BAYOU GREENBELT FEASIBILITY STUDY

Hydraulic and Salinity Modeling to Evaluate the Bayou Greenbelt Greenway

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Produced for the National Park Service and funded by the Federal Emergency Management Agency

September 6, 2024

#P-00813-01

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SUGGESTED CITATION

Georgiou, I.Y., Bregman, M., Hemmerling, S.A., Partida, L., Pittman, G., Saharia, A., Wang, Y., (2024). Bayou Greenbelt Feasibility Study: Hydraulic and Salinity Modeling to Evaluate the Bayou Greenbelt Greenway. The Water Institute. Prepared for the National Park Service – Rivers, Trails & Conservation Assistance Program and funded by the Federal Emergency Management Agency. Baton Rouge, LA.

PREFACE

The Water Institute (the Institute) conducted this study for the National Park Service. This report is a project deliverable that describes the methods used to evaluate, at the conceptual level, the feasibility of the Bayou Greenbelt project, which aims to connect Contraband Bayou to Kayouche Coulee. The report discusses the datasets, previous models, and other information available that were leveraged to develop a new comprehensive hydraulic model to evaluate potential impacts to flooding from rainfall events and new models used to evaluate potential salinity impacts during droughts from the project. The hydraulic model was calibrated with observations and further confirmed and—where needed—improved, through a series of model competency group meetings. The final model was used to evaluate the installation of the project for the 10-year and the 100-year return period rainfall events. The salinity valuation was conducted during the drought of 2013, leveraging previous modeling and observations in the region.

ACKNOWLEDGEMENTS

The authors acknowledge the Federal Emergency Management Agency for funding and the National Park Service for managing the study and analysis presented in this report. Further, the authors thank the Community Foundation of Southwest Louisiana for their key role as stakeholders during the study and their valuable input during model development and analysis stemming from their experience and vision, having conceived the Bayou Greenbelt idea. Specifically, recognition is extended to Jill Galmarini, Sara Judson, Lee Boyer, Richard Rhoden, Mike Nodier, and Jon Manns for their support, discussions, feedback, and input throughout the study, for their contribution to make the model competency meetings a success, and for connecting the Institute with key members of state and local governments, experts, and stakeholders throughout the project. The Institute acknowledges the National Park Service team of Helen Siewers, Russell Clark, Deirdre Hewitt, and John Olivier, the FEMA team of Tonia Pence and Richard Martin, the Calcasieu Parish Gravity Drainage District #2 team of Greg LaFleur, Robert Goodson, Mike Polk, Mike Naquin, and Eddie Hebert, the Calcasieu Parish Police Jury's Terry Frelot and Jennifer Cobian, and C.H. Fenstermaker and Associates' Brooke Newlin and Jeanne A Hornsby.

Last but certainly not least, the research team would like to thank all the residents and local stakeholders from Calcasieu Parish and Lake Charles who participated in the three competency group meetings. Their input proved instrumental in the development of the numerical model used to assess the Bayou Greenbelt project. Their willingness to share their knowledge and expertise resulted in an improved model and confirmed that the results presented in this report are as accurate as possible.

This report was reviewed by Alyssa Dausman, and reviewed, edited, and formatted by Charley Cameron of the Institute.

EXECUTIVE SUMMARY

The work presented in this report uses numerical models calibrated with field observations to investigate the impact of the Bayou Greenbelt (BGB) project. This proposed recreational waterway would provide a water loop around Lake Charles by connecting Contraband Bayou and Kayouche Coulee at their headwaters. Two models with variable spatial resolution were developed to assess the project. The first model was a two-dimensional HEC-RAS model, which was developed to assess the potential project impacts on hydraulics and hydrology potential. The second model was a three-dimensional model based on Delft3D, which was developed to assess salinity impacts related to the project. The spatial extent of the hydraulic model included all relevant watersheds; it spanned from the Calcasieu River to the west and the north of the city, to English Bayou to the northeast, and extended to the Gulf Intracoastal Waterway (GIWW) to the south. The spatial extent of the salinity model focused on the waterways and included a portion of the Calcasieu River to the north and south of the entrance to Contraband Bayou, including the entire Bayou itself and the portion of the Kayouche Coulee up to the Kayouche Coulee pump station.

The hydraulic model was calibrated for the May 17, 2021 flood event using water level observations from the vast network of gauges operated by the Calcasieu Parish Police Jury (CPPJ). The model was further improved using participatory modeling methodology, whereby feedback on the model inputs and outputs were collected, validated, and confirmed through meetings with community leaders, members, stakeholders, and city officials. Following calibration, the BGB project was added to the model, connecting Contraband Bayou to Kayouche Coulee by dredging a hypothetical channel within the model (Gumbo Cut). Four scenarios were simulated and included two rainfall events with a return period of 10 and 100 years and two tidal conditions.

The simulations showed that the proposed construction of a new detention pond had a significant impact on water levels in the area where it will be built. In the simulations of a 10-year and 100-year rainfall event, noticeable water level changes were also observed in other areas, including Gumbo Cut, Contraband Bayou, and Kayouche Coulee. However, for the rest of the study area, the changes in water level due to the BGB project were negligible. The models predicted a reduction in water levels near the newly constructed detention pond and at McNeese farms, with a slight increase in water levels beyond McNeese State University.

Freshwater runoff during rainfall will reduce salinity concentrations and force the salt wedge downstream toward Calcasieu River. However, model results indicate that the implementation of Gumbo Cut will raise salinity levels in Contraband Bayou during drought conditions, especially upstream of McNeese State University. The change will allow for greater exchange between the salty Calcasieu River and fresher waters in Contraband Bayou, leading to higher salinity intrusion. This outcome can be offset by considering a controlled connectivity between the two water bodies that could improve salinity in Contraband Bayou during drought conditions. A field data campaign to collect salinity concentrations in Contraband Bayou is recommended to improve future analysis and modeling and provide baseline data.

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LIST OF ACRONYMS

Acronym	Term
AEP	Annual exceedance probability
AORC	Analysis of record for calibration
ARI	Annual return interval
BLE	Base level engineering
CFSWLA	Community Foundation of Southwest Louisiana
CG	Competency group
CPPJ	Calcasieu Parish Police Jury
CPRA	Coastal Protection and Restoration Authority
DEM	Digital elevation model
FEMA	Federal Emergency Management Agency
GIWW	Gulf Intracoastal Waterway
gSSURGO	Gridded Soil Survey Geographic Database
HEC-RAS	Hydrologic Engineering Center's River Analysis System
LKM	Local knowledge mapping
LULC	Land use land cover
MAE	Mean absolute error
MRMS	Multi-Radar/Multi-Sensor
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NSE	Nash-Sutcliffe model efficiency coefficient
PBIAS	Percent bias
RMSE	Root mean square error
RSR	RMSE-observations standard deviation ratio
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USGS	United States Geological Survey
UTC	Coordinated universal time

1.0 INTRODUCTION

The Community Foundation of Southwest Louisiana (CFSWLA) is a nonprofit community foundation that collaborates with public agencies and private enterprises to conduct projects for civic improvement throughout southwest Louisiana. CFSWLA has developed a vision for improving the quality of life for residents of Lake Charles, Louisiana, one which includes a publicly accessible water loop with corresponding trailheads, outboard and kayak boat launches, bike paths, and greenways that would connect people to the natural environment. The vision is called Bayou Greenbelt (BGB), and it would be formed, in part, by the connection of Contraband Bayou and Kayouche Coulee through a newly formed canal, called Gumbo Cut (Figure 1).

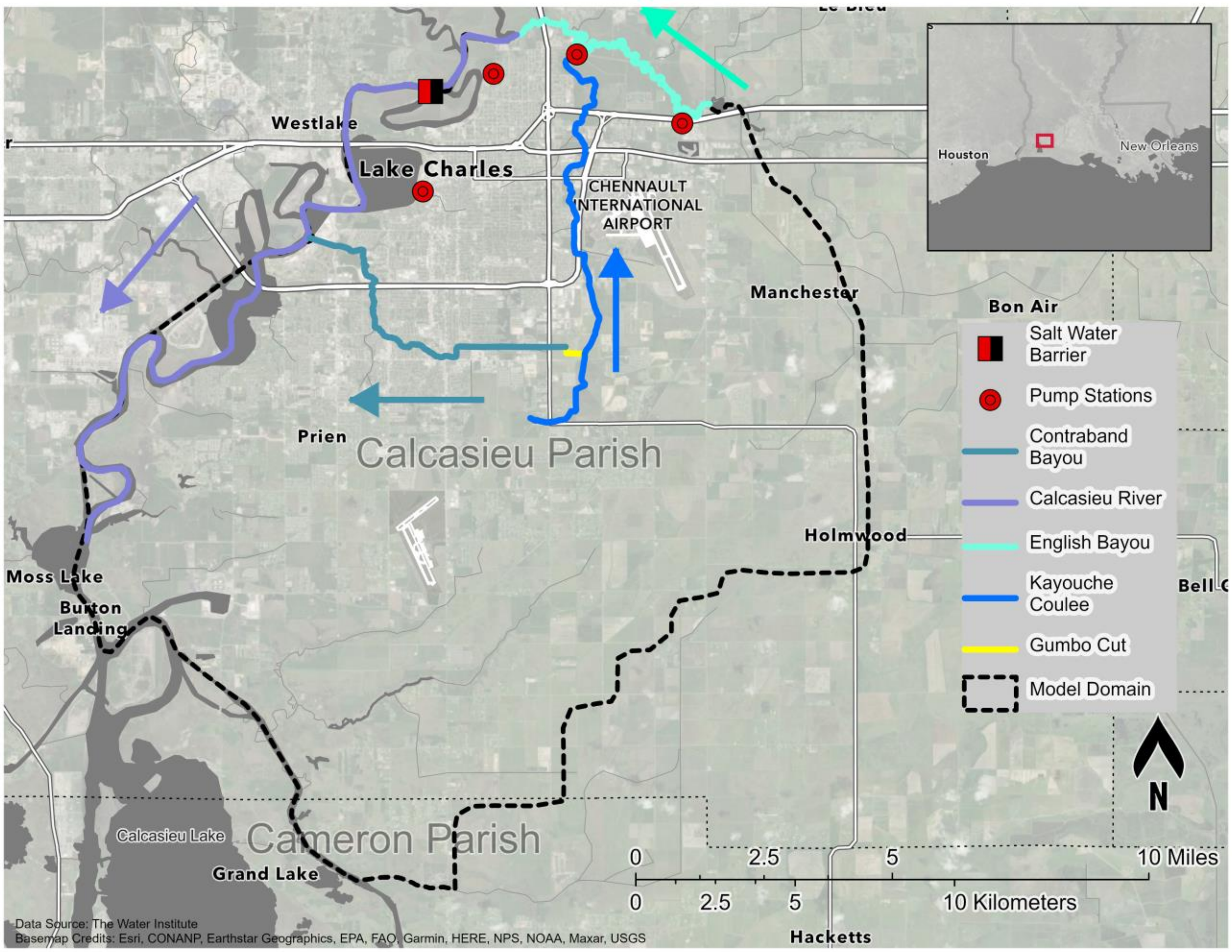

Figure 1. View of the study area in the greater area of Lake Charles, LA. The figure also shows the four watercourses relevant to the study (English Bayou, Contraband Bayou, the Calcasieu River, and Kayouche Coulee), the direction of flow for each watercourse shown with directional arrows, the extent of the hydraulic model domain (dashed black line), the location of the saltwater barrier in the Calcasieu River, and the location of pump stations throughout the city.

In March 2023, The Water Institute (the Institute) was contracted by the National Park Service (NPS), under its River, Trails, and Conservation Assistance Program, through funding from FEMA and on behalf of CFSWLA to investigate the potential hydraulic, hydrologic, and salinity impacts that could result from the construction of Gumbo Cut and the overall implementation of the BGB project. Residents and local stakeholders were actively involved throughout this research, using their local knowledge of the region to assess the accuracy of project outputs.

The City of Lake Charles, LA is in southwestern Louisiana and situated along the banks of the lower Calcasieu River, which drains into Calcasieu Lake, an oligohaline lake with an outlet to the Gulf of Mexico. The Calcasieu River is navigable due to the construction of the Calcasieu Ship Channel, which connects the Port of Lake Charles to the Gulf of Mexico. The Calcasieu Ship Channel was constructed in 1937 and has been enlarged several times as part of the Calcasieu River and Pass project (USACE, 2018). Contraband Bayou, located south of the city, is a tidal watercourse that provides drainage for the city's southern portion by discharging runoff to the Calcasieu River below the saltwater barrier. East of the city, Kayouche Coulee similarly provides drainage for the eastern portions of the city of Lake Charles, discharging runoff into the Calcasieu River north of the city above the saltwater barrier via its connection to English Bayou, which also abuts the northeastern part of the city. The connection of these two waterways would create a single watershed that would be tidally influenced by the Calcasieu River.

To evaluate the potential hydrologic impacts resulting from the implementation of the BGB project, the Institute developed a two-dimensional (2D) hydraulic model using the Hydrologic Engineering Center River Analysis System (HEC-RAS; USACE, 2024). The model developed for this study leveraged previous modeling efforts provided to the Institute by the city of Lake Charles (see Section 2.0) and focused on developing a single model domain encompassing the greater Lake Charles region (Figure 1). The model was calibrated to the May 17, 2021 rainfall event, which resulted in 16–18 inches of rain falling over a 6-hour period, resulting in an unprecedented flash flood event (NOAA, 2021). The model was improved using a participatory modeling methodology, whereby feedback on the model inputs and outputs were collected, validated, and confirmed through meetings with community leaders, members, stakeholders, and city officials. Following calibration, several scenarios corresponding to different annual exceedance probability (AEP) rainfall events (10-year and 100-year) as well as the May 17, 2021 event were used to evaluate the project, and compare it with existing (without project) conditions.

The deepening of the Calcasieu Shipping Channel over the years has also increased saltwater intrusion into the Calcasieu River, which led to the congressional approval of the Calcasieu Saltwater Barrier construction in 1962 (USACE, n.d.). In addition to examining the hydrological impacts of the BGB project, this study also investigated its impacts on salinity in Contraband Bayou. The intrusion of salinity from the Gulf of Mexico into the Calcasieu River also extends into interconnected water bodies downstream of the saltwater barrier, including Contraband Bayou. This study included the development of a Delft3D model to evaluate the impact of the BGB project on the ingress and egress of salinity from the Calcasieu River into Contraband Bayou. The salinity evaluation took place over a historical drought in 2013, with simulations and analysis comparing with- and without-project conditions.

2.0 BACKGROUND

2.1. FEMA BASE LEVEL ENGINEERING ANALYSIS

The Federal Emergency Management Agency (FEMA) conducted a base level engineering (BLE) analysis in the Upper Calcasieu watershed, encompassing a significant portion of the Kayouche Coulee watershed (FEMA BLE Study, 2020). The analysis used a BLE model based on 2D HEC-RAS, and included simulated events corresponding to the 10-, 25-, 50-, 100- and 500-year average recurrence intervals (ARIs), as well as a variance of the 100-year ARI with increase and a decrease of precipitation defined to be one standard deviation above and below the 100-year event. The model package contains inputs of flow and precipitation for each ARI simulation that was run.

While the BLE model offers valuable insights for the Upper Calcasieu portion of the watershed, it excludes Contraband Bayou, which is needed for the purpose of this study. Additionally, the digital elevation model (DEM) used in the BLE model to represent the terrain was based solely on LiDAR data and excluded bathymetry information. Due to the limited coverage of the BLE model and the absence of bathymetry data, the BLE model was not used in this study (see Figure 2 for the model extent of the BLE study).

2.2. C.H. FENSTERMAKER & ASSOCIATES, L.L.C. MODELING STUDIES

C.H. Fenstermaker & Associates, L.L.C. (hereafter Fenstermaker) have developed several models of varying complexity and detail throughout the study area. Through coordination with the Calcasieu Parish Police Jury (CPPJ), the Institute obtained access to those models to expedite model development for BGB. The Institute, however, was not able to obtain any additional related reports documenting the development and calibration of those models. Given the lack of documentation, information regarding the models is based on review of the shared model files by the Institute and is provided below:

1. One-Dimensional (1D) Unsteady State HEC-RAS model of Contraband Bayou.
    a. This model includes simulations of the 2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year ARI events as well as the same events for two different proposed events where alternative size detention basins were evaluated. The size of the pond is in the plan description, however, no further information on the model objective or purpose is available as part of the model setup. The model contains input of flow hydrographs and a terrain representing the bathymetry.
2. Calcasieu Parish Police Jury (CPPJ) 2D HEC-RAS model of Kayouche Coulee No. 1
    a. This model includes simulations of the 2-, 5-, 100-, and 500-year ARI events. The model is a 2D rain on mesh model. A readme PDF was provided with this model which states that Fenstermaker delivered this incomplete model in connection with the Regional Watershed Planning Project to the CPPJ project manager.
3. 2D HEC-RAS model of Kayouche Coulee No.2

   a. This model includes simulations of the 1-, 2-, 5-, 10-, 25-, 50-, 100-, and 500-year ARI events. This model contains all structures within the 2D model domain including the Kayouche Coulee pump station and information about the gates. This model also contains a LiDAR dataset which includes the bathymetry of Kayouche Coulee.

4. 1D Unsteady Pithon Pump Station Lake Charles HEC-RAS Model
   a. This model includes simulations of the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year ARI events. This is an unsteady state 1D model and includes all bridges, culverts, and pump stations in the northeast Lake Charles area. This model also contains a LiDAR dataset which includes bathymetry of relevant bayous and watercourses within the model domain.
5. 1D/2D Woodring HEC-RAS Model
   a. This model includes simulations of the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year ARI events. This model was contained in the same model as the 1D Pithon Pump Station model. It utilizes 1D cross sections connected to lateral structures to allow overflow into the 2D domain. There was only one culvert structure within this model. This model also contains a LiDAR dataset with bathymetry of relevant bayous and watercourses within the model domain.

The spatial coverage of these models is illustrated in Figure 2, which shows that none of the available models could be used on their own, as-is, to evaluate the feasibility of the BGB project. The information contained within these models, however, including the DEM, structures, and other relevant data, were used to the extent possible to develop the model for this study. This subject is discussed in more detail in Section 3.2.1.

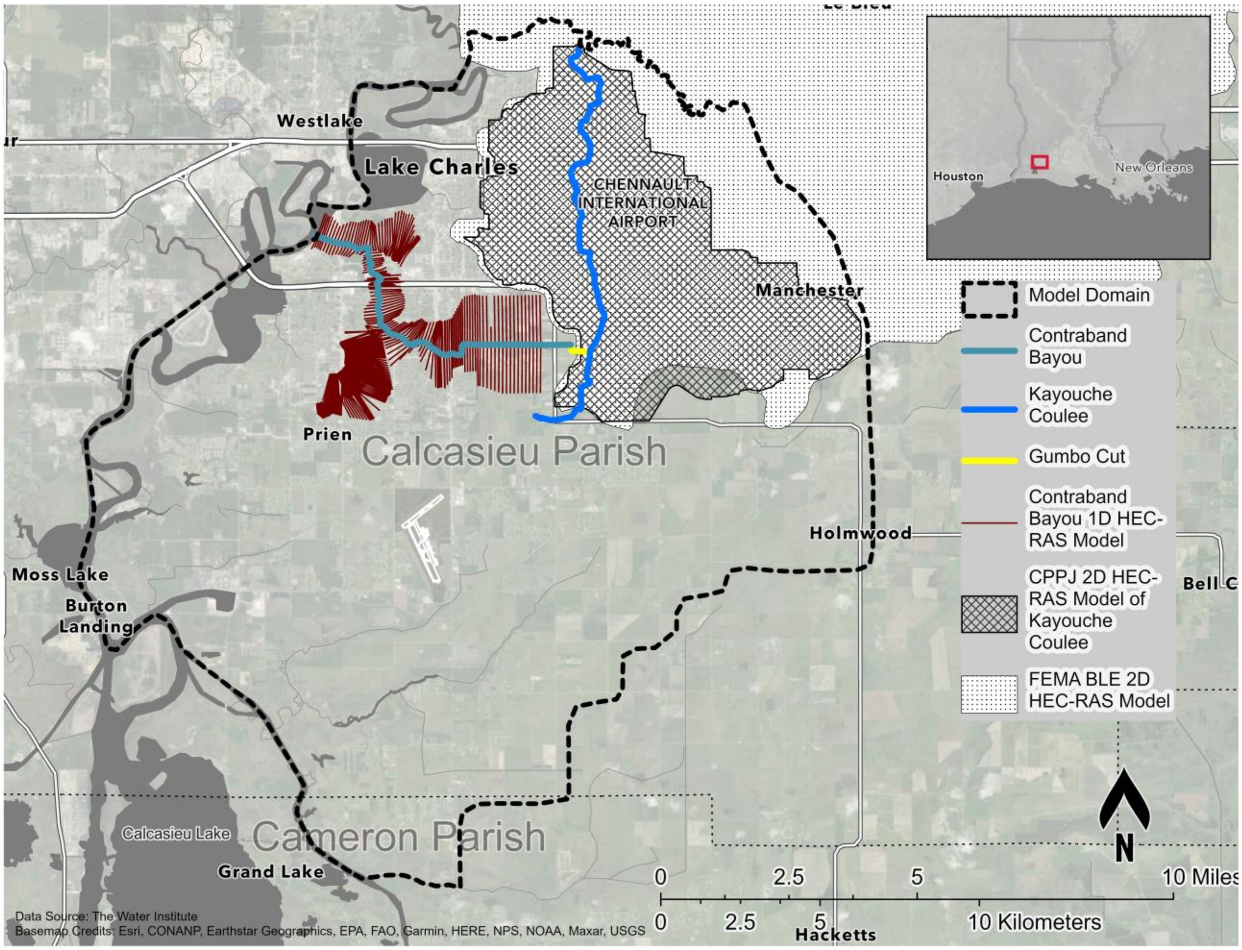

Figure 2. Project study area and the spatial domain extent of previous and existing models

2.3. SALINITY MODELING

Previous salinity studies in the Calcasieu River were conducted by the Institute for the Louisiana Coastal Protection and Restoration Authority (CPRA) under Task Order 14, and used 2D and 3D Delft3D (Deltares, 2017) and 1D/2D MIKE models (Danish Hydraulics Institute, 2011). These studies aimed to simulate salt wedge dynamics in the Calcasieu Ship Channel (Pereira & Meselhe, 2015; Roth & Meselhe, 2015) and encompassed the Calcasieu River; however, Contraband Bayou was not included in the scope of those studies. The model outputs served as input data for more detailed, high-resolution Flow3D models, which simulated salinity control measures in the Calcasieu Ship Channel. In the current study, the previously described Delft3D model (Pereira & Meselhe, 2015; Figure 3) was used as a starting point for developing a more detailed model that covers Contraband Bayou and a segment of the Calcasieu River.

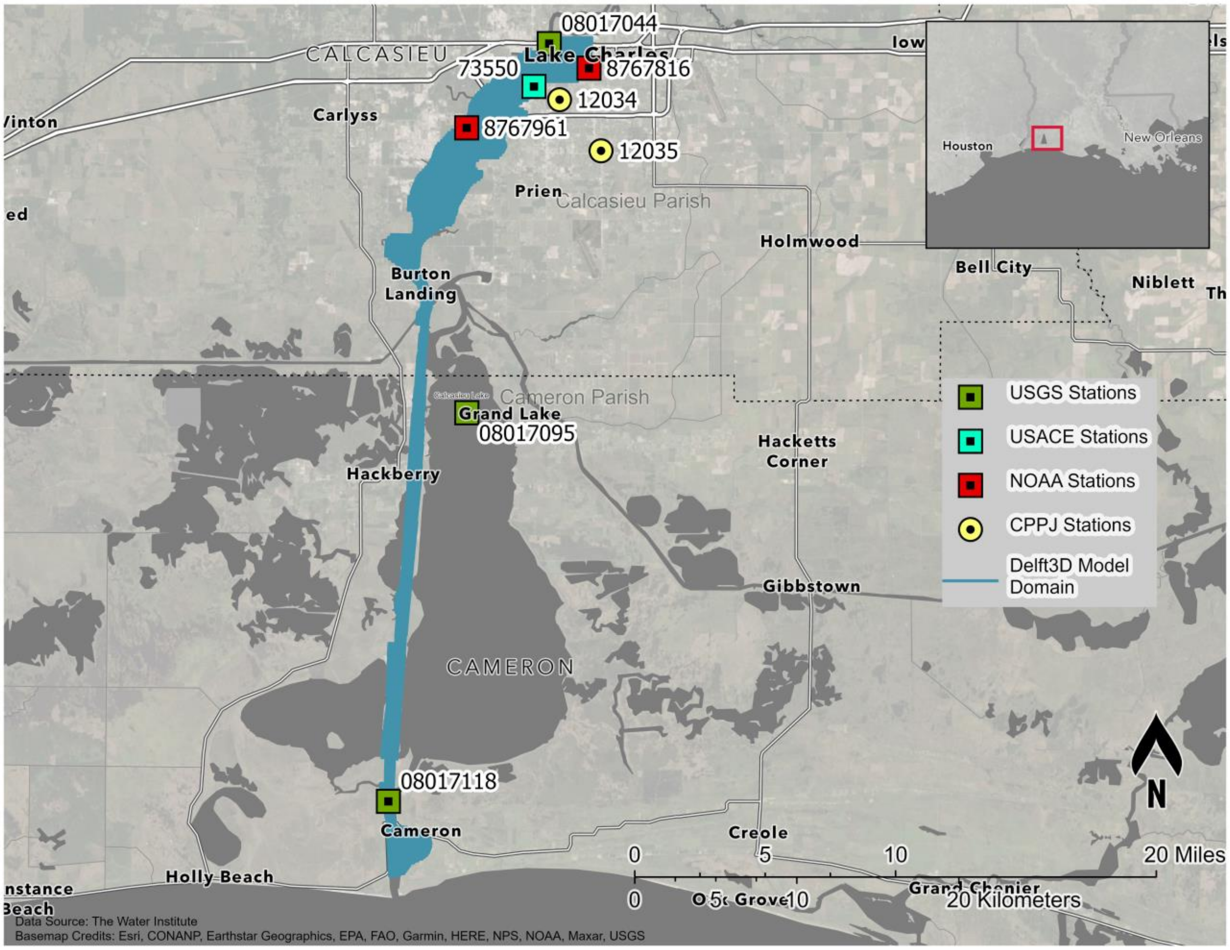

Figure 3. Previously developed 3D model of the Calcasieu River by the Institute for CPRA under Task Order 14 (Pereira & Meselhe, 2015).

One of the main concerns associated with salinity intrusion is the negative impacts on the cypress-tupelo swamps that are commonly found in coastal Louisiana. Several studies have indicated that coastal swamp forests in Lake Maurepas, Louisiana, have degraded considerably due to the adverse effects of saltwater intrusion, nutrient deprivation, and stagnant water (Hoeppner et al., 2008; Shaffer et al., 2009). A 5-year monitoring study in Lake Maurepas, which included intense drought conditions, reported that annual mean soil salinity reached 2–5 ppt during the drought, and cumulative tree mortality reached up to 85% in areas exposed to frequent saltwater intrusions (Hoeppner et al., 2008). In this study, the interpretation of model results focuses on saltwater intrusion events influencing the water column (not the soil), evaluating when salinity values fall within or exceed the concentration range of 2–5 ppt. This is a conservative approach because mean soil salinity values respond more slowly to changes in salinity in the water and require prolonged exposure to saltier conditions (Shaffer et al., 2009).

3.0 METHODS

3.1. DATA SYNTHESIS

The development of a 2D hydraulic model for a large spatial extent often requires the use of multiple datasets. The typical datasets that are required include a terrain file, which shows the topography and bathymetry of the area of interest throughout the model domain; a landcover dataset showing the habitat distribution; pervious and impervious surfaces that could influence drainage patterns and rainfall infiltration in the study area; and information on existing structures influencing drainage and relevant to the objective of the study that need to be implemented.

3.1.1 Terrain and Bathymetry

During the evaluation of the shared models developed by Fenstermaker, it was observed that bathymetry information for bayous and drainage ditches had been integrated into the terrain. While the date and source of the terrain used is not known, as no documentation was provided, it was determined that this was still the best source of terrain to use in this study, given that bathymetry is significant to conveyance. Areas outside of the available terrain were supplemented by the 2018 USGS 1-meter terrain (USGS, 2018). The missing bathymetry for Contraband Bayou, which was not included in either of the terrains, was added using bathymetry from the Fenstermaker Bayou Contraband 1D model. Elevations from the cross-sections of the 1D model were transferred and used to create the Contraband Bayou geometry in the final terrain. All the terrain data sources are listed in Table 1 and the final merged terrain is shown in Figure 4. To model salinity, bathymetric data for the Calcasieu River was required, in addition to the Contraband Bayou bathymetry. Similar to the Delft3D models described in Section 2.3 (Pereira & Meselhe, 2015), the bathymetry from the 2017 Coastal Master Plan (Couvillion, 2017) was used to define the bathymetry of the Calcasieu River within the salinity model.

*Table 1. Terrain data sources used to create the final terrain for the Bayou Greenbelt project. **The 1D cross sections contained bathymetry that was used to add to the terrain to represent Contraband Bayou conveyance.*

Terrain Source	Terrain Resolution (ft)
Fenstermaker 1D Unsteady Pithon Pump Station HEC-RAS model	**
Fenstermaker 1D/2D Woodring HEC-RAS model	3
Fenstermaker 2D HEC-RAS model No. 2	3
USGS Sabine River LiDAR	3.28

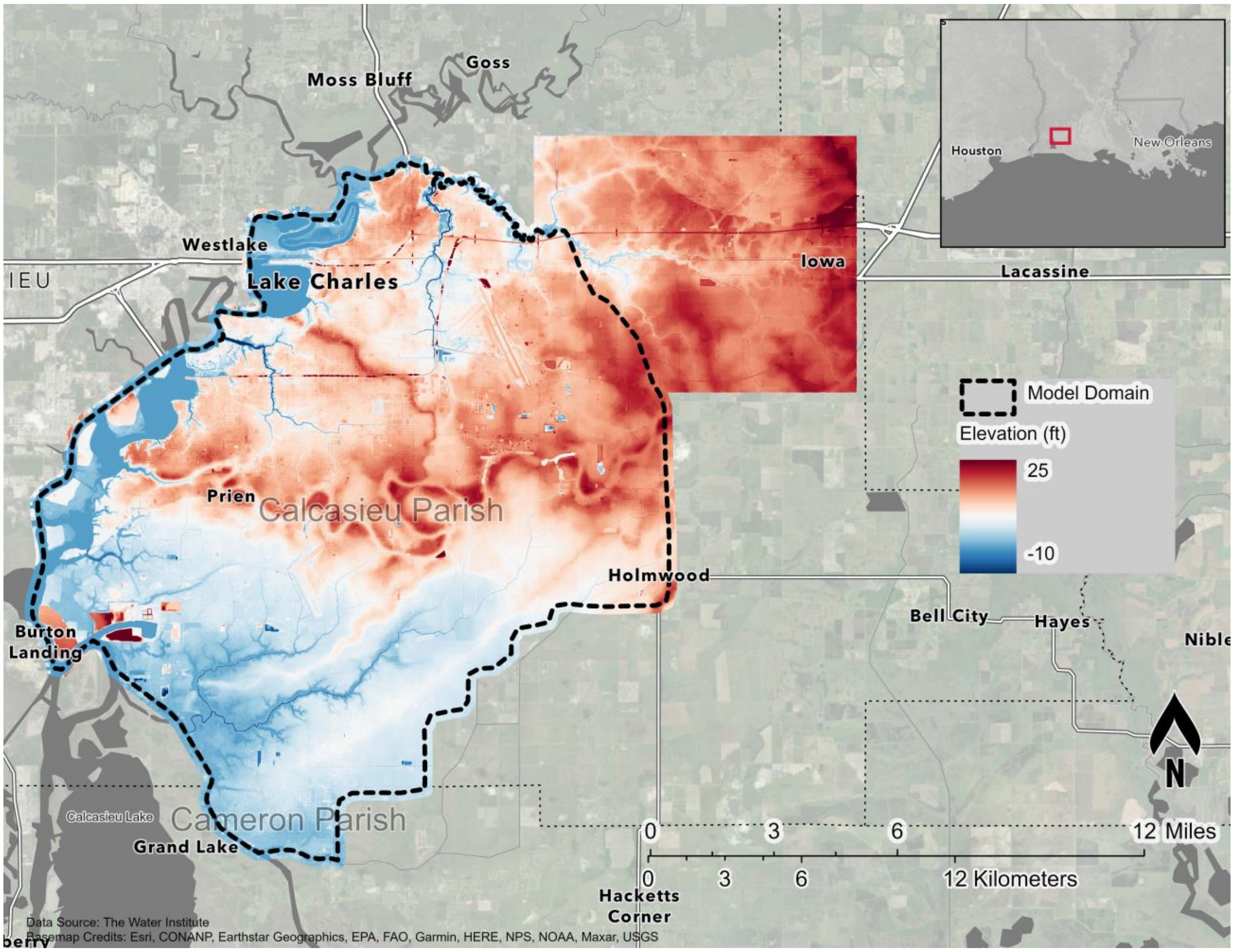

Figure 4. The final DEM used in the model , including all the datasets described in Table 1, with the embedded bathymetric cross sections from the 1D model into Contraband Bayou.

3.1.2 Land Cover and Impervious Cover

To properly define the land cover and impervious layers throughout the model domain, the 2019 National Land Cover Database (NLCD; Dewitz, 2021) was used to impose varying roughness coefficients (Manning's n values). Manning's n values are associated with the land cover type in the NLCD 2019 land use land cover (LULC) dataset. USACE provides recommendations for use of Manning's n values relative to the LULC type (USACE, 2024). Table 2 lists each land cover type, the associated ranges of Manning's n values recommended, and the corresponding percent imperviousness. The modeling in this study used the information included in Table 2 to select the initial values throughout the study area (Figure 5) to ensure the methods used to classify land use remained within recommendations during calibration. Where necessary, Manning's override regions were identified and digitized for the large waterways throughout the study area so as to isolate channel roughness coefficients and provide robustness during calibration (see further discussion in Section 3.2.3).

Table 2. Manning’s n values and percent impervious for various NLCD Land Cover Types shown in Figure 5.

NLCD Value	Land Type	Manning’s n			
		Low	Medium	High	Percent Impervious
11	Open Water	0.025	0.0375	0.05	100
21	Developed, Open Space	0.03	0.04	0.05	0
22	Developed, Low Intensity	0.06	0.09	0.12	20
23	Developed, Medium Intensity	0.08	0.12	0.16	40
24	Developed High Intensity	0.12	0.16	0.2	60
31	Barren Land (Rock/Sand/Clay)	0.023	0.0265	0.03	0
41	Deciduous Forest	0.1	0.15	0.2	0
42	Evergreen Forest	0.08	0.12	0.16	0
43	Mixed Forest	0.08	0.14	0.2	0
52	Shrub/Scrub	0.07	0.115	0.16	0
71	Grassland/Herbaceous	0.025	0.0375	0.05	0
81	Pasture/Hay	0.025	0.0375	0.05	0
82	Cultivated Crops	0.02	0.035	0.05	0
90	Woody Wetlands	0.045	0.0975	0.15	50
95	Emergent Herbaceous Wetlands	0.05	0.0675	0.085	75

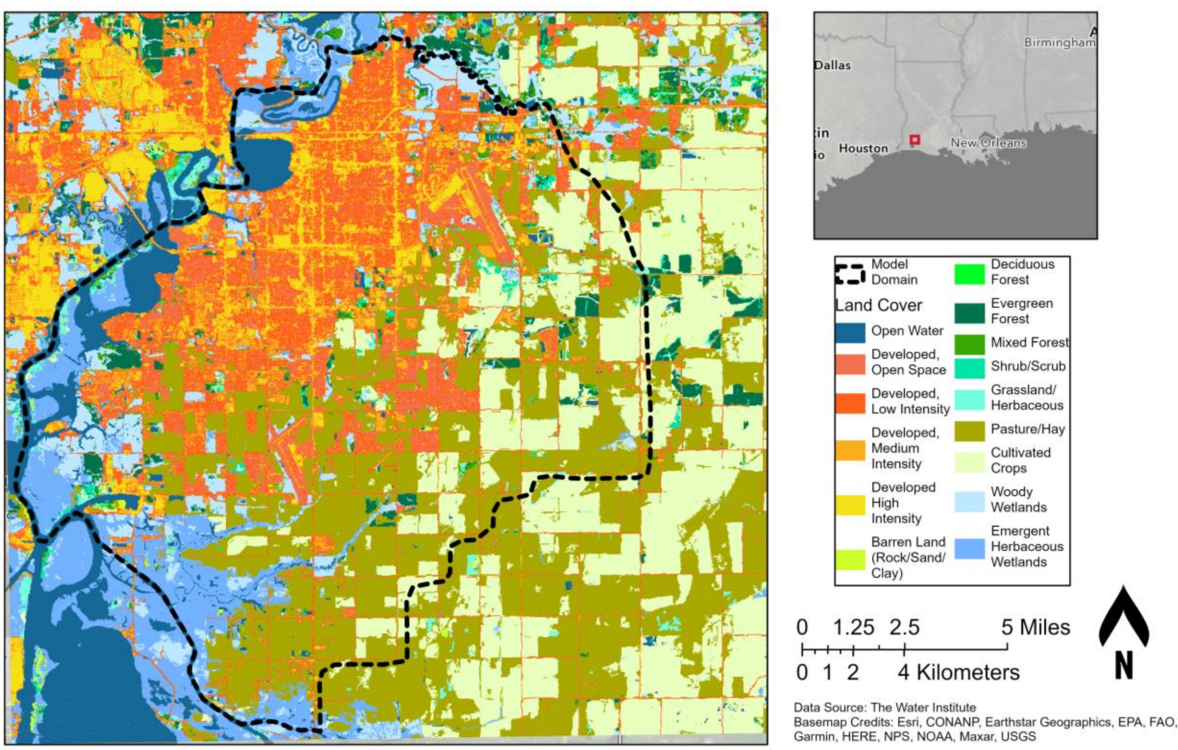

Figure 5. NLCD Land Cover Classification.

3.1.3 Soil Data

Soil data was obtained from the U.S. Department of Agriculture's (USDA's) Gridded Soil Survey Geographic Database (gSSURGO) 2023 (USDA, 2023) and used to spatially assign soil properties throughout the model domain (Figure 6). To establish a reference framework for hydrologic losses, soil data types were correlated to the corresponding soil zone classification. The HEC-RAS model used the maximum deficit input derived from the gSSURGO database (Table 3) combined with the NLCD landcover dataset to determine the rainfall deficit. The initial deficit and potential percolation rate parameters were assumed to be 50% of the maximum deficit.

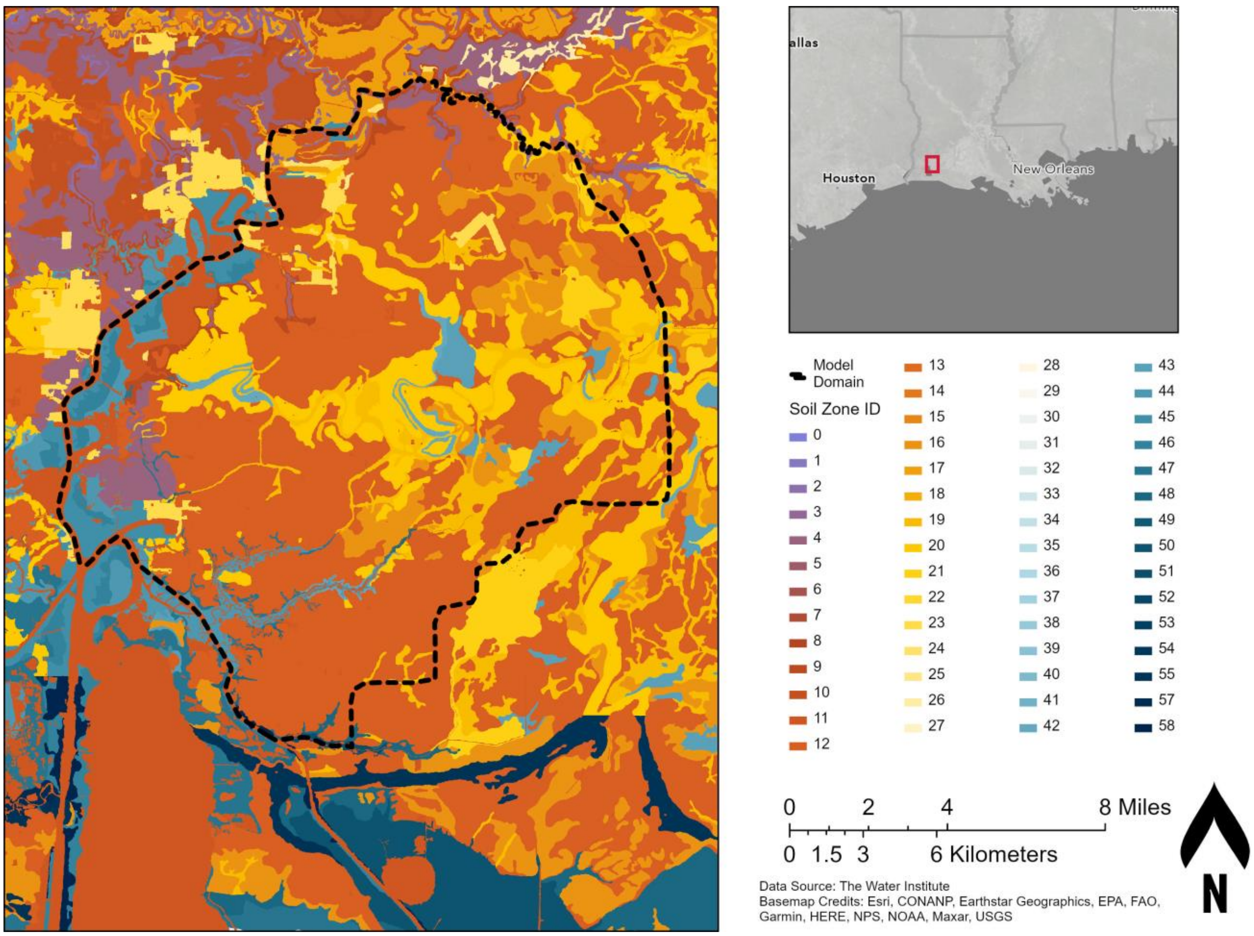

Figure 6. Soil data and the root zone storage per zone and hydrologic soil group. The root zone storage is used as the input data for the loss method in the HEC-RAS model.

Table 3. Range of the potential percolation rate

Hydrologic Group	Range of potential percolation rate (in/hr)		
	Min	Median	Max
A	0.3	0.38	0.45
B	0.15	0.23	0.3
C	0.05	0.1	0.15
D	0	0.03	0.05

3.1.4 Precipitation Data

Due to a spatial degradation in the quality of the Analysis of Record for Calibration (AORC) dataset during the May 17, 2021 flood event, Multi-Radar/Multi-Sensor (MRMS) historical precipitation data was used. The MRMS system was developed to produce severe weather precipitation products to improve decision-making capability for hazardous weather forecasts and warnings, along with hydrology, aviation, and numerical weather projections (MRMS, 2021). MRMS data were downloaded and processed into a spatially varied gridded format spanning the May 17, 2021 event duration for input into the hydraulic model. The MRMS data were then compared to in-situ rainfall observations at selected locations where observations of precipitation were available for the same period to ensure a good match. The precipitation observations used for comparison were sourced from the CPPJ gauge network and are freely available online. Following confirmation of a good match, the MRMS dataset was used in the calibration.

Project valuation for each of the ARI events (e.g., 10-year and 100-year) used NOAA Atlas-14 datasets, which were downloaded and processed in gridded format for input into the hydraulic model. NOAA Atlas-14 is a collection of rainfall frequency data for various locations in the U.S., providing information on the statistical likelihood of different rainfall events occurring over a specified duration (e.g., 12, 24 hours etc.) and return periods (e.g., 5-year, 10-year, 25 -year, 100-year, etc.). This study used a 24-hour duration, and an ARI of 10 and 100 years at two tailwater conditions, namely median tide and high tide conditions.

For assessment of freshwater runoff volumes during the drought period used for the evaluation of salinity impacts, the hydraulic model was used to simulate freshwater runoff flows entering the project area or existing canals. For those simulations, the study used AORC rainfall data, as MRMS data was unavailable for the required simulation period (later summer to early fall for the year 2013) in the salinity model. AORC precipitation data is a gridded record of near-surface weather conditions covering the continental U.S. and Alaska and their hydrologically contributing areas (AORC, 2021).

3.1.5 Gauge Data

Observed water levels were used for two primary purposes in this study. First, water levels at the perimeter of the study area, in the surrounding waterways, were used to set boundary conditions during model calibration and during scenario simulations, and second, water levels within the model domain, were used to assess model skill during the calibration, and ensure that the model reproduced observations reasonably well. Observed stage data used (Figure 7) were from NOAA, USGS, and from the network operated by the CPPJ (CPPJ, n.d.). Water levels from NOAA stations were used to determine downstream boundary conditions for the waterways around Lake Charles (Figure 7) while USGS stations (08017044, Calcasieu River at I-10 at Lake Charles, LA; USGS08017095 North Calcasieu Lake near Hackberry, LA) were used to assign salinity boundary conditions for the salinity model. Finally, CPPJ stations were used to calibrate water levels in the hydraulic model during the May 17, 2021, event. There is a total of 32 stations available from the CPPJ observation network with data collection intervals ranging from minutes to hours between stations (Table 4). For the hydraulic model calibration (May 17, 2021), observed data at 24 stations were available and were selected for comparison with the model. Observed stage time-series were adjusted to Coordinated Universal Time (UTC) to match water level observations by other agencies. Since many of the stations throughout the CPPJ network are reporting stage instead of water level or are reporting water level that is not directly tied to a datum for the period of interest in 2021 (e.g. NAVD88), adjustments and shifts were applied to selected gauges informed by other agency gauges that were reporting water levels to the NAVD88 datum (e.g. NOAA and USGS). Following conversations with CPPJ, and knowing that all stations were re-surveyed recently, the data from the May 17, 2021 event were adjusted based on the stage differences observed before and after the re-surveys. Additionally, for gauges under tidal influence, it was assumed that the model's predicted tidal signal should have the same mean and magnitude as the observed tidal signal. Consequently, the observed datasets were shifted to match the tidal signal before and after the event. The corrections applied are shown in Table 4.

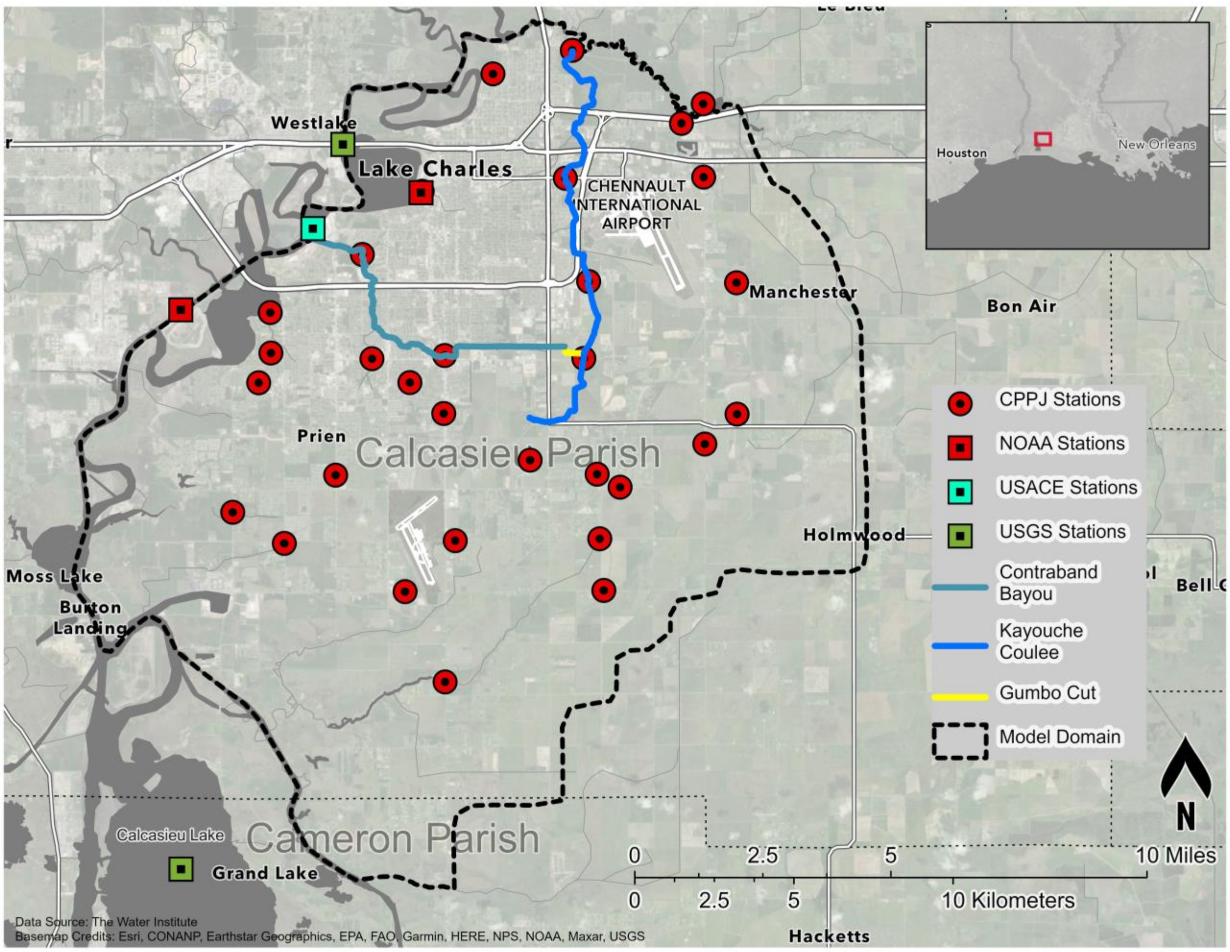

Figure 7. The CPPJ, NOAA, and USACE stations evaluated for this study for use in calibration and development of boundary condition information from historical data.

Table 4. CPPJ monitoring stations used in the hydraulic model calibration and corresponding correction factors.

Station ID	Correction Factors (ft)	Correction method
Antoine Pump Station_Antoine Gully (12129)	0.5	tidal
Antoine Pump Station_English Bayou (12129)	0.5	tidal
Black Bayou @ E Lincoln Road (12102)	-0.3	tidal
Black Bayou @ Gulf Hwy (12101)	-0.1	tidal
Contraband Bayou @ 18th Street (12034)	0.5	tidal
Contraband Bayou @ Common Street (12035)	0.5	tidal
English Bayou @ Pujol Road (12082)	0	n/a
Harless Pump Station_Downstream (12130)	0	tidal
Harless Pump Station_Upstream (12130)	0	tidal
Henderson Bayou @ Devon Lane (12121)	-0.35	tidal
Henderson Bayou @ W Prien Lake Road (12123)	0	n/a
Kayouchee Coulee @ Broad Street (12069)	0	n/a
Kayouchee Coulee @ East Prien Lake Road (12005)	0.07	re-surveyed
Kayouchee Coulee @ McNeese Street (12068)	0.13	re-surveyed
Kayouchee Coulee Pump Station_Coulee (12037)	0	tidal
Kayouchee Coulee Pump Station_English Bayou (12037)	0	tidal
L-1 @ Tank Farm Road (12063)	0	tidal
L-2 @ McNeese Street (12036)	0.4	tidal
L-3 @ Addison Loop (12066)	0	n/a/
L-3 @ Tank Farm Road (12064)	-1	tidal
L-5 @ Common Street (12067)	0	n/a
L-5 @ Gauthier Road (12065)	0	n/a
Pithon St Pump Station_Lateral (12135)	0	n/a
Pithon St Pump Station_Lake (12135)	-0.7	tidal
W-14 @ Joe Spears Road (12012)	0.24	re-surveyed
W-4 @ Elliott Road (12027)	0.5	tidal
W-4 @ Nelson Road (12026)	1.3	re-surveyed
W-5 @ Big Lake Road (12062)	1	tidal
W-6 @ Ward Line Road (12028)	-0.33	re-surveyed

3.1.6 Hydraulic Structures

The HEC-RAS 2D hydraulic model included several structures, with control gates and pump stations at five locations throughout the model domain (Figure 8). The geometry and operations for these structures were obtained from multiple sources and are outlined in Table 5. Following initial entry in the model, the Institute met twice with the Gravity Drainage District 2, first on May 18, 2023 and again on August 21, 2023, to verify information obtained by third parties, confirm key operations, and obtain as much information on pump stations and gates as possible. The meetings were held at the Kayouche Coulee pump station building. Following the meetings, Gravity Drainage District 2 shared information with the Institute outlining additional information and operational details. In some instances, the operational information described the overall approach, leaving some details required by the model still unavailable or incomplete. For those structures where additional information was required, operations were assumed based on proximal or similar pump or gate operations and were verified (iteratively) during calibration of model output to observations during the May 17, 2021 event.

Table 5. Information on pump stations and gates used in the hydraulic 2D model and the corresponding source of the operational data

Model ID	Description	Source of Data
KC_GATES	Kayouche Coulee Gates	Fenstermaker 2D HEC-RAS Model No. 2
KC_PS	Kayouche Coulee Pump Station	Fenstermaker 2D HEC-RAS Model No. 2
Pithon_GATES	Pithon Gates	1D Unsteady Pithon Pump Station Lake Charles HEC-RAS Model
Pithon_PS	Pithon Pump Station	1D Unsteady Pithon Pump Station Lake Charles HEC-RAS Model
Griffith_GATES	Griffith Gates	1D Unsteady Pithon Pump Station Lake Charles HEC-RAS Model
Harless_GATES	Harless Gates	Pump Capacity Memo -Gravity Drainage District 2
Harless_PS	Harless Pump Station	Pump Capacity Memo -Gravity Drainage District 2
Antoine_GATES	Antoine Gates	Pump Capacity Memo -Gravity Drainage District 2
Antoine_PS	Antoine Pump Station	Pump Capacity Memo -Gravity Drainage District 2

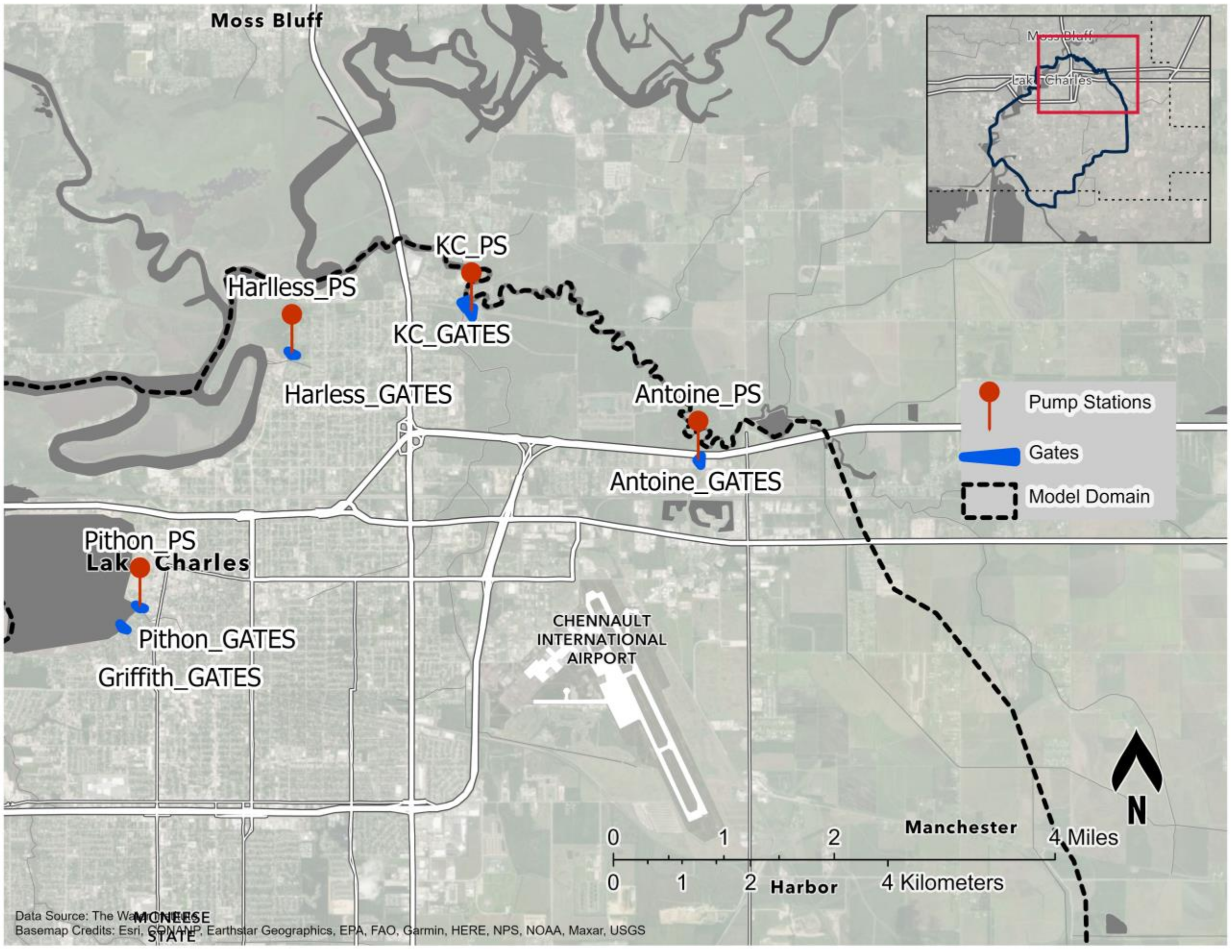

Figure 8. Locations of structures (pump stations and gates) used in the hydraulic model.

3.2. HYDROLOGY AND HYDRAULICS

This study used a 2D hydraulic model based on HEC-RAS version 6.4.1, with gridded precipitation data from MRMS, AORC, and NOAA Atlas-14 implemented throughout the model domain. The hydraulic model also included large structures, such as gates and pump stations (Table 5).

3.2.1 Model Domain

The model used a global square mesh spacing of 200 ft to best represent the underlying terrain. In addition, breaklines representing roadways, existing channels, waterway and topographic transitions, elevated features, and other areas or features of interest were added to promote local refinement and implement those features into the mesh. In some instances, the breaklines were assigned a smaller mesh spacing to better represent the underlying terrain or other necessary features. Along the proposed project route, the model domain was adjusted to ensure the grid followed high elevation points along the project area that encompass both Gumbo Cut, connecting Contraband Bayou to Kayouche Coulee, and extended south of the city toward the Gulf Intracoastal Waterway (GIWW). Figure 9 shows the extent of the final model domain and the locations of both proposed projects. The solver selected for the hydraulic model used the Shallow Water Eulerian–Local Inertia Approximation (SWE-LIA) equations which solves the unsteady state equations, and it is better suited for conditions where flows change both in direction and magnitude rapidly.

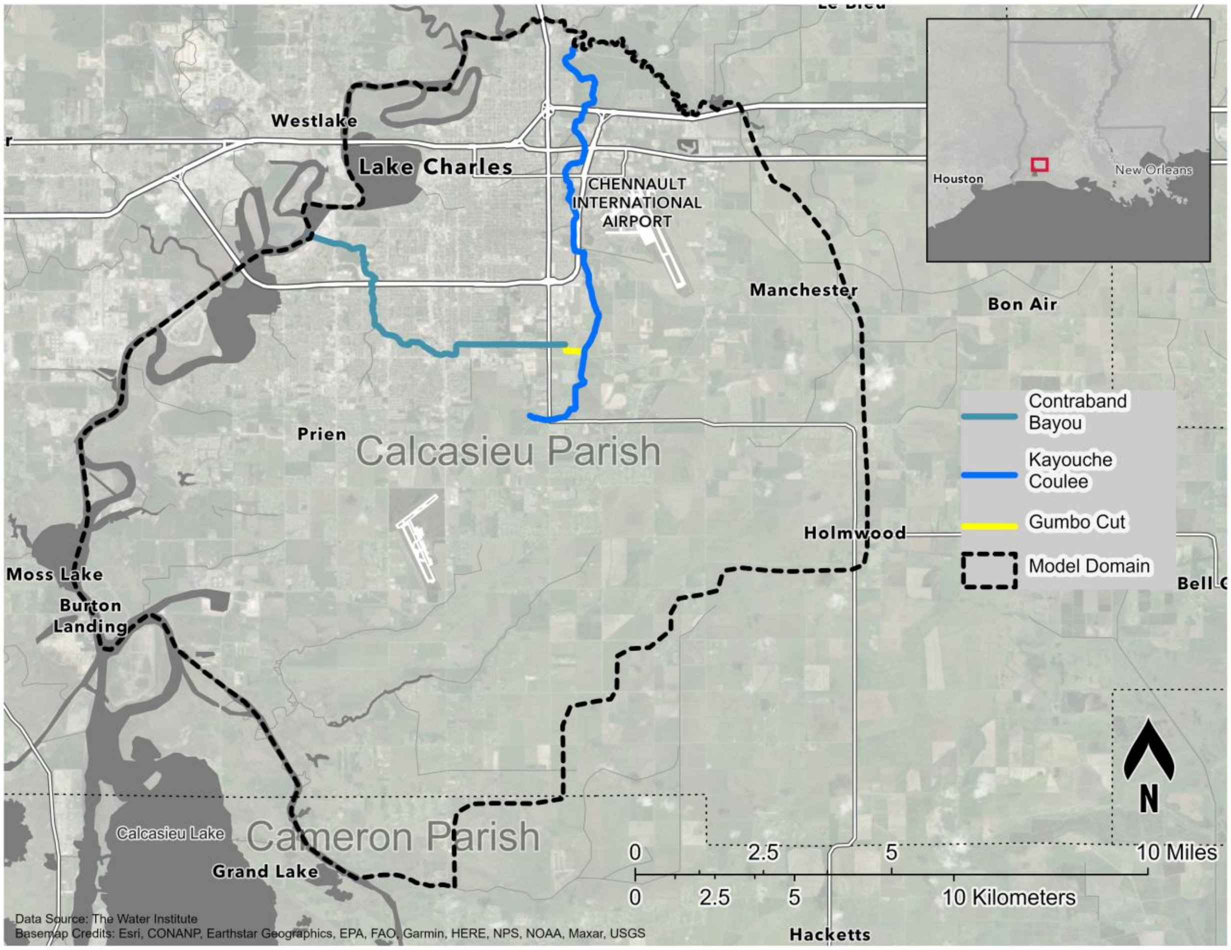

Figure 9. Major waterways within the model domain, showing the connection of Contraband Bayou to Kayouche Coulee via Gumbo cut (yellow line).

3.2.2 Downstream Boundary Conditions

During the calibration of the model for the May 17, 2021 event, the downstream boundary conditions (or tailwater conditions) were determined by using observations in the Calcasieu River and throughout Lake Charles at gauging stations operated by NOAA and the CPPJ. The observed time-dependent signal obtained from the gauging stations, which report water level to datum every 15 minutes, was used to force the downstream/tailwater boundary in the model. The model's downstream boundary was divided into five regions (Figure 10), namely Black Bayou, GIWW, Calcasieu River, English Bayou, and the inland region toward the city's northeast. For the Black Bayou and GIWW boundaries south of the city, where water level observations to datum are lacking, the study used the water level at the NOAA station at Bulk Terminal. This is considered a conversative assumption since both Black Bayou and GIWW are seaward of the NOAA gauge at Bulk Terminal and would likely experience lower water levels compared to the Calcasieu River, except potentially during storms where coastal setup north of Calcasieu Lake may be higher than Calcasieu River water levels due to backwater effects.

The selection of downstream water levels to align with a return period when using ARI events to evaluate project conditions is a complex task. It requires more detailed and sophisticated probabilistic (Kim et al., 2023) or multivariate analysis (Santos et al., 2021) and is beyond the scope of this study. As this study assesses the feasibility phase of the project, a simplified methodology was adopted to assign downstream water levels for each of the ARI events evaluated, which were 10 and 100 years. The study assumed that rainfall associated with an inland storm can occur independently of a marine tropical or extra-tropical system and could occur at any anytime during the year and during the day, regardless of high- or low-tide conditions. The median mid-tide and high-tide elevations were identified by analyzing a 10-year hourly record of water levels at the NOAA Bulk Terminal station. To begin, the 24-hour average water level (mean), and high tide water level elevations were calculated and extracted. Then, the 50% exceedance (median) elevation for each record (mean and high tide) was selected and used. This method is conservative because it captures water level peaks (high tide) for periods associated with meteorological events, wind tides, and astronomical tides (Table 6). As the water level for the Calcasieu River, GIWW, and Black Bayou is in proximity, it was assumed to be the same. However, the water level at English Bayou, located upriver from the Calcasieu saltwater barrier upstream, was adjusted to be higher than the water level established from the analysis at the NOAA gauge. This adjustment was made by extrapolating the previously established value at the NOAA gauge using the Calcasieu River water surface slope (Table 6. This adjustment was necessary as the Calcasieu River is ungauged above the saltwater barrier, and gauging information is lacking to provide accurate model boundary conditions in that region.

Table 6. Stage boundary conditions used to assign tailwater conditions during modeling of ARI events for project assessment.

Boundary Condition Line ID	Mid Tide (ft NAVD88) 50% exceedance for a 10-year period	High Tide (ft NAVD88) 50% exceedance for a 10-year period
Calcasieu	0.466	1.073
English Bayou	1.122	1.729
GIWW	0.466	1.073
Black Bayou	0.466	1.073

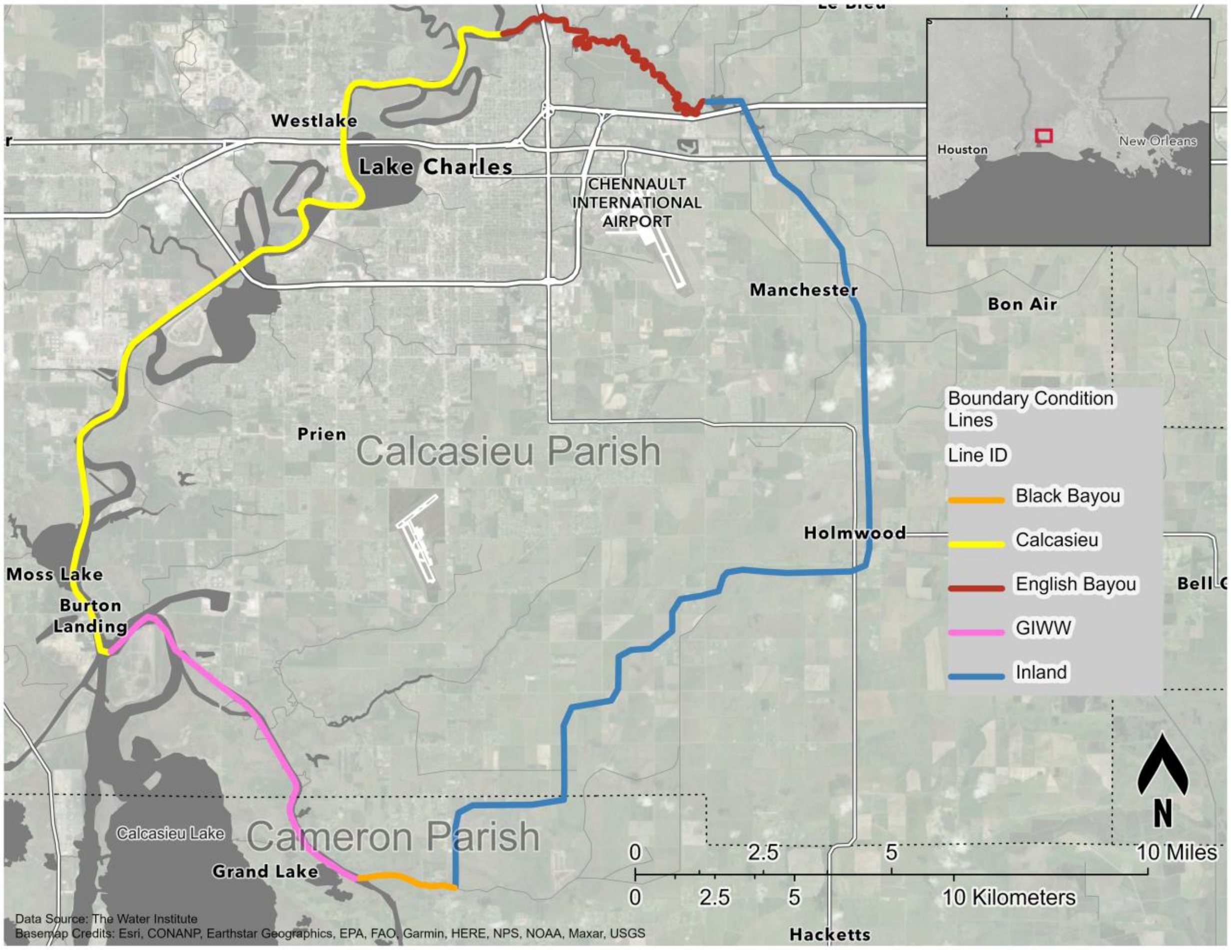

Figure 10. Each boundary condition line used in the HEC-RAS model is shown here. Each boundary condition line used the stage data in Table 6 except for Inland which used a normal depth.

3.2.3 Model Calibration

The process of calibrating the model required selecting the May 2021 flood, which took place over two days from May 16 to May 17, 2021 (May 17 event). Water levels from various gauges located in the Calcasieu River and the City of Lake Charles were used to represent the downstream and upstream ends of the model domain. Water level observations were interpolated between stations to ensure that the model boundary values were as close to observations as possible. For instance, water level observations were interpolated between stations such as NOAA 8767961 at Bulk Terminal and 8767816 at Lake Charles (Figure 7). To establish water levels for English Bayou to the north of the model domain, the water level boundary values were prepared using three stations, namely CPPJ 12082 at Pujol Road, CPPJ 12037 at Kayouche Coulee Pump Station, and NOAA 8767816 at Lake Charles. The water level boundary to the south and west used the NOAA 8767961 at the Bulk Terminal station. Lastly, the inland water level boundary condition was defined as normal depth to allow water to flow out of the computational domain if it encounters the edge of the model domain.

The May 17, 2021 event caused heavy rainfall in Lake Charles, and was the third-wettest day in the city's recorded history (NOAA, 2021). This event was chosen for use in the model calibration as it was a recent occurrence with overlapping water level observations from CPPJ and NOAA. Precipitation data was incorporated into the model using MRMS which is a spatially varying gridded dataset (see Section 3.1.4). During calibration, observed water levels at CPPJ stations in the study area (Figure 7) were used to compare the model results during the calibration with observations during the May 17 event. During discussions with city officials and stakeholders that took place during the model competency meetings, the project team heard that storms which took place prior to the May 17 event produced debris that, according to many accounts, clogged drains, stream crossings at culverts and bridges, and produced saturated soil conditions. Since the model in this study does not account for subsurface flow routing and does not resolve small structures such as culverts, the calibration procedure included iteratively increasing Manning's roughness within the model to indirectly account for these flow obstructions and represent debris within the model. Manning's override regions were digitized from bank to bank for each stream, and values were iteratively increased until model skill was acceptable during calibration. Figure 11 shows the model skill from the calibration for selected gauge stations operated by the CPPJ, comparing model output (blue lines) with observations (red lines), and Figure 12 shows the spatial extent of the flooding resulting from the event.

The model accurately predicts the timing of the flood peak and the flood recession, and for gauges that experience tides the model captures tidal fluctuations reasonably well (Figure 11). Some stations located far from the project location underestimated the flood peak, likely due to model resolution and uncertainties related to smaller structures such as culverts not resolved by the model. However, at most stations located along the project route, and within Contraband Bayou and Kayouche Coulee the model performed well (Table 7). Thirty-one available gauges were used during model calibration with valuation of model skill statistics which included percent bias (PBIAS), Nash-Sutcliffe model efficiency coefficient (NSE), mean absolute error (MAE), root mean square error (RMSE), the RMSE-observations standard deviation ratio (RSR), and the coefficient of determination (R^2). Across all 31 gauges (Table 7), the model had an average bias of 1.6% and variance of 6.3%, with only five stations exceeding 5% bias, suggesting that 26 of the 31 stations had a bias of less than 3%. Similarly, NSE average score was 0.89 (ranging from 0.86 to 0.92 for most locations), while the average R^2 score was 0.96 (ranging from 0.94 to 0.98 for most stations). MAE and RMSE were also relatively low, with averages of 0.15 ft and 0.22 ft respectively and corresponding standard deviation across all stations of 0.2 ft and 0.3 ft, respectively. While at some (five to six) of the gauging stations the model skill was lower, overall, these summary statistics are very good, and the calibration was accepted (Table 7).

Table 7. Model skill statistics and range of performance from all 31 gauges used during the calibration.

	BIAS (%)	NSE	RSR	MAE (ft)	RMSE (ft)	R^2
Average	-1.60	0.89	0.18	0.15	0.22	0.96
Maximum	9.11	1.00	1.13	0.84	0.97	1.00
Minimum	-32.74	-0.29	0.00	0.00	0.00	0.16
Standard Deviation	6.3	0.3	0.3	0.2	0.3	0.2

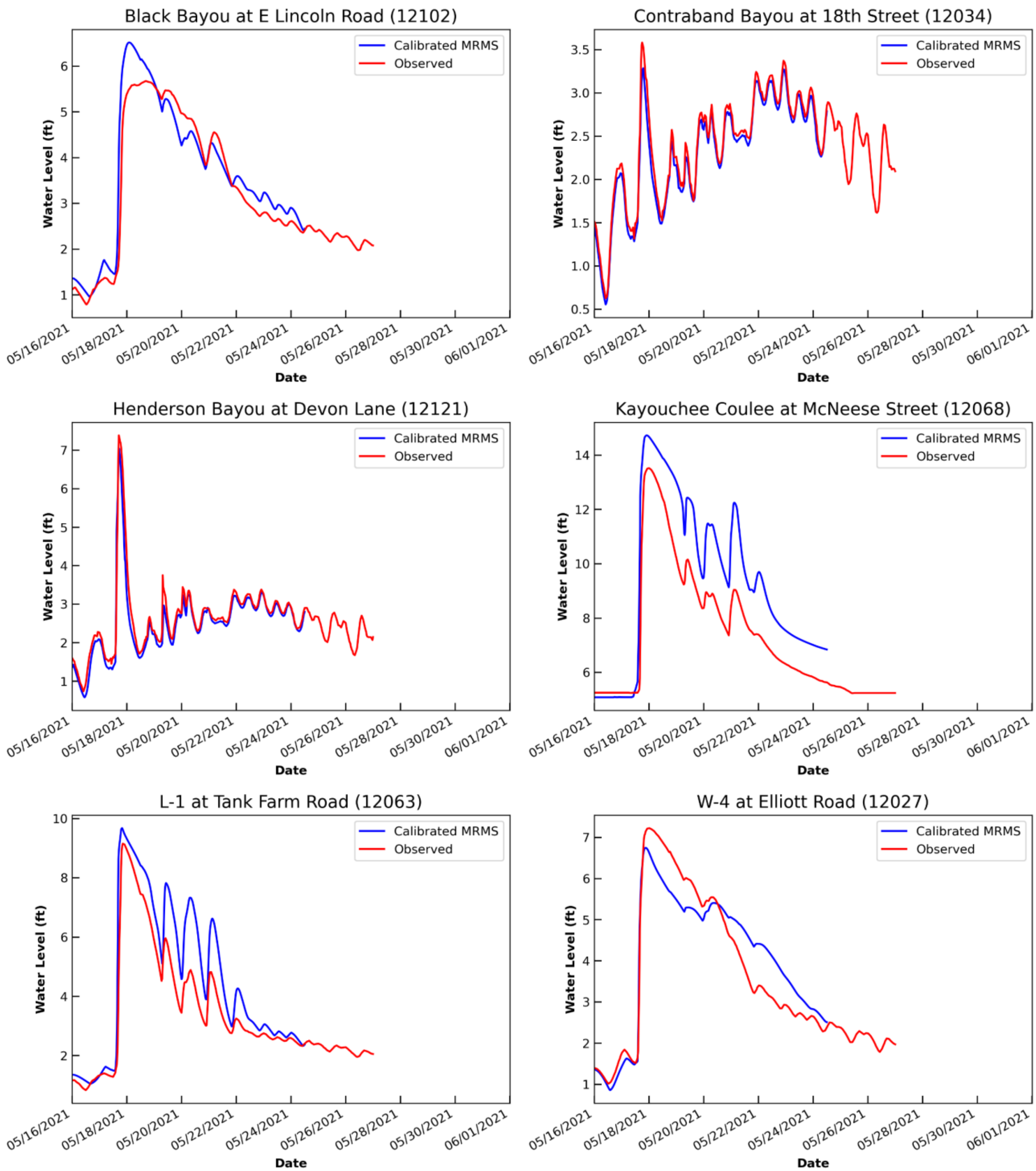

Figure 11. Model skill during calibration showing selected model output (blue line) compared to observations of water level (red line) from the CPPJ gauge network during the May 17, 2021 flood. The model reproduced water level observations very good at most of the stations, and reasonably well for the rest. Both examples are shown. For a range of model skill statistics from all thirty-one gauges used in the calibration see Table 7.

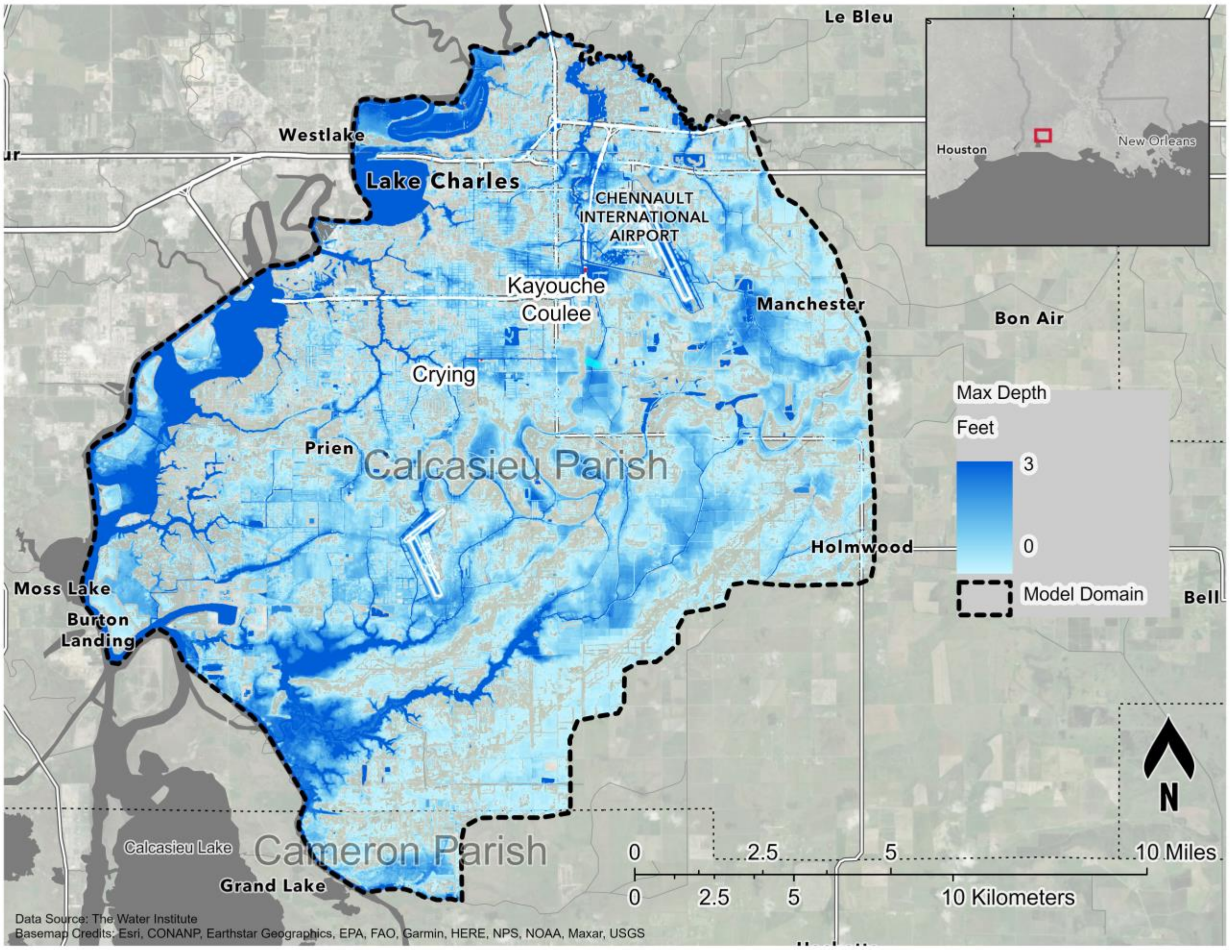

Figure 12. Flood inundation depth and extent produced by the May 17, 2021 storm event, showing maximum inundation depth resulting from the storm during the HEC-RAS model calibration (Note: the mean flood depth throughout the model domain was 1.32 ft with a standard deviation of 1.72 ft.

3.3. SALINITY MODEL

The Delft3D salinity model was developed exclusively for this project, but was informed by previous modeling efforts (Pereira & Meselhe, 2015) as described in Section 2.3. While the previous model did not include Contraband Bayou, it provides 3D simulation results in the Calcasieu River for the periods between September 1–November 23, 2013, as well as April 19–Aug 30, 2014. These simulation periods overlap with multiple hydrodynamic and salinity data collection efforts that were used to calibrate the previous model. Because of the presence of a previously calibrated model, and the availability of salinity observations, the same periods of analysis were selected for this study to leverage previous efforts as much as possible.

3.3.1 Model Domain

The model domain of the Delft3D salinity model (Figure 13) encompasses the entirety of Bayou Contraband, including the proposed Gumbo Cut, and the stretch of Kayouche Coulee between the Gumbo Cut and the Kayouche Coulee Pump Station at the confluence with English Bayou. For simulations without project implementation, the Gumbo Cut and the enlargement of Kayouche Coulee from Gumbo

Cut toward the pump station were inactive within the model domain, as they lack a connection to any coastal waterbody that could serve as a source of salinity. To represent conditions in the Calcasieu River at the mouth of Contraband Bayou, a 6-mile (10 km) segment of the Calcasieu River between the I-10 bridge and the NOAA Bulk Terminal gauge was included in the model domain. These locations were selected based on the availability of gauge data (refer to Section 3.3.2) and their proximity (approximately 3 miles in each direction) from Bayou Contraband. This distance is considered sufficiently far to enable the model to find a dynamic equilibrium at the mouth of Contraband Bayou, while also minimizing the computational overhead resulting from an unnecessary extensive model domain.

The grid resolution varies spatially, with 6 grid cells across the width of the Calcasieu River. The streamwise resolution ranges from approximately 1,000 ft (300 m) in straight segments of the river to about 200 ft (60 m) in curved sections. For Contraband Bayou, Gumbo Cut, and Kayouche Coulee, the grid includes 7 grid cells across the channel's width. The grid extends to a minimum width of approximately 90 ft (27 m), resulting in a grid cell width of at least 13 ft (4 m). The length of grid cells in the streamwise direction, similar to the Calcasieu River, varies in space ranging from 50 to 150 ft (15 to 45 m) depending on the curvature. The model utilizes a 3D Z-layer configuration with 20 layers spanning from -42.7 ft (-13 m) to +9.8 ft (+3 m) NAVD88. To enhance resolution at the depths of the salt wedge interface in Contraband Bayou, layers are set at 1.6 ft (0.5 m) thickness between -13.1 ft (-4 m) and +1.6 ft (+0.5 m) NAVD88. Below -13.1 ft (-4 m) NAVD88, nine layers each have a thickness of 3.3 ft (1 m). Above +1.6 ft (+0.5 m) NAVD88, a layer of 3.0 ft (0.9 m) is incorporated, and the top layer is 5.25 ft (1.6 m) thick. This layering scheme was used with the intent to provide a detailed representation of salinity dynamics within Contraband Bayou while keeping the vertical resolution coarser in the deeper parts of the water column, to minimize unnecessary computational overhead.

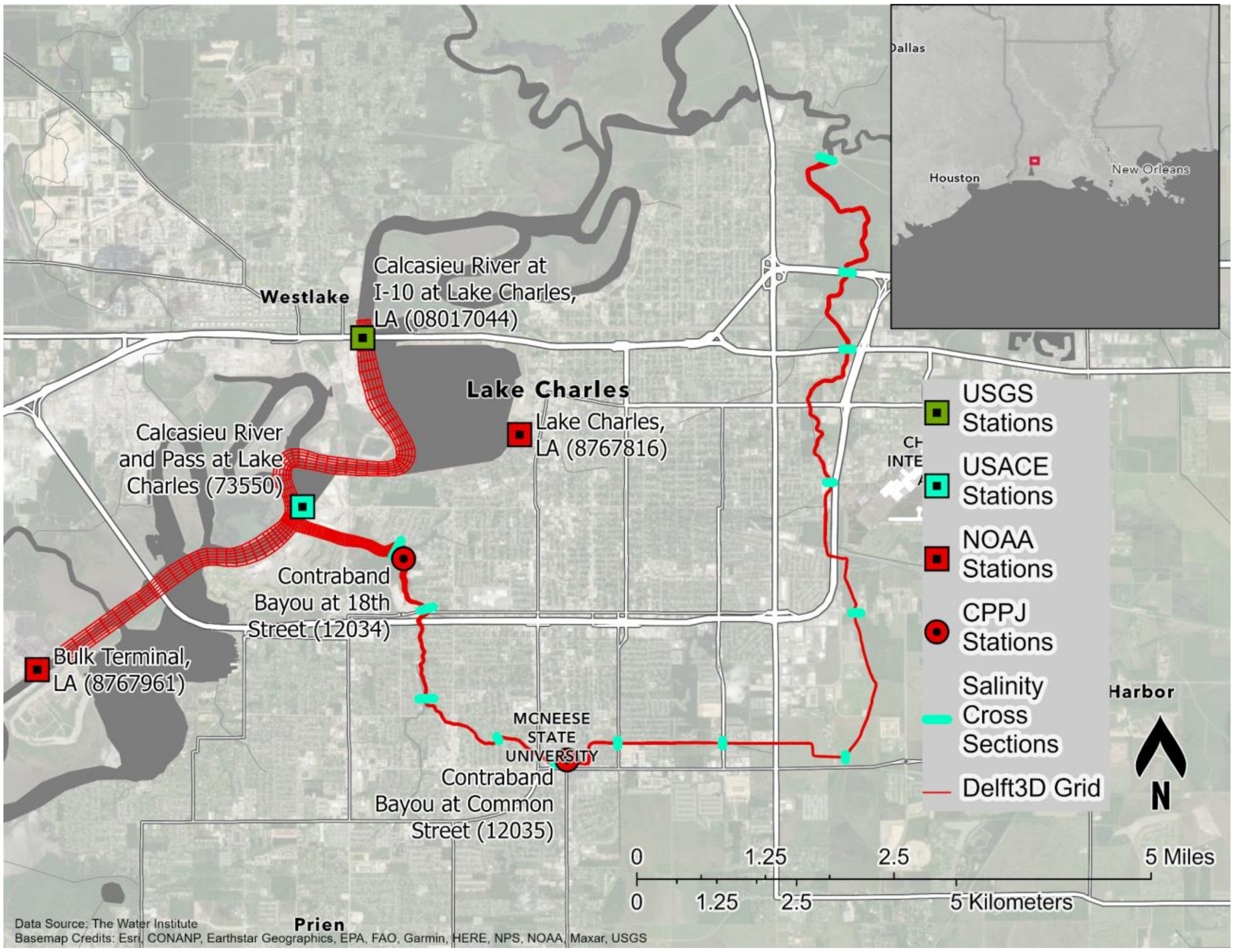

Figure 13. Model domain of the Delft3D salinity model developed for this study.

3.3.2 Boundary Conditions

Due to the lack of new field observations and the need to leverage the previously developed Delft3D model (Pereira & Meselhe, 2015) to establish boundary conditions for the current study, this study replicated the timeframe of September 1 to November 23, 2013, as employed in the earlier Delft3D salinity model (Pereira & Meselhe, 2015). Additionally, the simulation period was extended to encompass July 1 to November 23, 2013, to include the drier months of July and August of the same year. While the previous study (Pereira & Meselhe, 2015) also ran the model for April 19–Aug 30, 2014, conditions were much wetter during this timeframe resulting in lower salinity concentrations, making this time period less suitable for the objective of this study to investigate salinity intrusion during drought conditions.

3.3.2.1 Discharge and Stage

No discharge data is available at the upstream model boundary near the USGS I-10 gauge (Figure 13). Consequently, the upstream discharge boundary is established based on the nearest gauge with discharge records, USGS 08015500 Calcasieu River near Kinder, LA (Figure 14A), using the same approach as followed by the Institute when modeling the Calcasieu River under Task Order 14 (Pereira & Meselhe, 2015). The calculation involves multiplying the discharge from the gauge at Kinder, LA, by the difference in watershed surface area, resulting in a scaling factor of 1.82.

The NOAA Bulk Terminal gauge (Figure 13) was selected as downstream water level boundary condition due to its proximity to Contraband Bayou and its continuous long-term (>10 year) record of water level data referenced to NAVD88 (shown for the model simulation period in Figure 14B). When comparing these records with neighboring gauges, including NOAA gauge Lake Charles (8767816) and USACE gauge Calcasieu River & Pass at Lake Charles (73550), it was found that water levels closely aligned, affirming the likely accuracy of the selected data. Notably, the above mentioned USGS I-10 gauge consistently registers higher water levels, which likely cannot solely be attributed to its upstream location. This may be related to the fact that while the gauge is referenced to NAVD88, the specific GEOID used remains unknown, as it is not noted on the USGS website and was recently confirmed through email correspondence with USGS.

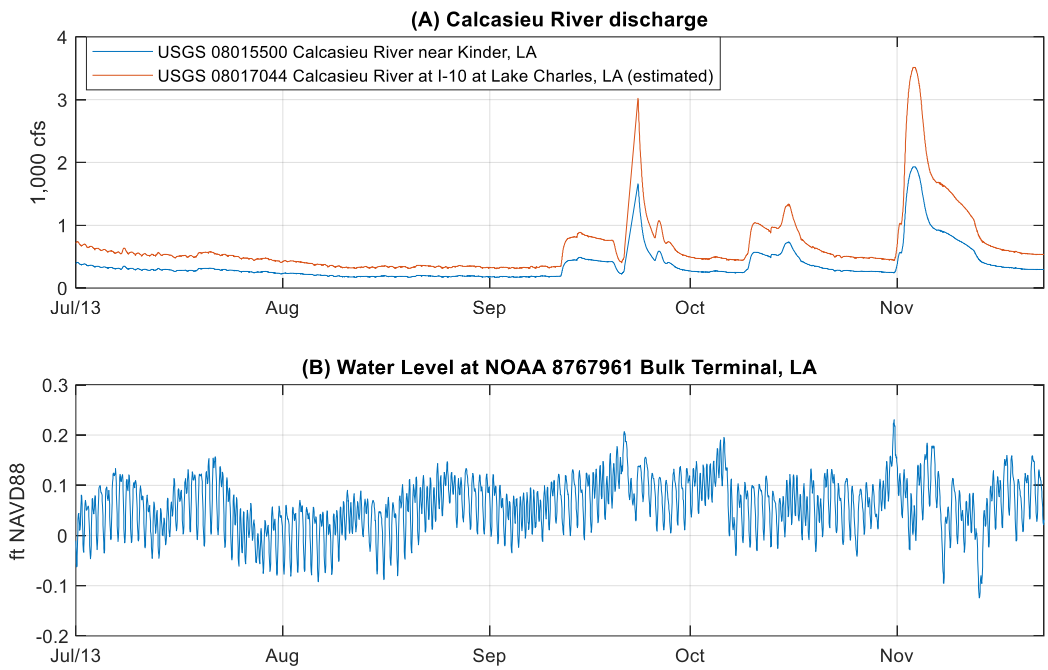

Figure 14. (A) Calcasieu River discharge measured at Kinder and estimated through watershed scaling at the I-10 bridge, (B) observed water level at the downstream model boundary near the NOAA Bulk Terminal gauge.

3.3.2.2 Salinity

The salinity boundary conditions at the upstream boundary are derived from the USGS I-10 gauge, which is the only gauge in the area for which long-term salinity records are available.

According to personal communication with USGS, the salinity gauge is positioned approximately 6 feet below the water surface. Similar to the approach used in the existing Calcasieu River model previously developed by the Institute, the assumption was made that salinity near the bed is 110% of the measured salinity, while salinity near the surface is 90% of the measured salinity (Figure 15B). Despite these basic assumptions, the model rapidly establishes a dynamic equilibrium immediately downstream of this gauge, resulting in a more stratified water column than initially defined at the boundary.

As there are no salinity gauges near the downstream model boundary (the nearest gauge is approximately 15 miles [24 km] downstream, situated in Calcasieu Lake and indirectly connected to the Calcasieu River), the existing Calcasieu River model previously developed by the Institute (Pereira & Meselhe, 2015) was used to obtain near-bed and near-surface salinity (Figure 15B) at the downstream boundary of the Contraband Bayou model in this study, near the NOAA Bulk Terminal gauge.

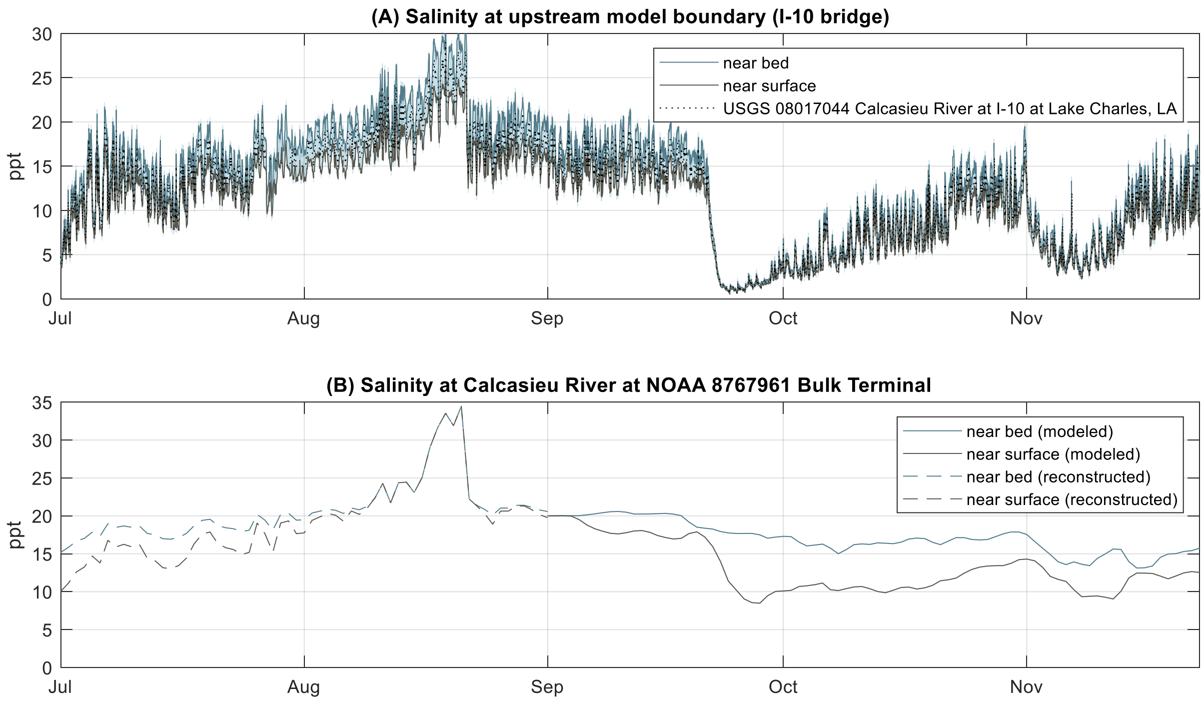

Figure 15. Salinity imposed at the upstream model boundary (A) based on the USGS I-10 gauge and (B) based on the previoulsy developed Calcasieu River model (Pereira & Meselhe, 2015).

To determine salinity at the downstream NOAA Bulk Terminal during the additional simulation period of July and August 2013, this study correlated the modeled results at the NOAA Bulk Terminal for the previously developed Calcasieu River model (September–November 2013) with the salinity imposed at the upstream boundary near the USGS gauge at the I-10 bridge (Figure 16). Salinity was found to be higher at the NOAA Bulk Terminal, both near-bed and near-surface, likely due to its closer proximity to the mouth of the Calcasieu River. This correlation was then utilized to estimate salinity at the NOAA Bulk Terminal for the months of July and August 2013, as illustrated in the reconstructed data shown as dashed lines in Figure 15B.

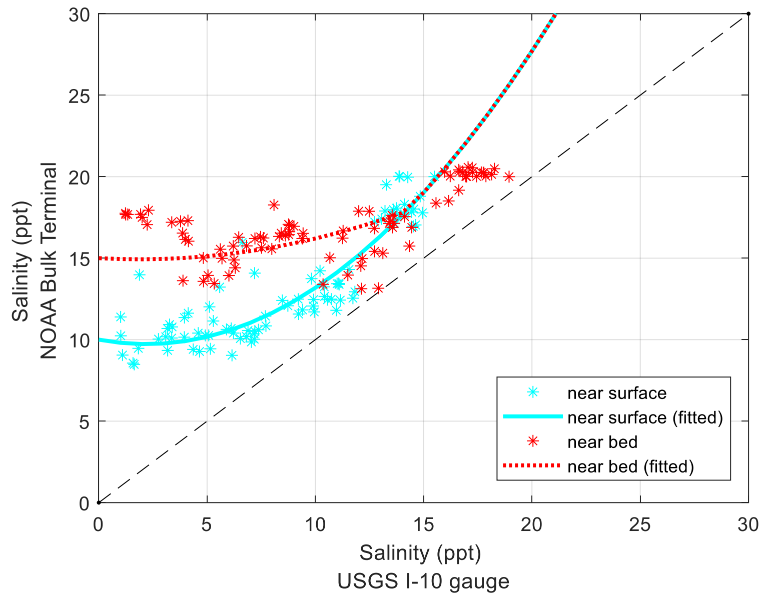

Figure 16. Salinity correlation between the NOAA Bulk Terminal gauge (as modeled in the previously developed Calcasieu River model (Pereira & Meselhe, 2015) and the salinity imposed at the upstream model boundary based on records from the USGS gauge near the I-10 bridge.

3.3.2.3 Freshwater Runoff in Contraband Bayou and Kayouche Coulee

To accurately model the salt wedge in Contraband Bayou, it is necessary to include freshwater input sources from the watershed that enter the bayou following rainfall and runoff. To determine the freshwater input from runoff, the HEC-RAS model developed in this study was utilized to simulate the July–November 2013 timeframe, using AORC rainfall data due to the unavailability of MRMS data. The simulations were performed for both existing conditions and with-project conditions. Thirteen cross-sectional reference lines (Figure 13) along Contraband Bayou and the Kayouche Coulee were defined to record discharges. An example of the discharge at the mouth of Contraband Bayou is shown in Figure 17. The results from the HEC-RAS model were used to calculate the difference (surplus in the downstream direction) of discharge between each reference line, representing the inflow of rainfall runoff in that respective section. These surpluses were applied in the Delft3D model as a “source,” representing a discharge in the model. Additionally, the Kayouche Coulee pump station was imposed as a “sink,” representing the removal of water from the Kayouche Coulee by the pumping station.

During the July–November 2013 timeframe, several rainfall events occurred, including one event on September 20–21 that was classified as a “significant weather event” by the National Weather Service.[1] The runoff volumes during this event were several times higher than any of the other rainfall events,

[1] https://www.weather.gov/lch/e092013

leading to model instabilities. This was attributed to the model's design for simulating dry conditions, with a relatively narrow channel incapable of replicating overbanking. To address this, maximum discharges were limited to 120% of the largest discharges during the July–November 2013 timeframe, excluding the September 20–21 event, to ensure model stability and to maintain drought conditions during the evaluation.

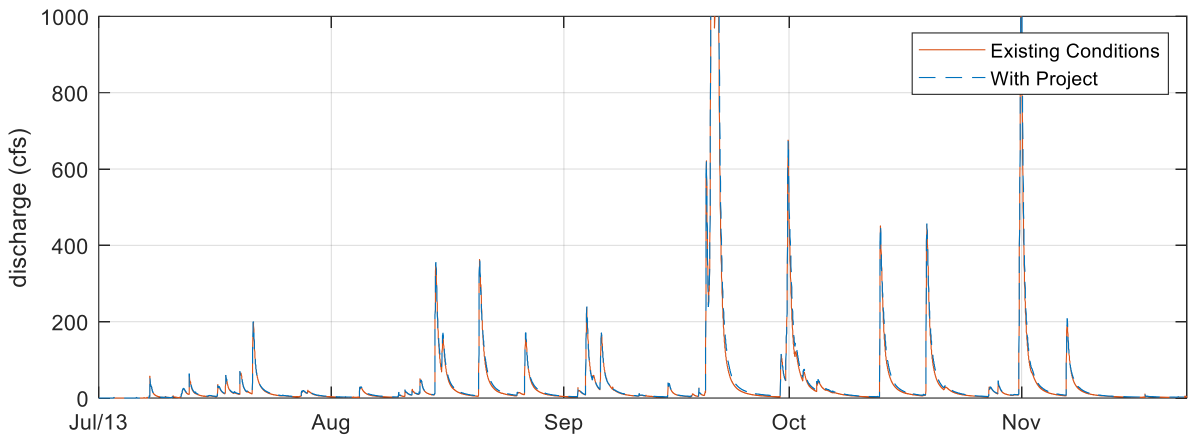

Figure 17. Freshwater runoff volumes at the mouth of Contraband Bayou derived from on HEC-RAS simulations for the timeframe between July and November 2013

3.3.3 Model Calibration

The water levels simulated by the model are calibrated for the years 2013–2014 and 2021–2022.

Due to datum issues or the unavailability of measured data at some gauges during the 2013–2014 timeframe, the focus was directed to 2021–2022. Data was available for all gauges during this period and vertical datums appeared to be accurate. The exception was the USGS I-10 gauge, as discussed in Section 3.3.2.1, which was therefore not considered a target for calibration. The comparison between modeled and observed instantaneous water levels is presented in Figure 18 for the period from March through June 2021, in the Calcasieu River near the mouth of Contraband Bayou (A), and for two locations in Contraband Bayou (B, C). The results indicate a close agreement between the modeled and measured levels, capturing the phase and amplitude of the astronomical tide, as well as the non-tidal water level excursions, during low discharges in the Calcasieu River (i.e., March and April 2021) and periods with higher discharges (late May 2021; Figure 18D). The peaks in Figure 18C (e.g., around May 20, 2021) are attributed to rainfall runoff, which was not considered during the calibration of the salinity model. Furthermore, the measured water levels during most of March 2021 in Figure 18C are likely the result of measurement errors, as they are lower than the levels indicated by downstream gauges (Figure 18A and B). Due to the absence of salinity records other than the USGS records at the I-10 bridge and the previous model results, both of which served as inputs for the salinity model in this study, no additional salinity records were available for model calibration.

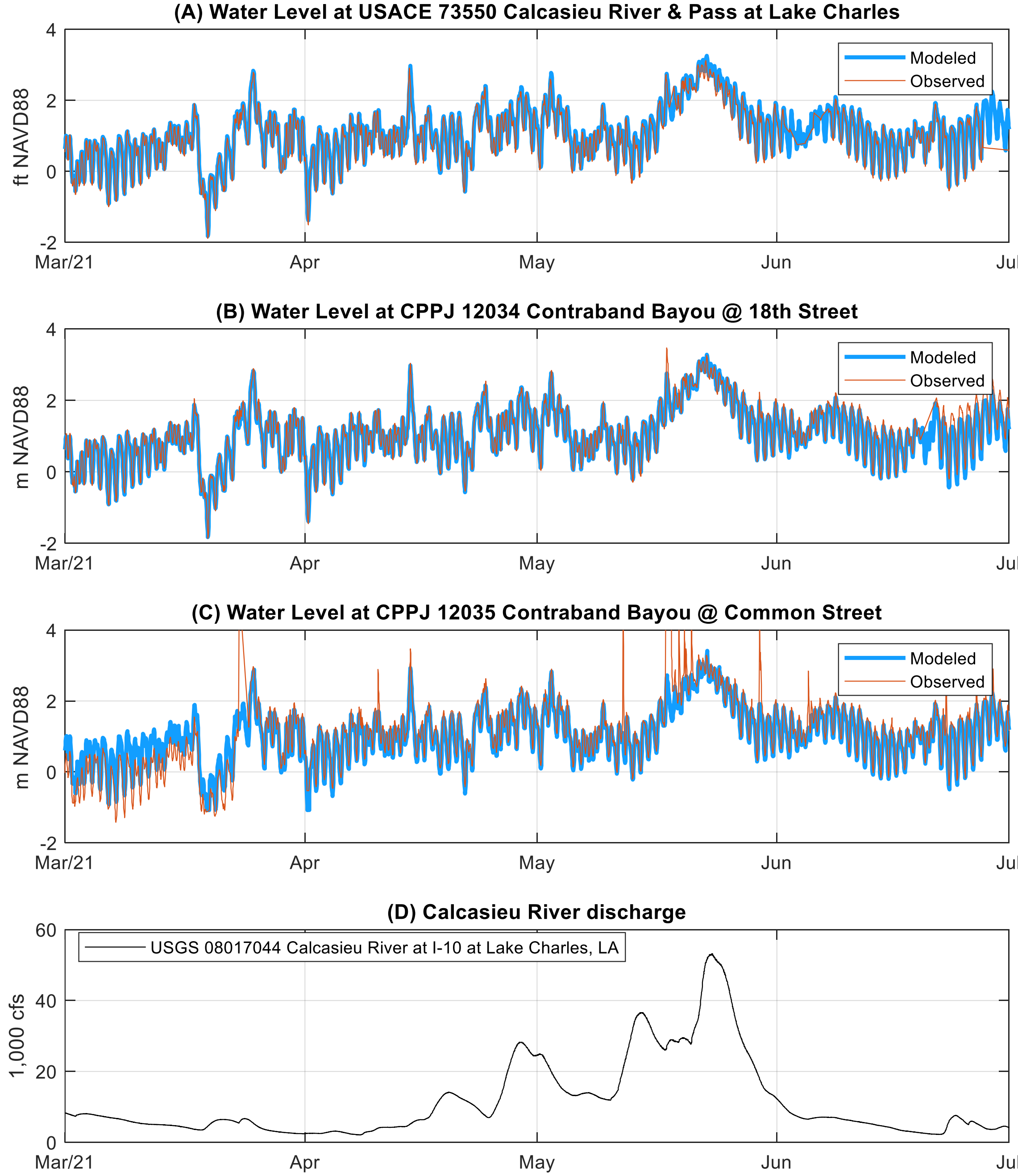

Figure 18. Water level calibration results spanning the period from March to June 2021 presented for (A) the USACE gauge situated in the Calcasieu River near the mouth of Contraband Bayou, and (B, C) the CPPJ gauges situated in Contraband Bayou, using the correction factors specified in Table 4. The locations of all gauges are shown in Figure 13. As a reference, (D) displays the discharge timeseries of the Calcasieu River during the corresponding timeframe.

3.4. QUALITATIVE METHODS AND MODEL GROUND TRUTHING

To improve model accuracy, the Institute employed a participatory modeling approach that allowed local stakeholders and residents with strong ties (economically, historically, and culturally) to the community to ground truth the outputs of an initially calibrated numerical model (Hemmerling et al., 2020; Meselhe et al., 2020). Participatory modeling uses a combination of fact-finding, process facilitation, and numerical modeling to engage non-scientists in the scientific process (Voinov et al., 2018). To assure that the participatory modeling approach fully incorporated both the technical knowledge of numerical modelers and scientists and the local knowledge of residents and local stakeholders, the Institute used a competency group (CG) approach, a process of engagement in which natural and social scientists collaborate over time with residents directly impacted by flooding in localities in which environmental management may result in local controversy. The CG approach allows residents and local stakeholders (*local knowledge experts*) to work directly with scientists and engineers (*technical knowledge experts*) in the collaborative management of environmental projects (Barra et al., 2020; Hemmerling et al., 2022). When utilized alongside participatory modeling, this approach allows for active dialogue between these expert groups, ensuring that both sources of knowledge are included and valued in the modeling process.

Local knowledge experts for the CG were identified and solicited by CFSWLA, while technical knowledge experts were selected from the Institute based upon their modeling expertise as well as their scientific knowledge of the hydrology and geology of southwest Louisiana. The final CG included residents, business owners, industry representatives, higher education, and representatives from both local and federal government, as well as modelers, engineers, and hydrologists from the Institute.

Over the course of three meetings, the CG engaged in a participatory modeling process whereby an initially calibrated model was reviewed and analyzed. The first meeting took place on May 9. 2023 at the Southwest Louisiana Entrepreneurial and Economic Development (SEED) Center in Lake Charles, Louisiana and included 20 group members (Table 8). This initial meeting was focused on introducing the members of the CG to one another and discussing the goals of the study with the group. This was also an opportunity for the local knowledge experts to discuss any changes to the landscape around Contraband Bayou and Kayouche Coulee that they have observed and to discuss what they think the future may look for communities living around these waterways.

Over the course of the meeting, the technical knowledge experts introduced the full group to the types of models that would be developed through this process and what these are intended to measure. Through a series of facilitated conversations, the CG identified both the timescale and geographical extent that the model predictions would cover. Through these conversations, the CG decided that the initially calibrated model would be tested using an extreme rainfall event that occurred in Lake Charles on May 17, 2021. Each of the local knowledge experts in attendance had experienced or knew individuals who had experienced flooding from this event. Using this event to test the model provided a unique opportunity to ground truth the model outputs.

Table 8. Stakeholders who participated in competency group meeting #1 by type.

Stakeholder Type	Number of Stakeholders
Researchers (e.g., geologist, ecologist)	2
Community Service & Outreach	3
Utility Company	3
Real Estate Company	1
Conservation Organization	1
Education & Research	3
Local Business	3
Local Government	2
Federal Government	2

Following this initial CG meeting, the modeling team developed the initially calibrated model and ran it using the parameters of the May 17, 2021 rainfall event. The model results were imported into ESRI Survey123, a mobile multi-platform application for field data collection based on surveys designed and shared online using a smartphone or tablet (Geman et al., 2017). Survey123 allows for the design of dedicated public surveys with a built-in geospatial component, allowing for real-time data collection and analysis. The Survey123 interface was designed to allow for local knowledge mapping (LKM), a process whereby participants are presented with a base map upon which they are asked to mark locations in response to a certain question (Curtis et al., 2018). LKM is a powerful tool to integrate qualitative data into numerical models that can support environmental decision-making (Hemmerling et al., 2020). For this project, the CG was provided with the model results for the 2021 flood event overlaid atop the most recent aerial imagery (Figure 19). The Survey123 was designed to allow participants to mark locations of model accuracy and inaccuracy, as well as other locations of interest relative to the flood event.

The second CG meeting took place on August 29. 2023 and was also held at the SEED Center in Lake Charles. Thirty-two people attended this second meeting. In addition to the CG members who attended the first meeting, a larger contingent of local government agency representatives attended and two additional members of the modeling team (Table 9). This meeting began with the technical knowledge experts presenting the details of the model to the group. This included a description of the model grid and mesh resolution as well as an explanation on how major highways and bayou centerlines are included in the model. They also presented the digital elevation model and bathymetry datasets that served as inputs to the model, including an explanation of how local bathymetry data was used to supplement these data. Finally, the technical knowledge experts explained how the model leveraged the existing local gauge network and was calibrated to the May 17, 2021 storm event. The preliminary calibration results were then presented to the group.

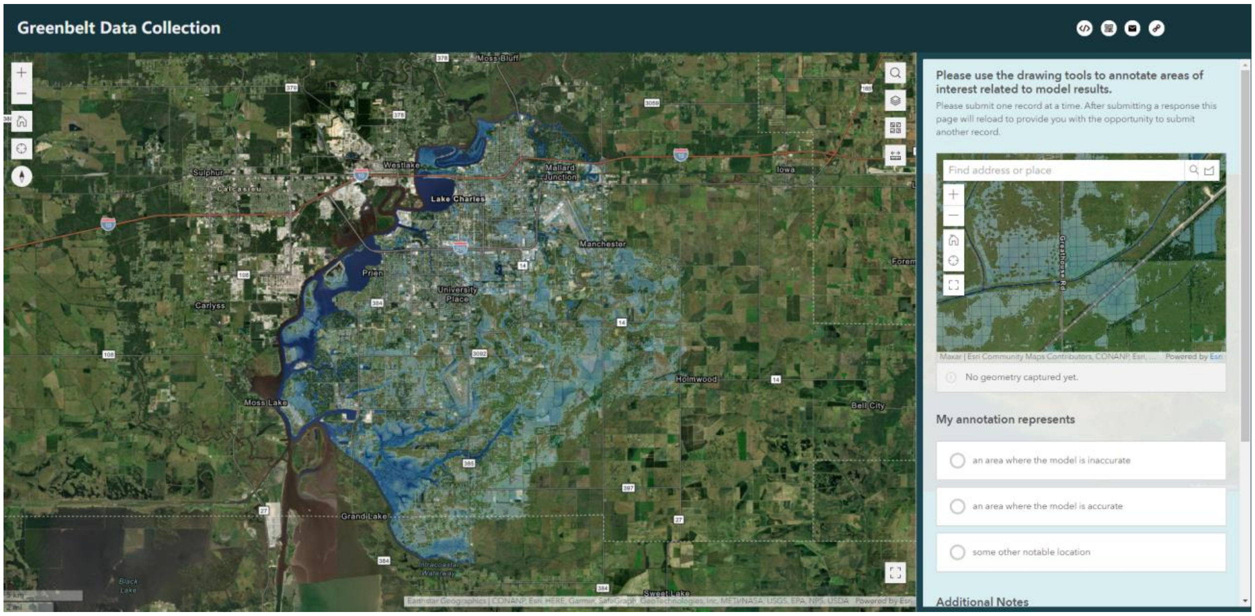

Figure 19. ESRI Survey123 local knowledge mapping interface.

Table 9. Stakeholders who participated in competency group meeting #2 by type.

Stakeholder Type	Number of Stakeholders
Modelers	2
Researchers (e.g., geologist, ecologist)	2
Community Service & Outreach	3
Utility Company	3
Real Estate Company	1
Conservation Organization	1
Education & Research	3
Local Business	3
Local Government	12
Federal Government	2

Following the presentation of the preliminary calibration results, data on the accuracy of the model results were gathered through facilitated small group discussions and LKM exercises. Facilitation of the LKM exercise began by dividing the CG into three smaller mapping groups containing between ten and eleven participants each, including both scientific and local knowledge experts. Dividing the CG into smaller mapping groups provided the opportunity for in-depth discussion about the model results as well as the underlying data that served as model inputs, including elevation, bathymetry, and landscape features. Each mapping group was facilitated by a breakout group chair while a modeler served as the map manager, navigating the Survey123 map interface as directed by the mapping group members. The map manager was also responsible for marking and annotating the Survey123 base map as well as identifying and labeling locations where group members believed the model results were correct or incorrect. The map manager was also responsible for annotating locations of interest relative to the underlying landscape, including locations where the underlying data appear to be inaccurate. Following the LKM exercise, the full CG reconvened and each breakout group chair reported their initial findings to the group. The Survey123 mapping tool was left open for two weeks following the CG meeting and participants were provided with a link to the tool.

After data collection was complete, the results of the Survey123 analysis were downloaded and brought into GIS for further analysis. In addition, a set of spatially explicit comments was received via email, in narrative form. In this case, the research team manually entered those comments into Survey123 and included them in the analysis. Members of the Institute modeling team reviewed each of the comments and adjusted the model parameters and inputs, as needed and appropriate.

The third and final CG meeting was held on January 30, 2024. The goals of this meeting were to show how the results of the small group discussions from the previous CG meeting and Survey123 were used to update and improve the model. Thirty participants attended this final meeting, which was again held at the SEED Center (Table 10). Several federal agency representatives attended this final meeting virtually. The results of Survey123 were presented to the group as well as a summary of how the model was adjusted based on the comments received from the CG. Lastly, the results of the final calibrated model were presented to the group.

Table 10. Stakeholders who participated in competency group meeting #3 by type.

Stakeholder Type	Number of Stakeholders
Researchers (e.g., geologist, ecologist)	2
Community Service & Outreach	5
Utility Company	2
Education & Research	2
Local Business	4
Industry	2
Local Government	6
Federal Government	7

In addition to the CG meetings, Institute researchers continuously coordinated with key stakeholders from the city and parish throughout the process (Table 11). During meetings with the Gravity Drainage District #2, details on operations related to pumps, gates, and water elevations influencing operational decisions, as well as discussions related to pump capacity, gate geometries and operational decisions, and other information that would improve the model. Meetings with the CPPJ were specific to the gauge network, datums related to the water level reported by their system, and an in-depth discussion related to precipitation patterns recorded during the May 17, 2021, flood event. Finally, the meeting with the City of

Lake Charles Mayor's Office, which took place prior to the last CG meeting, was intended to provide an update on the status of the project, share final results, and receive feedback.

Table 11. Project update meetings with city and parish (county) officials

Local Stakeholder	Date
Calcasieu Parish Consolidated Gravity Drainage District No.2	5/18/2023
Calcasieu Parish Consolidated Gravity Drainage District No.2	8/21/2023
Calcasieu Parish Police Jury (CPPJ)	10/12/2023
Calcasieu Parish Consolidated Gravity Drainage District No.2	12/27/2023
City of Lake Charles Mayor's Office	1/30/2024

3.5. BAYOU GREENBELT SCENARIO DEVELOPMENT

To implement the proposed BGB project in the model, a physical connection was necessary to connect Kayouche Coulee and Contraband Bayou via proposed Gumbo Cut (Figure 9) following input and geometries provided by NPS and the local partner for the project. Gumbo Cut is essentially a channel with dimensions that are conceptually presented in Figure 20. The project requires a channel that is navigable to recreational boaters from the Kayouche Coulee Pump Station to the Calcasieu River, having a minimum depth at low tide of at least 4 ft. Using this geometry, a channel was "dredged" in the model terrain to represent Gumbo Cut connecting the two waterways. Since the terrain elevation in the vicinity of Gumbo Cut is higher than either of the waterways that will be connected, the dredge cut needs to be sufficiently deep to not only enable the connection of the waterways but to satisfy the required navigation minimum depth of 4 ft. Figure 21 shows the Gumbo Cut With Project terrain plotted with the existing terrain profile extending from the Contraband Bayou to Kayouche Coulee Pump Station to show the approximate cut elevation.

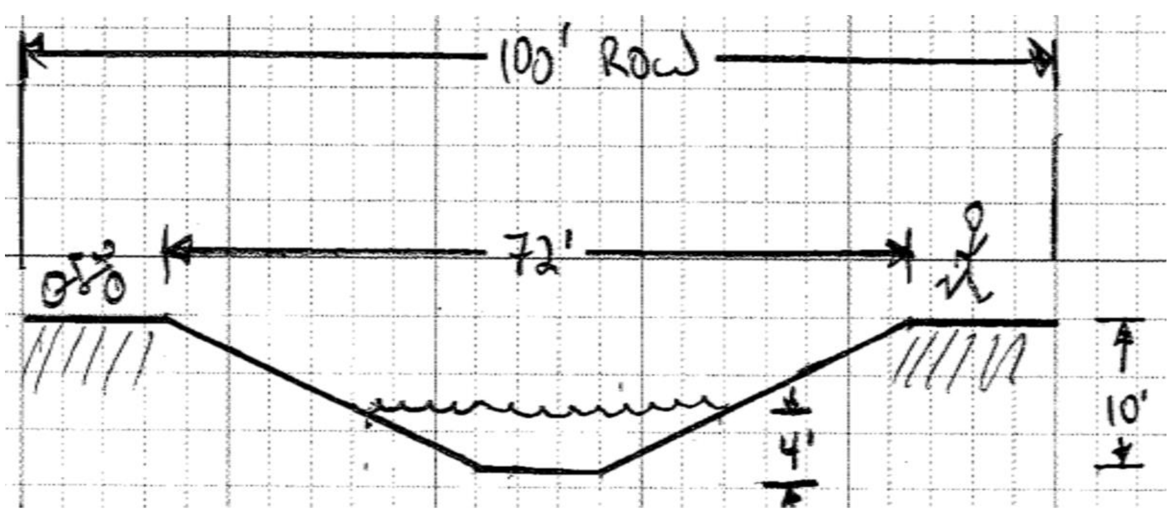

Figure 20. This sketch shows a general cross section of the Gumbo Cut with a total top width of 100 ft and a depth of 10 ft which will aim to always maintain 4 ft of water (sketch provided by Mike Nodier of the CFSWLA).

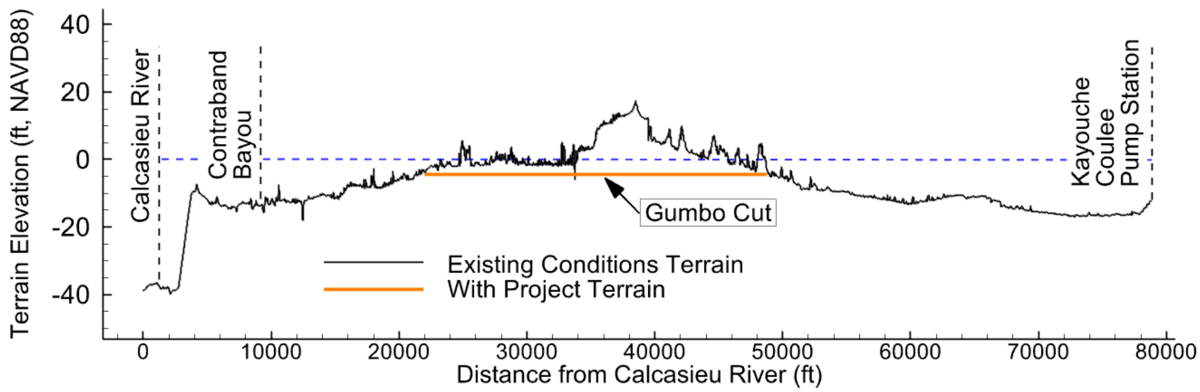

Figure 21. Profile of the terrain extending from the Calcasieu River where it connects with Contraband Bayou to the Kayouche Coulee Pump Station (black) plotted on the With Project Terrain cut (orange).

Once the projects were implemented on the terrain, the previously calibrated model was selected to perform the With Project simulations. The simulation matrix (Table 12) included evaluating the project compared to without project conditions for two ARIs, namely 10-year and 100-year rainfall events. For each of the ARI, the downstream water levels were selected following analysis previously described (Section 3.2.2) and included assessment at mid tide and high tide conditions.

Table 12. List of scenarios and corresponding model simulations used to evaluate the feasibility of the project (Note: Mid- and high-tide water levels were selected as described in Section 3.2.2).

Precipitation Event	Project Scenario	Downstream Boundary Condition
May 17, 2021 Flood Event (MRMS gridded rainfall)	With Project	Observed water levels
	Without Project	Observed water levels
10 year (NOAA Atlas-14 gridded rainfall)	With Project	Mid Tide
		High Tide
	Without Project	Mid Tide
		High Tide
100 year (NOAA Atlas-14 gridded rainfall)	With Project	Mid Tide
		High Tide
	Without Project	Mid Tide
		High Tide

Upon comparing the results of high tide with those of mid tide, it was found that the zone of influence of high tide on the model results in comparison with mid tide results is limited to within the perimeter of the model and did not affect the study area. Figure 22 depicts the results obtained by subtracting mid-tide from the existing high-tide conditions over a 100-year period. As anticipated, tidal waterbodies throughout the study area record a higher water level due to higher tidal conditions. Nevertheless, the difference between the two scenarios is negligible throughout the model domain and is well below 0.1 ft.

These results (Figure 22) indicate that there will be no significant impacts on the study area between the two tide scenarios. Consequently, for a conservative approach to impacts on the study area, this report will discuss the high tide results.

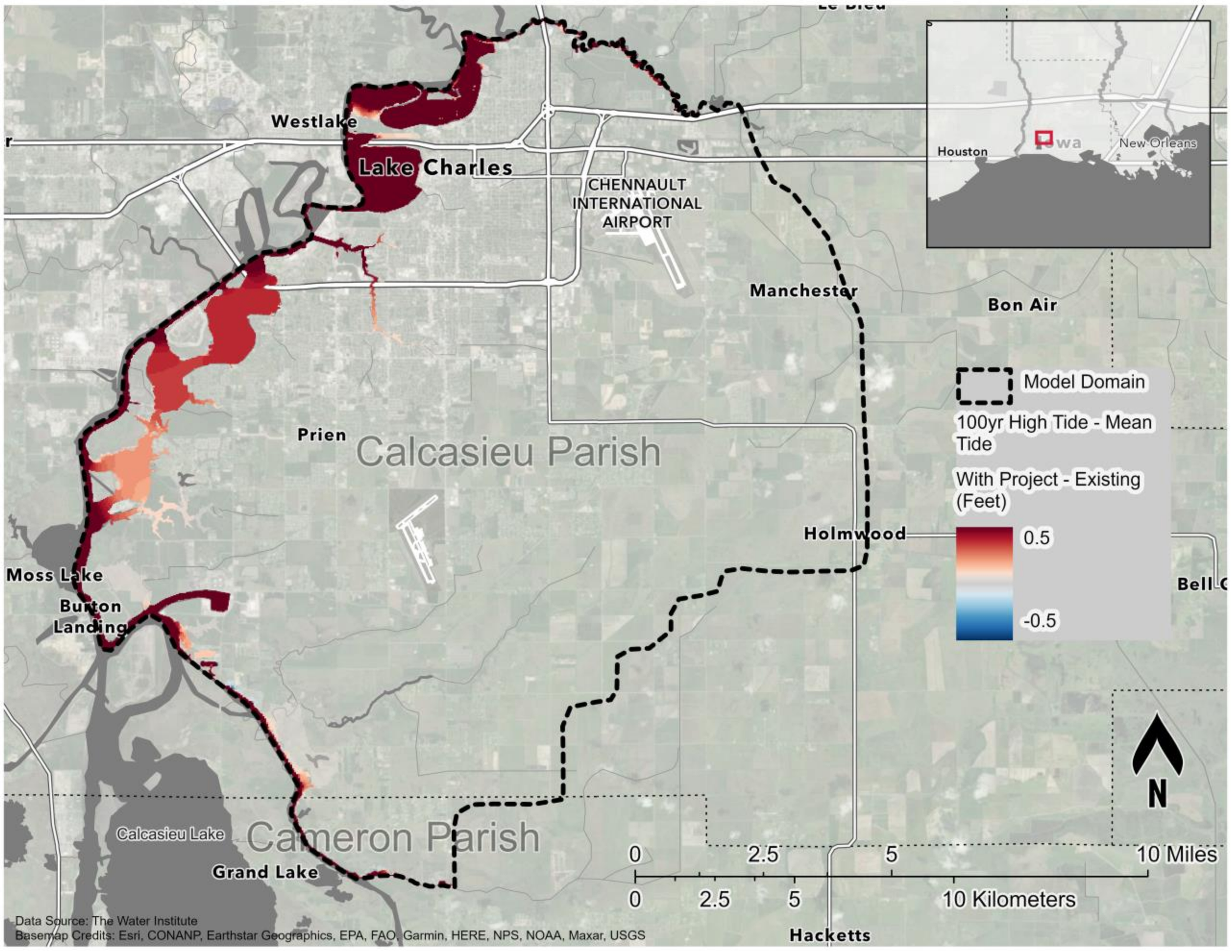

Figure 22. The existing 100-year high tide results minus the mid tide results show that differences are contained within the perimeter of the model domain and do not impact the With Project area. Water surface elevation (WSE) differences of +0.10 ft to -0.10 ft are not displayed.

4.0 RESULTS

4.1. GROUND TRUTHING CALIBRATION RESULTS

To ground truth the model outputs, The Institute convened a CG comprised of residents, local stakeholders, modelers, engineers, and scientists. On August 29, 2023, the group used a Survey123 mapping interface to review the outputs of a numerical model that was initially calibrated to an extreme rainfall event that was well known to residents and local stakeholders. The Survey123 interface was left open for additional review for two weeks following the CG meeting. In total, the group identified and mapped 59 locations of interest, including locations where the model was found to be accurate, locations where the results were inaccurate, and other locations that were determined to be important by CG members (Figure 23). Following this meeting, the technical team reviewed the resultant data outputs, identified discrepancies between the model outputs and the experiences of the residents and local stakeholders, and adjusted the model inputs and parameters as appropriate, providing detailed responses to the full CG (Table 13). This process served dual purposes. First, the review process was explicitly designed to provide contextualized environmental geospatial data that was used to perform quality assurance and quality control on the numerical model, utilizing the local knowledge of those who are on the ground every day. Secondly, this transparent process will enhance confidence in the models within the community and trust in the scientists that are developing them (Barra et al., 2020).

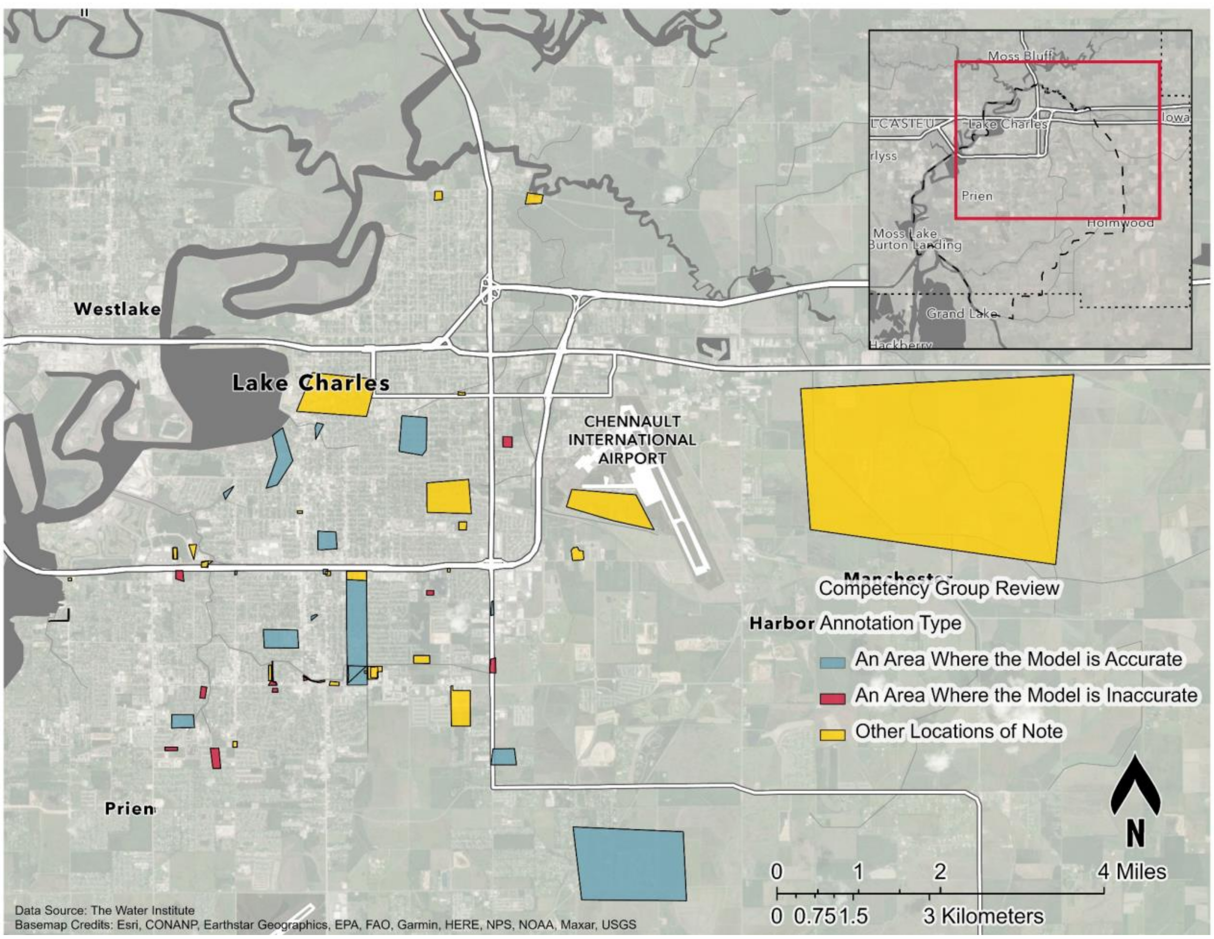

Figure 23. Locations annotated by CG members during the local knowledge mapping workshop.

The CG review of the model outputs identified several locations throughout the study area where the model showed little to no flooding that the local knowledge of residents and local stakeholders revealed to have flooded. In most cases, the locations identified in the Survey123 were spatially explicit, identifying precisely how far the floodwaters were observed relative to buildings, roads, and other features on the landscape. During the CG meeting one group member, a local government official with an extensive background in public works, noted that the AORC dataset used by the modeling team to model rainfall showed a large amount of spatial degradation during the May 17, 2021 flood event. The modeling team confirmed this spatial degradation of the data and replaced this rainfall dataset with MRMS historical precipitation data. As seen in Table 13, many of the model inaccuracies were resolved using the MRMS data.

Table 13. Locations within the study area where the model results were inaccurate, as identified by the CG during a review of the initially calibrated model.

Competency Group Review	Competency Group Comment	Model Adjustment
Model inaccurate	Check the terrain versus imagery for pond	Depth not known and we would be guessing. Far away from the project area and we are not modeling the outfall. Team decided to leave the original model as is and not make changes
Model inaccurate	Flooding up to 3 or 4 ft here (above the hood of several cars). Model shows no street flooding	Breaklines were investigated and no issue was seen. With the use of MRMS data, there does show to flooding but not in the range of 3ft.
Model inaccurate	W. College Street and Lake Street near 210, There was more water on the road during the event than shows up in the model. flood depth on street was 2 ft	Model now shows increased flooding in this area with the use of MRMS data
Model inaccurate	House flooded. Flood depths up to 3 ft. Alligator encounter...model shows street flooding, but not in these houses	Model now shows flooding in this area with the use of MRMS data
Model inaccurate	Flooding in several of the houses in this block...water had nowhere to go, storm drains full	The houses were elevated in the terrain not allowing the region to flood, the terrain was modified, and the model now shows flooding
Model inaccurate	Serious flooding during event, just south of McNeese St. Also at Autumnwood Lane. Water got into the houses. Check the data for if the storm gets here make adjustments to terrain	Model now shows flooding with the use of MRMS data
Model inaccurate	Flooding here. The animal clinic stayed dry because it's elevated. Surrounding homes flooded (note: likely the homes south of W McNeese, will check the audio)	Model now shows flooding comparable to the comment made with the use of MRMS data
Model inaccurate	University building flooded in storm	Model now shows flooding here with the use of MRMS data

Competency Group Review	Competency Group Comment	Model Adjustment
Model inaccurate	Water overran banks and flooded parking lots	Model now shows flooding in parking lots and overflow with the use of MRMS data
Model inaccurate	These houses flooded	Houses are now shown to flood with the use of MRMS data
Model inaccurate	Most of the water went to the houses (check audio, but assume this means to the house but not in the houses)	Results show that water now gets to houses with the use of MRMS data
Model inaccurate	Pretty much all homes around this lateral got anywhere up to 5 inches of flooding.	Houses are now shown to flood with the use of MRMS data
Other	Water came from street first, broke over levee	Updated MRMS rainfall data now shows flooding

In addition to reviewing the outputs for accuracy, the CG was given an opportunity to review the model inputs and the underlying terrain data used in the model (Table 14). Several locations were identified by the CG where the underlying landscape data used by the modeling team may have been inaccurate. The local knowledge experts identified several locations where development had occurred in locations that the terrain data showed as undeveloped. In these cases, the modeling team reviewed the landscape using aerial imagery and delineated the newly developed areas, altering the Manning's n values to more accurately reflect the roughness of the landscape in these locations. In some cases, landscape changes that occurred subsequent to the May 17, 2021 storm event were identified by the CG, such as a retention pond currently being built by the city. In such instances, the updated features were inserted into the input terrain data and included in both the with and without project model runs.

Not all comments were able to be implemented in the model. For example, several locations were noted throughout the study area where recent changes were made to existing roadways, such as expanding the number of lanes or adding roundabouts to the road. Because roads are inputted into the model as breaklines and not landscape features, the model was not altered in these cases, and the reasoning was noted and made available to the CG. Finally, one of the CG members identified a large area outside of the model domain that he believed should be included in the model. The modeling team assessed this location and determined that runoff transfer occurs there and extended the model domain to include this area.

Table 14. Notable locations within the study area identified by the CG during a review of the initially calibrated model.

Competency Group Review	Competency Group Comment	Model Adjustment
Other	Retention pond is being built here by the city. The CPPJ would have that information	Pond will be burned into terrain for with and without project scenarios with inflow and outflow structures. Will not be implemented into May 17 flood as it was not built during that event

Competency Group Review	Competency Group Comment	Model Adjustment
Other	Model needs to be investigated. CPPJ requested that this area be in the model domain	A test was conducted to determine if indeed there is a runoff transfer at this location and it was confirmed. The model domain was extended to include this area.
Other	Tree clearing for a significant housing development. The forested square will be cleared and developed.	No action necessary at this time
Other	Will be repurposed, the buildings demolished, but pavement remain.	Verified that the Landcover layer considered this impervious/developed
Other	Nursing home. It is likely elevated, which may explain why no flooding is seen	No action necessary
Other	Street was built in what used to be drainage canal, or right next to it. Known to flood easily	Verified that the terrain does show a depression correlating to a natural drainage path
Other	Downtown was not heavily affected, there was not as much rain as there was further south	No action necessary
Other	This has been developed hobby lobby	Manning's n change to represent developed as well as flattening the DEM to represent developed conditions
Other	Has been developed and north of it will be as well	Manning's n change to represent developed as well as flattening the DEM to represent developed conditions
Other	Hotel destroyed during hurricane. Will still will be redeveloped. Topo has changed	Verified that the landcover still considered this developed
Other	House flooded during Hurricane Ike (4.5 ft); white fence was flooded completely. Many new homes are built higher up	With new MRMS rainfall applied, this area now showed to have flooding up to the house as mentioned in the comment
Other	National guard to develop area near airport and there will be land use change with an airport expansion. Large parts of the future developed property have been a golf course (i.e., Land use change, foreseeable project, paving)	No action necessary at this time
Other	Pump station built in 1958 to keep the (back then) military airfield dry	No action necessary
Other	We do not know if this area flooded. Staff from the City of Lake Charles would know more about this	Email was sent and no response was received
Other	Amazingly, a new multilevel storage rental place has been added on Common at College Street that once was a large lot with only one home on it which had a "watch for flood" sign even then. I cannot imagine how	No action necessary

Competency Group Review	Competency Group Comment	Model Adjustment
	drainage is not going to be further impeded with almost the entire green space there replaced by concrete!	
Other	I was an educator at LaGrange HS…and LaGrange faculty were sometimes flooded in until waters drained to allow cars to exit parking lot.	No action necessary
Other	Detention Pond at Louisiana Ave @ Contraband Bayou (hopefully) may ease future flooding in those areas that experienced cataclysmic destruction following the hurricanes with the worst flood of all my years living here! Is this detention pond part of Bayou Greenbelt? If so, has depth measurement of Contraband Bayou been taken at its Louisiana Ave & Contraband Bayou location, and does it follow academic requirements for neighborhoods & thoroughfares of increased populations throughout the years? My former neighbors believe that the flooding was exacerbated due to its having been filled with sand, silt, & debris following hurricanes.	Pond will be implemented into with and without project simulations
Other	New round-about traffic circles (e.g., W Prien Lake Rd & Holly Hill area; Ham Reid Rd area, with more proposed for future),+ Sale Street renovations still underway	These features are accounted for in the model as breaklines. The conversion to round abouts will not alter model results.
Other	New round-about traffic circles (e.g., W Prien Lake Rd & Holly Hill area; Ham Reid Rd area, with more proposed for future),+ Sale Street renovations still underway	These features are accounted for in the model as breaklines. The conversion to round abouts will not alter model results.
Other	4-lane additions in progress near the entrance of Prien Lake Park make me question whether or not flooding will now begin in yards along W Prien Lake Rd which is bordered by a bayou (along with neighbors) in their back yards.	This road feature is accounted for in the model as a breakline. The additional lanes will not alter model results.
Other	Green spaces have been lessened throughout the city in the past few years...Prime examples are: A. RV Parks on E McNeese as well as Broad Streets	Green spaces were not specific enough to determine a model change and would not alter results
Other	Green spaces have been lessened throughout the city in the past few years...Prime examples are: B. At least 8 tiny houses have been recently built on corner of 5th Avenue & Prien Lake Rd where originally a single home lot existed.	Green spaces were not specific enough to determine a model change and would not alter result
Other	A vacant lot has now also been built up higher right across the street from the US Post Office (5000 Lake Street) appears to be 3 ft. higher than neighbors who live next door. Hope new home drainage also is included to spare neighbors flooding!	This was accounted for in the initial landcover and did not require change.

Competency Group Review	Competency Group Comment	Model Adjustment
Other	Vacant property where a motel was now been destroyed following hurricanes on W Prien Lake Rd, & rebuilt with a multilevel modern new motel that now has what appears to be a 6 ft. higher site that borders the bayou for what may become its new parking lot.	This was accounted for in the initial landcover and did not require change.
Other	Business tax incentives may possibly be the reason that businesses such as Hobby Lobby have left their original Hwy. 14 location for 1550 W Prien Lake Rd. Additionally, new roads meander through the area to house numerous other in-progress new buildings & motels with seemingly little green space planned!	No action necessary
Other	Two vacant lots on northeast corner of Cherryhill St & Louisiana Ave - buildings demolished following hurricanes	No action necessary
Other	Place Vendoome (formerly Johnson Hall) @ 1900 Prejean Dr in LC should be torn down due to closure since hurricanes. A historical & ethical disservice to our deceased former city councilman, Buddy Prejean, who represented us WELL! Place is becoming a place for criminals to hang out & start fires	No action necessary
Other	Former Wilson Motors on Ryan St also is an eyesore & needs to be removed because it has been vacant forever	No action necessary
Other	Clean-up of bayou on E side of Tamarack St where damaged trees still lie in bayou following hurricanes & erode water flow - perpetrating flooding!	No action necessary

As updates were made to improve model accuracy, efforts were made to ensure that these updates did not introduce any additional inaccuracies into the model. To this end, the technical team tracked locations where the CG specifically noted that the initially calibrated model was accurate (Table 15). These data served as a valuable check on the accuracy of each of the subsequent versions of the model.

Table 15. Locations within the study area where the model results were accurate, as identified by the CG during a review of the initially calibrated model.

Competency Group Input	Competency Group Comment
Model accurate	Flooding was observed here, as well as in recent history. Before May 14. Employees at the nearby vet clinic know more. Probably flooded during Delta (Oct 2020). It flooded from Contraband Bayou, combined surge + rainfall
Model accurate	Road and lots were elevated when area was developed. Correctly shows no flooding
Model accurate	Model looks correct

Competency Group Input	Competency Group Comment
Model accurate	Notorious place, cars stalled here. Model seems accurate. Afterwards, some street drainage systems have been cleaned which improved the flooding. Also flooded during more regular rainfall events. We do not know for sure whether the residential areas around it flooded too. Hodges St to the west had 8 inches of flooding
Model accurate	Flooding was between 2–3 ft or so. 2.5 ft was correct at Commons Street and 210. Agreed being deeper on Hodges Street like the model showed.
Model accurate	Flooding observed here, church building only just stayed dry...water up to doorstep (Note: model looks accurate, checked audio for details, categorization changed to accurate)
Model accurate	Up to 8 inches of water observed
Model accurate	Area known to flood regularly (around the racquet club)
Model accurate	Area indeed flooded
Model accurate	Area known to flood, also during hurricanes Rita and Ike. Ike was worse than Rita in terms of flooding. Area that was hit was not too big, but it was serious flooding
Model accurate	Open ditch system and floods often seems accurate
Model accurate	Between 3rd and 9th street and 4th and 2nd Ave. The flooding shown is correct. Repetitive loss properties along 6th street
Model accurate	Highway 397 and intersection of streams and 2 roads flood often
Model accurate	Flood waters inundated all neighborhoods & businesses between Kirkman Street & Louisiana Ave (beginning at their southern ends with FK White Middle School & new MSU Gym as reference points on E. McNeese Street) to their northern reference points of College Street that runs alongside 1-210.
Model accurate	Flooding observed here, church building only just stayed dry...water up to doorstep (Note: model looks accurate, checked audio for details, categorization changed to accurate)

4.2. HYDRAULIC MODEL

Model outputs include spatially explicit maps showing flood extent and depth and time-dependent output, at selected locations, showing how flow and water levels vary over time. The study focused on comparison maps, which typically show the spatial extent of differences in flood depths between a scenario with project by subtracting results from existing conditions. Water level outputs (WSE) for the duration of each event are shown at Crying Eagle Brewery and Greinwich Terrace, because they are located on either side of Gumbo Cut, and flow at Kayouche Coulee north of Gumbo Cut to examine the flow exchange resulting from the connection of the two watersheds (Figure 24). Foreseeable projects under construction relevant to drainage were also included in the model. This included a large detention pond adjacent to Crying Eagle Brewery and connected to Contraband Bayou. Because of the status of construction, the proposed pond was implemented in all With Project and Without Project condition simulations. Finally, since With Project conditions include the BGB waterway with water at high tide reaching the Kayouche Coulee pump station, and to avoid continuous pumping, pump station operations were slightly adjusted. As such, With Project pump operations were maintained consistent across all scenarios, turn on at a water surface elevation of 0.8 ft (NAVD88) and turn off at 0.6 ft (NAVD88).

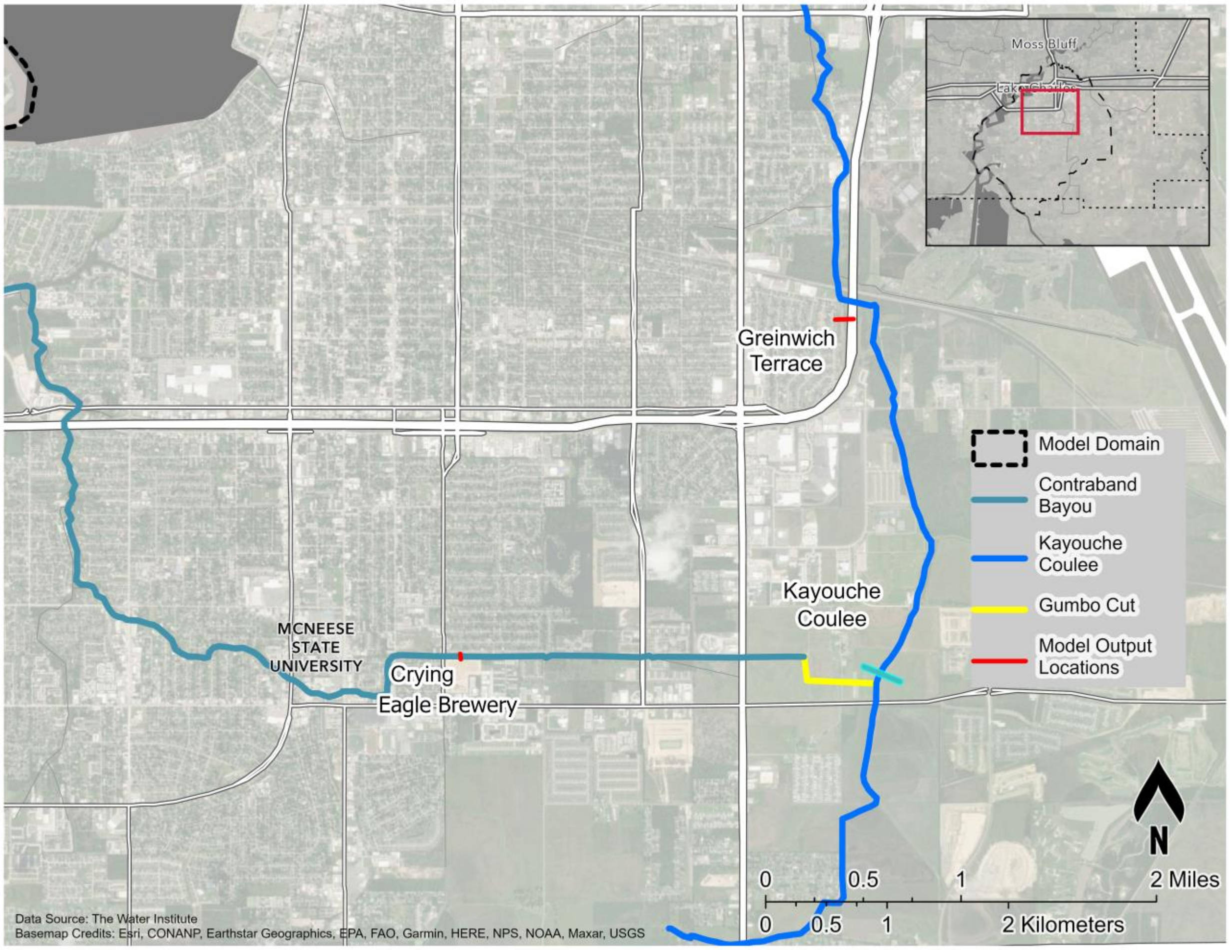

Figure 24 The 5 model output locations were selected based on the clients desired locations as well as investigating both Kayouche Coulee and Contraband Bayou.

4.2.1 10-year Precipitation Event With High Tide Conditions

The study simulated this scenario for Existing and With Project conditions to evaluate impacts throughout the watershed. Figure 25 shows the difference between the two simulations (With Project conditions minus the Existing conditions), where the red shading shows that the project increased water levels, and the blue shading shows that the project reduced water levels. Throughout the model domain, the average change in water levels was approximately 0.01 ft, with a standard deviation of 0.12 ft. The maximum reduction in water levels was 8.44 ft, and the maximum increase in water levels was 10.22 ft which occurred in the waterways or within the footprint of the detention pond, and away from populated areas (Figure 25).

The modeling conducted showed that the proposed detention pond caused the most significant reduction in water levels, which was expected since the pond was not present in the simulation of the Existing conditions. The area near McNeese farms, located east of Gumbo Cut, also experienced similar reductions in water levels as a result of the project. This reduction occurred both to the north and south of the BGB channel and was at least 0.5 ft proximal to the channel and up to 0.1–0.2 ft within one or two blocks from the channel. Water level reductions were also observed along Kayouche Coulee towards I-210, primarily due to the enlargement of the existing cross-section of the Coulee compared to the proposed BGB channel cut template and a corresponding increase in conveyance (Figure 25). The modeling also showed a significant reduction in water levels between McNeese State University and the new detention pond, with a reduction ranging from 0.1 to 0.3 ft. However, along the Gumbo Cut connection, the model shows the maximum increase in water levels (> 0.5 ft) because the project converted the high terrain to a channel that holds water. Along Contraband Bayou west of McNeese State University, water levels were higher (~0.2–0.3 ft) because of the project, but they diminished rapidly (~0.1–0.2 ft) before reaching the I-210 interstate. The water, however, remained within the banks of the Bayou (Figure 25).

To the north, along Kayouche Coulee, increased water levels were observed (~0.1–0.2 ft) because of the project along the east bank and floodplain of Kayouche Coulee south of I-210, with higher water levels shown north of I-210 (~0.2 – 0.3 ft). But, similar to Contraband Bayou, the water remained within the banks and floodplain of the Kayouche Coulee. For the rest of the study area, the changes in water level for this scenario due to the project were negligible and within the model accuracy (Figure 25).

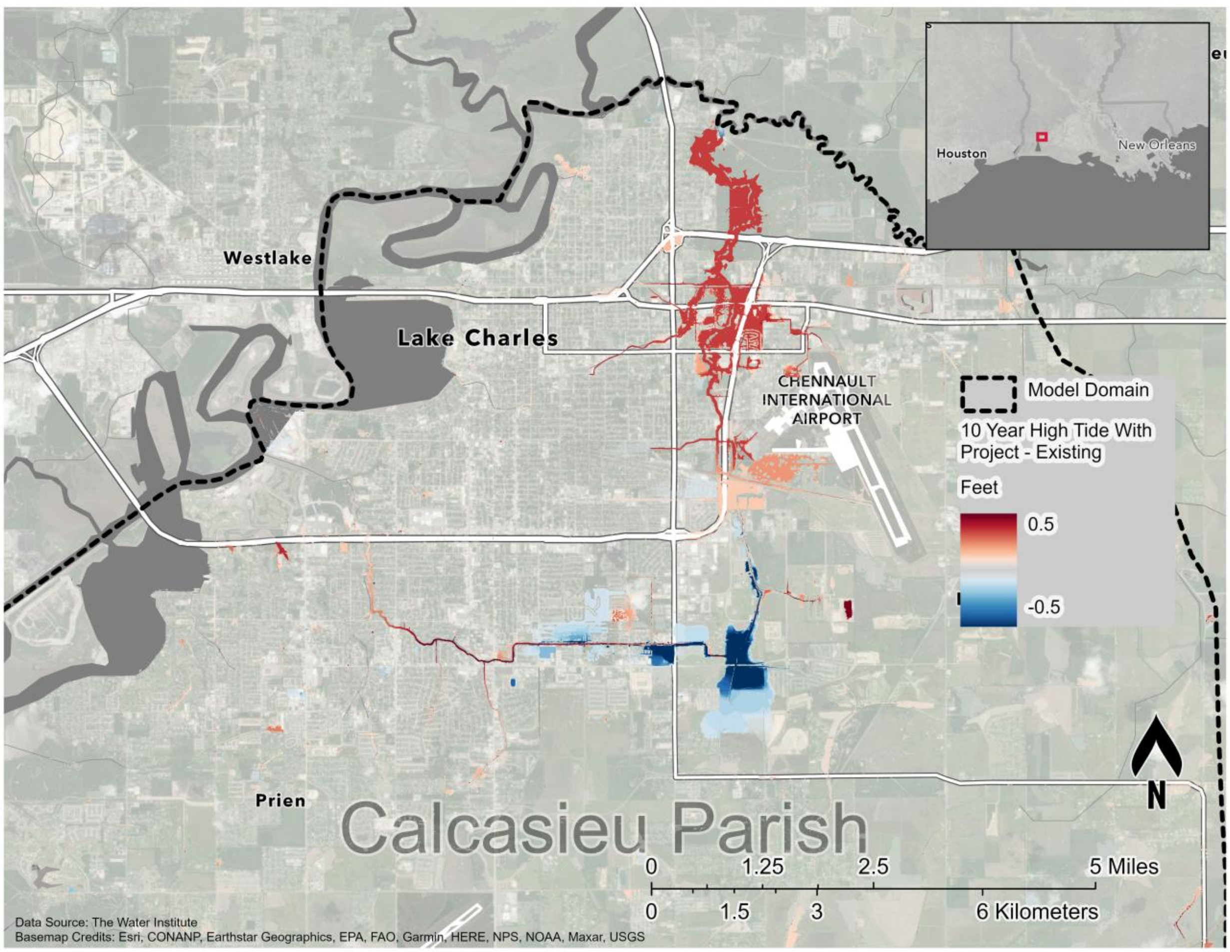

Figure 25. Model results from the 10-year precipitation event with high tide scenario, showing WSE With Project minus Existing Conditions WSE , where red shading indicating an increase in WSE and blue shading a decrease because of the project. WSE differences of +0.10 ft to -0.10 ft are not displayed.

Model output at selected locations (Figure 26) showing timeseries of flow throughout the BGB corridor were examined both with and without project conditions. The location for the output is shown in Figure 26, and the timeseries flow output for three of these locations is shown in subsequent figures (Figure 27 through Figure 29).

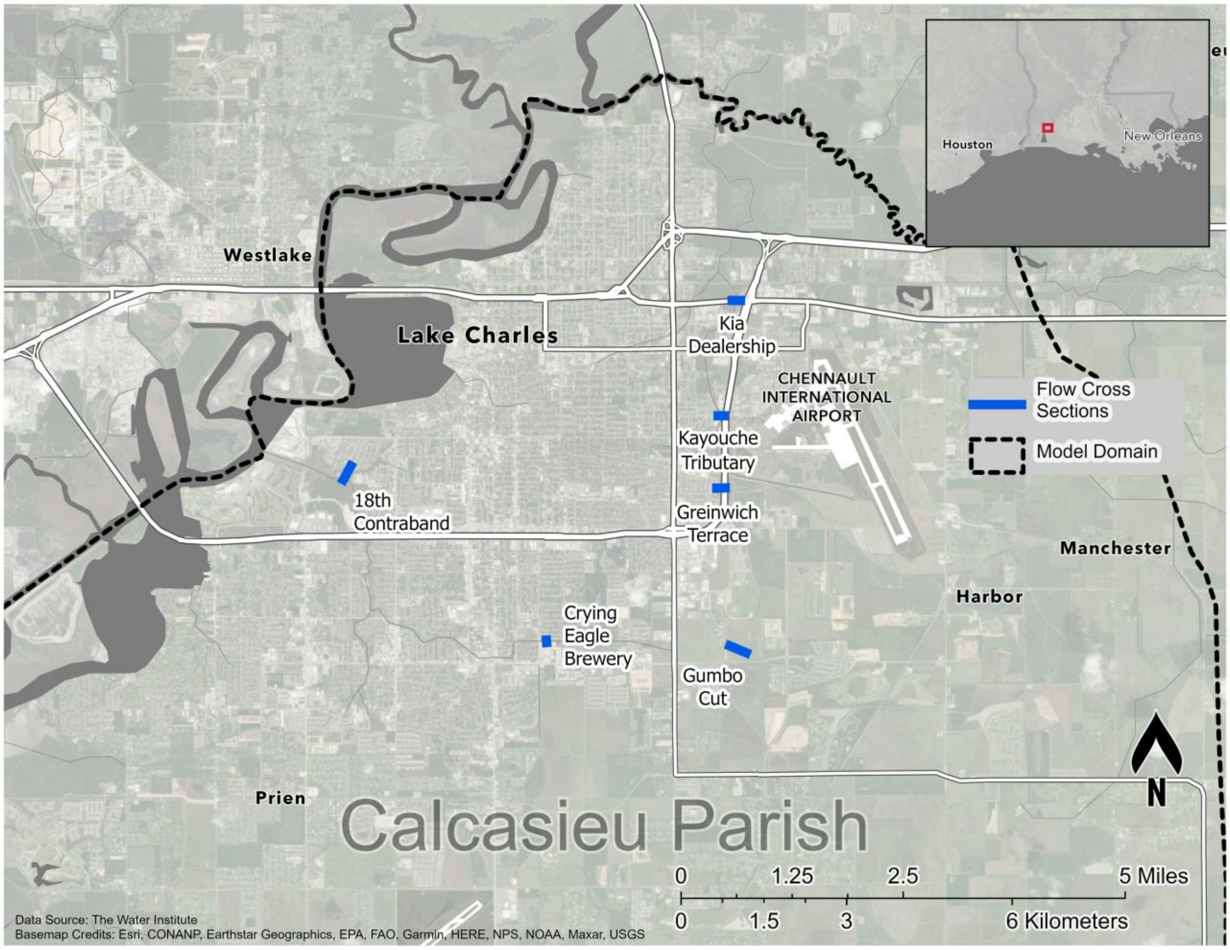

Figure 26 Locations were timeseries flows were extracted from the model for further analysis for additional comparisons of with and without BGB project conditions. Timeseries results are shown in subsequent figures at three of these locations.

The model outputs at Greinwich Terrace and Crying Eagle Brewery do not significantly impact the WSE. However, in the With Project condition, the Greinwich Terrace area drained faster (Figure 27). The Crying Eagle Brewery location, meanwhile, does not drain faster (Figure 28) but stayed within the banks of Contraband Bayou, which was expected and is also reflected in Figure 29 when observing the instantaneous flow output at Kayouche Coulee near Gumbo Cut. The modeling shows that in the Existing conditions, the flow is moving towards the Kayouche Coulee pump station. In the With Project conditions, the flow starts moving towards the pump station, but as soon as the pump station reaches its capacity, the flow reverses and moves toward Contraband Bayou (Figure 29).

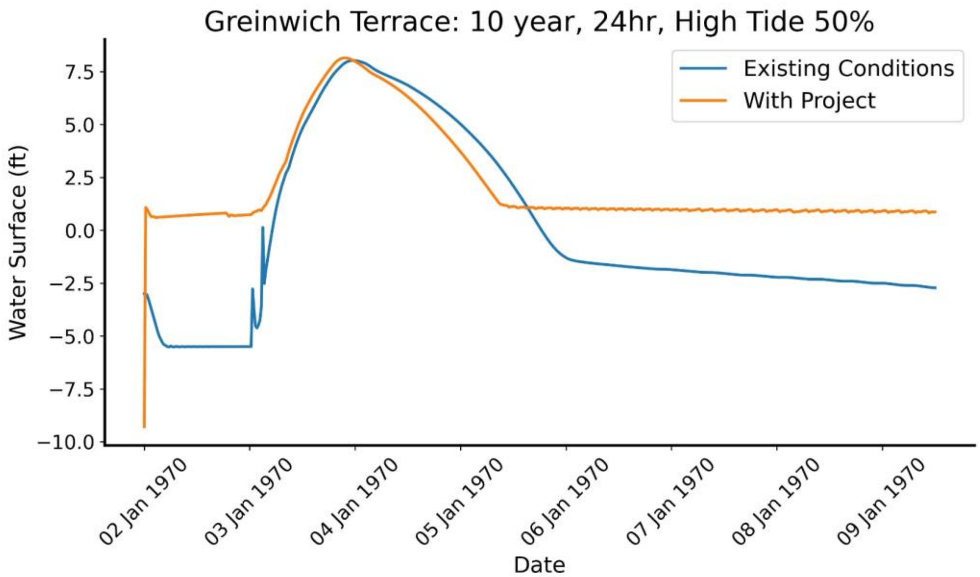

Figure 27. Evolution of water levels (WSE) at the Greinwich Terrace area for the 10 year, 24 hr duration, high tide scenario evaluated for with project and for existing conditions. The model depicts minor changes in water levels. The model, however, indicates that the area drains faster with the project installed (see Figure 26 for geographic location).

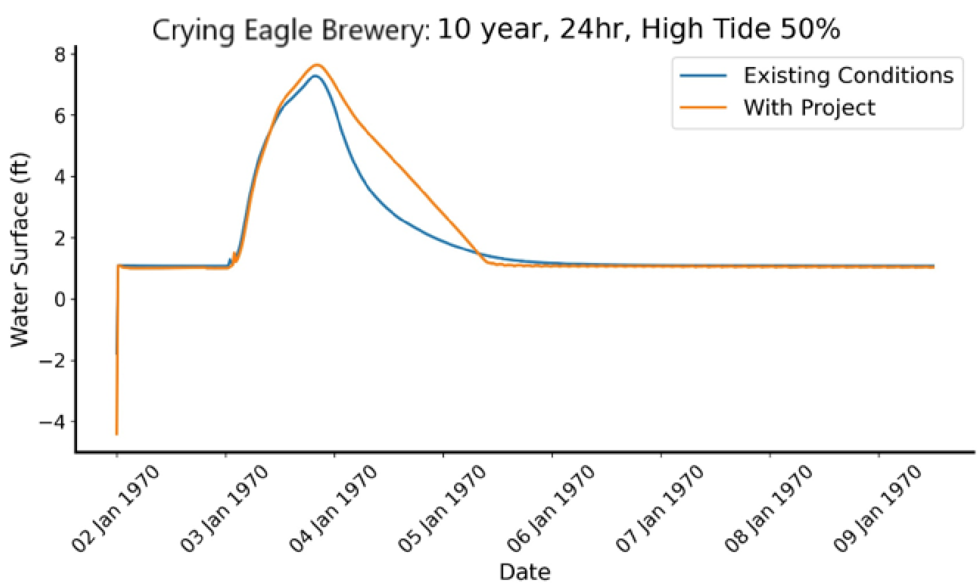

Figure 28. Evolution of water levels (WSE) at the Crying Eagle Brewery area at Contraband Bayou for the 10-year, 24-hour duration, high tide scenario evaluated for with project and for existing conditions. The model depicts a slight increase in WSE and takes longer to drain when the project is installed. This is because at one point during the storm event, the flow towards Kayouche Coulee reverses and flows towards Contraband Bayou (see Figure 29 for flow reversal; see Figure 26 for geographic location).

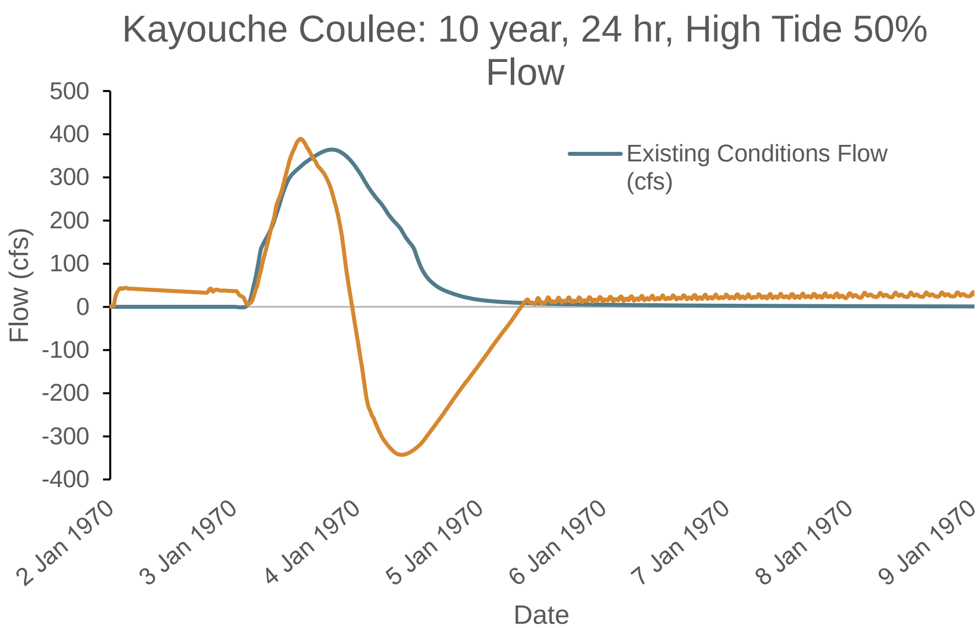

Figure 29. Instantaneous flow for Existing and With Project conditions at Kayouche Coulee near the Gumbo Cut from the 10-year, 24-hour duration, high tide scenario. Positive flow is toward the Kayouche Coulee pump station and negative flow is toward Contraband Bayou. With the watersheds connected, regardless of the spatial trends in precipitation, the project, with the presence of Gumbo Cut, can direct runoff differently compared to the existing conditions; the connection of the watersheds allows for flow to move west toward Contraband Bayou if there is limited capacity toward Kayouche Coulee area (see Figure 26 for geographic location).

4.2.2 100-year Precipitation Event With High Tide Conditions

The study simulated this scenario for Existing and With Project conditions to evaluate impacts throughout the watershed from a lower frequency event. Figure 30 illustrates the difference between the two simulations (With Project conditions minus the Existing conditions), where the red shading shows that the project increased water levels, and the blue shading shows that the project reduced water levels. The average change in water levels across the model domain was approximately 0.003 ft, with a standard deviation of 0.1 ft. The maximum reduction in water levels was 5.22 ft, and the maximum increase was 13.47 ft which occurred in the waterways or within the footprint of the detention pond, and away from populated areas (Figure 30).

The results of the simulations for the 100-year precipitation scenario showed that the project had the most significant impact on water levels at the proposed detention pond and the areas near McNeese farms. At the McNeese farms, the reduction occurred both north and south of the BGB channel, and the reduction was more than 0.5 ft in proximal areas to the channel and at least 0.5 ft up to two blocks from the channel. The enlargement of Kayouche Coulee by the proposed BGB channel cut template and a corresponding increase in conveyance led to water level reductions along Kayouche Coulee toward I-210 near East Prien Lake Rd (Figure 30). To the west past the Crying Eagle Brewery near McNeese State University, there was a reduction of more than 0.5 ft within the Contraband Bayou confines and 0.2 to 0.3 ft in proximal areas outside the Bayou footprint (Figure 30).

To the north, along Kayouche Coulee, increased water levels were observed (~0.1–0.2 ft) due to the project along the east bank and floodplain of Kayouche Coulee north and east of I-210. Higher water levels were observed north of I-10 and Highway 90 (~0.2–0.3 ft), and water levels exceeded the Kayouche Coulee banks and floodplain by approximately 0.1–0.2 ft. For the rest of the study area, the changes in water level due to the project were negligible and within the model accuracy (Figure 30).

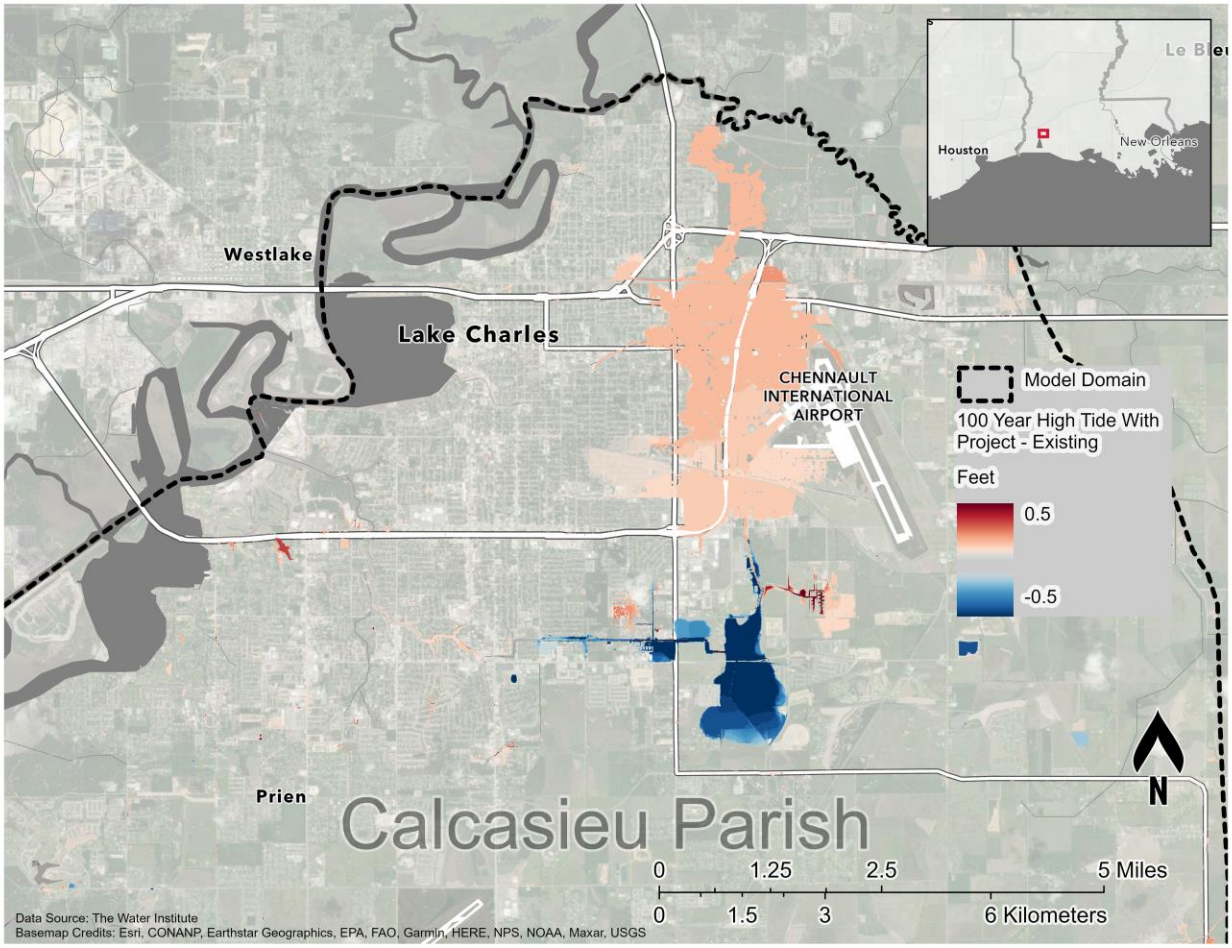

Figure 30. Model results from the 100-year precipitation event with high tide scenario, showing WSE With Project minus Existing Conditions WSE , where red shading indicating an increase in WSE and blue shading a decrease because of the project. WSE differences of +0.10 ft to -0.10 ft are not displayed.

Model output at selected locations (Figure 26) showing timeseries of flow throughout the BGB corridor were examined both with and without project conditions. The location for the output is shown in Figure 26, and the timeseries flow output for three of these locations is shown in subsequent figures (Figure 31 through Figure 33).

According to the model, the project is not expected to have a significant impact on water levels at the Greinwich Terrace and Crying Eagle Brewery. However, the Greinwich Terrace area will have a faster drainage rate in the With Project condition as seen in Figure 31. Near the Crying Eagle Brewery, the project will cause higher water levels to last longer, but the water will remain within the BGB channel as depicted in Figure 32. The model also indicates that currently, during existing conditions, water flows toward the Kayouche Coulee pump station. However, with the project installed, flow will initially move toward the pump station until it reaches its capacity. After that, it will reverse and move toward Contraband Bayou (as depicted in Figure 33). The WSE results at the Crying Eagle Brewery show that drainage will take longer, but the newly enlarged BGB channel will contain the flow within its banks as depicted Figure 32.

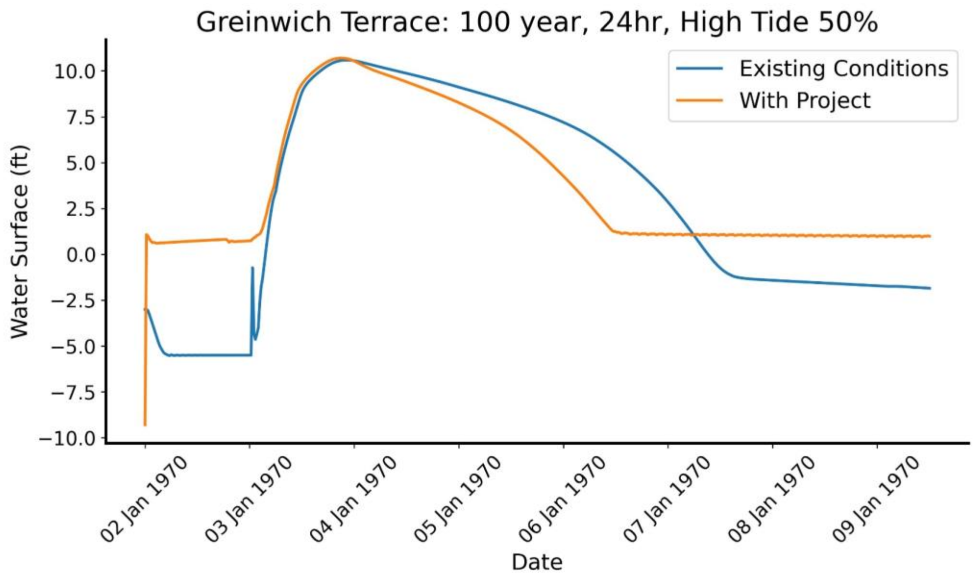

Figure 31. Evolution of water levels (WSE) at the Greinwich Terrace area for the 100-year, 24-hour duration, high tide scenario evaluated for with project and for existing conditions. The model depicts minor changes in water levels. The model, however, indicates that the area drains faster with the project installed (see Figure 26 for geographic location).

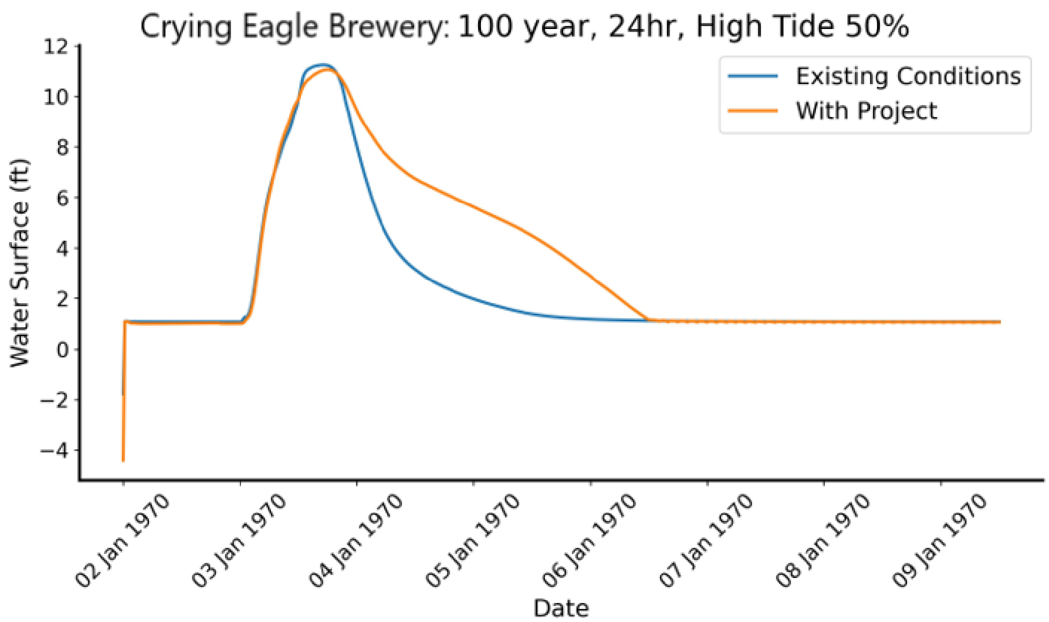

Figure 32. Evolution of water levels (WSE) at the Crying Eagle Brewery area at Contraband Bayou for the 100-year, 24-hour duration, high tide scenario evaluated for with project and for existing conditions. The model depicts a slight increase in WSE and takes longer to drain when the project is installed. This is because at one point during the storm event, the flow towards Kayouche Coulee reverses and flows towards Contraband Bayou (see Figure 33 for flow reversal, and Figure 26 for geographic location).

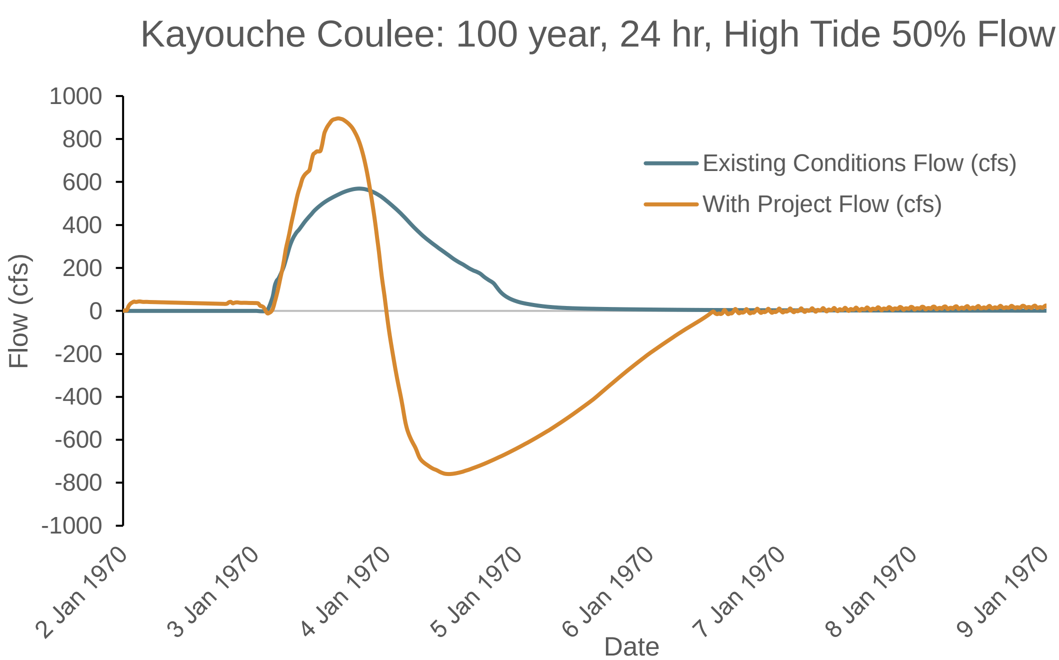

Figure 33. Instantaneous flow for Existing and With Project conditions on Kayouche Coulee near the Gumbo Cut from the 100 year, 24 hour duration high tide scenario. Positive flow is towards the Kayouche Coulee pump station and negative flow is towards Contraband Bayou. With the watersheds connected, regardless of the spatial trends in precipitation, the project, with the presence of Gumbo Cut, can direct runoff differently compared to the existing conditions; the connection of the watersheds allows for flow to move west toward Contraband Bayou if there is limited capacity towards Kayouche Coulee area (see Figure 26 for geographic location).

4.3. SALINITY MODEL

The model results indicate no change in salinity near the bottom of Contraband Bayou, but show small changes in salinity near the surface during With Project conditions up to McNeese State University as depicted in Figure 34 for July 2013, the driest month within the 5-month simulation period, a trend that continues during less dry conditions (i.e., October and November 2013). This study did not evaluate salinity control measures and as such, without salinity control measures, the model shows that the salinity could increase up to 1.5 to 2 miles upstream of McNeese State University, with small or minor salinity increases predicted to occur beyond that location. The model does not indicate any noticeable stratification upstream of McNeese State University Campus, likely due to the shallow nature of the Gumbo Cut, and shows increased water exchange during normal tidal conditions. In the existing conditions, the narrowing width and shallower depth of Contraband Bayou reduce it to a ditch approximately two miles upstream of McNeese State University Campus, resulting in a gradual salinity decrease to 0 ppt. The construction of the Gumbo Cut, along with the widening and deepening of parts of Contraband Bayou to match the proposed Gumbo Cut template dimensions, results in increase in simulated salinity, albeit small), up to approximately two miles north of the Gumbo Cut (i.e., in the Kayouche Coulee), beyond which modeled salinity values remain at or near 0 ppt.

The temporal dynamics are illustrated in Figure 35 through Figure 37 for three locations along Contraband Bayou—specifically, W Prien Lake Rd, McNeese State University Campus, and 5th Ave, (locations also indicated in Figure 34). In the far downstream section of Contraband Bayou (W Prien Lake Rd in Figure 35), the differences in salinity between existing and with-project conditions are small to negligible (typically <1 ppt). However, upstream toward McNeese State University Campus (Figure 36), salinity in with-project conditions is up to 5 ppt higher compared to existing conditions, resulting in frequent, but short lived, salinity spikes exceeding 10 ppt. Further upstream, near 5th Ave (Figure 37), where Contraband Bayou has a minimal footprint in existing conditions resulting in near freshwater salinity (~0 ppt), the simulated project conditions (without salinity controls) show an increase in salinity by more than 5 ppt during the driest part of the simulation period. The duration of the period during which the salinity exceeds 5 ppt is typically on the order of hours to days, with a maximum duration of about a week in early July 2013. The low duration of the simulated salinity increase suggests that there is higher likelihood that rainfall runoff would contribute to offset the salinity increase and prevent chronic exposure of some environments to higher salinity. Moreover, the low duration of these salinity increases also suggests that salinity control measures could be effective and more straightforward to implement and accomplish the intended results.

During the salinity analysis, the study examined how often salinity concentrations exceeds a threshold (4 ppt) that could influence vegetation that is less tolerant to salinity, such as cypress trees (if prolonged exposure takes place), along Contraband Bayou for both existing and with-project conditions (Figure 38). The threshold of 4 ppt falls within the range of salinity concentrations (2–5 ppt) that Hoeppner et al. (2008) and Shaffer et al. (2009) identified as threshold for increase in tree mortality in cypress-tupelo swamps in Lake Maurepas, Louisiana when exposure is prolonged (refer to Section 2.3). Figure 38 shows that the number of exceedances is slightly reduced (up to several tens of days) in the reach of Contraband Bayou between W Prien Lake Rd and McNeese State University Campus, suggesting that salinity conditions will remain the same if not improve with BGB project. However, upstream of McNeese State University Campus, simulation results indicate that the project increases the number of days of salinity exceedance appreciably up to the Gumbo Cut. It is noted again, however, that the simulated salinity exceedances along this portion of Contraband Bayou are without any salinity control measures.

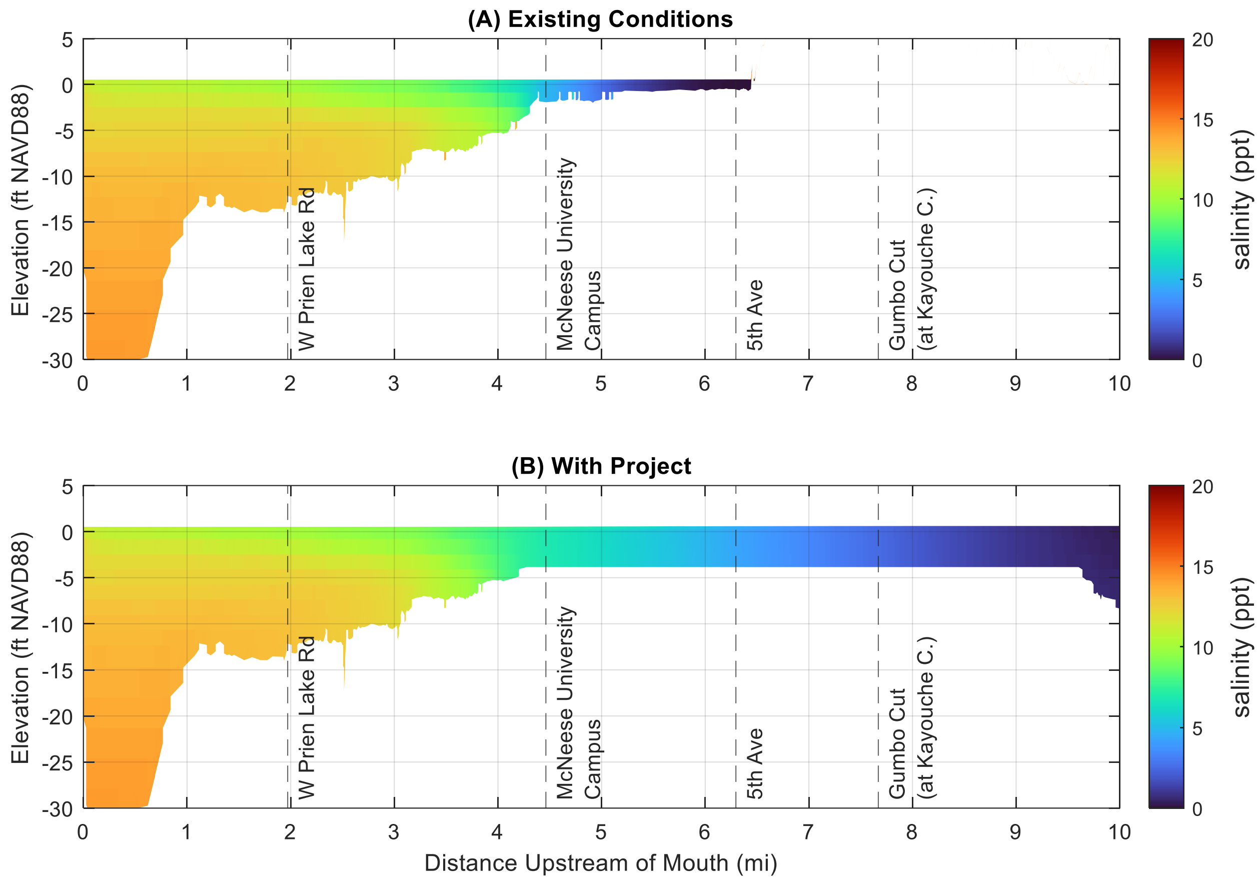

Figure 34. Transect along Contraband Bayou illustrating simulated salinity averaged over July 2013, the driest month within the 5-month simulation period , with subfigure (A) depicting existing conditions and subfigure (B) presenting conditions under the proposed project.

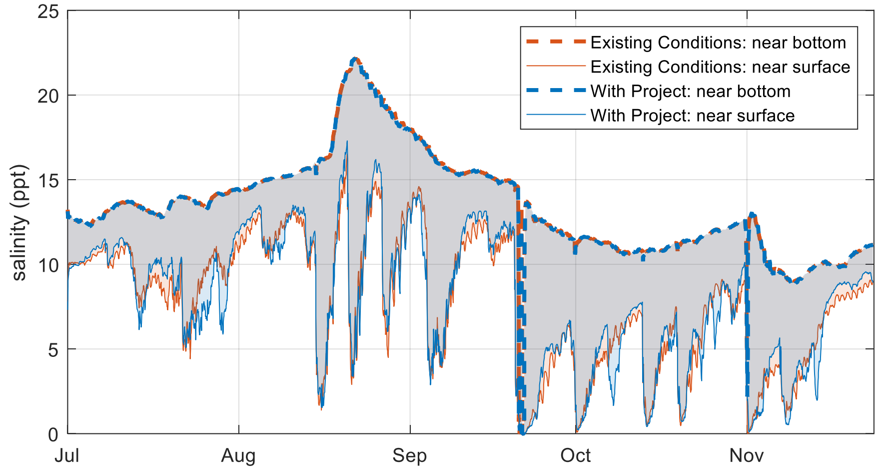

Figure 35. Timeseries of simulated salinity (near-bed and near-surface) in Contraband Bayou at W Prien Lake Rd for both existing conditions and the proposed project.

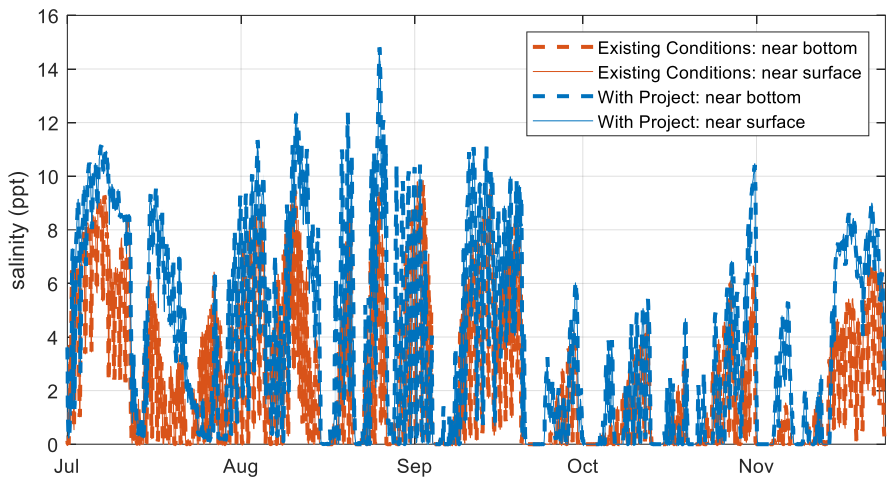

Figure 36. Timeseries of simulated salinity (near-bed and near-surface) in Contraband Bayou at McNeese State University Campus for both existing conditions and the proposed project.

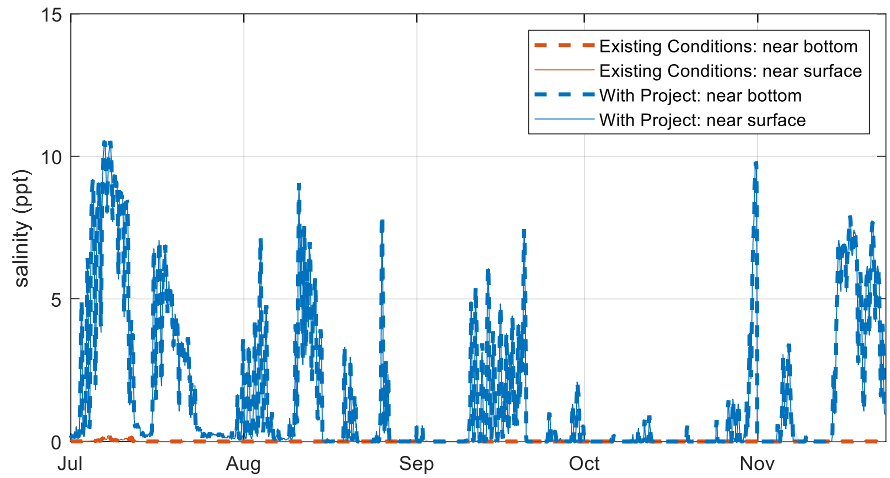

Figure 37. Timeseries of simulated salinity (near-bed and near-surface) in Contraband Bayou at 5th Ave for both existing conditions and the proposed project.

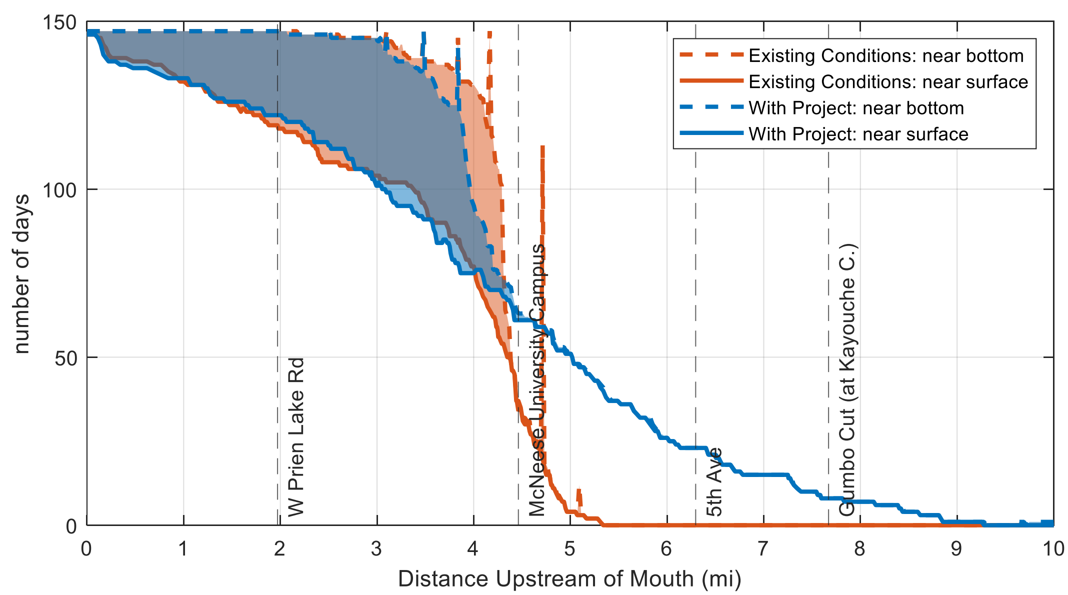

Figure 38. Number of days with daily averaged salinity concentrations exceeding a 4 ppt threshold along Contraband Bayou (near-bed or near-surface), compared between existing conditions and conditions with the project, for the 147-day simulation period representing relatively dry conditions from July 1–Nov 23, 2013. Vertical dashed lines indicate several locations that align with the cross-sections shown in Figure 13. A lower number of exceedances indicates more favorable conditions for cypress trees. The highest number of exceedances occurs near the mouth of Contraband Bayou (left side of the figure) for both existing (orange) and with project (blue) conditions. The number of exceedances decrease with distance upstream of the mouth. Between McNeese State University Campus and the Gumbo Cut (~4.5 and ~7.5 miles upstream of the mouth, respectively), the with-project scenario (blue) shows a significant increase of the number of days where salinity exceeds the threshold of 4 ppt.

5.0 SUMMARY AND DISCUSSION

5.1. HYDROLOGY AND HYDRAULICS

This study developed a comprehensive hydraulic model based on HEC-RAS encompassing the greater Lake Charles area to evaluate the feasibility of the BGB waterway. The model had variable resolution to resolve major waterways, capture and route runoff resulting from precipitation events, and included large regional structures such as pump stations, gates, and information regarding their operations. The model was calibrated for a significant flood event (May 17, 2021) using water level observations from the vast network of gauges operated by the CPPJ. The model was further improved using participatory modeling methodology, whereby input on the model inputs and outputs are collected, validated, and confirmed through meetings with community leaders, members, stakeholders, and city officials. Following calibration, the BGB project template was installed, connecting Contraband Bayou to Kayouche Coulee via the Gumbo Cut, and several scenarios were simulated. Two rainfall events with a return period of 10 and 100 years and two tidal conditions were considered.

The simulation of a 10-year rainfall event revealed that the proposed project had the most significant impact on water levels in the area where the new detention pond is being built. This is because the pond was already planned and included on the landscape. Other areas where water level changes were noticeable include Gumbo Cut, and to a lesser extent, the existing waterways of Contraband Bayou and Kayouche Coulee. However, the overall impact of the project on water levels throughout the study area was negligible.

Model results from the 100-year rainfall event showed that the project's most significant impact on water levels was near the proposed detention pond, similar to the 10-year rainfall event. Moreover, the 100-year simulation results showed that water levels near McNeese farms and for up to two blocks north and south of Gumbo Cut were reduced by at least 0.5 ft. Moreover, the increased conveyance afforded by the project reduced water levels between Gumbo Cut and the I-210 corridor. To the north of I-210, along Kayouche Coulee, increased water levels were approximately 0.1–0.2 ft but remained within the Kayouche Coulee floodplain. For the rest of the study area, the changes in water level due to the project were negligible and within the model accuracy.

5.2. SALINITY

Without additional means of salinity control, the implementation of the Gumbo Cut is anticipated to increase salinity in parts of Contraband Bayou, particularly upstream of the McNeese State University Campus. Gumbo Cut, along with the increased channel dimensions in Contraband Bayou towards Gumbo Cut, increase hydraulic connectivity, which increases the exchange between relatively saline waters in the Calcasieu River and fresher waters in Contraband Bayou. This leads to increased salinity intrusion into Contraband Bayou.

A slight salinity decrease is projected for a small (~ 1 mile) section upstream of the McNeese State University Campus. The predicted salinity decrease can likely be attributed to the increased volumes of freshwater runoff entering Contraband Bayou due to the construction of the Gumbo Cut, allowing some of the Kayouche Coulee watershed to drain into Contraband Bayou during rainfall events.

The modeling results demonstrate that freshwater runoff from rainfall events effectively reduces salinity concentrations and forces the salt wedge in the downstream direction toward Calcasieu River. In the absence of rainfall events, a similar effect can be achieved by allowing (if possible) freshwater from English Bayou to drain into the Kayouche Coulee, which would then enter Contraband Bayou though the Gumbo Cut and reduce salinity in Contraband Bayou. With appropriate modifications, Gumbo Cut would provide the ability to control salinity, where no such ability exists now.

The absence of salinity measurement data in Contraband Bayou created challenges for the salinity modeling effort. A field data campaign to collect salinity concentrations in Contraband Bayou would improve future analysis and modeling as well as provide baseline data and is recommended. Discrete observations at several locations along Contraband Bayou spanning weeks to months during relatively dry conditions are ideal. Continuous data collection efforts are likely not necessary but if available could help provide additional insights into the dynamics of the salt wedge in Contraband Bayou; weekly measurements are likely sufficient to enhance calibration and validation of the model. In the lower reaches of Contraband Bayou toward the Calcasieu River (i.e., depth greater than 5 ft), it is recommended to measure concentrations both near the surface and near the bed, to determine the occurrence and intensity of salinity stratification. In the upper reaches of Contraband Bayou (e.g., at the McNeese State University Campus; Figure 36), model results show that salinity concentrations exhibit diurnal variability of up to ~5 ppt. Therefore, at these locations, it is recommended to collect data throughout the day and at different tidal conditions, to better document diurnal variability in the field.

5.3. A COMMUNITY-INFORMED MODELING APPROACH

The participatory process used in this research brought numerical modelers and scientists together with a group of local residents with strong ties (economically, historically, and culturally) to the community. The local knowledge possessed by these residents was collected and used to improve model accuracy and reduce uncertainties in the model. Prior to running any current or future scenarios involving the planned BGB project, the model was first calibrated for a 2021 extreme rainfall event that directly or indirectly impacted nearly all the residents involved in this research. The results of this initially calibrated model run were incorporated into a web-based GIS tool that allowed residents to zoom into local areas of interest and locations known to have flooded (or to have not flooded) and review the model outputs. Testing the model in this way allowed residents to ground truth the results using their local knowledge of flood extents and depths in locations located throughout the study area. This participatory modeling approach identified several areas for improvement in the model, from the identification of boundary issues to recent landscape changes that the input datasets did not account for. Most notably, city government officials were aware of a significant error in the input rainfall dataset used in the initially calibrated model, promoting researchers to utilize an alternative rainfall dataset that was found to be more accurate. Allowing residents and local stakeholders to review the model results against a locally known event assured that subsequent model runs under current and future conditions, both with and without the BGB project in place, were as accurate as possible. This process also resulted in an increased level of public trust in the model results, as evidenced through public comments made during the last competency group meeting when the final modeling results for the BGB were presented.

5.4. CONSIDERATIONS FOR FUTURE WORK

The modeling tools developed for this project can further the analysis and have a broader impact than the results presented here through a combination of modeling tool refinement and application, and use of modeling results to support planning and operational decisions. Some of the next steps that may follow this study include:

- Further refinement and improvement of the modeling tools to provide a more robust platform with which to evaluate additional and more complicated alternatives.
- These models, whether used as-is or modified, provide a reassuring adaptability, and can inform a more extensive feasibility assessment with additional exploration of external and internal factors contributing to the project's performance.
- The models can help better understand watershed connectivity and their results used to inform local-to-regional planning in conjunction with the BGB project or separately.
- The models can be used to inform early stages of engineering and design.
- The models can be applied to help constrain or refine operational procedures for structures such as pump stations and gates.
- The models can be used to determine measures to reduce potential impacts for the project related to flow routing and salinity.

5.5. NEXT STEPS

The following next steps were identified by the BGB stakeholders following discussions, review of the study results, and analysis presented in this report. The next steps listed below are not part of this study.

- Using existing or new tools, define a suitable control structure near the Gumbo Cut location, including its purpose and function.
- Determine whether the design would require a portage to carry paddlecraft between Contraband Bayou and Kayouche Coulee.

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APPENDIX A.

In addition to evaluating the BGB project, NPS and the local partner requested analysis for an incremental evaluation and analysis of the BGB project, which included a second scenario for evaluation in this study. This second scenario includes a southern route with a suggested Southern Cut connecting Kayouche Coulee to Coulee Hippolyte, which drains this part of the watershed to the south toward the GIWW and the northern part of Calcasieu Lake. The Southern Cut scenario was evaluated incrementally in this study, in that both the Southern Cut, and Gumbo Cut (BGB project), were evaluated together under the conditions shown in Table A-1.

Table A-1. Description of the Southern Cut scenario and corresponding model simulations used to evaluate the feasibility of the BGB project with the inclusion of drainage to the south towards the GIWW.

Precipitation Event	Project Scenario	Downstream Boundary Condition
10 year (NOAA Atlas-14 gridded rainfall)	With BGB Project + Southern Cut	Mid Tide
	Without Project	

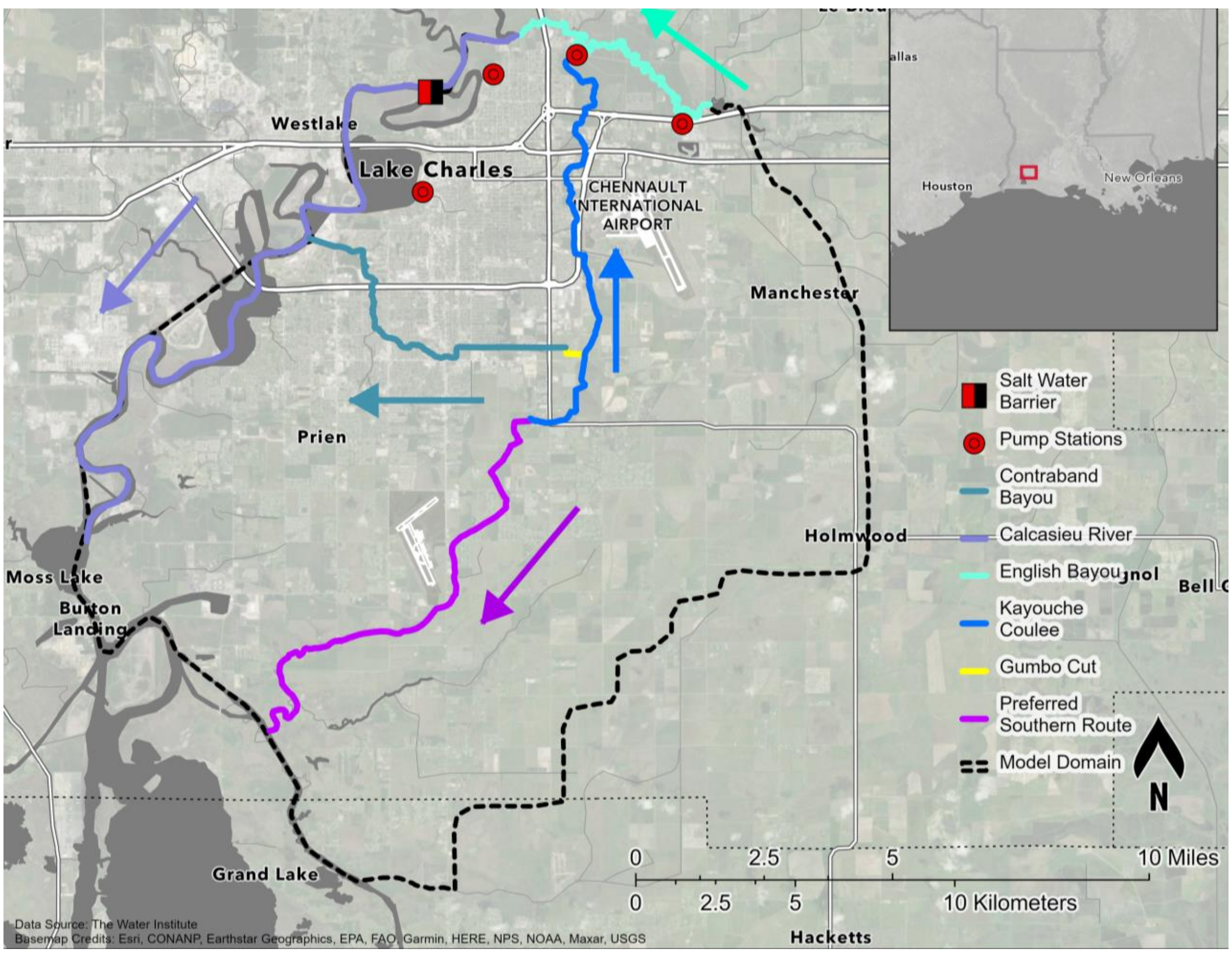

Figure A-1. View of the study area in the greater area of Lake Charles, LA. The figure also shows the four watercourses relevant to the study (English Bayou, Contraband Bayou, the Calcasieu River, and Kayouche Coulee), the direction of flow for each watercourse shown with directional arrows, the extent of the hydraulic model domain (dashed black line), the location of the saltwater barrier in the Calcasieu River, and the location of pump stations throughout the city.

A.1 SOUTHERN ROUTE SCENARIO

The study analyzed a proposal to expand the BGB project. The second scenario suggested a southern route with a proposed Southern Cut that connects Kayouche Coulee to Coulee Hippolyte. This would help drain this part of the watershed to the south toward the GIWW and the northern part of Calcasieu Lake. This study evaluated this scenario alongside the BGB, and the Southern Cut was connected east of the Gumbo Cut via an extension of Kayouche Coulee (Figure A-1). The study used the 10-year precipitation event and mid-tide (Table A-1) for this scenario. The same cross-section template used for the BGB was used to dredge the connection between Kayouche Coulee and Coulee Hippolyte. The Southern Cut invert elevation at its connection to the BGB was matched, and the remaining dredged cut to the south followed the plan as depicted in Figure 9 until the channel met the GIWW. All other information related to pump and gate operations remained the same as previous scenarios with BGB.

The Southern Cut scenario resulted in similar water level changes to the previous 10-year precipitation scenario along the BGB footprint. The average change was 0.01 ft, with a maximum reduction of 8.31 ft and a maximum increase of 14.44 ft (Figure A-2). The model confirmed a reduction in water levels at the newly constructed detention pond and near McNeese farms, with a similar decrease along Contraband Bayou until McNeese State University. Water levels increased slightly (0.1–0.2 ft) beyond McNeese State University, with the observed change decreasing toward I-210, and no changes in water level were noted in Contraband Bayou beyond I-210.

The Southern Cut scenario produced additional differences that are not present in the 10-year scenario without the Southern Cut. Along the Kayouche Coulee waterbody and floodplain, a slight reduction in water levels is predicted, around 0.1–0.2 ft. Additionally, the Southern Cut expands the area where significant water level reductions occur toward the south, extending east of Gumbo Cut, as expected, due to the added conveyance provided by connecting Hippolyte Coulee to Kayouche Coulee (Figure A-2). Lastly, the Southern Cut results in a considerable reduction in water levels to the south, primarily along the route of the dredged channel, with reductions of more than 0.5 ft, and sometimes outside of the channel footprint. The modeling indicates that the effect of the Southern Cut fades to negligible change near the Lake Charles Regional Airport (Figure A-2). Only insignificant increases in water level were predicted throughout the southern part of the watershed due to the Southern Cut and the resulting connection of Hippolyte Coulee to Kayouche Coulee, and those small water level increases remained within the channel banks.

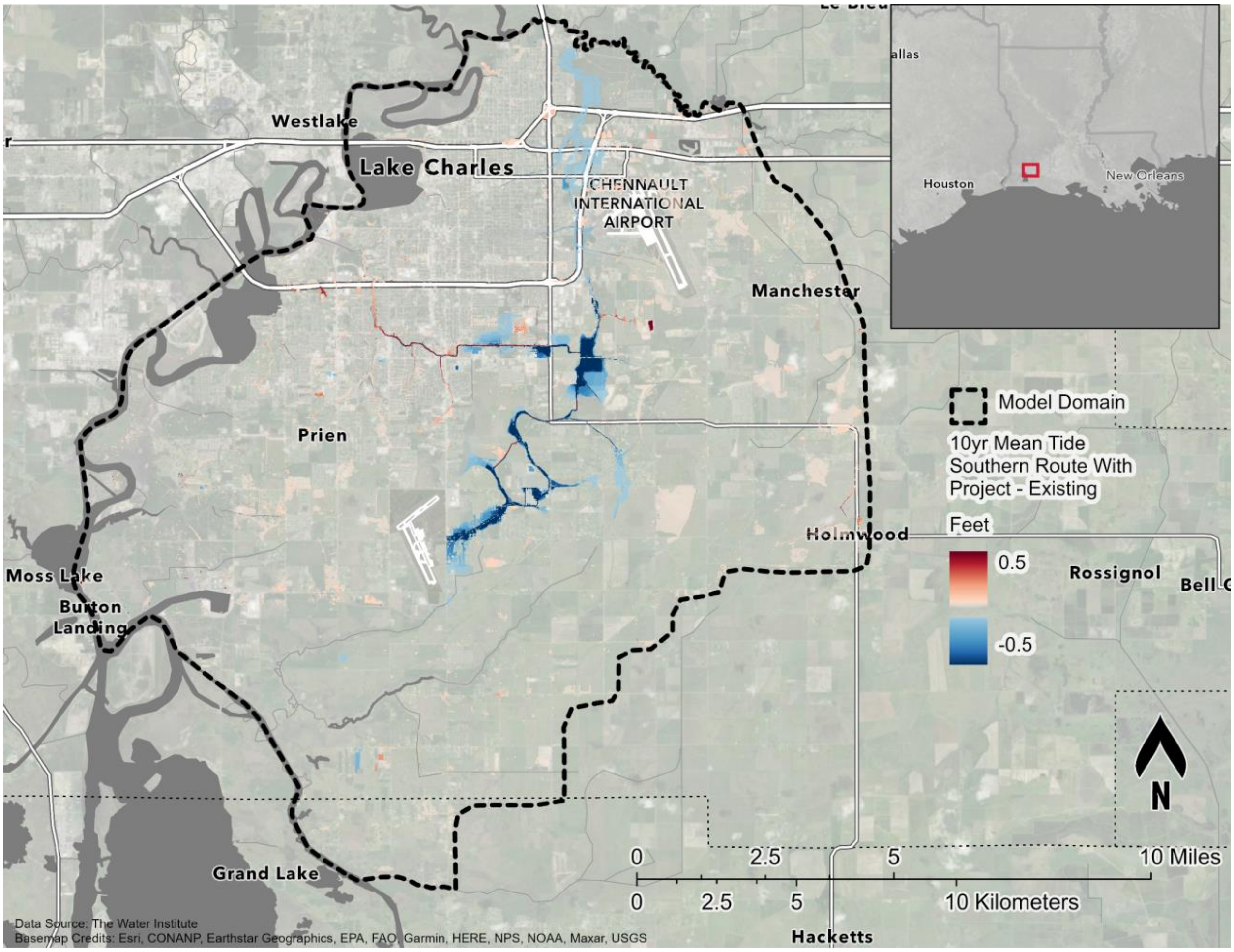

Figure A-2. Model results from the 10-year precipitation event with mid tide scenario, showing water level change (WSE) With Project (Southern Cut plus BGB) minus Existing Conditions WSE , where red shading indicates an increase in WSE and blue shading a decrease because of the project. WSE differences of +0.10 ft to -0.10 ft are not displayed.

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