service or treatment interruptions in those PWS. Follow-ups with the operators of the WWTFs may also be required to determine whether the cause of such interruptions would be mitigated by reduced flooding depths. If so, the standard value from the FEMA toolkit for the loss of water service per person per day ($49/person/day) may be applied in the final BCA.

Energy Savings

Energy savings were explored as a possible benefit type to include in the BCA. Energy consumption in the west south central region in 2015 was determined to be 38.1 Btu/SF

(https://www.eia.gov/consumption/residential/data/2015/c&e/pdf/ce1.4.pdf). This data for energy consumption includes natural gas, electricity, fuel oil/kerosene, and propane. A method to monetize is needed in order to include this benefit.

Recommendation: Do not include in the BCA as a benefit of flood mitigation projects. This benefit category was included in the paper[35] reviewed by FNI based on energy-efficient improvements through the installation of retrofits to improve building efficiency and produce energy cost savings.

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[33] *Hurricane Harvey Response 2017, After Action Review Report.* Texas Commission on Environmental Quality. April 3, 2018. Available at: https://www.tceq.texas.gov/assets/public/response/hurricanes/hurricane-harvey-after-action-review-report.pdf

[34] *"Raw sewage spilled in Houston after wastewater plants damaged by Harvey",* Stuckey, Alex. Houston Chronicle. September 19, 2017. Available at: https://www.chron.com/news/houston-texas/article/Nearly-a-dozen-wastewater-treatment-facilities-12209605.php

[35] *HUD National Disaster Resilience Competition (NDRC) Phase 2 Application, Attachment F Benefit Cost Analysis.* State of New York. October 25, 2015.

Damage Related to Potential Pollution Sources

NOAA's Coastal Flood Exposure Mapper includes potential pollution sources as a contributing factor to overall risk for areas subject to flood hazards. During FNI's research (including review of benefits quantified in HAZUS), no references were located for methods of monetizing risks associated with hazardous materials or other pollutants.

Recommendation: Describe the number and type of potential pollution sources in the project impact areas as part of the CDBG-MIT application, and include a qualitative discussion of the benefit of reducing flood risk to these facilities.

Elderly Care Centers

One reference included avoided costs of evacuating elderly residents of care facilities[35]. However, no elderly care centers were identified within Halls Bayou.

Recommendation: Do not include. This benefit category is not applicable to the Halls Bayou projects due to the lack of elderly care facilities in the project impact area.

Emergency Response and Recovery Efforts

After Hurricane Harvey, flooded roadways and non-functioning transportation services impeded travel. Flooded roads could (in the future) prevent emergency response vehicles—such as police cars, ambulances, or firefighting equipment—from reaching flood victims in time. The protection of these areas from flooding will serve to reduce emergency response times and give adequate access to crews that typically deal with fallen trees, downed power lines, or other disaster incidents. Flood risk reduction will also favorably impact post-disaster recovery efforts, allowing residents and property owners to return from evacuation safely in order to address possible damages. No method or associated data was found to quantify the reduction in need for and cost of emergency services, but this has been included as a qualitative benefit in other studies[36].

Recommendation: Discuss benefit to emergency response and recovery efforts as part of a qualitative benefits discussion in the CDBG-MIT application.

Economic Revitalization

Losses to economic output due to flooding have been estimated by other entities[36,37] using the IMPLAN economic impact assessment software. However, this approach requires significant detailed input data, and the use of this software is outside FNI's expertise.

Additionally, the flood mitigation projects within Halls Bayou will support local construction jobs. Although number of jobs could be estimated, this is a short-term benefit and thus cannot be included in the benefit-cost analysis as it will not last through the lifetime of the project.

Recommendation: Do not include in the Halls Bayou BCA.

[36] *HUD National Disaster Resilience Competition (NDRC) Phase 2 Application, Attachment F Benefit Cost Analysis.* Commonwealth of Virginia. 2015.
[37] *East Side Coastal Resiliency Updated Benefit-Cost Analysis.* New York City Department of Design and Construction. 2019.

Excerpt from Federal Register

"Allocations, Common Application, Waivers, and Alternative Requirements for Community Development Block Grant Mitigation Grantees", 84 FR 169 (August 30, 2019).

Agency: Office of the Assistant Secretary for Community Planning and Development, Department of Housing and Urban Development.

Action: Notice

Section V.A.2.h(2) Covered Project action plan or substantial amendment requirements

The following must be provided for each Covered Project proposed in an action plan or a substantial amendment:

(a) Project description and eligibility
[…]

(b) Consistency with the Mitigation Needs Assessment

(c) National Objective, including additional criteria. The action plan must describe how the Covered Project will meet a national objective, including additional criteria for mitigation activities and Covered Projects. The national objectives for CDBG-MIT projects are described in section V.A.13 HUD has established additional criteria for Covered Projects that require a plan for long-term efficacy and fiscal sustainability, a demonstration that the benefits outweigh the costs, and a demonstration that the Covered Project is consistent with other mitigation activities in the same MID area, as described below in (i) through (iii):

(i)Long-term efficacy and fiscal sustainability
[…]

(ii)Demonstration of benefits

(ii.a.) Demonstration of benefits through benefit cost analysis.

The action plan or substantial amendment must describe how the benefits of the Covered Project outweigh the costs of the Covered Project. Benefits outweigh costs if the Benefit Cost Analysis (BCA) results in a benefit-to-cost ratio greater than 1.0 (which aligns with FEMA's BCA ratio). The action plan or substantial amendment must include a description of the methodology and the results of the BCA that has been conducted for the Covered Project. The grantee must indicate whether another Federal agency has rejected a BCA for the Covered Project (including any BCA for an earlier version of the current proposed Covered Project). Grantees and subrecipients may use FEMA-approved methodologies and tools to demonstrate the cost- effectiveness of their projects. FEMA has developed the BCA Toolkit to facilitate the process of preparing a BCA. Using the BCA Toolkit will ensure that the calculations are prepared in accordance with OMB Circular A–94 and FEMA's standardized methodologies. It is imperative to conduct a BCA early in the project development process to ensure the likelihood of meeting the cost- effectiveness eligibility requirement. A non-FEMA BCA methodology may be used when: (1) A BCA has already been completed or is in progress pursuant to BCA guidelines issued by other Federal agencies such as the Army Corps or the Department of Transportation; (2) it addresses a non- correctable flaw in the FEMA-approved BCA methodology; or (3) it proposes a new approach that is unavailable using the FEMA BCA Toolkit. In order for HUD to accept any BCA completed or in progress pursuant to another Federal agency's requirements, that BCA must account for economic development, community development and other social/community benefits or costs and the CDBG–MIT project must be substantially the same as the project analyzed in the other agency's BCA.

(ii.b.) Alternate demonstration of benefits.

Alternatively, for a Covered Project that serves low- and moderate- income persons or other persons that are less able to mitigate risks or respond to and recover from disasters, the grantee may demonstrate that benefits outweigh costs if the grantee completes a BCA as described above and provides HUD with a benefit-to-cost ratio (which may be less than one) and a qualitative description of benefits that cannot be quantified but sufficiently demonstrate unique and concrete benefits of the Covered Project for low- and moderate-income persons or other persons that are less able to mitigate risks, or respond to and recover from disasters. This qualitative description may include a description of how the Covered Project will provide benefits such as enhancing a community's economic development potential, improving public health and or expanding recreational opportunities. The grantee shall include the BCA for a Covered Project, together with any qualitative description of benefits for projects benefitting low- and moderate- income persons and other persons that are less able to mitigate risks, or respond to and recover from disasters, as an appendix to the action plan or substantial amendment that proposes the project.

(iii)Consistency with other mitigation activities
[…]

DRAFT MEMORANDUM

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TO:	Dena Green, Alan Black, Xin He (Harris County Flood Control District)
CC:	Lars Zetterstrom, Chris Edwards, Michael Liga, Nick Barnett, Tak Makino, Laura Casset (LAN)
FROM:	Cory Stull, Courtney Corso, Shannon Mack, and Jordan Skipwith (FNI)
SUBJECT:	Draft for Coordination: Summary of Preliminary Scoring and Benefit-Cost Analyses
DATE:	May 8, 2020
PROJECT:	SCG17357 – Disaster Recovery Services: CDBG-MIT Grant Application for Halls Bayou

Introduction

HCFCD intends to submit two applications for grant funding to the Hurricane Harvey State Mitigation Competition for CDBG-MIT funds allocated to Texas and distributed by the Texas General Land Office (GLO). In coordination with LAN, FNI has assessed flood mitigation projects in the Halls Bayou sub-watershed to inform decisions on which projects should be grouped together as "Covered Projects" to be most competitive for grant funding.

This memorandum presents results of a preliminary benefit-cost analysis (BCA) performed on each of the individual mitigation projects. Additionally, individual projects and potential project groupings were scored based on available guidance from the GLO in the State of Texas CDBG Mitigation (CDBG-MIT) Action Plan (hereafter "Action Plan"), and scores are presented here. The intent of these analyses was to identify individual projects ("activities") which, when grouped together as "Covered Project" would be most competitive in the CDBG-MIT grant competition.

The Action Plan was approved by HUD on March 31, 2020, and additional guidance on requirements for the CDBG-MIT grant applications is expected to be available in early May from GLO. Methods of scoring and benefit-cost analysis will be revised per GLO guidance before performing final analyses on the selected Covered Projects.

Halls Bayou Mitigation Projects Considered for CDBG-MIT Funding

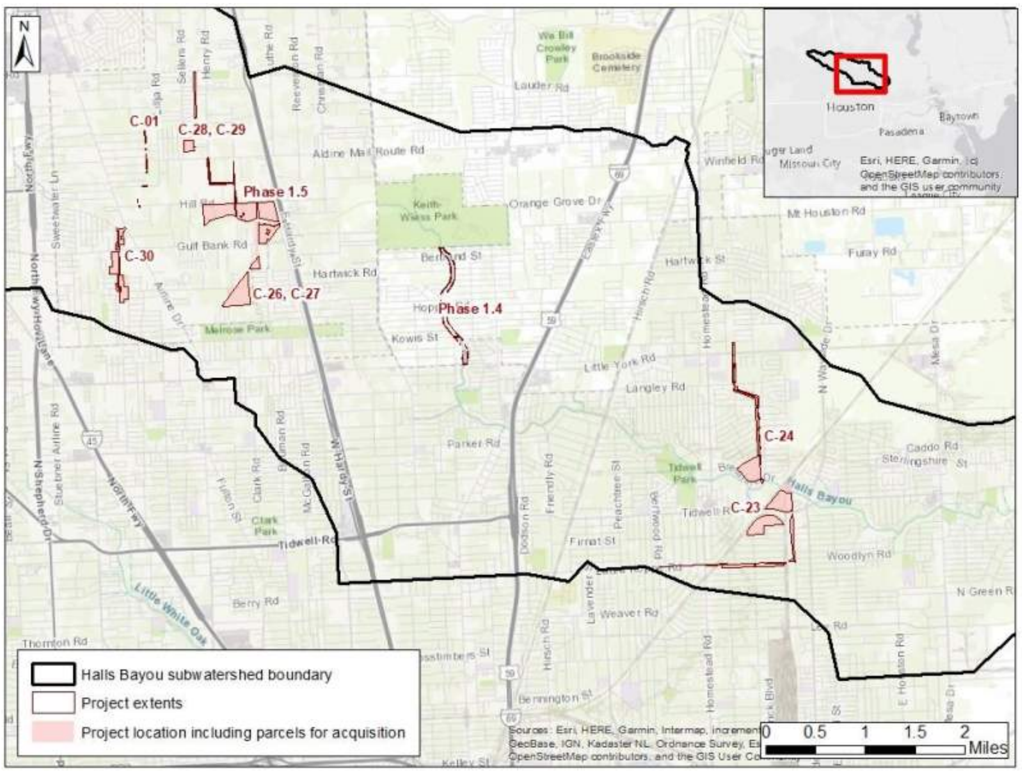
Table 1 lists the Halls Bayou mitigation projects which were considered, as provided by LAN. Project locations are shown in *Figure 1*.

Table 1 – Halls Bayou Flood Mitigation Projects Considered for CDBG-MIT Grant Applications

Bond ID	Unit ID / Description	Assessed?	Comments
C-01	P518-26-00-FP	Yes	
C-26	P118-23-00-FP	Yes	Assessed together (interdependent projects)
C-27	P118-23-02-FP		
C-28	P118-25-00-FP	Yes	Assessed together (interdependent projects)
C-29	P118-25-01-FP		
C-23	P118-08-00	Yes	
C-24	P118-09-00	Yes	
C-30	P118-27-00	Yes	

Bond ID	Unit ID / Description	Assessed?	Comments
Phase 1 DS of Bertrand	P118-00-00	Yes	
Phase 1 Hardy West	n/a	Yes	
C-35	P518-10-00-FP001; P118-14-00	No	Already Funded
C-02	P518-Aldine-CDBG	No	Already Funded
C-25	P118-21-00-FP	No	Already Funded
CI-006	P118-Brock	No	Estimated cost less bond funding exceeds CDBG-MIT funding maximum grant

Figure 1 – Halls Bayou Flood Mitigation Project Locations



Preliminary Scoring Assessment Results

Preliminary scoring assessments were performed to estimate localized scores and other metrics for Social Vulnerability, Poverty Rate, and Project Impact. Considering the size and population of Harris County, social vulnerability and poverty rates are highly variable at the local scale. This localized approach illustrates that projects in the Halls Bayou watershed score much higher in these categories than what was shown at the county level in the Action Plan. Other scoring criteria were constant across all projects, as they rely either on county-level data or on information at the sub-applicant level (HCFCD). Localized scores considered the approximate project impact area to be the 500-year floodplain of the associated channel under existing conditions. It should be noted that the Action Plan did not define how points are assigned in the scoring categories "Project Impact" and "Mitigation/Resiliency Measures." As such, the associated metrics have been estimated, but the scores in this preliminary analysis only indicate the minimum score before addition of points associated with Project Impact. Up to 25 additional points are available from this category. For now, it has been assumed that HCFCD will qualify for the 5 points related to Mitigation/Resiliency Measures. *Table 2* ranks individual projects by minimum expected score.

Table 2 – Projects Ranked by Individual Score and Number of Benefitted Persons

Rank	Bond ID	Expected Minimum Score[1]	Number of Beneficiaries[2]
1	C-24	78	2,109
2	C-23	78	1,551
3	C-28, C-29	76	3,600
4	C-30	76	2,422
5	C-26, C-27	76	938
6	Ph I DS of Bertrand	71	43,011
7	Ph I Hardy West	71	26,789
8	C-01	71	1,618

[1]Does not include points for Project Impact (up to 25 points).
[2]Related to Project Impact score.

Preliminary Benefit-Cost Analysis

Although a benefit-cost ratio (BCR) is not a factor in the competition score as set forth by GLO, applicants are required to demonstrate that the benefits of the Covered Project outweigh the costs. As described in the Federal Register,[1] this requirement may be met in two ways:

1. Benefit-cost ratio developed during a benefit-cost analysis (BCA) is greater than 1.0.
    a. Calculations should be prepared in accordance with OMB Circular A-94[2].
    b. BCA methodology should follow FEMA standardized methodologies unless
        i. A BCA for the project has already been completed or is in progress under guidelines of other Federal agencies, or
        ii. The BCA addresses a non-correctable flaw in the FEMA methodology, or
        iii. A new approach is proposed that is unavailable using the FEMA Toolkit.
2. Alternately, projects may have a benefit-cost ratio of less than 1.0 under these conditions:
    a. A BCA is still completed following the methodologies described above.
    b. The project "serves low- and moderate- income persons or other persons that are less able to mitigate risks or respond to and recover from disaster."
    c. A qualitative description is provided for "benefits that cannot be quantified but sufficiently demonstrate unique and concrete benefits of the Covered Project for low- and moderate- income persons or other persons that are less able to mitigate risks, or respond to and recover from disasters."

[1] Allocations, Common Application, Waivers, and Alternative Requirements for Community Development Block Grant Mitigation Grantees, 84 FR 169 (August 30, 2019).
[2] *Circular A-94*, Office of Management and Budget, last revised October 29, 1992.

In accordance with these requirements, a quantitative BCA has been performed for each proposed project in Halls Bayou. Additionally, numerous metrics have been compiled to demonstrate that the proposed projects not only benefit low- and moderate- income persons but also a population that is generally vulnerable to disasters. Data has also been compiled to demonstrate potential benefits of the projects that could not be reliably monetized in the BCA. The text of the relevant section of 84 FR 169 is attached to this memorandum.

Quantitative Benefit-Cost Analysis Results

The Halls Bayou quantitative BCA was based on methodologies in the FEMA BCA Toolkit (v6.0). However, the Toolkit itself was not used, as it is best suited to limited-area analyses. A separate tool was developed that uses many of the standard values and concepts in the FEMA BCA Toolkit with some exceptions. More detail on the benefit-cost analysis methodology is provided in a separate memorandum[3]. The BCA included the following benefit categories:

- Building damages (avoided losses)
- Content damages (avoided losses)
- Residential displacement (avoided costs)
- Non-residential displacement (avoided costs)
- Mental health treatment (avoided costs)
- Worker productivity (avoided losses)
- Ecosystem services (benefit of conversion of developed land)

Table 3 ranks projects by BCR.

Table 3 – Projects Ranked by Benefit-Cost Ratio

Rank	Bond ID	Comprehensive BCR
1	Ph I DS of Bertrand	2.66
2	C-30	2.08
3	Ph I Hardy west	0.48
4	C-01	0.37
5	C-23	0.34
6	C-26, C-27	0.33
7	C-24	0.32
n/a*	C-28, C-29	0.30 - 3.24

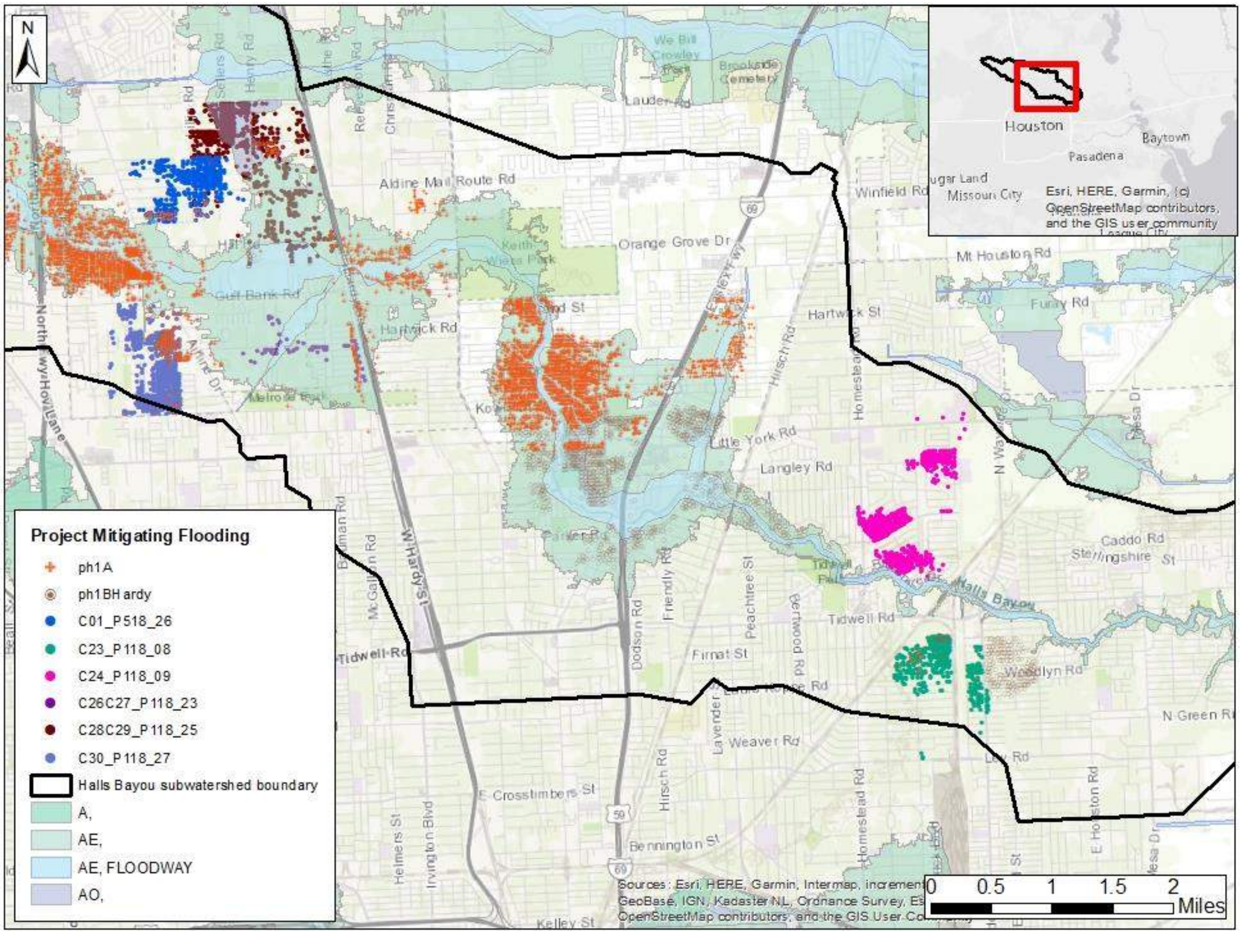
**BCR varies depending on inclusion of structures which are also at risk of flooding from the main stem of Halls Bayou and from P118-26.*

The benefit-cost analysis considered water surface elevations as modeled for existing and post-mitigation conditions in HEC-RAS. Most benefits were calculated for individual structures and totaled for the project area, with the exception of environmental benefits. *Figure 2* indicates structure locations at which the modeled 100-year storm water surface elevation was removed or reduced by implementation of the mitigation projects. Note that this preliminary assessment did not account for mainstem-tributary interactions. Subsequently, some of the structures shown to be benefitted by the tributary mitigation

[3] "Draft for Coordination: Preliminary Benefit-Cost Analysis Methodology and Discussion." Prepared by Freese & Nichols, Inc. for Harris County Flood Control District. April 2020.

projects may still be at risk of flooding from Halls Bayou. For reference, *Figure 2* also indicates the FEMA Special Flood Hazard Area.

Figure 2 – Structures Benefitted at 100-yr Level of Service



More details on BCA results for individual projects can be found in ***Attachment A***. Factors that had substantial effects on BCRs included:

- Detention
    - Conversion of developed area to green space provides environmental benefits.
- Non-residential buildings
    - Building damage values are based on building type and size. Large footprints of commercial buildings can result in high pre-mitigation damage values.
    - Contents in certain non-residential building types are valued at a greater amount than the structure itself.
- Baseline conditions
    - Benefits are greater in areas where existing flooding conditions are worse.
- Size of project service area

- In addition to reducing damage for more structures, the social benefits to residents of those structures are substantial and are not dependent on the magnitude of the structural benefit.

Recommendations for Qualitative Benefit Discussion in CDBG-MIT Application

1. Project Area Profiles – For each Covered Project, describe the population to indicate how the project would serve "LMI persons and other persons that are less able to mitigate risks or respond to and recover from disasters." The following metrics, when analyzed in the study area, indicate that the Halls Bayou watershed is home to a particularly vulnerable population (*Table 4*).
    a. LMI Percentage (required to meet LMI National Objective and attain 20 points from scoring matrix)
    b. Social Vulnerability Index (required to attain up to 10 points from scoring matrix)
    c. Percentage housing cost-burdened (households spending more than 30% of monthly income on housing-related costs)
    d. Percentage of population with poor or no internet access, which could impact their ability to benefit from early warning systems in case of flooding events

Table 4 – Metrics Indicating the Vulnerability of the Population to be Served by Proposed Projects

Analysis Area	Number of Census Tracts	Percent Low- and Moderate-Income	Percentage of Households			Percentage of Working-Age Population (16+)	
			Housing Cost-Burdened (30%+)	Severely Housing Cost-Burdened (50%+)	No Internet Access	Working Full-Time	Working, but less than Full-Time
Halls Bayou Project Areas	19	66%	33%	17%	38%	44%	22%
Halls Bayou	36	71%	38%	19%	35%	45%	23%
Harris County	786	47%	33%	15%	16%	53%	23%

2. Qualitative Discussion of Non-monetized Benefits
    a. Describe trends in property values following Hurricane Harvey and discuss the potential impacts to property owners of disaster-induced property value reductions.
    b. Estimate the number of part-time workers benefitted by the projects. (Methods to monetize avoided productivity losses are limited to full-time workers.)
    c. Other benefit categories as discussed in a separate memo[3], contingent on data availability.
3. Quantile-mapped BCA Comparison – Still needs Proof-of-Concept. If BCR of either Covered Project is ultimately less than 1.0, perform a quantile-mapping analysis that replaces Halls Bayou building replacement values (BRV) with values from a higher-income area (such as Buffalo Bayou watershed) in the same project analysis to demonstrate that LMI areas will by nature have lower

BCR scores. Thus, relying on a high BCR counteracts the intention of serving LMI populations. Replacement is performed by matching quantiles of the Halls Bayou BRV distribution to equal quantiles of the alternate area BRV distribution.

Potential Project Groupings: Assessment and Recommendations

Potential groupings of projects were considered to determine performance against the scoring matrix; these groupings comprised two sets of mutually exclusive project options (*Table 5),* representing options for two Covered Project applications. Additional proposed groupings can be assessed as requested by LAN or HCFCD.

The initial groupings considered inclusion of all assessed projects except for Phase 1 Hardy West Detention.

Table 5 – Project Groupings Assessed

Covered Project	1		2		
Group	**1**	**1a**	**2**	**2a**	**2b**
Included Projects	C-01	C-01			
	C-26, C-27	C-26, C-27			
	C-28, C-29	C-28, C-29			
			C-23		C-23
			C-24	C-24	
				C-30	C-30
	Ph I DS of Bertrand				

Results for assessments of these project groups are shown in *Table 6,* which also includes the total cost of included projects and the total available bond funding.

Table 6 – Performance of Project Groupings

Group	Total Cost ($ millions)	Bond Funding ($ millions)	Expected Minimum Score[1]	Number of Beneficiaries[2]	Average Poverty Rate	Comprehensive Benefit-Cost Ratio[3]
1	$110.2	$5.2	76	23,877	27%	1.06
1a	$95.2	$5.2	76	6,120	27%	0.80
2	$125.3	$3.7	78	3,261	26%	0.33
2a	$95.0	$2.4	76	4,239	28%	0.86
2b	$87.9	$3.7	76	3,686	24%	0.91

[1]Does not include points for Project Impact (up to 25 points).

[2]Related to Project Impact score. Sum of beneficiaries of individual projects. Total for combined project may be lower.

[3]BCR for groups equal to ratio of the sum of individual project benefits to sum of individual project costs. Total benefits for grouping may be lower when projects are modeled together.

A detailed record of BCA and scoring results for individual projects and potential project groupings can be found in ***Attachment A***.

Covered Project 1

Options 1 and 1a perform similarly in most scoring categories and tiebreaker. However, the inclusion of Phase 1 Downstream of Bertrand in Group 1 substantially increases the potential number of beneficiaries, which should increase the points available in the Project Impact criteria. Group 1 is also anticipated to have a higher BCR. However, the selection of this option is contingent upon the development of mitigation measures to prevent negative impacts resulting from the implementation of Phase 1 Downstream of Bertrand. Additionally, Option 1 would require $5 million in additional funding from another source due to the $100 million cap on CDBG-MIT funding per Covered Project.

Considerations for grouping:

- Option 1 may perform better in the CDBG-MIT competition due to a greater number of beneficiaries. However, application for funds for this option are contingent on
  - Mitigation of negative impacts associated with Phase 1 Downstream of Bertrand
  - Additional funding for the remaining $5,000,000.
- Interaction between the main channel of Halls Bayou and the tributaries may have significant effects on the anticipated scores and BCR once projects are modeled together.

Covered Project 2

For Covered Project 2, Option 2 has a slightly higher minimum score due to the Social Vulnerability Index of the project service areas. However, the projects included had some of the lowest individual BCRs. The inclusion of C-30 substantially increases the group BCR.

Recommendation:
Based on the groupings analyzed, Option 2a may be the best option for the second CDBG-MIT application for these reasons:

- Relatively high BCR.
- Tie-break score (poverty rate) is highest among 2, 2a, and 2b.
- Option 2a will be able to take advantage of $92.6 million in CDBG-MIT funds, whereas Option 2b would only be able to request $84.2 million.
- No additional funding sources would be required for C-24 and C-30 if CDBG-MIT funds are awarded.

It should be noted that mainstem interactions with the tributary projects considered for Covered Project 2 have not been modeled. Such interactions could impact the final project score and BCR. However, the service areas for the projects in options 2, 2a, and 2b have minimal overlap with the 100-year floodplain of Halls Bayou, so final scores are expected to be affected minimally.

Summary and General Recommendations

- Demonstration that project benefits outweigh costs is a requirement of any CDBG-MIT project. However, a quantitative analysis of monetized benefits does <u>not</u> have to demonstrate a benefit-cost ratio of greater than 1.0. Instead, a BCR less than 1.0 can be supplemented with a qualitative description of how the project benefits low- and moderate- income persons and other vulnerable populations.

- BCR is not a criterion used for awarding points in the Hurricane Harvey State Mitigation Competition. A project needs to demonstrate benefits to be eligible, but there is not a requirement to demonstrate that the benefit-cost ratio exceeds that of other competing projects.
- Project Impact scores cannot be determined until the application guides are available. Maximizing the number of project beneficiaries is the best way to increase this score.
- Bundles should be selected based on the ability to maximize Project Impact and Leverage scores, as well as maximizing the total requested grant amount.

Attachment A

Detailed Tables of Results from the Preliminary Benefit-Cost Analysis and Scoring Assessment for Halls Bayou CDBG-MIT Project Candidates

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Table 1 – Benefit-Cost Analysis: Costs, Benefits, and Benefit-Cost Ratios

Project Bond ID(s)	Unit ID(s)	Smallest Storm Included in BCA	Total Annualized Cost ($ millions)	Standard Expected Annual Benefits* ($ millions)	Ancillary Expected Annual Benefits* ($ millions)	Total Expected Annual Benefits* ($ millions)	BCR (Standard)	BCR (Comprehensive)	Comment
C-01	P518-26-00-FP	10-yr (10%)	$3.16	$0.16	$1.02	$1.18	0.05	0.37	Baseline damage amount is lower, making total standard benefit lower.
C-26, C-27	P118-23-00-FP, P118-23-02-FP	100-yr (1%)	$2.71	$0.01	$0.89	$0.90	0.00	0.33	Standard benefits are underestimated due to lack of data for smaller storms, but low BCR is still probably reasonable. Benefit is primarily in 500-yr, and average 100-yr benefit is low, as is the total count of structures benefitted.
C-28, C-29	P118-25-00-FP, P118-25-01-FP	10-yr (10%)	$1.08	$1.19	$2.33	$3.52	1.10	3.24	High BCR due to high baseline damage, non-residential structures along Aldine Mail Route, and high social benefit due to # residents impacted. However, service area significantly overlaps floodplain of the main channel of Halls Bayou and also receives overflow from P118-26.
C-23	P118-08-00	10-yr (10%)	$4.32	$0.41	$1.07	$1.48	0.10	0.34	Baseline damage amount is lower, making total standard benefit lower.
C-24	P118-09-00	100-yr (1%)	$4.82	$0.24	$1.32	$1.56	0.05	0.32	Standard benefits are underestimated due to removal of smaller storms from analysis. However, standard BCR is low regardless. Project includes negative impacts and associated negative benefits in the 500-year storm only.
C-30	P118-27-00	10-yr (10%)	$2.11	$2.62	$1.77	$4.39	1.24	2.08	Non-residential structures with large footprints contribute significantly to standard benefit amount. Benefit values shown here reflect exclusion of 5 commercial structures that were assumed to be overvalued.
Ph I DS of Bertrand	P118-00-00	10-yr (10%)	$1.09	(-$0.10)	$2.99	$2.89	-0.09	2.66	Significant social benefits due to number of residents impacted. Project includes negative impacts and associated negative benefits.
Ph I Hardy west	-	100-yr (1%)	$5.43	(-$0.01)	$2.61	$2.61	0.00	0.48	Significant social benefits due to number of residents impacted. Expected annual standard benefits may be underestimated due to the lack of storms other than 100-yr. Project includes negative impacts and associated negative benefits.

**Both standard and ancillary benefits include NET social benefits (positive – negative).*

Table 2 – Benefit-Cost Analysis: Additional Metrics

Project Bond ID(s)	Overlap with Mainstem FP	Baseline Structure + Content Damage	# Structures No Longer Damaged in 100yr Storm	Average EAB per Benefitted Structure	Average 100-yr Benefit per Benefitted Structure	BCR (Comprehensive)	Comment
C-01	yes	$155,777	327	$386	$5,994	0.37	Baseline damage amount is lower, making total standard benefit lower.
C-26, C-27	yes	$13,849	47	$51	$952	0.33	Standard benefits are underestimated due to lack of data for smaller storms, but low BCR is still probably reasonable. Benefit is primarily in 500-yr, and average 100-yr benefit is low, as is the total count of structures benefitted.
C-28, C-29	yes	$1,157,030	714	$1,257	$26,089	3.24	High BCR due to high baseline damage, non-residential structures along Aldine Mail Route, and high social benefit due to # residents impacted. However, service area significantly overlaps floodplain of the main channel of Halls Bayou and also receives overflow from P118-26.
C-23		$399,868	324	$769	$14,370	0.34	Baseline damage amount is lower, making total standard benefit lower.
C-24		$508,622	201	$337	$21,678	0.32	Standard benefits are underestimated due to removal of smaller storms from analysis. However, standard BCR is low regardless. Project includes negative impacts and associated negative benefits in the 500-year storm only.
C-30		$2,599,638	397	$3,867	$54,305	2.08	Non-residential structures with large footprints contribute significantly to standard benefit amount. Benefit values shown here reflect exclusion of 5 commercial structures that were assumed to be overvalued.
Ph I DS of Bertrand		#N/A	1,329	$238	$3,025	2.66	Significant social benefits due to number of residents impacted. Project includes negative impacts and associated negative benefits.
Ph I Hardy west		#N/A	501	$69	$5,648	0.48	Significant social benefits due to number of residents impacted. Expected annual standard benefits may be underestimated due to the lack of storms other than 100-yr. Project includes negative impacts and associated negative benefits.

Table 3 – Project Scoring Assessment Results

Project Bond ID(s)		C-01	C-26, C-27	C-28, C-29	C-23	C-24	C-30	Ph I DS of Bertrand	Ph I Hardy west	Comments
Unit ID(s)		*P518-26-00*	*P118-23-00 P118-23-02*	*P118-25-00, P118-25-01*	*P118-08-00*	*P118-09-00*	*P118-27-00*	*P118-00-00*	-	
Project Cost (Present Value Capital Cost, $ millions)		$43.6	$36.9	$14.7	$59.1	$66.2	$28.8	$15.0	$74.3	As provided in Halls Bayou Bundling Project List
# Persons Benefitted		1,618	938	3,600	1,551	2,109	2,422	43,011	26,789	Limited to residents of benefitted structures for now
Project Impact Scoring Category	**Max Points**									
Application Amount ($) per Person Benefitted	15	$26,947	$39,339	$4,083	$38,104	$31,389	$11,891	$349	$2,774	Using present value capital cost / # impacted persons
% of Jurisdiction Pop	10	0.04%	0.02%	0.08%	0.03%	0.05%	0.05%	0.93%	0.58%	HCFCD jurisdiction population represented as Harris County population (ACS, 2018).
Scoring Category	**Max Points**									
CCDI	10	10	10	10	10	10	10	10	10	County Composite Disaster Index (GLO-defined)
SoVI	10	8	8	8	10	10	8	8	8	Social Vulnerability Index
PCMV	10	8	8	8	8	8	8	8	8	Per Capita Market Value
LMI	20	20	20	20	20	20	20	20	20	Does / does not meet LMI National Objective
Local Plan	5	5	5	5	5	5	5	5	5	Assuming adoption by HCCC
Management Capacity	15	15	15	15	15	15	15	15	15	Assuming HCFCD in good standing on any existing CDBG contracts
Leverage	5	0	5	5	5	5	5	0	0	2018 Bond Table HCFCD Cost Share is at least 1% of Project Cost
Mitigation / Resiliency Measures	5	5	5	5	5	5	5	5	5	Assumed that this yes/no criterion will be met by HCFCD, but not yet defined in Action Plan. Pending application guides.
Total* (excluding Project Impact)	**105 (80)**	71	76	76	78	78	76	71	71	Not yet known how Project Impact metrics will be converted to scoring points.
Average Poverty Rate	**tiebreaker**	27.9%	24.6%	28.6%	20.6%	29.8%	26.3%	26.6%	26.6%	Average poverty rate in CDBG-eligible counties = 16.08%. (2017) Higher poverty rates given precedence as a tiebreaker.

**Applications that do not score a minimum of 65 points will only be considered after all applications scoring greater than this amount have been funded.*

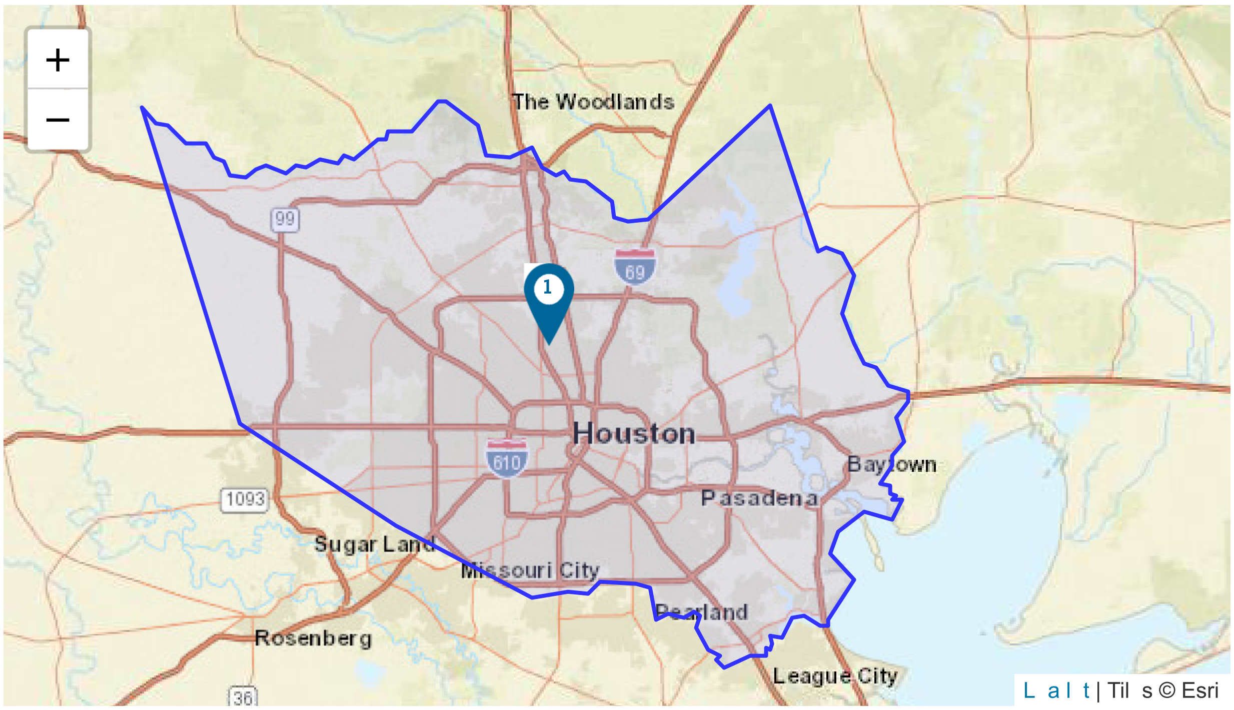
Appendix 5-4S:
P118-27-00 Drainage Improvements BCA Memorandum

Benefit-Cost Calculator

V.6.0 (Build 20221028.1600 | Release Notes)

Benefit-Cost Analysis

Project Name: P118-27-00 Conveyance and Detention Improvements



				Using 7% Discount Rate			Using 3% Discount Rate (For FY22 BRIC and FMA only)		
Map Marker ▲	Mitigation Title	Property Type	Hazard	Benefits (B)	Costs (C)	BCR (B/C)	Benefits (B)	Costs (C)	BCR (B/C)
1	Drainage Improvement @ 200 W Nellis Rd, Houston, Texas, 77037		DFA - Riverine Flood	$ 30,108,390	$ 19,953,832	1.51	$ 51,506,872	$ 23,679,032	2.18
TOTAL (SELECTED)				**$ 30,108,390**	**$ 19,953,832**	**1.51**	**$ 51,506,872**	**$ 23,679,032**	**2.18**
TOTAL				**$ 30,108,390**	**$ 19,953,832**	**1.51**	**$ 51,506,872**	**$ 23,679,032**	**2.18**

Property Configuration

Property Title:	Drainage Improvement @ 200 W Nellis Rd, Houston, Texas, 77037
Property Location:	77037, Harris, Texas
Property Coordinates:	29.880697005372824, -95.40030703665703
Hazard Type:	Riverine Flood
Mitigation Action Type:	Drainage Improvement
Property Type:	Residential Building
Analysis Method Type:	Professional Expected Damages

Cost Estimation
Drainage Improvement @ 200 W Nellis Rd, Houston, Texas, 77037

Project Useful Life (years):	50
Project Cost:	$15,644,128
Number of Maintenance Years:	50 Use Default:Yes
Annual Maintenance Cost:	$312,281

Comments

-

Project Useful Life:

Please see attached BCA Reference Guide for project type: Major Infrastructure (minor localized flood reduction projects).

-

Mitigation Project Cost:

Please see attached engineer's opinion of probable construction cost.

-

Annual Maintenance Cost:

Annual maintenance cost estimated as 6% of direct construction cost, per attached EPA Stormwater Best Management Practice whitepaper.

Damage Analysis Parameters - Damage Frequency Assessment
Drainage Improvement @ 200 W Nellis Rd, Houston, Texas, 77037

Year of Analysis was Conducted:	2022
Year Property was Built:	1966
Analysis Duration:	57 Use Default:Yes

Comments

-

Analysis Year:

This BCA analysis was performed in support of a FY22 Flood Mitigation Assistance grant application.

-

Year Built:

Harris County Appraisal District records were examined to determine date of neighborhood construction. Please see attached Harris County Appraisal District real property account information for representative homes within the project area.

Professional Expected Damages Before Mitigation

Drainage Improvement @ 200 W Nellis Rd, Houston, Texas, 77037

	OTHER	OPTIONAL DAMAGES			VOLUNTEER COSTS		TOTAL
Recurrence Interval (years)	Damages ($)	Structural	Contents	Displacement	Number of Volunteers	Number of Days	Damages ($)
10	0	5,086,975.5	4,880,292.84	642.44	0	0	9,967,911
50	0	17,309,926.43	15,695,681.44	127,002.91	0	0	33,132,611
100	0	21,311,511.08	19,311,737	232,243.44	0	0	40,855,492
500	0	31,818,958.7	31,874,094.18	788,720.31	0	0	64,481,773

Comments

-

Damages Before Mitigation:

Structural To calculate structural damages, building footprint GIS data was used to determine the square footage of flooded structures in all eight storm events examined (pre- and post-project 10-, 25-, 50-, and 100-year events). A FEMA-approved value of $100 per square foot was applied to the previously calculated square footage to estimate property value for each structure. Depth rasters from HEC-RAS were used to determine the maximum depth of floodwaters in the pre- and post-project conditions for all flooded structures for all eight storm events used in the analysis. A 6″ slab adjustment was used to estimate first finished floor for single family residential and commercial structures examined. A 24″ first finished floor adjustment was used to estimate first finished floor for mobile home structures. This adjustment likely underestimates damages and consequently, deflates the BCR. Many of the residential structures in the area appear to be elevated or on slabs less than 6″. US Army Corps of Engineers (USACE) Depth Damage Functions (DDF) published in the Final Report: Depth-Damage Relationships for Structure, Contents, and Vehicles and Contents-to-Structures Value Ratios (CSVR) in Support of the Donaldsonville to the Gulf, Louisiana, Feasiblity Study were used to estimate percentage of damage based on the depth of floodwaters relative to first finished floor elevations. Different DDF were used depending on the structure type (e.g. residential vs commercial). This percentage of damage was multiplied against the square-footage-estimated property value to estimate damages on a per-structure, per-event basis. Contents To calculate contents damages, building footprint GIS data was used to determine the square footage of flooded structures in all eight storm events examined (pre- and post-project 10-, 25-, 50-, and 100-year events). A FEMA-approved value of $100 per square foot was applied to the previously calculated square footage to estimate property value for each structure. Depth rasters from HEC-RAS were used to determine the maximum depth of floodwaters in the pre- and post-project conditions for all flooded structures for all eight storm events used in the analysis. A 6″ slab adjustment was used to estimate first finished floor for residential and commercial structures examined. A 24″ slab adjustment was used to estimate first finished floor for mobile home structures. This adjustment likely underestimates damages and consequently, deflates the BCR. Many of the residential structures in the area appear to be elevated or on slabs less than 6″. US Army Corps of Engineers (USACE) contents-specific Depth Damage Functions (DDF) were used to estimate percentage of structural damage based on the depth of floodwaters relative to first finished floor elevations. Different contents DDF were used depending on the structure type (e.g. residential vs commercial). The commercial DDF was based on the category of repairs and home use. This percentage of damage and content-to-structure value ratio was multiplied against the square-footage-estimated property value to estimate contents damages on a per-structure, per-event basis. Displacement There are too many residential structures (5,716) located within the project area to individually record the displacement benefits within the FEMA BCA toolkit. According to the U.S. General Services Administration FY 2023 Per Diem Rates for ZIP 77037, the maximum per diem in Harris County is $122. The FEMA Depth-Days curve estimates 45 days of displacement for every foot about the finished floor elevation. Depth rasters from HEC-RAS were used to determine the maximum depth of floodwaters in the pre- and post-project conditions for all flooded structures for all eight storm events used in the analysis. A 6″ slab adjustment was used to estimate first finished floor for all residential structures examined. This 6" adjustment likely underestimates damages and consequently, deflates the BCR. Many of the residential structures in the area appear to be elevated or on slabs less than 6". The maximum per diem of $122 was multiplied by the maximum depth of floodwaters minus the 6" slab adjustment times 45 to get the displacement benefits for each storm event. The reasoning behind this can be found in the Supplement to the Benefit-Cost Analysis Reference Guide on page 2-33.

Annualized Damages Before Mitigation

Drainage Improvement @ 200 W Nellis Rd, Houston, Texas, 77037

Annualized Recurrence Interval (years)	Damages and Losses ($)	Annualized Damages and Losses ($)
10	9,967,911	1,453,851
50	33,132,611	367,920
100	40,855,492	410,614
500	64,481,773	128,957
	Sum Damages and Losses ($)	Sum Annualized Damages and Losses ($)
	148,437,786	2,361,342

Professional Expected Damages After Mitigation

Drainage Improvement @ 200 W Nellis Rd, Houston, Texas, 77037

	OTHER	OPTIONAL DAMAGES			VOLUNTEER COSTS		TOTAL
Recurrence Interval (years)	Damages ($)	Structural	Contents	Displacement	Number of Volunteers	Number of Days	Damages ($)
10	0	322,697.18	226,139.88	0	0	0	548,837
50	0	8,595,856.4	8,720,527.97	83,648.45	0	0	17,400,033
100	0	11,616,983.33	11,757,788.65	148,463.68	0	0	23,523,236
500	0	19,813,169.69	20,449,310.94	520,298.63	0	0	40,782,779

Comments

-

Damages After Mitigation:

Structural To calculate structural damages, building footprint GIS data was used to determine the square footage of flooded structures in all eight storm events examined (pre- and post-project 10-, 25-, 50-, and 100-year events). A FEMA-approved value of $100 per square foot was applied to the previously calculated square footage to estimate property value for each structure. Depth rasters from HEC-RAS were used to determine the maximum depth of floodwaters in the pre- and post-project conditions for all flooded structures for all eight storm events used in the analysis. A 6″ slab adjustment was used to estimate first finished floor for single family residential and commercial structures examined. A 24″ first finished floor adjustment was used to estimate first finished floor for mobile home structures. This adjustment likely underestimates damages and consequently, deflates the BCR. Many of the residential structures in the area appear to be elevated or on slabs less than 6″. US Army Corps of Engineers (USACE) Depth Damage Functions (DDF) published in the Final Report: Depth-Damage Relationships for Structure, Contents, and Vehicles and Contents-to-Structures Value Ratios (CSVR) in Support of the Donaldsonville to the Gulf, Louisiana, Feasiblity Study were used to estimate percentage of damage based on the depth of floodwaters relative to first finished floor elevations. Different DDF were used depending on the structure type (e.g. residential vs commercial). This percentage of damage was multiplied against the square-footage-estimated property value to estimate damages on a per-structure, per-event basis. Contents To calculate contents damages, building footprint GIS data was used to determine the square footage of flooded structures in all eight storm events examined (pre- and post-project 10-, 25-, 50-, and 100-year events). A FEMA-approved value of $100 per square foot was applied to the previously calculated square footage to estimate property value for each structure. Depth rasters from HEC-RAS were used to determine the maximum depth of floodwaters in the pre- and post-project conditions for all flooded structures for all eight storm events used in the analysis. A 6″ slab adjustment was used to estimate first finished floor for residential and commercial structures examined. A 24″ slab adjustment was used to estimate first finished floor for mobile home structures. This adjustment likely underestimates damages and consequently, deflates the BCR. Many of the residential structures in the area appear to be elevated or on slabs less than 6″. US Army Corps of Engineers (USACE) contents-specific Depth Damage Functions (DDF) were used to estimate percentage of structural damage based on the depth of floodwaters relative to first finished floor elevations. Different contents DDF were used depending on the structure type (e.g. residential vs commercial). The commercial DDF was based on the category of repairs and home use. This percentage of damage and content-to-structure value ratio was multiplied against the square-footage-estimated property value to estimate contents damages on a per-structure, per-event basis. Displacement There are too many residential structures (5,716) located within the project area to individually record the displacement benefits within the FEMA BCA toolkit. According to the U.S. General Services Administration FY 2023 Per Diem Rates for ZIP 77037, the maximum per diem in Harris County is $122. The FEMA Depth-Days curve estimates 45 days of displacement for every foot about the finished floor elevation. Depth rasters from HEC-RAS were used to determine the maximum depth of floodwaters in the pre- and post-project conditions for all flooded structures for all eight storm events used in the analysis. A 6″ slab adjustment was used to estimate first finished floor for all residential structures

> examined. This 6” adjustment likely underestimates damages and consequently, deflates the BCR. Many of the residential structures in the area appear to be elevated or on slabs less than 6”. The maximum per diem of $122 was multiplied by the maximum depth of floodwaters minus the 6” slab adjustment times 45 to get the displacement benefits for each storm event. The reasoning behind this can be found in the Supplement to the Benefit-Cost Analysis Reference Guide on page 2-33.

Annualized Damages After Mitigation

Drainage Improvement @ 200 W Nellis Rd, Houston, Texas, 77037

Annualized Recurrence Interval (years)	Damages and Losses ($)	Annualized Damages and Losses ($)
10	548,837	247,222
50	17,400,033	202,313
100	23,523,236	247,786
500	40,782,779	81,561
	Sum Damages and Losses ($)	Sum Annualized Damages and Losses ($)
	82,254,885	778,882

Standard Benefits - Ecosystem Services

Drainage Improvement @ 200 W Nellis Rd, Houston, Texas, 77037

Total Project Area (acres):	13.6
Percentage of Urban Green Open Space:	100.00%
Percentage of Rural Green Open Space:	0.00%
Percentage of Riparian:	0.00%
Percentage of Coastal Wetlands:	0.00%
Percentage of Inland Wetlands:	0.00%
Percentage of Forests:	0.00%
Percentage of Coral Reefs:	0.00%
Percentage of Shellfish Reefs:	0.00%
Percentage of Beaches and Dunes:	0.00%
Expected Annual Ecosystem Services Benefits:	$211,358

Comments

-

Percent Urban Green Open Space:
According to the P118-27-00 Alternative Analysis Summary report, this area will be turned into a detention basin, so it is 100% green open space.

-

Total Project Area:
The project configuration includes a 13.6-acre detention pond. The entire area will be turned into a green open space detention basin. Please see the attached project area exhibit, including detention pond configuration.

Additional Benefits - Social
Drainage Improvement @ 200 W Nellis Rd, Houston, Texas, 77037

Number of Workers:	295
Expected Annual Social Benefits:	$5,352,368

Comments

-

Number of Residents:

The average household size within the Census Tract containing the preoject area, according to the American Community Survey S1101 Households and Families table, is 3.85. The total number of residential structures inside the project area is 1,118. In order to prevent the overestimation of residential structures, only one building per land parcel was counted. This brought the total number of residential structures on unique land parcels to 651. Based on these values, the total number of residents within the project area was estimated to be 2,506. This was calculated by multiplying the total number of residential structures in the project area on unique land parcels by the average household size. The total population of Census tract 2216, according to American Community Survey S0101 Age and Sex table is 9,403. The total number of people employed in Census tract 2216, according to DP03 Selected Economic Characteristics, is 3,866. This means that Census tract 2216 has an employment rate of 41%. This same employment rate was applied to the project area. The number of employed people in the project area was found to be 1,030. This was calculated by multiplying the employment rate by the total residents in the project area. This means that the number of working residents per household in the project area is 1.58. In order to be extremely conservative, the number of working residents per household was rounded down to 1.0. The number of residential structures in the project area with flooding is 401. The data from Census tract 2216 is gathered from the 2019 American Community Survey 5-Year Estimates Subject Tables.

-

Number of Workers:

The average household size within the Census Tract containing the preoject area, according to the American Community Survey S1101 Households and Families table, is 3.85. The total number of residential structures inside the project area is 1,118. In order to prevent the overestimation of residential structures, only one building per land parcel was counted. This brought the total number of residential structures on unique land parcels to 651. Based on these values, the total number of residents within the project area was estimated to be 2,506. This was calculated by multiplying the total number of residential structures in the project area on unique land parcels by the average household size. The total population of Census tract 2216, according to American Community Survey S0101 Age and Sex table is 9,403. The total number of people employed in Census tract 2216, according to DP03 Selected Economic Characteristics, is 3,866. This means that Census tract 2216 has an employment rate of 41%. This same employment rate was applied to the project area. The number of employed people in the project area was found to be 1,030. This was calculated by multiplying the employment rate by the total residents in the project area. This means that the number of working residents per household in the project area is 1.58. In order to be extremely conservative, the number of working residents per household was rounded down to 1.0. The number of residential structures in the project area with flooding is 401. The data from Census tract 2216 is gathered from the 2019 American Community Survey 5-Year Estimates Subject Tables.

Benefits-Costs Summary

Drainage Improvement @ 200 W Nellis Rd, Houston, Texas, 77037

Total Standard Mitigation Benefits:	$24,756,022
Total Social Benefits:	$5,352,368
Total Mitigation Project Benefits:	$30,108,390
Total Mitigation Project Cost:	$19,953,832
Benefit Cost Ratio - Standard:	1.24
Benefit Cost Ratio - Standard + Social:	1.51

Appendix 5-4T:
P118-26-00 Drainage Improvements BCA Memorandum

PLANNING

ENGINEERING

PROGRAM MANAGEMENT

memo

TEXAS
AUSTIN
COLLEGE STATION
CORPUS CHRISTI
DALLAS
FORT WORTH
FRISCO
HOUSTON
LAREDO
MONTGOMERY COUNTY
SAN ANTONIO
SAN MARCOS
WACO

CALIFORNIA
LOS ANGELES
ORANGE
SAN JOSE

FLORIDA
MIAMI

ILLINOIS
CHICAGO

MICHIGAN
FLINT
LANSING

OKLAHOMA
NORMAN

To: Gary Bezemek, P.E.

From: Tak Makino, CFM

Date: March 1, 2023

Subject: P118-26-00 Drainage Improvements
State Flood Plan BCA

Project Description

This BCA is for the project described as proposed drainage improvements along an unnamed tributary (HCFCD Unit No. P118-26-00) within Halls Bayou watershed. The Preliminary Engineering Report (PER) completed in 2019 by LAN evaluated and proposed project alternatives to improve local drainage problems. The location and the layout of the recommended improvements were established in coordination with Harris County Flood Control District. This BCA utilizes the PER for flood depths and the current 100% bid ready submittal (KCI, 2022) for cost estimates.

The project area is generally bounded by McFarland Road to the north, Sellers Road to the east, Halls Bayou to the south, and Sweetwater Lane to the west. The existing P118-26-00 channel consists of an open ditch section 1.1 miles in length and serves a contributing drainage area of 0.9 square miles.

The drainage improvements to P118-26-00 consists of approximately 119 acre-feet of total storage between two basins, replacement of the entire open channel with triple 9’x9’ RCBs, a dual 10’x10’ RCB connection between the two basins, and a flow restrictor on the downstream end to prevent adverse impacts on Halls Bayou due to the increased conveyance capacity of P118-26-00. The drainage improvements are designed to contain up to and including the 500-year storm event to reduce remove the floodplain from the maximum amount of structures and roadways in the service area.

The Texas Water Development Board (TWDB) requires each Flood Mitigation Project (FMP) included in a regional flood plan to have a benefit/cost analysis (BCA) performed. This memorandum documents to benefit cost analysis performed by LAN within the regional flood planning process.

Lockwood, Andrews
& Newnam, Inc.

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Benefit Cost Analysis

TWDB developed the Benefit-Cost Analysis (BCA) Input Tool to facilitate the calculation of flood mitigation benefits due to FMP. This tool receives input of existing and proposed conditions to determine expected benefits related to the construction of the FMP in question. The benefits considered in the analysis include the reduction in damages to residential structures, commercial structures, and social benefits. The BCA Input Tool was modified to handle the nearly 20,000 structures included in the analysis. The BCA Input Tool was used in conjunction with the Federal Emergency Management Agency (FEMA) BCA Toolkit v6.0.0. Social benefits used in the analysis were developed within the FMEA Benefit-Cost Calculator.

Structure Inventory

Two (2) datasets were used to obtain the information for Finished Floor Elevation (FFE), building footprint and building category.

- **Structure Inventory Dataset:** This information was obtained from Harris County Flood Control District (HCFCD). The FFE was obtained from this dataset.
- **Texas Buildings with SVI and Estimated Population (November 2021) –** This information was provided by TWDB for Regional Flood Planning. Building sizes and types were obtained from this dataset.

Project Schedule

The project is currently being designed. Construction is scheduled to commence between 2025-2027.

BCA Assumptions

For purposes of the BCA, project benefits are elimination of flooding damages to residential, commercial, and industrial structures. Based on the provided building types, structures were reclassified as either residential, commercial, industrial, or agricultural. Public buildings were reclassified as commercial structures. Buildings marked as "Vacant or Unknown" in the TWDB dataset were reclassified as agricultural buildings. Benefits were quantified by inputting structure FFE's and flood depths to the BCA_Pilot_v5 spreadsheet, provided by FNI.

Flood Damages

The flood depths for each structure within the study area was determined for the 50 percent, 10 percent, 1 percent, and 0.2 percent annual chance events. The flood hazard data was obtained from the PER, all hydrological and hydraulic analyses were completed by LAN. The structural flood damages are included in **Table 1**.

TABLE 1: PROJECT IMPACTS BY RECURRENCE INTERVAL

Flood Damages	2 - year storm		10 - year storm		100 - year storm		500 - year storm	
	Baseline	Project	Baseline	Project	Baseline	Project	Baseline	Project
Residential	$3,803,353	$100,637	$23,525,625	$9,020,612	$60,994,688	$36,845,004	$95,176,800	$64,887,362
Commercial	$186,123	$8,077	$6,564,047	$5,630,975	$17,232,262	$15,748,644	$42,706,537	$40,575,290
Total	$3,989,477	$108,714	$30,089,672	$14,651,587	$78,226,950	$52,593,648	$137,883,337	$105,462,652

Benefits

The damage estimates from the BCA_PILOT_v5 model were inputted to the FEMA BCA Calculator. The total benefit, discounted at 7 percent over the assumed 30-year project duration, is **$52,374,598** including **$73,516** in residual value from right-of-way acquisition and **$461,059** in environmental benefits from converting land to green space within one basin. These benefits include only include the mitigated damages to residential and commercial structures identified and no other additional mitigation.

Discounted Total Benefits: $52,374,598

Project Costs

According to the bid ready submittal, the overall cost to design and construct the project based on 2022 construction and Right-of-Way (ROW) costs. The features were assumed to have a useful life of 30 years. The total cost is **$19,151,213** including **$17,767,894** in construction costs, **$649,766** in utility relocation, and **$733,553** in ROW costs. The project construction cost used in the BCA includes Mobilization and Demobilization (5%). The annual maintenance cost is estimated at 4% of the construction cost: **$710,716**. Harris County Flood Control District will be responsible for long-term maintenance of Halls Bayou.

The adjusted project costs were input to the TWDB BCA Input Workbook v1.2 to calculate the project cost discounted by 7 percent over the construction period.

Discounted Total Costs: $22,385,161

Benefit Cost Ratio

Results from BCA Toolkit:	
Total Benefits from **FEMA** BCA Toolkit	$51,840,023
Other Benefits (Not Recreation)	$534,575
Recreation Benefits	$0
Discounted Total Costs from **TWDB** Spreadsheet	$22,385,161
Total Benefits	$52,374,598
Net Benefits	$29,989,438
Final BCR	**2.32**
Final BCR with Other Benefits	**2.34**

Appendix 5-4U:
Parker Road Drainage Improvements BCA Memorandum

PLANNING

ENGINEERING

PROGRAM MANAGEMENT

memo

TEXAS
AUSTIN
COLLEGE STATION
CORPUS CHRISTI
DALLAS
FORT WORTH
FRISCO
HOUSTON
LAREDO
MONTGOMERY COUNTY
SAN ANTONIO
SAN MARCOS
WACO

CALIFORNIA
LOS ANGELES
ORANGE
SAN JOSE

FLORIDA
MIAMI

ILLINOIS
CHICAGO

MICHIGAN
FLINT
LANSING

OKLAHOMA
NORMAN

To: Gary Bezemek, P.E.

From: Tak Makino, CFM

Date: March 1, 2023

Subject: Parker Road Detention Basin and Channel Improvements
State Flood Plan BCA

Project Description

This BCA is for the project described as "Parker Road Detention Basin" in the Halls Bayou Watershed Flood Risk Reduction Phasing Study (Phasing Study) prepared for Harris County Flood Control District by LAN. The Phasing Study completed in 2021 updated the 2013 Halls Ahead Study Vision Plan and developed a phasing strategy for identified bond projects. The concept for the Parker Road Detention Basin was refined and studied in a 2021 grant study performed by LAN in coordination with Harris County Flood Control District. This BCA is based on the models and cost estimates from the grant study.

The Parker Road Detention Basins are comprised of four basins identified as Northwest, Northeast, Southeast and Southwest. Combined, the basins provide approximately 602 acre-feet of storage. These basins are combined with channel improvements to help further reduce WSEs along Halls Bayou. At this location, the 500-year LOS channel improvements (300-foot-wide channel section) were able to be implemented for approximately one half-mile near the basins. Combined, the proposed improvements would require 68.2 acres of ROW acquisition, including the acquisition of 2 structures. The 100- and 500-year events show maximum depth reductions of up to 1.52 feet and 0.47 feet within Halls Bayou, respectively, compared to the Baseline Conditions model. There are no adverse impacts observed when compared to the Baseline Conditions water surface elevations.

The Texas Water Development Board (TWDB) requires each Flood Mitigation Project (FMP) included in a regional flood plan to have a benefit/cost analysis (BCA) performed. This memorandum documents to benefit cost analysis performed by LAN within the regional flood planning process.

Benefit Cost Analysis

TWDB developed the Benefit-Cost Analysis (BCA) Input Tool to facilitate the calculation of flood mitigation benefits due to FMP. This tool receives input of existing and proposed conditions to determine expected benefits related to the construction of the FMP in question. The benefits considered in the analysis include the reduction in damages to residential structures, commercial structures, and social benefits. The BCA Input Tool was modified to handle the nearly 20,000 structures included in the analysis. The BCA Input Tool was used in conjunction with the Federal Emergency Management Agency (FEMA) BCA Toolkit v6.0.0. Social benefits used in the analysis were developed within the FMEA Benefit-Cost Calculator.

Lockwood, Andrews
& Newnam, Inc.

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Suite 400
Houston, TX 77042
713.266.6900

lan-inc.com

Structure Inventory

Two (2) datasets were used to obtain the information for Finished Floor Elevation (FFE), building footprint and building category.

- **Structure Inventory Dataset:** This information was obtained from Harris County Flood Control District (HCFCD). The FFE was obtained from this dataset.
- **Texas Buildings with SVI and Estimated Population (November 2021) –** This information was provided by TWDB for Regional Flood Planning. Building sizes and types were obtained from this dataset.

Project Schedule

The project is currently being planned and will proceed to design phase. While currently this project has no start and end dates, this analysis assumes construction start and end dates of 2025-2027.

BCA Assumptions

For purposes of the BCA, project benefits are elimination of flooding damages to residential, commercial, and industrial structures. Based on the provided building types, structures were reclassified as either residential, commercial, industrial, or agricultural. Public buildings were reclassified as commercial structures. Buildings marked as "Vacant or Unknown" in the TWDB dataset were reclassified as agricultural buildings. Benefits were quantified by inputting structure FFE's and flood depths to the BCA_Pilot_v5 spreadsheet, provided by FNI.

Flood Damages

The flood depths for each structure within the study area was determined for the 4 percent, 2 percent, 1 percent, and 0.2 percent annual chance events. The flood hazard data was obtained from the grant study, all hydrological and hydraulic analyses were completed by LAN. The structural flood damages are included in **Table 1**.

Table 1: Project impacts by Recurrence Interval

Flood Damage	**25 - year storm**		**50 - year storm**		**100 - year storm**		**500 - year storm**	
	Baseline	Project	Baseline	Project	Baseline	Project	Baseline	Project
Residential	$231,599	$79,612	$2,731,144	$585,659	$7,699,598	$3,346,606	$24,192,647	$18,353,856
Commercial	$27,484	$13,217	$44,512	$32,242	$173,277	$1,004,168	$11,806,985	$11,317,761
Total	$259,083	$92,829	$2,775,657	$617,901	$7,872,875	$4,350,775	$35,999,632	$29,671,618

Benefits

The damage estimates from the BCA_PILOT_v5 model were inputted to the FEMA BCA Calculator. The total benefit, discounted at 7 percent over the assumed 30-year project duration, is **$7,403,120** including **$826,810** in residual value from right-of-way acquisition and **$5,348,287** in environmental benefits from converting land to green space within the basin. These benefits include only include the mitigated damages to residential and commercial structures identified and no other additional mitigation.

Discounted Total Benefits: $7,403,120

Project Costs

According to the grant study, the overall cost to design and construct the project based on 2021 construction and Right-of-Way (ROW) costs. The features were assumed to have a useful life of 30 years. The total cost is **$38,230,000** including **$26,310,000** in construction costs, **$3,670,000** in utility relocation, and **$8,250,000** in ROW costs. The project construction cost used in the BCA includes Engineering and Design (12%), Mobilization and Demobilization (5%), Construction Management (10%), and Contingency (30%). The annual maintenance cost is estimated at 4% of the construction cost: **$1,052,400**. Harris County Flood Control District will be responsible for long-term maintenance of Halls Bayou.

The adjusted project costs were input to the TWDB BCA Input Workbook v1.2 to calculate the project cost discounted by 7 percent over the construction period.

Discounted Total Costs: $41,217,563

Benefit Cost Ratio

Results from BCA Toolkit:	
Total Benefits from **FEMA** BCA Toolkit	$1,228,024
Other Benefits (Not Recreation)	$6,175,096
Recreation Benefits	$0
Discounted Total Costs from **TWDB** Spreadsheet	$41,217,563
Total Benefits	$7,403,120
Net Benefits	-$33,814,443
Final BCR	**0.03**
Final BCR with Recreation	**0.18**

Appendix 5-4V:
Upper South Mayde Creek BCA Memorandum

5engineering

Technical Memorandum

11200 Westheimer Rd. #353, Houston TX 77042 | 832-800-3483 | **U501-07 Technical Memorandum.docx**

February 24, 2023

To: Gary Bezemek, PE, HCFCD

From: 5engineering, LLC

Project: BCA

Job No.: 007A-002

Subject: BCA for U501-07

Introduction

Project Description & Location

The information presented is based on the report titled *Grand Parkway at Clay Stormwater Detention Basin U501-07-00-E001 Preliminary Engineering Report,* prepared by Midtown Engineers, dated June 2021. This project proposes multiple detention basins along South Mayde Creek (U101-00-00). The proposed area is along SH-99 north of Clay Road. The report recommends alternative 5. This alternative proposes three basins on the west side of SH-99 along South Mayde Creek. The objective of the proposed basins is to reduce flooding along South Mayde Creek, including reduced structural flooding, reduced roadway flooding, and reduce floodplain area acreage downstream. Some peak flows increased near SH99, but overall flood risk was reduced by lowering the water surface elevations in the channel.

Alternative 5 was recommended in the report. The report also indicates that these phases have no adverse impacts (pg. 18). This corresponds to the following HEC-RAS model files:

HEC-RAS Project File Name: HDR_SMC_GrandParkway.prj

Frequency	Existing Plan	Existing Geometry and Flow
10 - year	HDR_SMCGrandParkway.p01 (HDR_ExistingConditions_10PCT)	HDR_SMCGrandParkway.g01 (HDR_ExistingConditions)
		HDR_SMCGrandParkway.u01 (HDR_10PCT)
100 - year	HDR_SMCGrandParkway.p03 (HDR_ExistingConditions_1PCT)	HDR_SMCGrandParkway.g01 (HDR_ExistingConditions)
		HDR_SMCGrandParkway.u03 (HDR_1PCT)
500 - year	HDR_SMCGrandParkway.p04 (HDR_ExistingConditions_10PCT)	HDR_SMCGrandParkway.g01 (HDR_ExistingConditions)
		HDR_SMCGrandParkway.u04 (HDR_500PCT)
	Proposed Plan	**Proposed Geometry and Flow**
10 - year	HDR_SMCGrandParkway.p21 (HDR_Alternative-5_10PCT)	HDR_SMCGrandParkway.g06 (HDR_Alternative-5)

		HDR_SMCGrandParkway.u01 (HDR_10PCT)
100 - year	HDR_SMCGrandParkway.p23 (HDR_Alternative-5_1PCT)	HDR_SMCGrandParkway.g06 (HDR_Alternative-5)
		HDR_SMCGrandParkway.u03 (HDR_1PCT)
500 - year	HDR_SMCGrandParkway.p24 (HDR_Alternative-5_0.2PCT)	HDR_SMCGrandParkway.g06 (HDR_Alternative-5)
		HDR_SMCGrandParkway.u04 (HDR_500PCT)

Structural Inventory

Structural Inventory datasets were created using three data sets:

- Houston-Galveston Area Council (HGAC) Land use
- Harris County Flood Control District (HCFCD) building footprints
- 2018 LiDAR

These data sets were joined using ArcGIS and used to estimate ground elevation at each structure. The FNI provided BCA Pilot v5 spreadsheet assumes the finished floor elevation (FFE) to be 6" above LiDAR. Aerial imagery and the HGAC Land use was used to categorize building types.

Project Schedule

Information on project schedule wasn't available within the provided PER. The project was assumed to be designed and delivered over a 4-year period beginning in 2026.

Project Costs

The total construction cost alternative 5 is expected to be $11,436,516. HCFCD has already acquired the necessary ROW for the proposed basins.

Project costs estimated in June 2021 were adjusted to September 2020 dollars using a factor of 0.96 taken from the construction cost index from Engineering News-Record. The adjusted cost is $10,979,055.

Operation and maintenance costs were not available within the provided PER. A conservative value of $100 per acre was assumed for the proposed 25 acres.

The adjusted project costs were input into the TWDB BCA Input Workbook v1.2 to calculate the project cost discounted by 7 percent over the 4-year construction period. The discounted cost of $7,863,795 is used in the benefit cost ratio calculation.

BCA Assumptions

Project benefits are considered to be the reduction of flooding damages to residential, commercial, and industrial structures. These benefits were quantified by comparing without the project and with the project conditions in the 10, 100, and 500-year frequencies. Benefits were quantified using the BCA Pilot v5 spreadsheet.

Benefit Summary

Benefits (Non-Discounted)

	10 - year storm		100 - year storm		500 - year storm	
Project Impacts by Recurrence Interval	Baseline	Project	Baseline	Project	Baseline	Project
Residential Flood Damage	$4,608,028	$4,543,931	$15,915,949	$13,857,118	$58,906,709	$56,628,624
Commercial Flood Damage	$355,197	$0	$450,041	$435,855	$1,711,649	$1,686,854
Total Damages	$4,963,226	$4,543,931	$16,365,990	$14,292,973	$60,618,359	$58,315,478
Net Benefit by Storm		**$419,294**		**$2,073,017**		**$2,302,881**

Discounted Benefits

The damage estimates from the FNI Provided BCA Pilot were entered into the FEMA BCA Calculator. Total benefits discounted at 7 percent over the project's assumed lifetime of 30 years are $1,383,087.

Benefit Cost Ratio

Discounted Project Benefits (FEMA BCA Toolkit)	$449,120
Total Benefits	$449,120
Discounted Project Cost	$7,863,795
Final BCR	**0.18**

Appendix 5-4W:
Little York Detention Basin BCA Memorandum

Technical Memorandum

11200 Westheimer Rd. #353, Houston TX 77042 | 832-800-3483 | **U500-01 Technical Memorandum.docx**

February 24, 2023

To: **Gary Bezemek, PE, HCFCD** **From:** **5engineering, LLC**

Project: **BCA** **Job No.:** **007A-002**

Subject: **BCA for U500-01**

Introduction

Project Description & Location

The information presented is based on the report titled *Drainage Impact Analysis for U500-01-00-E001 Regional Stormwater Detention Basin Along Langham Creek (U100-00-00),* prepared by Freese and Nichols, dated January 9th, 2020. This proposed project consists of 3 detention pond cells located along Langham Creek north of West Little York, and west of North Highway 6 within the Addicks Reservoir Watershed. These detention ponds will provide regional detention volume to mitigate the higher peak discharges along Langham Creek associated with the expected new developments. Harris County Flood Control District (HCFCD) currently has ownership of two of the three tracts. At the time of the report, a property exchange was underway for the remaining tract with Cypress-Fairbanks Independent School District.

The report also indicates the proposed detention ponds did not result in any impacts to water elevations along Langham Creek (pg. ES-2). This corresponds to the following HEC-RAS model files:

HEC-RAS Project File Name: U500-001-00-E001.prj

Frequency	Existing Plan	Existing Geometry and Flow
2 - year	U100-00-00.p25 (002-yr_Rev_existing_U500)	U100-00-00.g12 (Revised_Existing_U500)
		U100-00-00.u18 (002_YR_Rev_Exist)
10 - year	U100-00-00.p21 (010-yr_Rev_existing_U500)	U100-00-00.g12 (Revised_Existing_U500)
		U100-00-00.u17 (010_YR_Rev_Exist)
100 - year	U100-00-00.p17 (100-yr_Rev_existing_U500)	U100-00-00.g12 (Revised_Existing_U500)
		U100-00-00.u01 (100_YR_Rev_Exist)

<table>
<tr><th></th><th>Proposed Plan</th><th>Proposed Geometry and Flow</th></tr>
<tr><td rowspan="2">2 - year</td><td rowspan="2">U100-00-00.p74 (002-yr_FINAL Proposed U500)</td><td>U100-00-00.g62 (ED_U500_ExtendedCell2Vol)</td></tr>
<tr><td>U100-00-00.u22 (002_YR_Prop_U500wEXTCell2)</td></tr>
<tr><td rowspan="2">10 - year</td><td rowspan="2">U100-00-00.p73 (010-yr_FINAL Proposed U500)</td><td>U100-00-00.g62 (ED_U500_ExtendedCell2Vol)</td></tr>
<tr><td>U100-00-00.u23 (002_YR_Prop_U500wEXTCell2)</td></tr>
<tr><td rowspan="2">100 - year</td><td rowspan="2">U100-00-00.p72 (100-yr_FINAL Proposed U500)</td><td>U100-00-00.g62 (ED_U500_ExtendedCell2Vol)</td></tr>
<tr><td>U100-00-00.u21 (002_YR_Prop_U500wEXTCell2)</td></tr>
</table>

Structural Inventory

Structural Inventory datasets were created using three data sets:

- Houston-Galveston Area Council (HGAC) Land use
- HCFCD building footprints
- 2018 LiDAR

These data sets were joined using ArcGIS and used to estimate ground elevation at each structure. The FNI provided BCA Pilot v5 spreadsheet assumes the finished floor elevation (FFE) to be 6" above LiDAR. Aerial imagery and the HGAC Land use was used to categorize building types.

Project Schedule

Information on project schedule wasn't available within the provided PER. The project was assumed to be designed and delivered over a 4-year period beginning in 2026.

Project Costs

The total construction cost is expected to be $2,552,707.84.

Project costs estimated in February 2020 were adjusted to September 2020 dollars using a factor of 1.01 taken from the construction cost index from Engineering News-Record. The adjusted cost is $2,578,235.

Operation and maintenance costs were not available within the provided PER. It was assumed the only new O&M costs would be for the new 3 acre tract. A conservative value of $100 per acre was assumed for the acquired tract.

The adjusted project costs were input into the TWDB BCA Input Workbook v1.2 to calculate the project cost discounted by 7 percent over the 4-year construction period. The discounted cost of $1,846,846 is used in the benefit cost ratio calculation.

BCA Assumptions

Project benefits are considered to be the reduction of flooding damages to residential, commercial, and industrial structures. These benefits were quantified by comparing without the project and with the project conditions in the 2, 10, and 100-year frequencies. Benefits were quantified using the BCA Pilot v5 spreadsheet.

Benefit Summary

Benefits (Non-Discounted)

	2 - year storm		10 - year storm		100 - year storm	
Project Impacts by Recurrence Interval	Baseline	Project	Baseline	Project	Baseline	Project
Residential Flood Damage	$0	$0	$0	$0	$4,445,835	$3,710,786
Commercial Flood Damage	$0	$0	$0	$0	$0	$0
Total Damages	$0	$0	$0	$0	$4,445,835	$3,710,786
Net Benefit by Storm		**$0**		**$0**		**$735,049**

Discounted Benefits

The damage estimates from the BCA Pilot v5 spreadsheet were entered into the FEMA BCA Calculator. Total benefits discounted at 7 percent over the project's assumed lifetime of 30 years are $91,219.

Benefit Cost Ratio

Discounted Project Benefits (FEMA BCA Toolkit)	$91,219
Total Benefits	$91,219
Discounted Project Cost	$1,846,846
Final BCR	**0.05**

Appendix 5-4X:
Hahl North BCA Memorandum

PLANNING

ENGINEERING

PROGRAM MANAGEMENT

memo

TEXAS
AUSTIN
COLLEGE STATION
CORPUS CHRISTI
DALLAS
FORT WORTH
FRISCO
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MONTGOMERY COUNTY
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SAN MARCOS
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ORANGE
SAN JOSE

FLORIDA
MIAMI

ILLINOIS
CHICAGO

MICHIGAN
FLINT
LANSING

OKLAHOMA
NORMAN

To: Gary Bezemek, P.E.

From: Tak Makino, CFM

Date: March 1, 2023

Subject: Hahl North Detention Basin and Channel Improvements
State Flood Plan BCA

Project Description

This BCA is for the project described as “Hahl North Detention Basin” in the Halls Bayou Watershed Flood Risk Reduction Phasing Study (Phasing Study) prepared for Harris County Flood Control District by LAN. The Phasing Study completed in 2021 updated the 2013 Halls Ahead Study Vision Plan and developed a phasing strategy for identified bond projects. The concept for the Hahl North Basin was refined and studied in a 2021 grant study performed by LAN in coordination with Harris County Flood Control District. This BCA is based on the models and cost estimates from the grant study.

The Hahl North Basin is a proposed dry-bottom detention basin bound to the east by P118-21-00, to the west by Hardy Toll Road, to the north by Hill Road, and to the south by Halls Bayou. The total proposed usable area is approximately 37 acres and would require ROW acquisition for the whole area. The basin provides approximately 311 acre-feet of storage. Proposed channel improvements extend roughly 1000 feet. The improvements are minimal: approximately 20-foot channel widening on the north bank was the most that could be added without introducing impacts downstream. The 100- and 500-year events show maximum depth reductions of up to 0.2 feet and 0.1 feet just downstream of Hardy Toll Road.

The Texas Water Development Board (TWDB) requires each Flood Mitigation Project (FMP) included in a regional flood plan to have a benefit/cost analysis (BCA) performed. This memorandum documents to benefit cost analysis performed by LAN within the regional flood planning process.

Benefit Cost Analysis

TWDB developed the Benefit-Cost Analysis (BCA) Input Tool to facilitate the calculation of flood mitigation benefits due to FMP. This tool receives input of existing and proposed conditions to determine expected benefits related to the construction of the FMP in question. The benefits considered in the analysis include the reduction in damages to residential structures, commercial structures, and social benefits. The BCA Input Tool was modified to handle the nearly 20,000 structures included in the analysis. The BCA Input Tool was used in conjunction with the Federal Emergency Management Agency (FEMA) BCA Toolkit v6.0.0. Social benefits used in the analysis were developed within the FMEA Benefit-Cost Calculator.

Lockwood, Andrews
& Newnam, Inc.

A LEO A DALY COMPANY

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Suite 400
Houston, TX 77042
713.266.6900

lan-inc.com

Structure Inventory

Two (2) datasets were used to obtain the information for Finished Floor Elevation (FFE), building footprint and building category.

- **Structure Inventory Dataset:** This information was obtained from Harris County Flood Control District (HCFCD). The FFE was obtained from this dataset.
- **Texas Buildings with SVI and Estimated Population (November 2021) –** This information was provided by TWDB for Regional Flood Planning. Building sizes and types were obtained from this dataset.

Project Schedule

The project is currently being planned and will proceed to design phase. While currently this project has no start and end dates, this analysis assumes construction start and end dates of 2026-2027.

BCA Assumptions

For purposes of the BCA, project benefits are elimination of flooding damages to residential, commercial, and industrial structures. Based on the provided building types, structures were reclassified as either residential, commercial, industrial, or agricultural. Public buildings were reclassified as commercial structures. Buildings marked as "Vacant or Unknown" in the TWDB dataset were reclassified as agricultural buildings. Benefits were quantified by inputting structure FFE's and flood depths to the BCA_Pilot_v5 spreadsheet, provided by FNI.

Flood Damages

The flood depths for each structure within the study area was determined for the 10 percent, 2 percent, 1 percent, and 0.2 percent annual chance events. The flood hazard data was obtained from the grant study, all hydrological and hydraulic analyses were completed by LAN. The structural flood damages are included in **Table 1**.

TABLE 1: PROJECT IMPACTS BY RECURRENCE INTERVAL

Flood Damage	**10 - year storm**		**50 - year storm**		**100 - year storm**		**500 - year storm**	
	Baseline	Project	Baseline	Project	Baseline	Project	Baseline	Project
Residential	$40,609,166	$36,579,444	$149,621,744	$143,690,782	$228,556,407	$223,089,835	$473,561,570	$471,164,850
Commercial	$17,222,943	$16,079,822	$33,583,412	$32,700,354	$40,881,209	$40,218,494	$76,919,505	$76,190,942
Total	$57,832,108	$52,659,266	$183,205,155	$176,391,137	$269,437,617	$263,308,328	$550,481,075	$547,355,792

Benefits

The damage estimates from the BCA_PILOT_v5 model were inputted to the FEMA BCA Calculator. The total benefit, discounted at 7 percent over the assumed 30-year project duration, is **$7,657,359** including **$2,796,120** in residual value from right-of-way acquisition and **$3,411,838** in environmental benefits from converting land to green space within the basin. These benefits include only include the mitigated damages to residential and commercial structures identified and no other additional mitigation.

Discounted Total Benefits: $7,657,359

Project Costs

According to the grant study, the overall cost to design and construct the project based on 2021 construction and Right-of-Way (ROW) costs. The features were assumed to have a useful life of 30 years. The total cost is **$40,780,000** including **$12,030,000** in construction costs, **$850,000** in utility relocation, and **$27,900,000** in ROW costs. The project construction cost used in the BCA includes Engineering and Design (12%), Mobilization and Demobilization (5%), Construction Management (10%), and Contingency (30%). The annual maintenance cost is estimated at 4% of the construction cost: **$481,200**. Harris County Flood Control District will be responsible for long-term maintenance of Halls Bayou.

The adjusted project costs were input to the TWDB BCA Input Workbook v1.2 to calculate the project cost discounted by 7 percent over the construction period.

Discounted Total Costs: **$36,755,170**

Benefit Cost Ratio

Results from BCA Toolkit:	
Total Benefits from **FEMA** BCA Toolkit	$1,449,401
Other Benefits (Not Recreation)	$6,207,958
Recreation Benefits	$0
Discounted Total Costs from **TWDB** Spreadsheet	$36,755,170
Total Benefits	$7,657,359
Net Benefits	-$29,097,812
Final BCR	**0.04**
Final BCR with Other Benefits	**0.21**

Appendix 5-4Y:
Cypress Creek Watershed Regional Drainage Plan BCA Memorandum

TECHNICAL MEMORANDUM

To: Gary Bezemek, PE
Harris County Flood Control District – Planning Department

From: Mujahid Chandoo, PE

Date: February 10, 2023

Subject: Cypress Creek Watershed Major Tributaries Regional Drainage Plan Update (K100-00-00-P005) – Benefit Cost Analysis (BCA)

Project Description

This BCA is for the project described as "Alternative 1" in the Cypress Creek Watershed, Major Tributaries Regional Drainage Plan Update (HCFCD Project ID: K100-00-00-005)" by Michael Baker International. The location and the layout of the recommended detention basins for were established in coordination with HCFCD.

Alternative 1 recommends the construction of two detention basins. The existing HCFCD detention basin K500-01-00 at the confluence of Cypress Creek and Little Cypress Creek has a current area of 35 acres with 531 ac-ft of capacity. An expansion of the basin to 411 acres with a capacity of 9,336 ac-ft was modeled. The proposed (new) Stuebner-Airline detention basin is located downstream of Stuebner-Airline Road and has a proposed area of 142 ac with 4,576 ac-ft capacity. A comparison of proposed Alternative 1 with the Baseline (existing) model resulted in a maximum reduction in WSEL of 1.00 ft between Stuebner-Airline Road and Kuykendahl Road. The average reduction in peak flow and WSEL within the study limits is 400 cfs and 0.43 ft respectively. The resulting difference in flows and WSEL at key locations is presented below:

Location	Baseline Condition		Alternative 1		Difference	
	Flow (cfs)	WSEL (ft)	Flow (cfs)	WSEL (ft)	Flow (cfs)	WSEL (ft)
I-45	22,466.03	96.42	21,591.55	96.36	-874.48	-0.06
Kuykendahl Road	21,524.57	104.33	21,035.63	104.07	-488.94	-0.26
Stuebner-Airline Road	18,978.98	111.74	17,213.81	110.76	-1,765.17	-0.98
Champions Forest Drive	14,072.46	114.43	13,871.58	113.57	-200.88	-0.86
Cypresswood Drive	17,812.34	118.4	17,059.21	117.82	-753.13	-0.58
Cutten Road	15,910.16	119.86	15,654.71	119.32	-255.45	-0.54
SH249	20,673.94	122.57	19,308.4	122.08	-1,365.54	-0.49
Jones Road	14,043.1	124.82	13,715.12	124.34	-327.98	-0.48
Cypresswood Drive	14,715.02	126.22	14,352.88	125.76	-362.14	-0.46
Grant Road	8,061.88	129.02	8,118.23	128.62	56.35	-0.4
N. Eldridge Parkway	15,738.79	130.38	16,232.56	130.07	493.77	-0.31
Huffmeister Road	2,485.63	134.02	2,763.97	133.41	278.34	-0.61
Telge Road	7,648.93	136.73	8,339.05	136.7	690.12	-0.03
Barker Cypress Road	10,023.05	140.93	10,088.56	140.92	65.51	-0.01
US 290	7,476.91	141.4	7,477.57	141.39	0.66	-0.01

A comparison of the finished floor elevation (FFE) in the HCFCD structure inventory database and the resulting Alternative 1 WSEL was performed to identify structures removed from the floodplain. From this analysis, a preliminary cost-benefit of the project was prepared based on the structures removed from the floodplain and summarized as follows:

Scenario	Structures in Floodplain	Flooded Structures * (FFL < WSEL)	Value of Structures
Baseline Condition	7,094	4,592	$1,765,003,595
Alternative-1	6,267	4,073	$1,578,716,999
Structures Removed	827	519	$186,286,596

Alternative 1 Project Cost

The preliminary planning level cost estimate for Alternative 1 is summarized as follows:

Item	Unit	Quantity	Unit Cost ($)	Cost ($)
Clearing and Grubbing	Acre	554	2,000	1,108,000
Excavation and Haul	Ac-Ft	13,911	15,000	208,665,000
Bridge Installation	S.F.	0	100	0
Culvert Installation	S.F.	0	50	0
Drop/Control Structure			10% Excavation	20,866,500
Right of Way	Parcels	51	330,836	16,872,636
Seeding and Mulching	Acre	554	2,000	1,108,000
Sub Total				248,620,136
Contingencies (25%)				62,155,034
Total Construction Cost				310,775,170
Engineering and Administration (10%)				31,077,517
Total				**$ 341,852,687**

Structure Inventory

Two (2) datasets were used to obtain the information for Finished Floor Elevation (FFE), building footprint and building category.

- **Structure Inventory Dataset**: This information was obtained from Harris County Flood Control District (HCFCD). The FFE was obtained from this dataset.
- **National Structure Inventory (NSI):** The building (structure type) category (i.e. residential commercial and industrial) and building footprint (sq. ft) was obtained with this dataset.

Using ArcGIS these datasets were joined together using the parcel information.

Project Schedule

The project is expected to be planned, designed and delivered over a ten-year period beginning in 2026.

Adjusted Alternative 1 Project Cost Estimate

Project costs estimated in February 2020 were adjusted to September 2020 dollars using a factor of 1.01 as follows:

Cost Categories	2020 Dollars*
Engineering and Design	$31.39 million
Right of Way	$17.04 million
Construction (including contingency)	$296.90 million
Total Project Cost	**$345.33 million**

* - Updated from February 2020 cost estimate (Michael Baker International)

Discounted Project Cost

The adjusted project costs were input to the TWDB BCA Input Workbook v1.2 to calculate the project cost discounted by 7 percent over the 10-year construction period the discounted cost of $215.9 million is used to calculate the benefit cost ratio.

BCA Assumptions

For purposes of the BCA, project benefits are elimination of flooding damages to residential, commercial, and industrial structures. Benefits were quantified by inputting structure FFE's and flood depths to the BCA_Pilot_v5, provided by FNI. The output compares the baseline structure damages without the project to the project conditions in the 10-, 100- and 500-year storm scenarios:

Benefits Summary (non-discounted)

	500 - year storm		100 - year storm		10 - year storm	
	Baseline	Project	Baseline	Project	Baseline	Project
Residential Flood Damage	$901,158,027	$781,914,131	$492,294,251	$416,792,155	$40,203,986	$21,089,781
Commercial Flood Damage	$109,587,562	$107,638,418	$45,226,080	$21,882,187	$1,788,100	$1,978,759
Industrial Damages	$68,836,093	$56,339,650	$11,723,085	$8,894,150	$1,276,145	$0
Total Damages	$1,079,581,682	$945,892,199	$549,243,416	$447,568,492	$43,268,230	$23,068,541
Net Benefits		**$133,689,483**		**$101,674,924**		**$20,199,6870**

Total Net Benefits: $255,564,096

Discounted Benefits

The damage estimates from the BCA_PILOT_v5 model were inputted to the FEMA BCA Calculator. The total benefit, discounted at 7 percent over the assumed 30-year project duration, is $83,564,295 including $928,896 in residual value from right-of-way acquisition. These benefits include only include the mitigated damages to residential, commercial. and industrial structures identified and no other additional mitigation.

Benefit Cost Ratio

Discounted Project Benefits (damages calculated in FEMA BCA toolkit)	$83,564,295
Discount Residual Value (ROW)	$928,896
Total Benefits	$84,493,191
Discounted Project Cost	$215,879,680
Final BCR	**0.391**

Appendix 5-4Z:
South Mayde Creek BCA Memorandum

Assumptions for Mayde Creek - 063000315

TO: San Jacinto Regional Flood Planning Group

CC: Harris County Flood Control District

Texas Water Development Board

FROM: Judith Lamptey

SUBJECT: Lower South Mayde Creek Conveyance Improvements Benefit-Cost Analysis

DATE: 03/10/2023

PROJECT: San Jacinto Regional Flood Plan

Data Collection

- Texas Buildings with SVI and Estimated Population (November 2021) from the TWDB Datahub
- Land Parcels from the TWDB Datahub
- Waster Surface Elevation Raster
- Terrain
- Capital and Operation & Maintenance costs
- Project Lifespan

Tools

- TWDB Benefit-Cost Analysis (BCA) Input Tool
- FNI Adapted TWDBE BCA Input Tool
- FEMA BCA Toolkit

Data Processing

A residential threshold was in place to assure that the dataset has no extraneous buildings, such as garages and sheds which can skew the BCA's result. The Texas buildings are categories in Simp type that vary from public, residential, commercial, and industrial. Removing the extraneous building was performed by defining query for residential property under 500sq-ft in GIS, then inspected before deleting it from the dataset.

Extracting Damage Depths

Due to the lack of information for the Finished Floor Elevation, the initial assumption was that the homes were elevated 0.5ft from the terrain. the Water Surface Elevations (WSE) were used to access the damage depth. A new attribute field was added to the building inventory to generate the area of each structure before using the GIS tool, features to point to convert all the structures to points

Assumptions

All critical facilities, per FEMA BCA toolkit instruction, were to have a separate Mitigation Action from commercial property. Consequently, a new tab was added the FNI Adapted TWDBE BCA Input Tool spreadsheet. All critical Infrastructure were treated as school.

1. FFE assumed to be 6" above terrain. This can be varied spatially if regions are drawn in GIS and each structure has an associated value.

2. All structures were assumed to be 1 story.

3. Public Buildings were treated as commercial buildings.

4. Vacant or Unknown Buildings were treated as Agricultural Buildings and use the lowest structure value in TWDB spreadsheet.

5. Critical Infrastructures were treated as schools.

Results

Table 1. Total Number of Structure types in Mayde's Creek Benefit Cost Analysis

Agricultural	**5**
Correctional Facility	5
Commercial	**244**
Fast Food	244
Critical Infrastructure	**34**
Schools	34
Industrial	**61**
Industrial - Light	61
Public	**118**
Fast Food	118
Residential	**9996**
Average Home	2854
Large Home	6980
Small Home	162
Vacant or Unknown	**8**
Correctional Facility	8

Table 2. ***Mary's Creek Impact by Recurrence Intervals from Texas Water Development Board.***

	50 - year storm		**100 - year storm**		**500 - year storm**	
Project Impacts by Recurrence Interval	**Baseline**	**Project**	**Baseline2**	**Project2**	**Baseline3**	**Project3**
Residential Flood Damage	$8,719,333	-	$25,930,237	$405,695	$384,495,433	$55,228,493

Commercial Flood Damage	$1,025,353	$514,945	$1,216,516	$802,053	$13,257,654	$1,196,141
Critical Infrastructure	$393,107	$316,591	$417,213	$360,128	$3,170,805	$634,437
Total	$10,137,793	$831,536	$27,563,966	$1,567,876	$400,923,892	$57,059,071

Table 3. Mary's Creek Impact by Recurrence Intervals from Texas Water Development Board adapted Spreadsheet.

	50 - year storm		**100 - year storm**		**500 - year storm**	
Project Impacts by Recurrence Interval	Baseline	Project	Baseline2	Project2	Baseline	Project
Residential Flood Damage	$8,548,113	$0	$25,421,098	$397,728	$376,945,157	$54,143,980
Commercial Flood Damage	$1,358,989	$821,424	$1,521,614	$1,146,438	$16,096,705	$1,800,335
Flooded Streets from TWDB Spreadsheet	$0	$0	$0	$0	$0	$0
Utility Impacts from TWDB Spreadsheet	$0	$0	$0	$0	$0	$0
Agricultural Losses from TWDB Spreadsheet	$0	$0	$0	$0	$0	$0
Low Water Crossing Damages from TWDB Spreadsheet	$0	$0	$0	$0	$0	$0
	$9,907,102	$821,424	$26,942,713	$1,544,167	$393,041,862	$55,944,315

Other Project Impacts	Benefits
Water Supply Benefits from TWDB Spreadsheet	$0
Environmental Benefits from TWDB Spreadsheet	$0
Residual Value of Investment from TWDB Spreadsheet	$0
Recreational Benefits from TWDB Spreadsheet	$0

Table 4.Summary of Benefit Cost Analysis from Adapter Spreadsheet

Input Into BCA Toolkit

Project Useful Life	**30**	**years**

Event Damages	**Baseline**	**Project**
50 - year storm	**$9,907,102**	**$821,424**
100 - year storm	**$26,942,713**	**$1,544,167**

500 - year storm	$393,041,862	$55,944,315
Results from BCA Toolkit:		
Total Benefits from BCA Toolkit	$20,277,328	
Other Benefits (Not Recreation)	$0	
Recreation Benefits	$0	
Discounted Total Costs from TWDB Spreadsheet	$27,817,750	
Net Benefits	$20,277,328	
Net Benefits with Recreation	$20,277,328	
Final BCR	**0.73**	
Final BCR with Recreation	**0.73**	

Appendix 5-4AA:
White Oak Bayou – Woodland Trails BCA Memorandum

TORRES & ASSOCIATES, LLC
ENGINEERS | SCIENTISTS | PROFESSIONALS

MEMORANDUM

DATE: February 28th, 2023

TO: San Jacinto Regional Flood Planning Group

CC: Harris County Flood Control District; Texas Water Development Board

FROM: Evan Adrian, PE, CFM, ENV SP; Jacob Torres, PhD, PE, CFM, D.WRE; Cristian Ayala, EIT

PROJECT NO.: 10-220120-00

PROJECT: TWDB San Jacinto Regional Flood Plan

SUBJECT: White Oak Bayou - Woodland Trails Stormwater Detention Basin Project Benefit-Cost Analysis

The evaluation for the Woodlands Trails Stormwater Detention Basin was conducted in 2021 as part of the Final Engineering Report for the White Oak Bayou Watershed by CobbFendley prepared for Harris County Flood Control District (HCFCD). The proposed project objective is to reduce the existing flood risk along the White Oak Bayou mainstem by lowering peak flows and water surface elevations. Various alternatives were analyzed in terms of flood risk reduction, cost, environmental benefits, water quality, utility conflicts, maintenance requirements, aesthetics, wildlife habitat, and constructability to determine the most cost-effective alternative for design and implementation. Ultimately, the "Oxbow Alternative" was selected as the alternative best meeting the project objectives and for its constructability benefits. The preliminary engineering report is included as **Appendix 1**.

The Texas Water Development Board (TWDB) requires each Flood Mitigation Project (FMP) included in a regional flood plan to have a benefit/cost analysis (BCA) performed. The final engineering report prepared by CobbFendley did not include a BCA. This memorandum documents a benefit cost analysis performed for the Woodland Trails Stormwater Detention Basin by Torres and Associates within the regional flood planning process.

Benefit Cost Analysis Methodology

TWDB developed the Benefit-Cost Analysis (BCA) Input Tool to facilitate the calculation of flood mitigation benefits due to FMP. The TWDB BCA Input Tool is provided as **Appendix 2**. This tool receives input of existing and proposed conditions to determine expected benefits related to the construction of the FMP in question. The benefits considered in the analysis include the reduction in damages to residential structures, commercial structures, and social benefits. The BCA Input Tool was modified to handle the nearly 20,000 structures included in the analysis. The modified BCA Input Tool is provided as **Appendix 3**. The BCA Input Tool was used in conjunction with the Federal Emergency Management Agency (FEMA) BCA Toolkit v6.0.0. The FEMA BCA Toolkit is provided as **Appendix 4.** Social benefits used in the analysis were developed within the FMEA Benefit-Cost Calculator.

Project Costs

According to the report, the overall cost to design and construct the recommended alternative of the Woodland Trails Stormwater Detention Basin was estimated to be $42.6 million based on 2021 construction costs. The conveyance improvements were assumed to have a useful life of 30 years. The project cost used in the BCA includes Construction (80%) and Contingency (20%). The annual maintenance cost is estimated at $0. Harris County Flood Control District will be responsible for long-term maintenance of the Woodland Trails Stormwater Detention Basin.

Benefit Cost Analysis

1.1 Building Information

The “Texas Buildings with SVI and Estimated Population (November 2021)” dataset provided by TWDB for Regional Flood Planning was used to determine building sizes and building types. The Finished Floor Elevations (FFE) for all structures were assumed to 0.5 feet above ground level and all structures were assumed to be 1 story. The FFE assumption was gathered from the approximate median FFE from HCFCD’s structural inventory dataset for the project area. Based on the provided building types, structures were reclassified as either residential, commercial, industrial, or agricultural. Public buildings were reclassified as commercial structures. Buildings marked as “Vacant or Unknown” in the TWDB dataset were reclassified as agricultural buildings.

1.2 Flood Hazard Data

The flood depths for each structure within the study area was determined for the 10 percent, 1 percent, and 0.2 percent annual chance events. The flood hazard data was obtained from the hydraulic models developed as part of the Preliminary Engineering Report, all hydrological and hydraulic analyses were completed by CobbFendley. The baseline structural flood damages are included in **Table 1**.

Table 1. Summary of Damages by Recurrence Interval for Without and With Project Conditions

	1% AEP Storm Event		0.2% AEP Storm Event		10% AEP Storm Event	
	Without Project	With Project	Without Project	With Project	Without Project	With Project
Residential Flood Damage	$673,657,133	$569,915,782	$1,760,091,349	$1,605,187,432	$3,837,514	$3,834,031
Commercial Flood Damage	$167,510,578	$153,661,232	$575,114,130	$535,456,719	$6,958,711	$478,295
Total Structural Damage	**$841,167,711**	**$723,577,014**	**$2,335,205,479**	**$2,140,644,150**	**$10,796,225**	**$4,312,326**

1.3 Expected Flood Damages After FMP Implementation

For the structures analyzed, the Woodland Trails Stormwater Detention Basin FMP results in $64,458,243 in standard mitigation benefits.

1.4 Benefit-Cost Analysis Summary

The benefit-cost analysis for this project was completed using the FEMA BCA Tool Version 6.0. The final benefit-cost ratio (BCR) with standard benefits was determined to be 1.89. No other benefits (i.e., recreation, roadway, etc.) were analyzed during this analysis.

Table 2. Benefit-Cost Analysis Summary

Input Into BCA Toolkit		
Project Useful Life	**30 years**	
Event Damages	**Baseline**	**Project**
1% AEP storm event	**$841,167,711**	**$723,577,014**
0.2% AEP storm event	**$2,335,205,479**	**$2,140,644,150**
10% AEP storm event	**$10,796,225**	**$4,312,326**
Results from BCA Toolkit:		
Total Benefits from BCA Toolkit	$64,458,243	
Discounted Total Costs from TWDB Spreadsheet	$34,048,054	
Net Benefits	$64,458,243	
Final BCR	**1.89**	

List of Appendices

Appendix 5-4AB:
Willow Creek – M120 Detention and Preservation Project

TORRES & ASSOCIATES, LLC
ENGINEERS | SCIENTISTS | PROFESSIONALS

MEMORANDUM

DATE: February 28th, 2023

TO: San Jacinto Regional Flood Planning Group

CC: Harris County Flood Control District; Texas Water Development Board

FROM: Evan Adrian, PE, CFM, ENV SP; Jacob Torres, PhD, PE, CFM, D.WRE; Cristian Ayala, EIT

PROJECT NO.: 10-220120-00

PROJECT: TWDB San Jacinto Regional Flood Plan

SUBJECT: Willow Creek – M120 Detention and Preservation Project Benefit-Cost Analysis

The evaluation for the M120 Detention and Preservation Project was conducted in 2020 as part of the Final Engineering Report for the Dannenbaum Engineering Corporation prepared for Harris County Flood Control District (HCFCD). Overall, the project would reduce roadway and housing flooding in the area caused by rising water from the Willow Creek and its tributary channels. The proposed project includes a 1,640 acre-feet detention basin and 85 acres of floodplain preservation area. The Final Engineering Report is included as **Appendix 1** and the Summary Report is included as **Appendix 2**.

The Texas Water Development Board (TWDB) requires each Flood Mitigation Project (FMP) included in a regional flood plan to have a benefit/cost analysis (BCA) performed. The final engineering report prepared by Dannenbaum Engineering Corporation did not include a BCA. This memorandum documents a benefit cost analysis performed for M120 Detention and Preservation Project by Torres and Associates within the regional flood planning process.

Benefit Cost Analysis Methodology

TWDB developed the Benefit-Cost Analysis (BCA) Input Tool to facilitate the calculation of flood mitigation benefits due to FMP. The TWDB BCA Input Tool is provided as **Appendix 3**. This tool receives input of existing and proposed conditions to determine expected benefits related to the construction of the FMP in question. The benefits considered in the analysis include the reduction in damages to residential structures, commercial structures, and social benefits. The BCA Input Tool was modified to handle the nearly 20,000 structures included in the analysis. The modified BCA Input Tool is provided as **Appendix 4**. The BCA Input Tool was used in conjunction with the Federal Emergency Management Agency (FEMA)

BCA Toolkit v6.0.0. The FEMA BCA Toolkit is provided as **Appendix 5.** Social benefits used in the analysis were developed within the FMEA Benefit-Cost Calculator.

Project Costs

According to the report, the total cost for the M120 Detention and Preservation Project is approximately $64.9 million. The proposed improvements were assumed to have a useful life of 30 years. The project cost used in the BCA includes land acquisition costs ($27,316,672), excavation costs ($33,260,480), and non-excavation construction costs ($4,323,862). The annual maintenance cost is estimated at $0. Harris County Flood Control District will be responsible for long-term maintenance of the M120 Detention and Preservation Project.

Benefit Cost Analysis

1.1 Building Information

The "Texas Buildings with SVI and Estimated Population (November 2021)" dataset provided by TWDB for Regional Flood Planning was used to determine building sizes and building types. The Finished Floor Elevations (FFE) for all structures were assumed to be 8 inches above ground level and all structures were assumed to be 1 story. The FFE assumption was gathered from the approximate median FFE from HCFCD's structural inventory dataset for the project area. Based on the provided building types, structures were reclassified as either residential, commercial, industrial, or agricultural. Public buildings were reclassified as commercial structures. Buildings marked as "Vacant or Unknown" in the TWDB dataset were reclassified as agricultural buildings.

1.2 Flood Hazard Data

The flood depths for each structure within the study area was determined for the 10 percent, 1 percent, 0.2 percent annual chance events. The flood hazard data was obtained from the hydraulic models developed as part of the Final Engineering Report, all hydrological and hydraulic analyses were completed by Dannenbaum Engineering Corporation. The baseline structural flood damages are included in **Table 1**.

Table 1. Summary of Damages by Recurrence Interval for Without and With Project Conditions

	1% AEP Storm		0.2% AEP Storm		10% AEP Storm	
	Without Project	With Project	Without Project	With Project	Without Project	With Project
Residential Flood Damage	$67,348,047	$57,737,819	$215,064,458	$209,029,618	$10,818,299	$10,797,283
Commercial Flood Damage	$32,286,319	$29,068,254	$79,261,957	$78,356,661	$3,141,133	$6,271
Total Structural Damage	**$99,634,366**	**$86,806,072**	**$294,326,415**	**$287,386,279**	**$13,959,431**	**$10,803,553**

1.3 Expected Flood Damages After FMP Implementation

For the structures analyzed, the Willow Creek – M120 Detention and Preservation FMP results in $8,941,905 in standard mitigation benefits. With the inclusion of other benefits stemming from the preservation of floodplain, an additional $32,689,097 in benefit was incorporated into the BCA.

1.4 Benefit-Cost Analysis Summary

The benefit-cost analysis for this project was completed using the FEMA BCA Tool Version 6.0. The final benefit-cost ratio (BCR) with standard benefits was determined to be 0.80. Other benefits were analyzed including environmental benefits and residual value of investments.

Table 2. Benefit-Cost Analysis Summary

Input Into BCA Toolkit		
Project Useful Life	**30 years**	
Event Damages	**Baseline**	**Project**
1% AEP storm event	**$99,634,366**	**$86,806,072**
0.2% AEP storm event	**$294,326,415**	**$287,386,279**
10% AEP storm event	**$13,959,431**	**$10,803,553**
Results from BCA Toolkit:		
Total Benefits from BCA Toolkit	$8,941,905	
Other Benefits (Not Recreation)	$32,689,097	
Discounted Total Costs from TWDB Spreadsheet	$51,833,920	
Net Benefits	$41,631,002	
Final BCR	**0.80**	

List of Appendices

Appendix 01 – Final Engineering Report for the Willow Creek Watershed Plan

Appendix 02 – Summary Report for the Willow Creek Watershed Plan

Appendix 03 – TWDB BCA Input Workbook (included as an excel document)

Appendix 04 – Modified Benefit Cost Analysis Spreadsheet (Included as an excel document)

Appendix 05 – FEMA BCA Toolkit 6.0 (included as an excel document)

Willow Creek Watershed Plan

Final Engineering Report

December 9, 2020

Prepared by:

Dannenbaum Engineering Corporation

STATE OF TEXAS
STEVEN D. FITZGERALD
55832
LICENSED
PROFESSIONAL ENGINEER

March 10, 2021

Final Engineering Report for the Willow Creek Watershed Planning Project

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List of Exhibits

Acknowledgments

Organizations participating in the development of the Willow Creek Watershed Plan are:

Dannenbaum Engineering Corporation; Prime

Atkins North America, Inc.; Tributary H&H

Isani Consultants; 2D H&H modeling

Hollaway Environmental + Communications Services, Inc.; Environmental

HydroGeo Designs LLC; Fluvial Geomorphology

Kuo & Asssoicates, Inc.; Surveying

Appreciation is extended to Harris County Precinct 4, City of Tomball, TXDOT, HCTRA, and Northampton MUD for providing flooding and project information within the watershed.

This project is funded by Harris County, the Texas General Land Office of the State of Texas, and the United States Department of Housing and Urban Development through the Community Development Block Grant Program to provide for disaster recovery and restoration of infrastructure for communities impacted by Hurricane Harvey.

1. Introduction

The purpose of this Final Engineering Report as requested by the HCFCD Planning Department is to summarize the engineering planning activities for the Willow Creek Watershed Planning Study and reference the details in the Technical Memorandums, Immediate Project Reports, and other supporting document appendices. The primary audiences are HCFCD staff, consulting engineers, and sub-consultants who will be working on future activities such as updating the watershed plan, developing CIP project lists, preparing preliminary engineering reports or construction drawings, applying for grant applications, or other engineering and planning activities.

Prior Willow Creek Watershed Study Planning reports referenced in this report (Appendix B) are:

Technical Memo 1: Problem Identification, May 29, 2020 (TM-1)

Technical Memo 2: Recommended Alternatives, August 21, 2020 (TM-2)

Technical Memo 3: Strategy Development, October 23, 2020 (TM-3)

Preliminary Project Plan, Willow Creek Selective Clearing – Mouth to BNRR, October 30, 2020 (SC Project)

Preliminary Project Plan, M120 Detention-Preservation Site, November 13, 2020 (M120 Site Project)

2. Watershed Overview

Willow Creek (M100) in north Harris County flows 20 miles into Spring Creek. The 54 square mile watershed is primarily in Precinct 4 except the area west of Cypress-Rosehill Road is in Precinct 3. Tomball located in the middle of the watershed is the only city. There are several major roadways including FM 2920, SH 99, and SH 249, and two active railroads. (One carried President George H.W. Bush to College Station). The lower third is almost fully developed adjacent to and east of Kuykendahl Road, the middle third is partially developed, and the undeveloped upper third west of SH 249 is beginning to develop due to the completion of SH99 in 2016. Environmentally, the watershed east of SH 249 is mostly forested, M100 is a meandering, perennial stream with favorable aquatic and riparian habitats, and most tributaries are improved. West of SH 249 is primarily rural with moderate gradients except near M100 where it is relatively flat (Willow Flats). Most of the tributaries in the watershed have been channelized and extended to facilitate farming, road or development drainage and are grass-lined or natural. Willow Creek still has many opportunities for floodplain, forest, and habitat preservation; stream and riparian restoration; and mitigation of existing flooding and future development cumulative effects. See Exhibit 1, Watershed Overview. Technical Memorandum 1 contains important background information, photos, and maps.

3. Source of Flooding and History

The two primary sources of house and road flooding in the Willow Creek watershed are rising water from the Willow Creek or the tributary channels and rising or flowing water overland within a rural or urban subdivision trying to make it to an outlet or open channel. A common reason why houses flood is the first floor is too low. Most homes that flood in the Willow Creek watershed were constructed before the 1990's when minimum slab elevations and drainage criteria were less stringent.

Most of the historic house flooding in the Willow Creek watershed has been within the FEMA effective 1% floodplains along Willow Creek (Exhibit 2, Effective Floodplains and Historic Flooding), primarily in the lower reach near Kuykendahl Road and the Northampton Subdivision. Some of the homes in Northhampton and nearby have flooded from Spring Creek backwater, as well. Pockets of house flooding have occurred in Tomball and in or near various rural-type subdivisions due to local or internal drainage issues or overland sheet flow. Almost all homes flooded were constructed before the mid-1980's when minimum slab elevations and drainage criteria were less stringent. An exception occurred in a mid-2000's subdivision on the watershed divide with Cypress Creek at SH 99 and the Burlington Northern Railroad (BNRR). About 200 homes flooded in Northern Point when M100 rose to near 0.2% flood levels during Harvey.

The total number of homes flooded during the most severe floods ranges from 100-500 and most have flooded multiple times. The actual number of homes flooded is usually higher. The major flood events in the Willow Creek watershed are Hurricane Harvey (August 2017), Tax Day Flood 2016, Memorial Day Flood 2016, Hurricane Ike 2008, Tropical Storm Allison (June 2001), and the October 1994 flood.

Both excessive depth and duration of roadway flooding occur in many parts of the watershed especially where house flooding occurs. As the watershed transforms from a rural to urban community, the impacts of roadway flooding on the community have increased significantly.

4. H&H Modeling

The effective HEC-HMS and HEC-RAS models and floodplain maps for the main channel and studied tributaries were used to document the severity of prior flood events and to understand what the community and floodplain administrators have been using for minimum building and development criteria over the years. They were not used for this planning study because the HCFCD is in the process of updating and improving the H&H modeling and floodplain maps for Harris County using new H&H models, new rainfall data published in NOAA Atlas 14, and methods to facilitate updates more efficiently (MAPPnext).

After discussions between the Dannenbaum Engineering and HCFCD Planning teams, it was decided to use the San Jacinto Regional Watershed Study (SJRWS) draft H&H models because they represented the most current conditions of the Willow Creek watershed. Application of the draft SJRWS hydrology and hydraulic models is described below.

The HEC-HMS and HEC-RAS models used in this study are in Appendix F, Electronic File Submittals.

4.1 Hydrology Methodology

The draft HEC-HMS model (version 4.3) from the San Jacinto Regional Watershed Study (SJRWS) was adopted for this study. A description of the updates between the FIS hydrologic models and the SJRWS hydrologic models is provided below.

The hydrologic model included updates to the frequency storm totals based on Atlas 14 rainfall data. Clark Unit Hydrograph parameters were not changed from the effective models. Green & Ampt loss parameters were updated to reflect the reclassification of soils in the northwestern portion of Harris County.

4.2 Hydraulics Methodology

The draft HEC-RAS models (version 5.07) from the SJRWS were adopted for this study. For the SJRWS, hydrographs computed as described above and the FIS HEC-RAS model geometry were combined to create unsteady hydraulic models for the Willow Creek main stem.

Floodplains for the 10-, 100-, and 500-year storms were delineated based on the unsteady HEC-RAS model results and 2018 LiDAR. Note that the term “Study Floodplains” is used to distinguish floodplains delineated for this study from the FEMA effective floodplains.

Based on the Willow Creek Study existing profiles, the channel banks along the main stem are predominantly lower than the 2-year water surface profile indicating a level of service of less than 2-years for the entire studied portion of the Willow Creek main stem.

4.3 Rain-On-Grid Modeling

To understand existing house and roadway flooding away from the main channel but near or along existing tributaries, rain-on-grid modeling was conducted. The new Atlas 14 rainfall data for the 100-year, 24-hour event was used in conjunction with the GEOID 12B (2018) LiDAR topography. Exhibits in TM-1 show 100-year inundation depths for tributaries approximately west of the Burlington Northern Railroad, as well as east side tributaries M103-00-00 and M105-00-00 in the Northampton subdivision and M109-02-00 in the Wimbledon Country subdivision.

5. Problem Areas

Problem flood areas within the watershed were identified using these resources:

- Maps showing 1% and 0.2% effective floodplains and HCFCD flooded structures data from Hurricane Harvey 2017, Tax Day 2016, Memorial Day 2016, and Hurricane Ike 2008, FEMA repetitive loss data, and FEMA claim data through December 2017 (see Exhibit 2).
- Water surface profiles for the 10%, 2%, 1%, and 0.2% M100 Study events with estimated structural inventory elevations shown and maps showing structural inventory locations on 1% and 0.2% floodplain maps (see Exhibit 3).
- Topographic maps and engineering reports, and construction drawings, where available.
- Input from Harris County Precinct 4 and the City of Tomball identifying chronic roadway and house flooding problems areas.

Problem areas were initially identified using the floodplain and historic house flooding map by identifying groups of houses near a channel or within an urban or rural subdivision. Slight adjustments were made using the structural inventory maps and input from Precinct 4 and Tomball. Based on location, topography, knowledge of the area, field visits, and flood history, the problem area source of flooding was designated as Riverine or Local, Internal, or Sheet (LIS). Each of the original problem areas identified is summarized in Table 3 and described in Appendix A of TM-1. Exhibit 4 shows the Problem Areas and the revised identifiers updated later to be consistent with other ongoing HCFCD watershed studies.

Please note other riverine problem areas on Willow Creek and LIS problems in the watershed damage many homes and impact many families, but they are spread out through the watershed and the numbers are relatively low in each location.

Problem areas were categorized into three groups:

Tier 1 = most flooding

Tier 2 = some flooding, but possible to address in conjunction with another funded project

Tier 3 = less flooding

The four Tier 1 problem areas on Willow Creek shown on Exhibit 4 are:

PA-01 (M100-PA07) – Northern Point, SH 99 and BNRR

PA-02 (M100-PA02) – Just upstream and downstream of Kuykendahl Road

PA-03 (M100-PA01) – Northampton area

PA-04 (M100-PA06) – Willow Flats, Telge Road to Cypress Rosehill Road

The homes in the four areas are primarily subject to riverine flooding from Willow Creek. Since the most significant problem areas and number of homes impacted are along Willow Creek, the entire Main Stem was eventually used to compare alternatives and refine the recommended alternative.

Representative flooded homes in these problem areas along Willow Creek are shown below.

Northampton
(M100-PA01)
PA-03

Creekwood Acres
(M100-PA02)
PA-02

Suburban Ranches
(M100-PA02)
PA-02

Willow Oaks Mobile Home Park
(M100-PA02)
PA-02

Willow Forest
(M100-PA02)
PA-02

Northern Point
(M100-PA07)
PA-01

Willow Flats, Rural Area
(M100-PA06)
PA-04

In addition to house flooding, mobility issues for the public and emergency vehicles caused by excessive roadway flooding were also evaluated for major thoroughfares using the 1% floodplain inundation data and information provided by Harris County Precinct 4 staff and the City of Tomball engineering staff during meetings. Initial results are provided in TM-1 in a table and exhibit. Results were refined as reported in TM-3. Exhibit 3 shows the limits of the major highways and thoroughfares underwater for the 1% event along Willow Creek. Please note local and subdivision road flooding also occurs during high intensity rainfall events.

6. Conditions and Constraints

6.1. Introduction

Environmental conditions and physical, regulatory, or jurisdictional constraints in the watershed are identified to assist with determining and categorizing problem areas and identifying flood risk reduction and mitigation projects. The environmental baseline condition review, geomorphological assessment summary, and other important factors are summarized in the following sections. Additional details are in TM-1, TM-2, SC Project, and M120 Site Project reports.

6.2. Environmental Overview

Hollaway conducted a baseline environmental assessment utilizing data from HCFCD, the current Watershed Master Plan analysis, any available or pertinent environmental reports, and publicly available online resources in order to understand and describe the general environmental setting of the watershed (Hydrologic Unit Code [HUC] 12-digit number 120401020210). This assessment identifies key environmental characteristics relative to the proposed flood damage reduction overall plan and immediate projects within the watershed.

6.3. Environmental Baseline Condition Review

A thorough baseline environmental assessment identified environmental conditions and constraints that may impact the design or schedule of proposed projects within the watershed. Publicly available, high-resolution aerial photographs were utilized to determine the existing conditions and current land use/land cover. This information, along with several publicly available resources were utilized in this analysis as well as an ArcGIS database provided by HCFCD to identify potential Waters of the United States (WOUS), Threatened and Endangered (T&E) species, cultural and historic resources, and potentially hazardous materials that may need to be considered when designing projects in this watershed.

The constraints analysis identified the presence of potentially jurisdictional WOUS, historical observations of T&E species (as well as potentially suitable habitat for T&E species), several previously conducted historical surveys along waterways within the watershed, and many potential sources for soil and/or groundwater contamination. The constraints analysis identified habitat suitable for migratory bird nesting. Findings are mapped in Exhibit 5, Existing Environmental Conditions and Exhibit 6, Pipelines, Wells, and Hazardous Sites.

The following are recommended:

- Submit a Jurisdictional Delineation Report to the U.S. Army Corps of Engineers to verify the boundaries and jurisdiction of potential WOUS features prior to completing project designs
- Field verifying potentially suitable habitat for T&E species
- Conduct migratory bird nesting surveys and bird abatement, as needed, from March 15 through September 15
- Conduct a thorough analysis of cultural and historic resources of each proposed project
- Perform a Phase I Environmental Site Assessment to identify any potential RECs.

Further recommendations are to design the project to avoid natural resources where possible, and to implement minimization measures such as enhancement activities and BMPs when impacts are unavoidable. BMPs can help reduce and minimize impacts to WOUS, T&E species, and cultural resources (e.g. installing silt fencing along proposed construction areas, reporting any cultural or buried materials [should they be encountered], or conducting species-specific monitoring prior to clearing activities).

Prior to project design and engineering, it is recommended the proposed project areas be field-evaluated to confirm and better detail potential environmental conditions previously identified in this desktop effort.

6.4. Geomorphological Assessment

A baseline geomorphological condition of each drainage channel within the watershed system was evaluated by HydroGeo Designs utilizing a modified desktop approach of the U.S. Army Corps of Engineers (USACE) Galveston District's Level 1 Stream Condition Assessment methodology. An assessment was conducted of 20 drainage channels within the Willow Creek watershed totaling 63.4 stream miles.

Three parameters were considered when determining classifications: visual channel condition and channel alteration, riparian buffer, and desktop aquatic life use. The ratings of these parameters were compiled to assign a Reach Condition Index (RCI) ranging between 1 and 5. A lower RCI describes a reach that is less environmentally sensitive. A summary of the results in TM-1 is a table of index scores and a visual representation of the RCI ratings in the Geomorphological Assessment exhibit. In summary, almost all tributaries and Willow Creek upstream of SH 249 are rated poor and Willow Creek downstream of SH 249 is in good geomorphological and environmental condition.

These channel geomorphological assessments, when reviewed in conjunction with the associated environmental baseline conditions assessment, provides a better understanding of existing conditions, potential constraints to future channel improvements or detention, and opportunities for preservation, restoration or enhancement of existing aquatic and riparian environmental habitats. Field verification of these findings is required prior to the next phase of project planning and design.

7. Flood Risk Reduction Alternatives

7.1. Introduction

The primary cause of most house flooding in the Willow Creek watershed is from rising water along Willow Creek (riverine flooding). Exhibit 3 shows the existing 10% (10-yr), 1% (100-yr), and 0.2% (500-yr) floodplains along Willow Creek as well as house locations from the HCFCD structural inventory that could potentially flood. Exhibits 3A and 3B show the houses on a profile with the 10% (10-yr), 2% (50-yr), 1% (100-yr), and 0.2% (500-yr) water surface profiles.

With all four Tier 1 Problem Areas along Willow Creek (Exhibit 4), only alternatives that reduce flood levels along Willow Creek were evaluated. Since the other problem areas on Willow Creek would also benefit from the flood risk reductions, the entire Main Stem was eventually used to compare alternatives and refine the recommended alternative. Since the majority of potential and historic flooded houses are downstream of SH 249, the alternatives were focused on the middle and lower reaches of Willow Creek.

The seven tributary problem areas identified within rural subdivisions and other scattered flood areas are due to overland sheet flow or overwhelmed internal drainage systems, typically roadside ditch systems. It is recommended the entity responsible for the internal drainage system evaluate and address the specific flooding issue. In the Willow Creek watershed, it could be Harris County, a municipal utility district, or the City of Tomball.

Finally, with the relatively low numbers of houses flooded compared to the potential cost of structural alternatives, non-structural alternatives used successfully by the HCFCD that should continue are:

- Home buyouts – an alternative in rural areas and older subdivisions for houses that flood frequently.
- Floodplain and habitat preservation – acquisition of land deep in the floodplain to preserve the benefits of natural storm water storage and prevent filling by future development. In addition, this alternative preserves forests, grasslands, and natural habitats. There are many favorable preservation opportunities for upland, riparian, and aquatic habitats along Willow Creek.

The initial work to identify and evaluate alternatives, and then identify an alternative that best lowers flood levels and satisfies the multi-objectives is reported in TM-2. The recommended alternative is further refined and an implementation strategy proposed in TM-3.

7.2. Alternatives Considered

Structural alternatives considered individually and in various combinations to reduce flooding in the middle and lower reaches of Willow Creek were:

1. Selective clearing 100’ on both sides of the Willow Creek channel banks from the BNRR downstream to mouth (Exhibit 4 in TM-2). The purpose is to improve flow conveyance on both sides of the creek in the heavily wooded areas to reduce flood levels.
2. Strategic selective clearing beyond the Willow Creek channel banks from the BNRR downstream to Kuykendahl Rd, and 100’ on both sides of the channel from Kuykendahl Rd to the mouth. The purpose is to recognize and connect the reaches on both sides of the creek that already convey flood flows more efficiently than the heavily wooded areas.
3. Replace FM 2920, Hufsmith-Kohrville Road, Union Pacific Railroad, and Kuykendahl Road bridges to reduce water levels upstream of bridge crossings with moderate to high head losses.

   High bank channel benches upstream and downstream of the proposed bridge replacements to reduce water levels upstream of bridge replacement crossings even more (Exhibit 5 in TM-2).
4. Nine offline detention basins away from the channel where inflow begins at a higher water level begin storing storm water after channel water levels reach a specified elevation (Exhibit 6 in TM-2). This reserves storage in the detention basin when it is needed the most. Detention basins may also be needed to mitigate higher flows and water levels due to the conveyance improvement alternatives above. Inflows near both the 2-year and 10-year water levels were evaluated. Floodplain preservation and habitat preservation areas along Willow Creek are included in the sites, as well.

For the initial planning level assessment, the storage volume was estimated using 50-foot maintenance berms, 4:1 side slope, and a flat bottom 2 feet above the normal water level.

Other successful flood risk reduction alternatives used in Harris County are major channel conveyance improvements (widen, deepen, and/or concrete line) and large-scale regional detention basins. The reasons they were not evaluated for Willow Creek are provided in TM-2, Section 3.2.

Each alternative was evaluated for the 10% (10-yr) and 1% (100-yr) events based on the San Jacinto River Watershed Study draft 1-D unsteady HEC-RAS model which incorporated the Atlas 14 rainfall and 2018 LiDAR. Water surface profiles, peak flow profiles, and 1% (100-yr) floodplains were compared to existing conditions. The table below shows the alternatives and the conclusions reached based just on the H&H analysis.

Alternative	Description	Conclusion
1a Uniform Selective Clearing	Selective Clearing 100' each side from BNRR to Mouth	Reasonable water level reductions along entire reach.
1b Strategic Selective Clearing	Strategic Selective Clearing as designated from BNRR to M104; 100' each side from M104 to mouth	Water level reductions less than 1a. Don't pursue.
2a Bridge Replacement and High Bank Channel Benches	Evaluate replacing FM 2920, Hufsmith-Kuykendahl, UPRR, and Kuykendahl Bridges.	Reasonable water level reductions locally upstream. Slight increases downstream.
	High bank benches on both sides at least 6' above flowline, 4:1 SS, max cut 4-6'	
3a Offline Detention Basins	Main Stem - inflow near 10-yr WSEL	Better than expected water level reductions.
3b Offline Detention Basins	Main Stem - inflow near 2-yr WSEL	Water level reductions less than 3a. Don't pursue.
4a Combination	Alternatives 1a + 2a + 3a	Impressive water level reductions.
5a Combination	Alternatives 1a + 2a	Good water level reductions
6a Combination	Alternatives 1a + 3a	Impressive water level reductions.

The Project Scoring method for determining the overall benefits prescribed by the HCFCD was used to evaluate and compare the alternatives. The final scores for each alternative are available in Section 3.3 of TM-2.

The recommendations below are based on the Project Scores, number of homes that benefit, project cost per home benefited, and assessments of impacts and opportunities described in Section 4 of TM-2.

1. Pursue selective clearing beyond the channel banks approximately 100' on both sides of Willow Creek.
2. Pursue purchase of the M120 property and consider up to eight other properties in the future along Willow Creek for regional detention, floodplain preservation, and habitat preservation
3. The four bridge replacements and high bank channel benches are not recommended at this time. However, when a new bridge or bridge replacement is proposed in the future, it is recommended the bridge design accommodate the flow in the overbank to at least the limits of the selective clearing.
4. Continue buyouts of homes under the current HCFCD buyout program guidelines and purchase land for floodplain preservation when possible

7.3. Alternative and Components Refinement

In TM-3, the recommended alternative listed as Combination 6a was further refined to improve the project components' feasibly, performance, and suggested implementation sequence.

Refinements to the two major components consisted of the following:

1. The initial selective clearing layout of 100 feet on both sides of the Willow Creek just beyond the channel banks was refined to improve smooth and continuous flow downstream in the overbanks and reduce costs based on:
   - Easing sharp bends
   - Physical impediments such as roadways, buildings, etc.
   - Taking advantage of areas already cleared
   - Minimizing ROW acquisition based on existing HCFCD ROW and property lines
   - More detailed analysis and assessment of the potential effects on Spring Creek

   The refined selective clearing component resulted in a proposed right-of-way width of 300-450+ feet and slightly lower water surface elevations. The assessment and analysis of potential effects on Spring Creek are in TM-3 which concluded selective clearing can proceed without constructing detention mitigation on Willow Creek.

2. Nine detention basin and preservation sites were refined to improve their functionality and develop improved information (benefits and costs) for prioritizing implementation based on:
   - More realistic basin layout on the site
   - More conservative potential detention volume estimates (75% of maximum storage volume)
   - Reducing peak flows in Willow Creek
   - Evaluating qualitative benefits
   - Assessing additional basin sequences and combinations.

   The refined regional detention and floodplain/habitat preservation sites are shown in Exhibit 7 and listed below with summarized information and work maps for each site are in TM-3, Appendix C. The H&H priority was based on flood level and flooded house reduction trends from various HEC-RAS runs for individual basins and combinations of basins.

Basin Location	H&H Priority	Total Land Area (ac)	Preservation Area (ac)	Excavation Area (ac)	Excavation Volume (cy)
Kuykendahl	3	67	7	46	727
M112	6	72	17	61	348
FM 2920	2	110	33	65	826
M116	7	69	54	14	121
M120	1	300	84	130*	1718*
BNRR	5	112	33	69	705
M121	4	156	17	95	1010
W.F. North	8	150	0	135	430
W.F. South	8	285	0	252	836
Totals		1,322	245	867	6,721

Note: Consider the excavation areas and basin volumes listed as goals only. Actual areas and volumes will vary during preliminary engineering and design based on a variety of factors including, but not limited to oil and gas well and pipeline relocation costs, right-of-way acquisition, preservation area layouts, environmental permitting, up-to-date site survey, multi-use decisions, and geotechnical analysis including slope stability and groundwater table.

* *Refined during analysis and reevaluation as an immediate project. Values lower due to the proposed Holderrieth Road project and more conservative numerical assumptions.*

The refined alternatives are listed below. They include Selective Clearing and the Regional Detention and Floodplain/Habitat Preservation Sites separately, the recommended combination 6m with all nine detention basins, the recommended initial phase 6n with selective clearing and the four primary detention basins for reducing existing flood levels, and the M120 detention/preservation site. The implementation recommendations and exhibit references are also included.

Refined Alternatives

1c	Selective Clearing - BNRR to Mouth	Immediate Project	Exhibits 9A & 9B
3d	All Nine Detention/Preservation Sites	--	--
6m	1c + 3d	Recommended Willow Creek Plan	Exhibit 7
6n	1c + Four Primary Detention/Preservation Sites (Kuykendahl + FM2920 + M120 + M121)	Initial Phase	Exhibit 8
--	M120 Detention/Preservation Site	Immediate Project	Exhibit 10

7.4. Flood Level Reductions

Exhibits for each of the alternatives listed in the table above show the following for the 10% (10-yr) and 1% (100-yr) events for existing and with-project conditions based on the San Jacinto River Watershed Study draft 1-D unsteady HEC-RAS model:

- Water Surface Profile Comparisons
- Peak Flow Profile Comparisons
- 1% Floodplain Comparisons

The number of homes no longer inundated for the 100-yr event and PSF50 are in the Project Scores table below in Section 7.6, Results.

In addition to structure flooding, excessive roadway flooding is also a major problem for motorists during flood events along Willow Creek as shown in Exhibit 3. Portions of most of these thoroughfares flood during more frequent events, as well. The table below shows the length of highways, major thoroughfares, and local roadways impacted by the existing 100-year flood and the roadway length reductions based on the proposed selective clearing only and the recommended plan projects.

Roadway Inundation Lengths, miles (100-year Event)

	Existing		1c Selective Clearing Only Reductions		6m Recommended Plan Reductions	
	Total	> 1ft+	Total	> 1ft+	Total	> 1ft+
Highways	4.10	3.13	0.01	0.00	0.13	0.20
Major thoroughfares	6.78	5.25	0.39	0.30	0.79	1.22
Local Roadways	17.65	13.40	1.14	0.94	3.12	3.34

Due to the wide extent of the Willow Creek 100-year floodplain, the reductions are not large, but the people who travel the roadways would benefit from lower flood levels.

7.5. Cost Estimates

The total cost for each of the alternatives and the recommended plan is shown in the table below. These are planning level cost estimates with an uncertainty of ±20%.

		Costs Estimate ($1,000,000)					
Alternative		Land	Pipe/Util Adj	Selective Clearing	Excav.	Non-Excav. Constr.	Total
1c	**Immediate Project Selective Clearing**	$10	--	$2	--	--	$12
3d	**Detention/ Preservation Sites**	$93	$9	--	$130	$17	$249
6m	**Recommended Willow Creek Plan 1c+3d**	$103	$9	$2	$130	$17	$261
6n	**Initial Phase 1c+(Kuykendahl+FM 2920+M120+M121)**	$66	$5	$2	$83	$11	$167
--	**Immediate Project M120 Detention/ Preservation Site**	$27	--	--	$34	$4	$65

Detailed cost estimates for each alternative and project are in Appendix E of TM-3.

7.6. Results

Besides the Project Scores discussed above, the number of homes that benefit and the cost per home (project efficiency) was compared with the Project Scores for the Main Stem (see table below). The Project Scoring Summary tables for each of the alternatives are in Appendix C.2. (For the Social Vulnerability Index used in the Project Scoring tables, a composite value of 5.5 was used for the Main Stem as described in TM-2, Section 3.3)

	Total Project Score				
Alternative	**1c**	**3d**	**6m**	**6n**	**M120***
***100-yr Event*[1]**	**6.7**	**5.9**	**6.4**	**5.9**	**5.9**
***PSF50*[2]**	**7.1**	**6.9**	**6.9**	**6.4**	**5.2**

Total Cost Est		**$12M**	**$249M**	**$261M**	**$167M**	**$65M**
***100-yr Event*[1]**	# Homes ↓ (839 total)	**141**	**286**	**448**	**294**	**109**
	Total Cost/ # Homes ↓	**$85K**	**$871K**	**$583K**	**$568K**	**$596K**
***PSF50*[2]**	Cumulative # ↓ (1478 total)	**268**	**494**	**682**	**421**	**90**
	Total Cost/ Cumulative # ↓	**$45K**	**$504K**	**$383K**	**$397K**	**$722K**

[1] *Based on number of structures within the 1% (100-year) floodplain*

[2] *Based on total cumulative Probable Structural Flooding over a 50-year period for four events = [(N10yr x 5) + (N50yr x 1) + (N100yr x 0.5) + (N500yr x 0.1)]*

* *Refined during analysis and reevaluation as an immediate project. Values lower due to the proposed Holderrieth Road project and more conservative numerical assumptions.*

7.7. Qualitative Benefits

In addition to the quantifiable flood level reduction benefits presented above, the following qualitative benefits were considered and evaluated for each alternative component. The estimated total acreage for all nine sites is about 250 acres. Estimates for each site are in the table above in Section 7.3.

Floodplain Preservation – preserve existing flood plain areas to maintain their flood level reduction benefits and to prevent filling from future development

Habitat Preservation – preserve the high-quality forest, wildlife habitat, and aquatic habitat along Willow Creek

Recreation – open space for passive and active recreation such as nature, walking, and bike trails, picnicking, play fields (frisbee, soccer, soft ball, etc.)

Future Secondary Development Mitigation – offset potential cumulative impacts from individual mitigation constructed for land development and infrastructure projects

The table below indicates the recommendations/suggestions for each of the nine detention basin and preservation sites based on a planning level evaluation of potential qualitative benefits.

Potential Qualitative Benefits

Basin Location	Floodplain Preservation	Habitat Preservation	Recreation Opportunities	Future Secondary Development Mitigation	Notes
Kuykendahl	+	+	+	+	
M112	+	+	--	+	Limited public access
FM 2920	++	++	+	+	
M116	++	++	+	--	Limited detention area
M120	++	++	++	+	Good public access
BNRR	+	+	--	+	Partial active borrow site
M121	+	++	+	+	
W.F. North	--	--	--	++	Maximum site excavation proposed
W.F. South	--	--	--	++	Maximum site excavation proposed

Legend: ++ Recommended, + Suggested, -- See Notes

8. Implementation Strategy

8.1. Introduction

The recommendations below are based on the Main Stem Project Scores, number of homes that benefit, project cost per home benefited, mobility and qualitative benefits, and assessments of risks and opportunities described above and in prior technical memorandums.

Recommendation	Project ID	Description
Immediate Project	1c	Selective Clearing BNRR to Mouth
--	3d	All Nine Detention/Preservation Sites
Recommended Willow Creek Plan	6m	1c + 3d
Initial Phase	6n	1c + Four Primary Detention/Preservation Sites (Kuykendahl + FM2920 + M120 + M121)
Immediate Project	--	M120 Detention/Preservation Site

8.2. Immediate Projects

Two separate immediate projects are recommended below as first phase projects to provide immediate benefits to the community. Preliminary Project Plan Reports per HCFCD guidelines were developed for each of them to facilitate HCFCD implementation.

1. **Selective Clearing beyond the channel banks approximately 100 feet on both sides of Willow Creek** (Exhibits 9A and 9B). Use HCFCD selective clearing criteria to clear underbrush and small undesirable tree species by hand without using tracked or mechanized equipment within specified areas from the Burlington Northern Railroad (BNRR) to the mouth. Exact clearing limits to be refined in subsequent project development phases.

   The selective clearing objectives are to

   - increase riverine storm water conveyance,
   - maintain a tree canopy for shade to prevent dense vegetation regrowth,
   - maintain vegetation diversity,
   - minimize the impact on the riparian and uplands habitats, and
   - provide the opportunity for walking trails along the creek.

   HCFCD has developed and improved its selective clearing program since its inception in the early 1990's and has conducted the program in compliance with applicable USACE Section 404 conditions and requirements. This alternative scored the highest using the HCFCD Project Scoring method, is affordable, can be initiated soon in areas with sufficient channel right-of-way, and works well with any of the other alternatives pursued. The estimated total cost of $12 million is less than the HCFCD 2018 Bond Project F-106 amount of $15 million identified as a drainage improvement project in the Willow Creek watershed.

Additional project implementation information was developed and documented in the Preliminary Project Plan, Willow Creek Selective Clearing – Mouth to BNRR, October 30, 2020 in Appendix B.

2. **Pursue purchase of the M120 property and consider up to eight other properties in the future along Willow Creek for regional detention, floodplain preservation, and habitat preservation** (Exhibit 10). The M120 site was selected from the initial nine potential sites identified along Willow Creek for the following reasons:
   - location in the watershed for reducing flows and flood levels in Willow Creek,
   - quality of the existing riparian forest and habitat,
   - potential passive and/or active recreation opportunities,
   - accommodation of the proposed Holderrieth Rd extension across Willow Creek and its associated detention mitigation, and
   - potential partial mitigation of the future upstream Willow Creek deepening

   The estimated total cost of $65 million is more than the HCFCD 2018 Bond Project F-36 amount of $30 million identified as right-of-way acquisition and floodplain preservation on Willow Creek. However, the land acquisition cost estimate of $27 million is less than the bond amount.

   Additional project implementation information was developed and documented in the Preliminary Project Plan, M120 Detention-Preservation Site, November 13, 2020 in Appendix B.

8.3. Near-Term Projects

The near-term recommendations below are considered second phase projects as the community need or desire for flood risk reduction, flood plain preservation, or habitat preservation increases and funding becomes available.

- **Pursue purchase of the following regional sites, and excavate identified detention basins within them:**
  - **FM 2920**
  - **Kuykendahl**
  - **M121 and/or BNRR**
- **Address Overflow Flooding between Burlington Northern Railroad and Hufsmith-Kohrville Road.** A separate planning level analysis is proposed within this contract to identify the reasons for the flooding and develop alternatives to reduce the risk of flooding in the Northern Point subdivision south of SH 99. Potential funding partners are Harris County in conjunction with the future Hufsmith-Kohrville Road improvement project, Burlington Northern Railroad if work in their drainage system is involved, and/or a federal grant for urban areas with a high social vulnerability index.

8.4. Long-Term Projects

The long-term recommendations below are considered additional phase projects as the community need or desire for flood risk reduction, flood plain preservation, or habitat preservation continues and funding is available.

- **Pursue purchase of the following regional sites, and excavate identified detention basins within them:**
    - **M112**
    - **M116**
    - **Willow Flats North and South**

8.5. Ongoing Flood Risk Reduction Opportunities

Home Buyouts: While the projects proposed above will reduce flood risk for many homes and businesses, they do not eliminate flood risks. It is recommended the HCFCD continue buyouts of homes under the current HCFCD buyout program guidelines where feasible as FEMA and other federal matching funds become available.

Bridges: If a new, modified, or replacement bridge is recommended by a roadway agency, it is recommended the bridge design accommodate the flow in the overbank to at least the limits of the selective clearing. Mitigation of the potential downstream impacts from the bridge or conveyance modifications may be included in one of the proposed regional detention basins.

Rural Subdivisions: Seven tributary problem areas identified within rural subdivisions and other scattered flood areas are due to overland sheet flow or overwhelmed internal drainage systems, typically roadside ditch systems (see Exhibit 4). It is recommended the entity responsible for the internal drainage system evaluate and address the specific flooding issue. In the Willow Creek watershed, it could be Harris County, a municipal utility district, or City of Tomball.

9. Multi-Use Opportunities

The recommended flood risk reduction alternative offers many opportunities for multi-use similar to other HCFCD channels, regional detention basins, and preservation sites. With early and frequent coordination with potential sponsors during planning, preliminary engineering, design, and construction, problems and risks can be kept to a minimum and benefits to the community maximized. Environmental and recreation opportunities are described below.

Opportunities along the 11+ miles of proposed selective clearing and additional right-of-way along Willow Creek are:

- Preservation of the riparian and upland forest habitat in the expanded right-of-way which will also be the ultimate right-of-way needed.
- Low impact hiking trails along Willow Creek that could interconnect with other trails in the watershed and on Spring Creek.
- Also, hike and bike trails upstream of the selective clearing limits within future Willow Creek or tributary rights-of-way are possible.

Opportunities at the nine large detention basin and preservation sites are:

- Preservation of the high quality and sizable riparian and upland forest habitat and wetlands along Willow Creek and adjoining forested habitat areas. People could enjoy these areas from the perimeter.
- Enhancement or restoration of riparian forests, prairies, and/or wetlands.
- Typical open space recreation such as trails, picnic areas, playgrounds, fishing, and sports or play fields.

Note: Preserving existing flood plain areas along Willow Creek also preserves the benefits of natural storm water storage and prevents filling from future development.

Outside of the identified excavation areas for detention, approximately 250 acres of land is available for environmental habitat preservation or recreation. Each site is conducive to different multi-use opportunities based on its unique location and existing site conditions.

10. Future Development

In the lower half of the watershed east of SH 249, development is continuing to expand in a westward direction. With the completion of the Grand Parkway (SH 99) in 2016 near the watershed's southern boundary and the Tomball Parkway (SH 249) expansion, development pressure has increased significantly in the upper watershed.

The drainage and flood control challenges in the watershed are the following:

- Flat topography in upper watershed along Willow Creek just downstream of a relatively large steep area
- Shallow existing rural channels
- Channel conveyance and depth improvements will require detention mitigation creating the potential for pumped detention
- Environmental permitting for channel conveyance and depth improvements
- Numerous existing and abandoned pipelines and wells creating the potential for costly relocation expenses to lower or widen channels or construct large detention facilities.
- Lack of large tracts

In areas where additional development or redevelopment is anticipated, it was assumed they would comply with the regulations and criteria of the applicable jurisdictions' regulations or criteria, particularly the HCFCD no adverse impact policy. Depending on the location and what public infrastructure is impacted or involved, the jurisdictions are Harris County, HCFCD, City of Tomball, and/or TXDOT. In areas with unimproved or noncompliant outfall channels, alignments and ultimate right-of-way widths were estimated for use by the developer engineer and jurisdictions to prepare an acceptable drainage plan.

Willow Creek downstream of the BNRR is in a relatively natural condition and has sufficient depth for development outfalls. Preserving the existing channel, riparian corridor, and habitat is recommended. No channel modifications are proposed except through bridges where water level reductions can be realized with a bridge replacement or lengthening. A transition upstream and downstream of the bridge is recommended to reduce flood levels and erosion. The ultimate right-of-way recommended for the downstream reach is the same as the recommended selective clearing right-of-way which is 300-450+ feet wide. The wider right-of-way is in the channel bends.

For Willow Creek upstream of the BNRR, see Section 7.2 in TM-3. For tributaries, suggested alignments and estimated ultimate right-of-way widths for new or improved tributary channels were estimated based on current conditions (see Section 7.3 in TM-3). No changes were assumed for channels that currently serve developed areas, appear to have the adequate depth for outfalls, and are not likely to be widened.

The future development effects on existing channels and recommended alternatives were evaluated based on watershed conditions at the time of the study (2020), and it was assumed that future development would mitigate their impacts using the applicable jurisdictions' mitigation requirements. However, in recognition of the possibility of cumulative impacts from the multiple developments, additional storage volume in the regional detention basins is recommended. Further analysis is recommended outside of this study to estimate that amount of additional storage by using the MAPPnext H&H models currently being developed. These models will also be used to define FEMA effective floodplains and to determine drainage and mitigation requirements for future developments and infrastructure projects.

11. References

Harris County. (2020, February 17). *Home Page*. Retrieved from Harris County Flood Control District: https://www.hcfcd.org/

San Jacinto Regional Watershed Master Drainage Plan, Draft Existing Conditions Report, August 2019

"Prioritization Framework for the Implementation of the Harris County Flood Control District 2018 Bond Projects", August 27, 2019

"Watershed Planning Projects Guidance Document for Problem Identification and Evaluation", Harris County Flood Control District Planning Department, January 27, 2020

Appendices

A. Exhibits

Exhibit 1, Watershed Overview

Exhibit 2, Effective Floodplains and Historic Flooding

Exhibit 3, Main Stem Structural Inventory Potential Flooding

Exhibit 3A, Main Stem Structural Inventory Potential Flooding – Downstream Profile

Exhibit 3B, Main Stem Structural Inventory Potential Flooding – Upstream Profile

Exhibit 4, Problem Area and Categories

Exhibit 5, Existing Environmental Constraints

Exhibit 6, Wells, Pipelines, HTW Conflicts

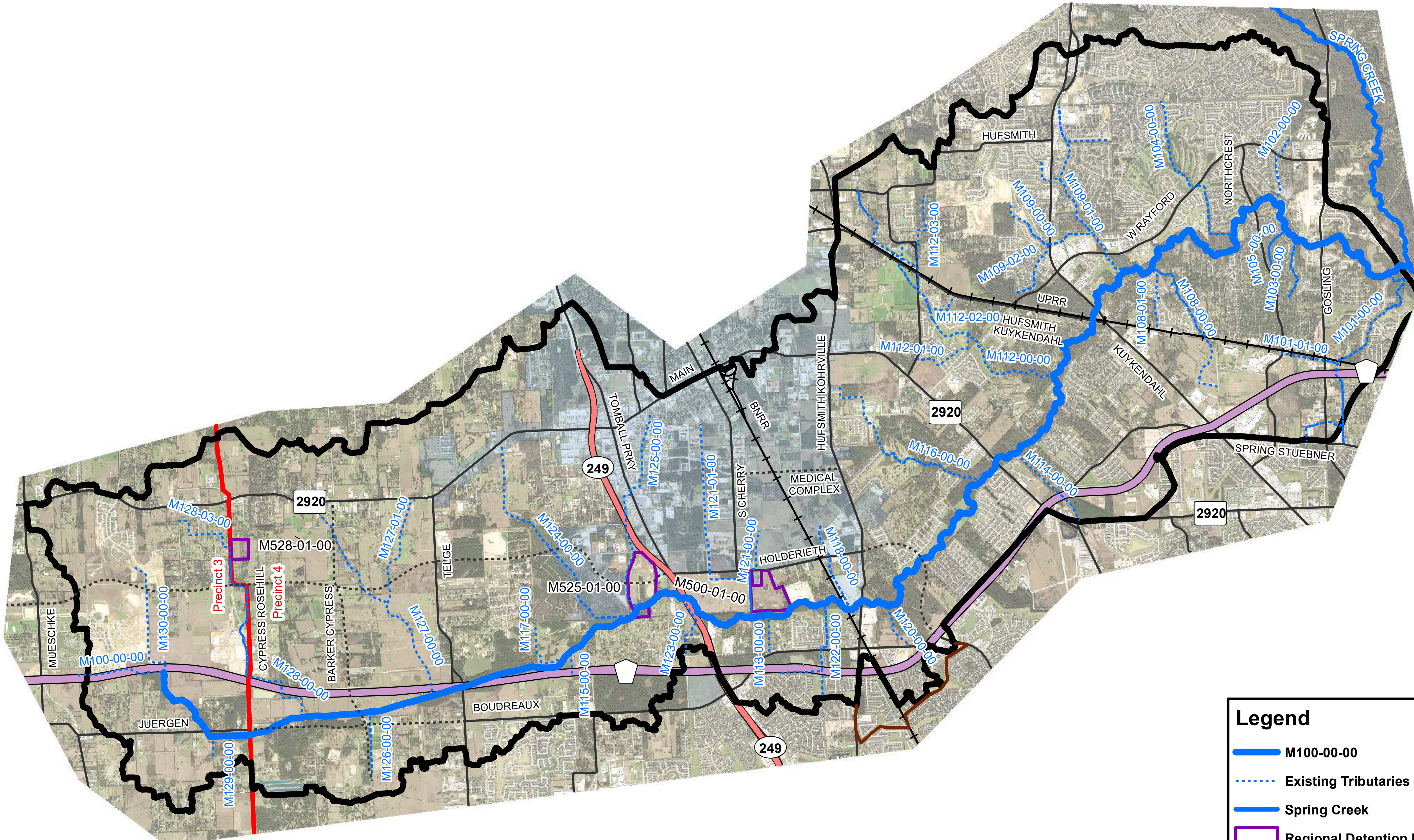
Exhibit 7, Recommended Plan Selective Clearing and Detention/Preservation Sites

Exhibit 8, Recommended Plan Initial Phase

Exhibit 9A, Selective Clearing Upstream

Exhibit 9B, Selective Clearing Downstream

Exhibit 10, M120 Detention & Preservation Site Overall



Legend

- M100-00-00
- Existing Tributaries
- Spring Creek
- Regional Detention Basins
- Large Event Drainage Boundary
- Watershed Limit
- Future Major Thoroughfares
- Harris County Prct 3 & 4 Boundary
- City of Tomball

2020 Aerial Photograph

Exhibit is from
Technical Memorandum 3
With Minor Modifications

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HCFCD PROJECT ID
M100-P003

DATUM & COORDINATE SYSTEM
NAD 1983 2011 State Plane
Texas South Central FIPS 4204 FIUS
Vertical Datum: NAVD 88, Geoid 12B (feet)

N

Feet
6,000

Willow Creek Watershed Plan

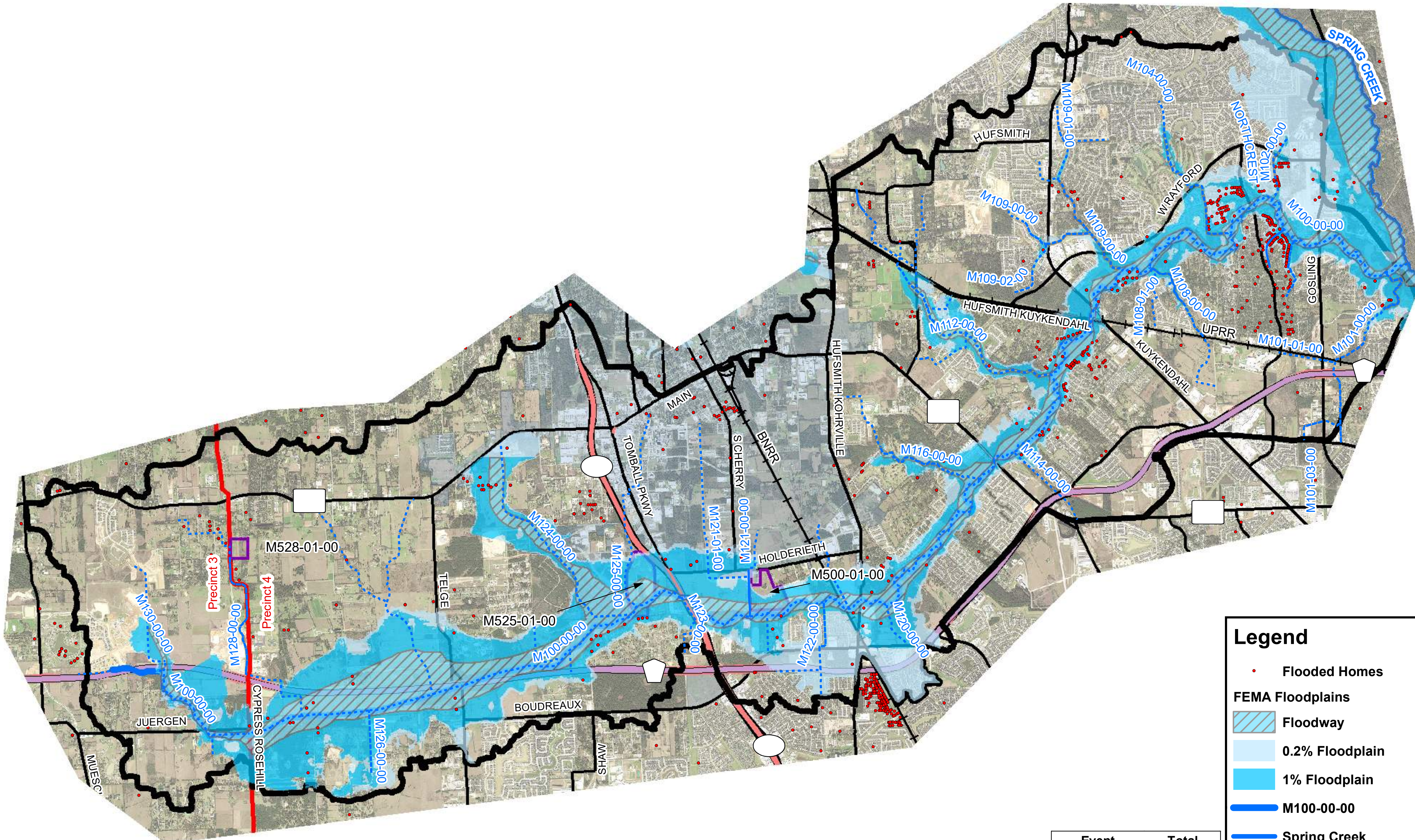
Watershed Overview

HARRIS COUNTY FLOOD CONTROL DISTRICT

DANNENBAUM ENGINEERING
EXCELLENCE SINCE 1945

Date: 12/09/2020

EXHIBIT
01



Legend

- Flooded Homes

FEMA Floodplains

- Floodway
- 0.2% Floodplain
- 1% Floodplain
- M100-00-00
- Spring Creek
- Existing Tributaries
- Regional Detention Basins
- Watershed Limit
- Harris County Prct 3 & 4 Boundary
- City of Tomball

Event	Total
Oct 1994	94
TS Allison 2001	77
Ike 2008	70
April 2016	240
May 2016	130
Harvey 2017	310

2020 Aerial Photograph

Exhibit is from Technical Memorandum 1 With Minor Modifications

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HCFCD PROJECT ID
M100-P003

DATUM & COORDINATE SYSTEM
NAD 1983 2011 State Plane
Texas South Central FIPS 4204 FtUS
Vertical Datum: NAVD 88, Geoid 12B (feet)

N

Feet
6,000

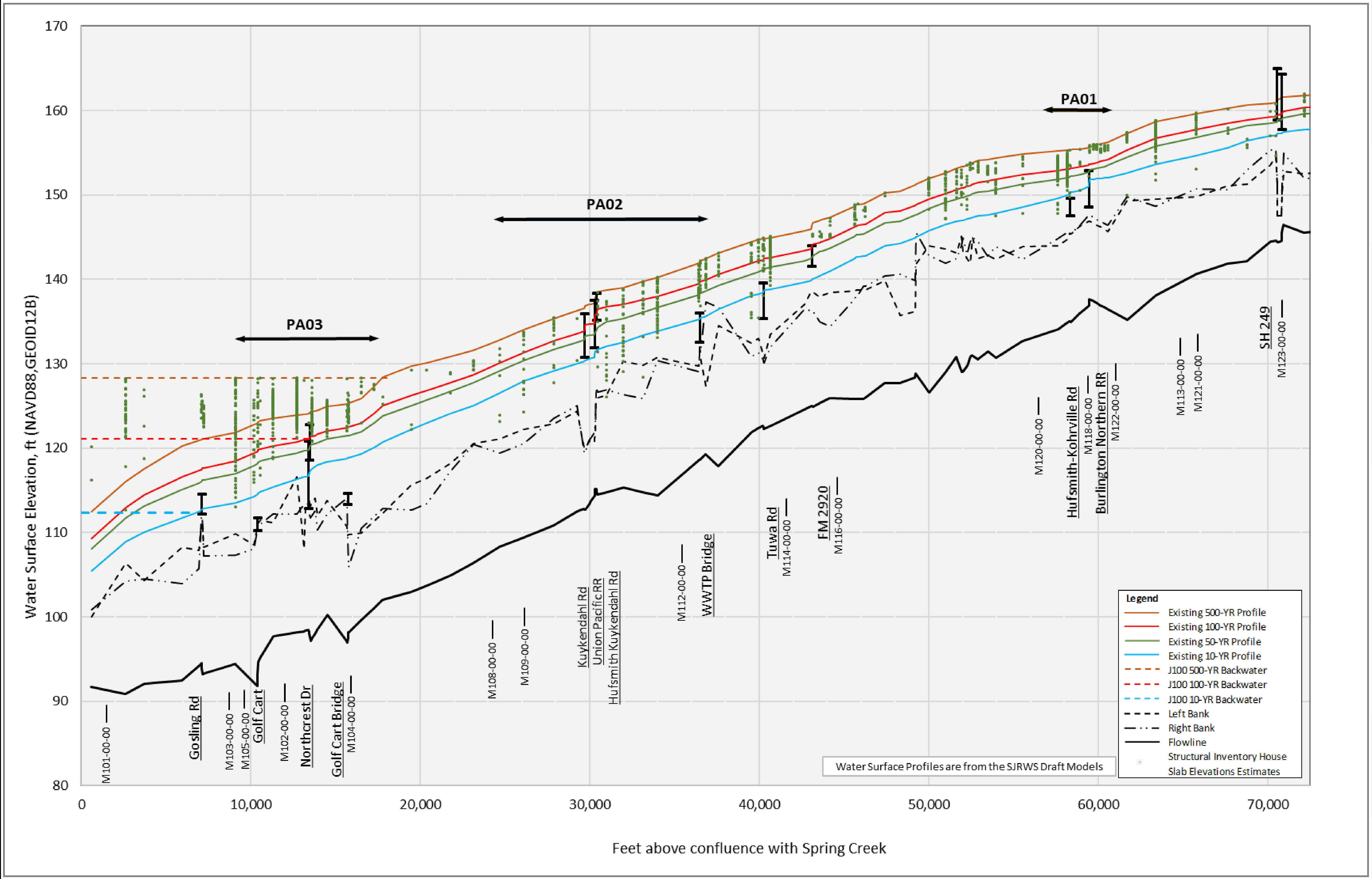
Willow Creek Watershed Plan

Effective Floodplains and Historic Flooding

DANNENBAUM ENGINEERING
EXCELLENCE SINCE 1945

Date: 12/09/2020

EXHIBIT
2



HCFCD PROJECT ID
M100-P003

DATUM & COORDINATE SYSTEM
NAD 1983 2011 State Plane
Texas South Central FIPS 4204 FtUS
Vertical Datum: NAVD 88, Geoid 12B (feet)

Willow Creek Watershed Plan

Main Stem Structural Inventory Potential Flooding - Downstream Profile

HARRIS COUNTY FLOOD CONTROL DISTRICT

DANNENBAUM ENGINEERING
EXCELLENCE SINCE 1945

Date: 12/09/2020

EXHIBIT 03A

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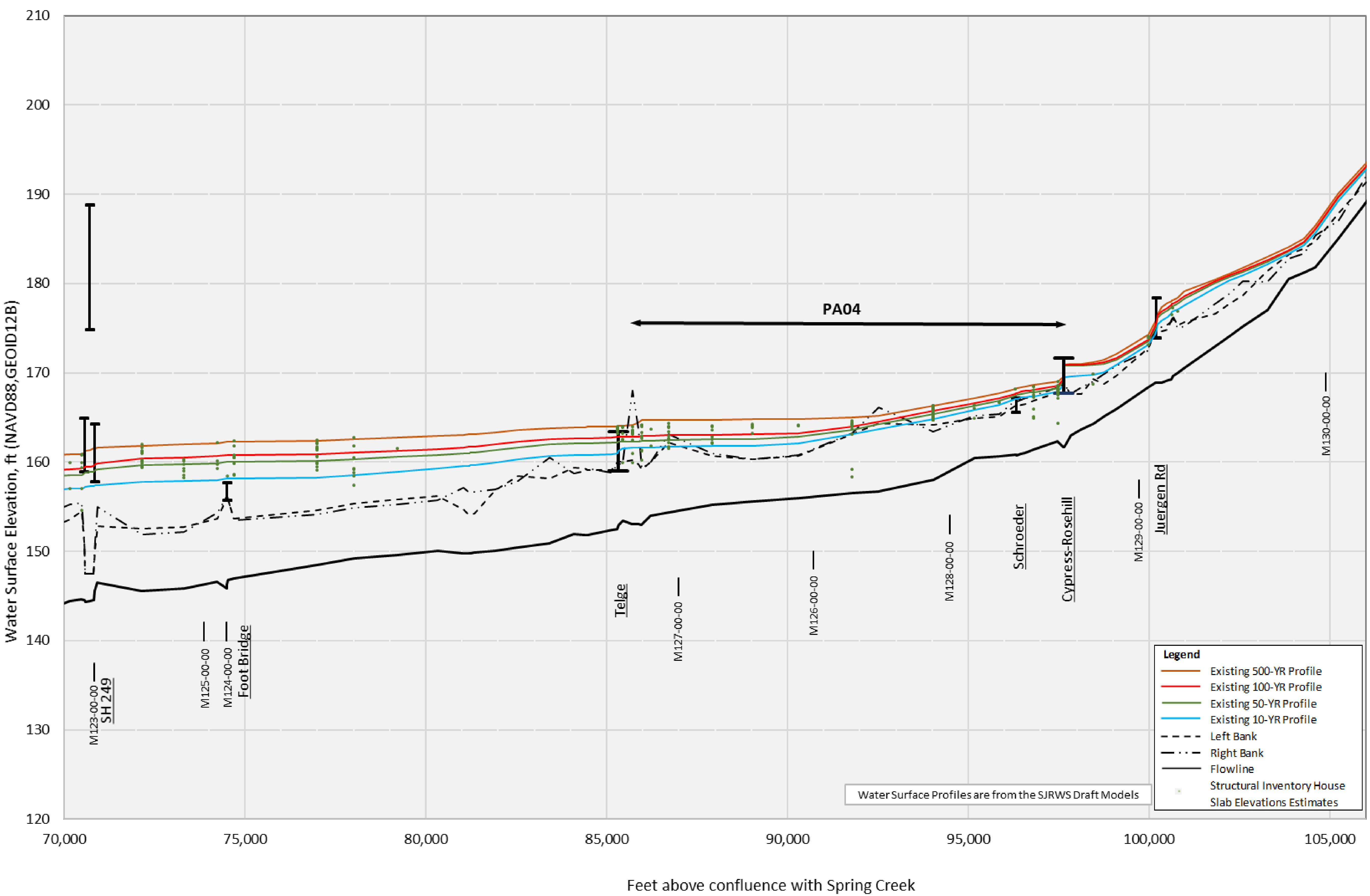


HCFCD PROJECT ID
M100-P003

DATUM & COORDINATE SYSTEM
NAD 1983 2011 State Plane
Texas South Central FIPS 4204 FIUS
Vertical Datum: NAVD 88, Geoid 12B (feet)

Willow Creek Watershed Plan

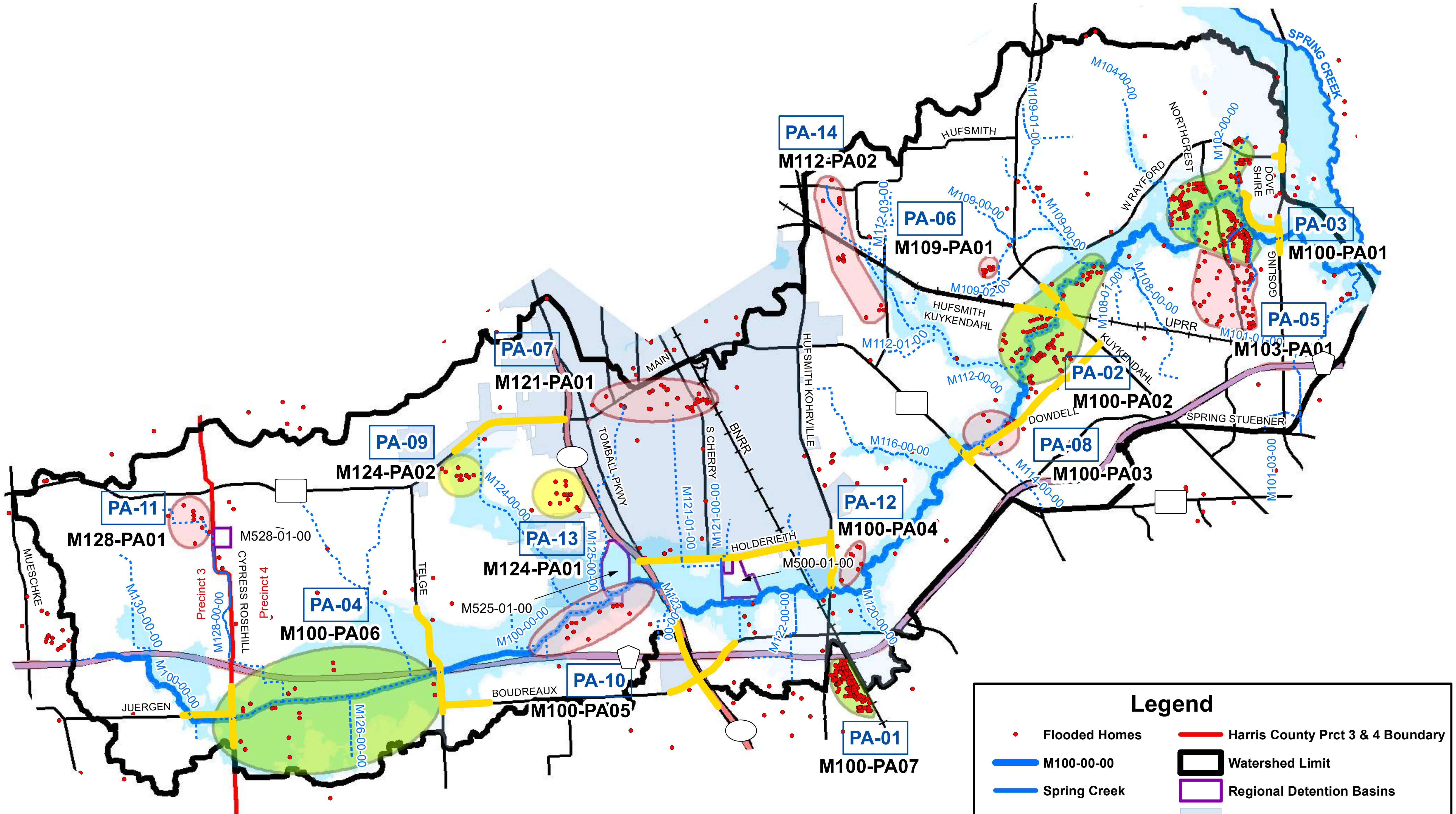
Main Stem Structural Inventory Potential Flooding - Usptream Profile

HARRIS COUNTY FLOOD CONTROL DISTRICT

DANNENBAUM ENGINEERING EXCELLENCE SINCE 1945

Date: 12/09/2020

EXHIBIT
03B



Legend

- Flooded Homes
- M100-00-00
- Spring Creek
- Existing Tributaries
- Harris County Prct 3 & 4 Boundary
- Watershed Limit
- Regional Detention Basins
- City of Tomball

FEMA Floodplain

- 0.2% Floodplain
- 1% Floodplain

Problem Area Categories

- Tier 1
- Tier 2
- Tier 3
- Mobility Problem Areas

New Naming Convention: PA-XX

Old Naming Convention: M1XX-PAXX

Exhibit is from
Technical Memorandum 1
With Minor Modifications

Document Path: G:\1150\5219-01_WillowCreek\GIS_Final Engineering Report\MXD\Exh_4.mxd

HCFCD PROJECT ID
M100-P003

DATUM & COORDINATE SYSTEM
NAD 1983 2011 State Plane
Texas South Central FIPS 4204 FtUS
Vertical Datum: NAVD 88, Geoid 12B (feet)

N

Feet
6,000

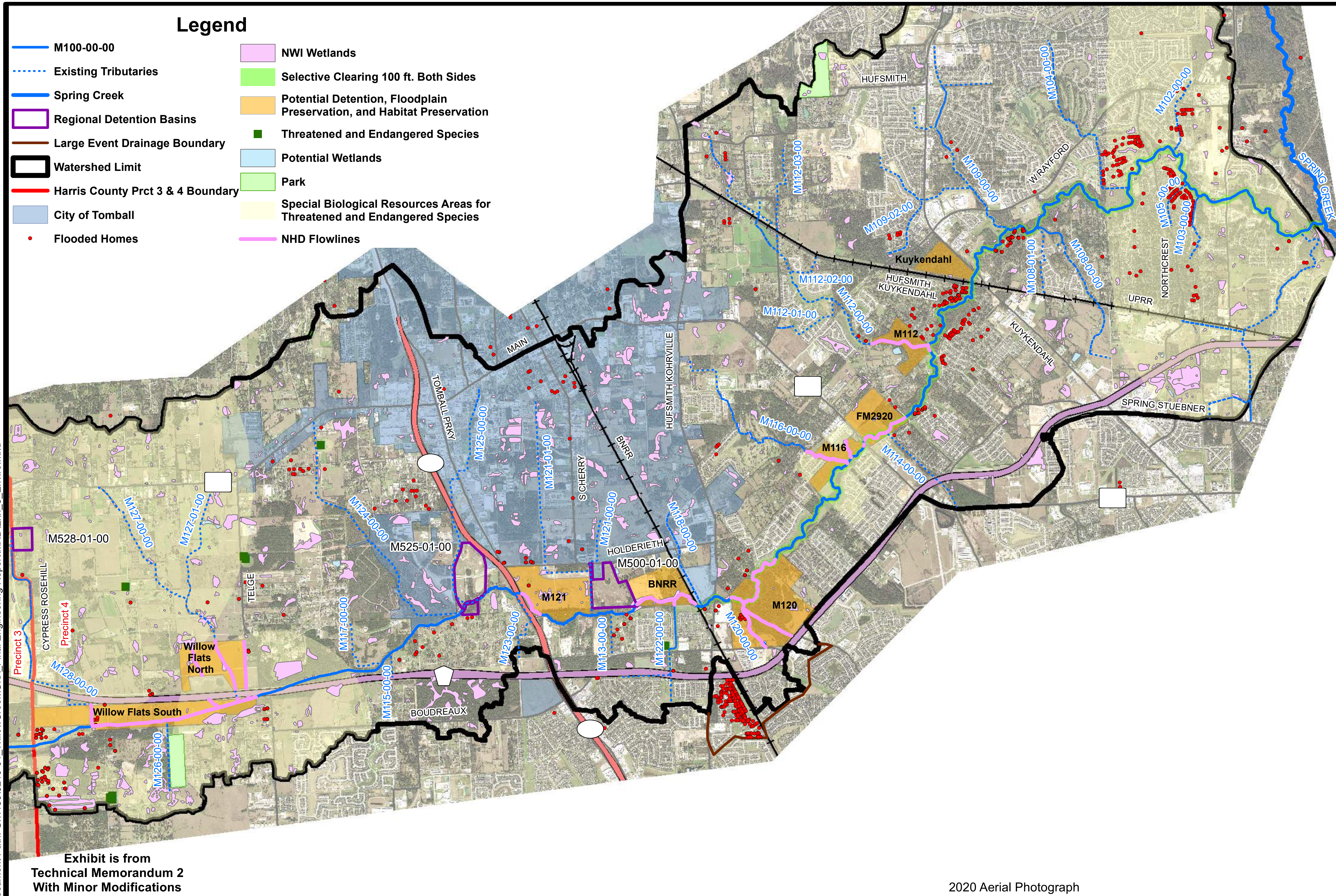
Willow Creek Watershed Plan

Problem Areas and Categories

DANNENBAUM ENGINEERING

Date: 12/09/2020

EXHIBIT
04



HCFCD PROJECT ID
M100-P003

DATUM & COORDINATE SYSTEM
NAD 1983 2011 State Plane
Texas South Central FIPS 4204 FIUS
Vertical Datum: NAVD 88, Geoid 12B (feet)

N
Feet
4,500

Willow Creek Watershed Plan

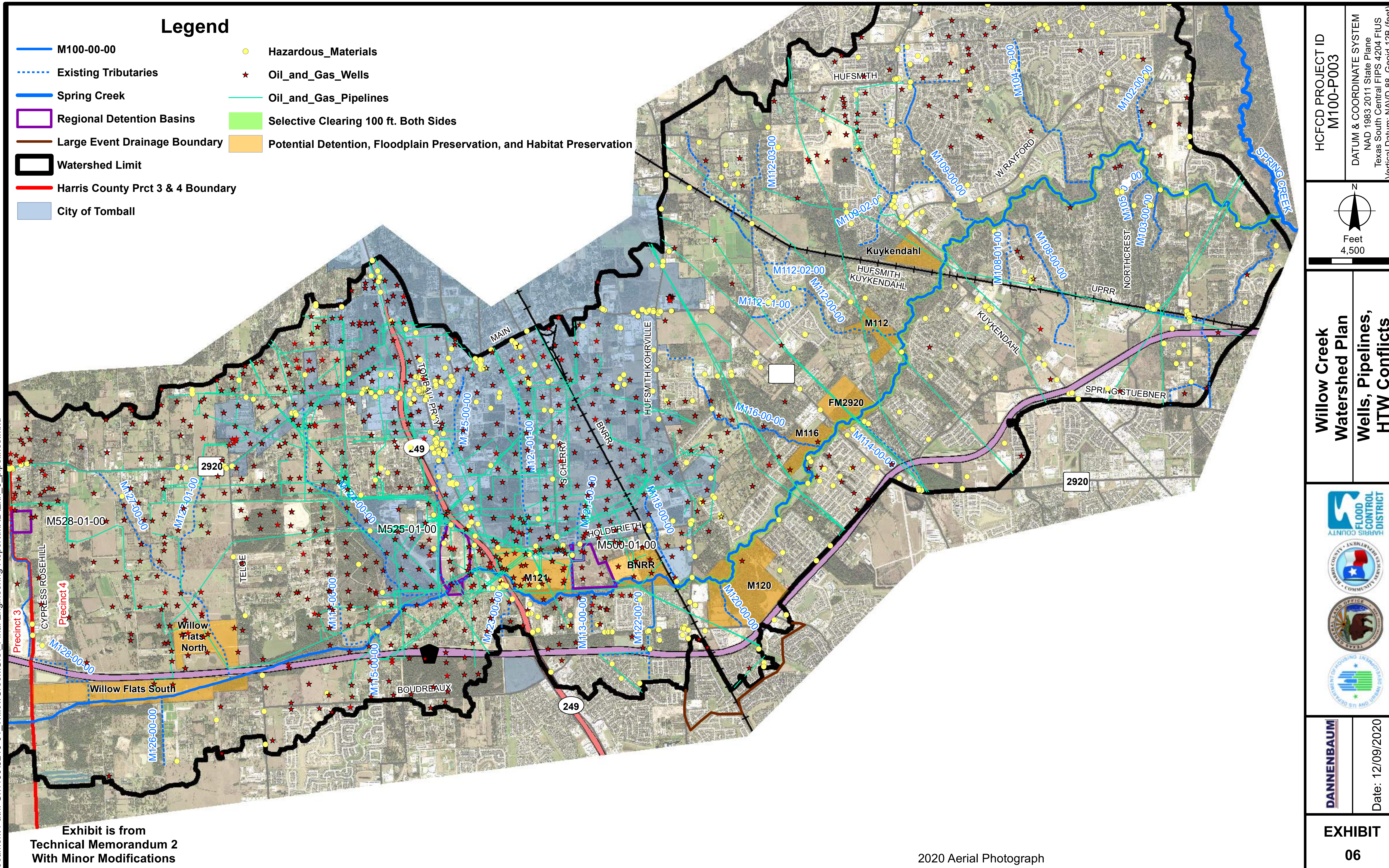
Environmental and Recreation Considerations

HARRIS COUNTY FLOOD CONTROL DISTRICT

DANNENBAUM ENGINEERING
EXCELLENCE SINCE 1945

Date: 12/09/2020

EXHIBIT
05



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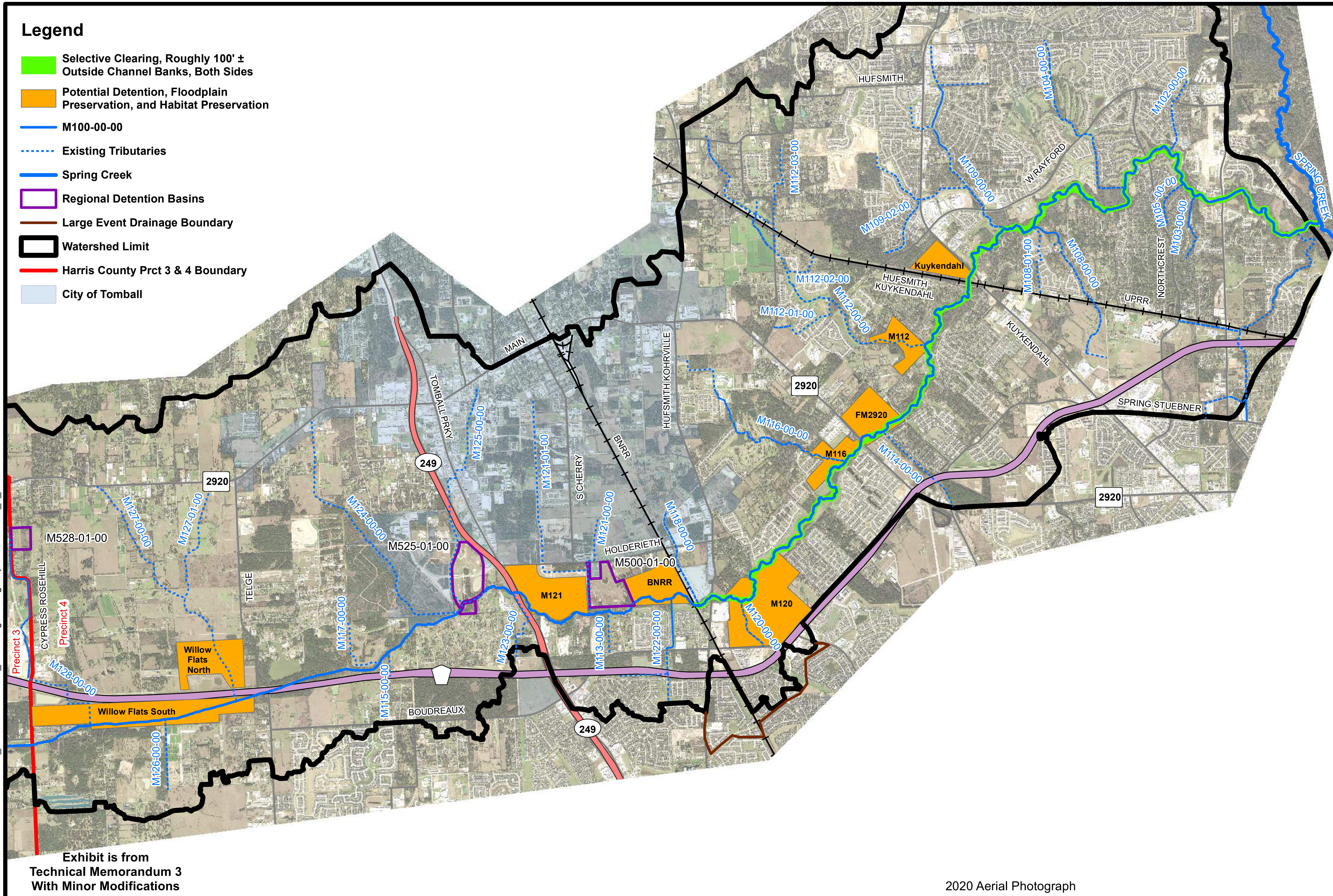

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HCFCD PROJECT ID
M100-P003

DATUM & COORDINATE SYSTEM
NAD 1983 2011 State Plane
Texas South Central FIPS 4204 FIUS
Vertical Datum: NAVD 88, Geoid 12B (feet)

N

Feet
4,500

Willow Creek Watershed Plan

Recommended Plan
Selective Clearing and
Detention/Preservation Sites

DANNENBAUM ENGINEERING
EXCELLENCE SINCE 1945

Date: 12/09/2020

EXHIBIT
07

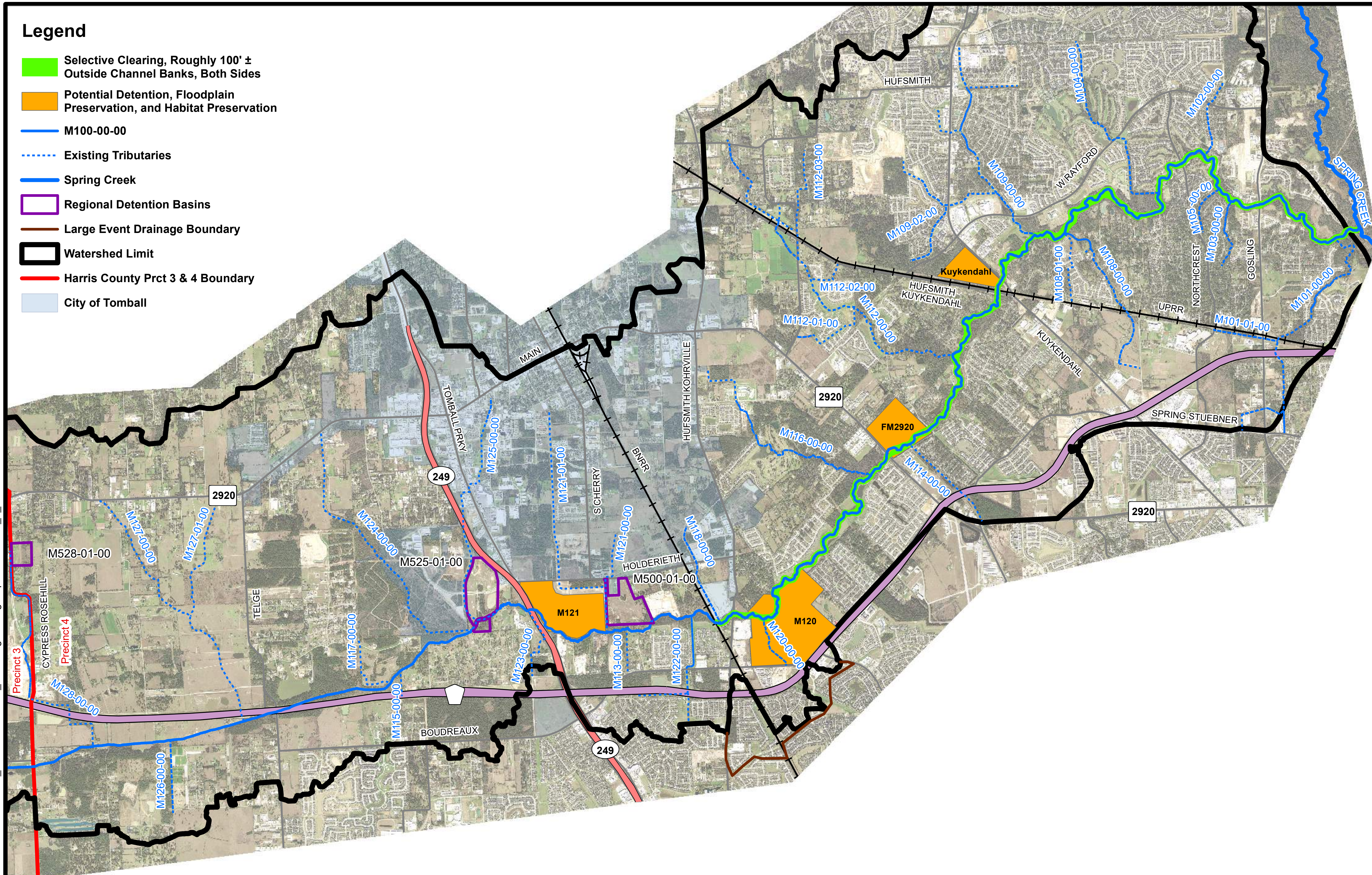


Exhibit is from Technical Memorandum 3 With Minor Modifications

2020 Aerial Photograph

Document Path: G:\1150\5219-01_WillowCreek\GIS_Final Engineering Report\MXD\Exh_8_Recommended Plan Initial Phase.mxd

HCFCD PROJECT ID
M100-P003

DATUM & COORDINATE SYSTEM
NAD 1983 2011 State Plane
Texas South Central FIPS 4204 FtUS
Vertical Datum: NAVD 88, Geoid 12B (feet)

Willow Creek Watershed Plan

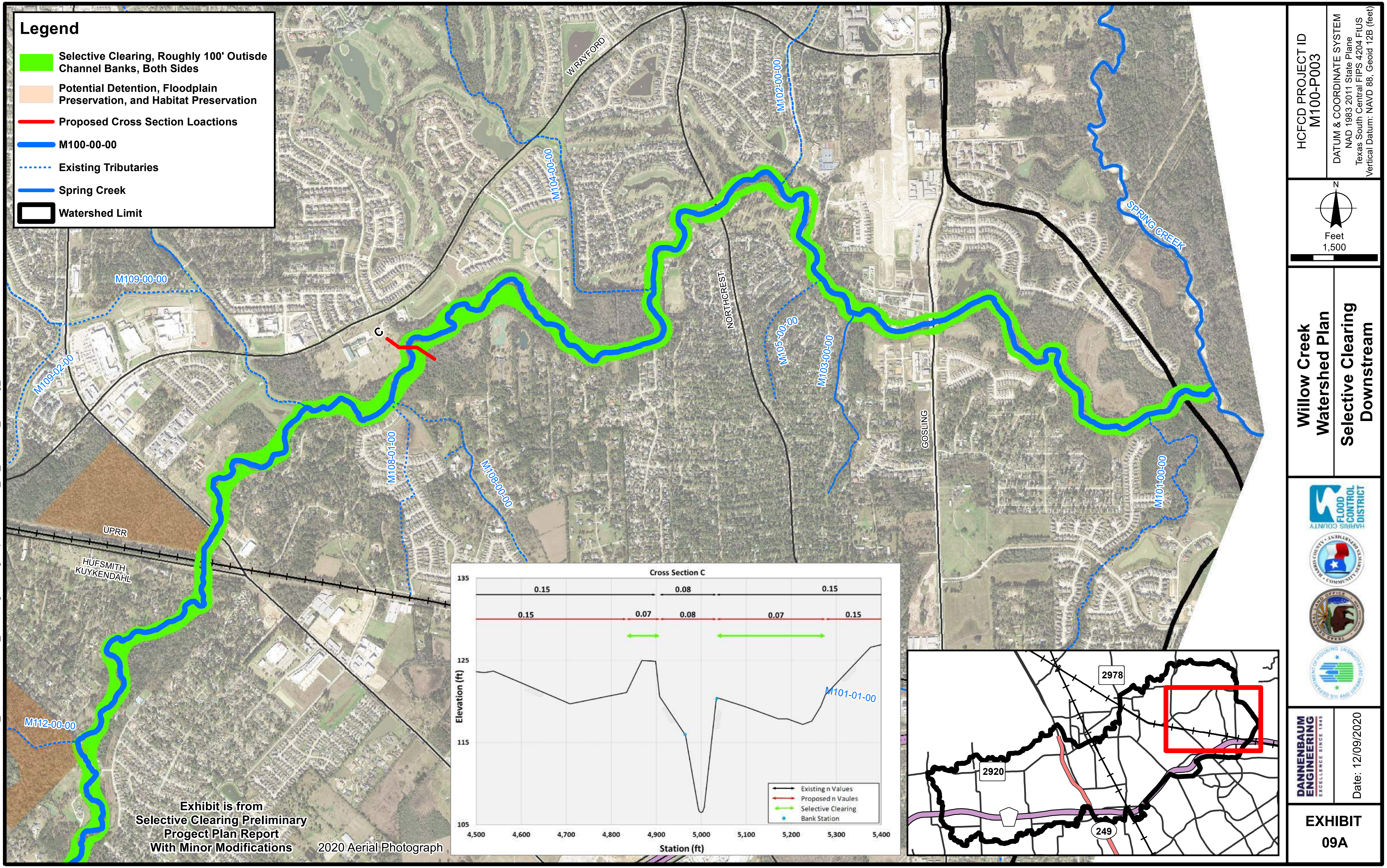
Recommended Plan Initial Phase

HARRIS COUNTY FLOOD CONTROL DISTRICT

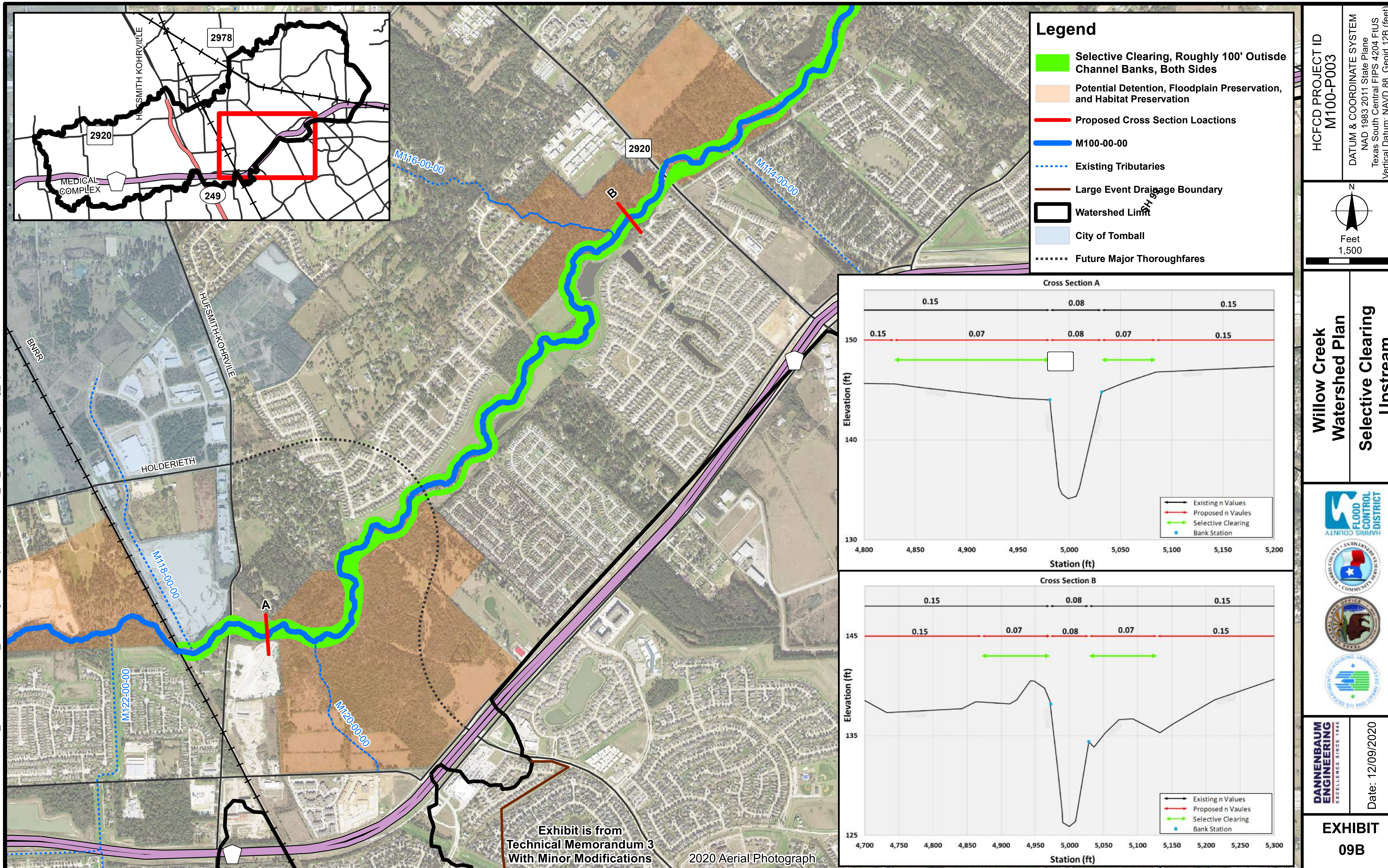
DANNENBAUM ENGINEERING
EXCELLENCE SINCE 1945

Date: 12/09/2020

EXHIBIT
08



Legend
Selective Clearing, Roughly 100' Outisde Channel Banks, Both Sides
Potential Detention, Floodplain Preservation, and Habitat Preservation
Proposed Cross Section Loactions
M100-00-00
Existing Tributaries
Spring Creek
Watershed Limit
W RAYFORD
M102-00-00
M104-00-00
M109-00-00
M109-02-00
NORTHCREST
M105-00-00
M103-00-00
GOSLING
SPRING CREEK
M108-01-00
M108-00-00
M101-00-00
M101-01-00
M112-00-00
UPRR
HUFSMITH KUYKENDAHL
C
Cross Section C
0.15
0.08
0.15
0.15
0.07
0.08
0.07
0.15
Elevation (ft)
Station (ft)
Existing n Values
Proposed n Values
Selective Clearing
Bank Station
2978
2920
249
Exhibit is from Selective Clearing Preliminary Progect Plan Report With Minor Modifications
2020 Aerial Photograph
Document Path: G:\1150\5219-01_WillowCreek\GIS_Final Engineering Report\MXD\Exh_9a_Selective_Clearing_Downstream.mxd
HCFCD PROJECT ID M100-P003
DATUM & COORDINATE SYSTEM
NAD 1983 2011 State Plane
Texas South Central FIPS 4204 FtUS
Vertical Datum: NAVD 88, Geoid 12B (feet)
N
Feet
1,500
Willow Creek Watershed Plan
Selective Clearing Downstream
HARRIS COUNTY FLOOD CONTROL DISTRICT
DANNENBAUM ENGINEERING
Date: 12/09/2020
EXHIBIT 09A



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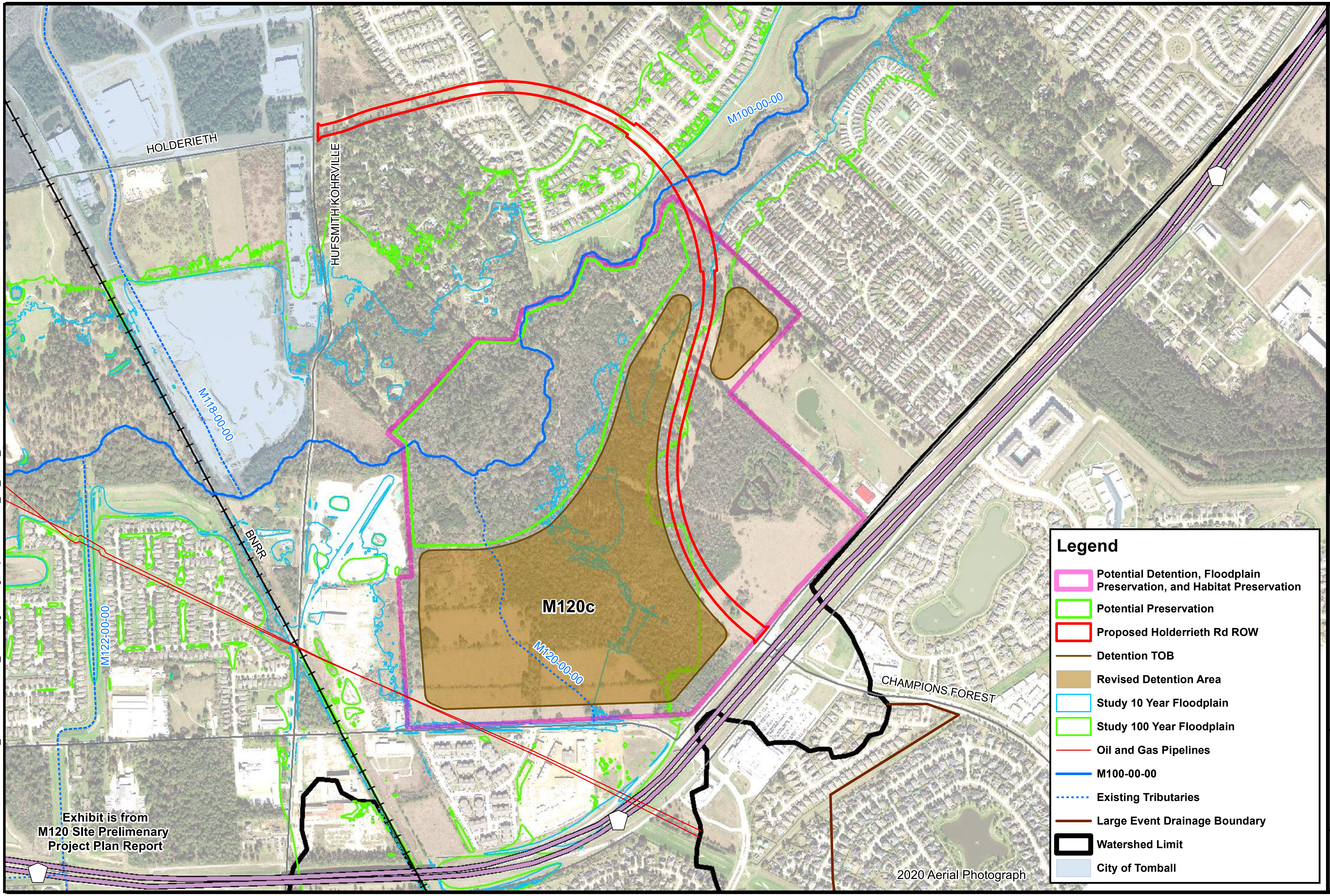

HCFCD PROJECT ID
M100-P003

DATUM & COORDINATE SYSTEM
NAD 1983 2011 State Plane
Texas South Central FIPS 4204 FtUS
Vertical Datum: NAVD 88, Geoid 12B (feet)

N
Feet
800

Willow Creek Watershed Plan

M120 Detention & Preservation Site Overall

HARRIS COUNTY FLOOD CONTROL DISTRICT

DANNENBAUM ENGINEERING

Date: 12/09/2020

EXHIBIT 10

B. Prior Willow Creek Watershed Study Reports

The following reports are provided separately as e-files:

Technical Memo 1: Problem Identification, May 29, 2020 (TM-1)

Technical Memo 2: Recommended Alternatives, August 21, 2020 (TM-2)

Technical Memo 3: Strategy Development, October 23, 2020 (TM-3)

Preliminary Project Plan, Willow Creek Selective Clearing – Mouth to BNRR, October 30, 2020 (SC Project)

Preliminary Project Plan, M120 Detention-Preservation Site, November 13, 2020 (M120 Site Project)

C. Hydrology and Hydraulics Information

The hydrology and hydraulic analytical information, working spreadsheet summaries, and list of models used for identifying the Willow Creek Recommended Plan, Implementation Strategy, and Immediate Projects are provided in this appendix. Contact Dannenbaum Engineering for additional information.

Existing Conditions

See Section 4. H&H Models above for a description of the models used.

The total number of flooded structures for existing conditions along the main stem.

	10-yr	50-yr	100-yr	500-yr
Existing Condition	105	410	844	2094

Alternatives Considered

Water surface elevations were used to evaluate Flooded Structure Reductions along the channel and summed as shown in the table below for each alternative. Peak flow changes were also evaluated along the channel, but particularly at the mouth to assess potential impacts on Spring Creek. Whether Peak Flow Mitigation from the selective clearing is achieved at the mouth or not is included in the table below, as well.

Alternative 6A – combination of 1A (selective clearing) and 3A (offline detention basins), appeared to be more effective than Alternatives 4A and 5A, and thus was further studied.

Alternatives 6A-6L were created during the initial detention refinement process. Alternative 6K generated an impressive result.

Alternatives	Flooded Structure Reduction				Peak Flow Mitigation	
	10-yr	50-yr	100-yr	500-yr	10-yr	100-yr
1A (Uniform Sel. Clearing)	16	105	114	185	No	No
1B (Strat. Sel. Clearing)	8	74	80	157	No	No
2A (Bridge Benching)	8	6	22	22	No	No
3A (Offline Det - High Spill)	28	237	407	315	Yes	Yes
3B (Offline Det - Low Spill)	47	213	227	294	Yes	Yes
4A (1a+2a+3a)	36	251	531	506	No	Yes
5A (1a+2a)	23	128	151	203	No	No
6A (1a+3a)	33	247	527	485	No	Yes

Initial Alternatives Refinement

Alternatives 6A-6L were created during the initial detention refinement process. Alternative 6K generated the best results relative to project costs.

Alternatives	Flooded Structure Reduction				Peak Flow Mitigation	
	10-yr	50-yr	100-yr	500-yr	10-yr	100-yr
6A (1a+3a)	33	247	527	485	No	Yes
6B (1a+ Kuykendahl+FM2920+M120)	12	189	293	258	No	Yes
6C (6B, lower spill)	24	141	163	238	Yes	Yes
6D (1a+FM2920+M120)	20	140	163	238	No	Yes
6E (1a+M120)	16	127	137	223	No	No
6F (1a+FM2920)	23	110	120	192	No	Yes
6G (1a+Kuykendahl)	19	107	115	187	No	No
6H (1a+Kuykendahl+FM2920)	25	110	121	194	Yes	Yes
6I (1a+Kuykendahl+FM2920+M112)	25	113	137	209	Yes	Yes
6J (1a+ Kuykendahl+FM2920+M120+BNRR)	16	192	296	287	Yes	Yes
6K (1a+ Kuykendahl+FM2920+M120+M121)	17	205	401	279	Yes	Yes
6L (1a+ Kuykendahl+FM2920+M120+BNRR+M121)	18	209	405	318	Yes	Yes

Final Alternatives Refinement

With refined selective clearing (Alternative 1C) and refined offline detention basin (Alternatives 3C and 3D), previous alternatives were further investigated. Results are summarized in the table below. Alternative 6M is the Recommended Willow Creek Plan. Alternative 6N is recommended as the Initial Phase.

Alternatives	Flooded Structure Reduction				Peak Flow Mitigation	
	10-yr	50-yr	100-yr	500-yr	10-yr	100-yr
1C (Refined Sel. Clearing)	10	129	141	185	No	No
3C (Offline Det - Elevated; 100% Volume)	28	225	353	174	Yes	Yes
3D (Offline Det - Elevated; 75% Volume)	27	206	286	96	Yes	Yes
6M (1c+3d)	38	251	438	329	Yes	Yes
6N (1c+ Kuykendahl+FM2920+M120+M121)	14	200	294	252	Yes	Yes
6O (1c + M120)	10	174	217	220	No	No
6P (1c + Kuykendahl)	13	131	139	189	No	No

Willow Creek Selective Clearing – Spring Creek Historical Flow Timing Analysis

This analysis and results are presented in Technical Memorandum 3, Appendix D. Potential Effects on Spring Creek. This required incorporating the proposed Selective Clearing Alternative 6C into the Spring Creek HEC-RAS model developed by Halff and Associates for the San Jacinto River Watershed Study. The models and other analytical products are available upon request.

Immediate Project: M120 Detention-Preservation Site - Weir Structure Adjustment

Plan ID	M120 (base)	M120-a	M120-b	M120-c	M120-d	M120-e (c+d)
% Storage Volume	75	100	75	75	75	75
Weir Elevation (ft)	149	149	148	150	149	150
Weir Length (ft)	1300	1300	1300	1300	726	726

<u>Results:</u>

M120-c has the lowest 100-year WSE profile between Kuykendahl and BNRR (identified in TM-2 as PA-01 and PA-02, the areas with the most vulnerable structures).

List of HEC-RAS Models

Plan ID	Description	Note
M100	Existing Conditions	Draft SJRWS Model
Alt1a	Uniform Selective Clearing	
Alt1b	Strategic Selective Clearing	
Alt1c	Refined Selective Clearing	Selective Clearing Immediate Project
Alt2a	Bridge Benching	
Alt3a	Offline Det - High Spill	
Alt3b	Offline Det - Low Spill	
Alt3c	Refined Offline Det; 100% Volume	
Alt3d	Refined Offline Det; 75% Volume	
Alt4a	1a+2a+3a	
Alt5a	1a+2a	
Alt6a	1a+3a	
Alt6b	1a+ Kuykendahl+FM2920+M120	
Alt6c	6b, lower spill	
Alt6d	1a+FM2920+M120	
Alt6e	1a+M120	
Alt6f	1a+Kuykendahl+FM2920	
Alt6g	1a+Kuykendahl	
Alt6h	1a+Kuykendahl+FM2920	
Alt6i	1a+Kuykendahl+FM2920+M112	
Alt6j	1a+ Kuykendahl+FM2920+M120+BNRR	
Alt6k	1a+ Kuykendahl+FM2920+M120+M121	
Alt6l	1a+ Kuykendahl+FM2920+M120+BNRR+M121	
Alt6m	1c+3d	Recommended Plan
Alt6n	1c+ Kuykendahl+FM2920+M120+M121	Recommended Plan Initial Phase
Alt6o	1c + M120	
Alt6p	1c + Kuykendahl	
M120	Refined M120 Detention/Preservation Site	
M120-a	M120; 100% volume	
M120-b	M120; lower spill	
M120-c	M120; higher spill	M120 Detention Site Immediate Project
M120-d	M120; shorter weir	
M120-e	M120; higher spill and shorter weir (c+d)	

D. Detention Basin-Preservation Analysis Information

Work maps of each site are in TM-3, Appendix C.

All nine sites were evaluated as offline detention basins, whereby inflow would begin at a higher water level. The purpose is to begin storing storm water at a specified elevation, which reserves storage in the detention basin when it is needed the most.

These sites along Willow Creek are recommended to:

- reduce flood flows and water levels even further in coordination with the selective clearing
- preserve forests areas along Willow Creek to safeguard the existing aquatic, riparian, and upland habitats and minimize creek erosion.
- preserve existing floodplain areas to maintain their flood level reduction benefits and to prevent filling from future development (most of this site is relatively deep in the floodplain).
- Provide outdoor recreation opportunities to the public

The nine detention basins' preliminary volumes were estimated based on the design procedures recommended in the latest HCFCD Policy, Criteria, and Procedure Manual (PCPM) and HCFCD regional detention basin design parameters that typically exceed the minimums in the PCPM. The assumptions adopted are listed in the following table:

Detention Basin Parameter	Assumption
Side Slope	4:1
Volume Contingency %	25%
Berm Width	50 feet
Permanent Pool Depth	3 feet
Clearance between Outfall Pipe and Channel Bottom	2 feet
Pond Initial Condition	Wet

The detention volumes calculated for the hydraulic analysis are reduced by 25 % to account for contingencies due to land acquisition, excavation, utility conflicts, and other reasons. The proposed basins at this planning analysis phase have a wet bottom to maximize the available detention volume. The average detention bottom is 3 feet below the permanent pool elevation, resulting in higher excavation volumes compared to the available storage volume.

The stage-storage values utilized in the hydraulic model for each basin are presented in the tables below:

Kuykendahl Detention Basin

Description	Elevation (ft)	Cumulative Volume (ac-ft)	75% Volume (ac-ft)
Permanent Pool Elevation	117	0	0
Slope	118	31	24
Slope	119	63	47
Slope	120	96	72
Slope	121	128	96
Slope	122	162	121
Slope	123	196	147
Slope	124	230	172
Slope	125	265	198
Slope	126	300	225
Slope	127	336	252
Slope	128	372	279
Slope	129	409	306
Slope	130	446	334
Top of Pond	131	484	363

M112-North Detention Basin

Description	Elevation (ft)	Cumulative Volume (ac-ft)	75% Volume (ac-ft)
Permanent Pool Elevation	121	0	0
Slope	122	10	7
Slope	123	20	15
Slope	124	30	23
Slope	125	41	31
Slope	126	52	39
Slope	127	64	48
Slope	128	76	57
Slope	129	88	66
Slope	130	101	75
Slope	131	113	85
Slope	132	127	95
Slope	133	140	105
Top of Pond	134	154	116

M112-South Detention Basin

Description	Elevation (ft)	Cumulative Volume (ac-ft)	75% Volume (ac-ft)
Permanent Pool Elevation	121	0	0
Slope	122	6	5
Slope	123	13	10
Slope	124	20	15
Slope	125	27	20
Slope	126	34	26
Slope	127	42	32
Slope	128	50	38
Slope	129	58	44
Slope	130	67	50
Slope	131	76	57
Slope	132	85	64
Top of Pond	133	95	71

FM 2920 Detention Basin

Description	Elevation (ft)	Cumulative Volume (ac-ft)	75% Volume (ac-ft)
Permanent Pool Elevation	126	0	0
Slope	127	50	38
Slope	128	101	76
Slope	129	153	115
Slope	130	205	154
Slope	131	257	193
Slope	132	310	233
Slope	133	364	273
Slope	134	418	314
Slope	135	473	355
Slope	136	529	397
Slope	137	585	439
Top of Pond	142	845	634

M116 Detention Basin

Description	Elevation (ft)	Cumulative Volume (ac-ft)	75% Volume (ac-ft)
Permanent Pool Elevation	131	0	0
Slope	132	8	6
Slope	133	16	12
Slope	134	24	18
Slope	135	32	24
Slope	136	41	31
Slope	137	50	38
Slope	138	59	45
Slope	139	69	52
Slope	140	79	59
Slope	141	89	67
Slope	142	99	74
Top of Pond	144	115	86

M120 Detention Basin *(modified during Immediate Project refinement)*

Description	Elevation (ft)	Cumulative Volume (ac-ft)	75% Volume (ac-ft)
Permanent Pool Elevation	136	0	0
Slope	137	103	77
Slope	138	207	155
Slope	139	311	234
Slope	140	417	313
Slope	141	524	393
Slope	142	632	474
Slope	143	741	556
Slope	144	851	638
Slope	145	962	722
Slope	146	1074	806
Slope	147	1188	891
Slope	148	1302	977
Top of Pond	149	1417	1063

BNRR Detention Basin

Description	Elevation (ft)	Cumulative Volume (ac-ft)	75% Volume (ac-ft)
Permanent Pool Elevation	140	0	0
Slope	141	54	40
Slope	142	109	81
Slope	143	164	123
Slope	144	220	165
Slope	145	277	207
Slope	146	334	250
Top of Pond	147	392	294

M121 Detention Basin

Description	Elevation (ft)	Cumulative Volume (ac-ft)	75% Volume (ac-ft)
Permanent Pool Elevation	145	0	0
Slope	146	75	56
Slope	147	151	113
Slope	148	228	171
Slope	149	306	229
Slope	150	384	288
Slope	151	464	348
Slope	152	544	408
Slope	153	625	469
Slope	154	708	531
Top of Pond	155	791	593

Willow Flats North and Willow Flats South Detention Basins

Due to the relative flat topography, the HEC-RAS cross-sections were modified based on the detention basin geometry.

E. Cost Estimate Summaries

Alternative 1C: Selective Clearing - Roughly 100± feet Outside Channel Banks, Both Sides

Item #	Description	Qty (ac)	Qty (sf)	Unit Price ($/sf)	Cost
1	Land Acquisition	110	4,782,757	$2.16	$10,330,755
2	Selective Clearing	250	--	$4,320.00	$1,080,000
	Total Cost				$11,410,755

Use $12,000,000

Note:
Used 3.0 multiplier (HCAD average = $0.72) to account for purchasing some ROW to parcel boundary.

Selective Clearing Area Estimates	Area (acres)
Total Area	278
Area in Existing Detn Basins	30
Area to be Cleared	**249**
Area within Existing ROW	139
Area Outside Existing ROW to be Acquired	**110**

Selective Clearing Work Cost Estimate (HCFCD Maintenance Division unit costs)

Selective Clearing		$2,220	per acre
Est removing 12 trees/acre @ $115/tree		$1,380	per acre
	Total	$3,600	per acre
		1.2	x Contingency
	Use	**$4,320**	**per acre**

Alternative 3D: Nine Regional Detention and Preservation Sites on Willow Creek

Cost Summary Table

Basin Location	Land	Excavation	Pipeline Adj	Non-Excav. Constr	Basin Total	Basin Total Rounded
Kuykendahl	$12,998,844	$14,074,720	$652,800	$1,829,714	$29,556,078	$29.6
M112	$2,414,966	$6,737,280	$532,800	$875,846	$10,560,893	$10.6
FM 2920	$9,450,281	$15,991,360	$1,248,000	$2,078,877	$28,768,518	$28.8
M116	$2,851,220	$2,342,560	$1,152,000	$304,533	$6,650,313	$6.7
M120	$27,316,672	$33,260,480	$0	$4,323,862	$64,901,014	$64.9
BNRR	$3,282,459	$13,648,800	$1,056,000	$1,774,344	$19,761,603	$19.8
M121	$5,771,983	$19,553,600	$2,688,000	$2,541,968	$30,555,551	$30.6
W.F. North	$7,066,599	$8,324,800	$1,872,000	$1,082,224	$18,345,623	$18.3
W.F. South	$21,510,416	$16,184,960	$235,200	$2,104,045	$40,034,621	$40.0
Item Totals	$92,663,441	$130,118,560	$9,436,800	$16,915,413	$249,134,214	$249.1
Item Totals Rounded	$92.7	$130.1	$9.4	$16.9	$249.1	

Land Area (ac)	Cost/SF x 2.5	Excavation (ac-ft)	Total Cost /ac-ft
67	$ 4.44	727	$40,655
72	$ 0.77	348	$30,347
110	$ 1.98	826	$34,829
69	$ 0.95	121	$54,961
300	$ 2.09	1718	$37,777
112	$ 0.67	705	$28,031
156	$ 0.85	1010	$30,253
150	$ 1.08	430	$42,664
285	$ 1.73	836	$47,888
1,322	$1.62	6,721	$37,068
	Numeric Average		

Individual Basin/Preservation Site – Kuykendahl

Kuykendahl Total Cost					Contingency and	Total Cost Est
Item #	Description	Qty	Unit Price	Cost	Professional Services	
1	Land Acquisition (ac), ($/sf)	67	$ 4.44	$12,998,844	0	$12,998,844.14
2	Excavation (ac-ft), ($/cy)	727	$ 12.00	$14,074,720	0	$14,074,720.00
3	Pipeline Adjustments (lf), ($/lf)	1360	$ 320.00	$435,200	50%	$652,800.00
4	Non-Excavation Constrution			$1,407,472	30%	$1,829,713.60
Total Cost				$28,916,236		$29,556,078

Notes for all tables:

Land acquisition contingency built into 2.5 multiplier
Highest excavation unit cost used, so no contingency used
Non-Excavation Construction = 10% of excavation cost

Individual Basin/Preservation Site – M112

M112 - Total Cost					Contingency and	Total Cost Est
Item #	Description	Qty	Unit Price	Cost	Professional Services	
1	Land Acquisition (ac), ($/sf)	72	$ 0.77	$2,414,966	0	$2,414,966.40
2	Excavation (ac-ft), ($/cy)	348	$ 12.00	$6,737,280	0	$6,737,280.00
3	Pipeline Adjustments (lf), ($/lf)	1110	$ 320.00	$355,200	50%	$532,800.00
4	Non-Excavation Constrution			$673,728	30%	$875,846.40
Total Cost				$10,181,174		$10,560,893

Individual Basin/Preservation Site – FM 2920

FM2920 Total Cost					Contingency and	Total Cost Est
Item #	Description	Qty	Unit Price	Cost	Professional Services	
1	Land Acquisition (ac), ($/sf)	110	$ 1.98	$9,450,281	0	$9,450,281.02
2	Excavation (ac-ft), ($/cy)	826	$ 12.00	$15,991,360	0	$15,991,360.00
3	Pipeline Adjustments (lf), ($/lf)	2600	$ 320.00	$832,000	50%	$1,248,000.00
4	Non-Excavation Constrution			$1,599,136	30%	$2,078,876.80
Total Cost				$27,872,777		$28,768,518

Individual Basin/Preservation Site – M116

M116 Total Cost					Contingency and	Total Cost Est
Item #	Description	Qty	Unit Price	Cost	Professional Services	
1	Land Acquisition (ac), ($/sf)	69	$ 0.95	$2,851,220	0	$2,851,219.80
2	Excavation (ac-ft), ($/cy)	121	$ 12.00	$2,342,560	0	$2,342,560.00
3	Pipeline Adjustments (lf), ($/lf)	2400	$ 320.00	$768,000	50%	$1,152,000.00
4	Non-Excavation Constrution			$234,256	30%	$304,532.80
Total Cost				$6,196,036		$6,650,313

Individual Basin/Preservation Site – M120

M120 Total Cost					Contingency and	Total Cost Est
Item #	Description	Qty	Unit Price	Cost	Professional Services	
1	Land Acquisition (ac), ($/sf)	300	$ 2.09	$27,316,672	0	$27,316,672.02
2	Excavation (ac-ft), ($/cy)	1718	$ 12.00	$33,260,480	0	$33,260,480.00
3	Pipeline Adjustments (lf), ($/lf)	0	$ 320.00	$0	50%	$0.00
4	Non-Excavation Constrution			$3,326,048	30%	$4,323,862.40
Total Cost				$63,903,200		$64,901,014

Individual Basin/Preservation Site – BNRR

BNRR Total Cost					Contingency and	Total Cost Est
Item #	Description	Qty	Unit Price	Cost	Professional Services	
1	Land Acquisition (ac), ($/sf)	112	$ 0.67	$3,282,459	0	$3,282,459.44
2	Excavation (ac-ft), ($/cy)	705	$ 12.00	$13,648,800	0	$13,648,800.00
3	Pipeline Adjustments (lf), ($/lf)	2200	$ 320.00	$704,000	50%	$1,056,000.00
4	Non-Excavation Constrution			$1,364,880	30%	$1,774,344.00
Total Cost				$19,000,139		$19,761,603

Individual Basin/Preservation Site – M121

M121 Total Cost					Contingency and	Total Cost Est
Item #	Description	Qty	Unit Price	Cost	Professional Services	
1	Land Acquisition (ac), ($/sf)	156	$ 0.85	$5,771,983	0	$5,771,983.14
2	Excavation (ac-ft), ($/cy)	1010	$ 12.00	$19,553,600	0	$19,553,600.00
3	Pipeline Adjustments (lf), ($/lf)	5600	$ 320.00	$1,792,000	50%	$2,688,000.00
4	Non-Excavation Constrution			$1,955,360	30%	$2,541,968.00
Total Cost				$29,072,943		$30,555,551

Individual Basin/Preservation Site – W.F.North

Willow Flats - North Total Cost					Contingency and	Total Cost Est
Item #	Description	Qty	Unit Price	Cost	Professional Services	
1	Land Acquisition (ac), ($/sf)	150	$ 1.08	$7,066,599	0	$7,066,599.41
2	Excavation (ac-ft), ($/cy)	430	$ 12.00	$8,324,800	0	$8,324,800.00
3	Pipeline Adjustments (lf), ($/lf)	3900	$ 320.00	$1,248,000	50%	$1,872,000.00
4	Non-Excavation Constrution			$832,480	30%	$1,082,224.00
Total Cost				$17,471,879		$18,345,623

Individual Basin/Preservation Site – W.F.South

Willow Flats - South Total Cost					Contingency and	Total Cost Est
Item #	Description	Qty	Unit Price	Cost	Professional Services	
1	Land Acquisition (ac), ($/sf)	285	$ 1.73	$21,510,416	0	$21,510,415.87
2	Excavation (ac-ft), ($/cy)	836	$ 12.00	$16,184,960	0	$16,184,960.00
3	Pipeline Adjustments (lf), ($/lf)	490	$ 320.00	$156,800	50%	$235,200.00
4	Non-Excavation Constrution			$1,618,496	30%	$2,104,044.80
Total Cost				$39,470,672		$40,034,621

F. Summary Project Scoring Tables

Preliminary Alternatives

Alternative 1a

Harris County Flood Control District Project Scoring Form
Scenario #1 (100-Year Event) SUMMARY - Alt. 1a

		SCORING CRITERIA:		1	2	3	4	5	6	7	8		
		Weight:		25%	20%	20%	10%	10%	5%	5%	5%		
Original Problem Area Name	Problem Area:	Project ID:	Tier:	Flood Risk (100-Year Event) Reduction	Existing Conditions Drainage LOS	Social Vulnerability Index (SVI)	Project Efficiency	Partnership Funding	Long Term Maintenance Costs	Minimize Environmental Impacts	Potential for Multiple Benefits	TOTAL SCORE	Channel / Trib
M100-PA07	PA-01	M100-WP01	1	1.50	2.00	1.40	0.20	0.00	0.50	0.50	0.50	6.60	M100
M100-PA02	PA-02	M100-WP02	1	1.50	2.00	0.80	0.20	0.00	0.50	0.50	0.50	6.00	M100
M100-PA01	PA-03	M100-WP03	1	0.75	2.00	0.20	1.00	0.00	0.50	0.50	0.50	5.45	M100
M100-PA06	PA-04	M100-WP04	1	0.75	2.00	0.80	0.20	0.00	0.50	0.50	0.50	5.25	M100
M103-PA01	PA-05	M103-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M103
M109-PA01	PA-06	M109-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M109
M121-PA01	PA-07	M121-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M121
M100-PA03*	PA-08	M100-WP05	2	1.50	2.00	0.80	0.20	0.00	0.50	0.50	0.50	6.00	M100
M124-PA02	PA-09	M124-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M100-PA05	PA-10	M100-WP06	3	0.00	2.00	0.80	0.20	0.00	0.50	0.50	0.50	4.50	M100
M128-PA01	PA-11	M128-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M128
M100-PA04*	PA-12	M100-WP07	3	1.50	2.00	0.80	0.20	0.00	0.50	0.50	0.50	6.00	M100
M124-PA01	PA-13	M124-WP02	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M112-PA01	PA-14	M112-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M112
All 7 PAs	7-PAs	M100-Many		1.50	2.00	1.10	0.40	0.00	0.50	0.50	0.50	6.50	M100
Main Stem	All	M100-All		1.50	2.00	1.10	0.60	0.00	0.50	0.50	0.50	6.70	M100

Harris County Flood Control District Project Scoring Form
Scenario #2 (PSF50) SUMMARY - Alt. 1a

		SCORING CRITERIA:		1	2	3	4	5	6	7	8		
		Weight:		25%	20%	20%	10%	10%	5%	5%	5%		
Original Problem Area Name	Problem Area:	Project ID:	Tier:	Flood Risk (100-Year Event) Reduction	Existing Conditions Drainage LOS	Social Vulnerability Index (SVI)	Project Efficiency	Partnership Funding	Long Term Maintenance Costs	Minimize Environmental Impacts	Potential for Multiple Benefits	TOTAL SCORE	Channel / Trib
M100-PA07	PA-01	M100-WP01	1	1.50	2.00	1.40	0.40	0.00	0.50	0.50	0.50	6.80	M100
M100-PA02	PA-02	M100-WP02	1	1.50	2.00	0.80	0.40	0.00	0.50	0.50	0.50	6.20	M100
M100-PA01	PA-03	M100-WP03	1	1.50	2.00	0.20	0.20	0.00	0.50	0.50	0.50	5.40	M100
M100-PA06	PA-04	M100-WP04	1	0.75	2.00	0.80	0.20	0.00	0.50	0.50	0.50	5.25	M100
M103-PA01	PA-05	M103-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M103
M109-PA01	PA-06	M109-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M109
M121-PA01	PA-07	M121-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M121
M100-PA03	PA-08	M100-WP05	2	1.50	2.00	0.80	0.20	0.00	0.50	0.50	0.50	6.00	M100
M124-PA02	PA-09	M124-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M100-PA05	PA-10	M100-WP06	3	0.75	2.00	0.80	0.20	0.00	0.50	0.50	0.50	5.25	M100
M128-PA01	PA-11	M128-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M128
M100-PA04	PA-12	M100-WP07	3	1.50	2.00	0.80	0.20	0.00	0.50	0.50	0.50	6.00	M100
M124-PA01	PA-13	M124-WP02	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M112-PA01	PA-14	M112-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M112
All 7 PAs	7 - PAs	M100-Many		1.50	2.00	1.10	0.60	0.00	0.50	0.50	0.50	6.70	M100
Main Stem	All	M100-All		1.50	2.00	1.10	1.00	0.00	0.50	0.50	0.50	7.10	M100

Alternative 2a

Harris County Flood Control District Project Scoring Form

Scenario #1 (100-Year Event) SUMMARY - Alt. 2a

		SCORING CRITERIA:		1	2	3	4	5	6	7	8		
		Weight:		25%	20%	20%	10%	10%	5%	5%	5%		
Original Problem Area Name	Problem Area:	Project ID:	Tier:	Flood Risk (100-Year Event) Reduction	Existing Conditions Drainage LOS	Social Vulnerability Index (SVI)	Project Efficiency	Partnership Funding	Long Term Maintenance Costs	Minimize Environmental Impacts	Potential for Multiple Benefits	TOTAL SCORE	Channel / Trib
M100-PA07	PA-01	M100-WP01	1	0.00	2.00	1.40	0.20	0.00	0.50	0.30	0.20	4.60	M100
M100-PA02	PA-02	M100-WP02	1	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.20	5.50	M100
M100-PA01	PA-03	M100-WP03	1	0.75	2.00	0.20	1.00	0.00	0.50	0.30	0.20	4.95	M100
M100-PA06	PA-04	M100-WP04	1	0.00	2.00	0.80	0.20	0.00	0.50	0.30	0.20	4.00	M100
M103-PA01	PA-05	M103-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M103
M109-PA01	PA-06	M109-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M109
M121-PA01	PA-07	M121-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M121
M100-PA03*	PA-08	M100-WP05	2	0.75	2.00	0.80	0.20	0.00	0.50	0.30	0.20	4.75	M100
M124-PA02	PA-09	M124-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M100-PA05	PA-10	M100-WP06	3	0.00	2.00	0.80	0.20	0.00	0.50	0.30	0.20	4.00	M100
M128-PA01	PA-11	M128-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M128
M100-PA04[1]	PA-12	M100-WP07	3	0.00	2.00	0.80	0.20	0.00	0.50	0.30	0.20	4.00	M100
M124-PA01	PA-13	M124-WP02	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M112-PA01	PA-14	M112-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M112
All 7 PAs	7 - PAs	M100-Many		0.75	2.00	1.10	0.20	0.00	0.50	0.30	0.20	5.05	M100
Main Stem	All	M100-All		0.75	2.00	1.10	0.20	0.00	0.50	0.30	0.20	5.05	M100

Harris County Flood Control District Project Scoring Form

Scenario #2 (PSF50) SUMMARY - Alt. 2a

		SCORING CRITERIA:		1	2	3	4	5	6	7	8		
		Weight:		25%	20%	20%	10%	10%	5%	5%	5%		
Original Problem Area Name	Problem Area:	Project ID:	Tier:	Flood Risk (100-Year Event) Reduction	Existing Conditions Drainage LOS	Social Vulnerability Index (SVI)	Project Efficiency	Partnership Funding	Long Term Maintenance Costs	Minimize Environmental Impacts	Potential for Multiple Benefits	TOTAL SCORE	Channel / Trib
M100-PA07	PA-01	M100-WP01	1	0.00	2.00	1.40	0.20	0.00	0.50	0.30	0.20	4.60	M100
M100-PA02	PA-02	M100-WP02	1	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.20	5.50	M100
M100-PA01	PA-03	M100-WP03	1	0.75	2.00	0.20	1.00	0.00	0.50	0.30	0.20	4.95	M100
M100-PA06	PA-04	M100-WP04	1	0.75	2.00	0.80	0.20	0.00	0.50	0.30	0.20	4.75	M100
M103-PA01	PA-05	M103-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M103
M109-PA01	PA-06	M109-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M109
M121-PA01	PA-07	M121-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M121
M100-PA03	PA-08	M100-WP05	2	0.75	2.00	0.80	0.20	0.00	0.50	0.30	0.20	4.75	M100
M124-PA02	PA-09	M124-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M100-PA05	PA-10	M100-WP06	3	0.00	2.00	0.80	0.20	0.00	0.50	0.30	0.20	4.00	M100
M128-PA01	PA-11	M128-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M128
M100-PA04	PA-12	M100-WP07	3	0.00	2.00	0.80	0.20	0.00	0.50	0.30	0.20	4.00	M100
M124-PA01	PA-13	M124-WP02	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M112-PA01	PA-14	M112-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M112
All 7 Pas	7 - PAs	M100-Many		0.75	2.00	1.10	0.20	0.00	0.50	0.30	0.20	5.05	M100
Main Stem	All	M100-All		0.75	2.00	1.10	0.20	0.00	0.50	0.30	0.20	5.05	M100

Alternative 3a

Harris County Flood Control District Project Scoring Form

Scenario #1 (100-Year Event) SUMMARY - Alt. 3a

		SCORING CRITERIA:		1	2	3	4	5	6	7	8		
		Weight:		25%	20%	20%	10%	10%	5%	5%	5%		
Original Problem Area Name	Problem Area:	Project ID:	Tier:	Flood Risk (100-Year Event) Reduction	Existing Conditions Drainage LOS	Social Vulnerability Index (SVI)	Project Efficiency	Partnership Funding	Long Term Maintenance Costs	Minimize Environmental Impacts	Potential for Multiple Benefits	TOTAL SCORE	Channel / Trib
M100-PA07	PA-01	M100-WP01	1	2.00	2.00	1.40	0.20	0.00	0.50	0.30	0.30	6.70	M100
M100-PA02	PA-02	M100-WP02	1	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	5.60	M100
M100-PA01	PA-03	M100-WP03	1	1.50	2.00	0.20	0.20	0.00	0.50	0.30	0.30	5.00	M100
M100-PA06	PA-04	M100-WP04	1	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	5.60	M100
M103-PA01	PA-05	M103-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M103
M109-PA01	PA-06	M109-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M109
M121-PA01	PA-07	M121-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M121
M100-PA03*	PA-08	M100-WP05	2	2.00	2.00	0.80	0.20	0.00	0.50	0.30	0.30	6.10	M100
M124-PA02	PA-09	M124-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M100-PA05	PA-10	M100-WP06	3	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	5.60	M100
M128-PA01	PA-11	M128-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M128
M100-PA04*	PA-12	M100-WP07	3	2.00	2.00	0.80	0.20	0.00	0.50	0.30	0.30	6.10	M100
M124-PA01	PA-13	M124-WP02	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M112-PA01	PA-14	M112-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M112
All 7 PAs	7 - PAs	M100-Many		2.00	2.00	1.10	0.20	0.00	0.50	0.30	0.30	6.40	M100
Main Stem	All	M100-All		2.00	2.00	1.10	0.20	0.00	0.50	0.30	0.30	6.40	M100

Harris County Flood Control District Project Scoring Form

Scenario #2 (PSF50) SUMMARY - Alt. 3a

		SCORING CRITERIA:		1	2	3	4	5	6	7	8		
		Weight:		25%	20%	20%	10%	10%	5%	5%	5%		
Original Problem Area Name	Problem Area:	Project ID:	Tier:	Flood Risk (100-Year Event) Reduction	Existing Conditions Drainage LOS	Social Vulnerability Index (SVI)	Project Efficiency	Partnership Funding	Long Term Maintenance Costs	Minimize Environmental Impacts	Potential for Multiple Benefits	TOTAL SCORE	Channel / Trib
M100-PA07	PA-01	M100-WP01	1	2.00	2.00	1.40	0.20	0.00	0.50	0.30	0.30	6.70	M100
M100-PA02	PA-02	M100-WP02	1	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	5.60	M100
M100-PA01	PA-03	M100-WP03	1	1.50	2.00	0.20	0.20	0.00	0.50	0.30	0.30	5.00	M100
M100-PA06	PA-04	M100-WP04	1	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	5.60	M100
M103-PA01	PA-05	M103-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M103
M109-PA01	PA-06	M109-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M109
M121-PA01	PA-07	M121-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M121
M100-PA03	PA-08	M100-WP05	2	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	5.60	M100
M124-PA02	PA-09	M124-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M100-PA05	PA-10	M100-WP06	3	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	5.60	M100
M128-PA01	PA-11	M128-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M128
M100-PA04	PA-12	M100-WP07	3	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	5.60	M100
M124-PA01	PA-13	M124-WP02	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M112-PA01	PA-14	M112-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M112
All 7 PAs	7 - PAs	M100-Many		2.00	2.00	1.10	0.20	0.00	0.50	0.30	0.30	6.40	M100
Main Stem	All	M100-All		2.50	2.00	1.10	0.20	0.00	0.50	0.30	0.30	6.90	M100

Alternative 4a

Harris County Flood Control District Project Scoring Form

Scenario #1 (100-Year Event) SUMMARY - Alt. 4a

		SCORING CRITERIA:		1	2	3	4	5	6	7	8		
		Weight:		25%	20%	20%	10%	10%	5%	5%	5%		
Original Problem Area Name	Problem Area:	Project ID:	Tier:	Flood Risk (100-Year Event) Reduction	Existing Conditions Drainage LOS	Social Vulnerability Index (SVI)	Project Efficiency	Partnership Funding	Long Term Maintenance Costs	Minimize Environmental Impacts	Potential for Multiple Benefits	TOTAL SCORE	Channel / Trib
M100-PA07	PA-01	M100-WP01	1	2.50	2.00	1.40	0.20	0.00	0.50	0.30	0.30	7.20	M100
M100-PA02	PA-02	M100-WP02	1	2.00	2.00	0.80	0.20	0.00	0.50	0.30	0.30	6.10	M100
M100-PA01	PA-03	M100-WP03	1	1.50	2.00	0.20	0.20	0.00	0.50	0.30	0.30	5.00	M100
M100-PA06	PA-04	M100-WP04	1	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	5.60	M100
M103-PA01	PA-05	M103-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M103
M109-PA01	PA-06	M109-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M109
M121-PA01	PA-07	M121-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M121
M100-PA03*	PA-08	M100-WP05	2	2.00	2.00	0.80	0.20	0.00	0.50	0.30	0.30	6.10	M100
M124-PA02	PA-09	M124-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M100-PA05	PA-10	M100-WP06	3	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	5.60	M100
M128-PA01	PA-11	M128-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M128
M100-PA04*	PA-12	M100-WP07	3	2.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	6.60	M100
M124-PA01	PA-13	M124-WP02	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M112-PA01	PA-14	M112-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M112
All 7 PAs	7 - PAs	M100-Many		2.00	2.00	1.10	0.20	0.00	0.50	0.30	0.30	6.40	M100
Main Stem	All	M100-All		2.50	2.00	1.10	0.20	0.00	0.50	0.30	0.30	6.90	M100

Harris County Flood Control District Project Scoring Form

Scenario #2 (PSF50) SUMMARY - Alt. 4a

		SCORING CRITERIA:		1	2	3	4	5	6	7	8		
		Weight:		25%	20%	20%	10%	10%	5%	5%	5%		
Original Problem Area Name	Problem Area:	Project ID:	Tier:	Flood Risk (100-Year Event) Reduction	Existing Conditions Drainage LOS	Social Vulnerability Index (SVI)	Project Efficiency	Partnership Funding	Long Term Maintenance Costs	Minimize Environmental Impacts	Potential for Multiple Benefits	TOTAL SCORE	Channel / Trib
M100-PA07	PA-01	M100-WP01	1	2.00	2.00	1.40	0.20	0.00	0.50	0.30	0.30	6.70	M100
M100-PA02	PA-02	M100-WP02	1	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	5.60	M100
M100-PA01	PA-03	M100-WP03	1	1.50	2.00	0.20	0.20	0.00	0.50	0.30	0.30	5.00	M100
M100-PA06	PA-04	M100-WP04	1	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	5.60	M100
M103-PA01	PA-05	M103-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M103
M109-PA01	PA-06	M109-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M109
M121-PA01	PA-07	M121-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M121
M100-PA03	PA-08	M100-WP05	2	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	5.60	M100
M124-PA02	PA-09	M124-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M100-PA05	PA-10	M100-WP06	3	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	5.60	M100
M128-PA01	PA-11	M128-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M128
M100-PA04	PA-12	M100-WP07	3	2.00	2.00	0.80	0.20	0.00	0.50	0.30	0.30	6.10	M100
M124-PA01	PA-13	M124-WP02	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M112-PA01	PA-14	M112-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M112
All 7 PAs	7 - PAs	M100-Many		2.00	2.00	1.10	0.20	0.00	0.50	0.30	0.30	6.40	M100
Main Stem	All	M100-All		2.50	2.00	1.10	0.20	0.00	0.50	0.30	0.30	6.90	M100

Alternative 5a

Harris County Flood Control District Project Scoring Form

Scenario #1 (100-Year Event) SUMMARY - Alt. 5a

		SCORING CRITERIA:		1	2	3	4	5	6	7	8		
		Weight:		25%	20%	20%	10%	10%	5%	5%	5%		
Original Problem Area Name	Problem Area:	Project ID:	Tier:	Flood Risk (100-Year Event) Reduction	Existing Conditions Drainage LOS	Social Vulnerability Index (SVI)	Project Efficiency	Partnership Funding	Long Term Maintenance Costs	Minimize Environmental Impacts	Potential for Multiple Benefits	TOTAL SCORE	Channel / Trib
M100-PA07	PA-01	M100-WP01	1	1.50	2.00	1.40	0.20	0.00	0.50	0.50	0.50	6.60	M100
M100-PA02	PA-02	M100-WP02	1	1.50	2.00	0.80	0.20	0.00	0.50	0.50	0.50	6.00	M100
M100-PA01	PA-03	M100-WP03	1	1.50	2.00	0.20	0.20	0.00	0.50	0.50	0.50	5.40	M100
M100-PA06	PA-04	M100-WP04	1	0.75	2.00	0.80	0.20	0.00	0.50	0.50	0.50	5.25	M100
M103-PA01	PA-05	M103-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M103
M109-PA01	PA-06	M109-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M109
M121-PA01	PA-07	M121-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M121
M100-PA03*	PA-08	M100-WP05	2	1.50	2.00	0.80	0.20	0.00	0.50	0.50	0.50	6.00	M100
M124-PA02	PA-09	M124-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M100-PA05	PA-10	M100-WP06	3	0.00	2.00	0.80	0.20	0.00	0.50	0.50	0.50	4.50	M100
M128-PA01	PA-11	M128-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M128
M100-PA04*	PA-12	M100-WP07	3	1.50	2.00	0.80	0.20	0.00	0.50	0.50	0.50	6.00	M100
M124-PA01	PA-13	M124-WP02	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M112-PA01	PA-14	M112-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M112
All 7 - PAs	7 - PAs	M100-Many		1.50	2.00	1.10	0.40	0.00	0.50	0.50	0.50	6.50	M100
Main Stem	All	M100-All		1.50	2.00	1.10	0.40	0.00	0.50	0.50	0.50	6.50	M100

Harris County Flood Control District Project Scoring Form

Scenario #2 (PSF50) SUMMARY - Alt. 5a

		SCORING CRITERIA:		1	2	3	4	5	6	7	8		
		Weight:		25%	20%	20%	10%	10%	5%	5%	5%		
Original Problem Area Name	Problem Area:	Project ID:	Tier:	Flood Risk (100-Year Event) Reduction	Existing Conditions Drainage LOS	Social Vulnerability Index (SVI)	Project Efficiency	Partnership Funding	Long Term Maintenance Costs	Minimize Environmental Impacts	Potential for Multiple Benefits	TOTAL SCORE	Channel / Trib
M100-PA07	PA-01	M100-WP01	1	1.50	2.00	1.40	0.20	0.00	0.50	0.50	0.50	6.60	M100
M100-PA02	PA-02	M100-WP02	1	1.50	2.00	0.80	0.20	0.00	0.50	0.50	0.50	6.00	M100
M100-PA01	PA-03	M100-WP03	1	1.50	2.00	0.20	0.20	0.00	0.50	0.50	0.50	5.40	M100
M100-PA06	PA-04	M100-WP04	1	1.50	2.00	0.80	0.20	0.00	0.50	0.50	0.50	6.00	M100
M103-PA01	PA-05	M103-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M103
M109-PA01	PA-06	M109-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M109
M121-PA01	PA-07	M121-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M121
M100-PA03	PA-08	M100-WP05	2	1.50	2.00	0.80	0.20	0.00	0.50	0.50	0.50	6.00	M100
M124-PA02	PA-09	M124-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M100-PA05	PA-10	M100-WP06	3	0.00	2.00	0.80	0.20	0.00	0.50	0.50	0.50	4.50	M100
M128-PA01	PA-11	M128-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M128
M100-PA04	PA-12	M100-WP07	3	1.50	2.00	0.80	0.20	0.00	0.50	0.50	0.50	6.00	M100
M124-PA01	PA-13	M124-WP02	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M112-PA01	PA-14	M112-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M112
All 7 - PAs	7 - PAs	M100-Many		1.50	2.00	1.10	0.40	0.00	0.50	0.50	0.50	6.50	M100
Main Stem	All	M100-All		2.00	2.00	1.10	0.60	0.00	0.50	0.50	0.50	7.20	M100

Alternative 6a

Harris County Flood Control District Project Scoring Form

Scenario #1 (100-Year Event) SUMMARY - Alt. 6a

		SCORING CRITERIA:		1	2	3	4	5	6	7	8		
		Weight:		25%	20%	20%	10%	10%	5%	5%	5%		
Original Problem Area Name	Problem Area:	Project ID:	Tier:	Flood Risk (100-Year Event) Reduction	Existing Conditions Drainage LOS	Social Vulnerability Index (SVI)	Project Efficiency	Partnership Funding	Long Term Maintenance Costs	Minimize Environmental Impacts	Potential for Multiple Benefits	TOTAL SCORE	Channel / Trib
M100-PA07	PA-01	M100-WP01	1	2.50	2.00	1.40	0.20	0.00	0.50	0.30	0.30	7.20	M100
M100-PA02	PA-02	M100-WP02	1	2.00	2.00	0.80	0.20	0.00	0.50	0.30	0.30	6.10	M100
M100-PA01	PA-03	M100-WP03	1	1.50	2.00	0.20	0.20	0.00	0.50	0.30	0.30	5.00	M100
M100-PA06	PA-04	M100-WP04	1	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	5.60	M100
M103-PA01	PA-05	M103-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M103
M109-PA01	PA-06	M109-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M109
M121-PA01	PA-07	M121-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M121
M100-PA03*	PA-08	M100-WP05	2	2.00	2.00	0.80	0.20	0.00	0.50	0.30	0.30	6.10	M100
M124-PA02	PA-09	M124-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M100-PA05	PA-10	M100-WP06	3	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	5.60	M100
M128-PA01	PA-11	M128-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M128
M100-PA04*	PA-12	M100-WP07	3	2.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	6.60	M100
M124-PA01	PA-13	M124-WP02	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M112-PA01	PA-14	M112-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M112
All 7 PAs	7 - PAs	M100-Many		2.00	2.00	1.10	0.20	0.00	0.50	0.30	0.30	6.40	M100
Main Stem	All	M100-All		2.50	2.00	1.10	0.20	0.00	0.50	0.30	0.30	6.90	M100

Harris County Flood Control District Project Scoring Form

Scenario #2 (PSF50) SUMMARY - Alt. 6a

		SCORING CRITERIA:		1	2	3	4	5	6	7	8		
		Weight:		25%	20%	20%	10%	10%	5%	5%	5%		
Original Problem Area Name	Problem Area:	Project ID:	Tier:	Flood Risk (100-Year Event) Reduction	Existing Conditions Drainage LOS	Social Vulnerability Index (SVI)	Project Efficiency	Partnership Funding	Long Term Maintenance Costs	Minimize Environmental Impacts	Potential for Multiple Benefits	TOTAL SCORE	Channel / Trib
M100-PA07	PA-01	M100-WP01	1	2.00	2.00	1.40	0.20	0.00	0.50	0.30	0.30	6.70	M100
M100-PA02	PA-02	M100-WP02	1	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	5.60	M100
M100-PA01	PA-03	M100-WP03	1	2.00	2.00	0.20	0.20	0.00	0.50	0.30	0.30	5.50	M100
M100-PA06	PA-04	M100-WP04	1	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	5.60	M100
M103-PA01	PA-05	M103-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M103
M109-PA01	PA-06	M109-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M109
M121-PA01	PA-07	M121-WP01	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M121
M100-PA03	PA-08	M100-WP05	2	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	5.60	M100
M124-PA02	PA-09	M124-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M100-PA05	PA-10	M100-WP06	3	1.50	2.00	0.80	0.20	0.00	0.50	0.30	0.30	5.60	M100
M128-PA01	PA-11	M128-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M128
M100-PA04	PA-12	M100-WP07	3	2.00	2.00	0.80	0.20	0.00	0.50	0.30	0.30	6.10	M100
M124-PA01	PA-13	M124-WP02	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M124
M112-PA01	PA-14	M112-WP01	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	M112
All 7 PAs	7 - PAs	M100-Many		2.00	2.00	1.10	0.20	0.00	0.50	0.30	0.30	6.40	M100
Main Stem	All	M100-All		2.50	2.00	1.10	0.20	0.00	0.50	0.30	0.30	6.90	M100

Refined Alternatives

These summary Project Scoring Tables are for the entire main stem of Willow Creek.

Harris County Flood Control District Project Scoring Form

Scenario #1 (100-Year Event) SUMMARY

			1 25%	2 20%	3 20%	4 10%	5 10%	6 5%	7 5%	8 5%	
Alternative	Problem Area:	Project ID:	Flood Risk (100-Year Event) Reduction	Existing Conditions Drainage LOS	Social Vulnerability Index (SVI)	Project Efficiency	Partnership Funding	Long Term Maintenance Costs	Minimize Environmental Impacts	Potential for Multiple Benefits	TOTAL SCORE
1c	All	M100-All	1.50	2.00	1.10	0.60	0.00	0.50	0.50	0.50	6.70
3d	All	M100-All	1.50	2.00	1.10	0.20	0.00	0.50	0.30	0.30	5.90
6m	All	M100-All	2.00	2.00	1.10	0.20	0.00	0.50	0.30	0.30	6.40
6n	All	M100-All	1.50	2.00	1.10	0.20	0.00	0.50	0.30	0.30	5.90
M120	All	M100-All	1.50	2.00	1.10	0.20	0.00	0.50	0.30	0.30	5.90

Harris County Flood Control District Project Scoring Form

Scenario #2 (PSF50) SUMMARY

			1 25%	2 20%	3 20%	4 10%	5 10%	6 5%	7 5%	8 5%	
Alternative	Problem Area:	Project ID:	Flood Risk (PSF50 Event) Reduction	Existing Conditions Drainage LOS	Social Vulnerability Index (SVI)	Project Efficiency	Partnership Funding	Long Term Maintenance Costs	Minimize Environmental Impacts	Potential for Multiple Benefits	TOTAL SCORE
1c	All	M100-All	1.50	2.00	1.10	1.00	0.00	0.50	0.50	0.50	7.10
3d	All	M100-All	2.50	2.00	1.10	0.20	0.00	0.50	0.30	0.30	6.90
6m	All	M100-All	2.50	2.00	1.10	0.20	0.00	0.50	0.30	0.30	6.90
6n	All	M100-All	2.00	2.00	1.10	0.20	0.00	0.50	0.30	0.30	6.40
M120	All	M100-All	1.50	2.00	1.10	0.20	0.00	0.50	0.30	0.30	5.90

G. Proposed Holderrieth Road and Bridge Assessment

DANNENBAUM ENGINEERING
EXCELLENCE SINCE 1945

MEMORANDUM

DATE: November 20, 2020

TO: Kent Wu
HCFCD Study Manager

FROM: Steve Fitzgerald, P.E.
DEC Project Manager

RE: Willow Creek Watershed Planning Study
Proposed M120 Detention/Preservation Site and M100 Selective Clearing
Proposed Holderrieth Road and Bridge Assessment

Purpose: Summarize the evaluation of the proposed M120 Detention/Preservation and proposed Selective Clearing immediate projects with the currently proposed Harris County Holderrieth Road and Bridge project. Goal is to maximize benefits of the two HCFCD projects and for the proposed road and bridge to have no adverse impact on flood levels or the integrity of the channel itself. See Figures 1 and 2.

KIT Professionals Bridge Analysis: Per August 2019 drainage report, used effective 1D-steady HEC-RAS model and modified 2008 LIDAR to represent recent development.

Proposed Bridge: Span 285' at low chord, width 80', low chord elevation at center of bridge 153.5' and 151.3 at north end (effective 500-yr WSEL 151.1', M100 Study 100-yr WSEL 150.8-151.0. Effective floodway width is 680' between filled floodplains on both sides of Willow Creek).

Proposed Roadway: Total length ±1.55 miles, length of fill across Willow Creek floodplain ±1,500 feet (located where 150' wide road ROW proposed). Roadway generally follows existing topography through rest of the proposed M120 site to SH 99.

Proposed Mitigation: ±200' of channel concrete lining from 90' upstream to 25' downstream of bridge (used "n" = 0.013, HCFCD criteria is 0.015). ±250' of overbank clearing and grubbing from 90' upstream to 80' downstream of bridge (used "n" = 0.03, HCFCD criteria is 0.04).

DEC Bridge and Roadway Analysis: Used draft SJRWS 1D-unsteady HEC-RAS existing conditions model that includes 2018 LIDAR and Atlas-14 rainfall (base model was the effective 1D-steady HEC-RAS model). Imported six cross sections from KIT HEC-RAS model for the proposed Holderrieth bridge and roadway.

1

Results – Holderrieth Road and Existing Conditions: All three frequencies (2-yr, 10-yr, and 100-yr) show small WSEL reductions downstream (D/S) to the mouth, except just downstream of the proposed bridge as shown in table below.

Frequency	WSEL Increases	Location
10-yr	0.07'-0.09' increase	±350' D/S of bridge
100-yr	0.16'-0.18' increase	±350' D/S of bridge

WSEL increases D/S are likely due to higher velocities under new bridge (4.6 fps compared to about 2.2 fps). Energy grade lines are reasonable.

Results – Holderrieth Road and Proposed Selective Clearing: No 10-yr or 100-yr increases ±350' D/S of bridge. Small differences elsewhere, mostly beneficial.

Results – Holderrieth Road and Proposed M120 Detention Basin: Similar 10-yr increase, but no 100-yr increase ±350' D/S of bridge. Small WSEL reductions and flow decreases downstream to the mouth.

Observations:

- Clearing overbanks 80'-90' upstream and downstream of bridge is reasonable.
- Concrete channel lining potential issues → erosion and maintenance, transitioning back to existing earthen channel, and Section 404 permitting (no concrete lining is in the channel under existing bridges on Willow Creek)
- Bridge opening only ~40% of floodway width.
- Downstream flow beyond the south bank would be impeded for existing conditons and proposed selective clearing conditions.
- Some modeling refinements are suggested for the bridge and proposed channel modifications.
- Detention requirements for the proposed roadway and bridge could be coordinated with the proposed M120 site detention basin.
- Roadway drainage from the bridge to SH 99 could be coordinated with the proposed M120 site detention basin.

Figure 1. Proposed Bridge/Roadway and Selective Clearing
Yellow outline – Proposed bridge; Hatched area - proposed concrete lining; Red outline - Proposed clearing and grubbing; Green shading - Proposed selective clearing; Red cross sections - higher 10-yr and 100-yr WSEL

Figure 2. Proposed Bridge/Roadway and Floodway/Floodplain
Hatched area - effective FEMA floodway; Blue shading - 100-yr floodplain draft SJTWS 1D-unsteady HEC-RAS with 2018 LIDAR and Atlas-14 rainfall

H. Photos

Field photos taken during this study from November 2019 to November 2020 are provided in electronic files. Example photos are provided in this appendix.

IMG_20191101_112948.jpg
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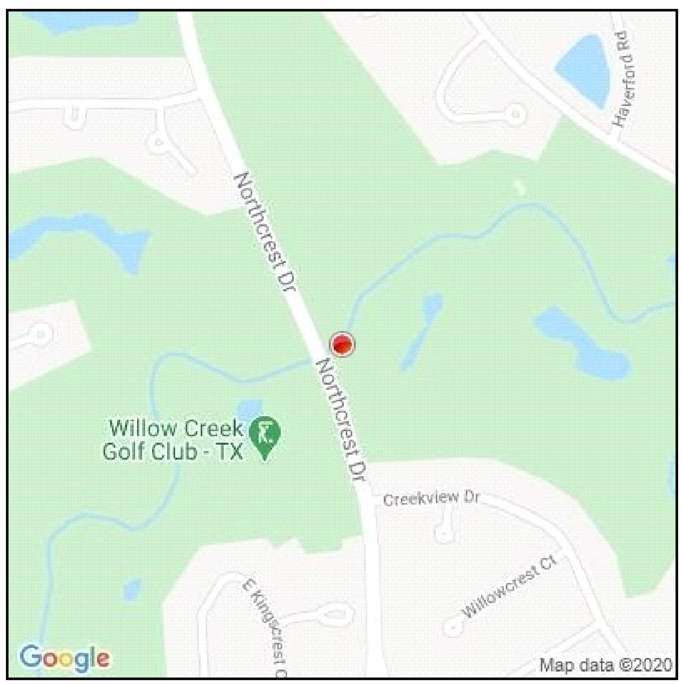

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EXCELLENCE SINCE 1945

IMG_5143.JPG
Title:

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ENGINEERING
EXCELLENCE SINCE 1945

Kuykendahl Bridge-looking downstream.jpg
Title:

DANNENBAUM ENGINEERING
EXCELLENCE SINCE 1945

IMG_6571.JPG
Title:

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EXCELLENCE SINCE 1945

IMG_20200227_111341.jpg
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EXCELLENCE SINCE 1945

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ENGINEERING
EXCELLENCE SINCE 1945

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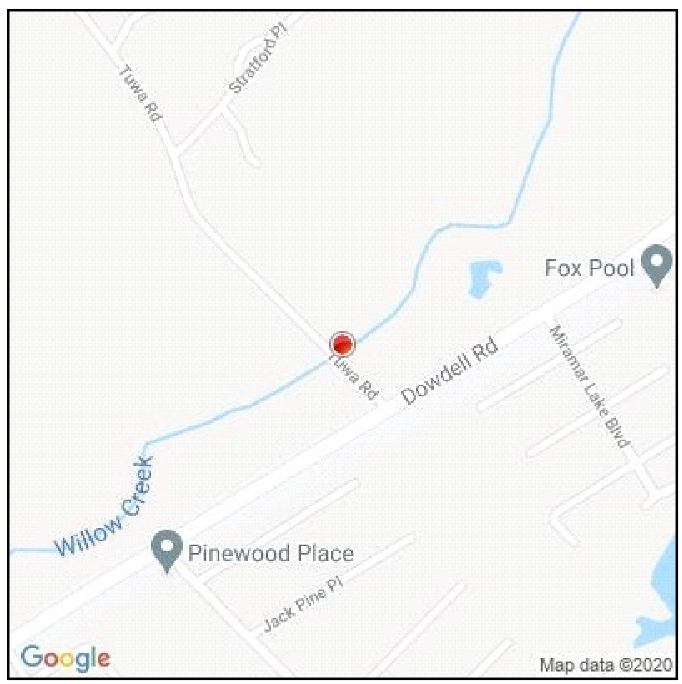

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EXCELLENCE SINCE 1945

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ENGINEERING
EXCELLENCE SINCE 1945

IMG_6175_Looking US.JPG
Title:

DANNENBAUM ENGINEERING
EXCELLENCE SINCE 1945

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DANNENBAUM ENGINEERING
EXCELLENCE SINCE 1945

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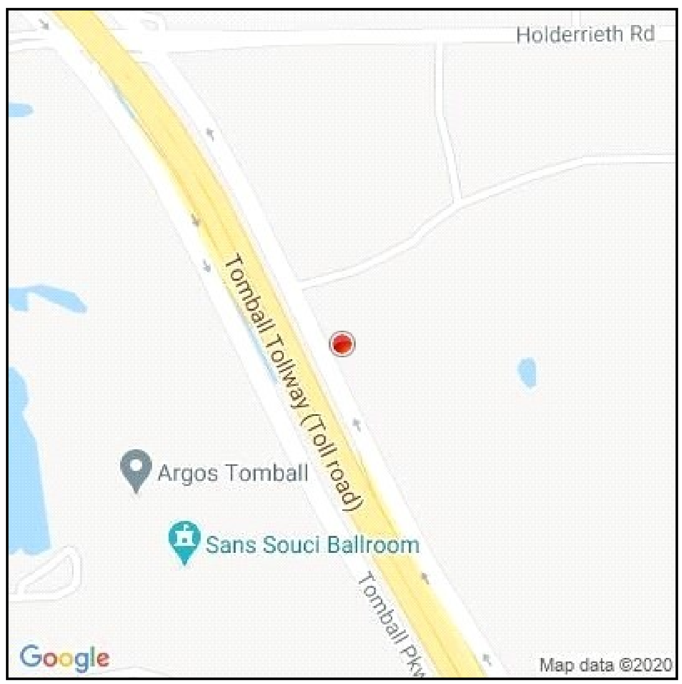

DANNENBAUM ENGINEERING
EXCELLENCE SINCE 1945

IMG_2403.JPG
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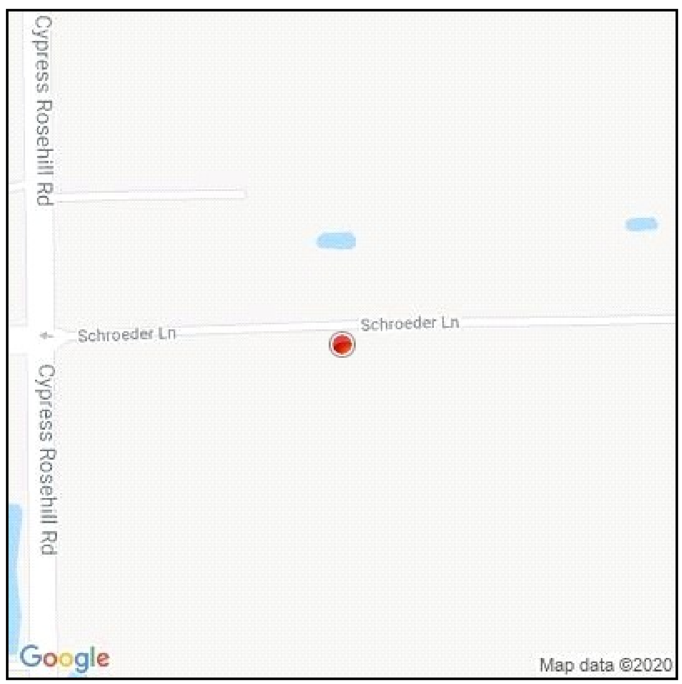
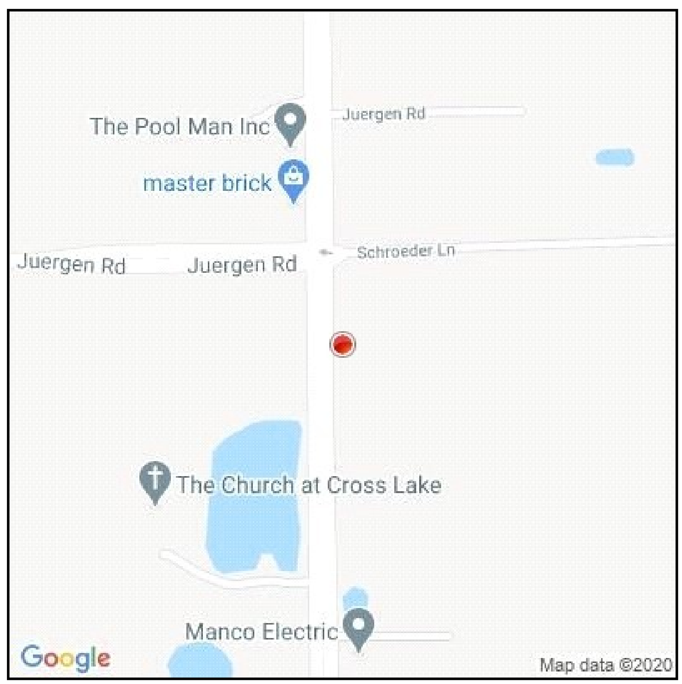


Cypress Rosehill-looking upstream.jpg
Title:



DANNENBAUM ENGINEERING
EXCELLENCE SINCE 1945

I. Electronic File Submittals

Overall Study Files

File Type	File Name	Content	Source
kmz, shp	WillowCreek_Wtrshd	Watershed Boundary	HCFCD with DEC modifications
shp	Large_Event_Drainage_Bndy.shp	Large Event Drainage Boundary	DEC
kmz, shp	Existing_Channels_Updated_20200708	Channel locations from HCFCD-FEMA TSARP 2007 FIRM Updates	HCFCD with DEC modifications
kmz, shp	WMP_Channels	Channel locations from HCFCD Watershed Master Plan - Phase 1	HCFCD
kmz, shp	Existing_HCFCD_ROW_2020	Existing HCFCD channel ROW as of 2020	HCFCD
tif	Rain on Grid Inundation Raster File	ROG Rasters	Isani
tif/shp	Multiply (1 raster and 1 floodplain boundary per alternative)	Alternatives 100YR depth rasters and Boundary	DEC
shp	SI_May11_Simplt_Y	HCFCD Updated Structural Inventory, May 2020	HCFCD
xls	SI_Full_WS	HCFCD SI Structural Inventory, May 2020 – minor refinements	HCFCD with DEC refinements
shp	DEC_Problem_Area20200423	Problem Areas – Old and new naming conventions plus tiers	DEC
shp	Potential_Detention_20200611	Recommended Detention-Preservation Sites: Site Boundary,	DEC
shp	Detention_Preservation_Aeras	Detention Presentation Areas	DEC
shp	Potential_Excavation_Areas	Detention Excavation Area	DEC
kmz, shp	Parcels_Clipped_to_Possible_ Detention	Applicable HCAD parcels for recommended detention/ preservation sites	HCAD
xls	Detn Basins Summary	Detention Basin Cost Estimates	DEC
xls	Detn Stg-Storage Volumes	Detention basin stage-storage tables used in the Hydraulic Models	DEC

File Type	File Name	Content	Source
xls	Detn Excavation Volumes	Detention basin excavation volumes used in the cost estimates	DEC
pdf	HGD Willow Creek Desktop Geomorphic Assessment Memo FINAL 25FEB2020	Desktop Geomorphic Analysis Results Memorandum	HyrdoGeo Designs
pdf	Willow Creek Watershed_Env Constraint Assessment_Hollaway_ 012020	Baseline Environmental Constraints Assessment Memo	Hollaway Environmental
shp	Environmental_Shapefiles_MPK	Baseline environmental assessment data	Hollaway Environmental
kmp	Holderrieth_RD_ROW	Harris County proposed road ROW	Harris County consultant
pdf	M100 Watershed Photos as of 2020-12 Folder	Field photos taken by DEC for this study through December 2012	DEC
pdf	Prior Willow Creek Watershed Study Reports Folder	Five prior reports	DEC

Note: All DEC shapefiles are in a .MPK file named DEC_Shapefiles_FER

M120 Detention-Preservation Site Immediate Project Files

File Type	File Name	Content	Source
kmz, shp	M120_D_Boundary_refined	M120 Site proposed ROW boundary	DEC
kmz, shp	M120_Preservation_Area	M120 Site proposed floodplain and habitat preservation area	DEC
kmz, shp	M120c_Potential_Detention_ Top_of_Bank	M120 proposed detention top of bank with M120c weir	DEC
xls	M120_Parcels_Costs_Clipped_ to_Site_Boundary	Used to estimate ROW needed, identify owners, and estimate cost	DEC
kmz, shp	M120c_Weir_Length_1300'	Approximate location of M120c weir	DEC
shp	Layout_Small_Pond	Layout of the small pond	DEC
shp	Layout_Large_Pond	Layout of the large pond	DEC
pdf	M120 Detention_Env. Constraints Memo_11092020	Detailed Environmental Constraints Assessment Memo, M120 Detention/Preservation Site	Hollaway Environmental

Notes: All DEC shapefiles are in a .MPK file named DEC_Shapefiles_M120.

Selective Clearing Immediate Project Files

File Type	File Name	Content	Source
kmz, shp	Selective_Clearing_Refinement_2.0_final	Proposed alignment. Outside limit = selective clearing and ultimate ROW	DEC
kmz, shp	Parcels_Clipped_to_Selective_Clearing	Applicable HCAD parcels for selective clearing	HCAD
kmz	sf_Layout_Notes	Use with both files above and existing ROW. Includes reasons for current alignment, recommendations for next refinement, proposed detention/ preservation sites, etc.	DEC
xls	Parcel_Owners_Selective_Clearing_Outside_ROW	Used to estimate ROW needed, identify owners, and estimate cost	DEC
kmz, shp	Selective_Clearing_BNRR_to_Mouth_100ft_Both_Sides	Original selective clearing alignment FYI. Uniform 100 ft both sides	DEC

Notes: All DEC shapefiles are in a .MPK file named DEC_Shapefiles_Selective_Clearing.

Appendix 5-4AC:
P118-E006 (Hardy West) BCA Memoranndum

PLANNING
ENGINEERING
PROGRAM MANAGEMENT

memo

TEXAS
AUSTIN
COLLEGE STATION
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FORT WORTH
FRISCO
HOUSTON
LAREDO
MONTGOMERY COUNTY
SAN ANTONIO
SAN MARCOS
WACO

CALIFORNIA
LOS ANGELES
ORANGE
SAN JOSE

FLORIDA
MIAMI

ILLINOIS
CHICAGO

MICHIGAN
FLINT
LANSING

OKLAHOMA
NORMAN

To: Gary Bezemek, P.E.

From: Tak Makino, CFM

Date: March 1, 2023

Subject: Hardy West Detention Basin
State Flood Plan BCA

Project Description

This BCA is for the project described as "Hardy West Detention Basin" in the Halls Bayou Watershed Flood Risk Reduction Phasing Study (Phasing Study) prepared for Harris County Flood Control District by LAN. The Phasing Study completed in 2021 updated the 2013 Halls Ahead Study Vision Plan and developed a phasing strategy for identified bond projects. The concept for the Hardy West Basin was refined and studied in the 2021 Alternatives Analysis performed by LAN in coordination with Harris County Flood Control District. This BCA is based on the models and cost estimates from the Alternatives Analysis.

The Hardy West Detention Basin consists of two ponds offset from Hill Road and separated by P118-25-00 bounded by Halls Bayou to the south, Woodmoss Road to the west, and Hardy Toll Road to the east. The east and west basins are 12 and 11 feet deep, respectively, and have a total pond footprint of 55 acres, providing a storage volume of 400 ac-ft, including 1 foot of freeboard. The 100- and 500-year events show maximum depth reductions of up to 0.33 feet and 0.57 feet within Halls Bayou, respectively, compared to the Baseline Conditions model. There are no adverse impacts observed when compared to the Baseline Conditions water surface elevations.

The Texas Water Development Board (TWDB) requires each Flood Mitigation Project (FMP) included in a regional flood plan to have a benefit/cost analysis (BCA) performed. This memorandum documents to benefit cost analysis performed by LAN within the regional flood planning process.

Benefit Cost Analysis

TWDB developed the Benefit-Cost Analysis (BCA) Input Tool to facilitate the calculation of flood mitigation benefits due to FMP. This tool receives input of existing and proposed conditions to determine expected benefits related to the construction of the FMP in question. The benefits considered in the analysis include the reduction in damages to residential structures, commercial structures, and social benefits. The BCA Input Tool was modified to handle the nearly 20,000 structures included in the analysis. The BCA Input Tool was used in conjunction with the Federal Emergency Management Agency (FEMA) BCA Toolkit v6.0.0. Social benefits used in the analysis were developed within the FMEA Benefit-Cost Calculator.

Lockwood, Andrews
& Newnam, Inc.

A LEO A DALY COMPANY

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Suite 400
Houston, TX 77042
713.266.6900

lan-inc.com

Structure Inventory

Two (2) datasets were used to obtain the information for Finished Floor Elevation (FFE), building footprint and building category.

- **Structure Inventory Dataset:** This information was obtained from Harris County Flood Control District (HCFCD). The FFE was obtained from this dataset.
- **Texas Buildings with SVI and Estimated Population (November 2021) –** This information was provided by TWDB for Regional Flood Planning. Building sizes and types were obtained from this dataset.

Project Schedule

The project is currently being planned and designed. Construction is scheduled to commence between 2026-2027.

BCA Assumptions

For purposes of the BCA, project benefits are elimination of flooding damages to residential and commercial structures. Based on the provided building types, structures were reclassified as either residential, commercial, industrial, or agricultural. Public, industrial, and agricultural buildings were reclassified as commercial structures. Buildings marked as "Vacant or Unknown" in the TWDB dataset were reclassified as agricultural buildings. Benefits were quantified by inputting structure FFE's and flood depths to the BCA_Pilot_v5 spreadsheet, provided by FNI.

Flood Damages

The flood depths for each structure within the study area was determined for the 10 percent, 2 percent, 1 percent, and 0.2 percent annual chance events. The flood hazard data was obtained from the Alternatives Analysis, all hydrological and hydraulic analyses were completed by LAN. The structural flood damages are included in **Table 1**.

TABLE 1: PROJECT IMPACTS BY RECURRENCE INTERVAL

Flood Damages	10 - year storm		50 - year storm		100 - year storm		500 - year storm	
	Baseline	Project	Baseline	Project	Baseline	Project	Baseline	Project
Residential	$47,422,441	$39,383,495	$180,475,248	$159,539,308	$230,738,075	$215,858,539	$361,365,732	$338,383,992
Commercial	$14,368,172	$10,397,958	$34,783,277	$29,823,585	$49,641,671	$43,263,148	$108,203,671	$95,719,922
Total Damages	$61,790,613	$49,781,453	$215,258,526	$189,362,893	$280,379,747	$259,121,687	$469,569,403	$434,103,914

Benefits

The damage estimates from the BCA_PILOT_v5 model were inputted to the FEMA BCA Calculator. The total benefit, discounted at 7 percent over the assumed 30-year project duration, is **$13,258,812** including **$1,583,466** in residual value from right-of-way acquisition and **$5,071,651** in environmental benefits from converting land to green space within the basin. These benefits include only include the mitigated damages to residential and commercial structures identified and no other additional mitigation.

Discounted Total Benefits: $13,258,812

Project Costs

According to the Alternatives Analysis, the overall cost to design and construct the project based on 2021 construction and Right-of-Way (ROW) costs. The features were assumed to have a useful life of 30 years. The total cost is **$35,355,800** including **$19,555,800** in construction costs and **$15,800,000** in ROW costs. The project construction cost used in the BCA includes Engineering and Design (10%), Mobilization and Demobilization (5%), Construction Management (10%), and Contingency (30%). The annual maintenance cost is estimated at 4% of the construction cost: **$782,232**. Harris County Flood Control District will be responsible for long-term maintenance of Halls Bayou.

The adjusted project costs were input to the TWDB BCA Input Workbook v1.2 to calculate the project cost discounted by 7 percent over the construction period.

Discounted Total Costs: **$35,322,050**

Benefit Cost Ratio

Results from BCA Toolkit:	
Total Benefits from **FEMA** BCA Toolkit	$6,603,695
Other Benefits (Not Recreation)	$6,655,117
Recreation Benefits	$0
Discounted Total Costs from **TWDB** Spreadsheet	$35,322,050
Total Benefits	$13,258,812
Net Benefits	-$22,063,238
Final BCR	**0.19**
Final BCR with Other Benefits	**0.38**

Appendix 5-4AD:
U520-01 – Dinner Creek Technical Memorandum

5engineering

Technical Memorandum

11200 Westheimer Rd. #353, Houston TX 77042 | 832-800-3483 | **U520-01 Technical Memorandum.docx**

February 24, 2023

To: **Gary Bezemek, PE, HCFCD**

From: **5engineering, LLC**

Project: **BCA**

Job No.: **007A-002**

Subject: **BCA for U520-01**

Introduction

Project Description & Location

The information provided is based on the report *U520-01-00 Detention Basin Final Conceptual Design Report*, prepared by Freese and Nichols, dated September 2019. This BCA is for alternative 3 of a project to improve an existing basin located within the Addicks Reservoir watershed (U100-00-00). The existing basin provides regional detention for surrounding developments and provides off-line detention along Dinner Creek (U120-00-00). The proposed alternative 3 expands the existing basins to create a wet bottom basin. It achieves both objectives of 100-year level of service and meets HCFCD's new retention requirements.

The report indicates alternative 3 has no adverse impacts (pg. ES-3). This corresponds to the following HEC-RAS model files:

HEC-RAS Project File Name: U520.prj

Frequency	Existing Plan	Existing Geometry and Flow
10 - year	U520-01-00.p52 (10-yr_Rev_existing)	U520.g04 (Revised_existing)
		U520.u04 (10_YR_Rev_Exist)
100 - year	U520-01-00.p04 (100-yr_Rev_existing)	U520.g04 (Revised_existing)
		U520.u01 (100_YR_Rev_Exist)
500 - year	U520-01-00.p65 (500-yr_Rev_existing)	U520.g04 (Revised_existing)
		U520.u10 (500_YR_Rev_Exist)
	Proposed Plan	**Proposed Geometry and Flow**
10 - year	U520.p23 (010-yr_Ultimate_Ret1.4_119_65)	U520.g24 (Ultimate_Ret1.4_119_65)
		U520.u13 (10-yr_Prop_Ret_1.4)
100 - year	U520.p05 (100-yr_Ultimate_Ret1.4_119_65)	U520.g24 (Ultimate_Ret1.4_119_65)
		U520.u08 (100-yr_Prop_Ret_1.4)
500 - year	U520.p09 (500-yr_Ultimate_Ret1.4_119_65)	U520.g24 (Ultimate_Ret1.4_119_65)

		U520.u25 (10-yr_Prop_Ret_1.4)

Structural Inventory
Structural Inventory datasets were created using three data sets:

- Houston-Galveston Area Council (HGAC) Land use
- Harris County Flood Control District (HCFCD) building footprints
- 2018 LiDAR

These data sets were joined using ArcGIS and used to estimate ground elevation at each structure. The FNI provided BCA Pilot v5 spreadsheet assumes the finished floor elevation (FFE) to be 6" above LiDAR. Aerial imagery and the HGAC Land use was used to categorize building types.

Project Schedule
Information on project schedule wasn't available within the provided PER. The project was assumed to be designed and delivered over a 10-year period.

Project Costs
The total construction cost for alternative 3 is $32,431,600.

Project costs estimated in June 2018 were adjusted to September 2020 dollars using a factor of 1.02 taken from the construction cost index from Engineering News-Record. The adjusted cost is $33,080,232.

The adjusted project costs were input into the TWDB BCA Input Workbook v1.2 to calculate the project cost discounted by 7 percent over the 10-year construction period. The discounted cost of $19,696,670 is used in the benefit cost ratio calculation.

BCA Assumptions
Project benefits are considered to be the reduction of flooding damages to residential, commercial, and industrial structures. These benefits were quantified by comparing without the project and with the project conditions in the 10, 100, and 500-year frequencies. Benefits were quantified using the BCA Pilot v5 spreadsheet.

Benefit Summary

Benefits (Non-Discounted)

	10 - year storm		100 - year storm		500 - year storm	
Project Impacts by Recurrence Interval	Baseline	Project	Baseline	Project	Baseline	Project
Residential Flood Damage	$0	$0	$7,111,009	$3,877,638	$44,908,086	$40,023,811
Commercial Flood Damage	$0	$0	$0	$0	$2,880,863	$2,373,931
Total Damages	$0	$0	$7,111,009	$3,877,638	$47,788,950	$42,397,742
Net Benefit by Storm		**$0**		**$3,233,371**		**$5,391,207**

Discounted Benefits

The damage estimates from the BCA_Pilot_V1.2PILOT model were entered into the FEMA BCA Calculator. Total benefits discounted at 7 percent over the project's assumed lifetime of 30 years are $690,948.

Benefit Cost Ratio

Discounted Project Benefits (FEMA BCA Toolkit)	$690,948
Total Benefits	$690,948
Discounted Project Cost	$19,696,670
Final BCR	**0.04**

Appendix 5-4AE:
Armand Bayou – B500-04 BCA Memorandum

5engineering

Technical Memorandum

11200 Westheimer Rd. #353, Houston TX 77042 | 832-800-3483 | **B500-04 Technical Memorandum.docx**

February 28, 2023

To: **Gary Bezemek, PE, HCFCD**

From: **5engineering, LLC**

Project: **BCA**

Job No.: **007A-002**

Subject: **BCA for B500-04**

Introduction

Project Description & Location

The information presented is based on the models provided by Costello in February 2023. The associated report is not yet available. Cost information from the original planning study by Atkins was used. This project proposes the expansion and extension of existing basins to alleviate historical and potential future riverine flooding within Armand Bayou Watershed. The proposed location is along channel B115-00-00 south of Spencer Highway and Red Bluff Road. This corresponds to the following HEC-RAS model files:

HEC-RAS Project File Name: MAAPnext_Armand.prj

Frequency	Existing Plan	Existing Geometry and Flow
10 - year	MAAPnext_Armand.p03 (202007_10PCT_RevisedExisting)	MAAPnext_Armand.g07 (ArmandBayou_RevisedExisting)
		MAAPnext_Armand.u07 (202007_10PCT_RevisedExisting)
50 - year	MAAPnext_Armand.p04 (202007_4PCT_RevisedExisting)	MAAPnext_Armand.g07 (ArmandBayou_RevisedExisting)
		MAAPnext_Armand.u08 (202007_4PCT_RevisedExisting)
100 - year	MAAPnext_Armand.p13 (202007_1PCT_RevisedExisting)	MAAPnext_Armand.g07 (ArmandBayou_RevisedExisting)
		MAAPnext_Armand.u04 (202007_1PCT_RevisedExisting)
	Proposed Plan	**Proposed Geometry and Flow**
10 - year	MAAPnext_Armand.p01 ((ATL1 (OPT3B + ON3_10pct)I)	MAAPnext_Armand.g25 (ALT1 (OPT3B + ON3)I)
		MAAPnext_Armand.u07 (202007_10PCT_RevisedExisting)
50 - year	MAAPnext_Armand.p02 ((ATL1 (OPT3B + ON3_4pct)I)	MAAPnext_Armand.g25 (ALT1 (OPT3B + ON3)I)
		MAAPnext_Armand.u08 (202007_4PCT_RevisedExisting)

100 - year	MAAPnext_Armand.p26 ((ATL1 (OPT3B + ON3)I)	MAAPnext_Armand.g25 (ALT1 (OPT3B + ON3)I)
		MAAPnext_Armand.u04 (202007_1PCT_RevisedExisting)

Structural Inventory

Structural Inventory datasets were created using three data sets:

- Houston-Galveston Area Council (HGAC) Land use
- Harris County Flood Control District (HCFCD) building footprints
- 2018 LiDAR

These data sets were joined using ArcGIS and used to estimate ground elevation at each structure. The FNI provided BCA Pilot v5 spreadsheet assumes the finished floor elevation (FFE) to be 6" above LiDAR. Aerial imagery and the HGAC Land use was used to categorize building types.

Project Schedule

Information on project schedule wasn't available within the provided PER. The project was assumed to be designed and delivered over a 4-year period beginning in 2026.

Project Costs

The total construction cost for phase 1 and 2 is expected to be $9.45 Million.

Project costs, assumed estimated in December 2020, were adjusted to September 2020 dollars using a factor of 0.99 taken from the construction cost index from Engineering News-Record. The adjusted cost is $9,355,500.

The adjusted project costs were input into the TWDB BCA Input Workbook v1.2 to calculate the project cost discounted by 7 percent over the 4-year construction period. The discounted cost of $6,768,603 is used in the benefit cost ratio calculation.

BCA Assumptions

Project benefits are considered to be the reduction of flooding damages to residential, commercial, and industrial structures. These benefits were quantified by comparing without the project and with the project conditions in the 10, 25, and 100-year frequencies. Benefits were quantified using the BCA Pilot v5 spreadsheet.

Benefit Summary

Benefits (Non-Discounted)

	10 - year storm		25 - year storm		100 - year storm	
Project Impacts by Recurrence Interval	Baseline	Project	Baseline	Project	Baseline	Project
Residential Flood Damage	$8,164,868	$8,067,324	$14,166,837	$12,936,020	$63,448,989	$55,783,245
Commercial Flood Damage	$5,685,372	$2,126,689	$6,232,043	$4,994,875	$19,009,162	$17,070,203
Total Damages	$13,850,239	$10,194,013	$20,398,880	$17,930,895	$82,458,151	$72,853,448
Net Benefit by Storm		**$3,656,226**		**$2,467,985**		**$9,604,703**

Discounted Benefits

The damage estimates from the BCA Pilot v5 spreadsheet were entered into the FEMA BCA Calculator. Total benefits discounted at 7 percent over the project's assumed lifetime of 30 years are $5,453,277.

Benefit Cost Ratio

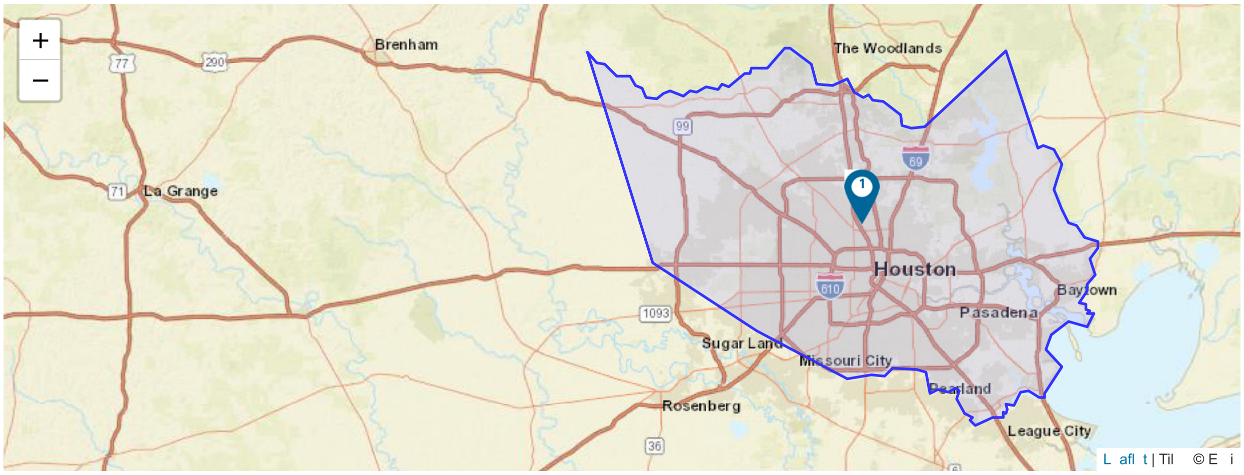
Discounted Project Benefits (FEMA BCA Toolkit)	$5,453,277
Total Benefits	$5,453,277
Discounted Project Cost	$6,768,603
Final BCR	**0.81**

Appendix 5-4AF:
Clear Creek BCA

FEMA Benefit-Cost Calculator
V.6.0 (Build 20230103.1822 | Release Notes)

Benefit-Cost Analysis

Project Name: Clear Creek Federal Flood Risk Management PED 2020



				Using 7% Discount Rate			Using 3% Discount Rate (For FY22 BRIC and FMA only)		
Map Marker ▲	Mitigation Title	Property Type	Hazard	Benefits (B)	Costs (C)	BCR (B/C)	Benefits (B)	Costs (C)	BCR (B/C)
1	Drainage Improvement @ Harris County, Texas	•••	DFA - Riverine Flood	$ 158,749,460	$ 295,267,680	0.54	$ 295,968,498	$ 302,216,977	0.98
TOTAL (SELECTED)				**$ 158,749,460**	**$ 295,267,680**	**0.54**	**$ 295,968,498**	**$ 302,216,977**	**0.98**
TOTAL				**$ 158,749,460**	**$ 295,267,680**	**0.54**	**$ 295,968,498**	**$ 302,216,977**	**0.98**

Property Configuration

Property Title:	Drainage Improvement @ Harris County, Texas
Property Location:	77076, Harris, Texas
Property Coordinates:	29.857629892000034, -95.39311564099995
Hazard Type:	Riverine Flood
Mitigation Action Type:	Drainage Improvement
Property Type:	Other
Analysis Method Type:	Professional Expected Damages

Cost Estimation
Drainage Improvement @ Harris County, Texas

Project Useful Life (years):	50
Project Cost:	$287,228,000
Number of Maintenance Years:	50 Use Default:Yes
Annual Maintenance Cost:	$582,554

Comments

- **Project Useful Life:**
Based on HCFCD Standard
- **Mitigation Project Cost:**
Construction = $180,049,400 Lands = $45,703,000 Engineering = $20,127,100 Construction Management = $41,348,446
- **Annual Maintenance Cost:**
Total O&M Estimate over the 50yr lifespan of the project = $29,127,700

Damage Analysis Parameters - Damage Frequency Assessment
Drainage Improvement @ Harris County, Texas

Year of Analysis was Conducted:	2023
Year Property was Built:	0
Analysis Duration:	10 Use Default:Yes

Professional Expected Damages Before Mitigation
Drainage Improvement @ Harris County, Texas

	OTHER	OPTIONAL DAMAGES			VOLUNTEER COSTS		TOTAL
Recurrence Interval (years)	Damages ($)	Category 1 ($)	Category 2 ($)	Category 3 ($)	Number of Volunteers	Number of Days	Damages ($)
100	616,472,826	0	0	0	0	0	616,472,826
500	2,288,047,662	0	0	0	0	0	2,288,047,662

Annualized Damages Before Mitigation
Drainage Improvement @ Harris County, Texas

Annualized Recurrence Inter al ear	Damage and Lo e $	Annualized Damage and Lo e $
100	616,472,826	9,501,223
500	2,288,047,662	4,575,867
	Sum Damages and L sses ($)	Sum Annualized Damages and L sses ($)
	2,904,520,488	14,077,090

Professional Expected Damages After Mitigation
Drainage Improvement @ Harris County, Texas

	OTHER	OPTIONAL DAMAGES			VOLUNTEER COSTS		TOTAL
Recurrence Interval (years)	Damages ($)	Category 1 ($)	Category 2 ($)	Category 3 ($)	Number of Volunteers	Number of Days	Damages ($)
100	505,643,424	0	0	0	0	0	505,643,424
500	157,665,391	0	0	0	0	0	157,665,391

Annualized Damages After Mitigation

Drainage Improvement @ Harris County, Texas

Annualized Recurrence Interval (years)	Damages and Losses ($)	Annualized Damages and Losses ($)
100	505,643,424	2,258,813
500	157,665,391	315,315
	Sum Damages and Losses ($)	Sum Annualized Damages and Losses ($)
	663,308,815	2,574,128

Standard Benefits - Ecosystem Services

Drainage Improvement @ Harris County, Texas

Total Project Area (acres):	0
Percentage of Urban Green Open Space:	0.00%
Percentage of Rural Green Open Space:	0.00%
Percentage of Riparian:	0.00%
Percentage of Coastal Wetlands:	0.00%
Percentage of Inland Wetlands:	0.00%
Percentage of Forests:	0.00%
Percentage of Coral Reefs:	0.00%
Percentage of Shellfish Reefs:	0.00%
Percentage of Beaches and Dunes:	0.00%
Expected Annual Ecosystem Services Benefits:	$0

Benefits-Costs Summary

Drainage Improvement @ Harris County, Texas

Total Standard Mitigation Benefits:	$158,749,460
Total Social Benefits:	$0
Total Mitigation Project Benefits:	$158,749,460
Total Mitigation Project Cost:	$295,267,680
Benefit Cost Ratio - Standard:	0.54
Benefit Cost Ratio - Standard + Social:	0.54