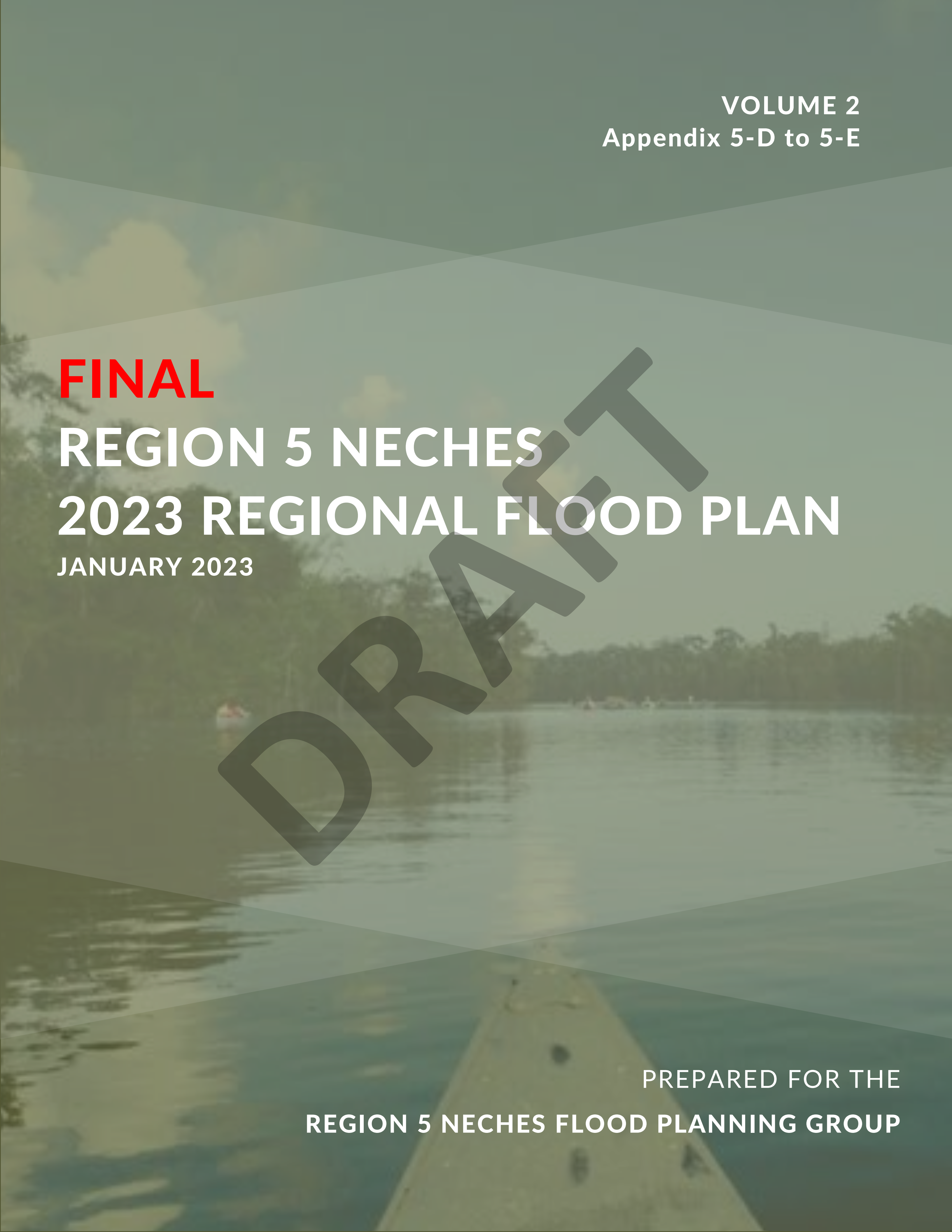

VOLUME 2
Appendix 5-D to 5-E

FINAL
REGION 5 NECHES 2023 REGIONAL FLOOD PLAN

JANUARY 2023

PREPARED FOR THE

REGION 5 NECHES FLOOD PLANNING GROUP

APPENDIX 5-D
RECOMMENDED FLOOD MITIGATION PROJECT (FMP) DETAILS

	General Project Data												
Project Name	FMP	Project Description:	Flood Region	Project Type	FIUP Project Category	Project Watershed	Rural Applicant	Project Cost	Benefit Cost Ratio	Cost per Structure Removed	Pre-Project Level-of-Service	Post-Project Level-of-Service	# of Structures in 1% Annual Chance FP (Pre-Project)	Project Status
Bayou Din Detention Basin	053000001	Construct a new detention basin with nearby channel and crossing improvements in the vicinity of Bayou Din.	Neches	Detention Pond	3	Sabine Lake	N	$ 85,000,000	4.9	$ 442,708	Unknown	Project will be designed to the 500-YR event with an estimated project useful life of 75 years.	534	Design
Bessie Heights Drainage Ditch Extension Project	053000002	Expand the Bessie Heights Drainage Ditch to address flooding risk to residential properties in the area.	Neches	Channel	2	Lower Neches	N	$ 4,250,000	0	$ 531,250	Unknown	Project will be designed to reduce impact from the 100-YR event.	139	Planning
Channel 100-A Concrete Repair	053000003	Conduct repairs and install improvements to Channel 100-A located within the city of Beaumont.	Neches	Channel	2	Sabine Lake	N	$ 39,570,866	11.21	$ 1,978,543	Unknown	Project will be designed to the 500-YR event with an estimated project useful life of 75 years.	1622	Design
Port Arthur and Vicinity Coastal Storm Risk Management Project	053000004	Construct levees, floodwalls, pump stations, drainage structures, and other flood mitigation infrastructure to reduce adverse flood impact in the vicinity of the city of Port Arthur.	Neches	Comprehensive	3	Lower Neches, Sabine Lake	N	$ 119,900,000	4.6	$ 163,708	Unknown	Project will be designed to reduce impact from the 500-YR event.	23310	Design
Orange County Coastal Storm Risk Management Project	053000005	Construct levees, floodwalls, pump stations, drainage structures, and other flood mitigation infrastructure to reduce adverse flood impact in Orange County.	Neches	Comprehensive	2	Lower Neches, Lower Sabine, Sabine Lake	N	$ 2,400,000,000	1.2	$ 193,387	Unknown	Project will be designed to reduce impact from the 500-YR event.	3872	Design

	Score 1: Severity - Pre-Project Average Depth of Flooding (100-year)				Score 2: Severity - Community Need (% Population)						Score 3: Flood Risk Reduction			
Project Name	**Average Flood Depth (100yr)**	**Notes**	**Severity Ranking: Pre-Project Average Depth of Flooding (100-year)**	**Score 1**	**Communities Served by Project**	**Community Population Served**	**Flood Plain Population**	**Notes 2**	**Severity Ranking: Community Need (% Population)**	**Score 2**	**# of Structures Removed from 1% Annual Chance FP**	**Notes 3**	**Flood Risk Reduction**	**Score 3**
Bayou Din Detention Basin	1.48	From 100-YR depth raster acquired from HEC-RAS models	Baseline average flood depth > 1ft	6	City of Beaumont	115282	1774	2%	<25% of project community affected	1	101	19% of structures removed from 1% ACE Flood Risk	Reduced risk to <50% of structures in floodplain	4
Bessie Heights Drainage Ditch Extension Project	1.13	From 100-YR depth raster acquired from HEC-RAS models	Baseline average flood depth > 1ft	6	City of Bridge City	9546	228	2%	<25% of project community affected	1	8	6% of structures removed from 1% ACE Flood Risk	Reduced risk to <10% of structures in floodplain	1
Channel 100-A Concrete Repair	2.67	From 100-YR depth raster calculated from WSEL raster acquired from HEC-RAS models	Baseline average flood depth > 2ft	8	City of Beaumont	115282	9745	8%	<25% of project community affected	1	10	~1% of structures removed from 1% ACE Flood Risk	Reduced risk to <10% of structures in floodplain	1
Port Arthur and Vicinity Coastal Storm Risk Management Project	N/A	Flood depth data not available from USACE	Baseline average flood depth < 0.5ft	2	City of Port Arthur, City of Nederland, City of Port Neches, City of Groves	105922	73381	69%	50%-75% of project community affected	7	3275	14% of structures removed from 1% ACE Flood Risk	Reduced risk to <50% of structures in floodplain	4
Orange County Coastal Storm Risk Management Project	N/A	Flood depth data not available from USACE	Baseline average flood depth < 0.5ft	2	City of Bridge City, Orange County	9546	9830	This project's extents are split between the Sabine and Neches regions; the area in the Neches region is used for this instance.	>75% of project community affected (by population)	10	201	5% of structures removed from 1% ACE Flood Risk	Reduced risk to <10% of structures in floodplain	1

	Score 4: Flood Damage Reduction						Score 5: Critical Facilities Damage Reduction				Score 6: Life and Safety			
Project Name	**# of Structures with Reduced 1% Annual Chance Flood Risk**	**Pre-Project Damage $**	**Post-Project Damage $**	**Notes 4**	**Flood Damage Reduction**	**Score 4**	**# of Critical Facilites Removed from 1% Annual Chance FP**	**Notes 5**	**Reduction in Critical Facilities Flood Risk**	**Score 5**	**Adjusted Injury Risk (%)**	**Notes 6**	**Life and Safety Ranking (Injury/Loss of Life)**	**Score 6**
Bayou Din Detention Basin	97			18% of structures have reduced impact from 1% ACE Flood Risk	Flood damage reduction < 25%	2	4		Reduced risk for <10% of critical facilities in floodplain	1	N/A			
Bessie Heights Drainage Ditch Extension Project	3			2% of structures have reduced impact from 1% ACE Flood Risk	Flood damage reduction < 25%	2	0		Reduced risk for 0 structures in floodplain	0	N/A			
Channel 100-A Concrete Repair	452			28% of structures have reduced impact from 1% ACE Flood Risk	Flood damage reduction > 25%	4	0		Reduced risk for 0 structures in floodplain	0	N/A			
Port Arthur and Vicinity Coastal Storm Risk Management Project	441			2% of structures have reduced impact from 1% ACE Flood Risk	Flood damage reduction < 25%	2	71		Reduced risk for <10% of critical facilities in floodplain	1	N/A			
Orange County Coastal Storm Risk Management Project	175			5% of structures have reduced impact from 1% ACE Flood Risk	Flood damage reduction < 25%	2	0		Reduced risk for 0 structures in floodplain	0	N/A			

	Score 7: Water Supply						Score 8: Social Vulnerability				Score 9: Nature-Based Solution			
Project Name	**Water Supply Benefit in Acre-Feet**	**SourceID**	**WMS_ID**	**Notes 7**	**Water Supply Yield Ranking**	**Score 7**	**SVI Score**	**Notes 8**	**Social Vulnerability Ranking**	**Score 8**	**% Nature Based Solution by Cost**	**Notes 9**	**Nature-Based Solutions Ranking**	**Score 9**
Bayou Din Detention Basin	N/A				No impact on water supply	0	0.21314375		SVI between 0.01-0.25 (low vulnerability)	1	0		<25% of the project cost is nature-based	1
Bessie Heights Drainage Ditch Extension Project	N/A				No impact on water supply	0	0.1558259		SVI between 0.01-0.25 (low vulnerability)	1	0		<25% of the project cost is nature-based	1
Channel 100-A Concrete Repair	N/A				No impact on water supply	0	0.72570948		SVI between 0.5-0.75 (moderate to high vulnerability)	7	0		<25% of the project cost is nature-based	1
Port Arthur and Vicinity Coastal Storm Risk Management Project	N/A				No impact on water supply	0	0.57444668		SVI between 0.5-0.75 (moderate to high vulnerability)	7	0		<25% of the project cost is nature-based	1
Orange County Coastal Storm Risk Management Project	N/A				No impact on water supply	0	0.16443804		SVI between 0.01-0.25 (low vulnerability)	1	0		<25% of the project cost is nature-based	1

	Score 10: Multiple Benefits				Score 11: O&M				Score 12: Admin, Regulatory Obstacles			Score 13: Environmental Benefit		
Project Name	**Multiple Benefits Description**	**Notes 10**	**Multiple Benefit Ranking**	**Score 10**	**O&M Cost (Annual)**	**Notes 11**	**Operations and Maintenance Ranking**	**Score 11**	**Notes 12**	**Administrative, Regulatory and Other Obstacle Ranking**	**Score 12**	**Notes 13**	**Environmental Benefit Ranking**	**Score 13**
Bayou Din Detention Basin	Annual ecosystem services benefits of $20,673,627.		Project delivers benefits in 3 wider benefit categories	7	15000		Project requires regular, ongoing operation and maintenance; and/or O&M requirements are well defined (Regular);	7		Project has a typical number of administrative, regulatory and limitations / requirements	6		Project will deliver a moderate level of environmental benefits (2-3 categories)	6
Bessie Heights Drainage Ditch Extension Project			Project delivers benefits in only 1 wider benefit category	1		O&M information unavailable for the project				Project has a typical number of administrative, regulatory and limitations / requirements	6		Project will deliver a low level of environmental benefits (1 category)	3
Channel 100-A Concrete Repair	Annual ecosystem services benefits of $1,944,072.		Project delivers benefits in 2 wider benefit categories	4	15000		Project requires regular, ongoing operation and maintenance; and/or O&M requirements are well defined (Regular);	7		Project has a typical number of administrative, regulatory and limitations / requirements	6		Project will deliver a moderate level of environmental benefits (2-3 categories)	6
Port Arthur and Vicinity Coastal Storm Risk Management Project			Project delivers benefits in 2 wider benefit categories	4	195000		Project will require ongoing operation and maintenance outside of the owner's regular maintenance practices; long-term O&M requirements are undefined; and/or high annual O&M cost > 1% of project (high);	4		Project has a high number of administrative, regulatory and limitations / requirements	2		Project will deliver a moderate level of environmental benefits (2-3 categories)	6
Orange County Coastal Storm Risk Management Project			Project delivers benefits in 2 wider benefit categories	4	4565000		Project will require ongoing operation and maintenance outside of the owner's regular maintenance practices; long-term O&M requirements are undefined; and/or high annual O&M cost > 1% of project (high);	4		Project has a high number of administrative, regulatory and limitations / requirements	2		Project will deliver a moderate level of environmental benefits (2-3 categories)	6

	Score 14: Environmental Impact			Score 15: Mobility				Score 16: Regional		
Project Name	**Notes 14**	**Environmental Impact Ranking**	**Score 14**	**Traffic Count for LWC Project**	**Notes 15**	**Mobility Ranking**	**Score 15**	**Project Count**	**Regional Ranking**	**Score 16**
Bayou Din Detention Basin		Project has no adverse environmental impacts	10			Project will protect some major access routes in floodplain and the majority (>50%) of emergency service access. Some major and many minor access routes will remain flooded, and emergency services access may be restricted in some areas	4	5	Project region has recommended <10% of total projects	10
Bessie Heights Drainage Ditch Extension Project		Project has no adverse environmental impacts	10			Project will protect some major access routes in floodplain and the majority (>50%) of emergency service access. Some major and many minor access routes will remain flooded, and emergency services access may be restricted in some areas	4	5	Project region has recommended <10% of total projects	10
Channel 100-A Concrete Repair		Project has no adverse environmental impacts	10			Project will protect some major access routes in floodplain and the majority (>50%) of emergency service access. Some major and many minor access routes will remain flooded, and emergency services access may be restricted in some areas	4	5	Project region has recommended <10% of total projects	10
Port Arthur and Vicinity Coastal Storm Risk Management Project		Project has no adverse environmental impacts	10			Project will protect some major access routes in floodplain and the majority (>50%) of emergency service access. Some major and many minor access routes will remain flooded, and emergency services access may be restricted in some areas	4	5	Project region has recommended <10% of total projects	10
Orange County Coastal Storm Risk Management Project		Project has no adverse environmental impacts	10			Project will protect some major access routes in floodplain and the majority (>50%) of emergency service access. Some major and many minor access routes will remain flooded, and emergency services access may be restricted in some areas	4	5	Project region has recommended <10% of total projects	10

APPENDIX 5-E
SUPPORTING DOCUMENTATION FOR RECOMMENDED FLOOD MITIGATION PROJECTS

TECHNICAL MEMORANDUM

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TO:	Karen Stewart, Chief Business Officer JCDD6
FROM:	Dane Schneider, P.E., ENV SP Matt Lewis, P.E., CFM
SUBJECT:	Bayou Din Drainage Improvements
PROJECT:	JFC21835
DATE:	November 28, 2022

STATE OF TEXAS
MATTHEW S. LEWIS
140929
LICENSED
PROFESSIONAL ENGINEER
11-28-2022

FREESE AND NICHOLS, INC.
TEXAS REGISTERED
ENGINEERING FIRM
F-2144

1.00 STUDY PURPOSE

Bayou Din and Kidd Gully have a history of coming out of bank during heavy rain events and causing flooding damage and major flooding problems. Typically, major flooding is associated with tropical systems or hurricanes resulting in heavy rainfall. However even smaller more frequent events have the potential to cause flooding damage to the undersized channels, restrictive crossing and rapid development within portion of the watershed. To reduce flood damages improvements to localized drainage infrastructure and large-scale detention has been investigated and found to be effective at reducing water surface elevations and potential damages.

2.00 PROJECT DESCRIPTION

Existing channels and many crossings (bridges or culverts) are undersized for the amount of water that drains through the Bayou Din/Kidd Gully system. Drainage improvements are proposed throughout the area to reduce the risk of flooding damages structures, reducing risk to life, and improving emergency response and transit throughout the area during flooding events. The proposed project will improve channel conveyance through widening and correcting channel impairments along Bayou Din and Kidd Gully. Approximately 3339 acre-feet of detention is planned to be included near the confluence of Bayou Din and Kidd Gully. This detention will provide regional detention that will reduce water surface elevations along both streams. The detention provided will additionally provide mitigation for the channel conveyance improvements preventing any adverse impact downstream of the improvements.

The basins will be designed to function during both low flow and high flow events in a way that allows all flood events up to the 500-year storm event to pass through the system with no adverse impacts. In high flow events the basin intake structures consisting of overflow weirs will activate and take on flows during the peak of the storm reducing maximum water surface elevations throughout the benefit area. In addition to channel conveyance improvements there are 14 bridges or culverts that are undersized or in a state of disrepair that prohibits sufficient flow capacity. **Figure 1** provides a summary of the proposed conveyance and detention improvements. Four pipelines are anticipated to be relocated to allow the proposed drainage improvements to be constructed.

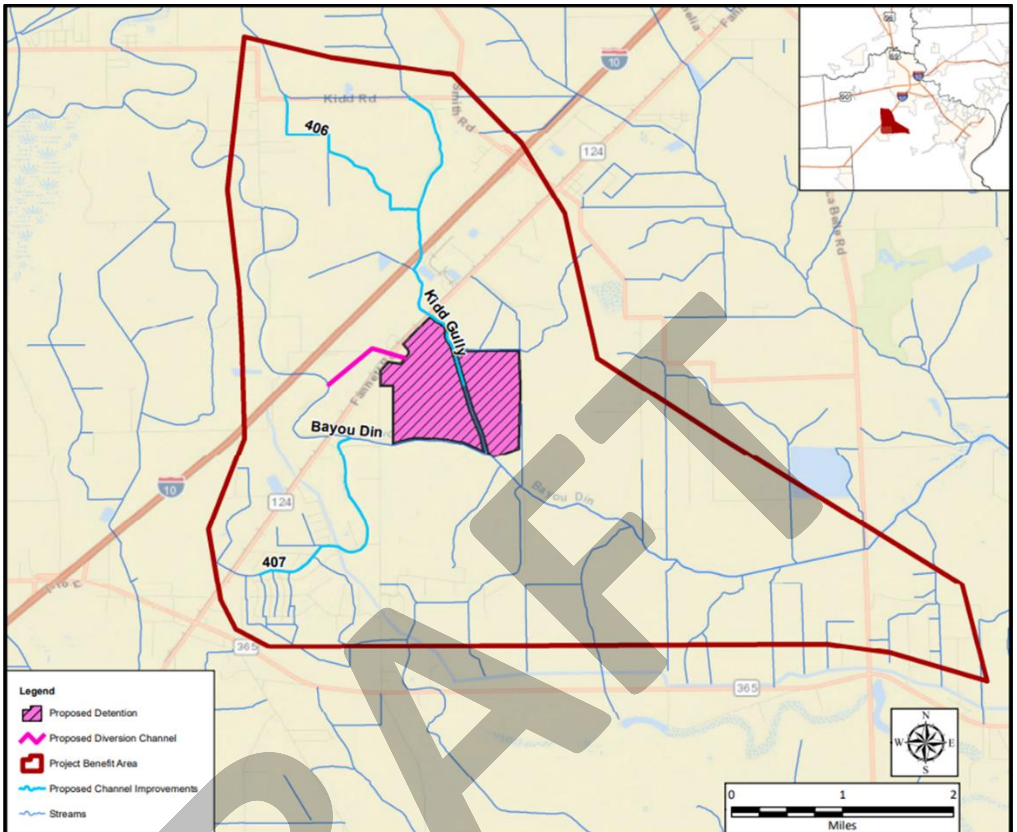

Figure 1: Project Location Map

3.00 H&H METHODOLOGY

3.01 HYDROLOGY

Atlas 14 rainfall totals were collected from the NOAA server for the project area. The 24-hour rainfall totals used in this analysis are listed below in **Table 1** below. Rainfall was directly applied to the hydraulic model for this analysis. Therefore, only minor adjustments to the hydrology were required. A HEC-HMS v4.8 model was prepared to subtract expected infiltration losses from the rainfall prior to becoming runoff. The amount of rainfall that becomes runoff is then applied across the hydraulic model. Infiltration losses were based on NRCS soil groups, the project area is fully covered by group D soils.

Table 1: Atlas 14 24-Hour Rainfall Totals

	Frequency Events						
	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	500-YR
24-HR Total (inches)	5.5	7.4	9.3	12.3	15	18.2	27.6

3.02 HYDRAULICS

To evaluate the existing flood risk and analyze potential flood risk reduction projects A 2D hydraulic model was created in HEC-RAS v6.0. This model utilized the rain-on-grid functionality of HEC-RAS to apply the rainfall calculated across the entire model extents. Topographic features that control the flow of water across the landscape were noted and included within the model using breaklines or 2D structures. This includes bridges, culverts, berms, roadways, canals, railroads and other notable features. This allows for a more realistic tracking of water as it falls as rain and flows towards and into streams. The extent of the hydraulic model was extended beyond the limits shown in Figure 1 to capture the full contributing area of Bayou Din and Kidd Gully as seen in **Figure 2**.

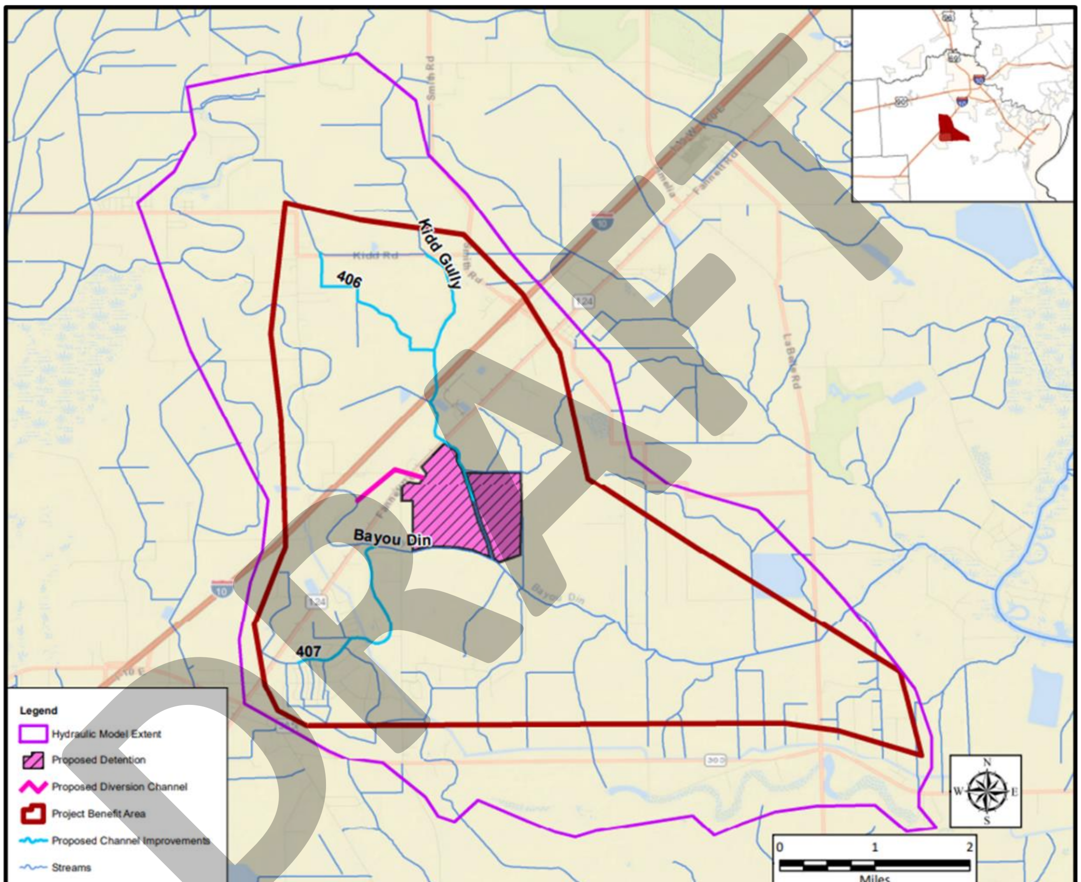

Figure 2: Hydraulic Model Extents

The existing condition model was run for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-YR storm events. The existing floodplain is wide along Bayou Din starting near the confluence with Kidd Gully and Kidd Gully north of the confluence with Bayou Din also has a wide deep floodplain at various points. **Figure 3** show the existing 100-year flood depths. **Figure 3** additionally highlights major damage centers in red boxes. Improvements focused on reducing flooding at these locations is expected to reduce the flooding experienced by residents and businesses in the area.

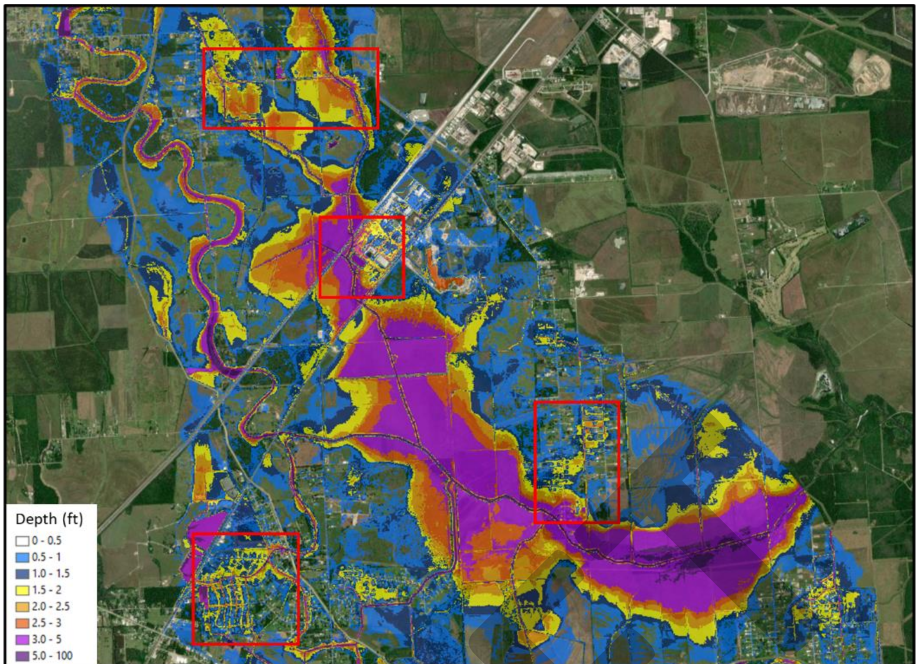

Figure 3: Existing Flood Depths

Figure 4 highlights the potential improvement locations that were investigated to identify a flood reduction project. Using a combination of increased channel conveyance and large regional detention the floodplain width is reduced and depth is reduced across much of the area.

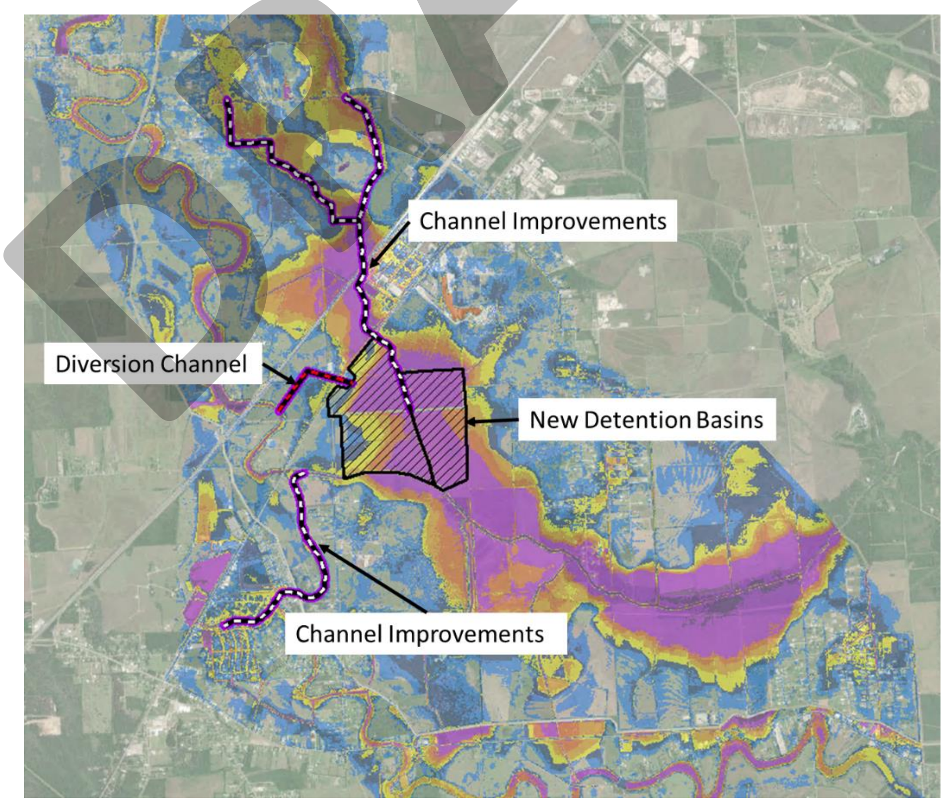

Figure 4: Proposed Improvement Areas

After analyzing the areas experiencing flood damages a proposed hydraulic model was created that included large regional detention basins, hydraulic structure replacements or modifications, and channel conveyance improvements along multiple streams and a diversion channel on Bayou Din that outfalls directly to the detention basins. Multiple geometries were studied to find an alternative that resulted in lowered water surface elevations throughout the project while also not resulting in any adverse impacts.
A typical section of the proposed channel improvements can be seen in **Figure 5**.

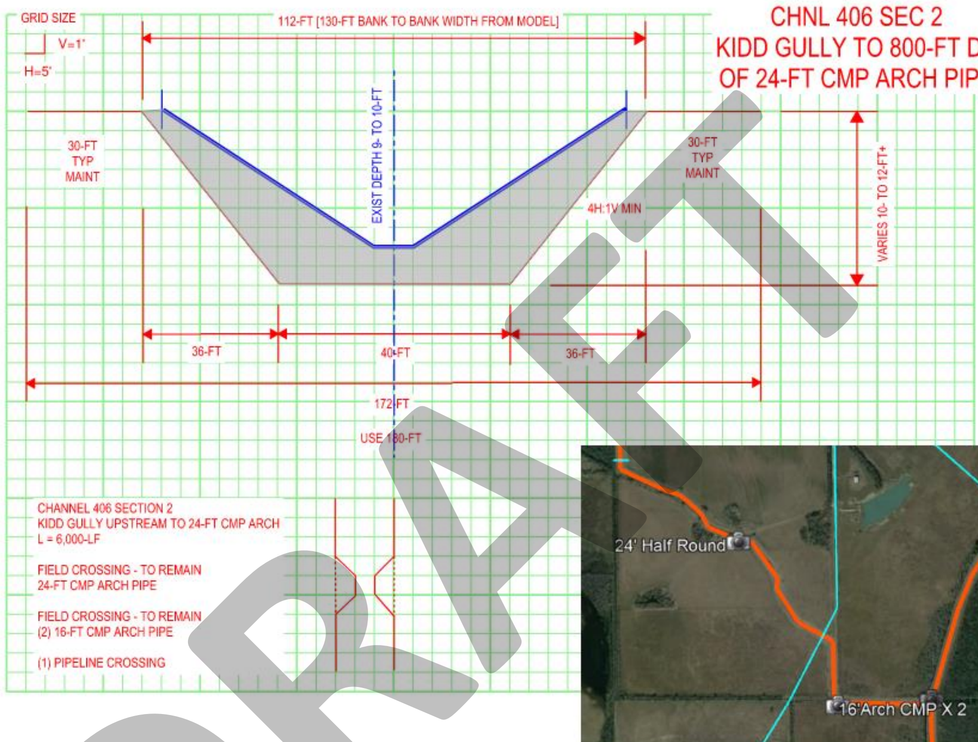

Figure 5: Typical Channel Improvement

The recommended alternative is summarized in **Figure 6** below while **Figure 7** displays the delta in water surface elevations across the project because of the proposed improvements.

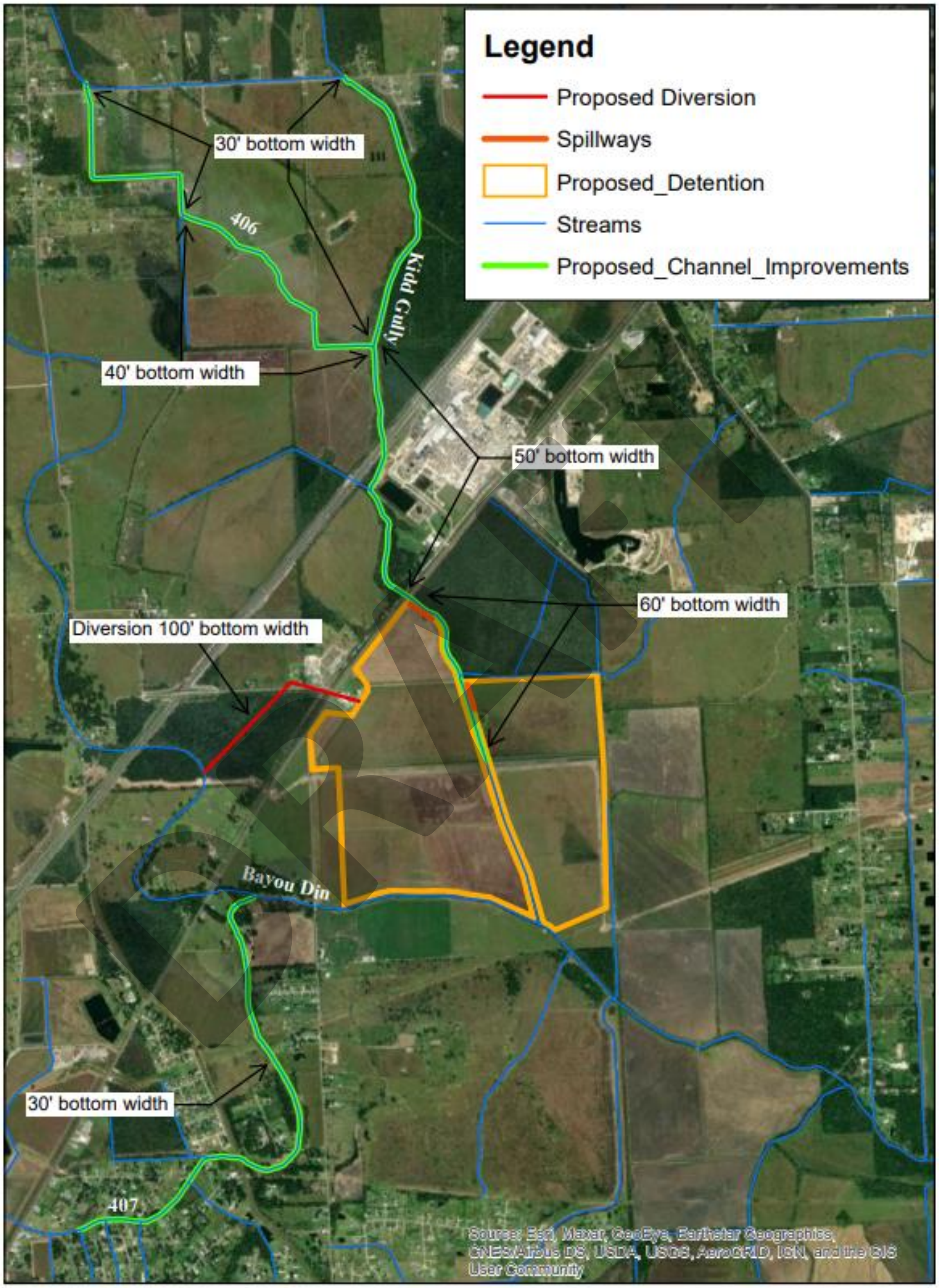

Figure 6: Proposed Drainage Improvements Summary

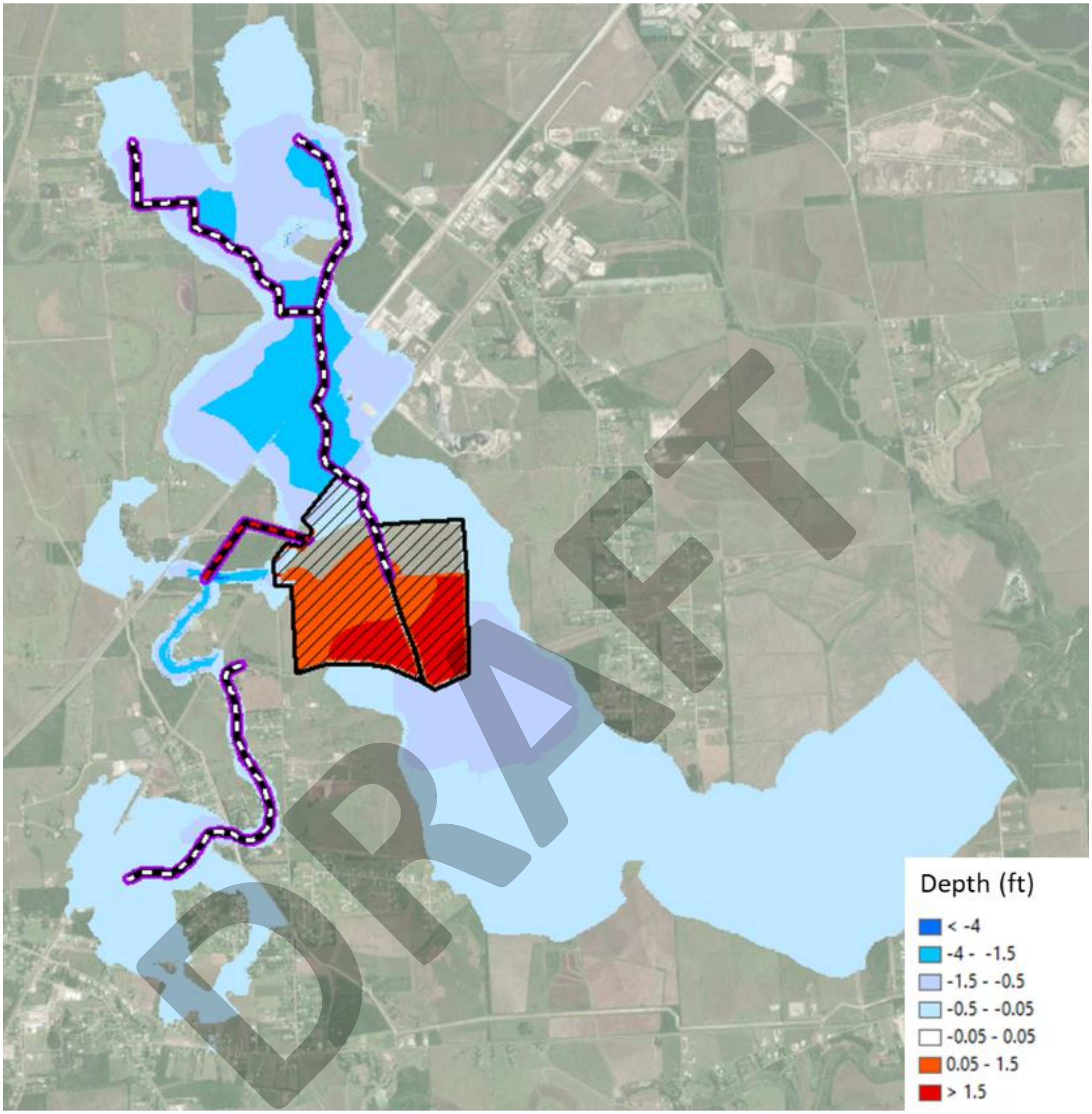

Figure 7: Water Surface Elevation Decreases – Post Project

4.00 BCA METHODOLOGY

4.01 METHODOLOGY

FEMA's BCA v6.0.0 toolkit, as well as FEMA procedures, and guidelines were followed to generate the BCA. The BCA is intended to compare annualized damages with and without a proposed project to determine the benefits provided by a proposed project on its financial costs. The Benefit-Cost Ratio (BCR) is determined by dividing the project benefit by the total project cost.

For this analysis, data was gathered from available sources including 2022 Jefferson County appraisal district data, 2018 LiDAR, and desktop analysis of street level imagery. Building replacement values were calculated using the default value of $100/sf was used in conjunction with livable square footage obtained from county appraisal district information. The generic USACE riverine damage curves obtained from FEMA were used to calculate damages. The specific damage curve used for each residential structure was based on the classification given to the structure by the Jefferson County Appraisal District. Structures fell into four categories, 1-story without basement, 2-story without basement, mobile home, or split level. For this analysis only residential structures were considered, any commercial or industrial structures were not considered.

JCDD6 additionally collected FFE information via survey at 431 residential structures. This information was used to determine an estimated FFE at the benefitting structures throughout the area by comparing the estimated LiDAR value versus the known FFEs obtained via survey. Two classifications were set for estimated FFEs depending on the structure type mentioned above.

Table 2: LiDAR to FEE conversation for structures not surveyed

Structure Class	Elevation added to LiDAR value
Mobile Home	1.5
Residential (1-Story, 2-Story, Split-Level)	0.75

The existing condition flood extents and proposed flood extents were modeled using HEC-RAS to generate water surface elevation information across the study area. Many structures will benefit from lowered water surface elevations in smaller, more frequent events such as the 2-year, 5-year or 10-year flood events.

4.02 BCA WORKBOOK

A structural inventory was developed for this project to calculate the damages to existing structures in existing conditions and with the proposed project constructed. Structures benefiting were limited to only residential structures, commercial and industrial were removed from the inventory for a more conservative analysis. The building replacement value of each structure was based on the default value of $100/sf. All values for damages were set using default values.

4.03 BCA TOOLKIT

Water surface elevations at each structure were determined using the HEC-RAS model results and the summation of damages for each storm event from the 2-year to the 500-year event were calculated to input into the BCA toolkit. Damages for structures, contents and displacement were calculated based on the generic USACE riverine damage curves. Social benefits were calculated by including the number of impacted workers based on 2016-2020 American Community Survey (ACS).

5.00 CONCULSION

The H&H analysis of the Bayou Din drainage improvements indicates that by providing detention, improving channel conveyance, and constructing a diversion channel many structures throughout the area can benefit from lower future flood risk and less damage. There are no adverse impacts as a result of the proposed improvements in any storm events up to and including the 500-year event. The BCA analysis using the BCA toolkit calculates an overall BCR of 1.55 indicating that project is cost effective.

LJA ENGINEERING

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4 May 2022

Orange County Drainage District
Attn: Mr. Don Carona
Mr. Doug Manning
8081 Old Highway 90
Orange, Texas 77630

Re: Orange County Drainage District's Flood Management Projects; Engineer's Certification Regarding No Negative Impact

To: Orange County Drainage District

Pursuant to the request of the Orange County Drainage District (the "OCDD"), I have reviewed the projects identified below for the purpose of determining whether the design and construction of the identified projects will create a negative impact on surrounding properties. The OCDD projects that I have reviewed are as follows:

PROJECT	SRFPG ID
* Cow Bayou #1 Detention Pond	043000001
* Cow Bayou #2 Detention Pond	043000002
* Terry Gully #1 Detention Pond	043000003
* Terry Gully #2 Detention Pond	043000004
* Terry Gully #3 Detention Pond	043000005
* Terry Gully #4 Detention Pond	043000006
* Cole Creek #1 Detention Pond	043000007
* Adams Bayou #1 Detention Pond	043000008
* Adams Bayou #2 Detention Pond	043000009
* Adams Bayou #3 Detention Pond	043000010
* Adams Bayou #4 Detention Pond	043000011
* Sabine River Relief Ditch Improvement and Extension Project	043000013
* Tiger Creek Detention Pond	043000020
* Lawrence Road Detention Pond	043000021
* Bridge City Drainage Outfall Improvement Project	043000023

*	Bessie Heights Drainage Ditch Extension Project	Not Yet Assigned
*	Elevation of Feeder Road Bridge Along IH-10 at Cole Creek	Not Yet Assigned
*	Installation of New Culverts along FM 1442 (Bridge City) at the Colonial Outfall Ditch	Not Yet Assigned
*	Orange County Coastal Storm Risk Management Project (Levee, Floodwalls and Pump Stations)	Not Yet Assigned

I have reviewed, and I am familiar with the Technical Guidelines issued by the Texas Water Development Board ("TWDB") for determining whether or not a project creates a "negative impact", defined to be an increase in flood risk to surrounding properties. The Technical Guidelines further note that the increase in flood risk must be measured by the 1 percent (1%) annual chance event assuming a given water surface elevation and peak discharge, and that a determination of no negative impact can be established if stormwater does not increase inundation of infrastructure such as residential and commercial buildings and structures.

As Orange County is located on the north end of Sabine Lake, at the confluence of the Neches River and Sabine River, with no other county located downstream, projects developed to improve drainage within the county have no negative impact on any other county. Furthermore, the OCDD has a strict policy, as documented in its Drainage Criteria Manual and Regulations, that no development (residential subdivision, commercial, governmental or industrial) may have an adverse impact on the drainage of another area. This policy of no adverse impact is evaluated and strictly enforced for all drainage improvement projects planned and constructed within Orange County or by the OCDD.

I have evaluated all of the above-referenced projects submitted by OCDD for inclusion in the Sabine Regional Flood Plan, and hereby certify that none of the proposed projects identified herein will negatively impact the existing drainage conditions of any other area, as defined and described in the TWDB Technical Guidelines.

Respectfully submitted,

STATE OF TEXAS
DAWN PILCHER
87863
REGISTERED
PROFESSIONAL ENGINEER

Dawn Pilcher, P.E., R.P.L.S.

4 MAY 2022

LJA ENGINEERING
3600 W Sam Houston Pkwy S, Suite 600, Houston, Texas 77042
t 713.953.5200 LJA.com TBPE F-1386 TBPLS 10110501

November 29, 2021

Mr. Don Carona, General Manager
Orange County Drainage District
8081 Old Highway 90
Orange Texas 77630

RE: Drainage Analysis (H&H Letter Report) for Bessie Heights Drainage Ditch Extension Project at the Nelda Stark Unit of the Lower Neches WMA

Dear Mr. Carona

This report presents the results of the drainage analysis for a proposed drainage project serving the Bessie Heights Area in Orange County, Texas. There is significant flooding in the area due to its location on the Gulf Coastal plain and influence from the adjacent Cow Bayou watershed. Characteristics of the project area that significantly contribute to the flooding issues include the relatively flat terrain, frequent intense rainfall events, fluctuating tidal influence, and restricted capacity of the existing Bessie Heights Drainage Ditch. The proposed project is designed help reduce structural flooding in residential developments within the project area. The project consists of the construction of an extension channel to improve discharge from the existing Bessie Heights Drainage Ditch, improvements to the existing Bessie Height Drainage Ditch south of FM 1442, and a short extension of the BH Road Ditch to connect it to the proposed Bessie Heights Drainage Ditch extension.

The project is located within Orange County on the northwest side of Bridge City, Texas as shown in the attached **Vicinity Map** exhibit. The analyzed system is located in the lower portion of the Neches River watershed. The proposed modification will improve the conveyance of stormwater runoff from developments located within the Bessie Heights subbasin to the open water areas of the marsh, in route to the Neches River. This improved conveyance will decrease flood levels experienced in residential developments and neighborhoods within the project area.

The models used as the basis for the analysis were developed as part of the US Army Corps of Engineers study of internal drainage for the Sabine Pass to Galveston Bay Hurricane Flood Protection Program. The hydraulic models used are Rain-on-Grid two-dimensional models developed in HEC-RAS 6.0. and the terrain is based on LiDAR data available from the Texas Natural Resource Information System (TNRIS).

With recent climate changes and more frequent/more severe rainfall events, the National Weather Service (NWS) recently updated its statistical precipitation probability tables which resulted in the statistical "100-year" rainfall event for Orange County changing from approximately 12 inches of precipitation in 24 hours to over 17 inches of rain in the same 24 hour period. The latest NWS models are referred to as “NOAA Atlas-14” rainfall data, and this data set was used in the development of the precipitation runoff models for this study. For this study, the recurrence intervals of interests were the 10 year, 25 year, 50 year, and 100 year events.

The following Table summarizes the data applied to drainage models associated with this project:

TABLE 5-5: RAINFALL DATA FOR ORANGE COUNTY
NOAA Atlas 14, volume 11, Version 2, Orange, TX

Recurrence Interval (years)	Rainfall Depth (inches) for Given Duration								
	5 MIN	15 MIN	30 MIN	1 HR	2 HR	3 HR	6 HR	12 HR	24 HR
2	0.61	1.23	1.76	2.35	2.97	3.35	4.04	4.80	5.62
5	0.75	1.51	2.16	2.90	3.77	4.33	5.32	6.36	7.48
10	0.87	1.74	2.47	3.35	4.45	5.19	6.50	7.85	9.29
25	1.02	2.05	2.90	3.95	5.41	6.43	8.26	10.1	12.1
50	1.15	2.26	3.19	4.37	6.15	7.43	9.73	12.0	14.5
100	1.25	2.49	3.50	4.82	6.95	8.54	11.4	14.3	17.3
500	1.56	3.11	4.41	6.19	9.30	11.7	16.1	20.8	25.8

Several configurations of proposed conveyance improvements were analyzed.

A base project was first developed which considered only the construction of an extension of the Bessie Heights Drainage Ditch, without including improvements to the existing Bessie Heights Drainage Ditch. The best design for the Bessie Heights Drainage Ditch extension consists of a trapezoidal channel with a 50 to 60-foot bottom width and varying side slopes. In addition to the Bessie Heights Drainage Ditch extension, improvement and extension of the BH Road Ditch were evaluated. The optimum design for the BH Road Ditch, which draws additional run-off from residential areas and currently discharges to the vegetated marsh, involves extending the existing BH Road Ditch to the proposed Bessie Heights Drainage Ditch Extension. The proposed BH Road Ditch extension is a trapezoidal channel with a 20-foot bottom width and 3:1 side slopes, approximately 3’ deep routed from the current termination of the BH Road Ditch to meet the proposed Bessie Heights Drainage Ditch extension west of the power line corridor.

With a full understanding of the impacts of the proposed Bessie Heights Drainage Ditch extension, additional improvements were considered on the existing Bessie Heights Drainage Ditch upstream from the proposed extension to the FM 1442 bridge crossing. The channel improvements from FM 1442 to the proposed ditch extension would expand the existing Bessie Heights Drainage Ditch to a trapezoidal channel with a 40-foot bottom width and 3:1 side slopes. For this evaluation, the Bessie Heights Drainage Ditch extension and the BH Road Ditch remain the same size and geometry as previously described for the base project in the previous paragraph.

While the Bessie Heights Drainage Ditch extension provides significant benefits in the form of reduced water surface elevations at each level of storm evaluated, when coupled with improvements to the existing Bessie Heights Drainage Ditch from FM 1442 to the proposed extension, the upstream benefits are further increased without adverse impacts to any of the nearby residential properties.

The best combined scenario for the ditch system resulted in the following configurations:

Ditch/Location	Bottom Width	Flowline Elevation through TPWD Property	Side Slopes
BH Road Ditch	20’	-1.5’	3:1
Bessie Heights Ditch, FM 1442 to Relief Ditch	40’	-2’	3:1
Bessie Heights Ditch Extension, EAST of power line corridor	50’	-2’ to -2.5’	3:1
Bessie Heights Ditch Extension, WEST of power line corridor	60’	-2.5’ to -3’	4:1

As the drainage outfalls progress further into the marsh area, flatter side slopes are necessary to accommodate slope stability in the soft, saturated soils conditions.

As shown in the maps on following pages, the above-described ditch improvements result in the following water surface elevation reductions within the area of interest:

Storm Event Annual Exceedance Probability (Statistical Return Interval)	Anticipated Water Surface Reductions depending on location (see maps)
10% (10 year)	~3” to >6” reduction
4% (25 year)	~3” to >6” reduction
2% (50 year)	~3” to >6” reduction
1% (100 year)	~3” to >6” reduction

The following tables show the comparison of water surface elevations for the alternatives. The locations where the comparisons are made is shown in the **Bessie Heights Cross Section Data** exhibit.

Improved Bessie Heights Ditch Between FM 1442 and Proposed Extension			
Annual Exceedance Probability	With Existing Conditions	With Ditch Extension and Improvements South of FM 1442	WSE Change from Existing to Proposed Conditions
Evaluated Storm	WSE (Feet)	WSE (Feet)	Change in WSE
10% (10-yr)	6.09	5.39	-0.70’ (-8.4”)
4% (25-yr)	6.51	5.89	-0.62’ (-7.4”)
2% (50-yr)	6.82	6.25	-0.57’ (-6.8”)
1% (100-yr)	7.12	6.58	-0.54’ (-6.5”)

Existing Bessie Heights Ditch South of Proposed Extension (no excavation)			
Annual Exceedance Probability	With Existing Conditions	With Ditch Extension and Improvements South of FM 1442	WSE Change from Existing to Proposed Conditions
Evaluated Storm	WSE (Feet)	WSE (Feet)	Change in WSE
10% (10-yr)	5.30	4.65	-0.65’ (-7.8”)
4% (25-yr)	5.62	5.04	-0.58’ (-7.0”)
2% (50-yr)	5.85	5.32	-0.53’ (-6.4”)
1% (100-yr)	6.08	5.57	-0.51’ (-6.1”)

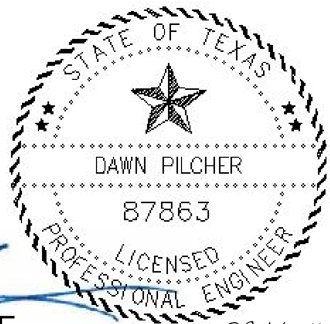
Proposed Bessie Heights Ditch Extension, between Improved Section of Bessie Heights Ditch and BH Road Ditch			
Annual Exceedance Probability	With Existing Conditions	With Ditch Extension and Improvements South of FM 1442	WSE Change from Existing to Proposed Conditions
Evaluated Storm	WSE (Feet)	WSE (Feet)	Change in WSE
10% (10-yr)	5.51	4.75	-0.76’ (-9.1”)
4% (25-yr)	5.86	5.18	-0.68’ (-8.2”)
2% (50-yr)	6.12	5.48	-0.64’ (-7.7”)
1% (100-yr)	6.37	5.76	-0.61’ (-7.3”)

BH Road Ditch near Proposed Bessie Heights Ditch Extension			
Annual Exceedance Probability	With Existing Conditions	With Ditch Extension and Improvements South of FM 1442	WSE Change from Existing to Proposed Conditions
Evaluated Storm	WSE (Feet)	WSE (Feet)	Change in WSE
10% (10-yr)	3.97	3.52	-0.45’ (-5.4”)
4% (25-yr)	4.15	3.86	-0.29’ (-3.5”)
2% (50-yr)	4.30	4.07	-0.23’ (-2.8”)
1% (100-yr)	4.46	4.26	-0.20’ (-2.4”)

As shown in the above tables, the proposed improvements provide a reduction in water surface elevation (WSE) for all storm frequencies. The overall extent of the reductions can be seen in the attached Water Surface Comparison exhibits.

If you have any questions or need any additional information, please do not hesitate to contact me at dpilcher@lja.com or at 409.284.8581.

Sincerely,

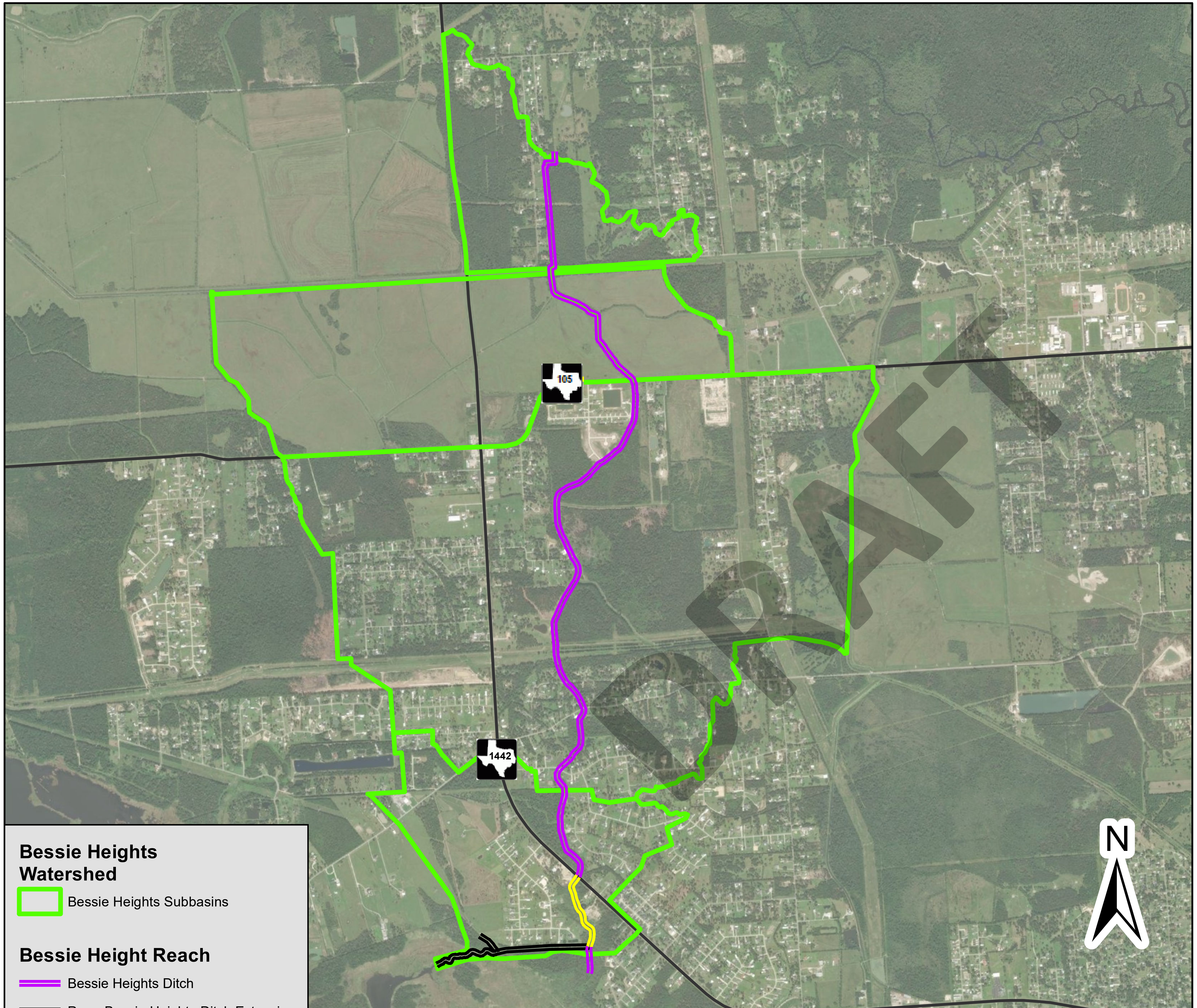


29 November 2021

Dawn Pilcher, PE
Sr. Project Manager

ATTACTMENTS:

- Vicinity Map
- Bessie Heights Cross Section Locations
- 10-YR WSE Comparison
- 25-YR WSE Comparison
- 50-YR WSE Comparison
- 100-YR WSE Comparison



Bessie Heights Watershed

Bessie Heights Subbasins

Bessie Height Reach

Bessie Heights Ditch

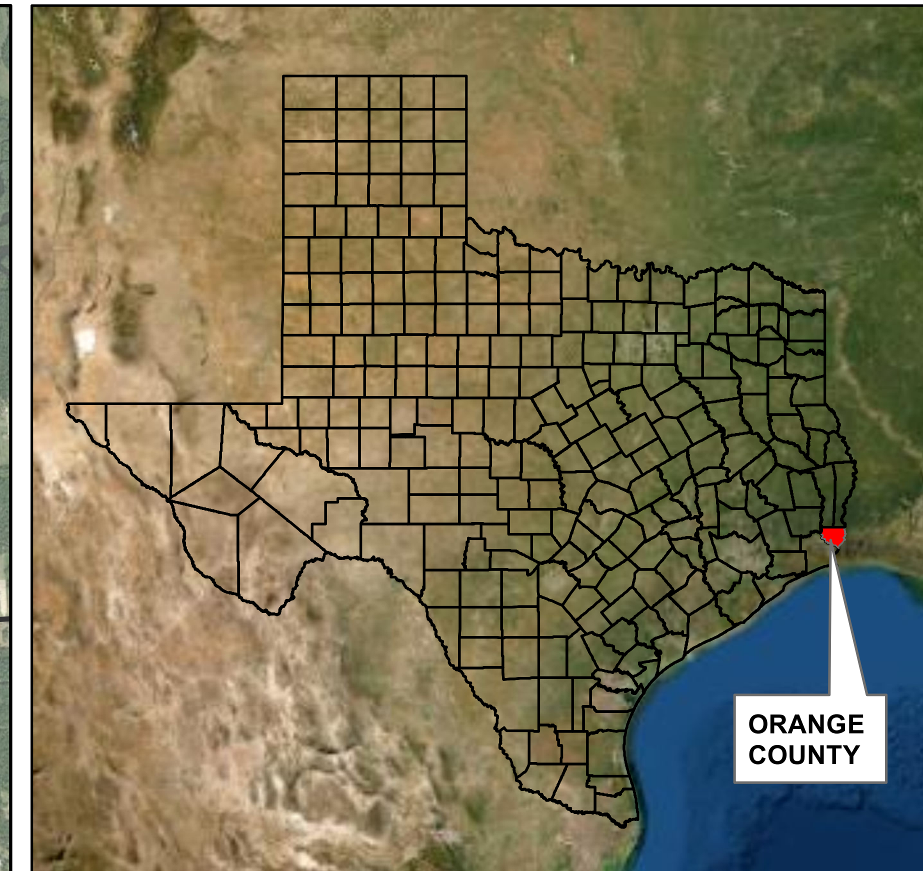
Prop, Bessie Heights Ditch Extension

Additonal Channel Improvements Upsteam of Ditch Extension

TxDOT

0 1,100 2,200 4,400 Feet

1 inch = 2,200 feet



LJA Engineering, Inc.

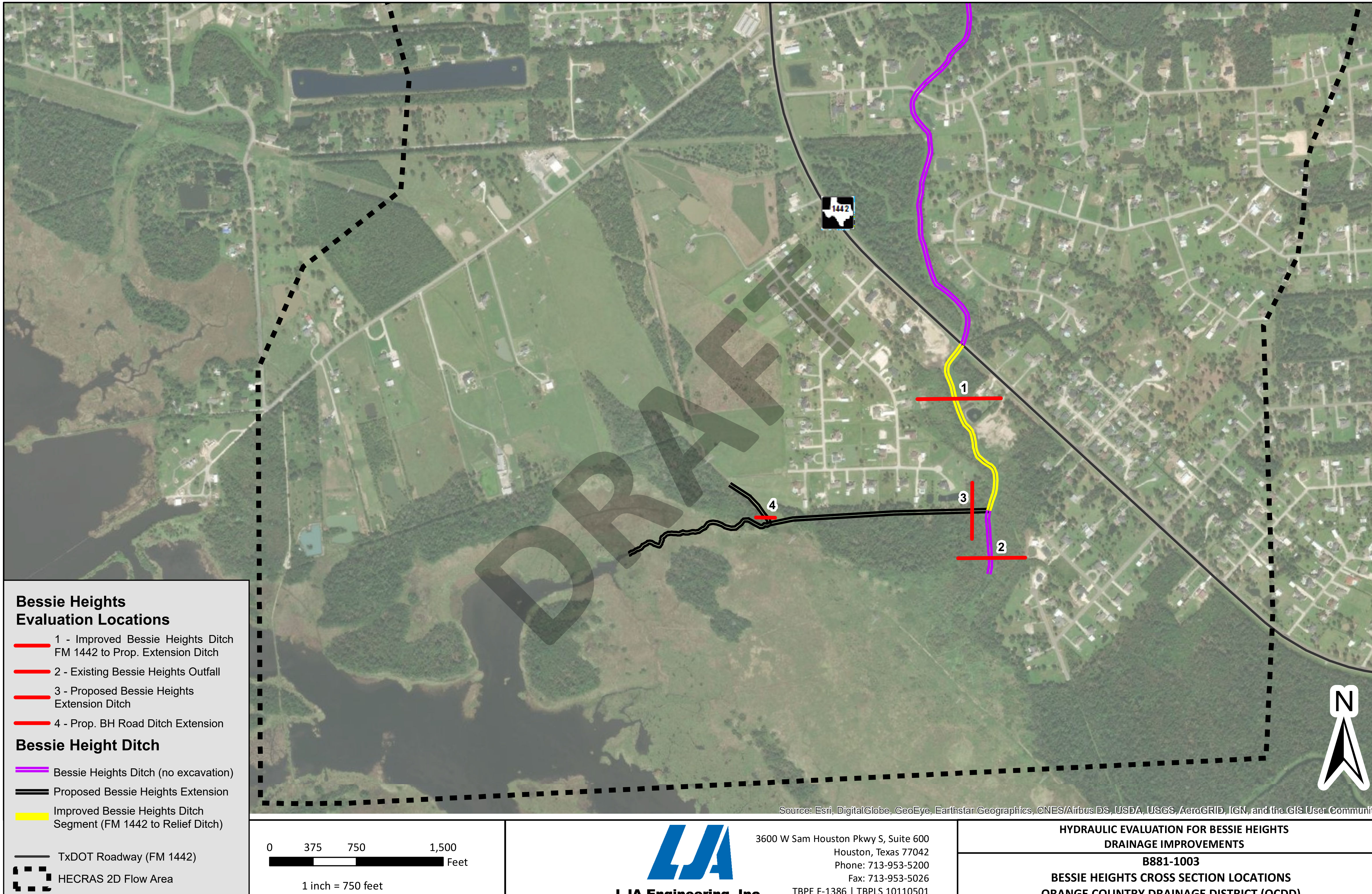
3600 W Sam Houston Pkwy S, Suite 600
Houston, Texas 77042
Phone: 713-953-5200
Fax: 713-953-5026
TBPE F-1386 | TBPLS 10110501

HYDRAULIC EVALUATION FOR BESSIE HEIGHTS DRAINAGE IMPROVEMENTS

B881-1003

VICINITY MAP

ORANGE COUNTRY DRAINAGE DISTRICT (OCDD)



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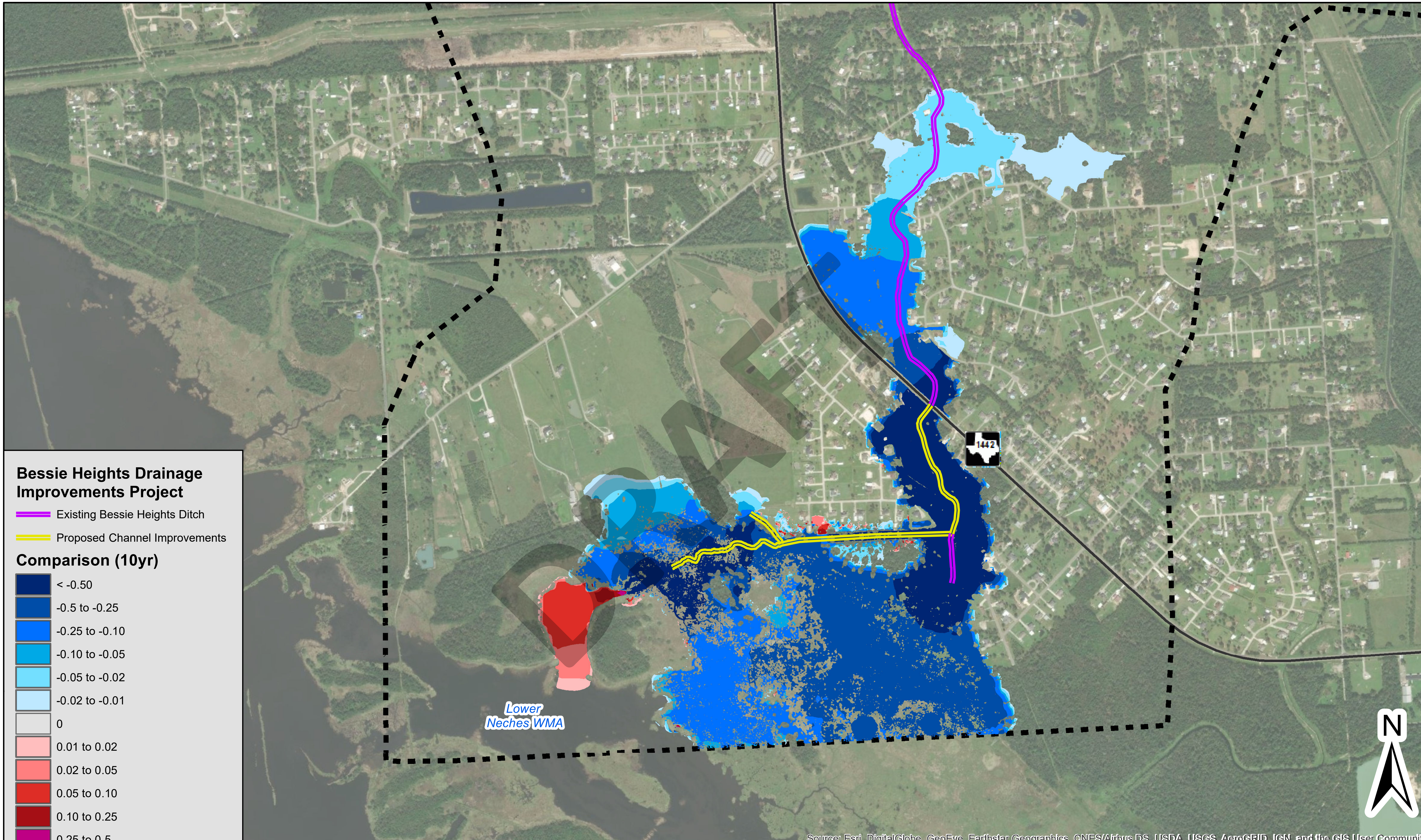
HYDRAULIC EVALUATION FOR BESSIE HEIGHTS DRAINAGE IMPROVEMENTS

B881-1003

BESSIE HEIGHTS CROSS SECTION LOCATIONS

ORANGE COUNTRY DRAINAGE DISTRICT (OCDD)



0 500 1,000 2,000 Feet

1 inch = 1,000 feet

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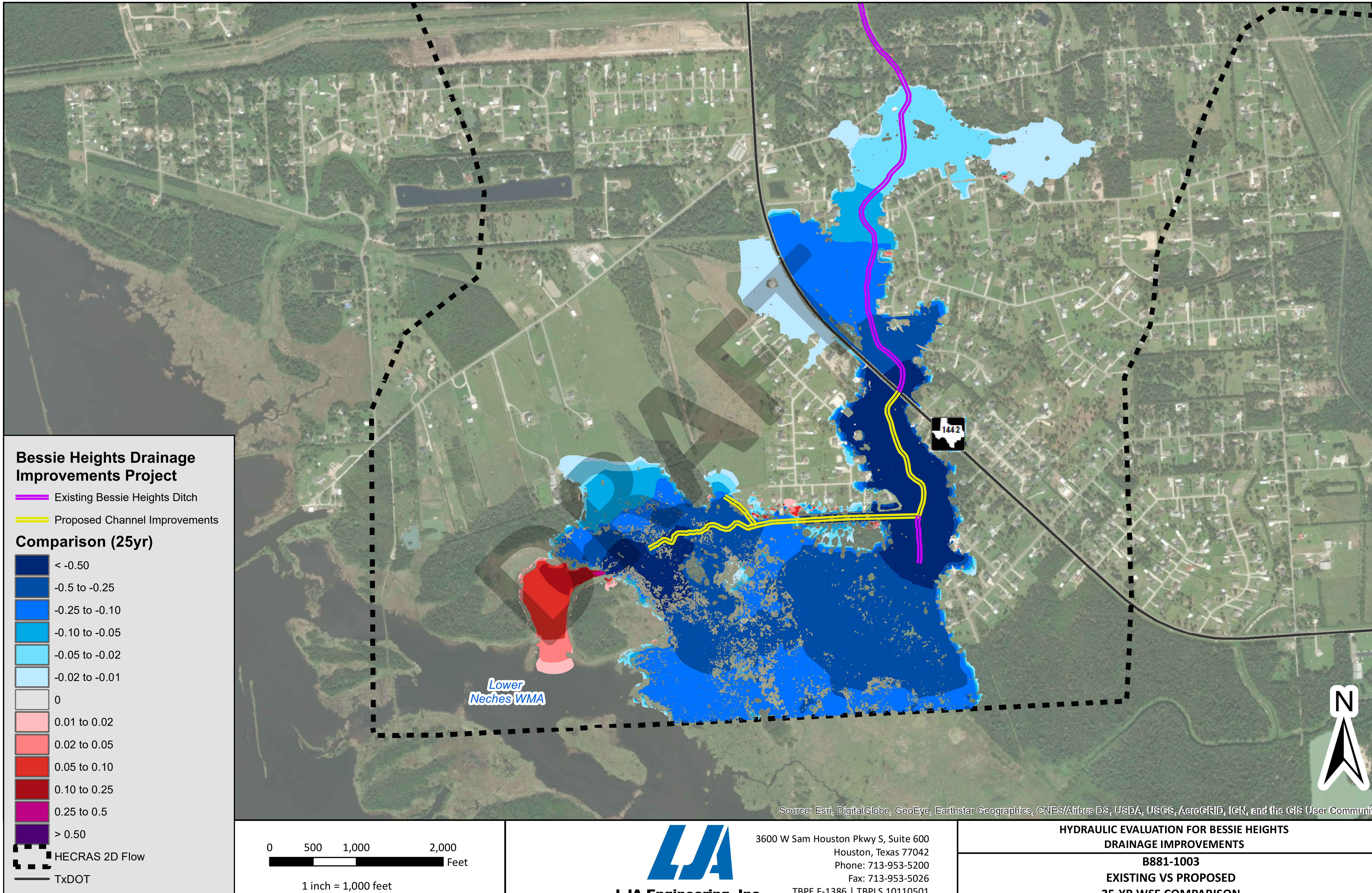
HYDRAULIC EVALUATION FOR BESSIE HEIGHTS DRAINAGE IMPROVEMENTS

B881-1003

EXISTING VS PROPOSED 10-YR WSE COMPARISON



0 500 1,000 2,000 Feet

1 inch = 1,000 feet

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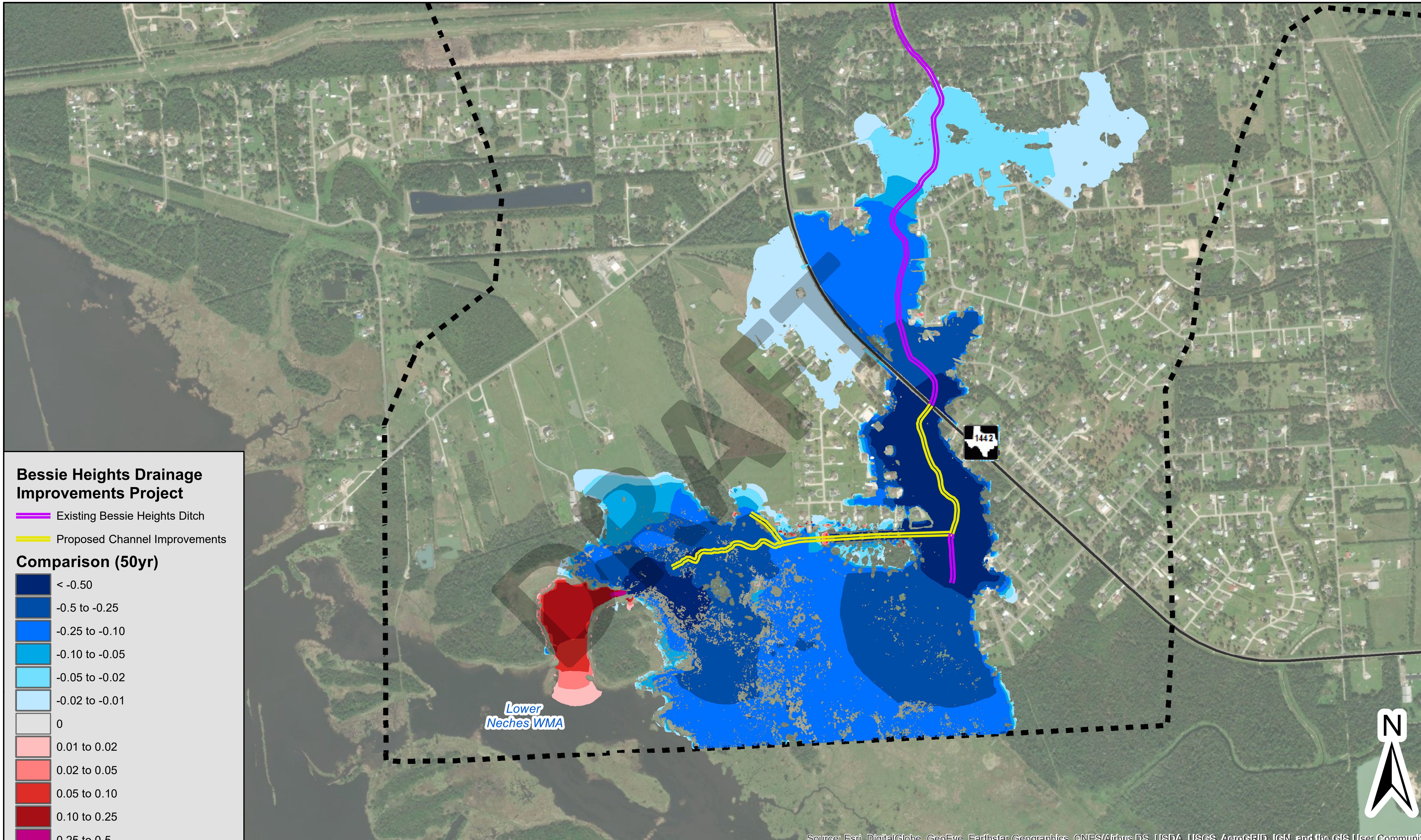
HYDRAULIC EVALUATION FOR BESSIE HEIGHTS DRAINAGE IMPROVEMENTS

B881-1003

EXISTING VS PROPOSED 25-YR WSE COMPARISON

S:\CBI-Data\Projects\Projects LJA B000 - BXXX\B881 - OCDD\B881-1003 Emergency Flood Response Support\400 Bessie Heights\GIS\Exhibits\10_12-2021 LATEST EXHIBITS\11_2021 Proposed Exhibits Alternative 2 (Updated)\25yr WSE Comparison - Alternative 2.mxd



0 500 1,000 2,000 Feet

1 inch = 1,000 feet

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HYDRAULIC EVALUATION FOR BESSIE HEIGHTS DRAINAGE IMPROVEMENTS

B881-1003

EXISTING VS PROPOSED

50-YR WSE COMPARISON

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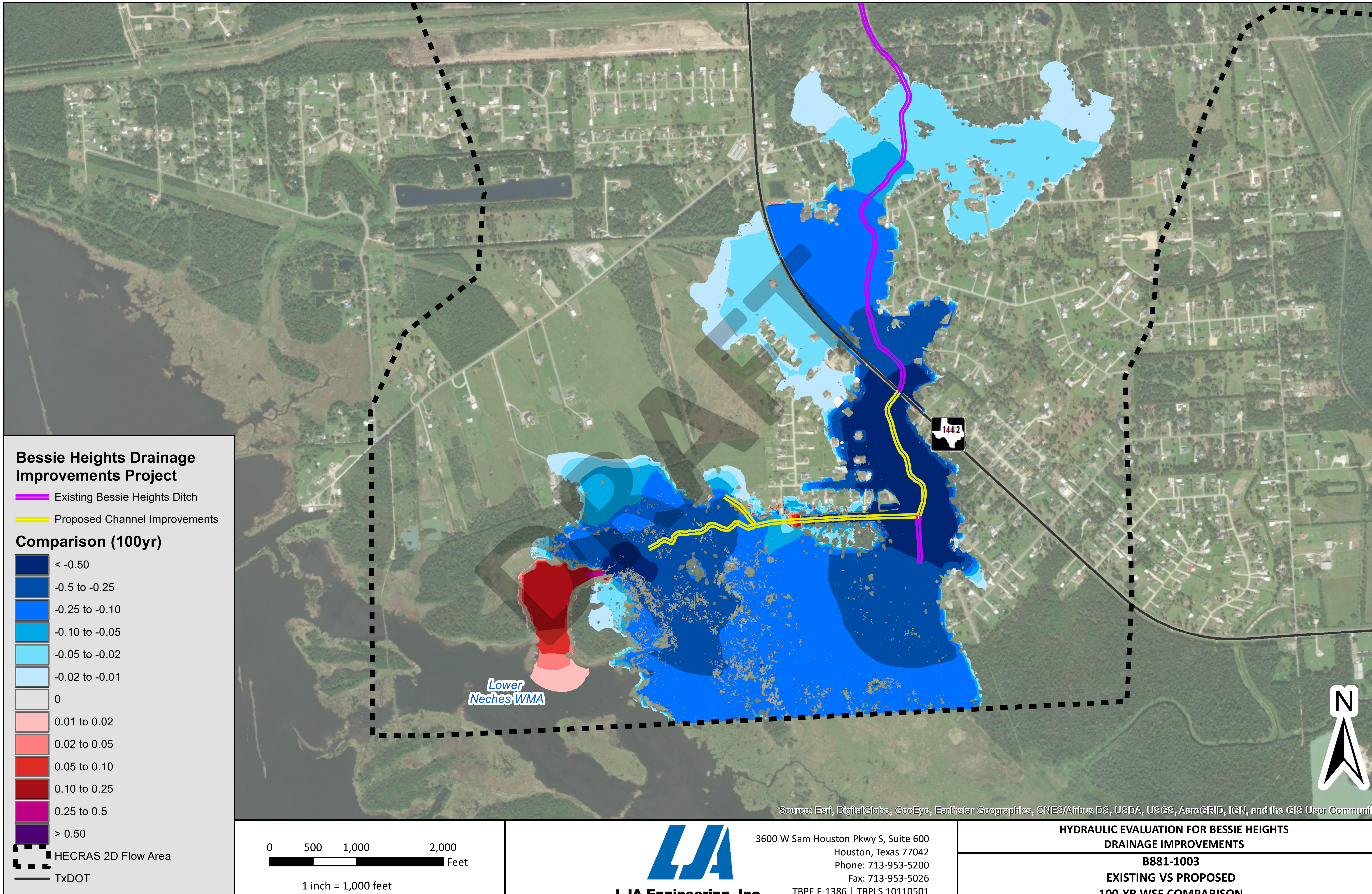

1 inch = 1,000 feet

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TBPE F-1386 | TBPLS 10110501

HYDRAULIC EVALUATION FOR BESSIE HEIGHTS DRAINAGE IMPROVEMENTS

B881-1003

EXISTING VS PROPOSED 100-YR WSE COMPARISON

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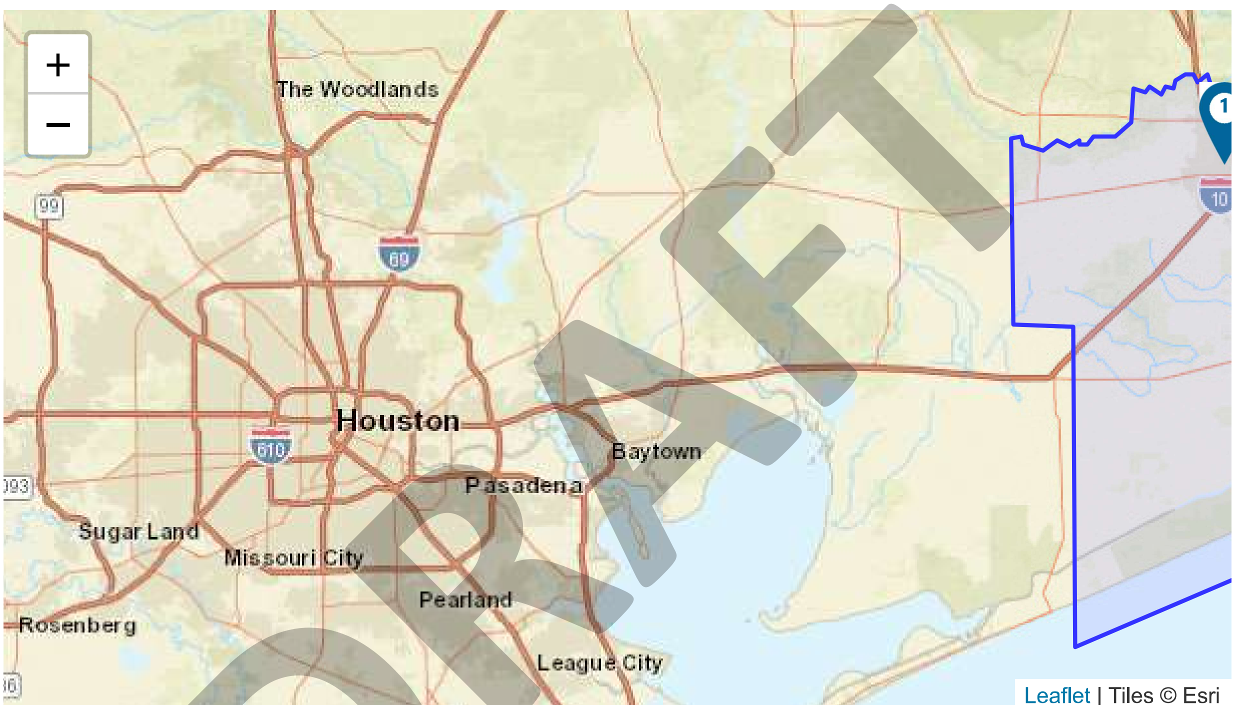
FEMA

Benefit-Cost Calculator

V.6.0 (Build 20220513.1658 | Release Notes)

Benefit-Cost Analysis

Project Name: Channel 100-A [Jefferson County Drainage District No. 6]



Map Marker ▲	Mitigation Title	Property Type	Hazard	Benefits (B)	Costs (C)	BCR (B/C)
1	Drainage Improvement @ 30.0818340; -94.1487680		DFA - Riverine Flood	$ 445,896,483	$ 39,783,811	11.21
TOTAL (SELECTED)				**$ 445,896,483**	**$ 39,783,811**	**11.21**
TOTAL				**$ 445,896,483**	**$ 39,783,811**	**11.21**

Property Configuration

Property Title:	Drainage Improvement @ 30.0818340; -94.1487680
Property Location:	77707, Jefferson, Texas
Property Coordinates:	30.0818340, -94.1487680
Hazard Type:	Riverine Flood
Mitigation Action Type:	Drainage Improvement
Property Type:	Residential Building
Analysis Method Type:	Professional Expected Damages

Cost Estimation

Drainage Improvement @ 30.0818340; -94.1487680

Project Useful Life (years):	75
Project Cost:	$39,570,866
Number of Maintenance Years:	75 Use Default:Yes
Annual Maintenance Cost:	$15,000

Comments

-

Project Useful Life:

Default value for storm sewer infrastructure is 50-years with concrete lined flood control channels up to 75-years.

-

Mitigation Project Cost:

Total Project Cost worksheet is attached FEMA GO application.

-

Annual Maintenance Cost:

Approx. $5,000 per year for mowing new concrete lined channel - to be done up to three (3) times per year.

Damage Analysis Parameters - Damage Frequency Assessment

Drainage Improvement @ 30.0818340; -94.1487680

Year of Analysis Conducted:	2020
Year Property was Built:	1950
Analysis Duration:	71 Use Default:Yes

Professional Expected Damages Before Mitigation

Drainage Improvement @ 30.0818340; -94.1487680

	OTHER	OPTIONAL DAMAGES			VOLUNTEER COSTS		TOTAL
Recurrence Interval (years)	Damages ($)	Structural Value ($)	Contents Value ($)	Displacement ($)	Number of Volunteers	Number of Days	Damages ($)
10	0	814,461	700,469	460,951	0	0	1,975,881
25	0	20,295,455	35,526,395	5,714,282	0	0	61,536,132
50	0	67,347,485	104,661,309	18,568,842	0	0	190,577,636
100	0	130,276,898	195,322,723	39,432,846	0	0	365,032,467
500	0	248,639,357	345,973,979	83,943,258	0	0	678,556,594

Comments

-

Damages Before Mitigation:

DDF worksheet attached to FEMA GO application.

Annualized Damages Before Mitigation

Drainage Improvement @ 30.0818340; -94.1487680

Annualized Recurrence Interval (years)	Damages and Losses ($)	Annualized Damages and Losses ($)
10	1,975,881	661,602
25	61,536,132	2,165,863
50	190,577,636	2,637,556
100	365,032,467	3,981,519
500	678,556,594	1,357,045
	Sum Damages and Losses ($)	Sum Annualized Damages and Losses ($)
	1,297,678,710	10,803,585

Professional Expected Damages After Mitigation

Drainage Improvement @ 30.0818340; -94.1487680

	OTHER	OPTIONAL DAMAGES			VOLUNTEER COSTS		TOTAL
Recurrence Interval (years)	Damages ($)	Structural Value ($)	Contents Value ($)	Displacement ($)	Number of Volunteers	Number of Days	Damages ($)
10	0	375,745	281,468	215,939	0	0	873,152
25	0	17,686,935	27,336,481	5,907,410	0	0	50,930,826
50	0	60,312,061	95,636,581	16,461,755	0	0	172,410,397
100	0	127,095,388	190,255,843	38,612,817	0	0	355,964,048
500	0	248,179,288	345,859,338	83,943,258	0	0	677,981,884

Annualized Damages After Mitigation
Drainage Improvement @ 30.0818340; -94.1487680

Annualized Recurrence Interval (years)	Damages and Losses ($)	Annualized Damages and Losses ($)
10	873,152	400,117
25	50,930,826	1,874,140
50	172,410,397	2,477,335
100	355,964,048	3,930,086
500	677,981,884	1,355,896
	Sum Damages and Losses ($)	Sum Annualized Damages and Losses ($)
	1,258,160,307	10,037,574

Standard Benefits - Ecosystem Services
Drainage Improvement @ 30.0818340; -94.1487680

Total Project Area (acres):	1,950
Percentage of Green Open Space:	12.00%
Percentage of Riparian:	0.00%
Percentage of Wetlands:	0.00%
Percentage of Forests:	0.00%
Percentage of Marine Estuary:	0.00%
Expected Annual Ecosystem Services Benefits:	$1,944,072

Comments

-

Percent Green Open Space:
undeveloped tracts of land

Additional Benefits - Social
Drainage Improvement @ 30.0818340; -94.1487680

Number of Workers:	3,654
Expected Annual Social Benefits:	$43,220,219

Comments

-

Number of Workers:
https://www.census.gov/quickfacts/fact/table/beaumontcitytexas/LND110210 in civilian labor force, total, percent of population age 16 years+, 2015-2019

Benefits-Costs Summary

Drainage Improvement @ 30.0818340; -94.1487680

Total Standard Mitigation Benefits:	$402,676,264
Total Social Benefits:	$43,220,219
Total Mitigation Project Benefits:	$445,896,483
Total Mitigation Project Cost:	$39,783,811
Benefit Cost Ratio - Standard:	10.12
Benefit Cost Ratio - Standard + Social:	11.21

CESWG-Z 26 APRIL 2021

MEMORANDUM FOR RECORD

SUBJECT: HYDRAULIC DESIGN CRITERIA FOR THE INTERIOR AREA OF THE SABINE PASS TO GALVESTON BAY ORANGE CSRM LEVEE

References

- *i.* Public Law 115-270. Section 1401 (3)3., Water Resources Development Act of 2018
- *ii.* *USACE. Chief's Report-Sabine Pass to Galveston Bay, Texas, Coastal Storm Risk Managementand Ecosystem Restoration Study* 2017
- *iii.* USACE, *Sabine Pass to Galveston Bay, Texas Coastal Storm Risk Management and Ecosystem Restoration Final Integrated Feasibility Report – Environmental Impact Statement*, May 2017
- *iv.* TxDOT, *New Rainfall Coefficients -- Including tools for estimation of intensity and hyetographs inTexas,* 2015
- *v.* TxDOT, *Hydraulic Design Manual* 2019
- *vi.* Orange County Drainage District, *Drainage Criteria Manual* October 6, 2020
- *vii.* U.S. Geological Survey, *Water-Resources Investigations Report 96–4307 USGS Regional Equations for Estimation of Peak-Streamflow Frequency for Natural Basins in Texas,* 1996
- *viii.* Galveston Coastal Services, *Interior Drainage – Progress Summary andObservations* – 05 FEB 2021
- *ix.* USACE *Hydrologic Analysis for Interior Areas EM 1110-2-1413,* 2018
- *x.* USACE *CECW-PA MEMORADUM SUBJECT: Policy Guidance Letter No. 37, CostSharing of Interior Drainage Facilities,* No Date
- *xi.* USACE and UCF, *Assessing the Potential for Compound Flooding in Parts the Sabine And Brazoria River Basins: Joint probability analysis of high river discharge and storm surge.* No Date

1. The purpose of this memo is to establish the design criteria for the interior drainage area of theOrange CRSM levee for the Sabine Pass to Galveston Bay Project and how results of the performance of the design criteria will be determined and implemented.

2. The Sabine Pass to Galveston Bay Project was authorized in Section 1401 of the Water Resources Development Act of 2018 (P.L. 115-270) (Ref. i). The authorization states that the Sabine to Galveston Project will be carried out substantially in accordance with the plans and subject to the conditions described in the Chief's Report (Ref ii). The Chief's Report details the Orange CSRM plan which will build seven pump stations, 56 drainage structures, and 32 closuregates located at road and railway crossings to mitigate interior flooding during surge events. Twonavigable sector gates with adjacent vertical lift floodgates for normal channel flows would be constructed in Adams and Cow Bayous to reduce surge penetration.

3. The development of the interior drainage analysis in support of the study was summarized in the Sabine Pass to Galveston Bay Integrated Feasibility and Environmental Analysis Report (Ref iii). The analysis documented in the report is based on the USACE standard

covered in Ref ix which governs Hydrologic Analysis for Interior Areas. Ref ix requires that the minimum facilities design event be based on the local drainage system design event, which is published by Orange County Drainage District (Ref vi). A hydrologic analysis using the Rational Method determined the frequency-discharge values for small watersheds and regression equations were used to determine the frequency-discharge values of large watersheds. The rainfall intensity parameters used for the Rational Method were based on rainfall estimates published in 2015 by TxDOT (Ref. iv). TxDOT has since updated their Hydraulic Design Manual (Ref. v) with new parameters which are published in the current Orange County Drainage District Design Criteria Manual and Regulation (Ref. vi). For large watersheds, discharges were conservatively chosen based on the higher results of two regressions equations published by TxDOT (Ref. v) and the USGS (Ref. vii).

4. In the Feasibility Study, drainage provided by culverts through the design levee were placed in areas of known flow paths and sized to allow the 100-year discharge plus a 10% increase for climate change to pass without backwater effects. No pumps were required or anticipated for the “open gate” condition. As a result, it was assumed that there were no interior flood impacts for low exterior, or “open gate” conditions. Under a surge conditions or “closed gate conditions”, it was assumed that the gravity drained flood waters equivalent to a 25-year storm behind the interior would be pumped over the levee. Pump sizes were reduced based on a Joint Probability Analysis(JPA) on the nearby Neches River due to the assumed non-coincident nature of riverine and costal surge events.

5. Due to the simplistic methods used to generate interior hydrology (Regression Equations and Rational Method) and the assumptions on culvert performance, a more detailed analysis was recommended for PED. There is concern that the interior drainage design will not perform as well as in feasibility. Reasons for reduced performance for drainage could be attributed to an increase in runoff due to application of NOAA Atlas14 precipitation values and reduced culvertperformance due to inclusion of tailwater conditions and frictional losses.

6. With any changes to the design, the hydraulic performance must meet the minimum facility requirement stated in multiple USACE guidance documents (Refs. ix, x). Minimum interior drainage facilities are defined as the measures required to provide interior drainage relief such that, during low exterior stages, the local storm drainage system will function as it did without the line-of-protection in place to accommodate the flows from the storm water system design storm. Minimum facilities may also include higher storm water design standards than accommodated by the local storm water system if these higher standards are mandated by validly promulgated Federal, State or local regulations. The current standard to which the minimum facilities is to be based on is defined in the Orange County Drainage District Drainage Criteria Manual and Regulation (Ref. vi).

7. Orange County Drainage District Drainage Criteria Manual has developed separate criteria forwhat is referred to as "primary" and "secondary" drainage features. Primary drainage facilities include open channels, bridges, culverts, and enclosed drainage systems (i.e., open channel thathas been enclosed). Secondary drainage facilities include storm sewer systems, roadside ditchesand associated structures, and other facilities such as sheet flow swales, small culverts, local detention facilities, and other structures which typically serve relatively small drainage areas, as well as lot grading and drainage requirements.

8. Primary features adopt a 100-year level of protection for future primary drainage facilities. Channels shall be designed to convey 100-year peak flow rates with a minimum freeboard of 1 foot. These channels should also be analyzed using a 10-year design storm event to ensure the channel has adequate capacity to accept and convey a more frequent and more intense storm of shorter duration which could cause "flash flooding". For open channel studies involving FederalEmergency Management Agency (FEMA) submittals, the 10-year, 50-year, 100-year, and 500- year storm frequencies must be analyzed. Other criteria existing beyond these critical regulationsare within the Orange County Drainage Manual. Conversations with the local stakeholders clarified the residual flooding requirement to mean 0.0 ft rise in water surface elevation for areas inundated by the 50% CL 100-year 24-hour storm defined in NOAA Atlas 14.

9. The minimum requirement does not address a surge or "closed gate" condition. However, the intent of the feasibility design performance was to size pump stations to pass the 25-year interiorflood over the levee. The closed condition should evaluate a design to meet this performance goal under updated inputs (NOAA Atlas 14) and methods (computational modeling using HEC-HMS and HEC-RAS). Ultimately, the closed condition should be evaluated under a coincident inland flood event to a condition or event that necessitates a "closed gate" condition, including a predicted coastal flood event. This information is resolved by developing a JointProbability Analysis. The Joint Probability Analysis should determine the coupled surge/interior flood conditions and assign a frequency probability to them. A recent JPA analysis was conducted on the Adams and Cow Bayou by USACE and UCF (Ref. xi) following the FeasibilityStudy. The analysis provided return periods for compounding flood events. For the Cow Bayou,a relationship between the Cow Bayou discharge gage at the Mauriceville and surge levels at Sabine Pass Tidal Gage were developed. For Adams Bayou, due to a lack of gage data, a relationship was developed between precipitation the weather station at Orange and surge levels at the Sabine Pass Tidal Gage. The relationships were developed by investigated correlations in the data sets and applying best-fit distributions and copulas. The results are shown in the Figures1 and 2.

10. Measures to solve residual interior flooding may include larger capacity outlets, diversion structures, pressure conduits, excavated detention storage, ponding areas, pumping plants andnonstructural solutions. Residual flooding will be analyzed using risk informed analysis, which

includes delineation of multiple storm events from the 2 year to the 500 year.

11. To summarize, the Government, during design, will follow this procedure to finalize the interior drainageanalysis:
    a. Under open gate low exterior conditions, the interior design must meet the minimum design facility standard. Evaluation will be for eight flood frequency (i.e.., 2-, 5-, 10-, 25-, 50-, 100- and 500-year) events. The final system will be designed for the NOAA Atlas 14 100-year, 24-hour, 50% CL precipitation. The Joint Venture scope will be developed to address the local residual flooding requirement of 0.0 ft rise in water surface elevation by analyzing 2 alternatives; 1) an alternative that eliminates increased water level on the interior of the system and, 2) an alternative that minimizes, but may not eliminate, increased water level on the interior of the system.
    b. Under a closed gate condition for surge events, the interior drainage system including pump stations and minimum pump capacity will be designed for the greater of the minimum facility design, or a design sized for the NOAA Atlas 14 25-year 24 hour 50% CL precipitation event (as authorized in the feasibility study). As with the open condition, evaluation will be for eight flood frequencies (i.e.., 2-, 5-, 10-, 25-, 50-, 100- and 500-year) events. However, actual probability of occurrence will be assigned through a JPA analysis (to be included inthe task order if greater fidelity than *ref. xi* can be reasonably expected to be obtained). Residual flooding will be documented for each of the flood frequencies considering the JPA.

12. The point of contact for this memorandum is Robert Thomas at 409-766-3975 or email Robert.c.thomas@usace.army.mil.

Encl

TIMOTHY R. VAIL
COL, EN
Commanding

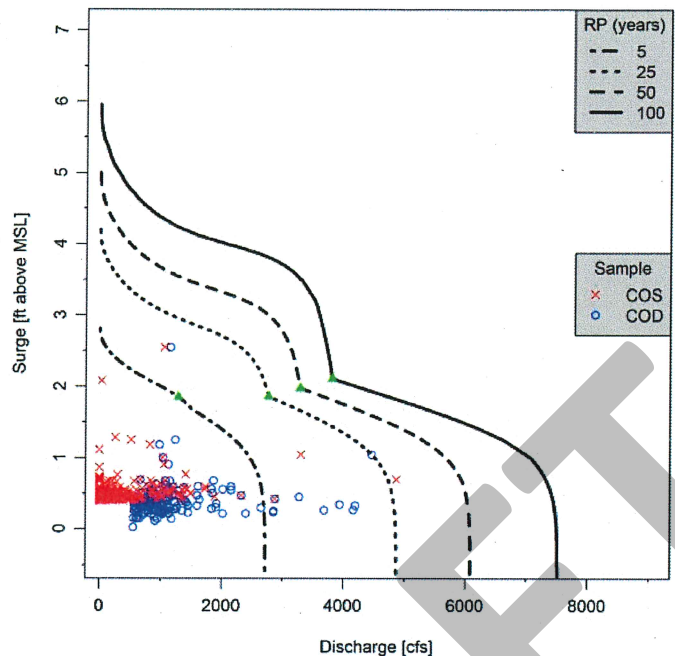


Figure 1: Cow Bayou RP for Discharge Values at the Mauriceville gage and Surge levels at the Sabine River Tidal Gare (fromFigure 21 of Ref i)

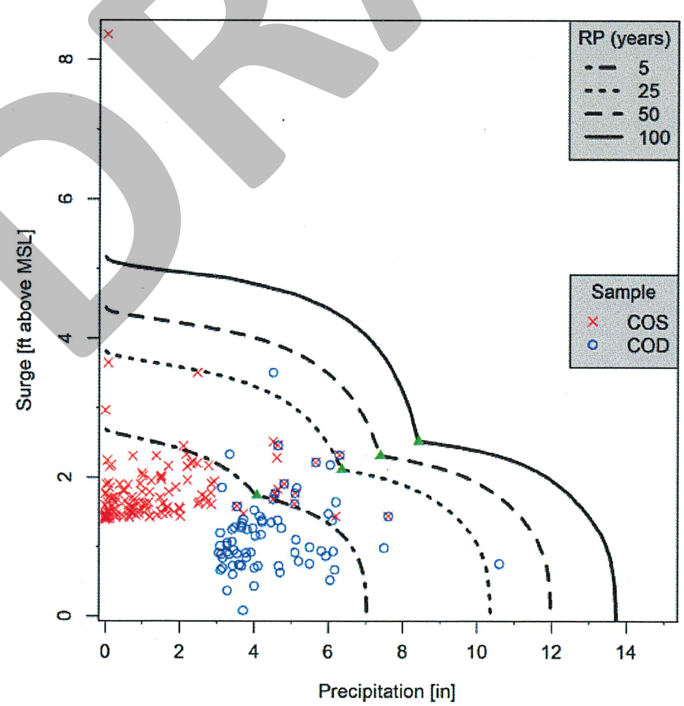


Figure 2: Compound Flood Return period for Adams Bayou with Precipitation Values at the Orange Station and Surge levels atthe Sabine River Tidal Gare (from Figure 32 of Ref i)

Sabine Pass to Galveston Bay, Texas
Coastal Storm Risk Management and Ecosystem Restoration
Final Integrated Feasibility Report and Environmental Impact Study

Appendix C

Economic Analysis

May 2017

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1 COASTAL STORM RISK MANAGEMENT

1.1 PURPOSE

The purpose of this appendix is to describe the economic methodology, its associated assumptions, and the use of economic and engineering tools used to assess, evaluate, and recommend a plan for the Sabine Pass to Galveston Bay, Texas Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study.

1.2 INITIAL SCREENING OF ALTERNATIVES

Prior to the Alternatives Milestone Meeting, development of an initial array of alternatives from a wide range of measures for three regions covering six counties along the Texas Gulf Coast that would address coastal storm risk management and ecosystem restoration. The initial study was scoped during a planning charrette in August 2012 to comply with SMART Planning guidelines. Following the first Alternatives Milestone Meeting (AMM) in July 2013, a determination was made that a study encompassing the three-region, six-county area could not be done within the constraints of SMART Planning. Options were developed in order to minimize risk as much as possible and while still adhering to the basic tenets of SMART Planning. The Galveston District developed an option for completing a study of low to moderate risk that would cost $4.4 million and would drop the Galveston region concentrating instead on the Brazoria and Sabine regions. The study also dropped any ecosystem restoration measures and would only analyze CSRM alternatives in Brazoria, Jefferson, and Orange Counties.

The initial array of alternatives can be found in Appendix B – Plan Formulation. The final array of alternatives is shown in Table 1-1. This array was agreed to in the Alternatives Milestone Meeting (AMM) that occurred on April 9, 2014. This final array of alternative plans does not include alternatives in Galveston Bay region, nor does it include Ecosystem Restoration (ER) measures. Instead, those potential actions are to be included in future interim feasibility studies, including the ongoing Coastal Texas study. Appendix B further describes the formulation process that produced this final array.

Table 1-1. Sabine Pass to Galveston Bay, TX - Final Array of Alternatives

Alternative Number	Alt Name / Description
No Action	No Action or Future Without Project (FWOP)
S5	Sabine Inland Barrier CSRM Focus (Neches Gate/Sabine Levees/Hurricane Flood Protection)
S11	Sabine Nonstructural Alternative/ Buyouts and Lone Star-type Conservation Plan
B2	Brazoria Coastal Barrier CSRM Focus (revised)

Alternative Number	Alt Name / Description
B5	Brazoria Nonstructural Alternative/ Buyouts and Lone Star-type Conservation Plan

An IPR was conducted on May 30, 2014, to discuss the results in the analysis supporting whether the Neches Gate should be dropped from further consideration. As a result of the decision to drop the Neches Gate and as means of clarifying the nomenclature for the final array, alternatives in the final array were renamed. The Sabine Inland Barrier Alternative has been split into two parts, one addressing the new levee system in Orange and Jefferson Counties, and the other addressing improvements to the existing Port Arthur hurricane flood protection (HFP). The Brazoria Coastal Barrier Coastal Storm Risk Management (CSRM) Focus has been renamed after its primary component – Freeport and Vicinity CSRM. Non-structural plans will be evaluated for both Brazoria and Sabine regions.

- Orange-Jefferson Coastal Storm Risk Management (CSRM)
- Freeport and Vicinity CSRM
- Port Arthur and Vicinity CSRM
- Brazoria and Sabine Non-Structural

1.3 REACH DETERMINATION

The determination of reaches for the initial array of alternatives was based on the original designation of the three regions with measures and the subsequent alternatives being assigned to the appropriate region. Following the approval of the exemption from SMART Planning and the successful concurrence of the final array of alternatives following the April 2014 AMM, reaches were developed for the areas according to the final array of alternatives. This was required since a different methodology would be employed for the optimization of any new proposed levees/floodwalls and for improvements to any of the existing hurricane flood protection systems (HFP). While the initial screening of alternatives used HEC-FIA with 1 % annual chance exceedance (ACE) depth grids in conjunction with HAZUS-MH data to determine without and with-project economic damages, the analysis for evaluating the final array would incorporate a risk-based analysis in compliance with ER-1105-2-101. The following describes the reaches that were established for evaluating the final array.

1.3.1 Orange-Jefferson CSRM

The initial configuration of new levees was based on alignments from the Orange County Flood Protection Planning Study (Orange Report), completed in 2012. Refinement of the alignments was made in some areas to increase potential benefits, reduce costs, and reduce potential environmental impacts, and to protect critical infrastructure. Without-project storm surge values were used to optimize levee heights and further refinement of the alignment for identification of the National Economic Development (NED) Plan and TSP. As part of the identification of the NED and TSP, analysis was conducted to determine levee sections that are incrementally justified. Alternatives analysis was based on utilizing the without-project surge elevations and frequencies. Without-project storm surge and waves were based on previous work by FEMA and revised to current joint probability method – optimum sampling (JPM-OS) methods to the appropriate ACE values. Figure 1-1 displays the initial configuration to be evaluated for these new levees at Jefferson and Orange Counties following the exclusion of the Neches Gate from further consideration. The system was set up with three major components based on their location. The following lists the major features.

- Orange 1 – 3
- Jefferson Main
- Beaumont A – C

The Orange component runs along the north side of the Neches River and was divided into three sections; Orange 1 on the western end that primarily protects Rose City, Orange 2 which begins just east of Rose City and ends roughly halfway between Rose City and Bridge City, and Orange 3 which encompasses the remainder of the Orange County component. Orange 1 consists of approximately 27,000 linear feet (LF) of levee and 16,500 LF of floodwall (total of 8.2 miles). Orange 2 consists of approximately 34,600 LF of levee (6.6 miles), while Orange 3 consists of a combination of 113,600 LF of levee and 29,800 LF of floodwall (total of 27 miles).

The Jefferson Main component consists of approximately 41,700 LF of levee and 16,200 LF of floodwall (11 miles). Beaumont A is combination of 3,100 LF of levee and 200 LF of floodwall (0.6 mile). Beaumont B is 2,500 LF of levee (0.5 mile) and Beaumont C is 6,800 LF of levee (1.3 mile).

1.3.2 Port Arthur and Vicinity CSRM

The draft findings of the Semi-Quantitative Risk Assessment (SQRA) for the Freeport system (to be discussed next) were applied to the plan formulation for the Port Arthur because one has not yet been done for this system. For the Port Arthur system, the detailed description of the needs is similar to what will be presented in the Freeport HFPS section. However, the Port Arthur system is different because there are no known deferred maintenance issues for the Port Arthur system at this time.

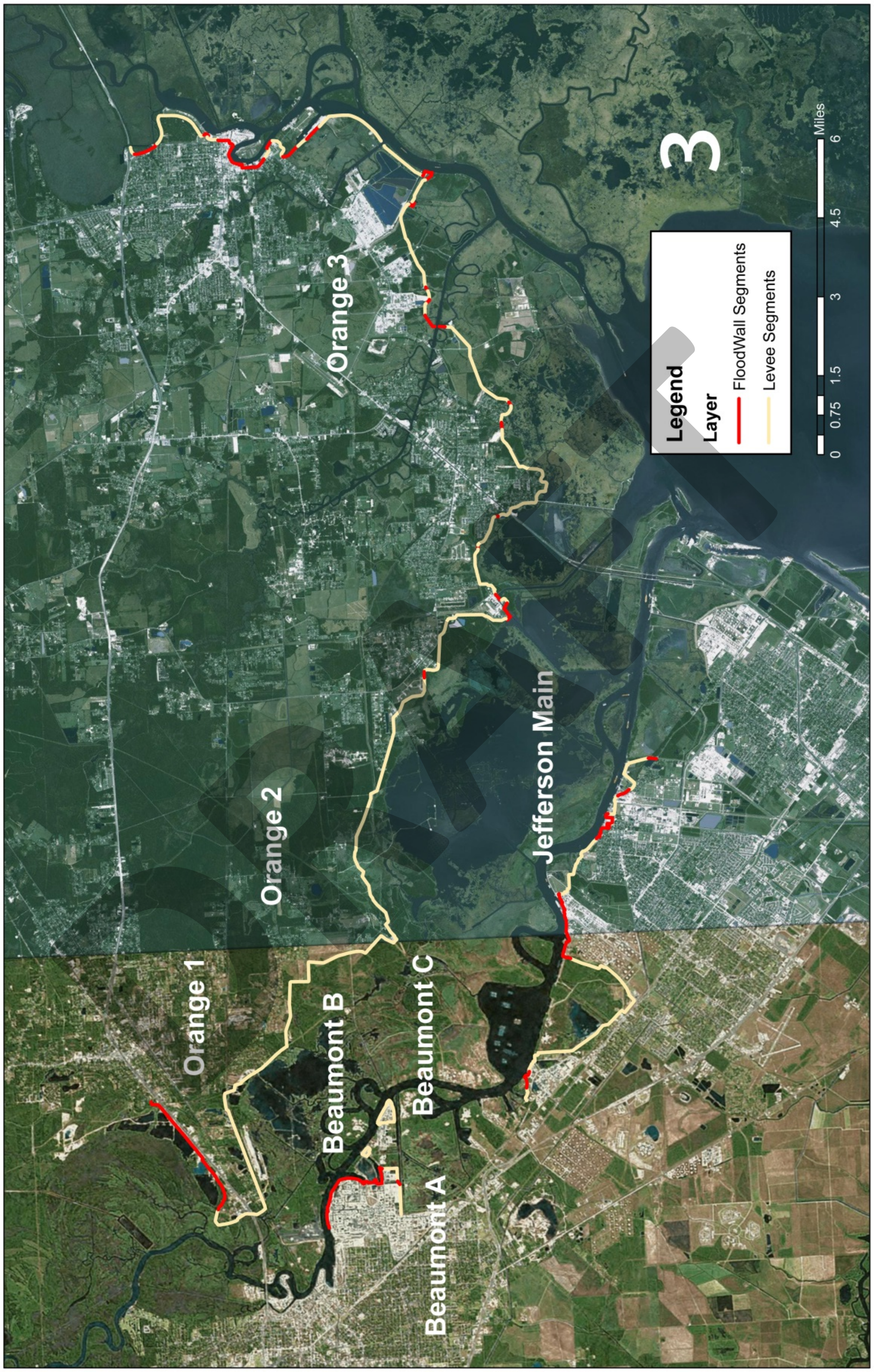

Figure 1-1. Configuration of the Orange-Jefferson CSRM

The formulation of alternatives for the Port Arthur and Vicinity CSRM began with defining reaches for the system. These were based on the failure locations identified by the levee safety program in the absence of a SQRA. Figure 1-2 displays the Port Arthur HFPS failure locations. These locations were included in formulation where improvements would positively impact the system's capacity for protection. The following lists the reaches at Port Arthur.

- Port Arthur 8feet-10feet I-Wall
- Port Arthur Closure Structure
- Port Arthur I-Wall Near Valero
- Port Arthur I-Wall Near Tank Farm

1.3.3 Freeport and Vicinity CSRM

The draft findings of the SQRA for the Freeport system show vulnerabilities primarily associated with floodwall and levee overtopping. Other performance issues identified during the SQRA were the result of deferred local sponsor maintenance, or alterations that local industrial stakeholders have constructed over time. Floodwall performance issues, at locations where the originally constructed floodwall is still in place and has been operated and maintained in an acceptable manner, are being evaluated to include stability and resiliency. Levee reaches that are non-uniform in height or otherwise susceptible to concentrated overtopping erosion during an event are being evaluated for raising or armoring to reduce the likelihood of breach.

The formulation of alternatives for the Freeport and Vicinity CSRM began with defining reaches for the system. These were based on the failure locations identified in the SQRA (Figure 1-3). These locations were then narrowed during formulation to those locations where improvements would positively impact the system's capacity for protection and to reduce any redundancies. For example, improvements to the Dow Barge Canal would negate any failures at the Dow Turning Basin. The following is the resulting list of reaches at the Freeport and Vicinity CSRM.

- Dow Barge Canal
- East Storm Levee
- Freeport Dock
- Old River at Dow Thumb
- Oyster Creek Levee
- South Storm Levee
- Tide Gate I-Wall

Figure 1-2. Port Arthur and Vicinity CSRM

Figure 1-3. Freeport and Vicinity CSRM

2 HEC-FDA ANALYSIS

Note: Sections 2.1 to 2.8 describes the HEC-FDA ANALYSIS used for alternative development, formulation, and evaluation processes that led to the identification of the TSP. The information contained herein was presented in the Sept 11, 2015 DIFR-EIS that was released for public review. Changes to the TSP have occurred since that public review which are briefly described explained in Section 2.9. The changes to the TSP resulted in the Recommended Plan presented in this final section.

2.1 ENGINEERING INPUTS

2.1.1 Stage-Probability Relationships

Water surface profiles representing stage-probability functions were imported into HEC-FDA utilizing data from Advanced Circulation model (ADCIRC) points for without-project storm surge and waves. This sub-set of 62 total storms (based on previous FEMA work and revised by ERDC using subject matter expertise for storms having the most effect on stage-frequency) was used in the revised to current JPM-OS simulation technique for the appropriate ACE values analysis. Mean water level, wave height and wave period responses were defined for each of the modeled return periods. In the absence of a Hydrologic Engineering Centers River Analysis System (HEC-RAS) stationing scheme which would also use a stage-discharge function, those ADCIRC points falling closest to the location of the levee/floodwall footprint were used to develop average ACE values for the seven events modeled by ERDC. For the existing Port Arthur and Freeport HFP systems, ADCIRC points representing average still water levels closest to the failure locations were used to quantify damages. An equivalent record length (15 years) for each study reach was used to generate a stage-probability relationship with uncertainty for the without-project and the with-project alternatives through the use of graphical analysis based on the appropriate gage data. A sensitivity analysis on the 0.1 percent modeled points found a consistent one standard deviation difference of 2.1 feet for the Freeport Region and 2.0 feet difference for the Sabine region. Stage/probability functions entered into HEC-FDA using the fifteen year period of record found the average difference for one standard deviation to be 1.64 for Jefferson, 1.8 feet for Orange, and 2.17 feet for Port Arthur. The average difference for Freeport was 3.18 feet. Increasing the period of record resulted in actual increases in the difference between the stated stage and the subsequent one standard deviation. Based on the fact that the storms ERDC used for modeling all occurred within the historical period of the last fifteen years and considering the results from analyzing the variation between data modeled by ERDC and what was entered into HEC-FDA, the fifteen year period of record is appropriate. The model used the eight stage-probability events together with the equivalent record length to define the full range of the stage-probability or stage-probability functions by interpolating between the data points. Values for the 0.999 and 0.5 percent ACE were set at 0.25 and 1.0 feet respectively in order to make HEC-FDA operational. Table 2-1 lists these values used for each region. The ADCIRC points for the Orange-Jefferson CSRM are shown in Figure 2-1. Points for the Port Arthur CSRM are shown in Figure 2-2 and the ADCIRC points for the Freeport CSRM are in Figure 2-3.

Still water levels were used to compare the economic efficiency of the alternatives. Once the recommended plan is determined, wave run-up and overtopping will be analyzed at specific system locations in conjunction with any necessary interior drainage analysis. The horizontal and vertical datums used in the engineering inputs are referenced to North American Datum (NAD) of 1983.

Table 2-1. Average Still Water Elevations at HEC-FDA Index Point

Orange-Jefferson

Exceedance Probability/Reach	***0.1 ACE***	***0.05 ACE***	***0.02 ACE***	***0.01 ACE***	***0.005 ACE***	***0.002 ACE***	***0.001 ACE***
Orange 1	3.62	5.05	6.69	7.76	8.66	9.66	10.35
Orange 2	3.6	5.36	7.24	8.52	9.6	10.77	11.57
Orange 3	2.78	4.25	6.11	7.51	8.64	9.81	10.57
Beaumont A	2.92	4.26	6	7.25	8.47	9.73	10.51
Beaumont B	2.71	3.88	5.62	6.86	7.94	9.07	10.34
Beaumont C	3.55	5.1	6.85	8.02	9	10.1	10.85
Jefferson Main	3.08	4.63	6.31	7.49	8.47	9.51	10.22

Port Arthur

Exceedance Probability/Reach	***0.1 ACE***	***0.05 ACE***	***0.02 ACE***	***0.01 ACE***	***0.005 ACE***	***0.002 ACE***	***0.001 ACE***
8ft-10ft I-Wall	2.85	4.31	6.98	9.25	10.94	12.68	13.81
Closure Structure	3.45	5.01	6.9	8.2	9.3	10.46	11.2
I-Wall Near Valero	3.87	5.97	8.47	10.47	12.61	14.77	16.08
I-Wall Near Tank Farm	3.77	5.72	8.1	9.99	12.02	14.08	15.31

Freeport Region

Exceedance Probability/Reach	***0.1 ACE***	***0.05 ACE***	***0.02 ACE***	***0.01 ACE***	***0.005 ACE***	***0.002 ACE***	***0.001 ACE***
South Storm Levee	4.21	6.68	9.59	11.63	13.71	16.31	17.93
Old River levee at Dow Thumb	4.43	7.08	10.15	12.41	14.69	17.43	18.97
Freeport Dock	4.47	7.17	10.3	12.63	14.97	17.79	19.38
Tide Gate	4.46	7.18	10.32	12.65	15.02	17.9	19.52
East Storm Levee	5.08	7.81	11.05	13.38	15.55	17.99	19.5
Dow Barge Canal	4.6	7.46	10.82	13.28	15.76	18.55	20.12
Oyster Creek	4.44	8.49	12.21	14.63	16.62	18.77	20.19

2.1.2 Fragility Curves

Fragility curves (the relationship between water surface stage on the exterior side of the levee versus the probability of levee failure) were developed based on the use of average still water levels for damage estimates. Fragility curves for the Freeport HFP system were initially developed as a result of the Freeport SQRA and were modified slightly due to the use of average still water levels for damage estimates. A similar approach was used for the development of the curves for the Port Arthur system. These curves for the Port Arthur and Freeport systems are listed in Tables 2-2 and 2-3, respectively. These fragility curves assume that all O&M is current and will be accomplished before implementing the Recommended Plan..

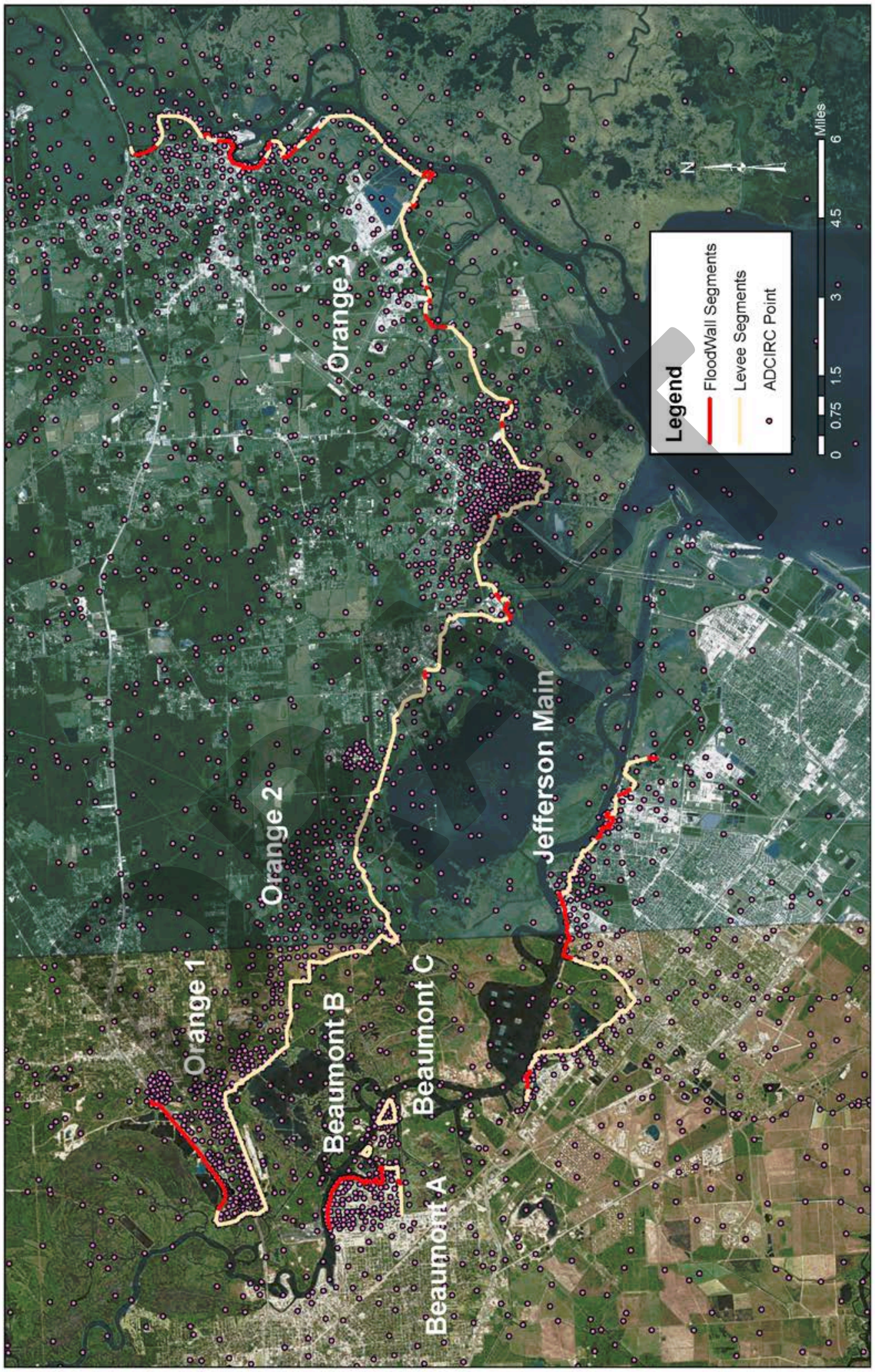

Figure 2-1. ADCIRC Points Orange-Jefferson CSRM

Figure 2-2. ADCIRC Points in Port Arthur and Vicinity CSRM

Figure 2-3. ADCIRC Points in Freeport and Vicinity CSRM

Table 2-2. Fragility Curves for Port Arthur and Vicinity CSRM

Stage	Tank Farm	8ft-10ft I-Wall	I-Wall Near Valero	Closure Structure
14	-	0.10	-	-
14.5	-	0.28	0.10	0.20
15	0.20	0.45	0.50	0.40
15.5	0.35	0.63	0.70	0.60
16	0.50	0.80	0.90	0.90
16.5	0.90	0.90	0.92	0.95
17	1.00	1.00	0.93	1.00
17.5	-	-	0.95	-
18	-	-	0.97	-
18.5	-	-	0.98	-
19	-	-	1.00	-

Table 2-3. Fragility Curves for Freeport and Vicinity CSRM

Stage	Dow Barge Canal	East Storm	Oyster Creek Levee	Freeport Dock	Tide Gate I-Wall	Old River at Dow Thumb
10.5	-	-	0.03	-	0.04	0.04
11	-	-	0.06	-	0.08	0.08
11.5	-	-	0.1	-	0.11	0.11
12	-	-	0.13	-	0.15	0.15
12.5	-	-	0.16	0.05	0.19	0.19
13	-	-	0.19	0.75	0.23	0.23
13.5	-	-	0.23	1.00	0.26	0.26
14	-	-	0.26	1.00	0.3	0.3
14.5	-	0.08	0.29	1.00	0.34	0.34
15	-	0.15	0.32	1.00	0.38	0.38
15.5	-	0.23	0.35	-	0.41	0.41
16	-	0.3	0.39	-	0.45	0.45
16.5	-	0.38	0.42	-	0.6	0.68
17	-	0.45	0.45	-	0.75	1.00
17.5	-	0.54	0.68	-	1.00	-
18	-	0.63	1.00	-	-	-
18.5	-	0.72	-	-	-	-
19	-	0.81	-	-	-	-
19.5	-	1.00	-	-	-	-
20	-	-	-	-	-	-
20.5	0.11	-	-	-	-	-
21	0.23	-	-	-	-	-
21.5	0.34	-	-	-	-	-
22	0.45	-	-	-	-	-
22.5	0.53	-	-	-	-	-
23	0.6	-	-	-	-	-

Table 2-3, continued

23.5	0.68	-	-	-	-	-
24	0.75	-	-	-	-	-
24.5	0.83	-	-	-	-	-
25	1.00	-	-	-	-	-

2.2 ECONOMIC INPUTS

2.2.1 Ground Elevations

Centroids were created for each parcel to represent the structures associated with that parcel. Ground elevations were derived from data processed using U.S. Geological Survey Digital Elevation Model (DEM) 0.05m elevation data for the appropriate Gulf Coast Counties. These data were obtained from Texas Natural Resources Information System (TNRIS). Residential structures in inland areas generally received a 0.5-foot floor correction (some areas were raised 1 to 1.5 feet) while many of the coastal areas received much higher raises as appropriate. Industrial, commercial, and public structures received floor corrections from 0 to 5 feet. The point at which damages for many high-value industrial and commercial structures is reflected in the ground elevation making floor correction was necessary. These floor corrections assumptions were verified through spot checks utilizing Google Earth and Google Street View. The horizontal and vertical datums used in the economic inputs are referenced to North American Datum (NAD) of 1983 or North American Vertical Datum (NAVD) of 1988.

2.2.2 Structure Inventory

All three study areas can be described as being relatively fully developed. As discussed under the study area demographics, Brazoria is expected to be the one county among the three that is expected to grow at a rate outpacing the State. Orange and Jefferson Counties are expected to grow at rates well below that of the State of Texas. For the purpose of this analysis, housing stock is assumed to remain relatively constant over the period of analysis. Since commercial and industrial make up a substantial amount of the structure inventory, those developments that are expected to come online with a reasonable amount of certainty and in the relatively near future are include in the inventory. The structure inventory was derived from data obtained from each of the appropriate appraisal districts for the 2015 tax appraisal year (Table 2-4). These data were adjusted to reflect a replacement cost less depreciation value. Due to tax abatements and incentives given to large industrial developers and due to the competitive nature of the petrochemical industry in the region, many high-value industrial and commercial properties are not listed on the tax appraisal rolls. In these instances, square footage values were developed from those properties that were listed on the tax rolls based on square footage values of similar structures from appraisal data. Therefore, a certain amount of uncertainty exists for these values in many cases, which could lead to an over- or underestimation of damages. Values to reflect replacement minus depreciation were calculated using Marshall and Swift Commercial and Residential Estimator based on information contained within the appraisal district data including structure type, age, square footage, building materials, and condition on a random selection of both residential and non-residential structures on the following the TSP milestone. Samples were taken for each of the residential and non-residential damage categories based on the depth/damage function applied to the specific structures. These adjustments were then averaged and applied to the appropriate damage category. Residential structures were adjusted by 24.4 percent and non-residential structures were adjusted by 14.6 percent. Two separate structure files with a high degree of overlap were created for the system since failures would impact slightly different numbers of structures. One structure file was used for a failure at the Dow Barge Canal and another for the remaining reaches. The following tables and figures depict the structure files used in the damage analyses. Parcels representing the structures at risk for the Orange-Jefferson CSRM are in Figure 2-4, while the parcels representing the structures at risk for the Port Arthur and Freeport CSRM are in Figures 2-5, 2-6, and 2-7 respectively.

Table 2-4. Structure and Content Values of Inventoried Structures by CSRM and Type 2015 Price and Development Levels

Orange-Jefferson CSRM

Orange County				
Category Name	**Count**	**Structure Value**	**Content Value**	**Total**
Commercial	268	$109,778,000	$109,203,000	$218,981,000
Industrial	20	$1,711,063,000	$1,711,061,000	$3,422,124,000
Multi-Family	193	$23,828,000	$23,828,000	$47,656,000
Mobile	699	$10,573,000	$10,573,000	$21,146,000
Public	214	$76,324,000	$83,913,000	$160,237,000
Vehicles	16,045	$200,448,000	$0	$200,448,000
Single-Family	12,734	$1,038,476,000	$1,038,443,000	$2,076,919,000
Grand Total	30,173	$3,170,490,000	$2,977,021,000	$6,147,511,000
Jefferson County				
Category Name	**Count**	**Structure Value**	**Content Value**	**Total**
Commercial	893	$319,062,000	$431,769,000	$750,831,000
Industrial	22	$662,341,000	$827,820,000	$1,490,161,000
Multi-Family	226	$186,264,000	$186,264,000	$372,528,000
Public	140	$124,284,000	$136,882,000	$261,166,000
Vehicles	15,954	$167,781,000	$0	$167,781,000
Single-Family	12,662	$2,539,056,000	$2,538,915,000	$5,077,971,000
Grand Total	29,897	$3,998,788,000	$4,121,650,000	$8,120,438,000

Port Arthur and Vicinity CSRM

Category Name	Count	Structure Value	Content Value	Total

Commercial	1,152	$5,190,935,000	$8,777,567,000	$13,968,502,000
Industrial	9	$201,486,000	$338,497,000	$539,983,000
Multi-Family	269	$69,382,000	$69,382,000	$138,764,000
Public	452	$217,266,000	$228,574,000	$445,840,000
Vehicles	26,431	$350,231,000	$0	$350,231,000
Single-Family	20,977	$1,911,200,000	$1,911,068,000	$3,822,268,000
Grand Total	43,968	$7,869,963,000	$11,325,088,000	19,265,588,000

Freeport and Vicinity CSRM

Dow Barge Canal				
Category Name	**Count**	**Structure Value**	**Content Value**	**Total**
Commercial	903	$117,426,000	$156,275,000	$273,701,000
Industrial	45	$5,557,849,000	$9,339,639,000	$14,897,488,000
Multi-Family	375	$68,916,000	$69,123,000	$138,039,000
Mobile	6	$135,000	$135,000	$270,000
Public	207	$225,032,000	$248,092,000	$473,124,000
Vehicles	8,832	$185,858,000	$0	$185,858,000
Single-Family	8,826	$377,405,000	$377,572,000	$754,977,000
Grand Total	19,194	$6,532,621,000	$10,190,836,000	$16,723,457,000
Lower Reaches				
Category Name	**Count**	**Structure Value**	**Content Value**	**Total**
Commercial	244	$39,019,000	$30,565,000	$69,584,000
Industrial	5	$13,383,000	$22,406,000	$35,789,000
Multi-Family	117	$13,168,000	$13,168,000	$26,336,000
Public	76	$28,620,000	$29,784,000	$58,404,000
Vehicles	2,323	$38,847,000	$0	$38,847,000
Single-Family	1,844	$74,744,000	$74,744,000	$149,488,000
Grand Total	4,609	$207,781,000	$170,667,000	$378,448,000

2.2.3 Vehicle Inventory

The number of vehicles associated with a residence was estimated based on the average number of vehicles per residence characteristic of the study area, and the probability of their being present at the time of a flood. This value is 1.26 vehicles per residence. Values were based on the national average price of new and used vehicles as reported by the U.S. Bureau of Transportation Statistics (BTS) prices for new vehicles. The most recent price reported by BTS is $13,105. Adjusting this value based on the percent difference in median income for each county compared to the median income for the U.S., the resulting value for Orange County vehicles was set at $15,411 and $13,251 for Jefferson County. Vehicle values for Brazoria were set at $21,044.

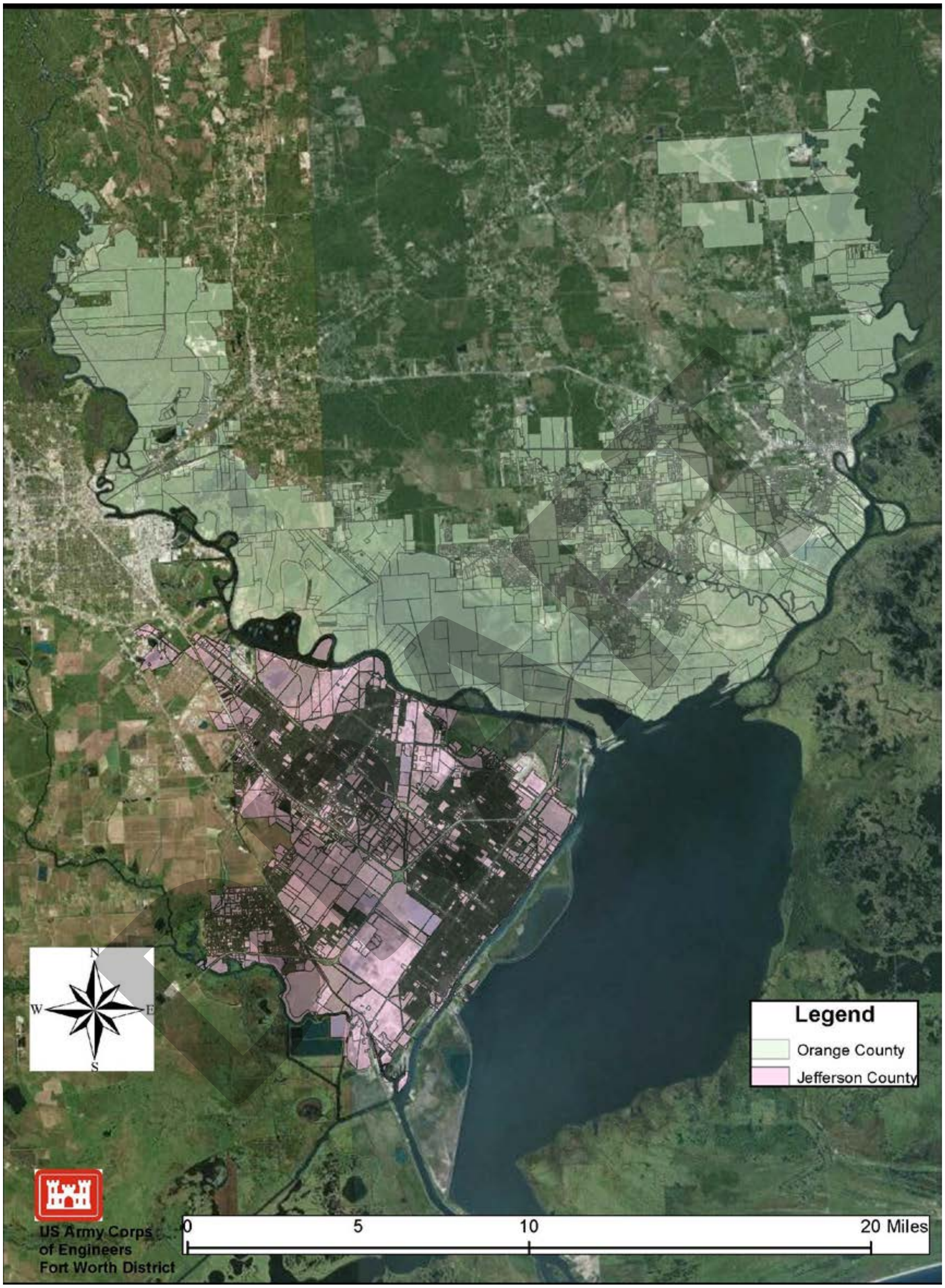

Figure 2-4. Orange-Jefferson CSRM Structures at Risk (Parcels)

Figure 2-5. Port Arthur and Vicinity CSRM Structures at Risk

Figure 2-6. Freeport and Vicinity CSRM Structures at Risk – Dow Barge Canal Reach

Figure 2-7. Freeport and Vicinity CSRM Structures at Risk – Remaining Reaches

2.2.4 Depth-Damage Functions

Depth-damage functions were obtained from the New Orleans District from the *Lower Atchafalaya and Morganza to the Gulf, Louisiana, Feasibility Study*. These functions reflect saltwater inundation for short durations. The following table lists the functions covering the following structure types and also the content-to-structure value ratio (CSVR) along with the uncertainties associated with the structure content values and the first-floor corrections. Uncertainties assumed a normal distribution (with the exception of vehicles which assumes a triangular distribution) and were based on coefficient of variation calculations for each of the sources of uncertainty and were also based on historic knowledge gleaned from based studies in the region.

These functions were used primarily since they addressed the incidence of inundation from saltwater for short durations and because these damage functions, while not derived from locally oriented data, were more reflective current building guidelines and potential damage estimation. Graphical representations for these for these functions are depicted at the end of this appendix.

Table 2-5. Depth-Damage CSVR, and Uncertainties.

Name	Description	CSVR (%)	Struc. Unc. (%)	Cont. Unc. (%)	FF Unc. (ft.)
1STY-SLAB	One-Story Single -Family Residential Slab Foundation	71	7.5	24	0.70
2STY-PIER	Two-Story single -Family Residential Pier and Beam Foundation	50	7.5	30	0.70
AUTO	Automobiles	0	15.4-21	0	0.55
EAT	Restaurants	428	17.97	36	0.66
GROC	Grocery Stores	128	6.6	98	0.70
MOBHOM	Mobile Homes	148	7.5	69	0.79
MULT	Multi-Family Residential	23	6.6	29.38	0.53
PROF	Professional Businesses	78	8.67	193.4	0.57
PUBL	Public & Semi Public Structures	82	6.5	71.4	0.70
REPA	Repairs & Home Use	251	5.98	62.2	0.71
RETA	Retail & Personal Services	148	13.37	39.7	0.62
WARE	Warehouse & Contractor Services	372	8.72	194.6	0.57
RESEMERG	Residential Emergency Cleanup Costs	-	13	-	0.70
COMEMERG	Commercial Emergency Cleanup Costs	-	20	-	0.65
HWY	Damage to Highways	-	-	-	0.55
RAILROAD	Damage to Railroads	-	-	-	0.80
STREETS	Damage to Streets	-	-	-	0.75

2.3 FUTURE WITHOUT-PROJECT STRUCTURE AND CONTENT DAMAGES

2.3.1 Methodology Overview

The methodology employed for this economic analysis is in accordance with current principles and guidelines and standard economic practices, as outlined in the Planning Guidance Notebook – ER 1105-2-100. Economic analysis is conducted at a given price level using the current Federal discount rate and a period of analysis of 50 years. Per the Planning Guidance Notebook, flood events will be expressed in probabilistic terms rather than the classic "x-Year" event. For example, the 100-Year event will be called a 1 percent ACE (equivalent to the HEC-FDA term Annual Exceedance Probability Event). Other equivalent probabilities can be obtained by dividing 1 by the year occurrence interval; the 500-year event is 1/500 = 0.2 percent ACE, and so forth.

A risk-based analysis (RBA) procedure has been used to evaluate without-project flood damages in the study area. Guidance for conducting RBA is included in Corps Engineering Regulation 1105-2-101, Risk-Based Analysis for Evaluation of Hydrology/Hydraulics, Geotechnical Stability and Economics in Flood Damage Reduction Studies (January 3, 2006).

The guidance specifies that the derivation of expected annual flood damage must take into account the uncertainty in hydrologic, hydraulic, and economic factors. Risk and uncertainty are intrinsic in water resource planning and design. They arise from measurement errors and the inherent variability of complex physical, social and economic situations. Best estimates of key variables, factors, parameters and data components are developed, but are often based on short periods of record, small sample sizes, measurements subject to error, and innate residual variability in estimating methods. RBA explicitly and analytically incorporates these uncertainties by defining key variables in terms of probability distributions, rather than single-point estimates. The focus of RBA is to concentrate on the uncertainties of variables having the largest impact on study conclusions.

The following are the primary sources of uncertainty for coastal storm damage analysis studies along with a discussion of the uncertainties associated with each of these sources.

- Stage/Probability – Uncertainty in the stage/probability curves are addressed by utilizing graphical exceedance probability functions which sets confidence limits for discharges at each discrete exceedance probability based on the equivalent record length. Uncertainties is also addressed by assigning distributions to stage-damage functions. In the case of this study, the equivalent record length is set at 15 years and the error for the stage-damage functions is set at 0.5 feet.

- Geo-technical Features – Fragility curves were developed for the two existing HFPSs from either completed or draft SQRAs conducted by a risk cadre in accordance to ER 110-2-1156 for various identified breach locations on each of the two systems. These curves were developed as part of the reevaluation of the initial SPRAs at each system. These curves were developed to a much higher definition than is typically done for flood-risk analysis in HEC-FDA. No uncertainties were assigned to the fragility curves themselves since HEC-FDA has no way of entering any uncertainty parameters.
- Structure Elevation – Stated earlier, USGS DEM 0.05m elevation data was obtained from TNRIS and used for ground elevations with the observed foundation elevations added to ground elevation for the first-floor elevations. Uncertainties based on calculated coefficients of variation produced first-floor errors ranging from 0.493 to 0.788 feet depending on structure type.
- Structure and Content Values – Uncertainties for structure and content values are based on calculated standard deviations by structure type. These standard deviations are expressed in terms of percentages and range anywhere from 6.5 to almost eighteen percent for structure values and range from 30 to almost 195 percent for content-to-structure ratios.
- Inundation Depth/Percent Damage – Depth/Damage functions were obtained from the New Orleans District and are based on a triangular probability density functions using minimum, maximum, and most likely estimates for the damage percentage at various stages based on the input from a panel of experts. These estimates were generated for the District's *Lower Atchafalaya and Morganza to the Gulf, Louisiana, Feasibility Study*. These curves are displayed in the back of this appendix.

The Army Corps of Engineers Hydrologic Engineering Center has developed software specifically designed for conducting risk based analysis, referred to as the HEC-FDA Program. Version 1.2.5 was used for this analysis with the exception of the final recommended plan which was run in Version 1.4. This program applies Monte Carlo simulation process, whereby the expected value of damages is determined explicitly through a numerical integration technique accounting for uncertainty in the basic parameters described above. For this analysis, the number of Monte Carlo simulations is set at 100 with the minimum and maximum number of intervals set at 20 and 30 respectively. Data requirements for the program include:

- Structure data, including structure I.D., category (single or multi-family residential, commercial, industrial, and public), stream location, ground and/or first floor elevation, structure value and content value. These data were developed in a Microsoft Excel spreadsheet and imported into the HEC-FDA program

- Hydrologic and hydraulic data, including water surface profiles and stage/probability relationships
- Depth-Damage functions

2.3.2 Future Without-Project Condition Expected Annual Damages

Estimates of Expected Annual Damages (EAD) under future without-project conditions were calculated, using the risk and uncertainty model, through integration of frequency-damage data. The future expected annual damages shown here are projected over the project life of 50 years. Table 2-6 shows a breakdown of where these damages are predicted to occur for each CSRM. Tables 2-7, 2-8, and 2-9 break down the number of structures by event in each reach of the three project areas along with the corresponding still water level for that event.

For the Orange 1, Orange 2, and Orange 3 alternative reaches, significant damages start at approximately the 1 percent ACE; the depth of flooding at the 1 percent ACE is approximately 8 feet. In the Jefferson Main alternative reach, significant damages start between the 2 percent and 1 percent ACE; the depth of flooding between the 2 percent and 1 percent ACE is approximately 6.5 feet and 7.5 feet. For the Beaumont A, Beaumont B and Beaumont C the significant damages start at the 1 percent ACE; the depth of flooding is approximately 7.5 feet.

The estimated start of damages for the Port Arthur and Vicinity alternative reaches is approximately 15 feet, which corresponds to an estimated high probability of failure of the existing HFPS based on the fragility curves. Flooding depths approximate the stage on the exterior side of the existing HFPS, and goes up to approximately 14 feet for the 0.1 percent ACE.

The estimated start of damages for the Freeport and Vicinity alternative reaches is approximately 15 feet, which corresponds to an estimated high probability of failure of the existing HFPS based on the fragility curves. Flooding depths approximate the stage on the exterior side of the existing HFPS, and goes up to approximately 19 feet for the 0.1 percent ACE.

2.4 ALTERNATIVE ANALYSIS

2.4.1 Orange-Jefferson CSRM

As agreed at the Alternative Milestone Meeting (AMM), future without-project (FWOP) damages were run with a rough order of magnitude costs to identify NED benefits. Costs representing a linear foot in both length and height for both levees and floodwalls were developed. The costs per linear foot of levee were estimated at $237.50 and floodwalls were estimated at $475.00. These costs included contingency, engineering and design, and constriction management. Real estate costs were also included with commercial and residential estimates of $100,000 per acre, industrial at $70,000 per acre, undeveloped land at $9,000 per acre, and marsh at $750. Operation, Maintenance, Repair, Replacement and Rehabilitation

Table 2-6. Equivalent Annual Damages Future Without-Project Condition (2015 price level) (FY 2015 Price Level/3.375 percent interest rate)

	Damage Categories							
Reach	**Commercial**	**Industrial**	**Multifamily**	**Mobile**	**Public**	**POV**	**SFR**	**Total**
Orange Jefferson CSRM								
Orange 1	$73,000	$0	$0	$7,000	$10,000	$33,000	$190,000	$312,000
Orange 2	$0	$0	$0	$4,000	$0	$10,000	$54,000	$68,000
Orange 3	$21,833,000*	$0	$93,000	$98,000	$409,000	$969,000	$6,585,000	$29,987,000
Beaumont A	$0	$6,937,000	$0	$0	$0	$0	$0	$6,937,000
Beaumont B	$0	$23,000	$0	$0	$0	$0	$0	$23,000
Beaumont C	$0	$262,000	$0	$0	$0	$0	$0	$262,000
Jefferson Main	$4,600,000	$929,000	$4,834,000	$0	$1,824,000	$536,000	$15,509,000	$28,231,000
Port Arthur CSRM								
8ft-10ft I-Wall	$19,302,000	$560,000	$83,000	$0	$368,000	$275,000	$2,824,000	$23,413,000
Closure Structure	$3,128,000	$86,000	$13,000	$0	$59,000	$44,000	$453,000	$3,784,000
I-Wall Near Valero	$50,798,000	$1,587,000	$228,000	$0	$975,000	$726,000	$7,553,000	$61,867,000
I-Wall Near Tank Farm	$31,139,000	$1,012,000	$143,000	$0	$599,000	$446,000	$4,670,000	$38,009,000
Freeport CSRM								
Dow Barge Canal	$3,070,000	$145,903,000	$884,000	$2,000	$4,815,000	$3,088,000	$8,897,000	$166,660,000
East Storm Levee	$346,000	$247,000	$99,000	$0	$233,000	$191,000	$587,000	$1,701,000
Freeport Dock	$768,000	$583,000	$217,000	$0	$549,000	$456,000	$1,387,000	$3,960,000
Old River at Dow Thumb	$489,000	$367,000	$139,000	$0	$349,000	$290,000	$882,000	$2,517,000
South Storm Levee	$52,000	$37,000	$15,000	$0	$35,000	$28,000	$87,000	$254,000
Tide Gate I-Wall	$541,000	$406,000	$154,000	$0	$387,000	$321,000	$977,000	$2,785,000
Oyster Creek	$744,000	$553,000	$211,000	$0	$526,000	$436,000	$1,329,000	$3,800,000

*Most of these commercial values are actually associated with industrial facilities. These were corrected in later analyses

Table 2-7. Structures and Damages by Event for Orange-Jefferson CSRM
(FY 2015 Price Level, $1,000)

Orange 1														
Event (ACE)	**0.1**		**0.05**		**0.02**		**0.01**		**0.005**		**0.002**		**0.001**	
Elevation (MSL)	3.62		5.05		6.69		7.76		8.66		9.66		10.35	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	0	$0	1	$469	1	$939	1	$1,150	1	$1,229	1	$1,288	7	$1,733
Industrial	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
MultiFamily	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
Mobile	2	$24	2	$35	7	$49	7	$69	8	$74	8	$93	19	$326
Public	0	$0	0	$0	2	$49	2	$285	2	$317	2	$410	4	$765
Vehicles	0	$0	11	$139	13	$185	72	$543	81	$1,134	87	$1,251	202	$1,322
Single-Family	2	$262	14	$675	23	$1,473	82	$3,581	92	$4,818	98	$5,899	232	$9,989
Grand Total	4	$286	28	$1,318	46	$2,695	164	$5,629	184	$7,572	196	$8,942	464	$14,136

Orange 2														
Event (ACE)	**0.1**		**0.05**		**0.02**		**0.01**		**0.005**		**0.002**		**0.001**	
Elevation (MSL)	3.60		5.36		7.24		8.51		9.60		10.77		11.57	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	0	$0	0	$0	1	$0	1	$1	1	$1	1	$1	1	$1
Industrial	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
Mobile	0	$0	0	$0	4	$61	4	$63	4	$77	11	$301	11	$317
Public	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
Vehicles	0	$0	3	$31	15	$46	16	$244	18	$270	40	$277	42	$607
Single-Family	1	$3	3	$123	15	$676	17	$999	17	$1,264	35	$2,460	36	$2,906
Grand Total	1	$3	6	$154	35	$783	38	$1,307	40	$1,612	87	$3,038	90	$3,831

Orange 3														
Event (ACE)	**0.1**		**0.05**		**0.02**		**0.01**		**0.005**		**0.002**		**0.001**	
Elevation (MSL)	2.78		4.25		6.11		7.51		8.64		9.81		10.57	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.

Commercial	0	$0	3	$2,832	4	$7,667	42	$15,849	48	$22,486	51	$31,342	198	$58,526
Industrial	0	$0	1*	$52,625	1*	$139,876	6*	$505,494	6*	$800,283	6*	$1,169,796	8*	$1,572,382
MultiFamily	0	$0	3	$32	3	$72	99	$2,702	102	$4,354	111	$6,810	180	$10,380
Mobile	0	$0	20	$385	23	$565	167	$2,769	173	$2,960	185	$3,489	385	$7,415
Public	2	$0	5	$36	6	$61	70	$10,642	76	$20,067	79	$26,546	166	$48,532
Vehicles	8	$105	267	$170	319	$4,563	3,157	$5,319	3,345	$49,671	3,506	$52,245	9,180	$54,070
Single-Family	11	$772	287	$15,608	347	$27,250	3,247	$171,623	3,404	$236,983	3,621	$294,110	9,146	$591,898
Grand Total	21	$876	586	$71,686	703	$180,054	6,788	$714,399	7,154	$1,136,804	7,559	$1,584,338	19,263	$2,343,202

* Represents the number of actual parcels containing damageable structures. Parcels may contain anywhere from one to several dozen structures.

Jefferson Main														
Event (ACE)	**0.1**		**0.05**		**0.02**		**0.01**		**0.005**		**0.002**		**0.001**	
Elevation (MSL)	3.08		4.63		6.31		7.49		8.47		9.51		10.22	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	0	$154	20	$22,233	22	$38,014	153	$87,131	160	$138,157	164	$167,493	240	$194,754
Industrial	0	$0	0	$2	1	$684	3	$40,301	3	$53,133	3	$68,150	4	$73,108
MultiFamily	0	$488	9	$33,171	10	$61,258	31	$90,713	31	$106,705	31	$118,311	55	$126,228
Public	1	$1,945	5	$5,859	5	$7,611	22	$14,466	22	$16,132	22	$18,555	32	$21,796
Vehicles	0	$0	267	$2,273	348	$4,137	1909	$5,034	1974	$25,480	2047	$26,425	2097	$27,102
Single-Family	0	$482	290	$63,639	388	$118,128	1940	$398,790	2010	$509,002	2078	$607,949	3418	$762,789
Grand Total	1	$3,070	591	$127,178	774	$229,832	4,058	$636,436	4,200	$848,609	4,345	$1,006,883	5,846	$1,205,777

Beaumont A														
Event (ACE)	**0.1**		**0.05**		**0.02**		**0.01**		**0.005**		**0.002**		**0.001**	
Elevation (MSL)	2.92		4.26		6.00		7.25		8.47		9.73		10.51	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
Industrial	0	$0	0	$0	0	$0	1	$121,360	1	$207,110	1	$273,565	2	$340,322
MultiFamily	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
Public	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
Grand Total	0	$0	0	$0	0	$0	1	$121,360	1	$207,110	1	$273,565	2	$340,322

Beaumont B&C														
Event (ACE)	**0.1**		**0.05**		**0.02**		**0.01**		**0.005**		**0.002**		**0.001**	
Elevation (MSL)	3.55		5.09		6.85		8.02		9.00		10.10		10.85	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Industrial	1	$385	1	$1,119	1	$1,584	1	$1,980	1	$3,334	1	$4,956	1	$4,956
Grand Total	1	$385	1	$1,119	1	$1,584	1	$1,980	1	$3,334	1	$4,956	1	$4,956

Table 2-8. Structures and Damages by Event for Port Arthur CSRM
(FY 2015 Price Level, $1,000)

8ft-10ft I-Wall														
Event (ACE)	**0.1**		**0.05**		**0.02**		**0.01**		**0.005**		**0.002**		**0.001**	
Elevation (MSL)	2.85		4.31		6.98		9.25		10.94		12.68		13.81	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	50	$12,673	549	$1,964,562	938	$4,551,332	956	$6,636,919	1,050	$7,946,501	1,057	$9,271,555	1,143	$9,589,158
Industrial	0	$0	4	$829	6	$2,068	7	$4,959	9	$92,393	9	$161,616	9	$194,575
MultiFamily	15	$245	119	$7,270	215	$27,158	217	$44,413	249	$55,287	252	$62,567	261	$67,713
Public	16	$2,802	189	$98,180	399	$202,523	401	$275,467	435	$311,283	437	$329,585	445	$337,484
Vehicles	939	$8,440	9,129	$24,024	12,007	$132,922	16,998	$223,811	19,478	$233,279	19,584	$258,901	20,538	$259,840
Single Family	1,197	$52,822	9,262	$486,400	16,626	$1,162,179	16,947	$1,710,962	19,378	$2,122,765	19,492	$2,395,681	20,443	$2,554,936
Grand Total	2,217	$76,981	19,252	$2,581,265	30,191	$6,078,183	35,526	$8,896,531	40,599	$10,761,508	40,831	$12,479,904	42,839	$13,003,707

I-Wall Near Valero														
Event (ACE)	**0.1**		**0.05**		**0.02**		**0.01**		**0.005**		**0.002**		**0.001**	
Elevation (MSL)	3.87		5.97		8.47		10.47		12.61		14.77		16.08	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	535	$1,657,699	637	$3,713,146	950	$6,101,335	1,050	$7,593,867	1,056	$9,240,514	1,144	$9,746,974	1,146	$9,866,247
Industrial	4	$586	5	$1,548	7	$4,147	9	$77,050	9	$159,439	9	$236,777	9	$272,478
MultiFamily	117	$5,718	124	$16,147	217	$39,439	247	$52,984	252	$62,231	261	$73,521	262	$81,171
Public	188	$70,949	315	$140,451	400	$256,829	435	$303,194	437	$328,916	445	$346,872	446	$355,637
Vehicles	8,981	$14,225	9,682	$124,636	16,888	$222,467	19,450	$226,172	19,581	$258,840	20,611	$272,392	20,680	$273,417
Single Family	9,126	$405,918	11,610	$750,402	16,838	$1,586,428	19,348	$2,024,867	19,484	$2,388,605	20,500	$2,677,915	20,582	$2,787,254
Grand Total	18,951	$2,155,095	22,373	$4,746,330	35,300	$8,210,645	40,539	$10,278,134	40,819	$12,438,545	42,970	$13,354,449	43,125	$13,636,204

Closure Structure														
Event (ACE)	**0.1**		**0.05**		**0.02**		**0.01**		**0.005**		**0.002**		**0.001**	
Elevation (MSL)	3.45		5.01		6.90		8.20		9.30		10.46		11.20	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	518	$581,099	562	$2,774,267	938	$4,483,372	948	$5,869,655	956	$6,672,436	1,050	$7,585,987	1,050	$8,139,242
Industrial	3	$193	5	$1,171	6	$2,005	7	$3,841	7	$5,002	9	$76,772	9	$105,511
MultiFamily	114	$2,160	119	$10,779	215	$25,754	216	$37,614	217	$44,713	247	$52,927	250	$56,575
Public	186	$25,192	192	$107,413	399	$195,062	400	$253,214	401	$276,761	435	$303,013	435	$314,034
Vehicles	1,269	$11,581	9,340	$120,815	11,949	$129,070	16,847	$221,849	17,003	$223,898	19,449	$226,151	19,495	$249,305
Single Family	9,002	$180,669	9,493	$582,269	16,611	$1,110,282	16,793	$1,513,337	16,955	$1,718,340	19,348	$2,023,183	19,392	$2,163,792
Grand Total	11,092	$800,894	19,711	$3,596,716	30,118	$5,945,545	35,211	$7,899,510	35,539	$8,941,150	40,538	$10,268,032	40,631	$11,028,459

Tank Farm														
Event (ACE)	**0.1**		**0.05**		**0.02**		**0.01**		**0.005**		**0.002**		**0.001**	
Elevation (MSL)	3.77		5.72		8.10		9.99		12.02		14.08		15.31	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	531	$1,567,287	572	$3,449,143	946	$5,752,432	1,050	$7,210,661	1,052	$8,861,927	1,143	$9,616,172	1,144	$9,850,235
Industrial	3	$526	5	$1,463	7	$3,743	9	$27,351	9	$140,998	9	$206,100	9	$251,925
MultiFamily	116	$5,323	123	$14,395	216	$36,807	246	$48,984	250	$59,898	261	$68,935	261	$77,359
Public	188	$63,836	208	$129,134	400	$251,210	434	$290,941	436	$322,815	445	$339,456	446	$352,879
Vehicles	1,580	$13,552	9,585	$123,602	16,836	$221,595	17,114	$225,227	19,549	$258,373	20,564	$260,222	20,636	$272,876
Single Family	9,102	$382,410	9,749	$707,373	16,781	$1,479,447	19,319	$1,852,854	19,445	$2,324,783	20,464	$2,590,490	20,530	$2,738,829
Grand Total	11,520	$2,032,933	20,242	$4,425,110	35,186	$7,745,233	38,172	$9,656,019	40,741	$11,968,794	42,886	$13,081,375	43,026	$13,544,104

Table 2-9. Structures and Damages by Event for Freeport CSRM
(FY 2015 Price Level, $1,000)

Dow Barge Canal														
Event (ACE)	**0.1**		**0.05**		**0.02**		**0.01**		**0.005**		**0.002**		**0.001**	
Elevation (MSL)	4.60		7.46		10.82		13.28		15.76		18.55		20.12	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	242	$23,201	284	$46,104	288	$60,385	289	$64,029	289	$65,606	289	$65,967	289	$65,999
Industrial	11	$42,981	13	$768,756	14	$1,859,908	14	$2,567,500	14	$3,217,335	14	$3,381,792	14	$3,382,450
MultiFamily	111	$7,963	115	$14,013	115	$16,356	115	$19,079	115	$23,671	115	$24,386	115	$24,403
Mobile	0	$0	0	$0	2	$64	2	$67	2	$75	2	$75	2	$75
Public	59	$45,413	62	$72,465	65	$85,390	65	$92,968	65	$98,788	65	$99,975	65	$99,987
Vehicles	2,342	$41,345	2,566	$50,260	2,605	$54,308	2,606	$54,830	2,607	$54,851	2,607	$54,851	2,607	$54,851
Single Family	2,348	$103,013	2,571	$142,945	2,605	$166,359	2,607	$173,954	2,607	$177,031	2,607	$177,640	2,607	$177,729
Grand Total	5,113	$263,916	5,611	$1,094,543	5,694	$2,242,770	5,698	$2,972,427	5,699	$3,637,358	5,699	$3,804,687	5,699	$3,805,494

Tide Gate														
Event (ACE)	**0.1**		**0.05**		**0.02**		**0.01**		**0.005**		**0.002**		**0.001**	
Elevation (MSL)	4.46		7.18		10.32		12.65		15.02		17.90		19.52	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	206	$8,898	238	$23,406	242	$34,982	242	$41,374	243	$46,185	243	$48,705	243	$49,016
Industrial	3	$6,132	3	$12,524	3	$19,426	3	$24,018	3	$25,000	3	$25,107	3	$25,107
MultiFamily	114	$6,788	117	$11,531	117	$13,472	117	$15,579	117	$18,985	117	$20,344	117	$20,380
Public	62	$25,274	68	$38,183	70	$43,033	70	$45,463	70	$46,474	70	$46,860	70	$46,941
Vehicles	1,656	$26,696	1,816	$35,404	1,832	$38,378	1,845	$38,819	1,846	$38,840	1,846	$38,840	1,846	$38,840
Single Family	1,657	$70,032	1,816	$94,166	1,843	$109,968	1,843	$115,628	1,844	$117,760	1,844	$118,518	1,844	$118,682
Grand Total	3,698	$143,821	4,058	$215,214	4,107	$259,258	4,120	$280,881	4,123	$293,244	4,123	$298,373	4,123	$298,966

East Storm Levee														
Event (ACE)	**0.1**		**0.05**		**0.02**		**0.01**		**0.005**		**0.002**		**0.001**	
Elevation (MSL)	5.08		7.81		11.05		13.38		15.55		17.99		19.50	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	209	$11,308	238	$26,277	242	$37,159	243	$42,674	243	$47,499	243	$48,748	243	$49,016
Industrial	3	$8,117	3	$14,301	3	$20,825	3	$24,693	3	$25,107	3	$25,107	3	$25,107
MultiFamily	115	$8,049	117	$12,212	117	$13,887	117	$16,277	117	$19,717	117	$20,348	117	$20,380
Public	65	$27,074	68	$39,777	70	$43,669	70	$45,664	70	$46,713	70	$46,871	70	$46,941
Vehicles	1,661	$34,822	1,820	$36,906	1,845	$38,622	1,845	$38,819	1,846	$38,840	1,846	$38,840	1,846	$38,840
Single Family	1,666	$78,199	1,819	$98,338	1,843	$111,773	1,844	$116,192	1,844	$118,109	1,844	$118,539	1,844	$118,682
Grand Total	3,719	$167,569	4,065	$227,811	4,120	$265,935	4,122	$284,319	4,123	$295,985	4,123	$298,452	4,123	$298,966

Oyster Creek														
Event (ACE)	**0.1**		**0.05**		**0.02**		**0.01**		**0.005**		**0.002**		**0.001**	
Elevation (MSL)	4.44		8.49		12.21		14.63		16.62		18.77		20.19	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	206	$8,803	239	$29,591	242	$40,613	243	$45,125	243	$48,497	243	$49,014	243	$49,019
Industrial	3	$6,065	3	$16,061	3	$23,456	3	$24,839	3	$25,107	3	$25,107	3	$25,107
MultiFamily	114	$6,746	117	$12,772	117	$15,171	117	$18,098	117	$20,185	117	$20,373	117	$20,383
Public	62	$25,222	68	$41,228	70	$45,271	70	$46,168	70	$46,777	70	$46,939	70	$46,941
Vehicles	1,656	$26,183	1,821	$38,266	1,845	$38,819	1,846	$38,840	1,846	$38,840	1,846	$38,840	1,846	$38,840
Single Family	1,657	$69,814	1,820	$103,564	1,843	$115,232	1,844	$117,425	1,844	$118,263	1,844	$118,663	1,844	$118,708
Grand Total	3,698	$142,833	4,068	$241,481	4,120	$278,561	4,123	$290,496	4,123	$297,669	4,123	$298,936	4,123	$298,998

Old River at Dow														
Event (ACE)	**0.1**		**0.05**		**0.02**		**0.01**		**0.005**		**0.002**		**0.001**	
Elevation (MSL)	4.43		7.08		10.15		12.41		14.69		17.43		18.97	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	206	$8,755	238	$22,955	242	$34,546	242	$40,986	243	$45,288	243	$48,539	243	$49,015
Industrial	3	$6,031	3	$12,331	3	$19,097	3	$23,760	3	$24,863	3	$25,107	3	$25,107
MultiFamily	114	$6,725	117	$11,406	117	$13,377	117	$15,346	117	$18,235	117	$20,322	117	$20,375
Public	62	$25,195	68	$37,976	70	$42,839	70	$45,396	70	$46,217	70	$46,821	70	$46,941
Vehicles	1,656	$25,927	1,814	$35,376	1,828	$38,361	1,845	$38,819	1,846	$38,840	1,846	$38,840	1,846	$38,840
Single Family	1,657	$69,706	1,816	$93,721	1,843	$109,306	1,843	$115,488	1,844	$117,485	1,844	$118,440	1,844	$118,672
Grand Total	3,698	$142,339	4,056	$213,765	4,103	$257,526	4,120	$279,794	4,123	$290,930	4,123	$298,069	4,123	$298,949

South Storm Levee														
Event (ACE)	**0.1**		**0.05**		**0.02**		**0.01**		**0.005**		**0.002**		**0.001**	
Elevation (MSL)	4.21		6.68		9.59		11.63		13.71		16.31		17.93	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	205	$7,965	238	$18,251	241	$33,086	242	$39,164	243	$43,275	243	$48,253	243	$48,719
Industrial	3	$5,396	3	$11,560	3	$18,009	3	$22,091	3	$24,693	3	$25,107	3	$25,107
MultiFamily	114	$6,284	117	$10,879	117	$13,106	117	$14,553	117	$16,658	117	$20,122	117	$20,345
Public	62	$23,852	68	$36,779	69	$42,203	70	$44,466	70	$45,756	70	$46,754	70	$46,864
Vehicles	1,654	$21,887	1,686	$35,277	1,824	$38,320	1,845	$38,819	1,846	$38,819	1,846	$38,840	1,846	$38,840
Single Family	1,657	$66,993	1,814	$89,695	1,825	$107,559	1,843	$113,575	1,844	$116,633	1,844	$118,222	1,844	$118,525
Grand Total	3,695	$132,376	3,926	$202,441	4,079	$252,283	4,120	$272,668	4,123	$285,834	4,123	$297,298	4,123	$298,399

Freeport Dock														
Event (ACE)	**0.1**		**0.05**		**0.02**		**0.01**		**0.005**		**0.002**		**0.001**	
Elevation (MSL)	4.47		7.17		10.30		12.63		14.97		17.79		19.38	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	206	8,946	238	23,361	242	34,931	242	41,340	243	46,050	243	48,652	243	49,016
Industrial	3	6,166	3	12,504	3	19,388	3	23,996	3	24,979	3	25,107	3	25,107
MultiFamily	114	6,809	117	11,519	117	13,461	117	15,560	117	18,872	117	20,338	117	20,379
Public	62	25,301	68	38,162	70	43,011	70	45,457	70	46,437	70	46,848	70	46,941
Vehicles	1,656	26,952	1,816	35,402	1,831	38,376	1,845	38,819	1,846	38,840	1,846	38,840	1,846	38,840
Single Family	1,657	70,141	1,816	94,122	1,843	109,907	1,843	115,615	1,844	117,725	1,844	118,498	1,844	118,679
Grand Total	3,698	144,315	4,058	215,069	4,106	259,072	4,120	280,787	4,123	292,902	4,123	298,282	4,123	298,962