Mississippi Valley Division
Regional Planning and Environmental Division South

St. Tammany Parish, Louisiana Feasibility Study

Appendix E – Hydrologic & Hydraulics

June 2021

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Section 1
General Description of Work

The U.S. Army Corps of Engineers (USACE), Mississippi Valley Division (MVD), New Orleans District (CEMVN), Hydraulics, Hydrology, and Coastal Engineering Branch (HH&C) performed hydrologic and hydraulic modeling for the St. Tammany Parish, Louisiana Feasibility Study (study). The purpose of this hydrologic and hydraulic modeling effort is to evaluate various design alternatives for Flood Risk Management (FRM) and Coastal Surge Risk Management (CSRM) within the 1,124 square miles of St. Tammany Parish.

Riverine Modeling was performed for the 2, 5, 10, 25, 50, 100, 200, and 500-year rainfall events for existing conditions and With-Project base (year 2032) and future conditions (year 2082). Coastal storm surge and wave modeling was completed for the without-project condition and statistical analysis determined the 10, 20, 50, 100, 200, 500, 1000-year base (year 2032) and future conditions (year 2082). Water surface elevation results for each frequency were extracted and provided to the Project Delivery Team (PDT) for use in economic, environmental, and engineering analyses.

With-Project model runs and analyses were performed for the structural FRM measures. Analysis of With-Project benefits and impacts was completed for the structural CSRM measures. The Final Array of Alternatives includes the No Action Alternative (Alternative 1), a Non-structural Alternative (Alternative 2), and six structural alternatives (numbered Alternatives 4 through 9), for a total of 8 alternatives and 26 measures evaluated for both FRM and CSRM structural projects (see Table E:1-1. for a summary of the structural measures in the Final Array of Alternatives that underwent hydrologic and hydraulic modeling and analysis). (Note: There is no Alternative 3 as it was screened out earlier in the planning process and is not contained in the Final Array of Alternatives.) Many of the proposed measures have no influence on other measures, making them independent or “separable and combinable” in planning terminology. The alternatives may be more clearly understood as regions of potential projects. FRM alternative analysis was completed through Hydraulic Engineering Center-River Analysis System (HEC-RAS) modeling. CSRM alternative analysis was completed through estimation of storm surge water level changes. With-project analyses are in Section 0 of this appendix.

Table E:1-1. Summary of Final Array Structural Alternatives Evaluated Prior to Tentatively Selected Plan (TSP) Milestone

	Alternative Name	Measure	Project Type
Alternative 4	Lacombe	4a Lacombe Levee	CSRM
		4a.1 Lacombe Levee Short	CSRM
		4.b Lacombe Levee combined with West Slidell Levee	CSRM
Alternative 5	Bayou Liberty/ Bayou Vincent/ Bayou Bonfouca	Bayou Liberty Channel Improvements	FRM
		Bayou Patassat Channel Improvements	FRM
		Bayou Bonfouca Detention Pond	FRM
Alternative 6	South Slidell	Slidell Levee with Eden Isle	CSRM
		Slidell Levee	CSRM
Alternative 7	Eastern Slidell	Doubloon Bayou Channel Improvements	FRM
		Poor Boy Canal Channel Improvements	FRM
		Pearl River Levee	FRM
		Gum Bayou Diversion	FRM
Alternative 8	Upper Tchefuncte/Covington	Mile Branch Channel Improvements	FRM
		Mile Branch Lateral A Channel Improvements	FRM
Alternative 9	Mandeville Lakefront	Mandeville Seawall Replacement	CSRM
		Ravine aux Coquilles Passive Barrier	CSRM
		Little Bayou Castine Passive Barrier	CSRM
		Pump Stations	CSRM

Section 2
Software and Model Development

2.1 HYDRAULIC ENGINEERING CENTER-HYDROLOGIC MODELING SYSTEM 4.4.1

The latest version of the USACE Hydraulic Engineering Center's (HEC)-Hydrologic Modeling System (HMS) available at the time of model development was used for the hydrologic modeling. The Southeast Louisiana Master Model (SLaMM) HEC-HMS model, developed by USACE New Orleans District (CEMVN)' s HH&C branch, was utilized as a starting point for application on the study. The existing model domain of the SLaMM was trimmed down to the extents of St. Tammany Parish. Further discussion on the HEC-HMS model utilized for this study may be found in Section 3.3 of this appendix.

2.2 HEC-RAS 5.0.7

The HEC-RAS modeling developed for this study began from the SLaMM, which was developed by CEMVN's HH&C branch. The model was trimmed down to only include hydraulic subbasins within St. Tammany Parish. In addition to the SLaMM, various other hydraulic models were utilized during model development to create one single HEC-RAS model. For the model domain, elements from CEMVN's SLaMM, a separate model focused on the Tchefuncte River Basin, and USACE Vicksburg District's (MVK's) Pearl River model were combined into a single model domain. St. Tammany Parish officials also provided the PDT with various HEC-RAS models developed for waterways and previous studies that took place in the parish. Elements from two models provided to the PDT by the parish were utilized in this study for stream bathymetry. Further discussion on the HEC-RAS model utilized for this study is presented in Section 0 of this appendix.

2.3 ADVANCED CIRCULATION (ADCIRC) MODEL

Coastal models ADCIRC+SWAN were used to simulate storm surge and waves, respectively. Results from the 2017 CPRA ADCIRC+SWAN study (Roberts and Cobell, 2017) were utilized for the study. No ADCIRC model runs were completed specifically for this study. CEMVN' s HH&C branch completed a statistical analysis on results generated for current and future conditions from a suite of storm simulations that were previously run for the study area.

Section 3

Hydrology, Climate Change, and Storm Surge

St. Tammany Parish is comprised of 10 major watersheds which include the Pearl River, Gum Bayou, W-14/W-15 basin, Bayou Bonfouca, Bayou Lacombe, Bayou Cane, Bayou Castine, Little Bayou Castine, Bayou Chinchuba and the Tchefuncte River. Figure E:3-1 depicts these 10 major watersheds.

The study area experiences flood risk from three primary sources: coastal storm surge and waves, local rainfall on and around the study area, and the Pearl River basin that outlets to the Gulf of Mexico along the eastern boundary of St. Tammany Parish.

Assessment of the parish waterways and drainage basins began with review of various flood studies performed for the St. Tammany Parish Government dating from 1986 to present-day. Following the analysis of existing documentation from previous studies, the PDT was able to accurately assess the hydrology and hydraulics of the study area.

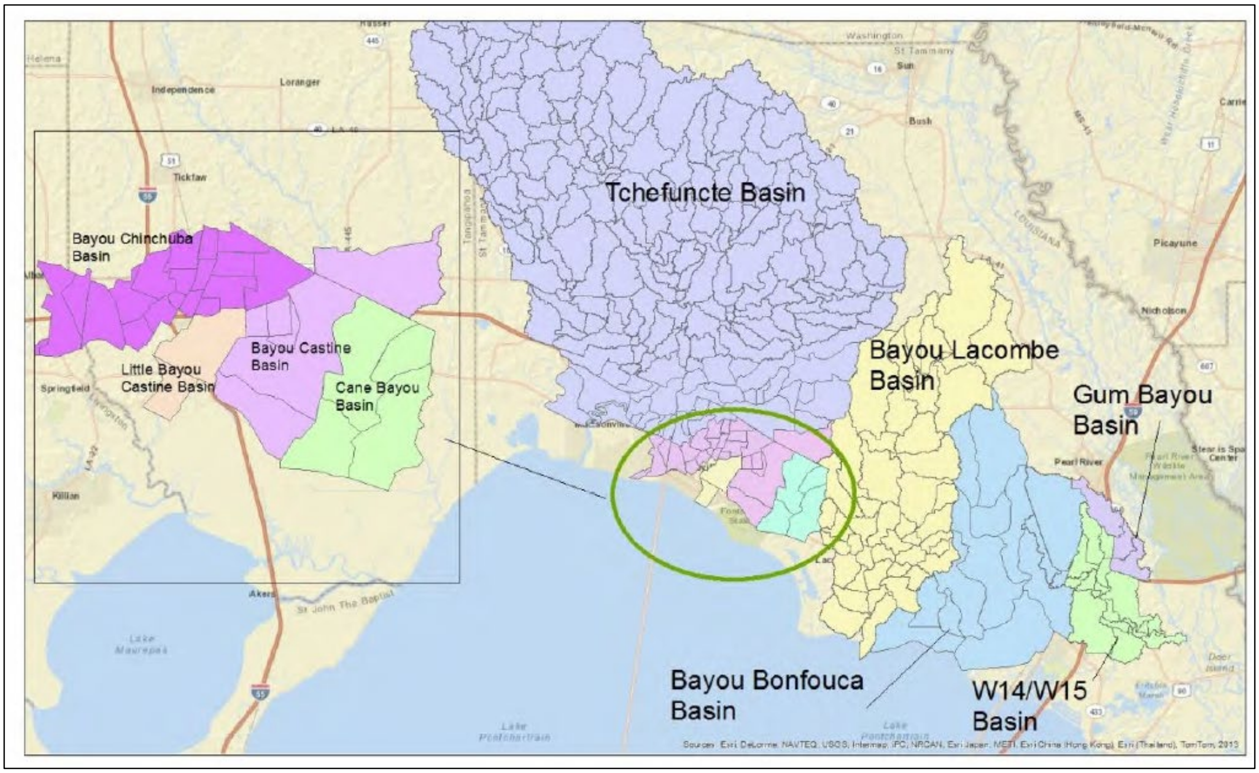


Figure E:3-1. CPRA St. Tammany Parish Watershed Study Drainage Basin Map

3.1 BASIN HYDROLOGY

As noted previously, St. Tammany Parish consists of 10 major watersheds. Hydrologic Unit Codes (HUC) 12 basins were chosen for hydrologic analysis for a more detailed analysis of the hydrology in the study area. The St. Tammany Parish boundary extents cover 30 HUC 12 basins. A comprehensive list is provided in Table E:3-1. and Figure E:3-2.

Table E:3-1. List of St. Tammany Parish HUC 12 Basins

St. Tammany Parish HUC-12 Basins	
1	Bull Branch-Tchefuncte River
2	Upper Bogue Falaya River
3	Berrys Creek-Bogue Chitto
4	Talleys Creek-Bogue Chitto
5	Pearl River Canal - Pearl River
6	Savannah Branch-Tchefuncte River
7	Simalusa Creek
8	Little Bogue Falaya River
9	Talisheek Creek
10	Wilson Slough-Pearl River
11	Bedico Creek
12	Soap and Tallow Branch-Tchefuncte River
13	Lower Bogue Falaya River
14	Black River
15	Ponchitalawa Creek-Tchefuncte River
16	Abita River
17	Bayou Chinchuba
18	Bayou Castine-Cane Bayou
19	English Branch
20	West Pearl River- Pearl River
21	Lacombe Bayou
22	Old Channel-Pearl River
23	Big Branch Bayou-Lacombe Bayou
24	Liberty Bayou-Bayou Bonfouca
25	Middle River-Pearl River
26	Pearlington-Pearl River
27	Salt Bayou
28	Rigolets-Pearl River
29	Lake Pontchartrain
30	Second Alligator Branch-Pearl River

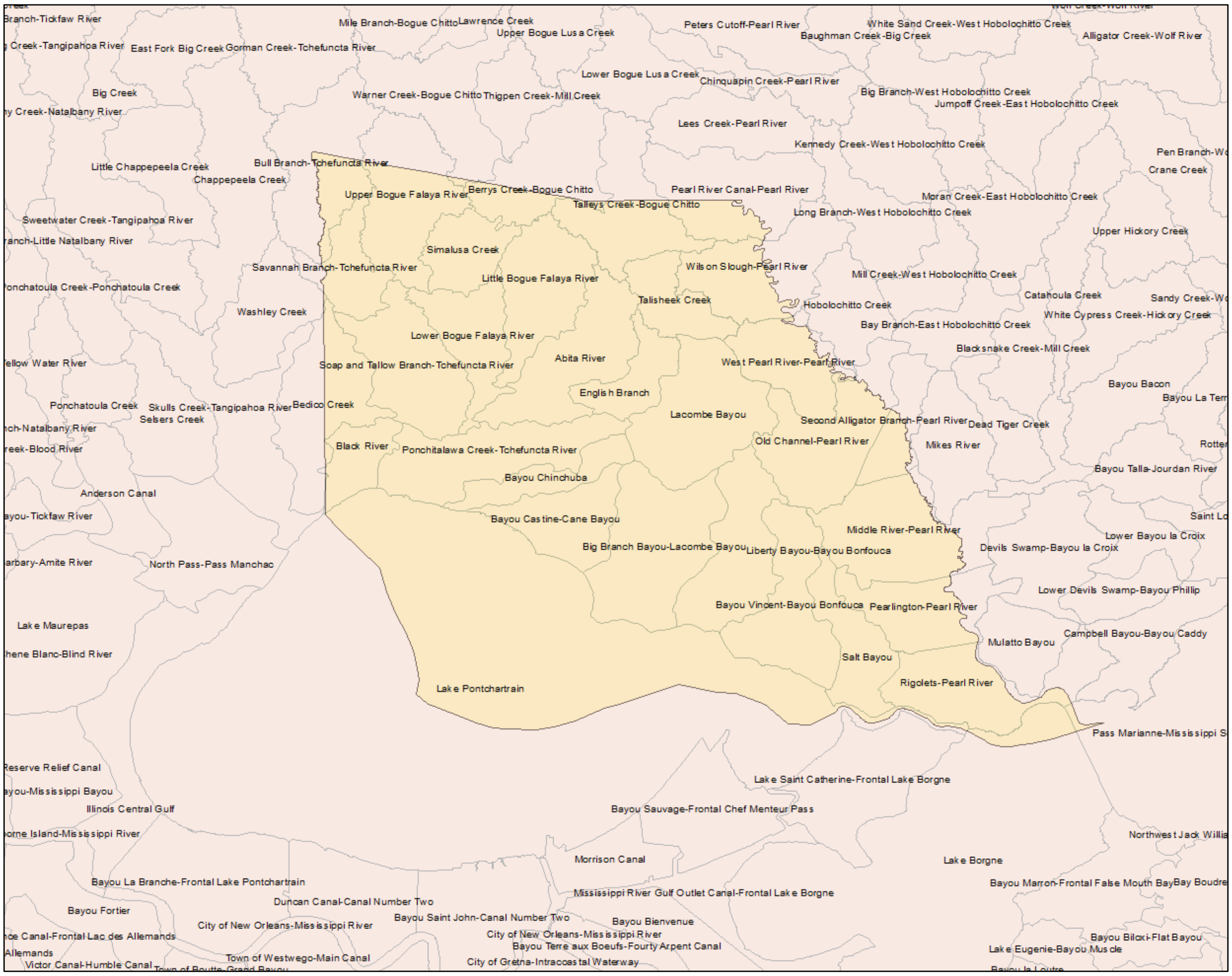


Figure E:3-2. St. Tammany Parish Hydrologic Unit Codes (HUC) 12 Basins

3.2 PRECIPITATION AND RUNOFF

Eight precipitation events were evaluated: the 2-year, 5-year, 10-year, 25-year, 50-year, 100-year, 200-year, and 500-year recurrence interval 24-hour duration events. Frequency storm precipitation hyetographs were developed for each of those events, based on rainfall intensities from the National Oceanic and Atmospheric Administration's (NOAA) Atlas 14 Volume 9 Point Precipitation Frequency Estimates. Figure E:3-3 and Figure E:3-4 depict NOAA Atlas 14 Precipitation frequency depth-duration and depth-frequency, respectively. Annual Maximum Series data was used for a site near the center of St. Tammany Parish. Aerial reduction was applied using the TP-40 method.

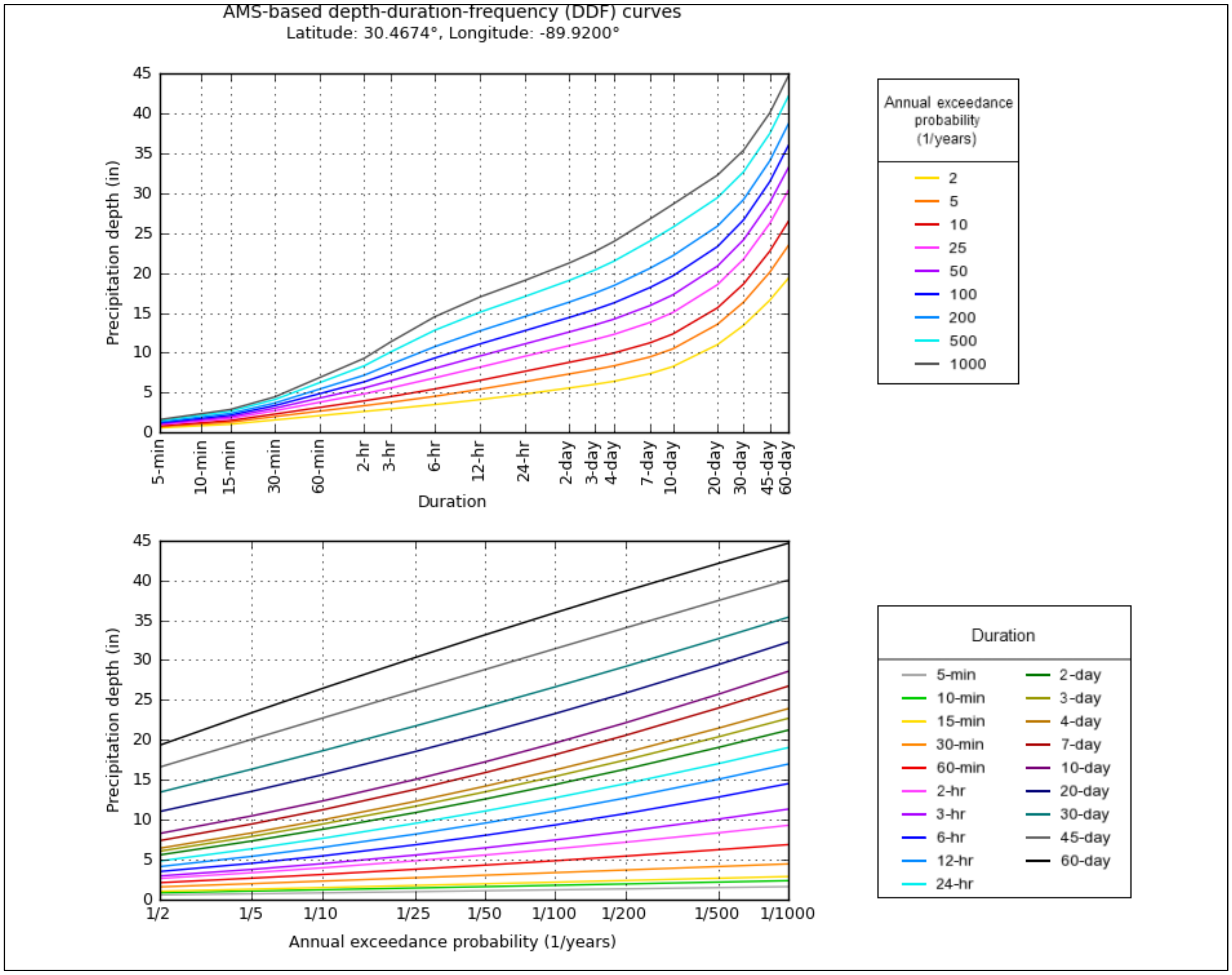
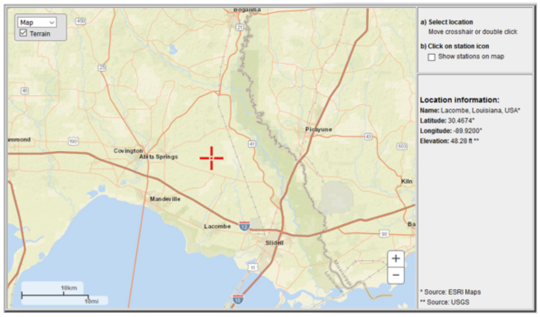


Figure E:3-3. NOAA Atlas 14 Precipitation Data by Annual Exceedance and Duration



AMS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Annual exceedance probability (1/years)								
	1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
5-min	**0.584** (0.471-0.721)	**0.729** (0.587-0.902)	**0.841** (0.673-1.04)	**0.991** (0.769-1.25)	**1.11** (0.841-1.42)	**1.22** (0.901-1.59)	**1.34** (0.953-1.78)	**1.50** (1.03-2.03)	**1.62** (1.09-2.22)
10-min	**0.855** (0.690-1.06)	**1.07** (0.859-1.32)	**1.23** (0.985-1.53)	**1.45** (1.13-1.84)	**1.62** (1.23-2.07)	**1.79** (1.32-2.33)	**1.96** (1.40-2.60)	**2.19** (1.51-2.97)	**2.37** (1.59-3.24)
15-min	**1.04** (0.841-1.29)	**1.30** (1.05-1.61)	**1.50** (1.20-1.86)	**1.77** (1.37-2.24)	**1.97** (1.50-2.53)	**2.18** (1.61-2.84)	**2.39** (1.70-3.18)	**2.67** (1.84-3.62)	**2.89** (1.94-3.96)
30-min	**1.59** (1.28-1.96)	**2.00** (1.61-2.47)	**2.31** (1.85-2.87)	**2.73** (2.12-3.46)	**3.06** (2.32-3.91)	**3.38** (2.49-4.40)	**3.70** (2.63-4.92)	**4.14** (2.84-5.60)	**4.47** (3.00-6.12)
60-min	**2.12** (1.71-2.61)	**2.68** (2.16-3.32)	**3.14** (2.52-3.90)	**3.79** (2.96-4.84)	**4.32** (3.30-5.56)	**4.87** (3.60-6.37)	**5.44** (3.88-7.27)	**6.25** (4.30-8.50)	**6.89** (4.62-9.43)
2-hr	**2.65** (2.15-3.24)	**3.37** (2.73-4.13)	**3.97** (3.20-4.89)	**4.85** (3.83-6.18)	**5.58** (4.30-7.16)	**6.36** (4.74-8.29)	**7.18** (5.17-9.55)	**8.36** (5.81-11.3)	**9.30** (6.29-12.7)
3-hr	**2.95** (2.41-3.60)	**3.78** (3.07-4.62)	**4.50** (3.64-5.51)	**5.57** (4.43-7.11)	**6.48** (5.02-8.31)	**7.47** (5.61-9.74)	**8.54** (6.18-11.3)	**10.1** (7.04-13.6)	**11.3** (7.69-15.4)
6-hr	**3.51** (2.88-4.25)	**4.55** (3.72-5.51)	**5.46** (4.45-6.65)	**6.86** (5.49-8.71)	**8.05** (6.29-10.3)	**9.35** (7.08-12.1)	**10.8** (7.86-14.2)	**12.8** (9.03-17.3)	**14.5** (9.92-19.6)
12-hr	**4.12** (3.41-4.96)	**5.41** (4.46-6.52)	**6.53** (5.35-7.89)	**8.19** (6.59-10.3)	**9.58** (7.52-12.1)	**11.1** (8.44-14.3)	**12.7** (9.33-16.7)	**15.1** (10.7-20.1)	**17.0** (11.7-22.7)
24-hr	**4.82** (4.01-5.74)	**6.36** (5.28-7.60)	**7.66** (6.32-9.18)	**9.54** (7.70-11.9)	**11.1** (8.75-13.9)	**12.7** (9.75-16.2)	**14.5** (10.7-18.9)	**17.0** (12.1-22.5)	**19.0** (13.2-25.3)
2-day	**5.58** (4.68-6.61)	**7.34** (6.13-8.70)	**8.79** (7.31-10.5)	**10.9** (8.84-13.4)	**12.6** (10.00-15.6)	**14.4** (11.1-18.2)	**16.3** (12.1-21.0)	**19.0** (13.6-25.0)	**21.2** (14.8-28.0)
3-day	**6.05** (5.08-7.13)	**7.91** (6.63-9.34)	**9.45** (7.88-11.2)	**11.7** (9.52-14.3)	**13.5** (10.8-16.7)	**15.4** (11.9-19.4)	**17.5** (13.0-22.4)	**20.4** (14.7-26.7)	**22.7** (15.9-29.9)
4-day	**6.42** (5.41-7.54)	**8.35** (7.02-9.83)	**9.96** (8.33-11.8)	**12.3** (10.1-15.0)	**14.2** (11.4-17.5)	**16.2** (12.6-20.4)	**18.4** (13.8-23.6)	**21.5** (15.5-28.0)	**23.9** (16.8-31.4)
7-day	**7.37** (6.25-8.61)	**9.47** (8.01-11.1)	**11.2** (9.45-13.2)	**13.8** (11.4-16.8)	**15.9** (12.8-19.5)	**18.2** (14.2-22.6)	**20.6** (15.5-26.2)	**24.0** (17.4-31.1)	**26.7** (18.9-34.9)
10-day	**8.27** (7.04-9.61)	**10.5** (8.90-12.2)	**12.3** (10.4-14.4)	**15.0** (12.4-18.2)	**17.2** (13.9-21.0)	**19.6** (15.3-24.4)	**22.1** (16.7-28.1)	**25.7** (18.7-33.2)	**28.6** (20.3-37.2)
20-day	**11.0** (9.44-12.7)	**13.6** (11.6-15.7)	**15.6** (13.3-18.1)	**18.5** (15.4-22.1)	**20.9** (16.9-25.2)	**23.3** (18.3-28.6)	**25.9** (19.6-32.4)	**29.4** (21.5-37.7)	**32.2** (23.0-41.6)
30-day	**13.4** (11.6-15.4)	**16.3** (14.0-18.8)	**18.6** (15.9-21.5)	**21.7** (18.0-25.7)	**24.2** (19.6-28.9)	**26.6** (21.0-32.5)	**29.2** (22.2-36.4)	**32.7** (24.0-41.6)	**35.4** (25.3-45.5)
45-day	**16.6** (14.3-18.9)	**20.1** (17.3-23.0)	**22.7** (19.5-26.1)	**26.2** (21.8-30.7)	**28.8** (23.5-34.2)	**31.4** (24.8-38.0)	**34.0** (25.9-42.1)	**37.5** (27.6-47.3)	**40.0** (28.8-51.3)
60-day	**19.3** (16.7-22.0)	**23.4** (20.2-26.7)	**26.4** (22.7-30.3)	**30.3** (25.2-35.3)	**33.2** (27.1-39.1)	**35.9** (28.4-43.2)	**38.6** (29.5-47.5)	**42.1** (31.0-52.9)	**44.6** (32.2-57.0)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of annual maxima series (AMS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and annual exceedance probability) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

Figure E:3-4. Precipitation Frequency for Lacombe, LA (Central Location of the Parish)

3.3 HYDROLOGIC MODELING

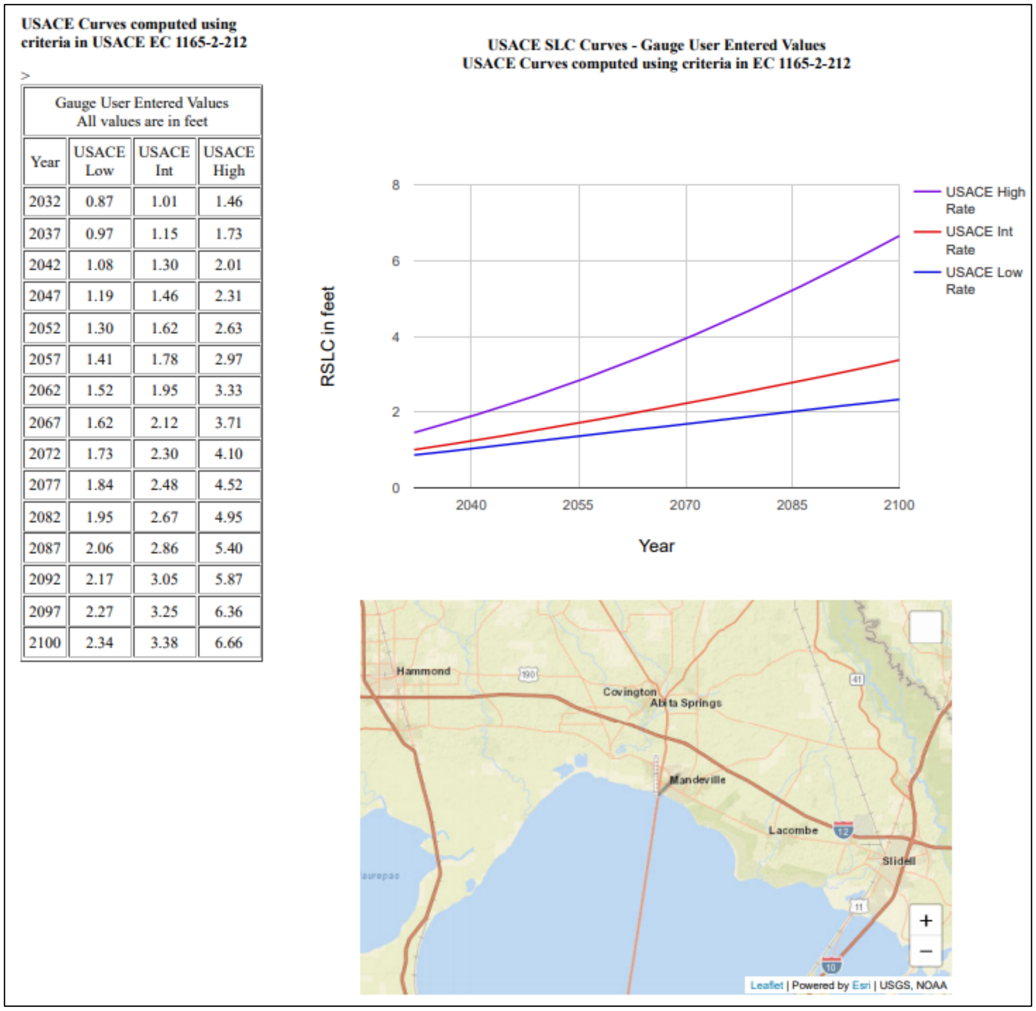
HEC-HMS was utilized to model the hydrology. A subsection of the SLaMM HEC-HMS model was adapted by removing subbasins that are not included within the parish. Hydrology for frequency storms 2, 5, 10, 25, 50, 100, 200, and 500 year were computed based on subbasin square mileage, canopy and loss calculations, and the model was run for a time period of three days. The SLaMM model has been calibrated for the March 2016 rain event, and no additional calibration of the HEC-HMS model was done for the study.

Hydrologic losses, or infiltration, were calculated in the HEC-HMS model using the deficit and constant loss method. The deficit and constant loss method uses a single soil layer to account for continuous changes in moisture content. The deficit is the amount of water required at any point in time to bring the soil layer to saturation. Four parameters must be estimated using the deficit and constant loss method. The first parameter, initial deficit, specifies the amount of available water storage capacity in the soil layer at the beginning of the simulation. An Initial Deficit of 0.08 in was used for all subbasins in the model domain. The second parameter, maximum deficit, specifies the maximum amount of water that can be held in the soil layer. A maximum deficit of 2 inches was used for all subbasins. The constant rate defines how quickly water enters the soil while it is saturated and precipitation is occurring. A constant rate of 0.05 inches/hour was used for each subbasin in the model domain. Impervious area was not explicitly defined.

Of the total precipitation depth at each computation interval, HEC-HMS computes the infiltration and runoff (excess precipitation) depth. This excess precipitation variable was used as the input for the local rainfall on the 2D Areas in the HEC-RAS model.

3.4 SEA LEVEL RISE

To evaluate potential future changes in project performance due to relative sea level change, ER 1100-2-8162 requires planning studies and engineering designs to be formulated and evaluated considering all possible rates of Sea Level Change (SLC): low, intermediate, and high. The ER directs to the USACE Sea Level Change Curve Calculator online tool to develop the three rates. For the high-subsidence area of coastal Louisiana, the Sea-Level Calculator for Non-NOAA Long-Term Tide Gauges was used specifically, results may be seen in Figure E:3-5. After comparing and evaluating the rates determined by the calculator, the PDT determined that the 'intermediate' rate of sea level rise should be used in this study for future conditions model runs in the analysis of alternatives. This topic is discussed further in Section 4.4.2.2.



USACE Curves computed using criteria in USACE EC 1165-2-212

>

Gauge User Entered Values All values are in feet			
Year	USACE Low	USACE Int	USACE High
2032	0.87	1.01	1.46
2037	0.97	1.15	1.73
2042	1.08	1.30	2.01
2047	1.19	1.46	2.31
2052	1.30	1.62	2.63
2057	1.41	1.78	2.97
2062	1.52	1.95	3.33
2067	1.62	2.12	3.71
2072	1.73	2.30	4.10
2077	1.84	2.48	4.52
2082	1.95	2.67	4.95
2087	2.06	2.86	5.40
2092	2.17	3.05	5.87
2097	2.27	3.25	6.36
2100	2.34	3.38	6.66

Figure E:3-5. USACE Sea Level Change Curves

Section 4
Hydraulic Modeling

4.1 OVERVIEW

Hydraulic modeling was performed using two-dimensional (2D) unsteady flow capabilities of HEC-RAS. The model covers the extents of St. Tammany Parish, all within the Lake Pontchartrain watershed, and features five connected 2D areas. The vertical datum of elevations in the model is NAVD 88 (Geoid 12B). Detailed discussion of model development and parameter selection is included in this Section.

4.2 MODEL GEOMETRY

Two versions of model geometry were utilized in this modeling effort. One model geometry represents the parish baseline, or without-project, conditions. Three different HEC-RAS models were combined to develop this geometry. Elements of stream bathymetry were integrated into the terrain for this model from two individual watershed models provided by St. Tammany Parish. The second model geometry represents the alternative analysis and incorporates the separate measures investigated in this study, as described in Section 6.1. Figure E:4-1 depicts the existing conditions model domain.

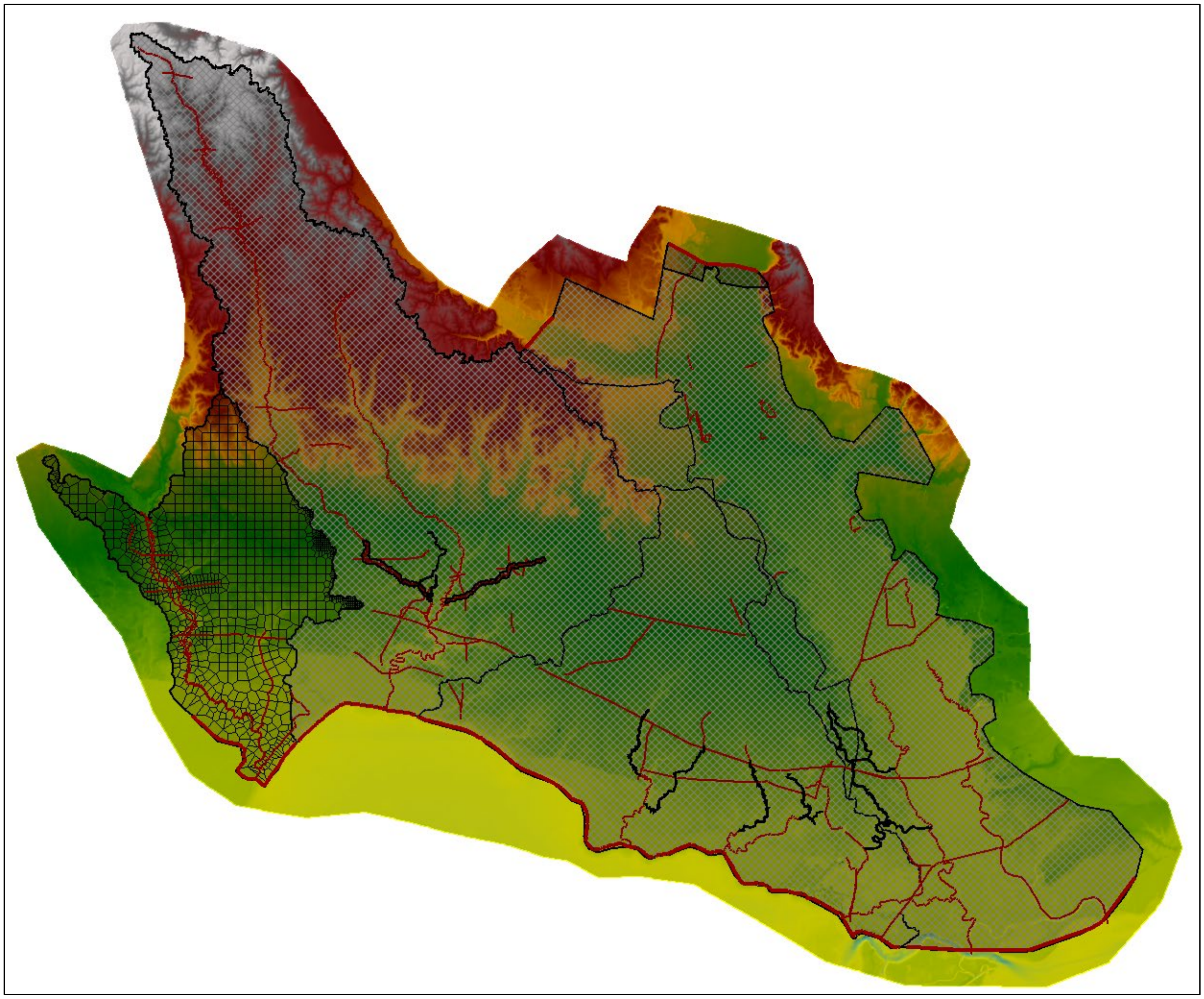


Figure E:4-1. Existing Conditions Model Domain

Both the existing conditions and with-project geometries utilize the 2D unsteady flow equations in HEC-RAS. The 2D areas encompass the spatial extent of the study area, including all rivers and streams. The 2D cell sizes in the geometry mesh varied. Waterways that intersect a potential alternative or measure being investigated in the study have finer resolution cells of 25x25 feet. Outside of these waterways and in areas the PDT was less interested in investigating in-depth, the cell definition increases with a range between 100x100 up to 2000x2000 feet cells. Also, for near model features such as culverts, lateral structures, 2D area connections, and 2D inflow points, smaller cells were used to allow better model stability and accuracy.

As discussed previously, this model integrates the domain of three separate models. Figure E:4-2 depicts the boundaries of each. From the SLaMM model two 2D areas, Basin 748 and Basin 726, were integrated into the Final Geometry. A separate model of the Tchefuncte River Basin that had been refined on the Tchefuncte and Bogue Falaya Rivers was utilized. A 2D model of the Pearl River Basin, used by MVK for flood forecasting, was also integrated into the model. Finally, a gap existed between the Pearl River Basin model and Eastern Extents of Basin 726 and the Tchefuncte River Basin model. A 2D area labeled as Gap was created with the appropriate connections to the adjacent 2D Areas.

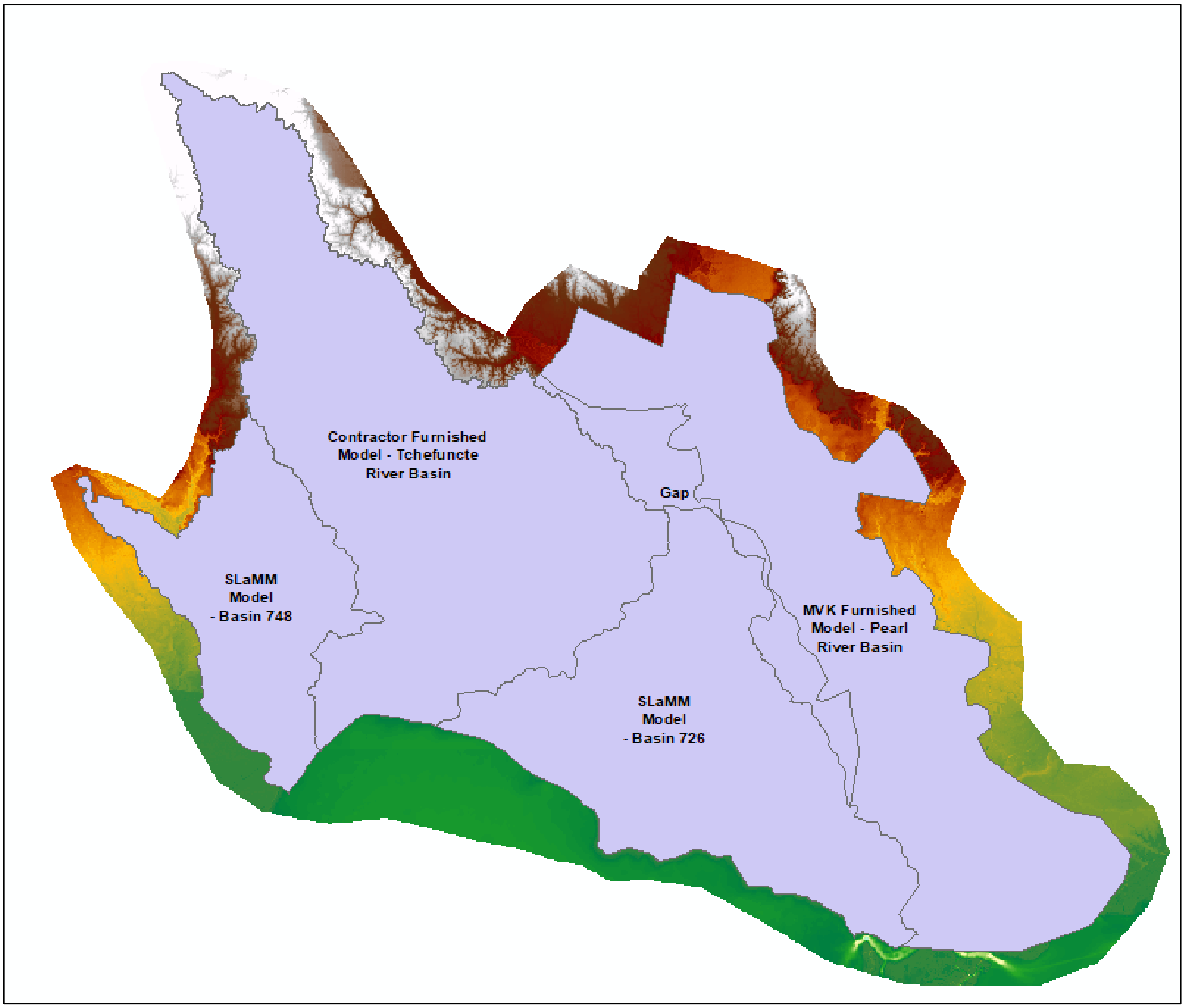


Figure E:4-2. Depiction of 2D Areas Pulled from Various HEC-RAS Models

4.3 TERRAIN AND LAND COVER

Elevation data is used by 2D flow areas to calculate storage within and flow between 2D cells. Topography data came from various sources. Pixel resolution, layer order, descriptions and the source of each Raster file can be seen in Table E:4-1. The layer order used for the final Terrain is numbered as one being the top-most and six being the bottom layer in Table E:4-1.. DEM 23, DEM 22, NG20ft, and USGS National Elevation DEMs cover the entirety of the domain of the study area. CE-Hyd and MVK Pearl TIFs were layered on top of the DEMs because they have higher resolution. Figure E:4-3. depicts the final model terrain and Table

E:4-2. tabulates the 17 waterways that have bathymetry burned into the terrain along with the estimation method or source utilized to estimate bathymetry.

Table E:4-1. Raster Resolution Sizes, Layer Order, Description, and Source Information

Raster File	**Resolution Scale**	**Resolution Cell Size (ft)**	**Layer Order: Top (1) to Bottom (6)**	Description	**Source**
CE-Hyd	1:55.810	4.79	1	The geographic extents of this file include the entirety of the Tchefuncte and Bogue Falaya River Basin. It is a combination of lidar and channel elevations in the Tchefuncte and Bogue Falaya Rivers.	Contractor furnished topography
MVK Pearl	1:38.192	7	2	The geographic extents of this file include the Pearl River Basin within the St. Tammany Parish Boundary	USACE Vicksburg District
DEM 23	1:27.179	9.83	3	The geographic extents of this file include the Bayou Lacombe, Bayou Bonfouca, and Bayou Liberty River Basin. Includes topographic and some bathymetric elevations.	USGS Topobathymetric Elevation Model of Northern Gulf of Mexico
DEM 22	1:27.167	9.84	4	The geographic extents of this file include the Tchefuncte River from the intersection of Hwy 1077 and 1078 westward to the St. Tammany Parish Boundary. Includes topographic and some bathymetric elevations.	USGS Topobathymetric Elevation Model of Northern Gulf of Mexico
NG20ft	1:13.367	20	5	The geographic extents of this file include the North Eastern extents of the Parish, West of the Pearl River Basin	USGS Northern Gulf of Mexico Topobathymetric Dataset
USGS National Elevation Dataset 11ft	1:2.805	95.30	6	The geographic extents of this file include the Bogue Falaya and Tchefuncte River from Folsom, Louisiana north to the St. Tammany Parish Boundary	USGS National Elevation Dataset topography

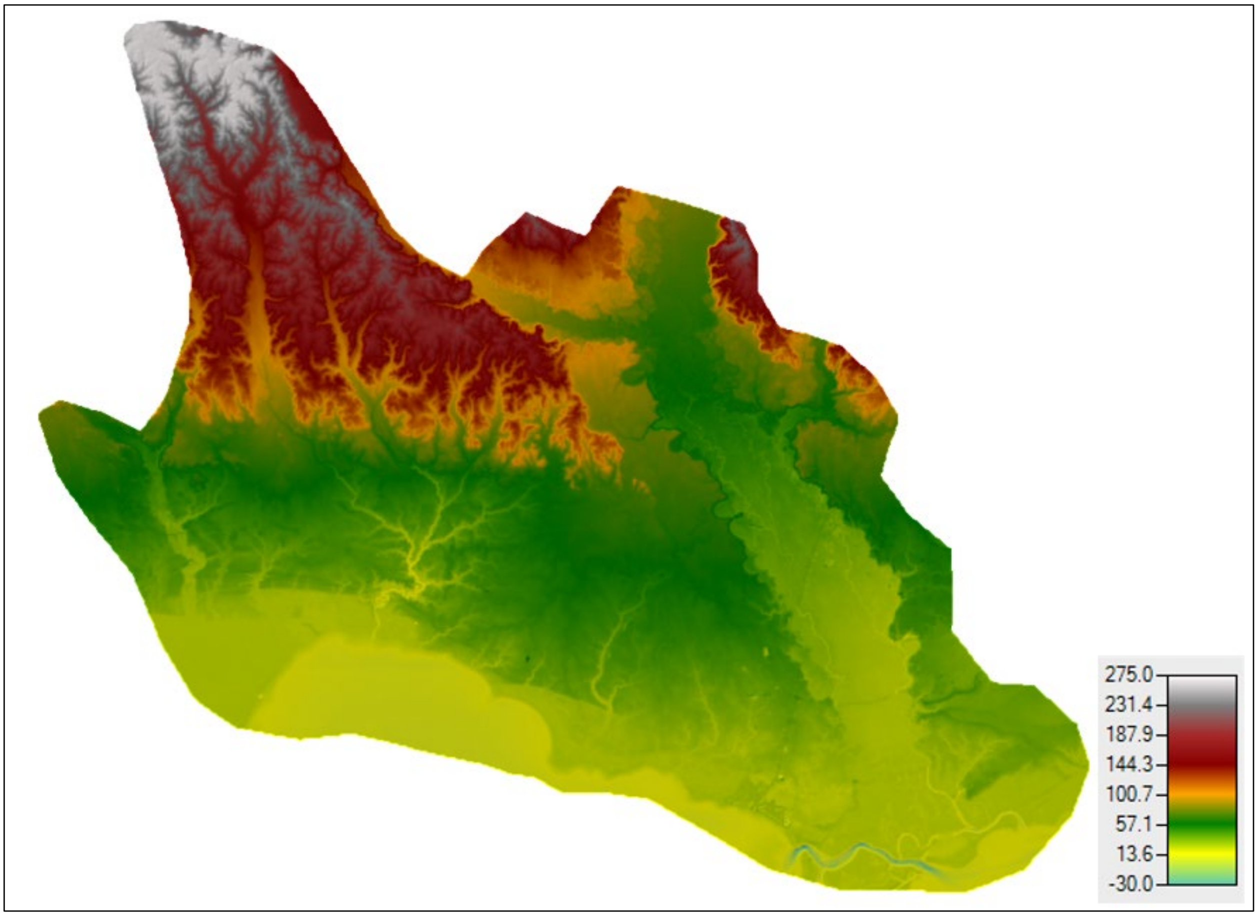


Figure E:4-3. Combined LiDAR Dataset

Table E:4-2. Bathymetry Estimation Methodology for Each Reach

Burned-in Bathymetry		
	Waterway Name	**Estimation Method**
1	Bayou Liberty	Parish-Furnished Bayou Liberty Model cross sections utilized
2	Bayou Patassat	Parish-Furnished W-14 Model cross sections utilized
3	Poor Boy Canal	Parish-Furnished W-14 Model cross sections utilized
4	Doubloon Bayou	Parish-Furnished W-14 Model cross sections utilized
5	Gum Bayou	Parish-Furnished W-14 Model cross sections utilized
6	W-14	Parish-Furnished W-14 Model cross sections utilized
7	W-15 French Branch	Parish-Furnished W-14 Model cross sections utilized
8	Salt Water Bayou	Parish-Furnished W-14 Model cross sections utilized
9	West Diversion Canal	Parish-Furnished W-14 Model cross sections utilized
10	Bayou Bonfouca	Estimated based on channel slope and prior study bathymetry
11	West Pearl River	Estimated based on channel slope and prior study bathymetry
12	Pearl River	Estimated based on channel slope and prior study bathymetry
13	Bayou Lacombe	Estimated based on channel slope and prior study bathymetry
14	Cypress Bayou	Estimated based on channel slope and prior study bathymetry
15	Tchefuncte River	Estimated based on channel slope and prior study bathymetry
16	Mile Branch	LIDAR capture of waterway was spotty. No bathymetry estimated but cross sections cut from existing terrain to ensure a continuous channel exists
17	Mile Branch Lateral A	LIDAR capture of waterway was spotty. No bathymetry estimated but cross sections cut from existing terrain to ensure a continuous channel exists

Land cover data is used to spatially vary the Manning's n roughness coefficients throughout the 2D flow areas. Manning's roughness coefficients are used in the calculation of flow between 2D cells. Land cover data came from the 2016 National Landcover Database (NLCD). An appropriate Manning's roughness coefficient was selected for each land cover type that is found in the study area. The literature source utilized to apply land cover values is from the Journal of Landcover Hydrology. Figure E:4-4. displays the tabulation of land cover coefficients from the Journal of Spatial Hydrology Article: Land use-based surface roughness on hydrologic model output.

Table 2 Manning's n values used for NLCD map

Land Cover	Description	Manning's n
21	Developed, open space	0.0404
22	Developed, low intensity	0.0678
23	Developed, medium intensity	0.0678
24	Developed, high intensity	0.0404
31	Barren land	0.0113
41	Deciduous forest	0.36
42	Evergreen forest	0.32
43	Mixed forest	0.40
52	Shrub/scrub	0.40
71	Grassland/herbaceous	0.368
81	Pasture/Hay	0.325
90	Woody wetlands	0.086
95	Emergent herbaceous wetlands	0.1825

Figure E:4-4. Table 2 from the Journal of Spatial Hydrology Article: Land Use-based Surface Roughness on Hydrologic Model Output

4.4 BOUNDARY CONDITIONS

Inflow and precipitation boundary conditions to the hydraulic model were calculated for each return period. The precipitation boundary conditions use HEC-HMS output to apply the calculated excess precipitation directly on the 2D areas. The inflow boundary conditions in this model are 2D inflow hydrographs that represent the Bogue Chitto and Pearl Rivers. The downstream boundary conditions in this model are stage hydrographs applied to each 2D area representing Lake Pontchartrain.

4.4.1 2D Inflow Hydrographs

Inflow hydrographs are applied to the 2D portions of the model at 2D boundary condition lines. At the northern and northwestern boundary of the Pearl River 2D area, the model has two inflow Boundary Condition lines: one is for the Bogue Chitto River and the other is for the Pearl River. Inflow for return periods 2-500 years were applied for both the Bogue Chitto and Pearl Rivers. The inflow boundary condition line extends the entire length of the 500-year floodplain for each river.

Flows for selected key frequencies were available from the most-recent Flood Insurance Studies (FIS) of the area. The 2009 Washington Parish FIS was used for the Bogue Chitto River flows of 10, 50, 100, and 500-year return periods. The 2019 Pearl River, Mississippi

FIS was used for the Pearl River flows of 10, 25, 50, 100, and 500-year return periods. Regression equations were developed to calculate flows for additional frequencies that were needed (1, 5, 200-year return period).

Figure E:4-5. depicts the return periods annual exceedance calculations graphically. Table E:4-3. depicts the calculated inflow for return periods 2-500 years. Figure E:4-6 shows the locations of the 2D inflow hydrograph for the Bogue Chitto and Pearl River.

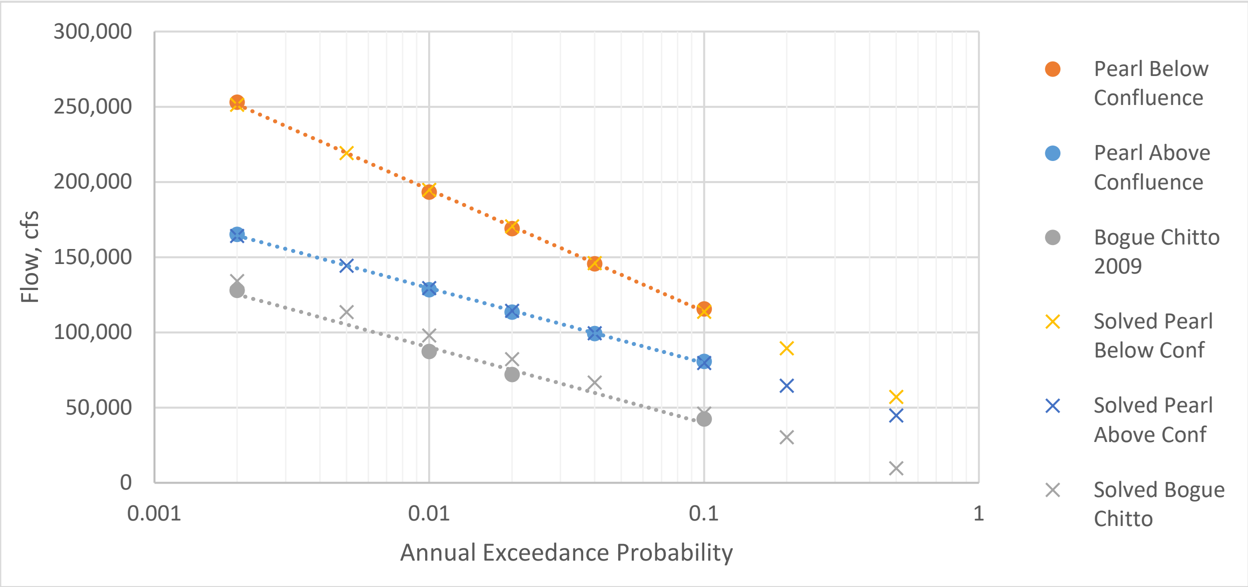


Figure E:4-5. Depiction of Return Periods Annual Exceedance Calculations

Table E:4-3. Tabulation of Return Period Calculations for Inflow Boundary Condition Lines at the Pearl and Bogue Chitto Rivers

Return Period	Annual Exceedance Probability	Pearl Above Confluence	Bogue Chitto
2	0.5	44,855	9,757
5	0.2	64,671	30,418
10	0.1	79,661	46,047
25	0.04	99,476	66,707
50	0.02	114,466	82,336
100	0.01	129,456	97,965
200	0.005	144,446	113,594
500	0.002	164,262	134,255

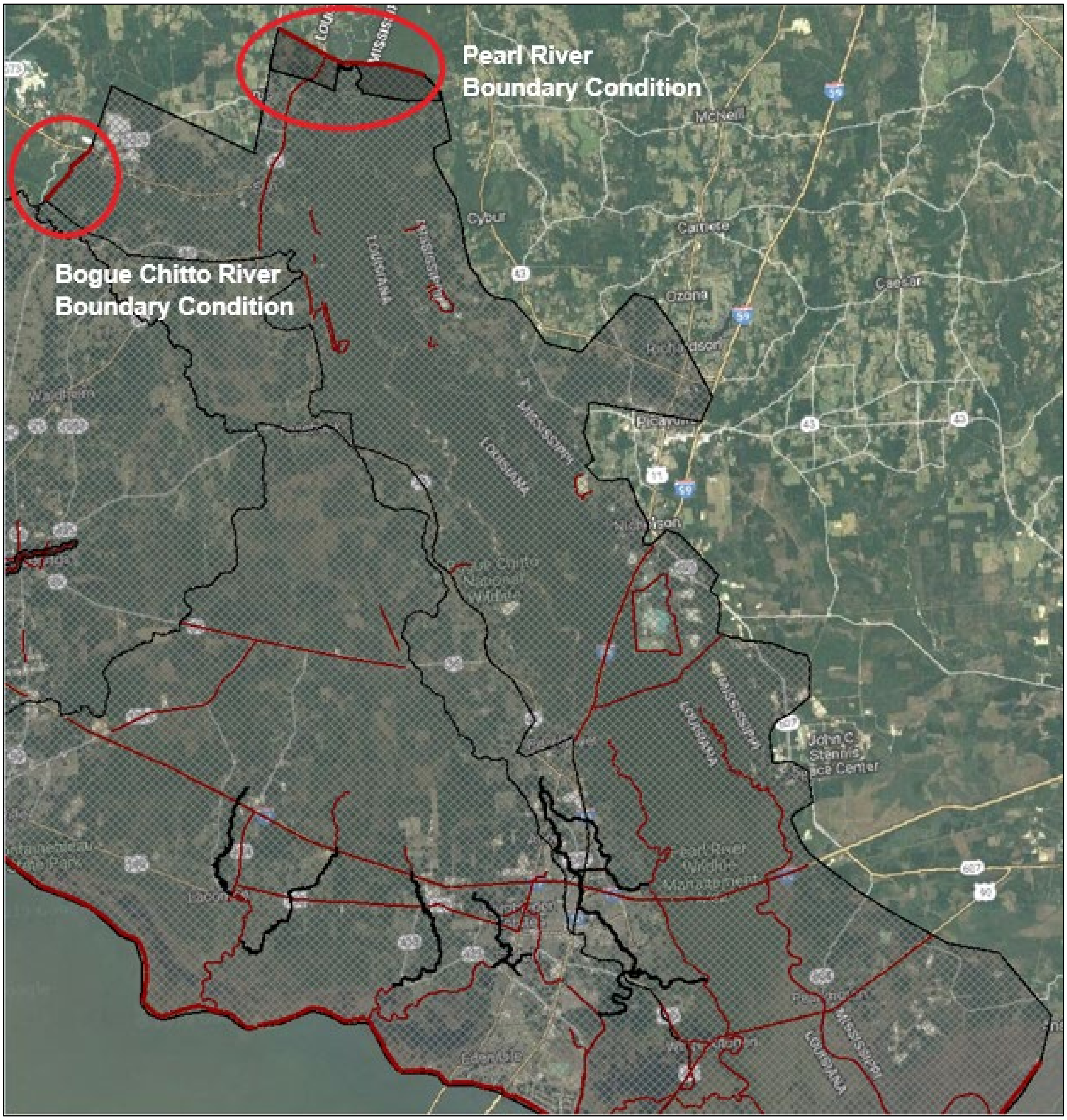


Figure E:4-6. 2D Boundary Condition Line for the Bogue Chitto and Pearl Rivers

4.4.2 Stage Hydrographs

4.4.2.1 Coincidence of Rainfall and Surge

Given the multiple sources of flood risk that threaten St. Tammany Parish, coincidence and joint probability of two sources is an issue that complicates any flood risk analysis. Flooding is experienced by people and property as a total water level, regardless of the source (rain, storm surge, or river flooding). Coastal flooding damage was analyzed separately from the rainfall and river-based flood damage. Rainfall associated with tropical cyclones is not normally modeled within ADCIRC, which likely results in underestimated flood levels and damages by some amount. This uncertainty is consistent across all the study alternative areas.

With coastal storm damage being modeled and analyzed separately, the rainfall and river-based flooding was modeled without a coastal storm surge influence present. The average daily stage from each gage's period of record was used for the Lake Pontchartrain boundary conditions. This represents a median water level expected in the lake.

Local rainfall and Pearl River flooding were modeled together in HEC-RAS, though the timing of the peaks was not coincident. This approach enabled the identification of flooding from each source. The rainfall boundary conditions are applied to the model domain starting at the beginning of the simulation, with the peak of the rainfall at 12 hours into the simulation. The Pearl River is rising to its peak at this time. The peak flow for the Pearl and Bogue Falaya Rivers takes 24-48 hours to propagate to the downstream end of the model domain, which results in peaks that are not coincident.

Results provided for economic damage analysis show the maximum water surface elevation throughout an entire simulation. Thus, in areas that experience flooding from both local rainfall and the Pearl River, the higher of the two peaks is counted in the maximum water surface output.

4.4.2.2 Relative Sea Level Change

Global, or eustatic, sea level rise and regional subsidence have affected the study area and are projected to continue affecting the area. Together, these two processes are referred to as "relative sea level change" in USACE guidance (USACE ER 1100-2-8162; EP 1100-2-1). River basins in St. Tammany Parish eventually drain to Lake Pontchartrain. Higher sea levels in the future reduce the hydraulic gradient which somewhat slows the drainage of storm runoff, increasing flooding levels from the same amount of rain. USACE guidance provides a low, intermediate, and high rate to use for project evaluation. The intermediate rate was selected for use in the alternative evaluation phase. For planning purposes, this study assumed a project completion, or base, year of 2032. The end of the 50-year planning horizon would be 2082. Calculated changes in relative sea level by the year 2032 are 0.5 feet for the Mandeville gage and 0.4 feet for the Rigolets gage. Calculated changes in relative sea level by the year 2082 are 2.2 feet for the Mandeville gage and 1.7 feet for the Rigolets gage. These values were added on to the established downstream boundary conditions.

4.4.2.3 Boundary Conditions

The downstream boundaries of the hydraulic model are stage boundaries that represent the water level of Lake Pontchartrain. Stage boundaries are used along the entire extents of the southern boundary of the model domain where the 2D domain interacts with Lake Pontchartrain. There are two long-term water level gauges on the north shore of Lake Pontchartrain that were used to determine downstream boundary conditions: Lake

Pontchartrain at Mandeville and Rigolets near Lake Pontchartrain. Downstream boundary conditions vary along the model extents. For downstream boundary conditions B3, B4, and B5-West a stage of 1.31 feet and 3.01 feet was used for the 2032 and 2082 events, respectively, levels that represent the mean daily stage for the Lake Pontchartrain at Mandeville gage. For downstream boundary condition B5-East a stage of 0.97 foot and 2.27 feet was used for the 2032 and 2082 events, respectively, levels that represent the mean daily stage for the Rigolets near Lake Pontchartrain gage. For downstream boundary condition B6 a stage of 1.50 feet and 2.80 feet was used for the 2032 and 2082 events respectively. These values are tabulated in Table E:4-4. Figure E:4-7. depicts the locations of the five total downstream boundary condition lines.

Table E:4-4. Downstream Boundary Condition Stages along the Extents where the Model Domain Interacts with Lake Pontchartrain

	Boundaries B3, B4, B5-West	**Boundary B5-East**	**Boundary B6**
Existing Conditions – 2032	1.31ft	0.97ft	1.50ft
Future Conditions – 2082	3.01ft	2.27ft	2.80ft

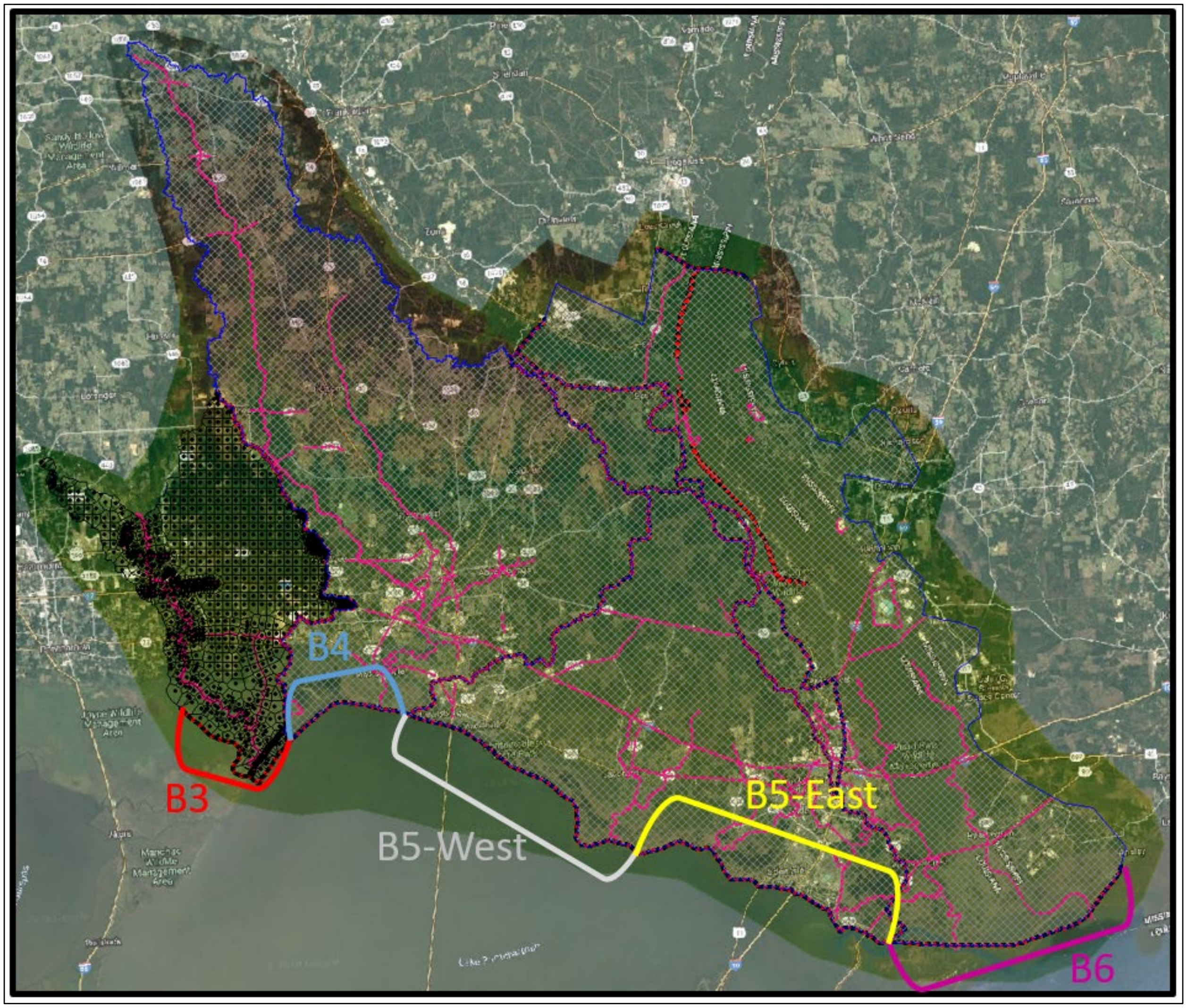


Figure E:4-7. Locations of Downstream Boundary Conditions B3, B4, B5-West, B5-East, and B6

4.5 CLIMATE CHANGE VULNERABILITY

Regional-scale climate change and hydrology trends for the study area are documented in the report "Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – Lower Mississippi River Region 08" (USACE, 2015). Vulnerability to Climate Change is the degree to which a system is susceptible to and unable to cope with adverse effects of climate change including climate variability and extremes. There are six climate variables that are impacted due to climate change including increased ambient temperatures, increased maximum temperatures, increased annual precipitation, increased storm intensity and frequency, streamflow variability, and sea level rise. According to the Climate Change Assessment for Water Resources Region 08 (Lower Mississippi River Region) these climate variables will create countless vulnerabilities on business lines within the region.

Air temperatures within Region 08 are expected to increase 3-6 degrees Celsius in the latter half of the 21st century, especially in the summer months. This is expected to create increased water temperatures leading to water quality concerns, particularly for dissolved oxygen (DO) levels, growth of nuisance algal blooms, and influence wildlife and supporting food supplies. Additionally, periods of prolonged drought and reduced stream flows should be expected. Drought and reduced stream flows will lead to the killing of diverse vegetation throughout the region, then impacting sediment stabilization in the watershed. Loss of non-drought resistant vegetation may result in an increase in sediment loading potentially causing geomorphic changes in the tributaries to the river system.

By the middle of the 21st century, annual precipitation is expected to increase in the region. Increased precipitation is expected to increase flows and runoff within the watershed. Increased runoff caries more pollutants to receiving water bodies, therefore depreciating water quality health. Increased erosion with subsequent changes in sediment accumulation is also anticipated. Flooding will also increase and have a negative consequence on infrastructure, habitats, and human life.

Extreme storm events are expected to become more frequent and intense over time. Higher intensity and more frequent storms will inherently increase flows and runoff, cause erosion with subsequent changes in sediment accumulation, increase groundwater recharge rates as residence times are shortened within areas where evapotranspiration takes place during high intensity events, and increase flooding, which has a negative impact on infrastructure, habitats, and human life. Additionally, increased sea level exacerbates saltwater intrusion into fresh water supplies and numerous Southern Louisiana fishery industries.

Additional, comprehensive assessment of climate trends in the project area will be completed in subsequent documentation and further evaluation of project performance under a range of possible sea level change scenarios will be completed.

4.6 HYDRAULIC MODEL CALIBRATION

Some calibration was completed on the previous models independently, prior to combining them into a single working model domain. Model calibration of the new combined HEC-RAS model was completed to benchmark and improve the performance of the model. Two events were chosen to calibrate the model. For the central portion of the parish, the March 2016 rain event was chosen as there was heavy flooding that this event caused in that portion of the parish. For the southeastern portion of the parish, an event that occurred in December 2009 that impacted Slidell, Louisiana, was chosen.

Existing USACE and USGS gages were utilized to evaluate the calibration runs of the novel model geometry and terrain. A complete list of gages utilized for each calibration event may be seen in Table E:4-5 and locations of the gages may be seen in Figure E:4-8. Calibration plots depicting the March 2016 and December 2009 events at the gage locations listed in Table E:4-5. compared with flows in the final calibrated model may be seen in Annex B of this appendix.

Table E:4-5. Calibration Gages for St. Tammany Parish

Gage Name	Gage ID	Gage Link
Lake Pontchartrain at Mandeville, LA	USACE 85575	https://rivergages.mvr.usace.army.mil/WaterControl/stationinfo2.cfm?sid=85575&fid=&dt=S
Tangipahoa River at Robert, LA	USGS 07375500	https://nwis.waterdata.usgs.gov/la/nwis/uv?cb_00065=on&format=html&site_no=07375500&period=&begin_date=2016-03-01&end_date=2016-03-31
Tchefuncte River at Madisonville, LA	USGS 07375230	https://nwis.waterdata.usgs.gov/usa/nwis/uv/?cb_00065=on&format=html&site_no=07375230&period=&begin_date=2016-03-01&end_date=2016-03-31
Bayou Liberty near Slidell, LA	USGS 07374581	https://nwis.waterdata.usgs.gov/usa/nwis/uv/?cb_00065=on&format=html&site_no=07374581&period=&begin_date=2016-03-01&end_date=2016-03-31
Rigolets at Hwy 90 near Slidell, LA	USGS 301001089442600	https://nwis.waterdata.usgs.gov/la/nwis/uv/?cb_00065=on&format=html&site_no=301001089442600&period=&begin_date=2016-03-01&end_date=2016-03-31
Bogue Chitto River near Bush, LA	USGS 02492000	https://nwis.waterdata.usgs.gov/nwis/uv?cb_00060=on&format=html&site_no=02492000&period=&begin_date=2016-03-01&end_date=2016-03-31
Pearl River near Bogalusa, LA	USGS 02489500	https://waterdata.usgs.gov/nwis/dv?cb_00060=on&format=html&site_no=02489500&referred_module=sw&period=&begin_date=2016-03-01&end_date=2016-03-31
Tchefuncte at Covington	USGS 07375050	http://waterdata.usgs.gov/usa/nwis/uv?site_no=07375050
Bogue Falaya at Boston St at Covington	USGS 07375175	http://waterdata.usgs.gov/usa/nwis/uv?site_no=07375175
Pearl River at Real River, LA	USGS 02492600	http://waterdata.usgs.gov/usa/nwis/uv?site_no=02492600
Bogue Falaya River near Camp Covington	USGS 07375105	http://waterdata.usgs.gov/usa/nwis/uv?site_no=07375105
Abita River at Abita Springs	USGS 7375222	https://waterdata.usgs.gov/la/nwis/uv/?site_no=07375222&PARAmeter_cd=00065,72020,63160,00060

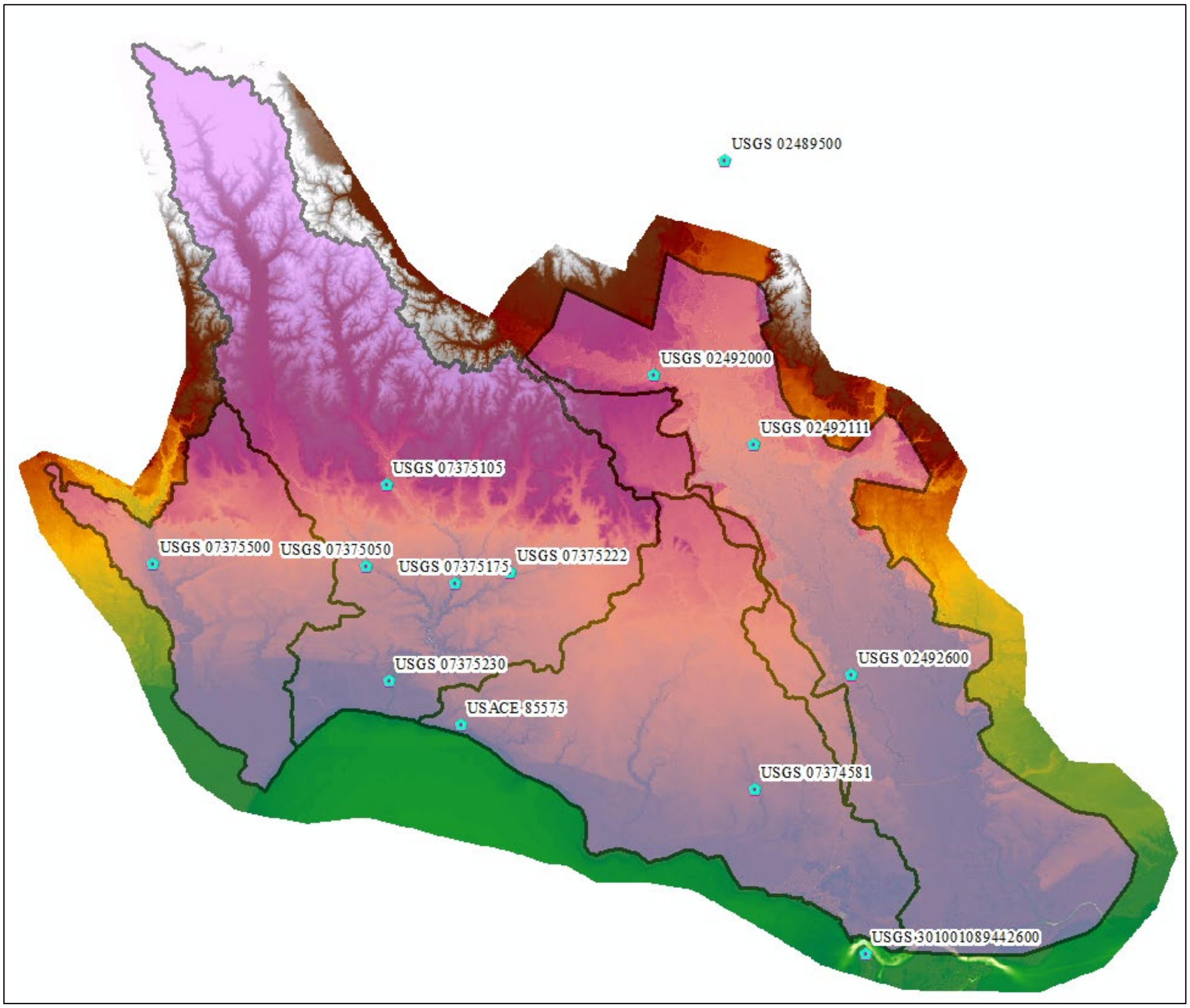


Figure E:4-8. Calibration Gage Locations for March 2016 and December 2009 Events

In HEC-HMS, precipitation was generated utilizing Next Generation Weather Radar (NEXRAD) hourly precipitation estimates and the simulation was run for 30 days to ensure precipitation data for each event was accessible. Centroids were determined for each 2D area and precipitation was pulled from the NEXRAD grid based on those coordinate locations. Precipitation pulled from each centroid was applied uniformly over each of the five corresponding 2D areas.

To ensure the model produces credible results, a few adjustments were required to adequately align the model and gages with the actualized December 2009 and March 2016 events. A warm-up period on the Pearl River 2D area of 24 hours was applied to both the 2016 and 2009 events to ensure flow was established at the beginning of the simulation. The inflow boundary condition for the Bogue Chitto is linked to the Bogue Chitto gage near Bush, Louisiana (USGS 02492000). The inflow boundary condition for the Pearl River inflow is linked to Pearl River gage near Bogalusa, Louisiana (USGS 02489500). Downstream boundary conditions for B3, B4, and B5-West were linked to the Mandeville gage (USACE 85575). Downstream boundary conditions for B5-East and B6 were linked to the Rigolets gage (USGS 301001089442600). For both the March 2016 and December 2009 calibration events, the HEC-RAS simulation was run for 5 days to ensure a peak was reached for the entire model domain. A 15 second computation interval was used for both events. Additional enforcement of a few hydraulic barriers was applied in the Slidell region with breaklines.

Revisions were also made to the roughness coefficients that represent the channel and floodplain areas. Manning’s n override regions were applied to 13 waterways to supersede the default landcover-based Manning’s n value, which achieved a more accurate calibration to observed gage records. Tabulation of the Manning’s n override regions may be seen in Table E:4-6. Additionally, the Journal of Spatial Hydrology Article: Land use-based surface roughness on hydrologic model output cited a roughness coefficient of 0.086 and 0.001 for Woody Wetlands and Open Water respectively. Following analysis of the first few calibration runs, it was determined that Woody Wetlands landcover type should be decreased to a Manning’s n value of 0.075 and Open Water should be changed to 0.03 throughout the entire model domain to more accurately represent the roughness coefficient of those landcover categories.

Table E:4-6. Manning's n Override Region Values for Waterways related to the Proposed Final Array FRM measures

Manning's n Override Region Values	
Waterway Name	**n**
Abita River	0.03
Tchefuncte River	0.07
Bayou Liberty	0.04
Mile Branch	0.04
Mile Branch Lateral A	0.04
Bayou Lacombe	0.04
Cypress Bayou	0.04
Bayou Bonfouca	0.04
Bayou Patassat	0.04
Doubloon Bayou	0.04
Gum Bayou	0.04
Poor Boy Canal	0.04
W-15 French Branch	0.04

Section 5
ADCIRC Modeling

The 2017 Coastal Protection and Restoration Authority (CPRA) dataset – existing conditions – was used to develop storm surge and wave parameters at specific frequencies. Using a MATLAB script, storm surge, significant wave height and wave period were extracted from the 2017 CPRA Master Plan ADCIRC dataset. This data set is based on the modeling results of 152 JPM-OS synthetic storms. The storms cover a range of hypothetical tracks, forward speeds, intensities and sizes. Figure E:5-1 displays the tracks for all 152 synthetic storms compared against a series of historically significant storms. The JPM-OS synthetic storms are basically an extension of the limited observed record. Figure E:5-2. compares the wind-speeds of the synthetic storms compared against the historically significant storms. The synthetic storms are parametrically similar to actual storms in the record. All 152 storms must be simulated to estimate storm surge statistics.

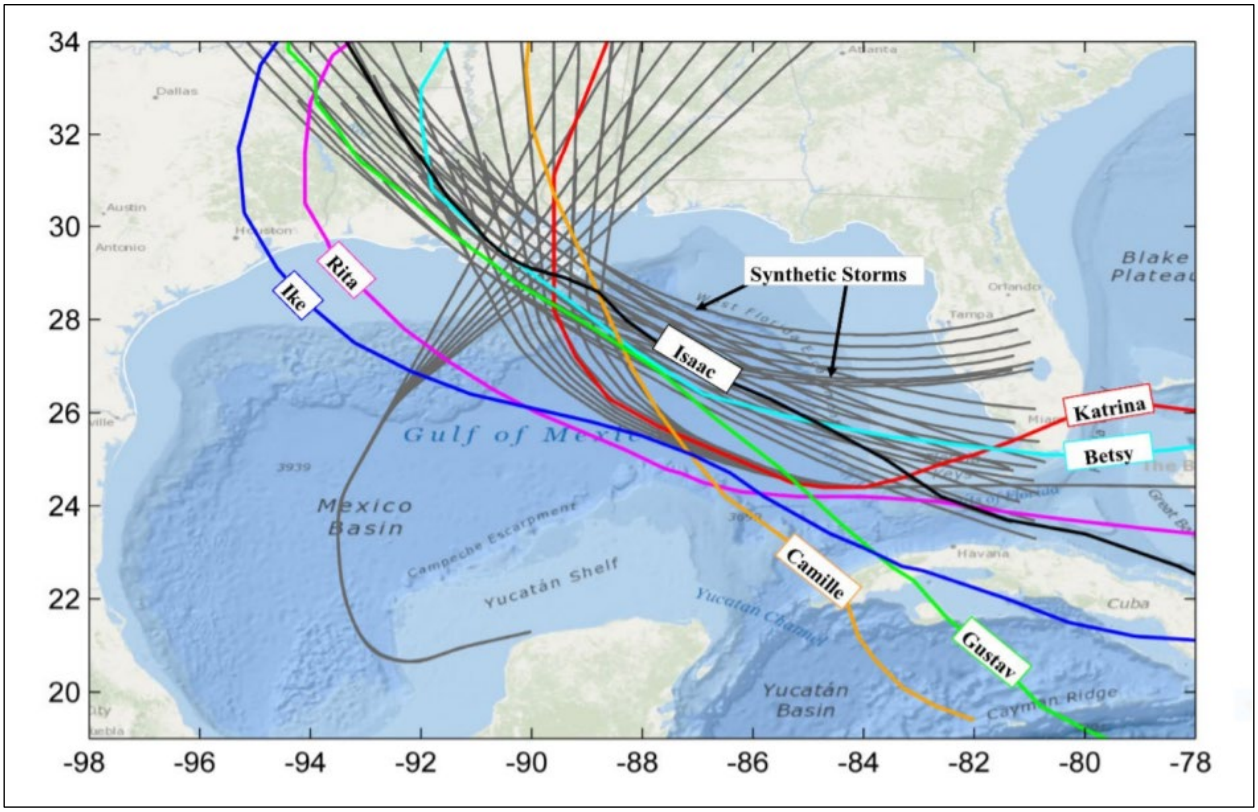


Figure E:5-1. Tracks for all 152 Synthetic Storms Compared against Historically Significant Events

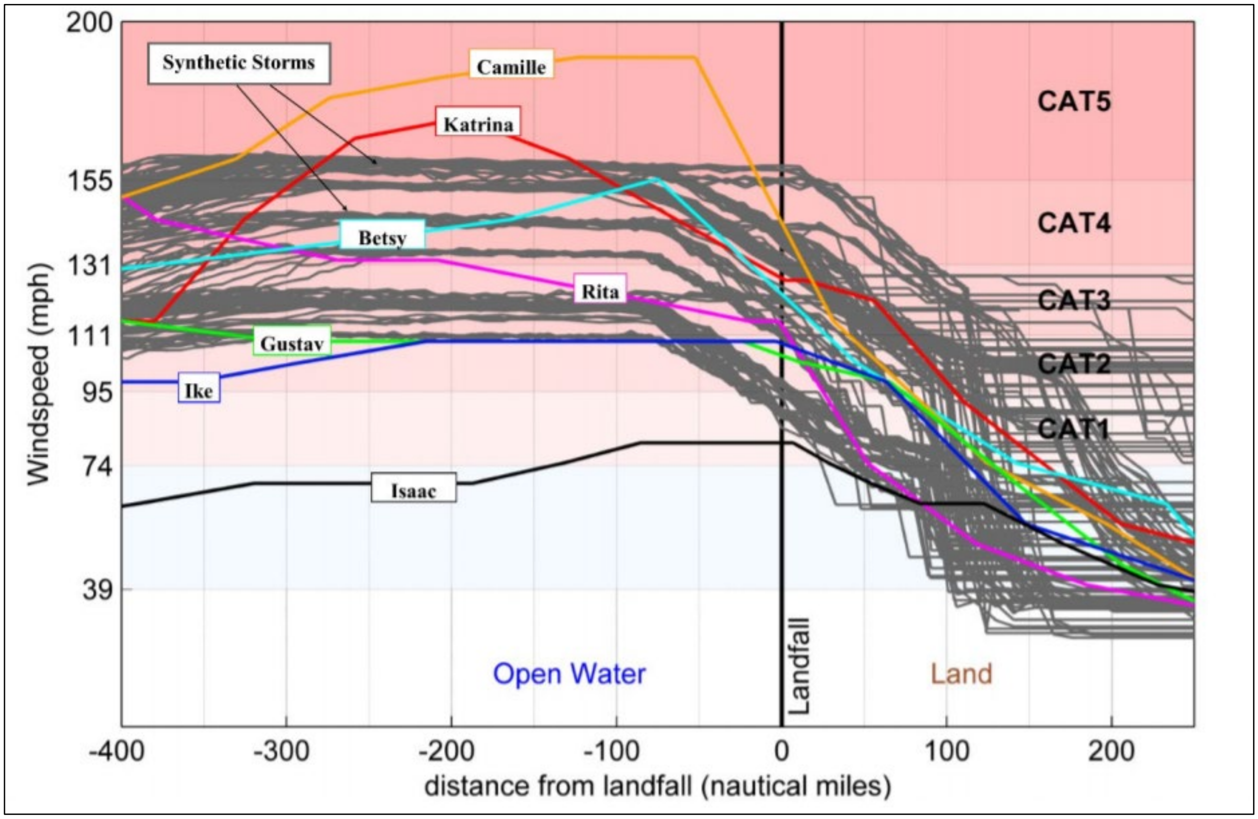


Figure E:5-2. Wind-speeds for all 152 Synthetic Storms Compared against Historically Significant Events

In the coastal and deltaic environment of south Louisiana, future conditions must account for sinking land and rising sea levels – two well-documented processes affecting the area. The 2015 Update to the Tide Gage Atlas of South Louisiana determined long-term trends of relative sea level change at numerous gages in the state, including those at Mandeville and the Rigolets.

CPRA had performed ADCIRC runs for the full suite of 152 storms for the future conditions.

The best estimate of the PDT for the date of project construction completion was 2032 ("base year"). Adding the 50-year window needed for economic analysis results in 2082 ("future year"). At 50+ years out, sea level rise and regional subsidence are significant. Surge, wave height, and wave period values for 2082 were interpolated or extrapolated for the specified return periods and three rates of sea level rise specified in USACE guidance (ER 1100-2-8162). The future conditions results based on the intermediate rate of sea level rise were used for the economic analysis, a PDT decision.

For storm surge inundation, MATLAB code was written to do a 3D interpolation on the CPRA results. The MATLAB function scattered Interpolant develops a 3D surface of the variables return period, sea level rise, and surge. By inputting return period and sea level rise, the function returns the surge levels. The code can produce water levels for nodes that are not wet in existing conditions but are wet in future conditions. Because the CPRA Future Without Action simulations used a eustatic sea level rise of 1.5 feet in 50 years, the low and intermediate rate future conditions were interpolated. Values were extrapolated for the high rate future condition. This introduces additional error but is a feasible solution at the planning study phase.

Wave periods and significant wave heights were also extracted from the CPRA data set. Results were obtained for Louisiana coastal inundation for storms with rates of return of 10, 20, 50, 100, 200, and 500 years.

5.1 LEVEE DESIGN ELEVATIONS FOR ALTERNATIVE ANALYSIS

The calculations for the design height of levees and floodwalls followed the EurOtop (2018) manual for computing design heights, which uses a slightly different overtopping formulation for levees versus floodwalls. Because a Monte Carlo analysis was used in creating the statistics for values of each variable, the mean value approach equations described in the EurOtop manual were used in the calculation of structure design height. A script was used to calculate the design height for each location allowing an overtopping criterion of 0.1 cfs per linear foot, which is consistent with the USACE's Hurricane Storm Damage Risk Reduction System (HSDRRS) design criteria. An Excel file contained the inputs at each location for the following parameters: levee/floodwall (uses binary input; floodwall = 0, levee = 1), surface water level (storm surge height) and its standard deviation, significant wave height (Hs) and its standard deviation, wave period and its standard deviation, levee slope (not used for flood wall calculation), berm factor, roughness factor, wave angle factor, and wall factor.

Alternatives in the final array included risk reduction systems in Mandeville, Lacombe, and the greater Slidell area. Each alignment was divided into smaller sections based on the geography, topography, or hydrodynamic characteristics (input variables storm surge height, wave height, etc.). A nearby point, or node, was selected for each section and the input variables for that node were used in the design elevation procedure. Some segments were further subdivided to avoid drastic changes in the design elevation. Further subdividing and refinement are recommended for future phases of design.

A levee slope of 3H:1V was assumed and was used by other disciplines for alternative analysis. The storm surge, wave height, and wave period values used for the coastal risk reduction system design elevation procedure were the 1 percent annual exceedance probability (AEP) values, which are commonly referred to as "100-year return period." The selection of the 1 percent AEP parameters was done for consistency across the different areas/alternatives, and not intended to be a recommendation nor optimized solution.

The assumption across all areas/alternatives for this study was that levee design elevations use existing conditions parameters because they can be built up in the future via levee lifts to achieve higher design elevations required by future relative sea level change. Future conditions (2082) design elevations were determined and used by other disciplines to develop quantity and lift schedule estimates. Hard structures (floodwalls and gates) would be designed to future conditions 2082 parameters because increasing their height is not as feasible. Alternative 9- Mandeville Lakefront, was analyzed with a designated elevation of 7.3 feet, based on input from local stakeholders and acceptability considerations.

Final design elevations could include additional considerations beyond the factors discussed here.

Section 6
Alternative Analysis and Results

FRM measures were modeled in HEC-RAS to determine responses during the final alternative analysis and selection of the Tentatively Selected Plan (TSP). CSRM measures were not specifically modeled in ADCIRC during this phase of the study. Protected area extents, preliminary levee and floodwall elevations, and general estimates of inducements were developed to support the analysis and comparison of alternatives.

6.1 HEC-RAS FRM ALTERNATIVE ANALYSIS

Measures within alternatives were analyzed to determine the response to the specific measure. Measures were modeled together in instances where they were not expected to affect the other. When one measure was expected to influence the hydrology and hydraulics of another measure, they were modeled in distinct model geometries. Table E:6-1. defines how each measure was modeled, either jointly or independently. To gain further efficiencies in model runs, precipitation and inflows were removed over the 2D areas far away from the proposed projects to streamline model run time. These are identified in Table E:6-1. as well. Each model geometry was run for each frequency event 2 yr-500-yr for both current (2032) and future (2082) conditions. This totaled to 80 model simulations and results to be processed for analysis. Hydraulic model results were provided for analysis of flood damages in the form of GIS Rasters showing the maximum water surface elevation during each frequency storm stimulation.

Table E:6-1. Modeling Plan for HEC-RAS FRM Alternative

Alternatives with FRM Measures	Alternative Name	FRM Measure	Modeling Plan	Simulation Efficiencies
Alternative 5	Bayou Liberty/ Bayou Vincent/ Bayou Bonfouca	Bayou Bonfouca Detention Pond	Each measure was modeled together in one geometry. Hydraulic influence of each measure can be identified under one geometry.	No efficiencies were taken for Alternative 5 simulations. The same precipitation and inflows were applied to each area as the optimized existing conditions model.
		Bayou Liberty Channel Improvements (Clearing and Snagging)		
		Bayou Patassat Channel Improvements (Clearing and Snagging)		
Alternative 7	Eastern Slidell	Doubloon Bayou Channel Improvements (Enlargement)	Doubloon Bayou and Poor Boy Canal were modeled jointly in Channel Improvement model domain.	Precipitation removed from 2D Areas CDHyd and 748 for Alternative 7 simulations.
		Poor Boy Canal Channel Improvements (Enlargement)		
		Pearl River Levee	Modeled Independently	Precipitation removed from 2D Areas CDHyd and 748 for Alternative 7 simulations.
		Gum Bayou Diversion (Channel Improvements)	Modeled Independently	Precipitation removed from 2D Areas CDHyd and 748 for Alternative 7 simulations.
Alternative 8	Upper Tchefuncte/Covington	Mile Branch Channel Improvements (Enlargement)	Mile Branch and Lateral A were modeled in Channel Improvement model geometry	Bogue Chitto and Pearl River Inflows were removed from simulations. Precipitation removed for 2D Areas Pearl and 726.
		Lateral A Channel Improvements (Enlargement)		

6.1.1 Alternative 5 – Bayou Liberty/Bayou Vincent/Bayou Bonfouca

As described previously in Table E:6-1., Alternative 5 measures were modeled jointly in a single geometry and simulation runs because it was expected that hydraulically, the Bayou Bonfouca Detention Pond, Bayou Liberty channel improvements (clearing and snagging), and Bayou Patassat channel improvements (clearing and snagging) measures in Alternative 5 would not influence each other. Figure E:6-1. depicts locations of all the Alternative 5 measures. Although shown on the figures, the CSRM measures are not discussed in the HEC-RAS modeling section. The CSRM measures are described further in Section 6.2.

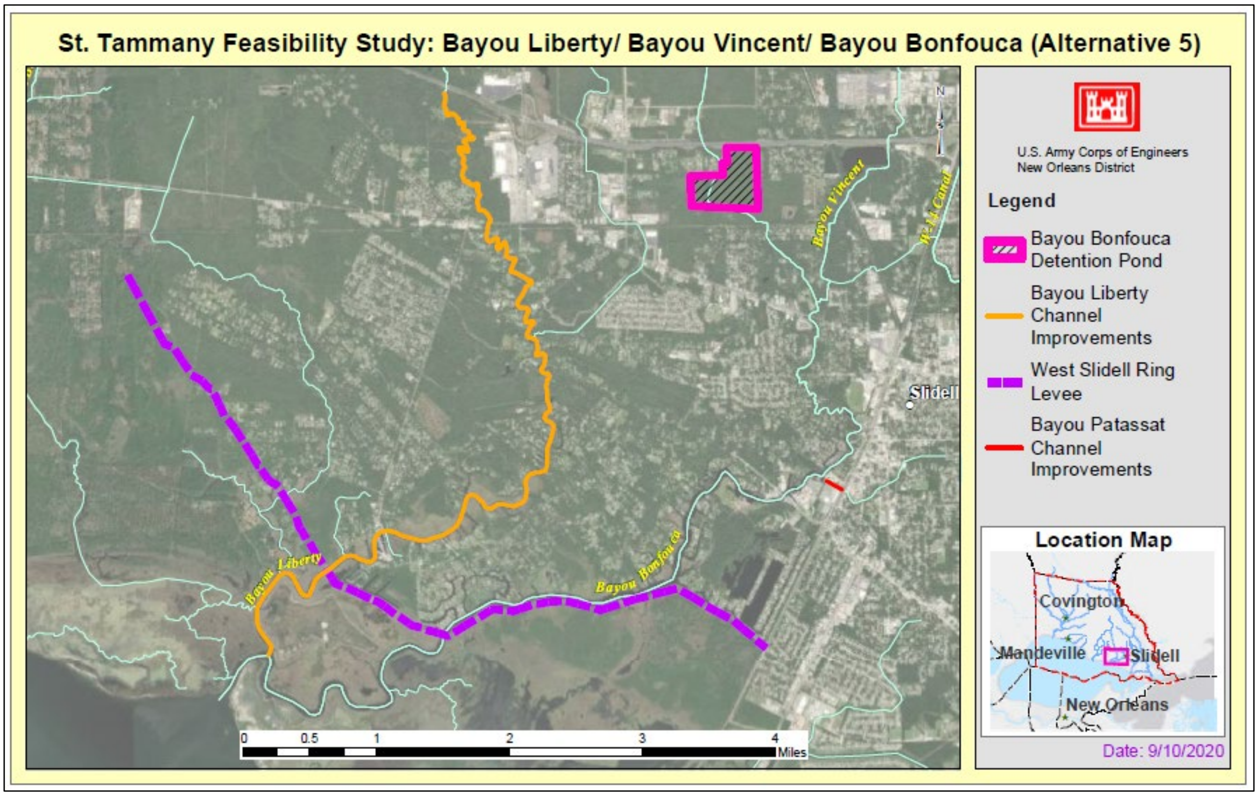


Figure E:6-1. Alternative 5 Final Array Map

The Bayou Bonfouca Detention Pond measure was modeled in HEC-RAS as a terrain modification. The detention pond located south of I-12 has a detention capacity of 1,308 acre-feet. The pond was modeled with 3:1 side slopes, has a footprint of 109 acres, and a depth of 12 feet. Figure E:6-2. depicts the terrain modification for the Alternative 5 simulations.

Figure E:6-2. With and With-out Project Terrain Modification for Bayou Bonfouca Detention Pond (Existing Conditions is on the Left, and With-Project Terrain is on the Right)

The Bayou Liberty Channel Improvements measure was modeled as a modification to the 2D Area by changing the roughness value in the channel. The Manning's n override region feature in HEC-RAS was used. Existing conditions model runs has a 0.04 Manning's n override region over the extents of Bayou Liberty going north of I-12 approximately 1.15 miles. For the with-project simulations, a Manning's n override region of 0.03 was placed over the channel improvement area from I-12 downstream to Lake Pontchartrain to simulate a cleared and snagged channel.

The Bayou Patassat Channel Improvements measure was modeled as a modification to the geometry mesh Manning's n override regions. Existing conditions model runs has a 0.04 Manning's n override region over the extents of Bayou Patassat. For the with-project simulations, a Manning's n override region of 0.03 was placed over the channel improvement area depicted, previously in Figure E:6-2., to simulate a cleared and snagged channel.

Difference maps that subtract the with-project from the without-project water surface elevation (WSE) results Rasters were developed for the 10-year and 200-year 2032 events to illustrate the reductions and inducements for each simulation. Each difference map for all alternatives may be seen in Annex A of this appendix.

6.1.2 Alternative 7 – Eastern Slidell

The measures in Alternative 7 were broken up in runs based on each measure's hydraulic influence to other measures. The Pearl River Levee and Gum Bayou Diversion were both modeled independently. The channel improvements measures for Doubloon Bayou and Poor Boy Canal were modeled jointly because their hydraulic impacts would not overlap. Figure E:6-3. depicts locations of all Alternative 7 measures.

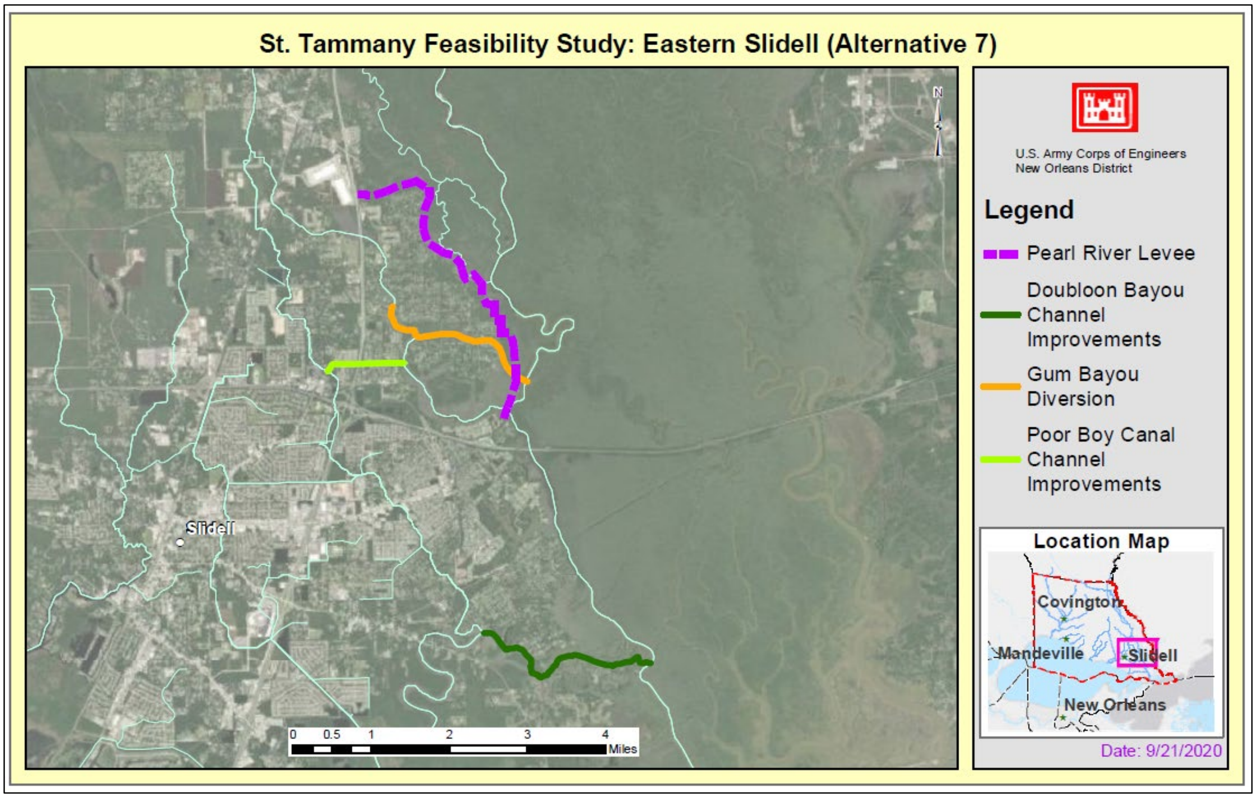


Figure E:6-3. Alternative 7 Map

The Pearl River Levee measure of Alternative 7 was modeled as a 2D area connection. The levee was designed to a 200-year flood level of protection plus 2 feet of uncertainty allowance. This measure initially came from the 1986 Pearl River Basin Reconnaissance Study and the alignment has been adapted due to development. Figure E:6-4 depicts the location in the mesh and 2D connection data editor alignment.

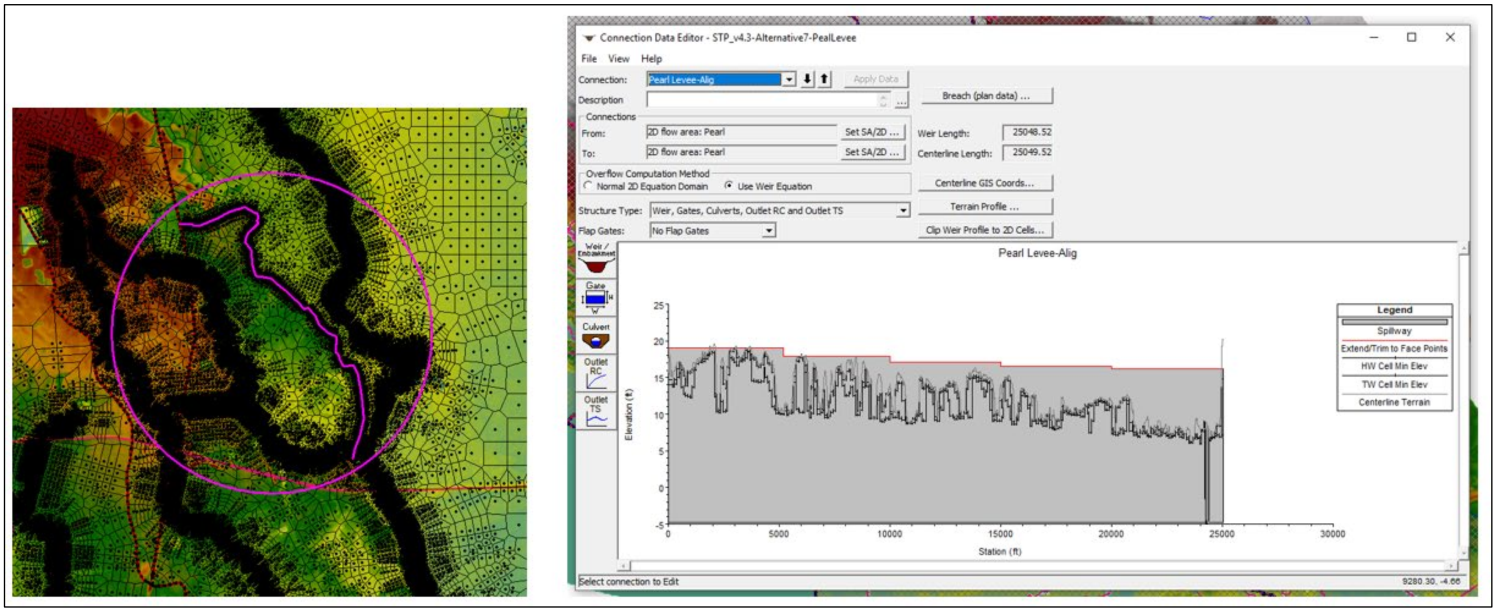


Figure E:6-4. Pearl River Levee 2D Area Connection Location (Left) and Levee Alignment Connection Data Editor

The Gum Bayou Diversion alignment was modeled as a terrain modification. The diversion channel alignment was placed to consider the number of real estate relocations, to follow a remnant past course of a stream that was evident in elevation maps, and to optimize hydraulic efficiency of the diversion. The Gum Bayou Diversion has 3H:1V side slopes and maintains the width beginning at the upstream end where the diversion ties into Gum Bayou. The invert at the upstream end of the diversion matches the invert at the upstream end where the diversion ties into Gum Bayou and the invert drops down 5 feet along the entire length of the alignment until it ties into the West Pearl River. Figure E:6-5. illustrates the Terrain modification for the Gum Bayou Diversion Channel.

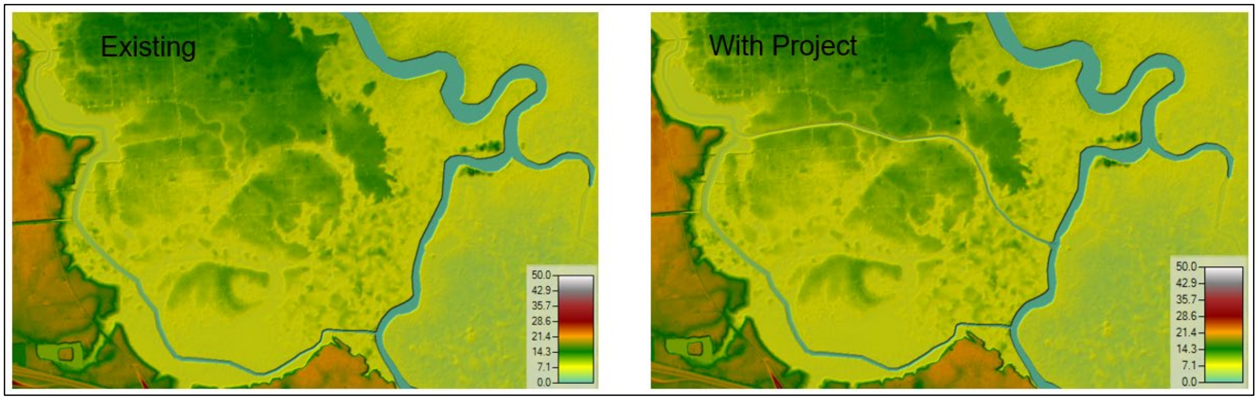


Figure E:6-5. Gum Bayou Diversion Channel Terrain Existing Conditions (Left) and With-Project (Right)

The Doubloon Bayou and Poor Boy Canal channel improvements dredging measures were modeled jointly in one geometry. These were modeled as a modification to the geometry mesh Manning's n override regions and terrain. Existing conditions model runs have 0.04 Manning's n override region over the extents of Doubloon Bayou and Poor Boy Canal. For the with-project simulations, a Manning's n override region of 0.03 was placed over the channel improvement extents for Doubloon Bayou and Poor Boy Canal to simulate a cleared channel. Additionally, both channels were deepened by 5 feet along the channel improvements extents from the existing invert elevation, maintain 3H:1V side slopes along each reach, maintain a 10 feet bottom width along each channel, and maintain the same channel slope as existing conditions. Figure E:6-6 depicts the channel improvements applied to both Doubloon and Poor Boy Canal.

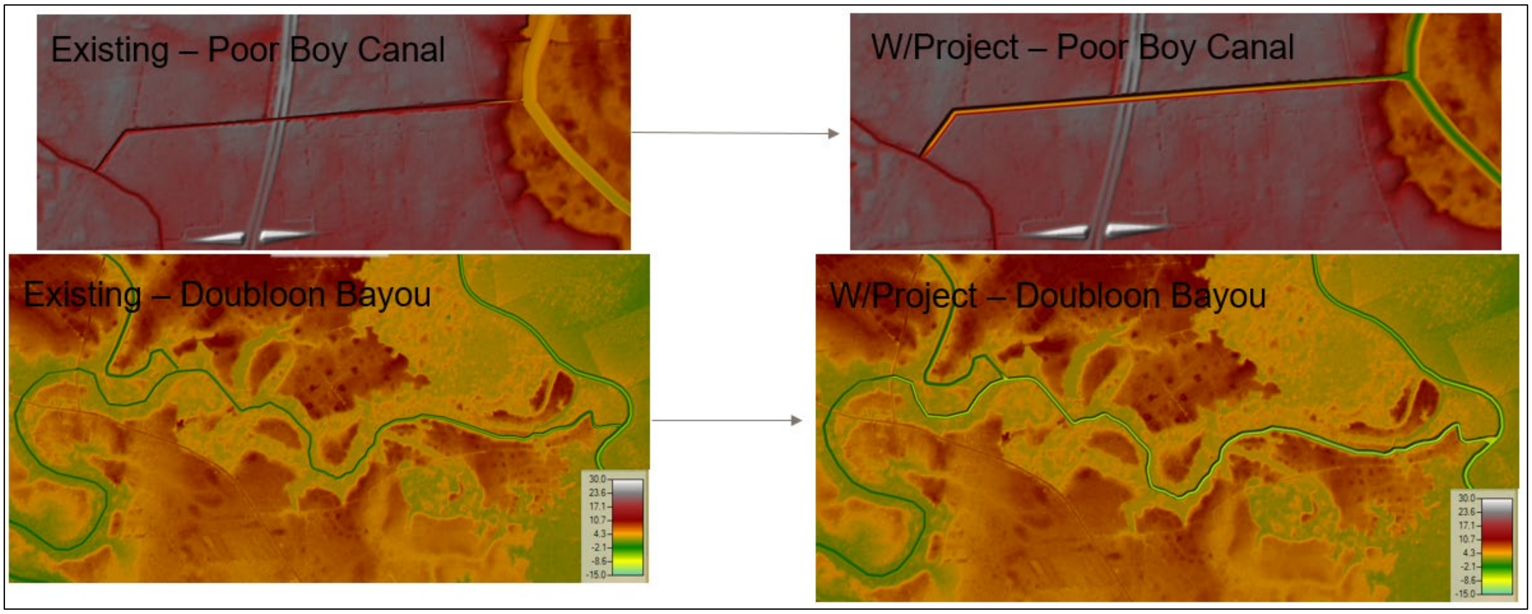


Figure E:6-6. Doubloon Bayou and Poor Boy Canal Existing Conditions (Left) and With-Project Dredging (Right)

Difference maps which subtract the with-project from the without-project WSE results Rasters were developed for the 10-year and 200-year 2032 events to illustrate the reductions and inducements for each simulation. Each difference map for all alternatives may be seen in Annex A.

6.1.3 Alternative 8 – Upper Tchefuncte/Covington

As described previously in Table E:6-1., it was determined that the Alternative 8 measures could be modeled jointly in a single geometry. Mile Branch and Lateral A were both modeled as a modification to the 2D Area mesh Manning's n override regions and terrain. Figure E:6-7. depicts locations of the Alternative 8 measures.

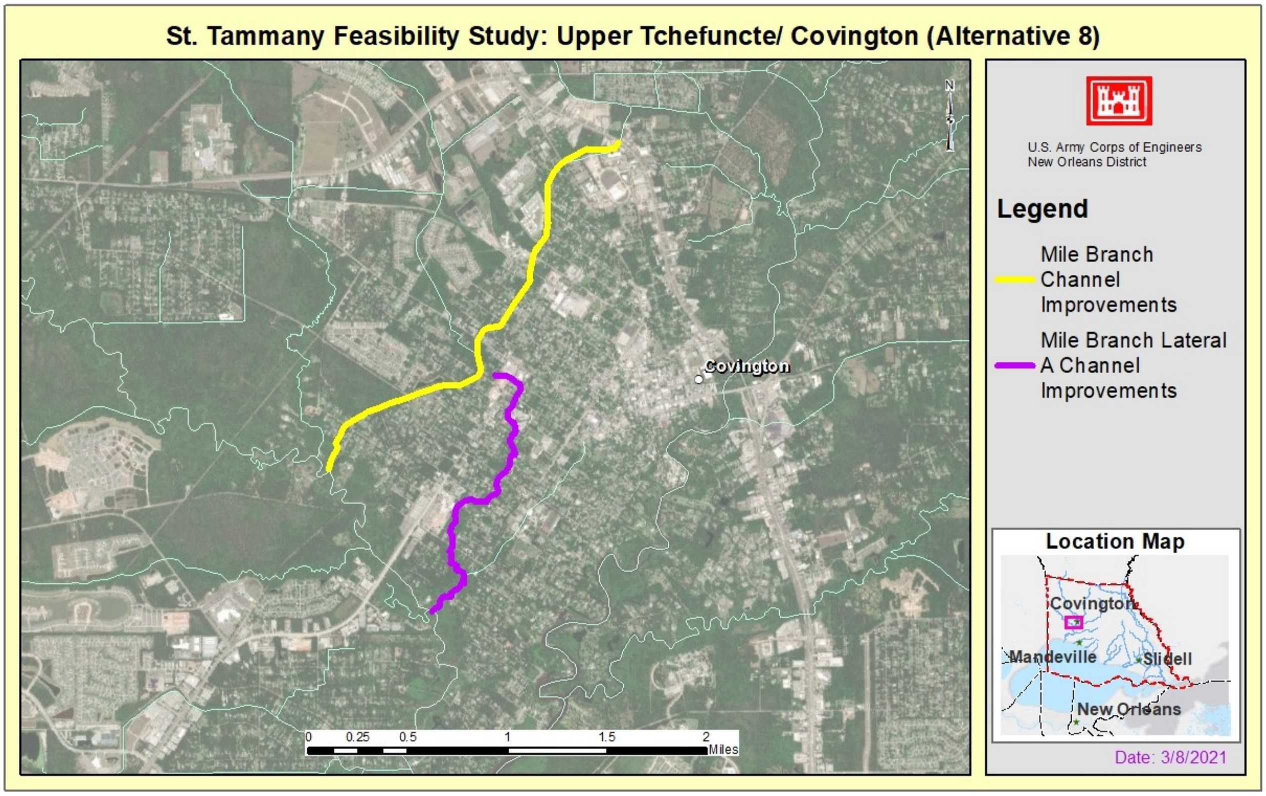


Figure E:6-7. Alternative 8 Upper Tchefuncte/Covington Measures

Existing conditions model runs have 0.04 Manning's n override region over the extents of Mile Branch and Lateral A. For the with-project simulations, a Manning's n override region of 0.03 was placed over the channel improvement extents for Mile Branch and Lateral A to simulate a cleared channel. Figure E:6-8. depicts the channel improvements applied to both Mile Branch and Lateral A. Additionally, both channels were deepened by 5 feet along the channel improvements extents from the existing invert elevation, maintain 3H:1V side slopes along each reach, maintain a 10 feet bottom width along each reach, and maintain the same channel slope as existing conditions.

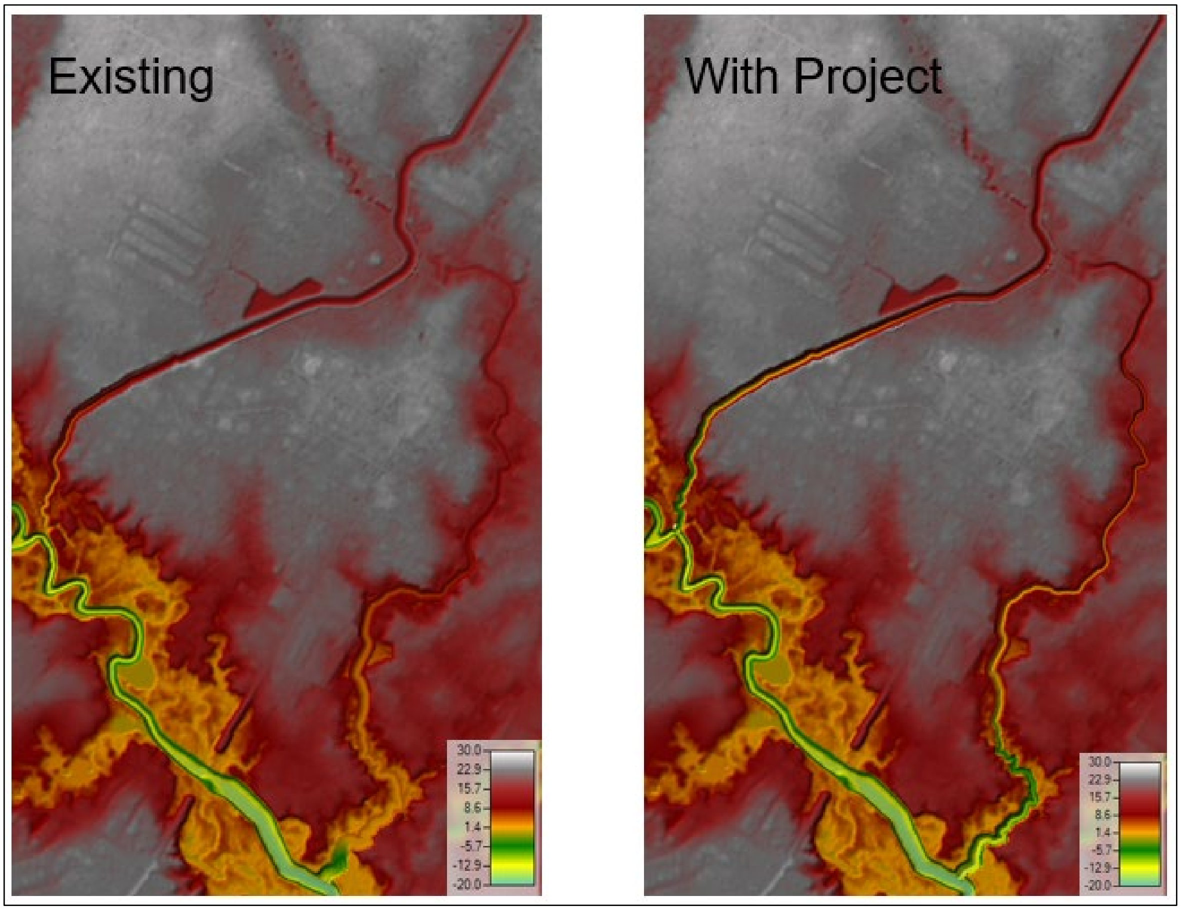


Figure E:6-8. Mile Branch and Lateral A Existing Conditions (Left) and With-Project Dredging (Right)

6.2 ADCIRC CSRM ALTERNATIVE ANALYSIS

Alternative analysis of the CSRM alternatives involved delineating areas protected by proposed alternatives, estimating impacts on the exterior of the proposed alternatives, determining preliminary design elevations for alignments, and estimating capacities of interior drainage facilities where proposed alignments cross large waterways.

The measures proposed in the Final Array of Alternatives were not directly modeled in ADCIRC. Determining storm surge response to proposed systems, and for a wide range of storms, requires numerous simulations of storms with different characteristics. Future modeling of the TSP is required to show detailed responses to the proposed system.

Areas that would be protected by proposed future Federal levees were determined using a Louisiana statewide lidar dataset. Design elevations, described in Section 5.1, were continued to meet existing high ground. Contour lines of that tie-in elevation form the remaining sides of the polygon that represents the area protected by each proposed levee alignment.

6.2.1 Alternative 4 - Lacombe

Figure E:6-9 illustrates the three measures investigated under Alternative 4. Alternative 4a Lacombe Levee protects the Lacombe area from flood risk. Alternative 4a.1 Bayou Lacombe Levee Short follows Alternative 4a, but does not include the western extension. Alternative 4b combines the Alternative 4a Lacombe Levee alignment with the West Slidell Levee (further investigated independently under Alternative 5). Figures E:6-10 and E:6-11 depict the alternative analysis performed for these measures explained previously in Section 6.2.

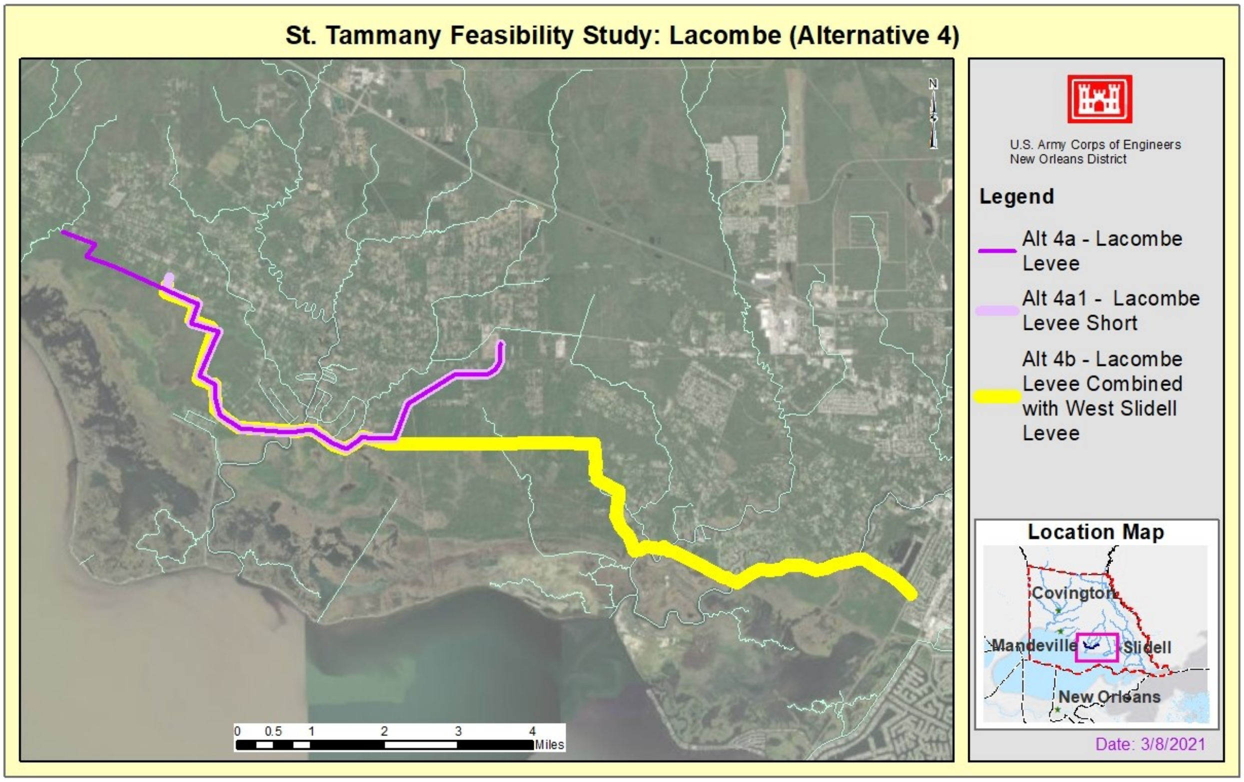


Figure E:6-9. Alternative 4 Measures: West Slidell and Lacombe Proposed CSRM Measures

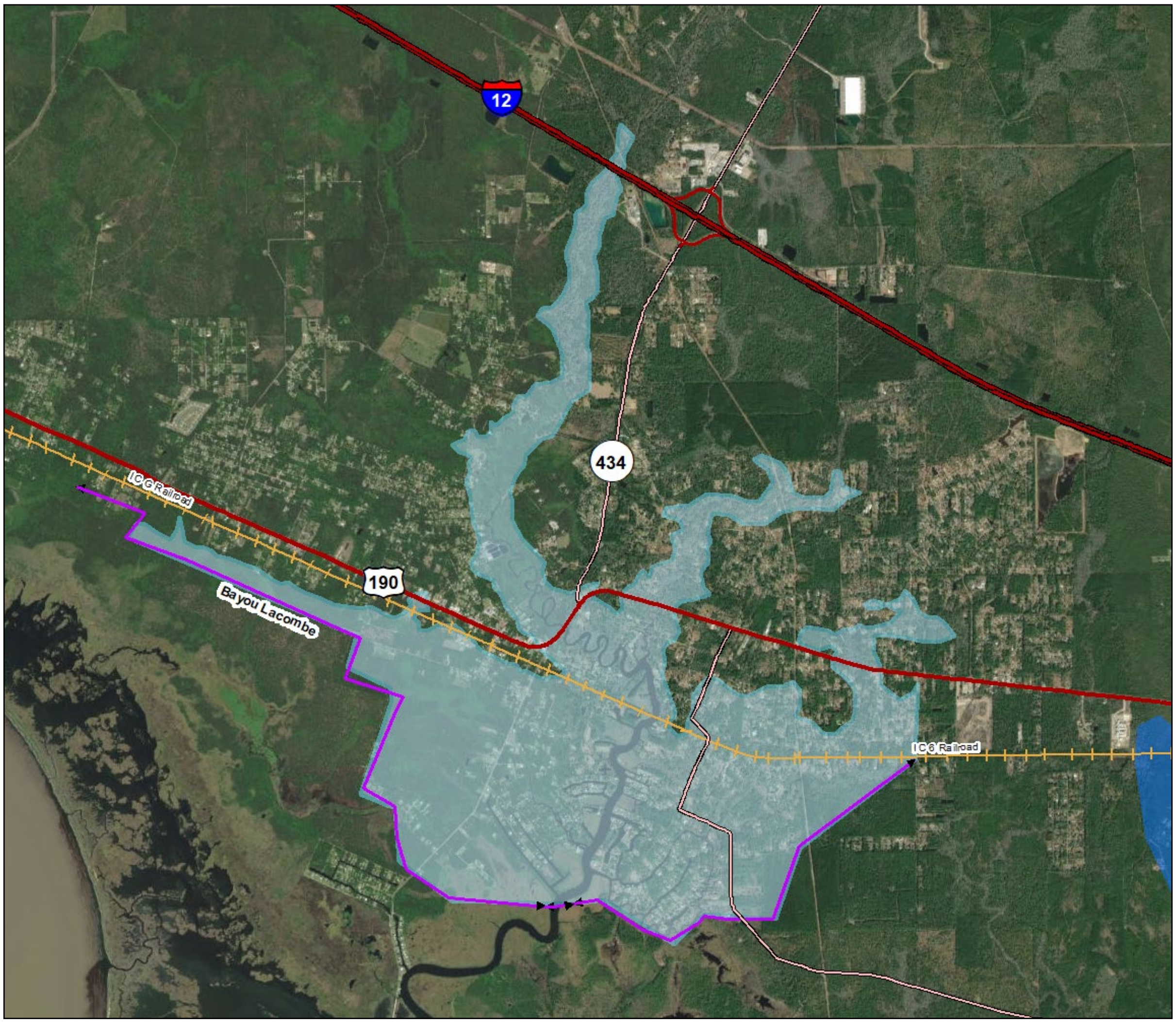


Figure E:6-10. Lacombe Protected Area

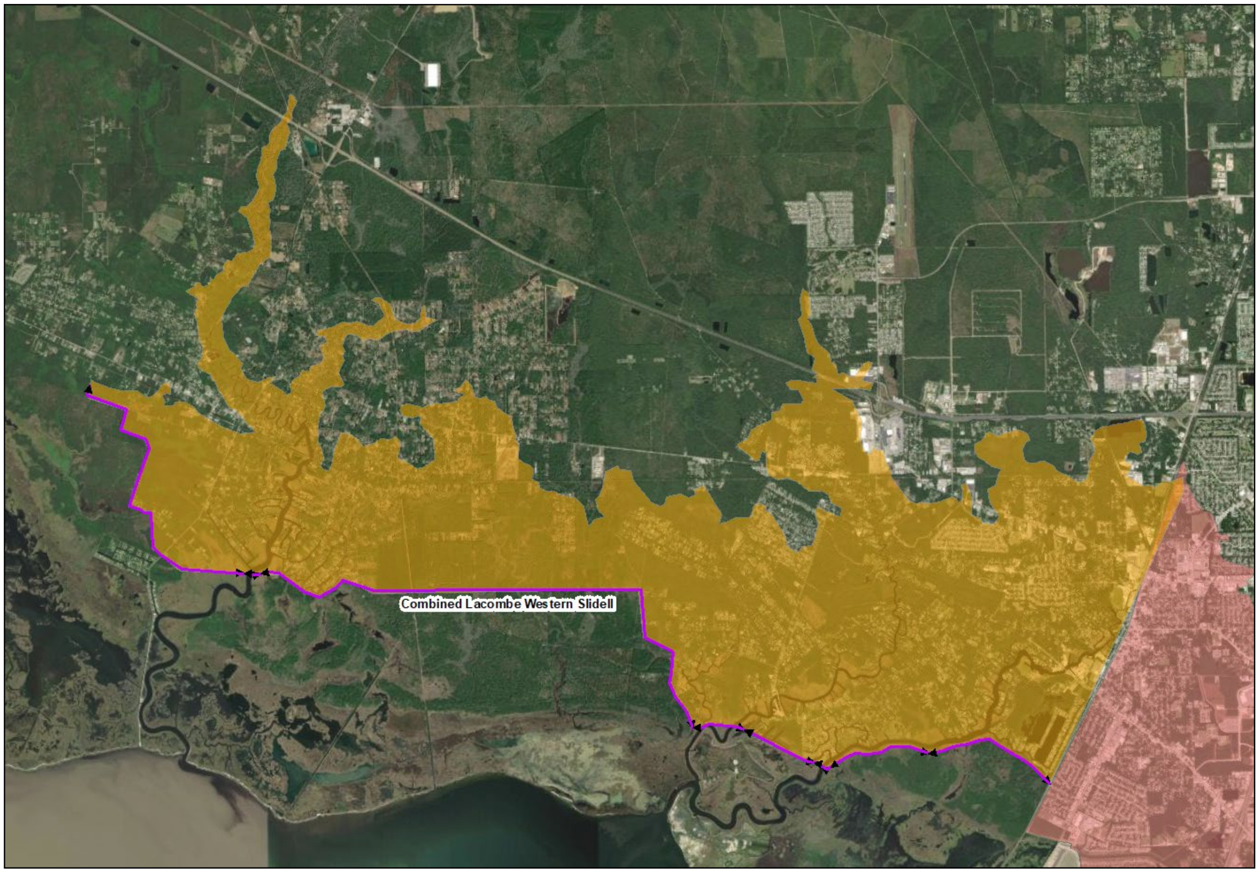


Figure E:6-11. Alternative 4A - Lacombe and West Slidell Protected Area

6.2.2 Alternative 5 – Bayou Liberty/Bayou Vincent/Bayou Bonfouca

Figure E:6-12 illustrates the four measures investigated under Alternative 5. Under Alternative 5, the only CSRM measure investigated was the West Slidell Levee. Figure E:6-13 depicts the alternative analysis performed for this measure explained previously in Section 6.2.

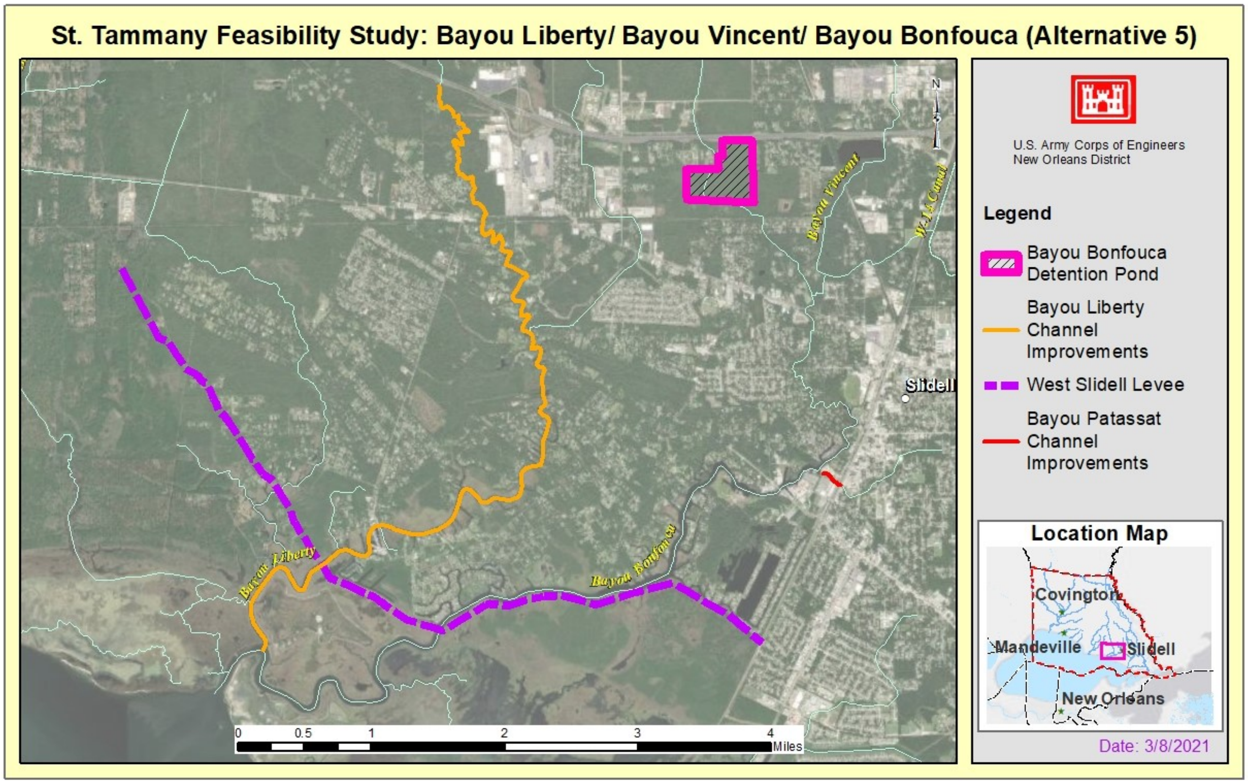


Figure E:6-12. Alternative 5 Measures: Bayou Bonfouca Detention Pond, Bayou Liberty Channel Improvements, West Slidell Levee, and Bayou Patassat Channel Improvements

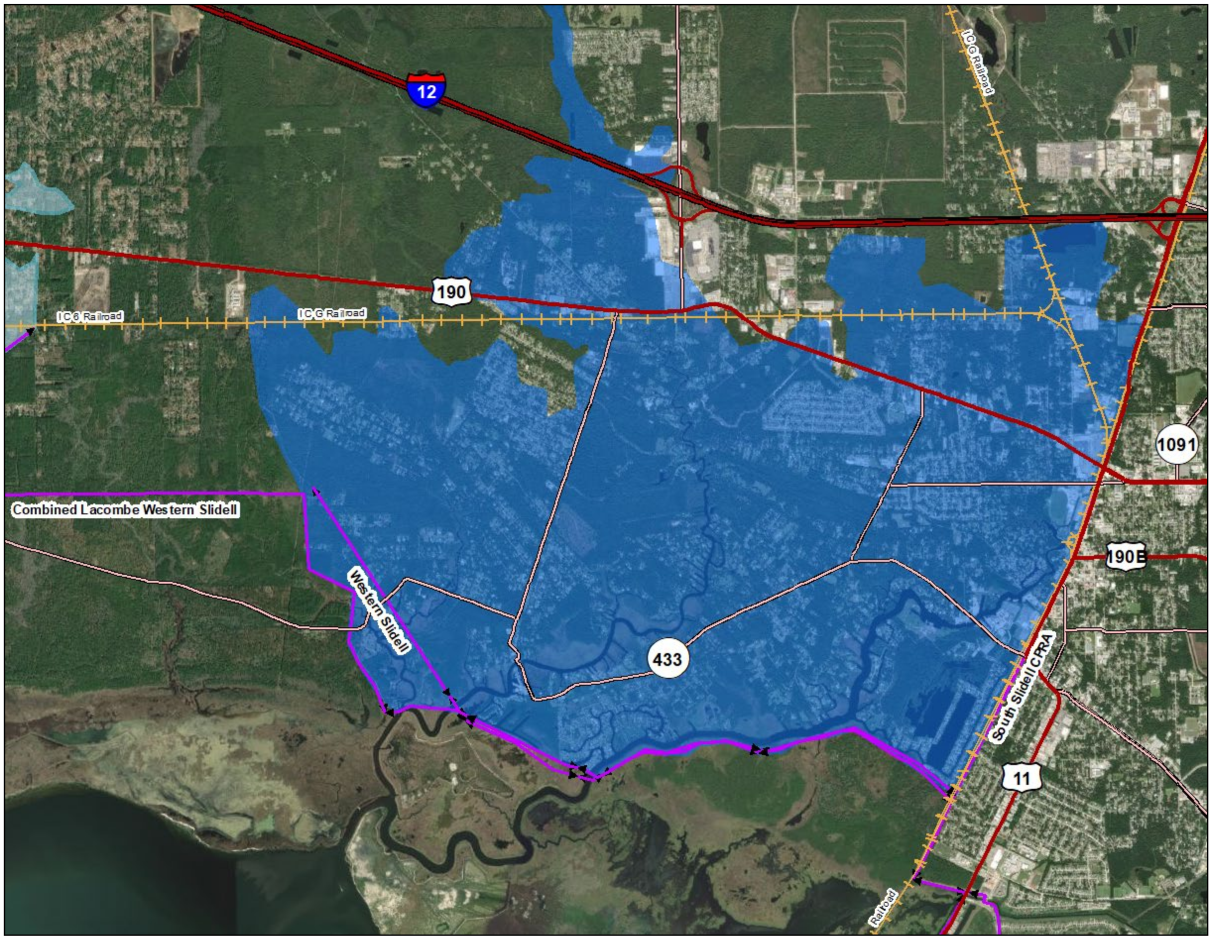


Figure E:6-13. West Slidell Protected Area

6.2.3 Alternative 6 – South Slidell Storm Surge

Figure E:6-14 illustrates the two measures investigated under Alternative 6 along with existing alignments in the South Slidell region. Figures E:6-15 and E:6-16 depict the alternative analysis performed for the following two measures of Alternative 6: Alternative 6a- the South Slidell Federal levee alignment with pump stations and Alternative 6b- the South Slidell Federal levee alignment with pump stations plus Eden Isle. The analysis for these measures is explained in Section 6.2. Please note Alternative 6c is a combination of features evaluated in Alternative 5 and 6.

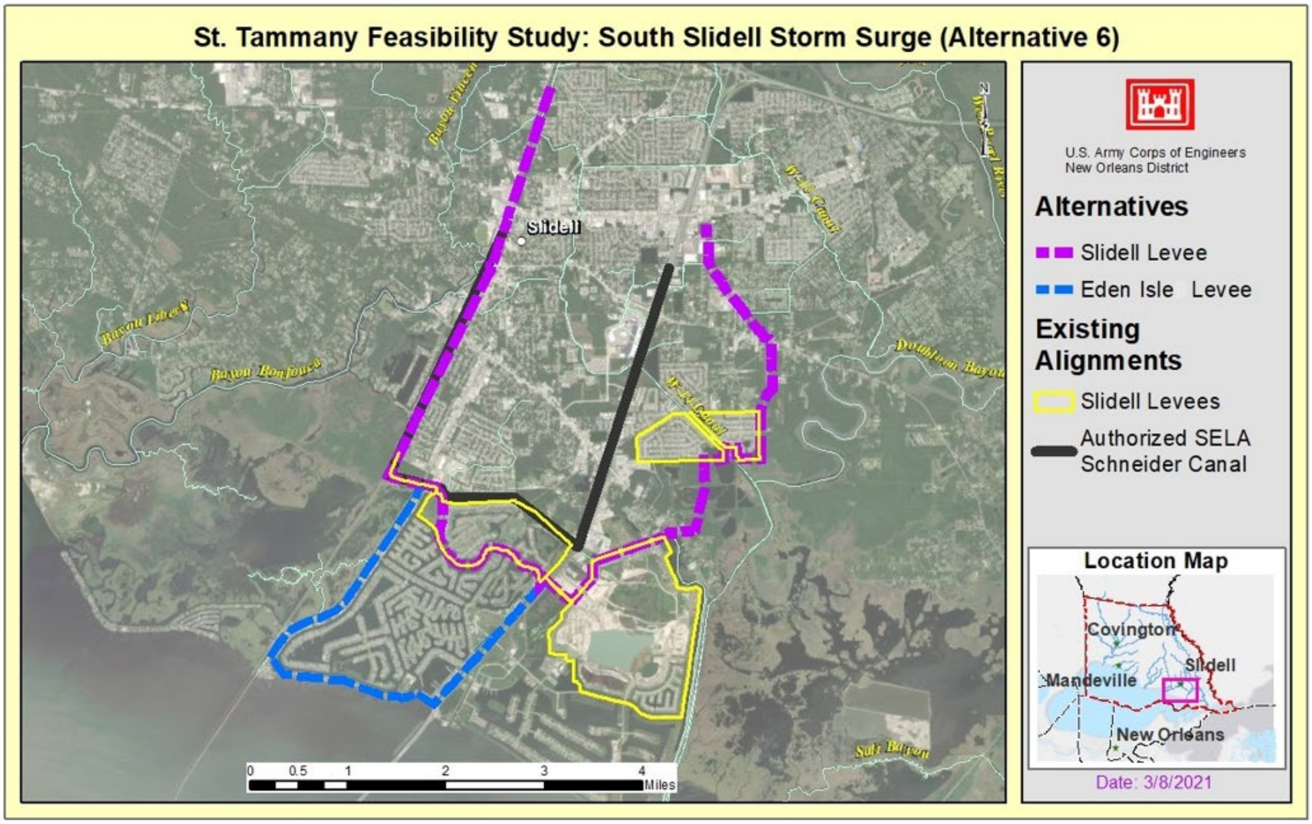


Figure E:6-14. Alternative 6 Measures: Proposed Slidell Levee Alignment and Eden Isle Levee

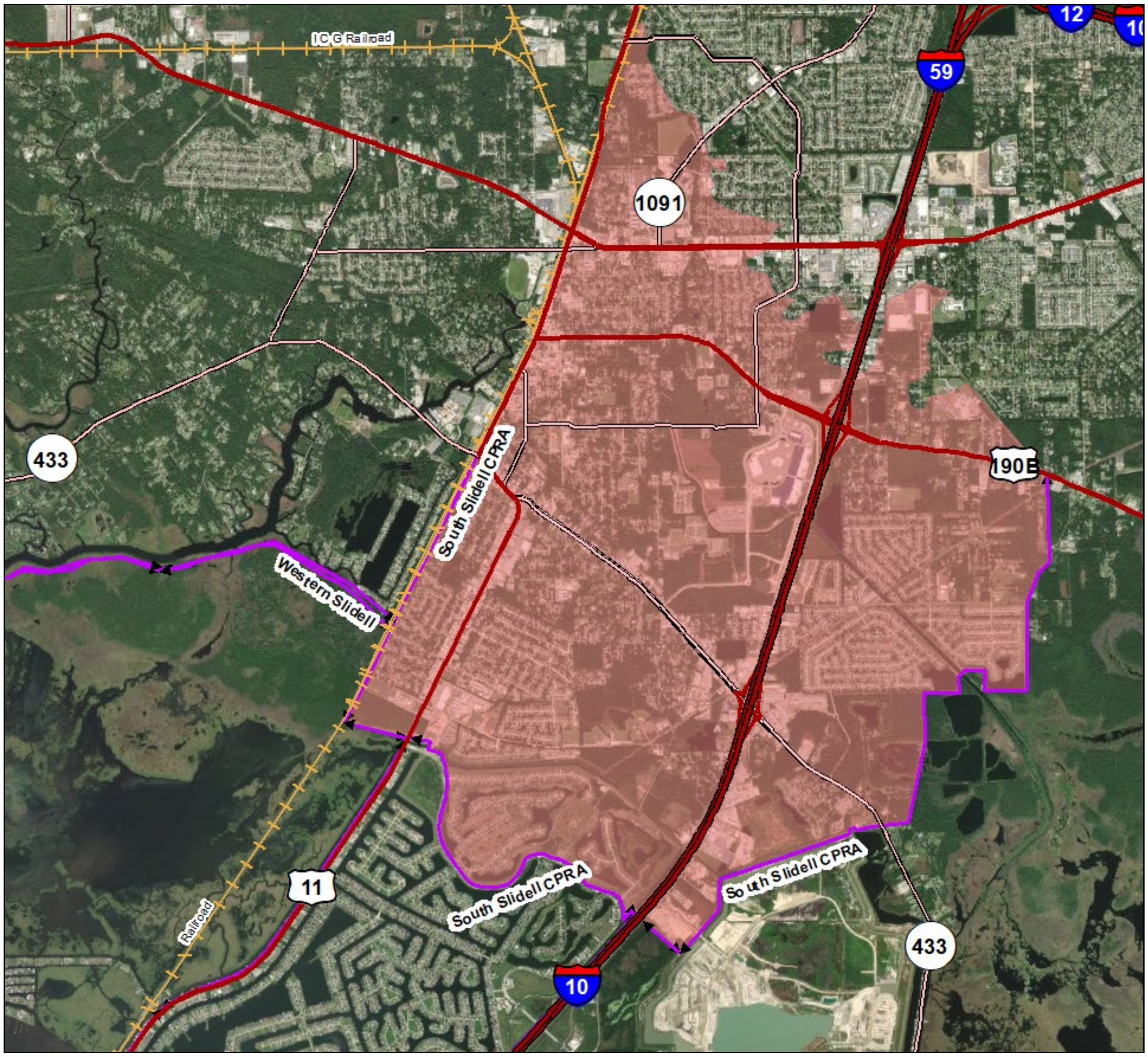


Figure E:6-15. South Slidell (CPRA Alignment) Protected Area

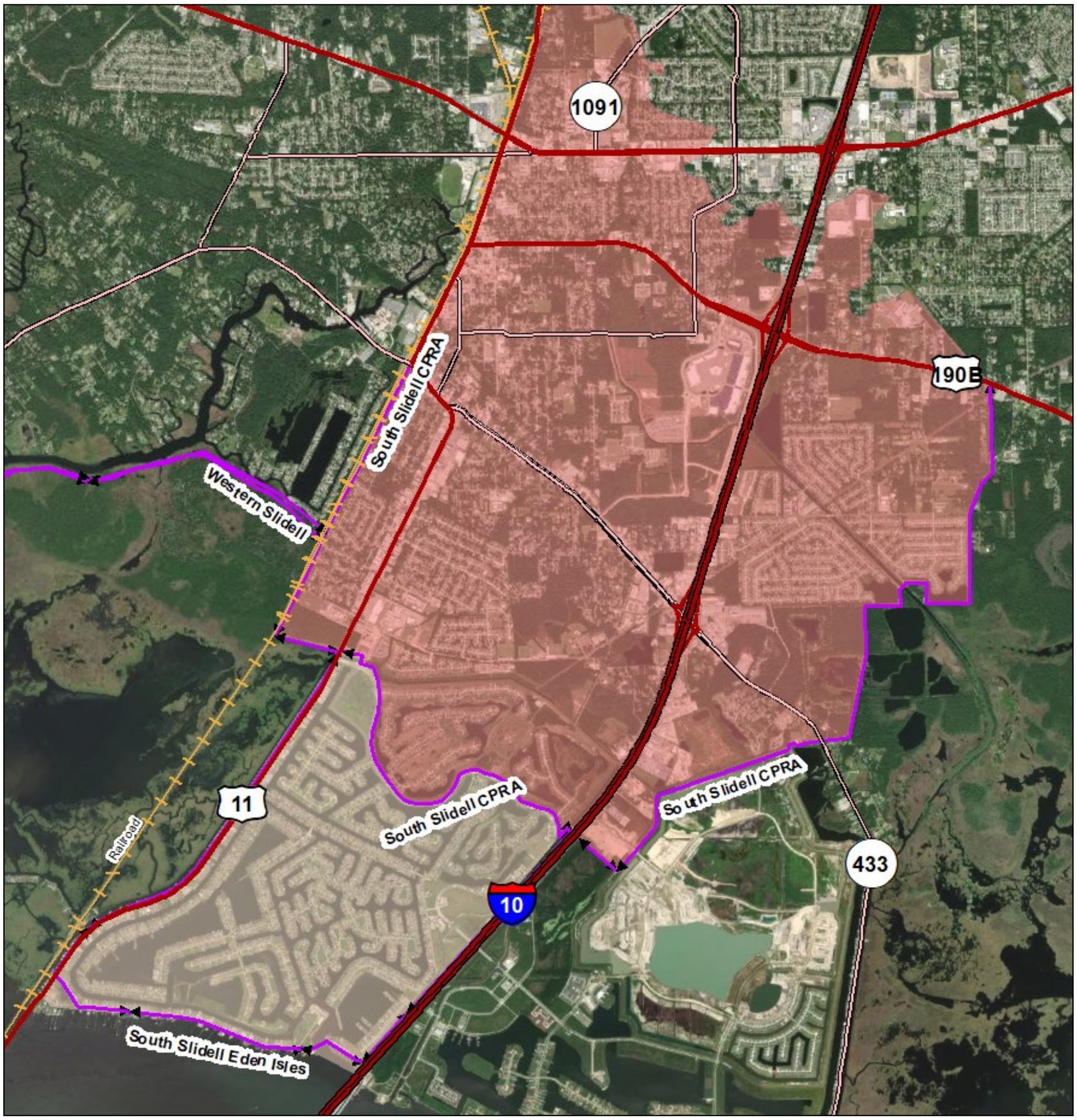


Figure E:6-16. South Slidell + Eden Isle Protected Area

6.2.4 Alternative 9 – Mandeville Lakefront

Figure E:6-17 illustrates measures investigated under Alternative 9 in the Mandeville Lakefront area. Figure E:6-18 depicts the alternative analysis performed for the Mandeville Lakefront region. The analysis for this Alternative is explained in Section 6.2. Variations of this alternative – in the form of 9a, 9b, and 9c – are desbribed in Section 7.1.4.

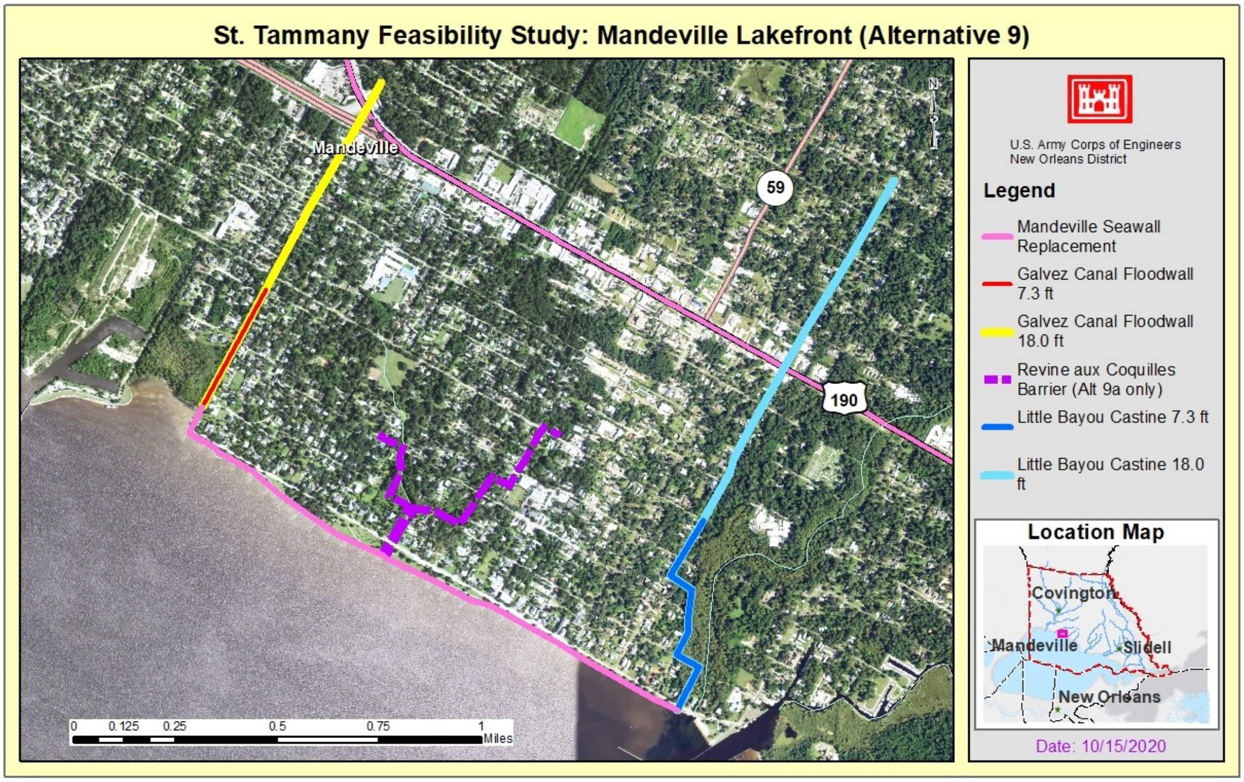


Figure E:6-17. Alternative 9 Measures: Mandeville Seawall Replacement, Galvez Canal Floodwall, Ravine Aux Coquilles Passive Barrier, and Little Bayou Castine Passive Barrier

Figure E:6-18. Mandeville (7.3') Protected Area

6.3 GENERAL ESTIMATES OF FLOODSIDE WATER LEVEL CHANGES FOR ALTERNATIVE ANALYSIS

The strongest caution and caveats should be taken with the quantitative estimates made for the purposes of making comparisons between the different alternatives. The measures proposed in the alternatives were not directly modeled in ADCIRC. Determining storm surge response to proposed measures, and for a wide range of storms, requires numerous simulations of storms with different characteristics. Modeling of the TSP is required to show detailed responses to the proposed measure. Prior coastal modeling for the 2009 LACPR study, the USACE Morganza to the Gulf project, and the ongoing USACE West Shore Lake Pontchartrain project provided some context for the estimates. However, storm surge and wave response are highly dependent on the geometry of the area. Therefore, response in one location cannot be assumed to be the same in another location.

Hurricane risk reduction systems that protect areas not currently protected reduce the “floodplain” volume available for storm surge. This reduction has the potential to increase water levels outside of the new alternatives and measures for some storms.

Based on modeling of other systems, it is possible to see increases of 1-3 feet in the 1 percent AEP water level on the floodside of the new system(s). The 1 percent AEP water level is computed based on a statistical analysis of a variety of storms with different characteristics. A particular storm could show changes near the high end of that estimated range, while another could show small to negligible changes.

The alternatives in the final array would not be expected to cause significant changes to storm surge levels for the USACE Lake Pontchartrain and Vicinity project nor to the USACE West Shore Lake Pontchartrain project.

Section 7
Interior Drainage Estimates

Interior drainage estimates were performed for alternative analysis to provide estimated capacities for hydraulic infrastructure for other disciplines' analysis. It should be noted that no in-depth interior drainage modeling has been completed for this phase of the study. All estimations provided herein must be re-evaluated for any measures that make it as the TSP.

7.1 CSRM DRAINAGE NOTES

7.1.1 Alternative 4 –Lacombe (4a. 4a.1 and 4b)

7.1.1.1 Drainage Features Associated with -**Lacombe Levee**

Bayou Lacombe Floodgate and Pump Complex: A new flood gate and pump control complex would be required at the intersection of Bayou Lacombe and the proposed alignment. 10-year 2032 flow for capacity calculation used is 3,200 cfs.

Bayou Paquet Floodgate and Pump Complex: A new floodgate and pump complex would be required where the proposed Combined Levee alignment intersects with Bayou Paquet. The 10-year 2032 flow for capacity calculation used is 500 cfs.

Bayou Paquet/Liberty Floodgate and Pump Complex: A new floodgate and pump control complex would be required at the confluence of Bayou Paquet and Bayou Liberty because the Combined Levee alignment crosses this confluence. The 10-year flow for capacity calculation used is 500 cfs.

7.1.2 Alternative 5 – Bayou Liberty/Bayou Vincent/Bayou Bonfouca

7.1.2.1 Drainage Features Associated with -**West Slidell Levee**

Bayou Liberty Floodgate and Pump Complex: A new floodgate and pump complex would be required at the intersection of the proposed West Slidell Levee alignment and Bayou Liberty. The 10-year flow for capacity calculation used is 3,200 cfs.

Bayou Bonfouca Floodgate and Pump Complex: A new floodgate and pump complex would be required for this measure at the intersection of the proposed West Slidell Levee alignment and Bayou Bonfouca. The 10-year flow for capacity calculation used is 3,700 cfs.

7.1.3 Alternative 6 – South Slidell (6a & 6b)

7.1.3.1 Drainage Features Associated with Slidell Levee

W-14 Floodgate/Pump Station: A new floodgate and pump complex would be required at the intersection of the Slidell Levee alignment and the W-14 canal. The 10-year flow used for capacity of pump station design is 1,200 cfs.

Schneider Canal Pump Complex: There is a pumping station at the intersection of Schneider Canal and the proposed levee alignment, which was constructed by the City of Slidell. The 1990 USACE Schneider Canal, Slidell, LA Hurricane Protection Reconnaissance Report previous report identified a capacity of 100 cfs. It is important to note that the Schneider Canal pump station was constructed by the City of Slidell at a capacity of 850 cfs. It is unlikely that additional capacity is needed there. The existing pump station does not have fronting protection, but that need has been identified in the ongoing USACE Southeastern Louisiana, Louisiana Project (SELA) Schneider Canal hurricane protection study.

7.1.4 Alternative 9 (9a, 9b, 9c) – Mandeville Lakefront

7.1.4.1 Alternative 9a Mandeville Lakefront-Seawall (Passive Drainage)

This alternative has the 7.3 feet wall at the lakefront, is open at Ravine Aux Coquille, and has walls along the banks of Ravine aux Coquille. In total, four pump stations are proposed for this alternative.

From information provided by Principal Engineering and later confirmed, the Rational Method Peak Flows are:

1. West Beach Parkway – 116 cfs
2. Lafayette Street – 33 cfs
3. Coffee Street – 106 cfs
4. Girod Street – 139 cfs

7.1.4.2 Alternative 9b - Mandeville Lakefront-Seawall (Pump Stations)

This alternative includes the 7.3 feet wall at the lakefront and closure with a pump station at Ravine aux Coquille. In total, two pump stations are proposed for this alternative. The Ravine aux Coquille pump station will accommodate a larger drainage area that includes the peak flows in-taken from the smaller pump stations stated in Alternative 9a previously. The smaller pump stations for individual basins are only needed when the natural drainage to ravine aux coquille is cut off by the passive alignment walls. The pump stations that would not be required include West Beach Parkway, Lafayette Street, and Coffee Street.

The two pump stations required and the capacity of each are:

1. **Girod St** (location to drain the area intercepted by the eastern side floodwall adjacent to Little Bayou Castine)**– 200 cfs**
2. **Ravine aux Coquille** (would be in conjunction with a 25 ft wide gate near the mouth of the waterway that can be closed when needed) – **500 cfs**

Note: For documentation, the sizing of these pump stations came from the report by GEC for the City of Mandeville and the pumping capacity is based on a 10-year, 24-hour storm. USACE H&H analysis of interior drainage inside proposed alternatives for coastal protection has been limited to high-level estimates and use of previous analyses.

7.1.4.3 Alternative 9c – Mandeville Lakefront – 18 feet

This alternative includes an 18 feet wall at the lakefront, and a closure and pump station at Ravine aux Coquille. In total, two pump stations are proposed for this measure.

The Ravine aux Coquille pump station would accommodate a larger drainage area that includes the peak flows in-taken from the smaller pump stations stated previously in Alternative 9a. The smaller pump stations for individual basins are only needed when the natural drainage to ravine aux coquille is cut off by the passive alignment walls. The pump stations that would not be required include West Beach Parkway, Lafayette Street, and Coffee Street.

The two pump stations required and the capacity of each are:

1. **Girod St (**location to drain the area intercepted by the eastern side floodwall adjacent to Little Bayou Castine and then continues inland)**– 450 cfs**
2. **Ravine aux Coquille** (would be in conjunction with a 25 ft wide gate near the mouth of the waterway that can be closed when needed) – **500 cfs**

Note: For documentation, the sizing of these pump stations came from the report by GEC for the City of Mandeville and the pumping capacity is based on a 10-year, 24-hour storm. USACE H&H analysis of interior drainage inside proposed alternatives for coastal protection has been limited to high-level estimates and use of previous analyses.

7.2 FRM DRAINAGE NOTES

7.2.1 Alternative 5 – Bayou Liberty/Bayou Vincent/Bayou Bonfouca

7.2.1.1 Bayou Liberty Channel Improvements

The Bayou Liberty Channel Improvements (clearing and snagging) measures includes the clearing and snagging of Bayou Liberty from I-12 downstream to the confluence with Bayou Bonfouca. This measure was originally documented in the 2007 Bayou Liberty Watershed Management Plan. This measure was modeled with a reduced Manning's n value of 0.3 along that section of the river. No specific interior drainage information was requested from the PDT.

7.2.1.2 Bayou Patassat Channel Improvements

The Bayou Patassat Channel Improvements measure was modeled as a clearing and snagging alternative. Bayou Patassat has a pump station at its confluence with Bayou Bonfouca, but this detail was not included in the model. The analysis was acceptable because Bayou Patassat drainage pattern in the Existing Conditions model acted as anticipated. No channel deepening was performed for this alternative. This was modeled with a reduced Manning's n value along the main stem of Bayou Patassat of 0.3. No specific interior drainage information was requested from the PDT.

7.2.1.3 Bayou Bonfouca Detention Pond

This measure was derived from the 2014 St. Tammany Watershed Management Study conducted by CPRA and St. Tammany Parish Government. That study recommended a

100-acre detention pond, but cited no recommended capacity or dimensions of the pond. The design team optimized the detention pond to maximize storage. Therefore, the optimized detention pond modeled has a footprint of 109 acres, a depth of 12 feet, and 1V:3H side slopes. This measure provides 1,308 acre-feet of storage capacity.

7.2.2 Alternative 7 – Eastern Slidell

7.2.2.1 Doubloon Bayou and Poor Boy Canal Channel Improvements

The Doubloon Bayou and Poor Boy Canal Channel Improvement measures were modeled as a deepened channel. This measure was modeled by lowering the existing conditions invert by 5 feet along the entire alignment. Poor Boy Canal flows in both directions between the W-15 Canal and Gum Bayou. No specific interior drainage information was requested from the PDT.

7.2.2.2 Pearl River Levee

A new flood gate and pump control complex would be required at the intersection of Gum Bayou and the proposed alignment. The necessary interior drainage modeling to give an accurate capacity estimate has not been completed. Therefore, the uncertainty of the below estimated ROM capacity of the Pearl River Levee may be +/- nearly 100 percent.

The protected side of the proposed Federal levee naturally drains overland to the West Pearl and by Gum Bayou. Rough model results show a 10-year flow around 540 cfs in the channel and up near 560 cfs if the entire channel and low-lying overbank is included. Therefore, 600 cfs is the proposed capacity for this pump station.

7.2.2.3 Gum Bayou Diversion (Channel Improvements)

The Gum Bayou Diversion alignment was placed along an old drainage path of the West Pearl River. The lowland areas surrounding Gum Bayou drain towards the West Pearl River. No specific interior drainage information was requested from the PDT.

7.2.3 Alternative 8 – Upper Tchefuncte/Covington

7.2.3.1 Mile Branch and Lateral A Channel Improvements

These measures came from the 1991 USACE Tangipahoa, Tchefuncte, and Tickfaw Rivers Reconnaissance Study. That study recommended the deepening of both Mile Branch and Lateral A to provide flood protection up to the 25-year frequency storm. These measures were modeled by deepening both rivers' inverts by 5 feet along the entire reach. Both Mile Branch and Lateral A drain into the Tchefuncte River. No specific interior drainage information was requested from the PDT.

References and Resources

EurOtop, 2018. Manual on wave overtopping of sea defences and related structures. An overtopping manual largely based on European research, but for worldwide application. Van derMeer, J.W., Allsop, N.W.H., Bruce, T., De Rouck, J., Kortenhaus, A., Pullen, T., Schüttrumpf, H., Troch, P. and Zanuttigh, B., www.overtopping-manual.com.

Kalyanapu, A. J., Burian, S. J., & McPherson, T. N. (n.d.). Effect of land use-based surface roughness on hydrologic model output. In *Journal of Spatial Hydrology* (2nd ed., Vol. 9).

National Weather Service. “PF Map: Contiguous US.” *Hdsc.nws.noaa.gov*, hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html.

Roberts, H. and Cobell, Z. (2017). 2017 Coastal Master Plan: Attachment C3-25.1: Storm Surge. Version Final. (pp. 1-110). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

USACE (2015). Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – Lower Mississippi River Region 08. Civil Works Technical Report, CWTS-2015-01, USACE, Washington, DC.

USACE (2019). INCORPORATING SEA LEVEL CHANGE IN CIVIL WORKS PROGRAMS, Engineer Regulation No. 1100-2-8162, USACE, Washington, DC.

US Army Corps of Engineers. Hurricane Storm Damage Risk Reduction System Design Guidelines. USACE, June 2012.

US Army Corps of Engineers. “Rivergages.com: Providing River Gage Data for Rivers, Streams and Tributaries.” *Army.mil,* rivergages.mvr.usace.army.mil

US Department of Commerce, NOAA. “Point Precipitation Frequency Estimates.” *PF Map: Contiguous US*, US Department of Commerce, National Oceanic and Atmospheric

US Department of Commerce, NOAA. “NEXRAD Products”. Retrieved July, 2020, from https://www.ncdc.noaa.gov/data-access/radar-data/nexrad-products

U.S. Geological Survey, National Water Information System data available on the World Wide Web (USGS Water Data for the Nation), at URL [http://waterdata.usgs.gov/nwis/rt]

List of Acronyms

ADCIRC – Advanced Circulation model

AEP – Annual Exceedance Probability

AMM – Alternatives Milestone Meeting

CPRA – Coastal Protection and Restoration Authority

CSRM – Coastal Storm Risk Management

FRM – Flood Risk Management

HEC – Hydrologic Engineering Center

HH&C – Hydrology, Hydraulics, and Coastal

HMS – Hydrologic Modeling System

HSDRRS – Hurricane Storm Damage Risk Reduction System

HUC – Hydrologic Unit Code

CEMVN – New Orleans District

NEXRAD – Next Generation Weather Radar

NLCD – National Land Cover Database

NOAA – National Oceanic and Atmospheric Administration

PDT – Project Delivery Team

RAS – River Analysis System

SLaMM – Southeast Louisiana Master Model

TSP – Tentatively Selected Plan

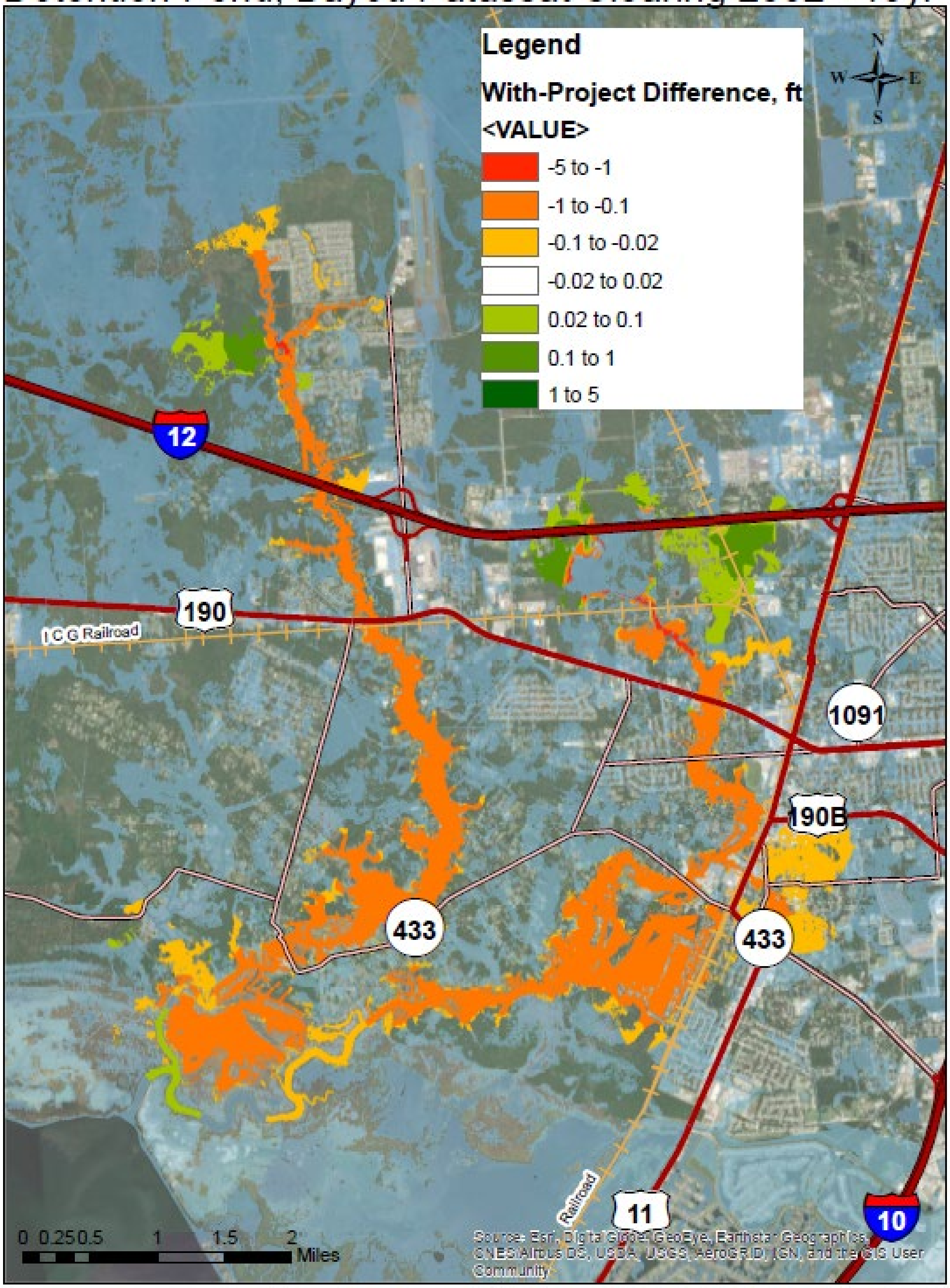
USACE – United States Army Corps of Engineers

USGS – United States Geological Survey

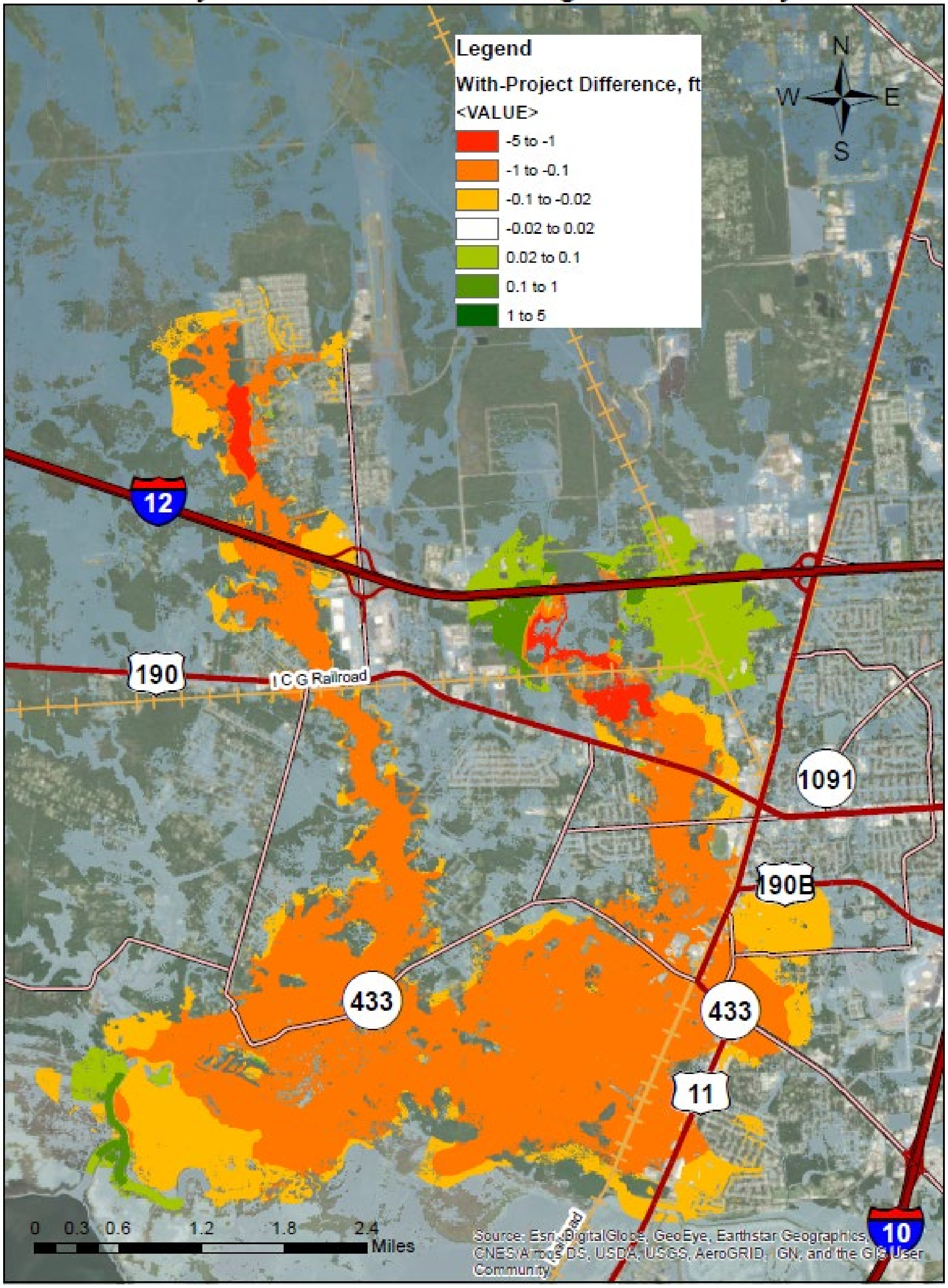
WSE – Water Surface Elevation

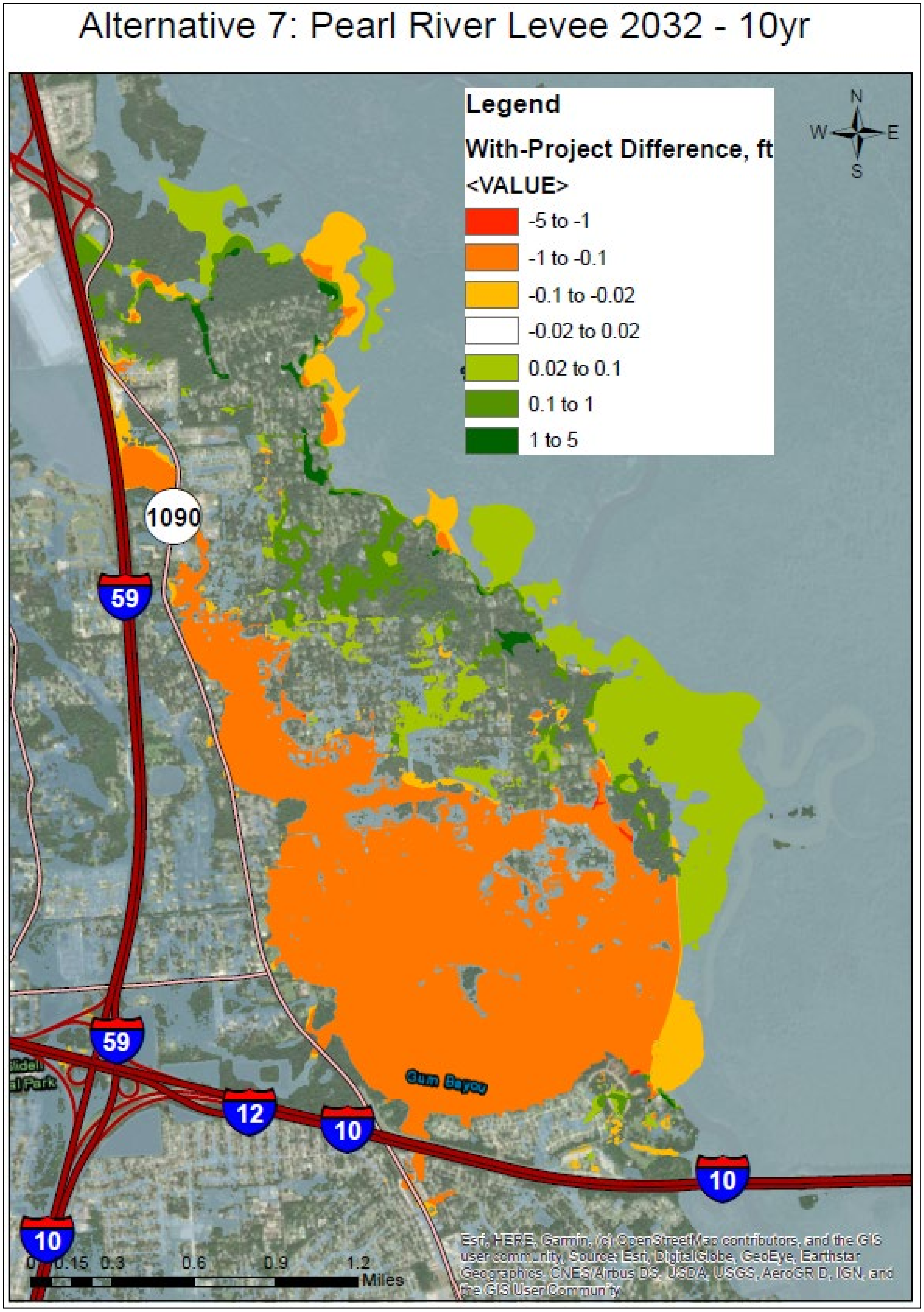
Annex A: With-Project Difference Maps

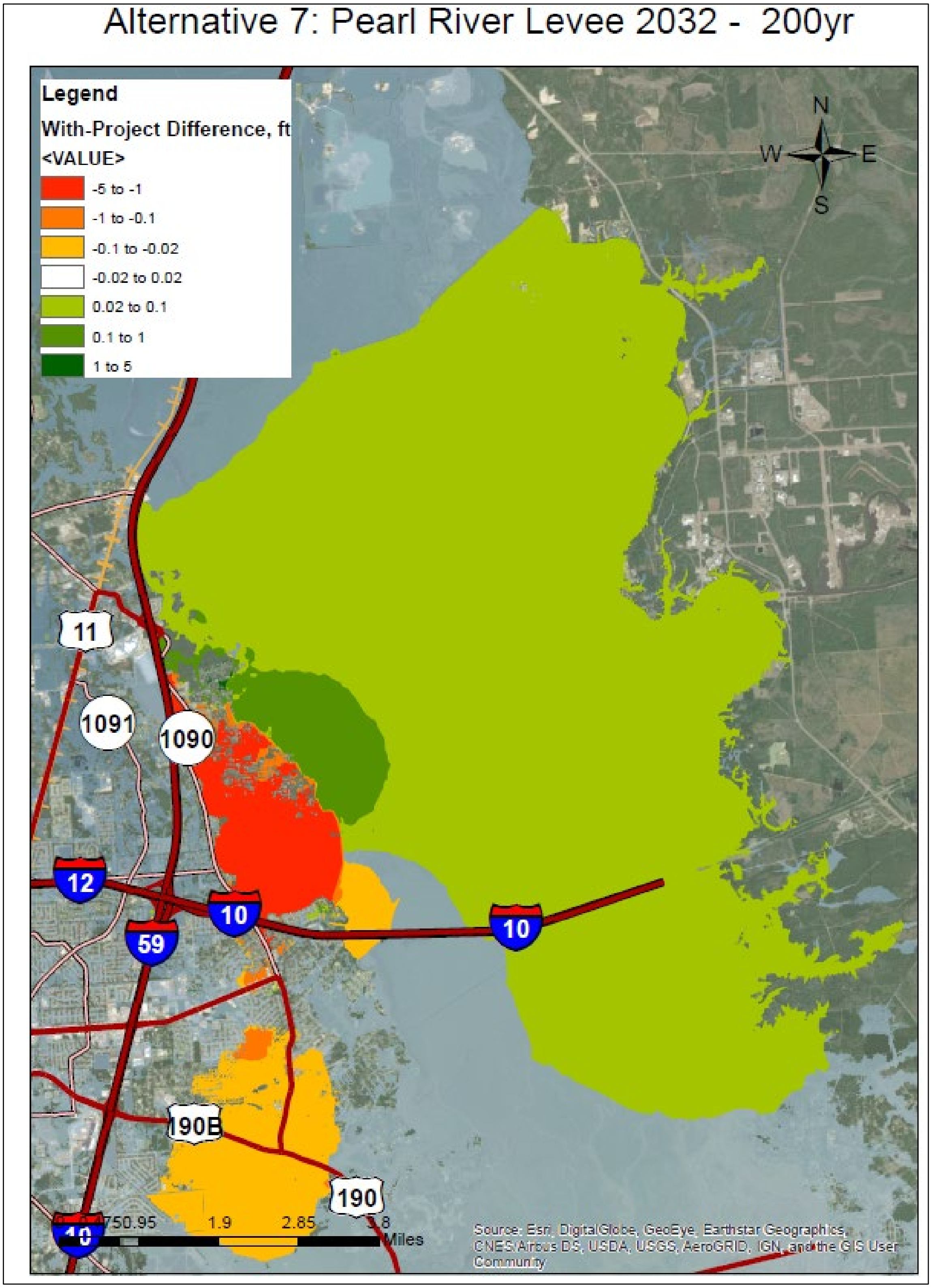
Alternative 5: Bayou Liberty Clearing, Bayou Bonfouca Detention Pond, Bayou Patassat Clearing 2032 - 10yr

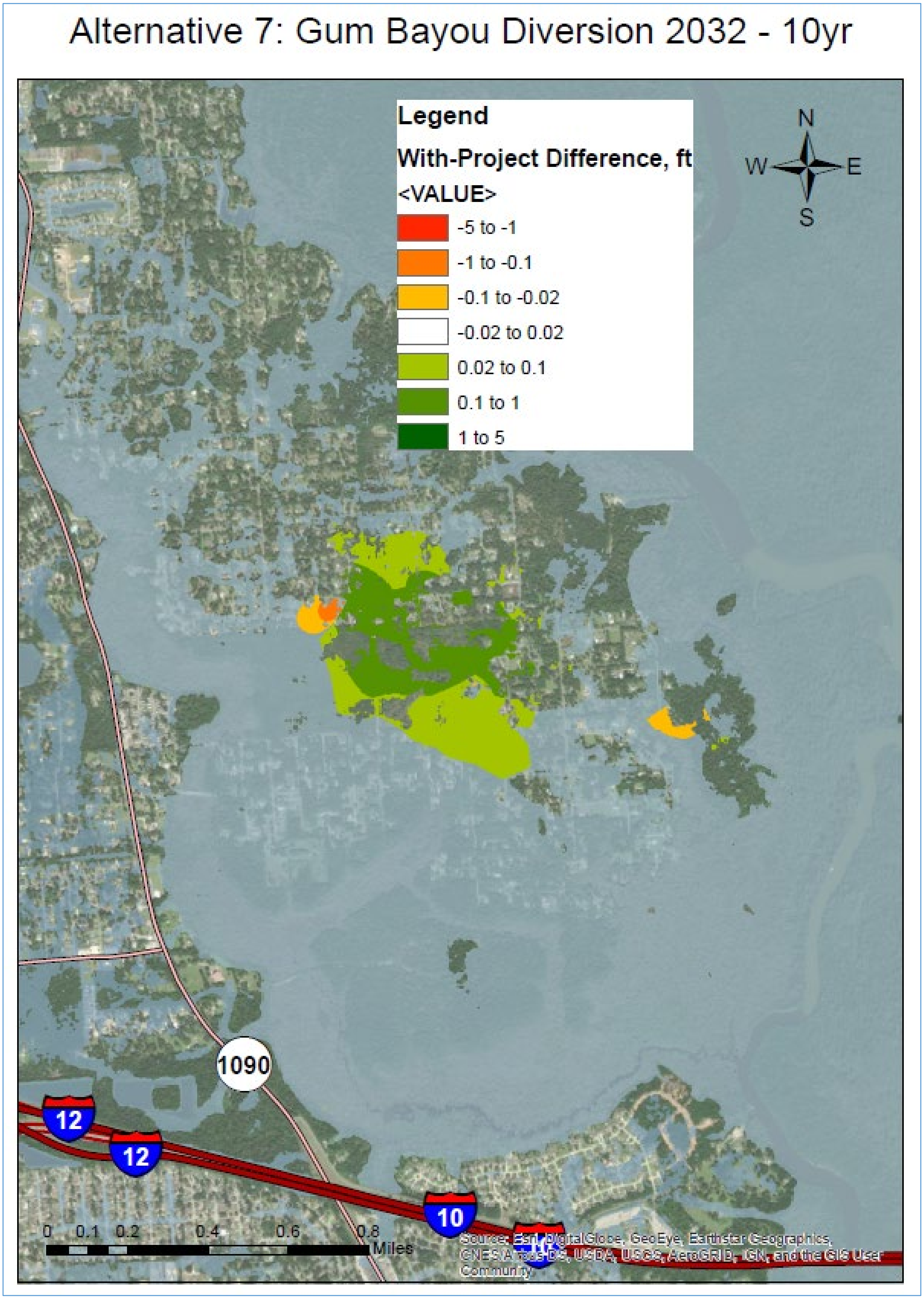


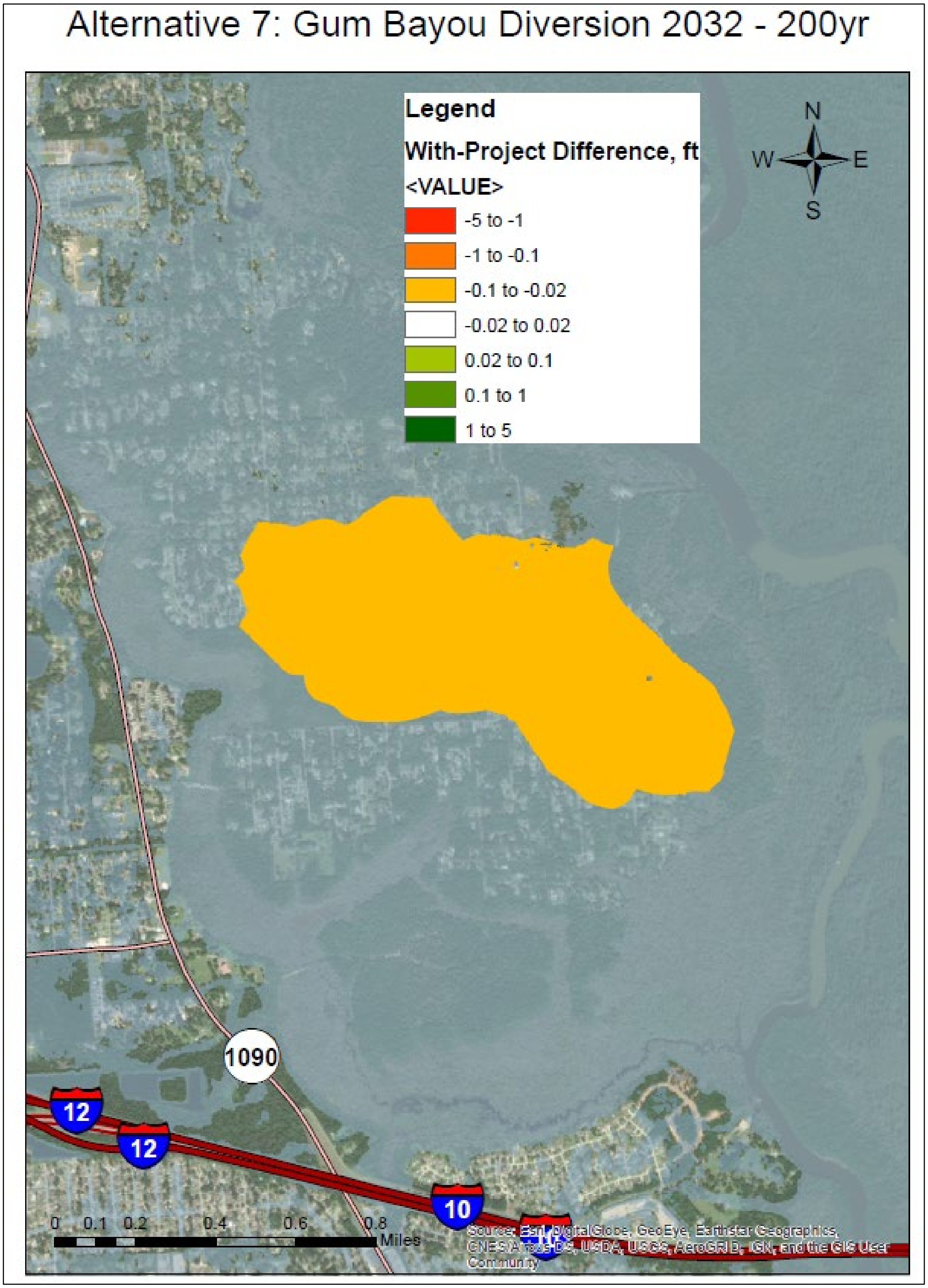
Alternative 5: Bayou Liberty Clearing, Bonfouca Detention Pond, Bayou Patassat Clearing 2032 - 200yr

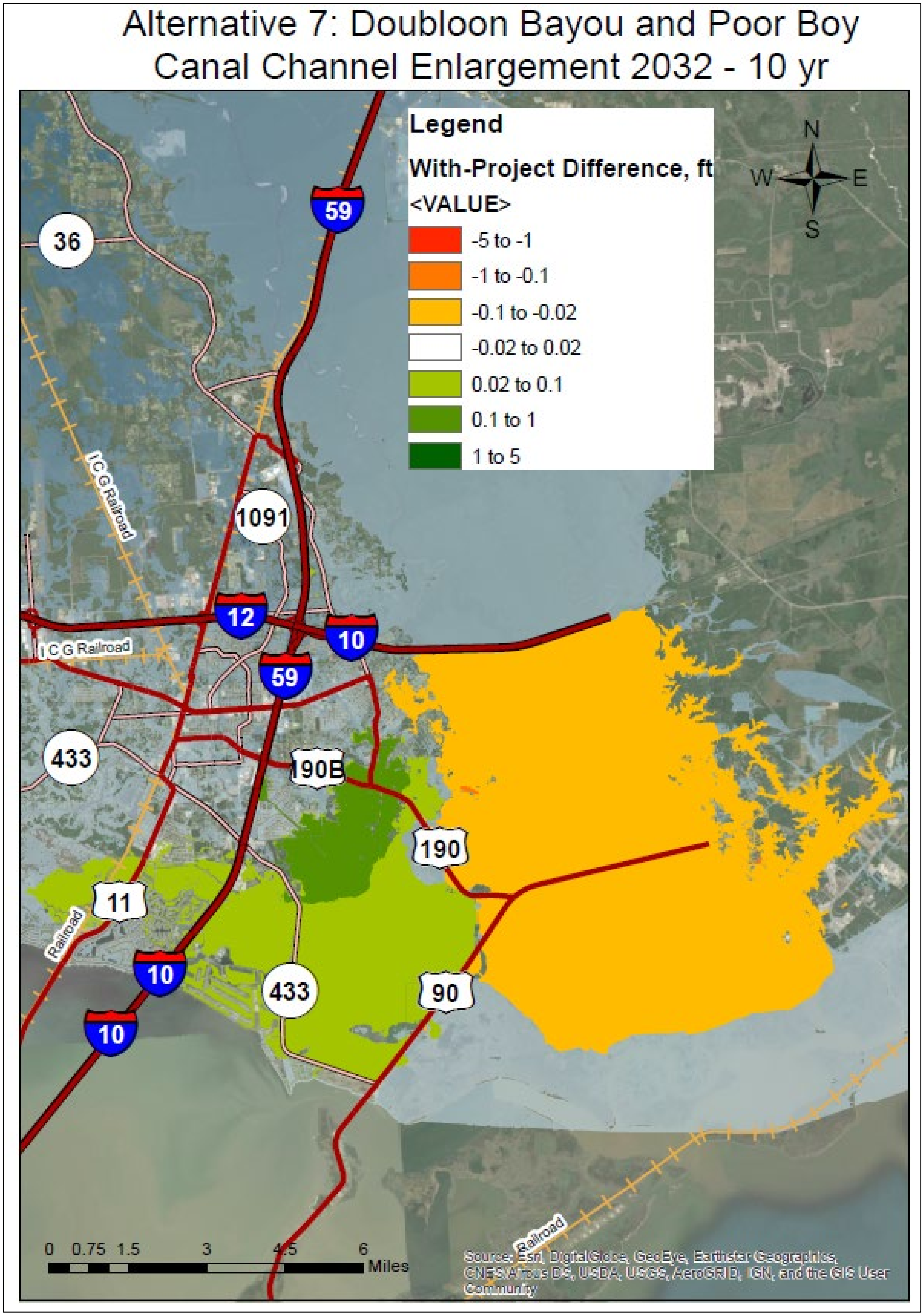


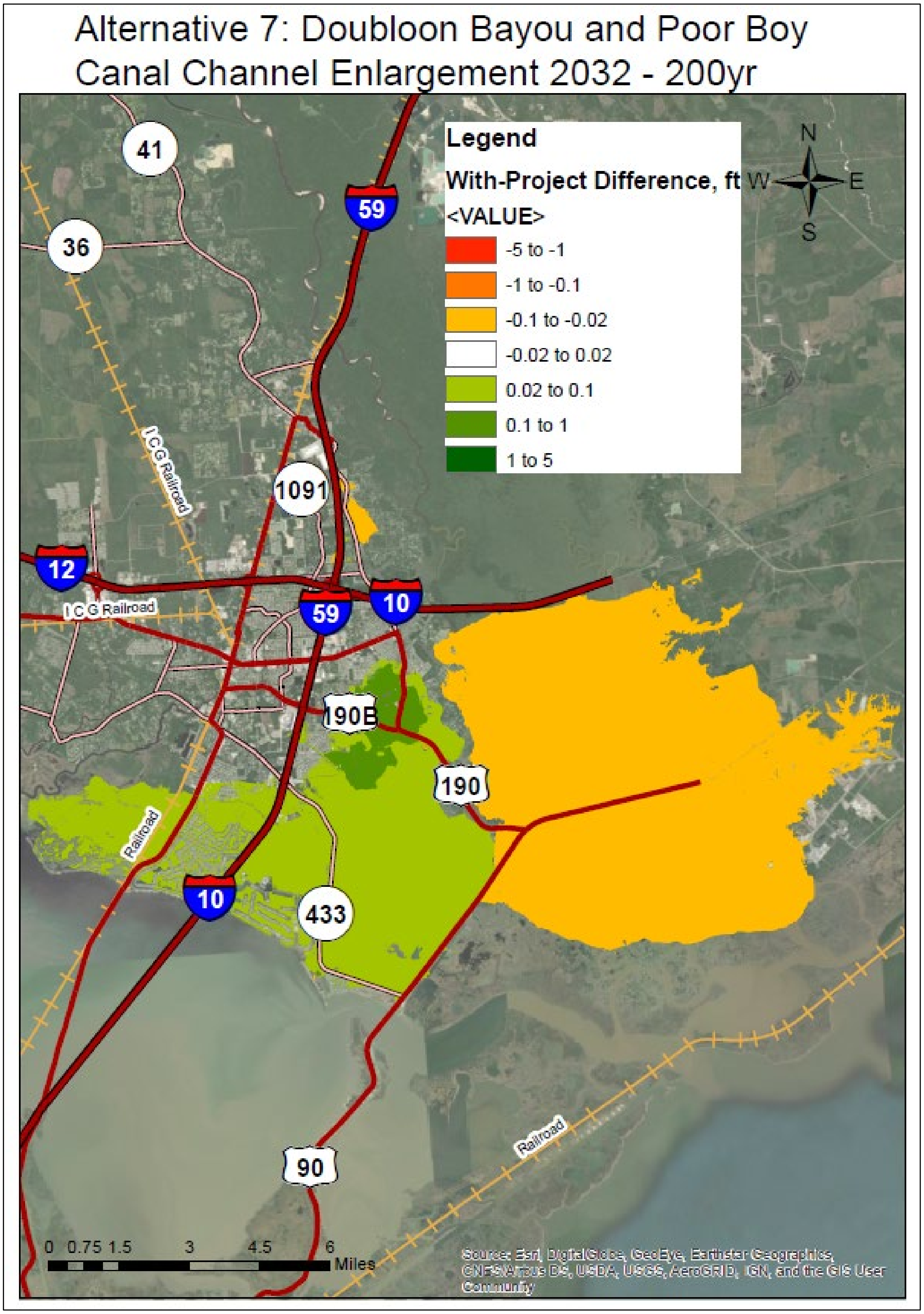

Alternative 7: Pearl River Levee 2032 - 10yr
Legend
With-Project Difference, ft
<VALUE>
-5 to -1
-1 to -0.1
-0.1 to -0.02
-0.02 to 0.02
0.02 to 0.1
0.1 to 1
1 to 5
N
W
E
S
1090
59
59
12
10
10
10
Gum Bayou
0 0.15 0.3 0.6 0.9 1.2
Miles
Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community, Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community


Alternative 7: Pearl River Levee 2032 - 200yr
Legend
With-Project Difference, ft
<VALUE>
-5 to -1
-1 to -0.1
-0.1 to -0.02
-0.02 to 0.02
0.02 to 0.1
0.1 to 1
1 to 5
N
W
E
S
11
1091
1090
12
10
59
10
190B
190
10
0.95
1.9
2.85
3.8
Miles
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

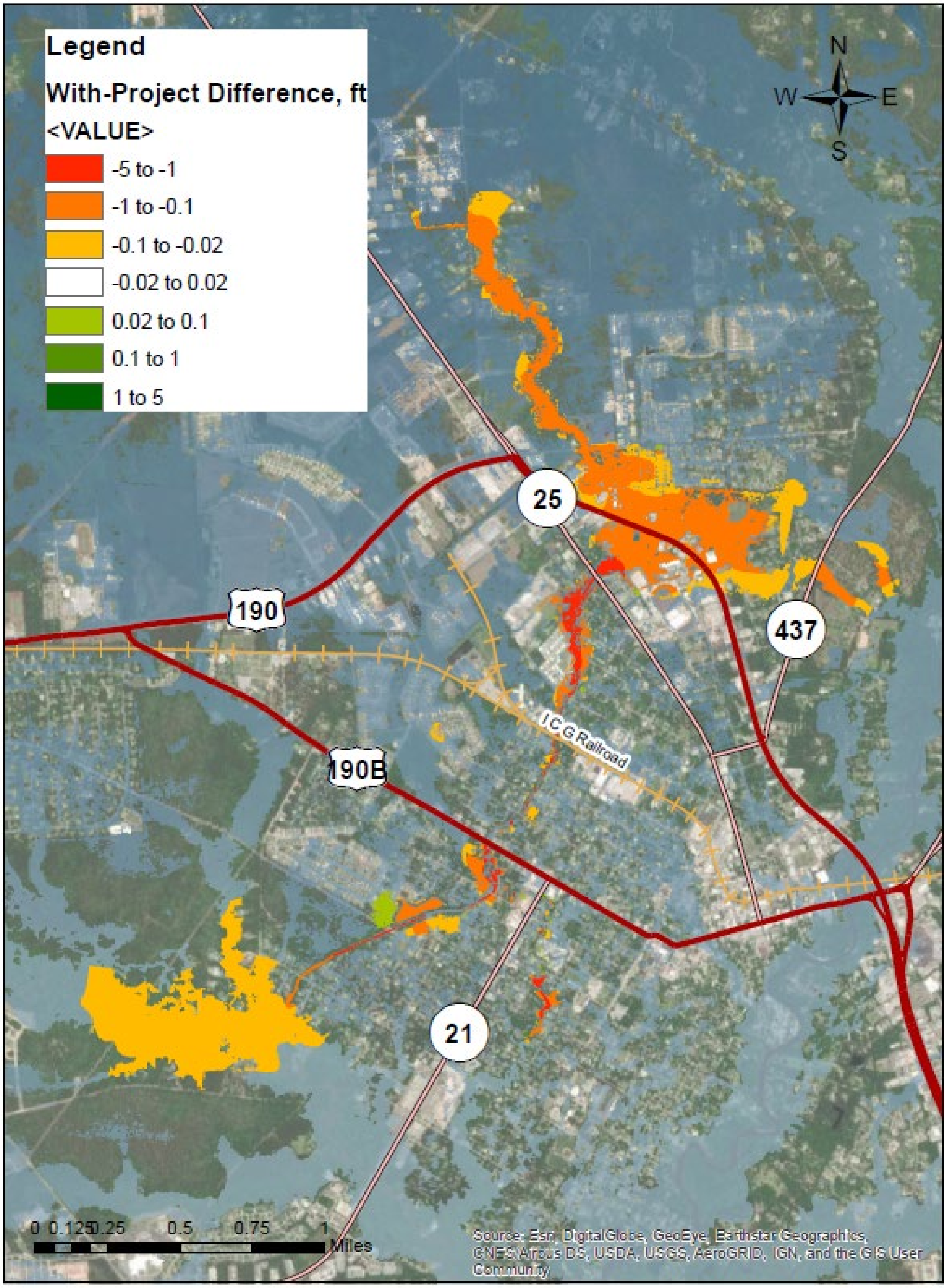

Alternative 7: Gum Bayou Diversion 2032 - 10yr
Legend
With-Project Difference, ft
<VALUE>
-5 to -1
-1 to -0.1
-0.1 to -0.02
-0.02 to 0.02
0.02 to 0.1
0.1 to 1
1 to 5
N
W
E
S
1090
12
12
10
0 0.1 0.2 0.4 0.6 0.8
Miles


Alternative 7: Gum Bayou Diversion 2032 - 200yr
Legend
With-Project Difference, ft
<VALUE>
-5 to -1
-1 to -0.1
-0.1 to -0.02
-0.02 to 0.02
0.02 to 0.1
0.1 to 1
1 to 5
N
W
E
S
1090
12
12
10
0 0.1 0.2 0.4 0.6 0.8
Miles

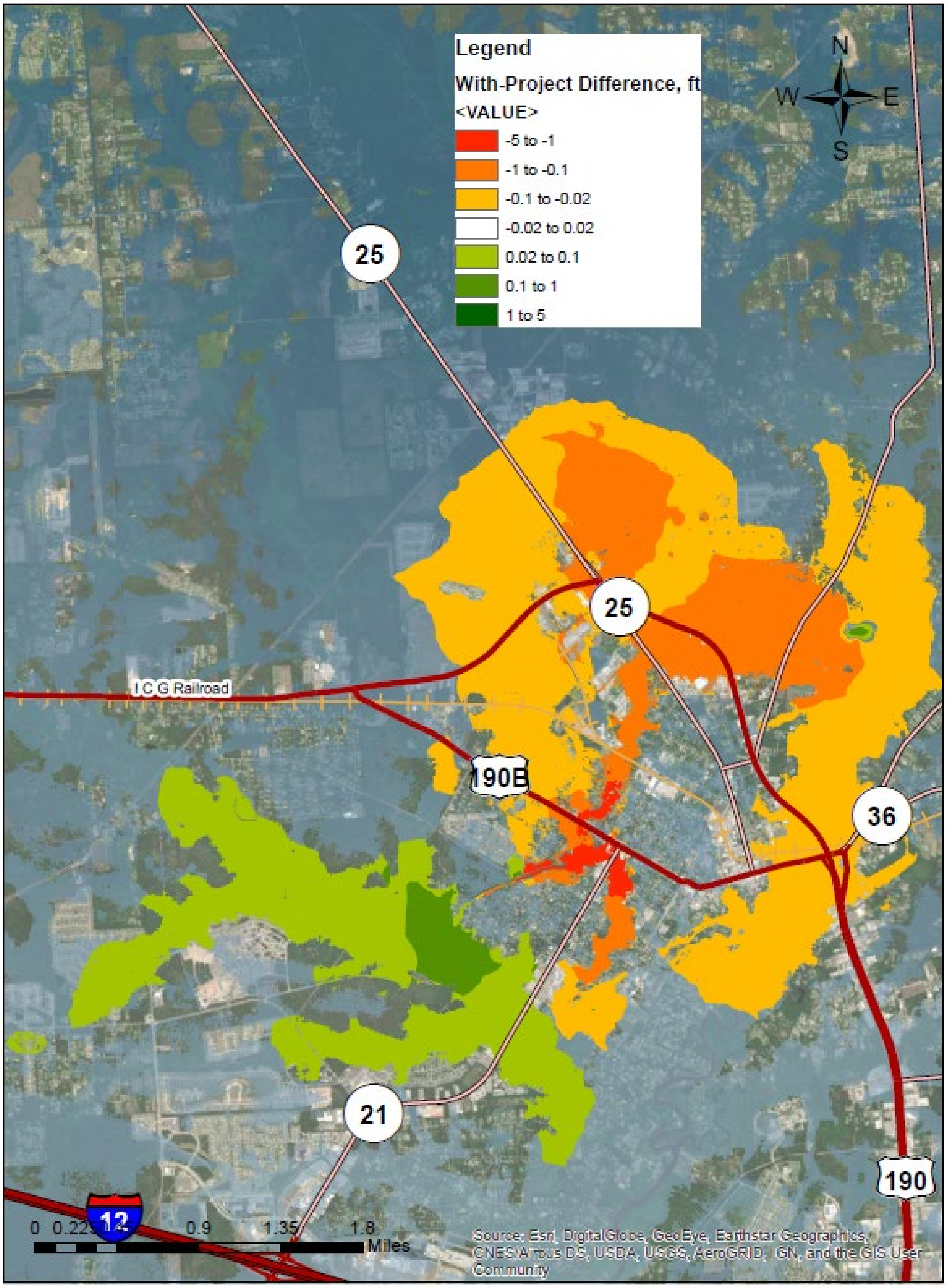

Alternative 7: Doubloon Bayou and Poor Boy Canal Channel Enlargement 2032 - 10 yr
Legend
With-Project Difference, ft
<VALUE>
-5 to -1
-1 to -0.1
-0.1 to -0.02
-0.02 to 0.02
0.02 to 0.1
0.1 to 1
1 to 5
N
W
E
S
36
59
1091
12
10
I C G Railroad
I C G Railroad
59
433
190B
190
11
Railroad
10
10
433
90
Railroad
0 0.75 1.5 3 4.5 6
Miles
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community


Alternative 7: Doubloon Bayou and Poor Boy Canal Channel Enlargement 2032 - 200yr
Legend
With-Project Difference, ft
<VALUE>
-5 to -1
-1 to -0.1
-0.1 to -0.02
-0.02 to 0.02
0.02 to 0.1
0.1 to 1
1 to 5
N
W
E
S
41
36
59
1091
12
I C G Railroad
I C G Railroad
10
190B
190
Railroad
433
90
Railroad
0 0.75 1.5 3 4.5 6
Miles
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Alternative 8: Mile Branch and Lateral A Dredging 2032 - 10yr

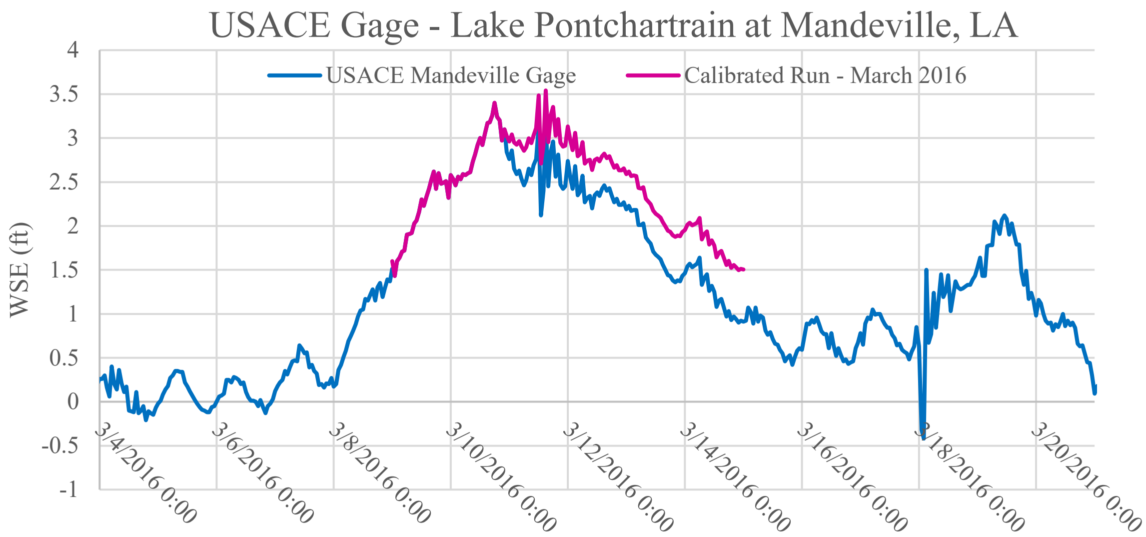


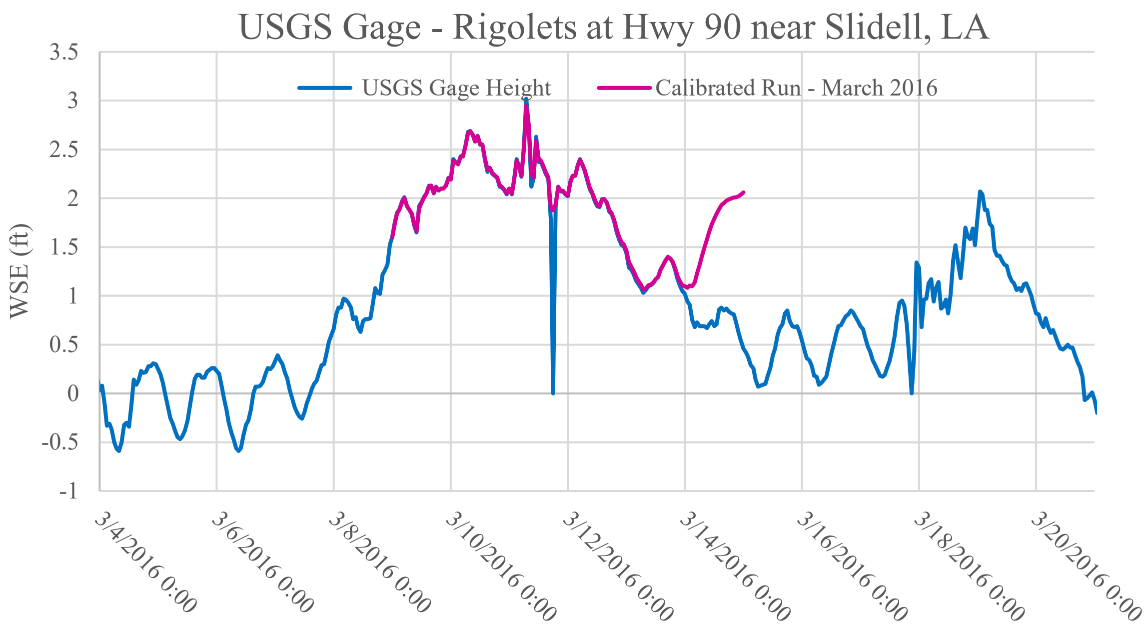
Alternative 8: Mile Branch and Lateral A Dredging 2032 - 200yr

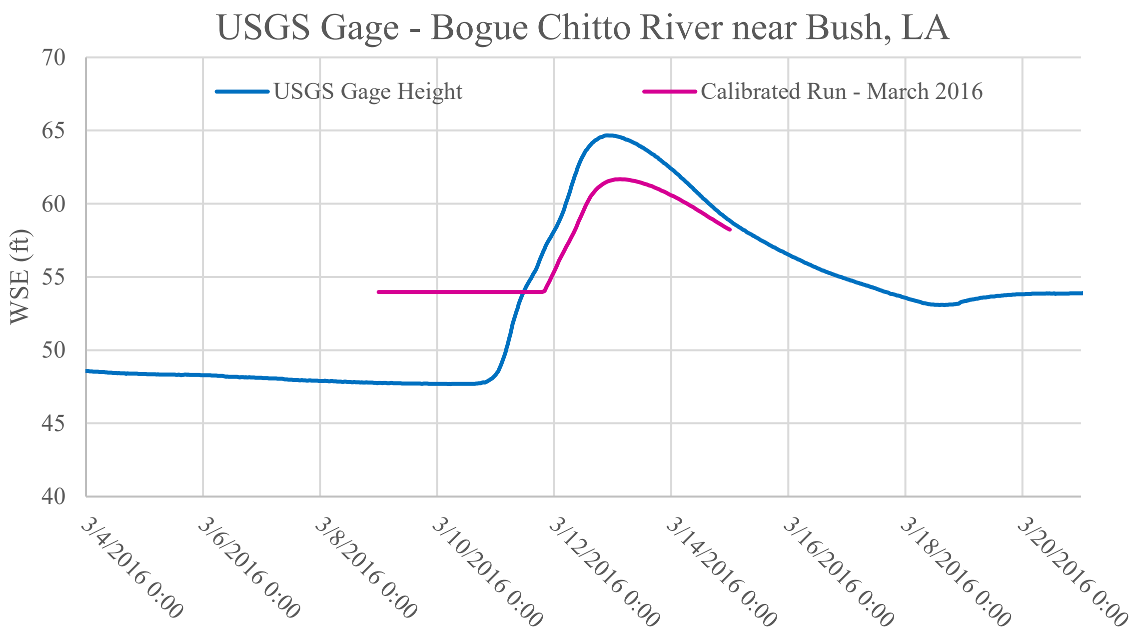


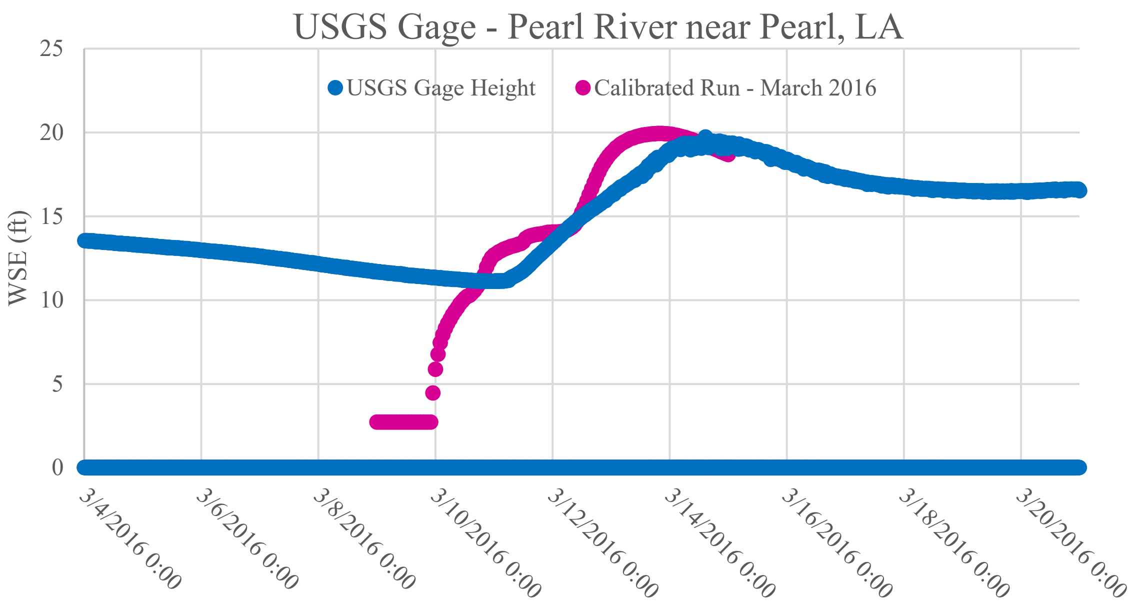
Annex B: Calibration Plots

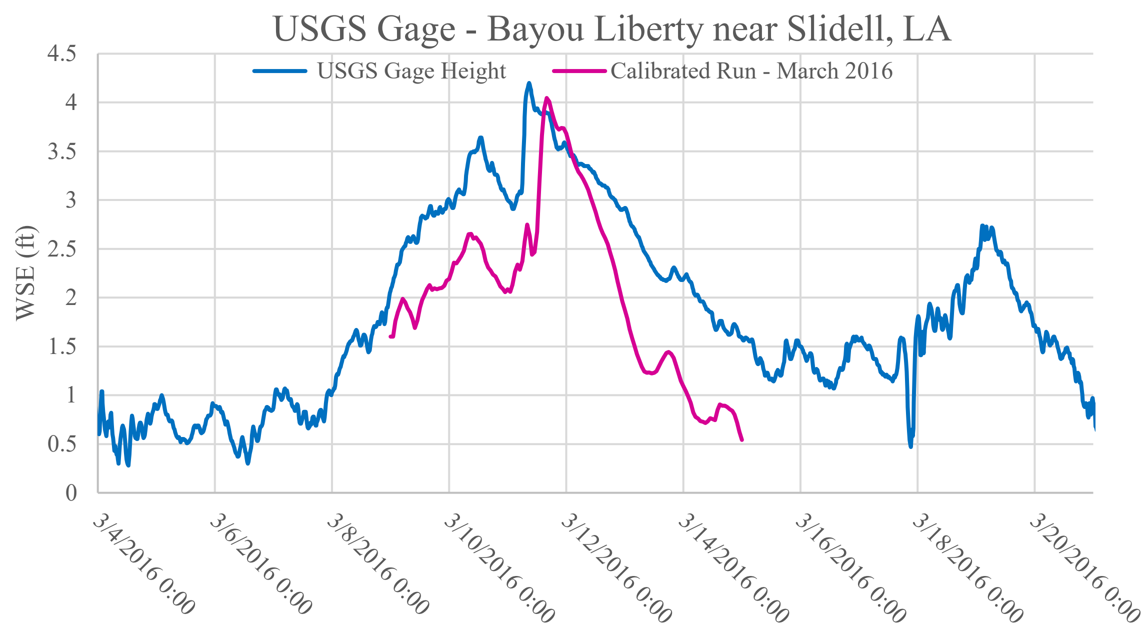
MARCH 2016 CALIBRATION

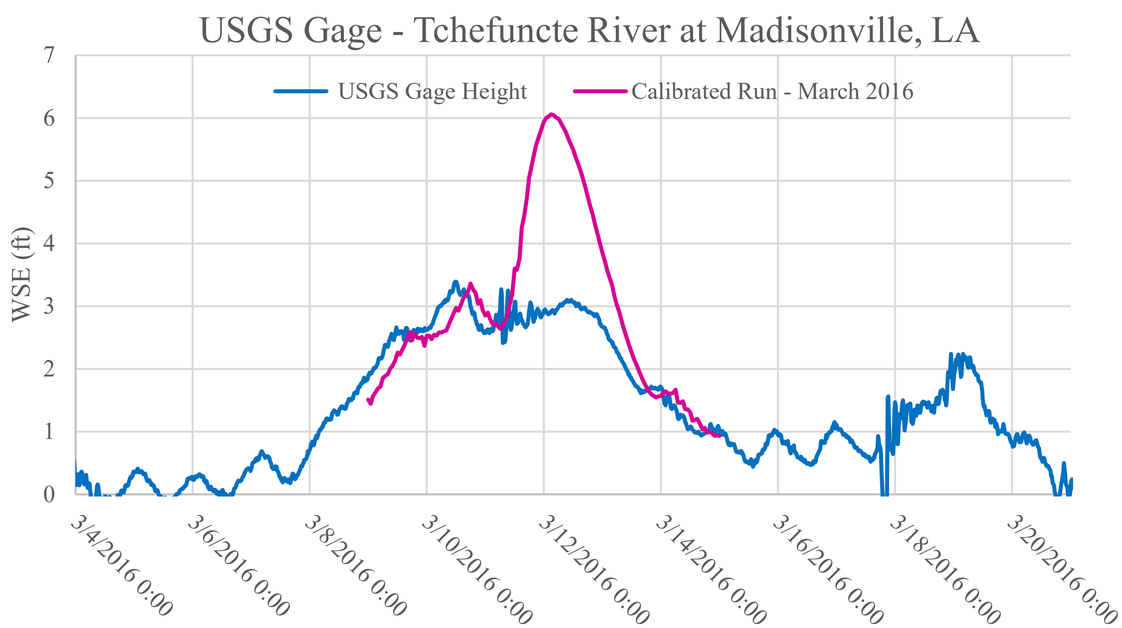




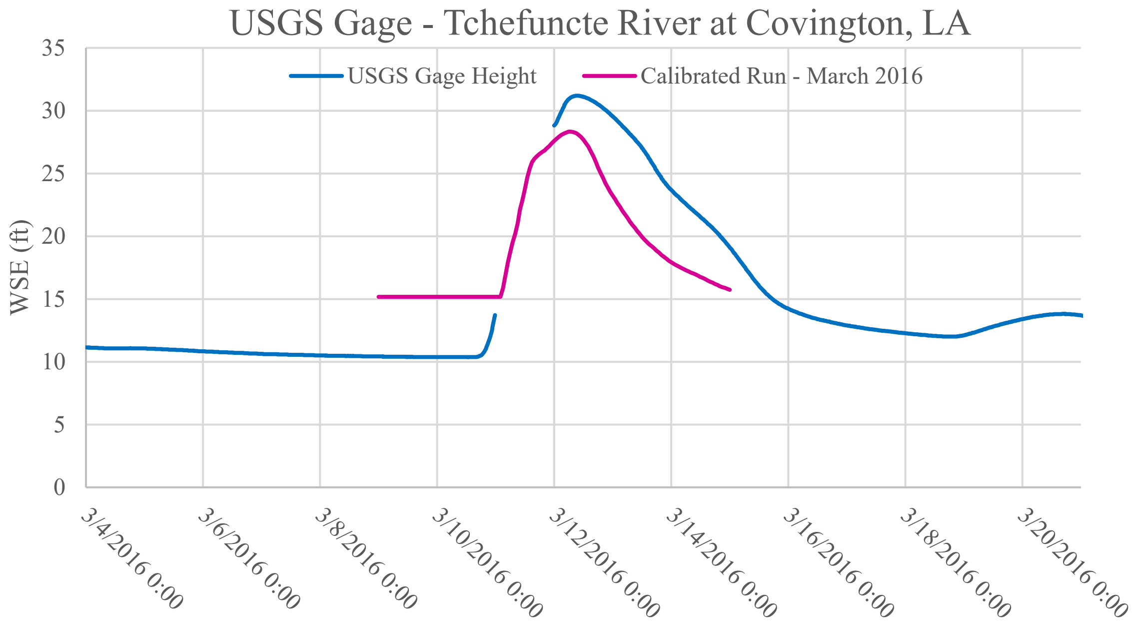

USGS Gage - Bogue Chitto River near Bush, LA
USGS Gage Height
Calibrated Run - March 2016
WSE (ft)
70
65
60
55
50
45
40
3/4/2016 0:00
3/6/2016 0:00
3/8/2016 0:00
3/10/2016 0:00
3/12/2016 0:00
3/14/2016 0:00
3/16/2016 0:00
3/18/2016 0:00
3/20/2016 0:00

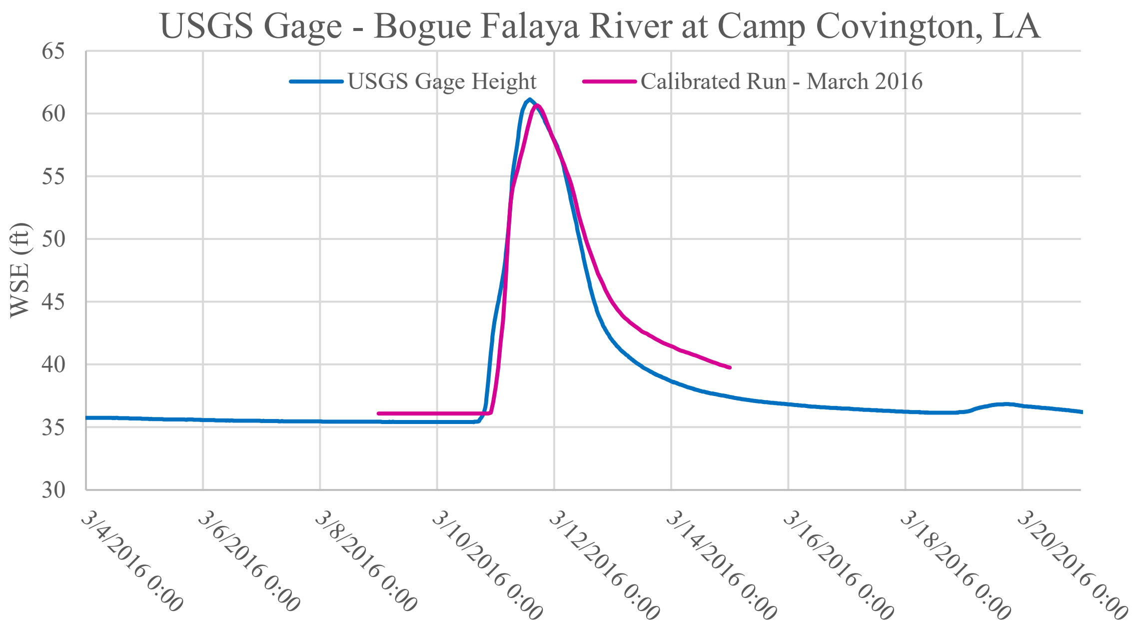

USGS Gage - Pearl River near Pearl, LA
USGS Gage Height
Calibrated Run - March 2016
WSE (ft)
25
20
15
10
5
0
3/4/2016 0:00
3/6/2016 0:00
3/8/2016 0:00
3/10/2016 0:00
3/12/2016 0:00
3/14/2016 0:00
3/16/2016 0:00
3/18/2016 0:00
3/20/2016 0:00

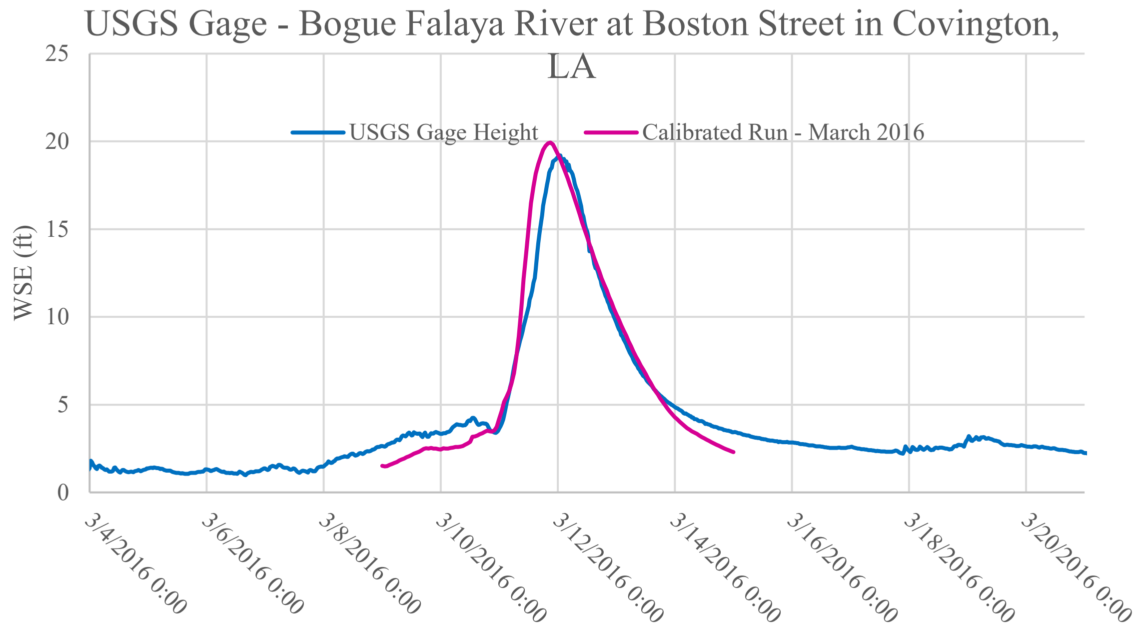


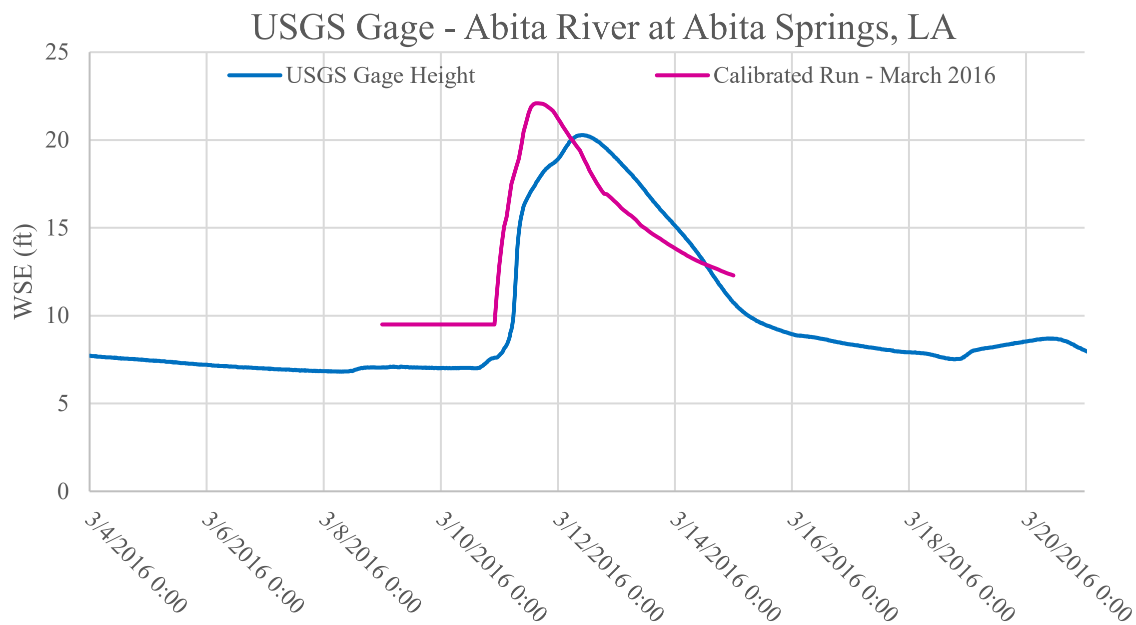


*The location of the USGS Gage – Tchefuncte River at Madisonville, LA has poorly defined channel bathymetry in the model domain which is causing the large discrepancy between the gage data and calibrated run results. This will be corrected in the TSP phase.

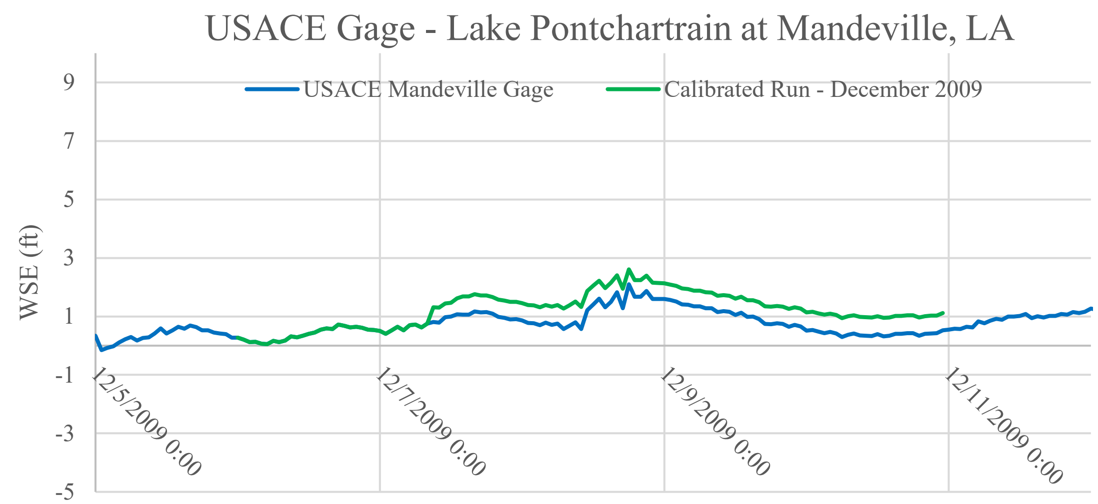

USGS Gage - Tchefuncte River at Covington, LA
USGS Gage Height
Calibrated Run - March 2016
WSE (ft)
35
30
25
20
15
10
5
0
3/4/2016 0:00
3/6/2016 0:00
3/8/2016 0:00
3/10/2016 0:00
3/12/2016 0:00
3/14/2016 0:00
3/16/2016 0:00
3/18/2016 0:00
3/20/2016 0:00

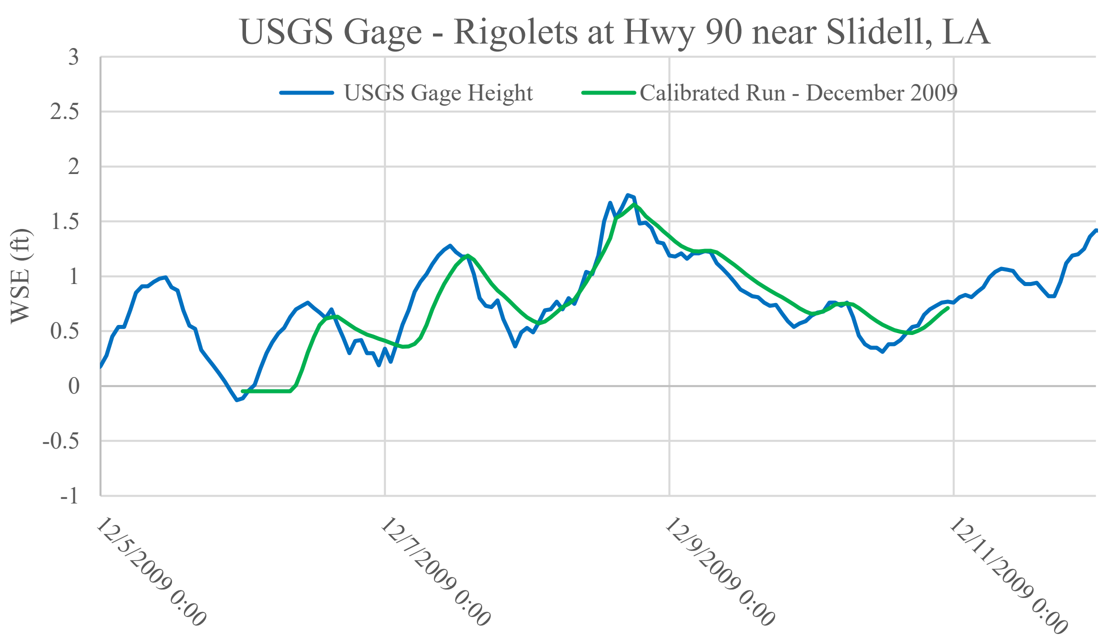

USGS Gage - Bogue Falaya River at Camp Covington, LA
USGS Gage Height
Calibrated Run - March 2016
WSE (ft)
65
60
55
50
45
40
35
30
3/4/2016 0:00
3/6/2016 0:00
3/8/2016 0:00
3/10/2016 0:00
3/12/2016 0:00
3/14/2016 0:00
3/16/2016 0:00
3/18/2016 0:00
3/20/2016 0:00

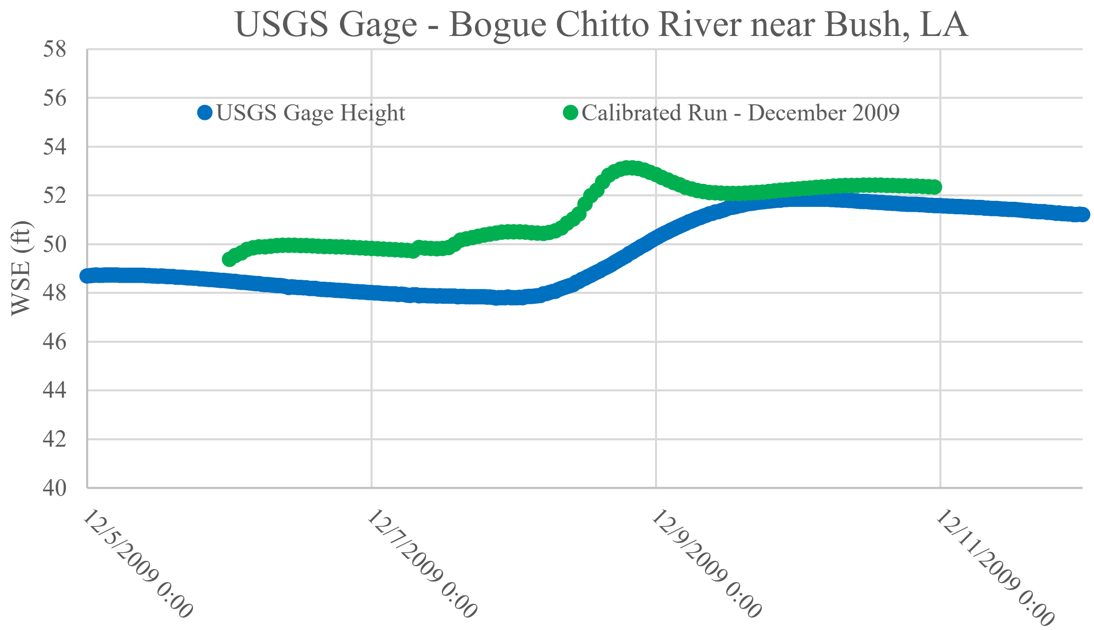

USGS Gage - Bogue Falaya River at Boston Street in Covington, LA
USGS Gage Height
Calibrated Run - March 2016
WSE (ft)
0
5
10
15
20
25
3/4/2016 0:00
3/6/2016 0:00
3/8/2016 0:00
3/10/2016 0:00
3/12/2016 0:00
3/14/2016 0:00
3/16/2016 0:00
3/18/2016 0:00
3/20/2016 0:00

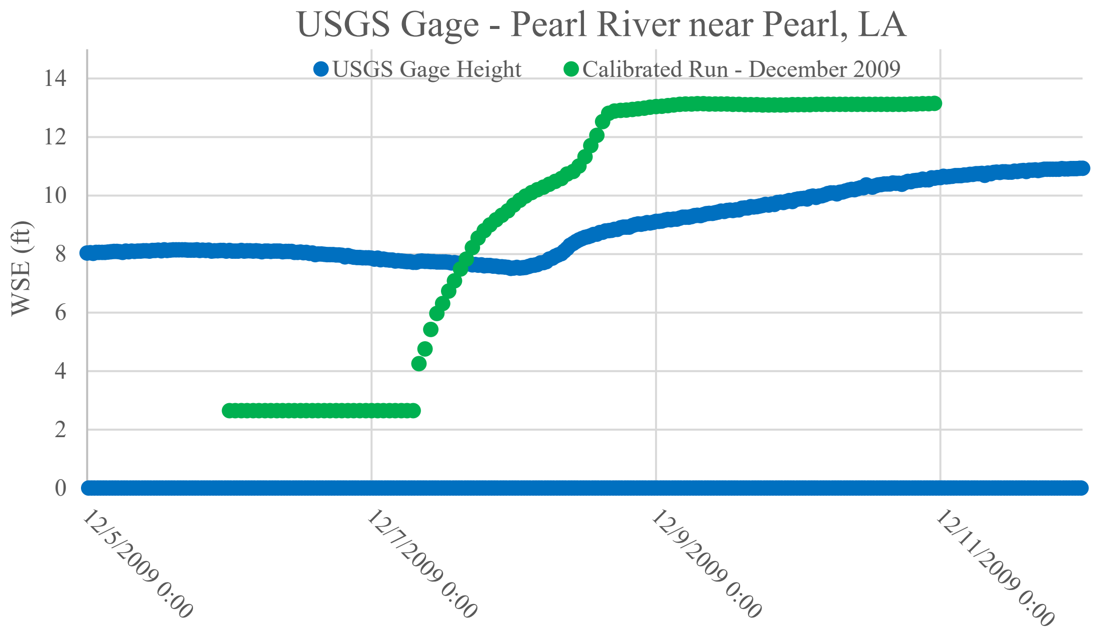

USGS Gage - Abita River at Abita Springs, LA
USGS Gage Height
Calibrated Run - March 2016
WSE (ft)
0
5
10
15
20
25
3/4/2016 0:00
3/6/2016 0:00
3/8/2016 0:00
3/10/2016 0:00
3/12/2016 0:00
3/14/2016 0:00
3/16/2016 0:00
3/18/2016 0:00
3/20/2016 0:00

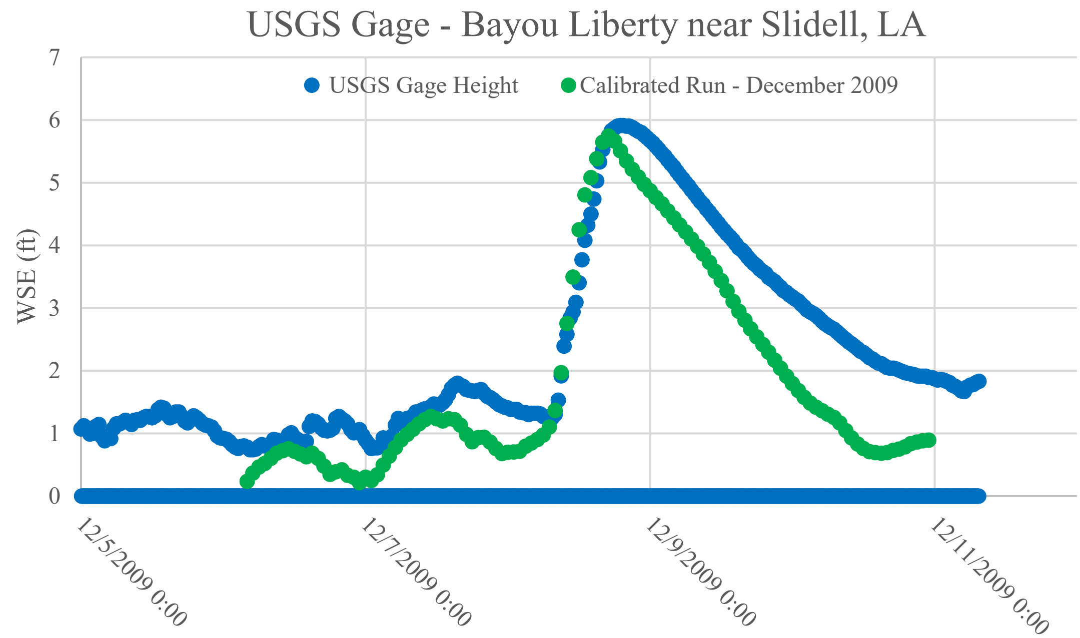
DECEMBER 2009 CALIBRATION

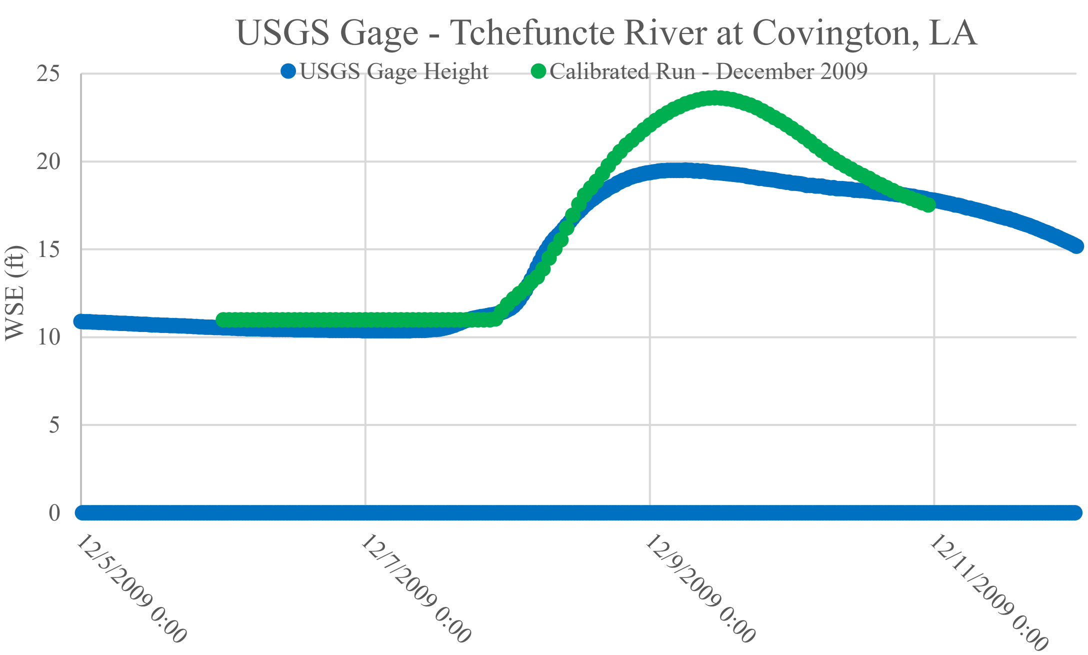


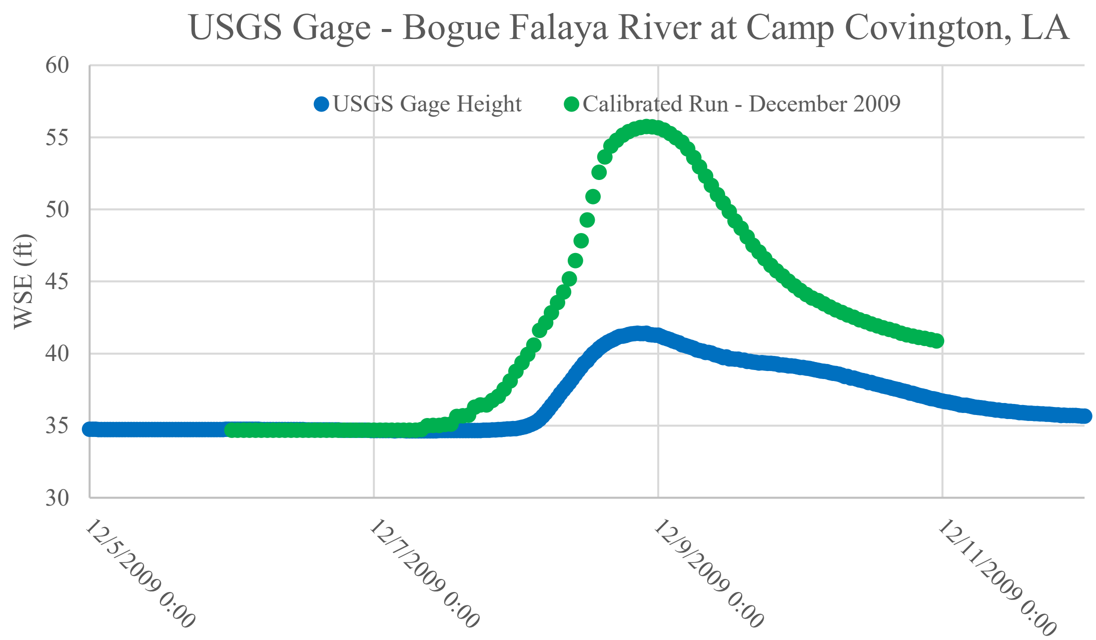


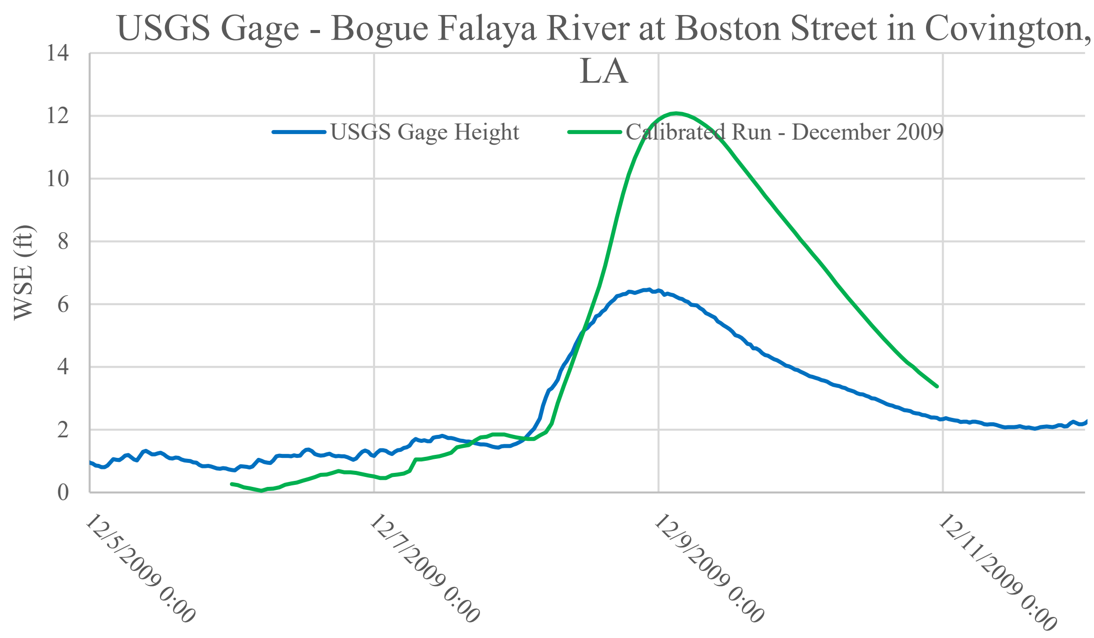

USGS Gage - Bogue Chitto River near Bush, LA
USGS Gage Height
Calibrated Run - December 2009
WSE (ft)
58
56
54
52
50
48
46
44
42
40
12/5/2009 0:00
12/7/2009 0:00
12/9/2009 0:00
12/11/2009 0:00


USGS Gage - Pearl River near Pearl, LA
USGS Gage Height
Calibrated Run - December 2009
WSE (ft)
14
12
10
8
6
4
2
0
12/5/2009 0:00
12/7/2009 0:00
12/9/2009 0:00
12/11/2009 0:00


USGS Gage - Bayou Liberty near Slidell, LA
USGS Gage Height
Calibrated Run - December 2009
WSE (ft)
0
1
2
3
4
5
6
7
12/5/2009 0:00
12/7/2009 0:00
12/9/2009 0:00
12/11/2009 0:00


USGS Gage - Tchefuncte River at Covington, LA
USGS Gage Height
Calibrated Run - December 2009
WSE (ft)
0
5
10
15
20
25
12/5/2009 0:00
12/7/2009 0:00
12/9/2009 0:00
12/11/2009 0:00


USGS Gage - Bogue Falaya River at Camp Covington, LA
USGS Gage Height
Calibrated Run - December 2009
WSE (ft)
60
55
50
45
40
35
30
12/5/2009 0:00
12/7/2009 0:00
12/9/2009 0:00
12/11/2009 0:00


USGS Gage - Bogue Falaya River at Boston Street in Covington, LA
USGS Gage Height
Calibrated Run - December 2009
WSE (ft)
14
12
10
8
6
4
2
0
12/5/2009 0:00
12/7/2009 0:00
12/9/2009 0:00
12/11/2009 0:00