DRAFT

ENGINEERING APPENDIX A

GULF INTRACOASTAL WATERWAY
BRAZOS RIVER FLOODGATES AND COLORADO RIVER LOCKS SYSTEMS FEASIBILITY STUDY

US Army Corps of Engineers

Texas Department of Transportation

REFERENCES

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1 INTRODUCTION

1.1 PROJECT LOCATION

The study area (Figure 1) encompasses approximately 40 miles of the GIWW in Texas, at the intersections of the Brazos and Colorado Rivers along the Gulf Coast and covers two counties, Brazoria and Matagorda. The Brazos floodgates are 7 miles southwest of Freeport, Texas in Brazoria County and are accessible via Floodgate Road, 3.5 miles south of State Highway 36. The Colorado locks are located near Matagorda, Texas in Matagorda County. The East Lock is located on Matagorda Street approximately 0.25 miles west of the FM 2031 Bridge over the GIWW. The West Lock is not accessible by road.

Figure 1 Location Map

1.2 EXISTING CONDITIONS

1.2.1 BRAZOS RIVER CROSSING

The Brazos River flows into the Gulf of Mexico, crossing the GIWW near Freeport, TX. In 1929, the Brazos River was diverted 8 miles south of its mouth at Freeport to reduce flooding and shoaling in the Port of Freeport. The Brazos River Floodgates were constructed in July 1941. Two 75 foot floodgates, one on each side of the Brazos River crossing of the GIWW, are provided to control flood flows from the Brazos River into the GIWW and to control sand and silt deposition from the Brazos River into the GIWW. The authorized channel in the GIWW is 125 feet wide and is typically about 12 feet deep. The floodgates were installed at a time when most tug boats pulled barges behind them instead of using the modern pushing method. The current angled approaches to each floodgate is not conducive to the pushing method with the limited forebay and narrow gate openings. The cross current and through gate flows cause eddies to form unstable approach conditions. When the floodgates were built in 1943, barges were typically 26 feet to 35 feet wide. The floodgate chamber is 75 feet wide, and the maximum width of the barge it can accommodate is 55 feet. Today, it is common for towboat operators to push two 35 feet dry cargo barges side by side, for a total width of 70 feet. A typical tank barge measures 54 feet across, so tank barges must transit singly. The necessity to break the tow to pass individual barges through the Floodgates causes time delays. Also, shoaling issues have occurred causing periodic grounding of vessels. This has increased the difficulties faced by pilots navigating between the floodgates. Frequent accidents occur when tows strike the facilities while trying to line up to enter the floodgates after crossing the Brazos River. The floodgates are only approximately 600 feet from the river. When crossing the river, towboat operators do not have enough time to recover their course after struggling with the river currents. As a result, an average of 36 accidents occurs per year, causing damages to the facility and to the barges. When these accidents involve tank barges, there is also a risk for hazardous material spills.

Tidal effects are present at the project location. Combined with the Brazos River flood stage, this can cause flow both into and out of the GIWW. In addition, the flow velocities through the west floodgate are greatly affected by the San Bernard River. The outlet dredging for the San Bernard River within the last decade has silted in due to low flow and the GIWW has become its outlet partly through the west gate structure. This has increased the difficultly on pilots to navigate the structures.

Restrictions are placed on the tows allowed to cross the Brazos River during high flow events by the USACE in accordance with 33CFR 207.187 (Table 1). Long periods of high flow through the Brazos River that require “tripping” barges through places a serious economic impact on operation of tows through the reach.

Table 1 Existing Navigation Restrictions – Brazos River Crossing

Condition	River Velocity	Head Differential	Restriction
1	Over 2 mph	0.7 to 1.8 ft	• Single vessel passage • Tows with single loaded barges • Tows with two empty barges • Velocity reaches 1.7 mph, tows with two empty barges only
2	-	Over 1.8 ft	Closed
3	Over 5 mph	-	• Single vessel passage • Tows with one barge only loaded or empty
4	Over 7 mph	-	Closed

Due to the well-known navigation issues associated with these floodgates, individual companies have instituted additional self-imposed regulation on their pilots above and beyond the USACE restrictions in order to minimize risks.

Currently, the project has multiple documented maintenance/operational issues outlined in the 2017 Operational Condition Assessment (OCA). Because of the low elevation of the top of the wall of the gate structure, barges routinely hit the walls and gates damaging the steel railing, concrete walls and machinery pit. There are up to 8 feet deep scour holes along the steel sheet pile guide walls on the West and East gates which extend towards the middle of the channel, exceeding the design elevations of the guidewalls. The steel sheet piling for the guidewalls is exhibiting corrosion at the waterline and the bolts for the wale beams are heavily corroded. The guidewall timber bumpers and steel tangent plates are missing or damaged from constant barge impact. Additionally, the existing design of the guidewall is not resilient to barge impact, requiring repairs to the guidewall for most barge impacts. The existing plumbing system (water and septic) and emergency generator/fuel systems are significantly deteriorated with no dependable backup power. The existing electrical power cables within the chamber crossovers are extremely deteriorated. The existing paint system has been ineffective preventing marine growth (particularly gulf oysters) on the structure. This growth has been substantial and adds significant weight causing damage to the hinges/machinery. Also, the gates have been binding during operation; this is speculated to be caused by the movement of the non-pile founded 2 feet thick slabs. The lock buildings continue to deteriorate with missing roof shingles, asbestos siding, leaking windows and doors, inadequate lighting, no GFI receptacles required by NEC, and panel boards that have deteriorated to the point of exposed wiring.

However, the most eminent of concerns is the ongoing high river silt deposits that form on the east and west side of the Brazos. These shoals are developing in the area required for vessel entry. In past years, barges have unexpectedly grounded on these shoals and dredging was required to maintain an open path to the gates.

1.2.2 COLORADO RIVER CROSSING

The Colorado River flows into West Matagorda Bay, crossing the GIWW near Matagorda, TX. Two 1,200 foot by 75 foot locks, one on each side of the Colorado River crossing of the GIWW, are provided to control flood flows from the Colorado River to the GIWW, improve navigation safety by controlling traffic flow and currents at the intersection of the Colorado River's connection with the GIWW and to control sand and silt deposition from the Colorado River into the GIWW. The authorized channel in the GIWW is 125 feet wide and is typically about 12 feet deep. The original course of the Colorado River southward of the GIWW was south-southwesterly through the Matagorda Peninsula into the Gulf of Mexico. In the early 1990s, a diversion channel was dredged from the intersection of the Colorado River and GIWW southwesterly to West Matagorda Bay. Diversion of flow into Matagorda Bay was performed to route the heavy sediment load into the bay to create shallow wetlands for environmental improvements of biologic productivity. When the original floodgates for the lock were built in 1943, barges were typically 26 feet to 35 feet wide. The lock chamber is 75 feet wide, and the maximum width of the barge it can accommodate is 55 feet. Today, it is common for towboat operators to push two 35 feet dry cargo barges side by side, for a total width of 70 feet. A typical tank barge measures 54 feet across, so tank barges must transit singly. The necessity to break the tow to pass individual barges through the locks causes time delays.

USACE restrictions are placed on the size of a tow that can cross the Colorado River when current speed in the river immediately upstream of the intersection exceeds 2.0 mph or 3.0 fps (Table 2). Long periods of high flow through the Colorado River that require "tripping" place a serious economic impact on operation of tows through the reach.

Condition	River Velocity	Restriction
1	2 mph (3.0 fps) or higher	• Single vessel passage • Tows with one loaded barge or two empty barges

Table 2 Existing Navigation Restrictions – Colorado River Crossing

The original Colorado River Floodgates were constructed in September 1943 with the conversion to locks in 1954.The locks are 75 feet wide with sills at El. -17.0 MLLW (NAD88: El. -15.2) and a top of monolith at El. 20.0 MLLW (17.8 top of wall). The locks are quite atypical compared to modern standards.

Currently, the project has multiple documented maintenance/operational issues outlined in the 2017 Operational Condition Assessment (OCA). There are 5 feet deep scour holes along the tie-back sheet pile guide walls on both the East and West locks, exceeding the design elevations of the guidewalls. There are up to 15 feet deep scour holes along the steel sheet pile guide walls and concrete gravity walls on the West and East gates which extend towards the middle of the channel. Wall timbers are missing or damaged. Additionally, the existing design of the guidewall is not resilient to barge impact, requiring repairs to the guidewall for most barge impacts. The existing plumbing system (water and septic) and emergency generator/fuel systems are significantly deteriorated. The existing gate controls, switchgears and transformers are very old and show signs of significant deterioration. The controls houses are in poor condition and do not meet modern codes. The existing electrical conduit running underneath the lock structure is damaged and has rendered the West gates inoperable. The existing paint system has been ineffective preventing marine growth (particularly gulf oysters) on the structure. This growth has been substantial and adds significant weight causing damage to the hinges/machinery.

1.2.3 GIWW DREDGING

Currently, the GIWW in the vicinity of the river crossings is dredged on a 2 year cycle. There is a finite amount of adjacent disposal area capacity remaining as no new disposal areas are currently identified. Future disposal may need to shift to the considerably more expensive offshore disposal option if additional disposal areas are not identified. Refer to Paragraph 4.3 for assumptions made to develop the with project dredging disposal cost estimate.

1.3 DESCRIPTION OF ALTERNATIVES

The following are the alternatives that were investigated past the AMM.

1.3.1 BRAZOS RIVER CROSSING ALTERNATIVES

1.3.1.1 Alternative 2A – Major Rehabilitation of Existing Structure

Key Features	• Remove, repair, sand blast, paint, and reinstall Sector Gates • Raise gate operating machinery and control house to avoid flooding • Add alignment dolphins • Rehabilitate and modify existing sheet pile guidewalls to better handle impacts

This alternative consists of a refurbishment of the existing 75 foot flood gate complex on both sides of the river. Some of the issues that cause delays and shutdowns of the existing gate structures include vessel impact damage to the existing anchored sheet pile guide walls, a low machinery pit elevation that makes equipment susceptible to flooding, and the accumulation of large amounts of crustacean life on the steel gate members which add a substantial amount of operating weight burden to the machinery. The rehabilitation focuses on addressing these items. The rehabilitation would be conducted without a navigation bypass. Rehabilitation efforts would be coordinated to minimize disruption to navigation. A composite panel system called UHMW (Ultra High Molecular Weight Polyethylene) backed by steel plating is proposed to be installed on the river side of the anchored sheet pile guide walls. These panels have a dampening effect from the vessel impacts and can be changed out by panel instead of a full sheet pile replacement, minimizing delays to navigation from allisions and subsequent lengthy repairs. The GIWW guide wall approach side does not experience the same frequency and magnitude of allisions as the river side guidewalls; therefore, they will were not included in the rehabilitation alternative. The Brazos River Floodgates are minimally higher than the mean high water elevation of the Brazos River, resulting in frequent flooding of the machinery pits as they are below the top of the skin plate on the river side. This causes additional shutdown and delays to navigation. This alternative proposes to relocate the machinery in the pit to a higher elevation (minimum 4 feet) and raise the operator buildings. A raised new foundation floor slab is required. The gates will be modified to accept the machinery drive at the higher elevation. Electrical work would consist of new power and controls for the machinery. The sector gates would be rehabilitated including replacement of damaged steel members such as on the fender rack and skin plate and repainting the gates with coal tar epoxy or similar upgraded coating system capable of reducing crustacean growth. The improved sector gates with upgraded coating system may reduce delays to navigation from gate shutdown and maintenance. Finally, a dolphin alignment structure on the river side would be provided to assist navigation and reduce impact to the guidewall structure. Reduced impacts as a result of the dolphin structure were not quantified because ship simulation was not performed to quantify the accident reduction.

1.3.1.2 Alternative 3A – Move Gates Farther Back in Existing Channel

Key Features	• Demolish existing gate structures • Construct new 125’ wide gate structures set back further from river • Construct new guidewalls • Construct new and improved dewatering system

This alternative consists of construction of new 125 foot flood gates along the existing alignment, set back approximately 1300 feet from the river from the existing gate structure (See Figure 2). This setback allows the full length of a tow protection from the river’s cross currents enabling an easier, more efficient and safer approach. This increased length of fore bay is estimated to provide an overall safer transit and potentially fully eliminate allisions. The first phase of the construction of the alternative would be the creation of a temporary by-pass channel to run along the south side of the existing channel routing traffic around both existing flood gates and new flood gate locations. The temporary by-pass channel would be constructed to the authorized channel width of 125 feet and was assumed to not change delays or safety risks when compared to the existing river crossing. Excavation material was assumed to be disposed in adjacent placement areas along the GIWW. Demolition of the existing flood gates is required. This will include removal of sector gates, vertical masonry walls, buildings, and anchored sheet pile guide walls. The existing base slab is to remain in place. Once the guide walls are removed, the remaining fill is to be excavated and sloped to accommodate a new 125 foot channel to pass through the site. The channel is also to be excavated for a new pile founded base slab with a sill elevation of EL. -16.0. The new wall and gate height is to match that of the Colorado Locks, approximately EL 16.0. The foundation slab is estimated to be 9 foot thick and the walls have an estimated 6 foot thickness. The sector gate layout has an upper, center, and lower frame with two outside trusses and one in the middle. The new sector gates are to have new control houses that house hydraulic power unit, panels, control hub, and personnel. The drive system is a Hagglund or Eaton motor splined into a gear rack along the skin plate of the gate. A dewatering system that allows for unwatering of the gate bays to service the gates while keeping the channel open through the structure for navigation would be provided. In order to construct the sector gate in the existing channel, a full Temporary Retaining Structure (TRS) is required. This is likely to be a rectangular sheet pile enclosure with upper and lower whales braced with interior struts. A connection of the main structure to dry land on the channel edges is to be accomplished with a build out of embankment and use of a retaining wall similar to the existing configuration. Other features are to include a guide wall with impact dolphins, a storage platform for dewatering materials, and placement of 3 foot thick rip rap adjacent to the structures for erosion control. Operator buildings are located in the vicinity of the bank area to house maintenance equipment. After completion of the new structures, the temporary bypass channel will be filled in as necessary to prevent flow, with the remaining excavated channel turned into a barge mooring/storage channel after construction.

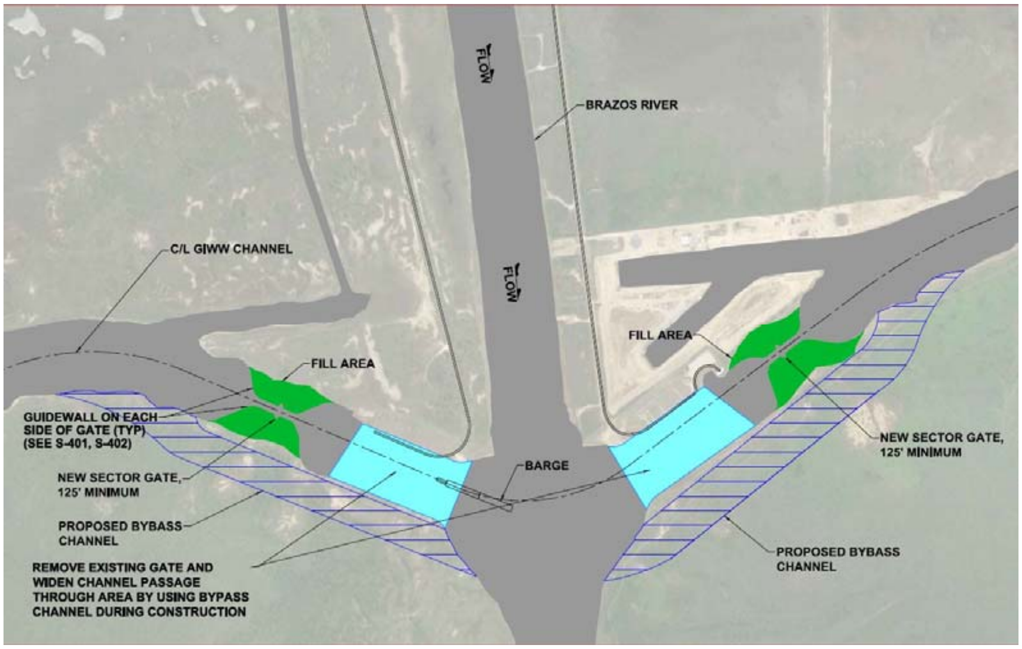

Figure 2 Brazos River Crossing – Alt 3a

1.3.1.3 Alternative 3A.1 – Remove Existing Gates, Open Channel West Side and New 125' Gate Further Back in GIWW on East Side

Key Features	• Demolish existing gate structures • Construct new 125' opening gate structures set back further from river on the east side • Construct new guidewalls • Construct new and improved dewatering system • No structure, full open channel on the west side

This alternative consists of construction of a new 125 foot flood gates along the existing alignment, set back approximately 1300 feet from the river from the existing gate structure on the east side, and a minimum 125 foot open channel on the west side of the river crossing (See Figure 3). The increased fore bay is to assist with an overall more safe and efficient vessel operation through the system, reducing allisions. The open channel will have a bottom depth of -12 ft NAVD88 and a bank-to-bank width of approximately 500 feet. The first phase of the construction of the alternative would be the creation of a temporary by-pass channel to run along the south side of the existing channel routing traffic around both existing flood gates and new flood gate locations. The temporary by-pass channel would be constructed to the authorized channel width of 125 feet and would not be expected to increase any delays or safety risks from the existing structures. Demolition of the existing flood gates is required. This will include removal of sector gates, vertical masonry walls, buildings, and anchored sheet pile guide walls. The existing base slab is to remain in place. Once the guide walls are removed, the remaining fill is to be excavated and sloped to accommodate a new 125 foot channel to pass through the site. Sector gate design and features for the new 125 foot gate on the east side will be the same as described for Alternative 3a above.

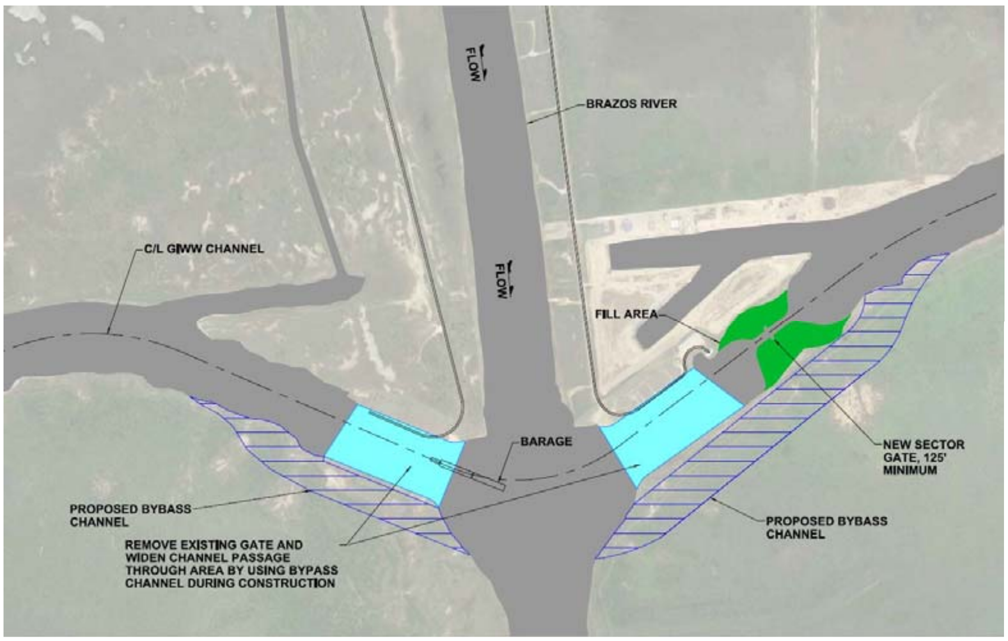

Figure 3 Brazos River Crossing – Alt 3a.1

1.3.1.4 Alternative 9a – Open Channel on Straight Alignment North of Existing Gates

Key Features	• Demolish existing gate structures • Open channel on new alignment north of Texas Boat and Barge facility

This alternative consists of a new authorized 125 foot wide open channel alignment placed on an optimized straight line across the Brazos River north of the existing channel where the gates are currently located (See Figure 4). This allows navigation to pass through the existing alignment while the new open channel is under construction. The open channel will have a bottom depth of -12 ft NAVD88 and a bank-to-bank width of approximately 500 feet. A temporary by-pass channel is not required. Construction in the new alignment requires the relocation of one business and the roadway that provides access to existing flood gates. Once the new channel is established, demolition operations are to begin on the existing flood gates. Demolition includes the removal of sector gates, vertical masonry walls, buildings, and anchored sheet pile guide walls. The existing base slabs are to remain in place. Once structure removal is complete, the existing channel can be closed off.

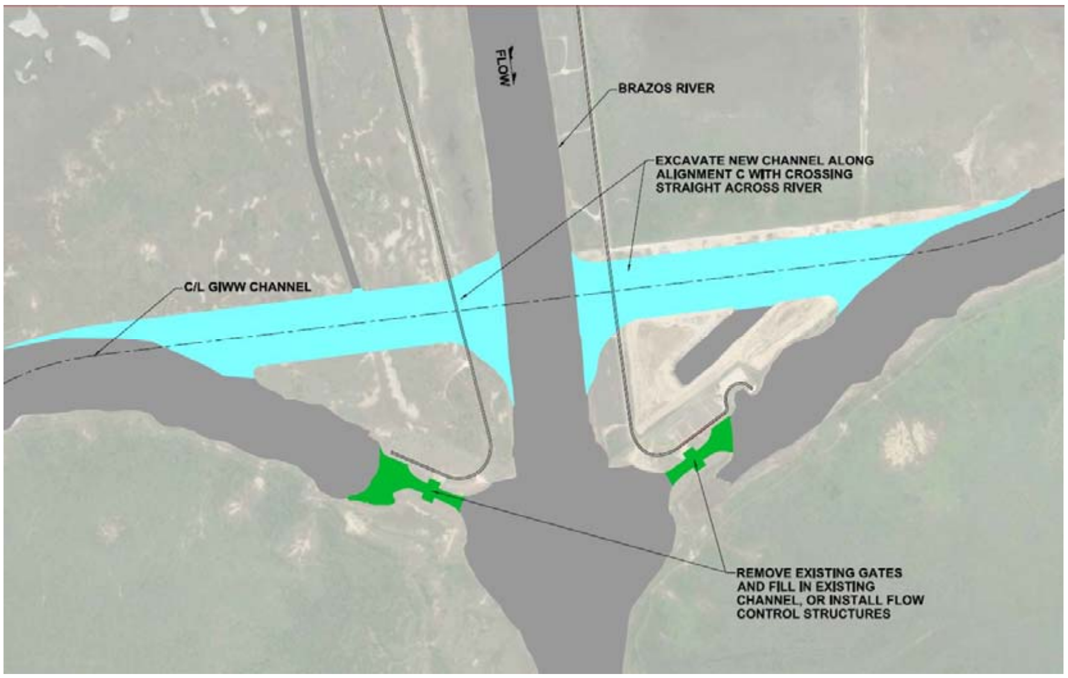

Figure 4 Brazos River Crossing – Alt 9a

1.3.1.5 Alternative 9b – New 125' Gates on Straight Alignment North of Existing Gates

Key Features	• Demolish existing gate structures • Construct new 125' opening gate structures on new alignment north of Texas Boat and Barge facility • Construct new guidewalls • Construct new and improved dewatering system

This alternative consists of construction of new 125 foot flood gates placed in an optimized straight line channel alignment across the Brazos River north of the existing channel where the gates are currently located (See Figure 5). This allows navigation to pass through the existing alignment while the new channel and gates are under construction. A temporary by-pass channel is not required. Construction in the new alignment requires the relocation of one business and the roadway that provides access to existing flood gates. Once the new channel and flood gates are installed, demolition operations are to begin on the existing flood gates. Demolition includes the removal of sector gates, vertical masonry walls, buildings, and anchored sheet pile guide walls. The existing base slabs are to remain in place. Once structure removal is complete, the existing channel can be closed off. Sector gate design and features for the new 125 foot gate on the east side will be the same as described for Alternative 3a above. Additionally, a connection of the main structure to dry land on the channel edges is to be accomplished with a build out of embankment and use of a retaining wall similar to the existing configuration.

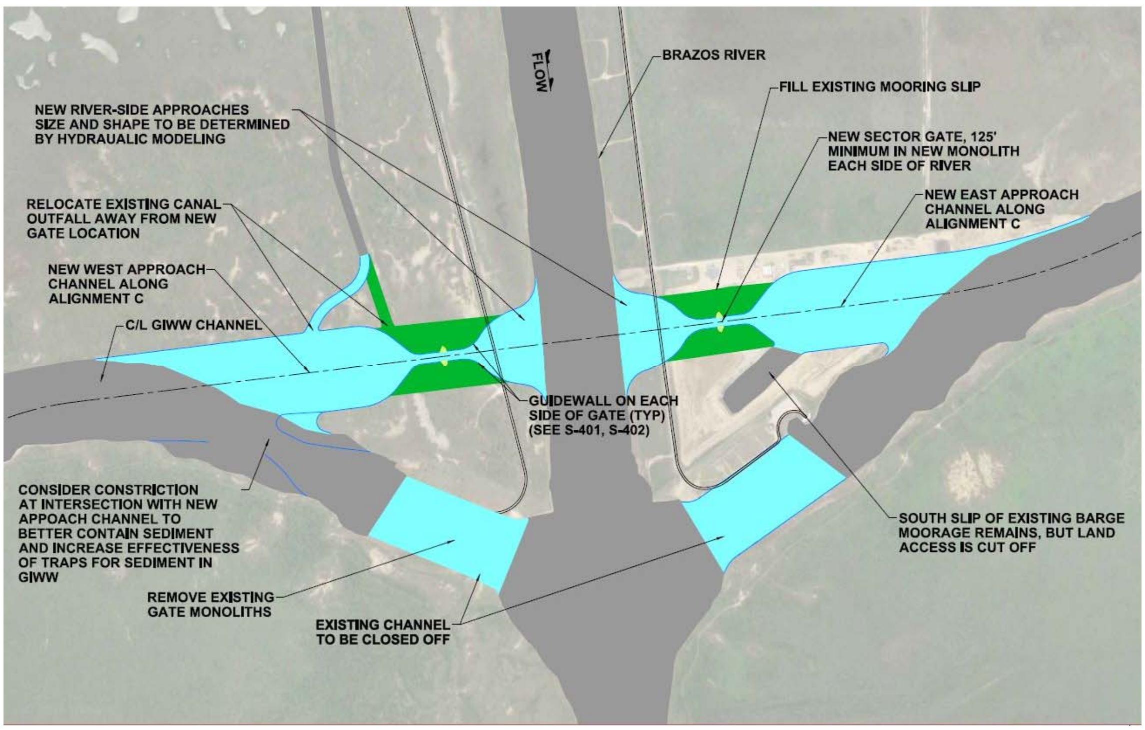

Figure 5 Brazos River Crossing – Alt 9b

1.3.1.6 Alternative 9c – New 125' Gates on Straight Alignment North of Existing Gates With Flow Control Structure

Key Features	• Demolish existing gate structures • Construct new 125' opening gate structures on new alignment north of Texas Boat and Barge facility • Construct new guidewalls • Construct new and improved dewatering system

	• An addition of a flow control structure on the west side existing alignment

This alternative incorporates all the features of work describe in Alternative 9b with the addition of a flow control structure in the existing west side channel on the river side of flood gate foundation (See Figure 6). The purpose of this flow control structure is to regulate input into the GIWW coming from the San Bernard River. The structure is to be located to the river side of the existing flood gate foundation. It consists of a sluice gate structure including a pile foundation, base slab, inlet walls/towers, 3 vertical sluice gates, Rodney hunt type lifting system, dewatering bulkheads, scour control riprap, and a tie-in to land by either floodwall or embankment. The base slab is 7 foot thick and 50 foot wide. The pier wall thickness is 3 feet. The wall height is approximately 31 feet. The sluice gate is approximately 16 foot high. The layer or riprap is 3 foot thick. The bulkheads consist of a skin plate with horizontal support members and vertical stiffeners.

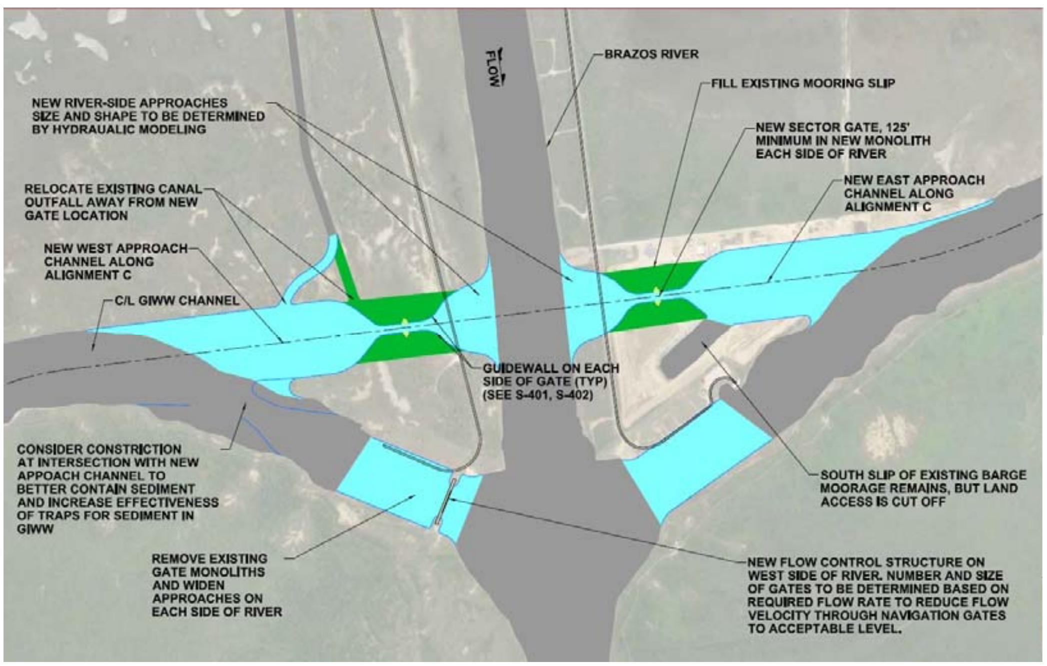

Figure 6 Brazos River Crossing – Alt 9c

1.3.2 COLORADO RIVER ALTERNATIVES

1.3.2.1 Alternative 2B – Major Rehabilitation of Existing Lock

	• Remove, repair, sand blast, paint, and

Key Features	reinstall Sector Gates • Replace and update machinery • Rehabilitate and modify existing sheet pile guidewalls to better handle impacts • Installing new machinery houses

This alternative consists of a refurbishment of the existing 75 foot lock complex on both sides of the river. Some of the issues that cause delays and shutdowns of the existing lock structures include vessel impact damage to the existing anchored sheet pile guide walls, outdated machinery, and the accumulation of large amounts of crustacean life on the steel gate members which add a substantial amount of operating weight burden to the machinery. The rehabilitation focuses on addressing these items. The rehabilitation would be conducted without a navigation bypass. Rehabilitation efforts would be coordinated to minimize disruption to navigation. A composite panel system called UHMW (Ultra High Molecular Weight Polyethylene) backed by steel plating is proposed to be installed on the river side of the anchored sheet pile guide walls. These panels have a dampening effect from the vessel impacts and can be changed out by panel instead of a full sheet pile replacement, minimizing delays to navigation from allisions and subsequent lengthy repairs. The GIWW guide wall approach side does not experience the same frequency and magnitude of allisions as the river side guidewalls; therefore, they will were not included in the rehabilitation alternative. The machinery is to be replaced with a new Hagglund or Eaton Motor/Hydraulic Power Unit (HPU) system. New machinery houses are to be constructed with slabs on grade to house the new HPU units. Hydraulic lines are run from the motor to HPU. The gates are to be modified with a gear rack to spline into the motor. Electrical work consist of new power and controls for the machinery. The sector gates would be rehabilitated including replacement of damaged steel members such as on the fender rack and skin plate and repainting the gates with coal tar epoxy or similar upgraded coating system capable of reducing crustacean growth. The improved sector gates with upgraded coating system may reduce delays to navigation from gate shutdown and maintenance.

1.3.2.2 Alternative 3B – Open Channel

Key Features	• Demolish existing locks • Construct new open channel through lock alignment

This alternative consists of the removal of both locks on either side of the river crossing and creation of a 125 foot wide open channel crossing in the existing alignment (See Figure 7). A temporary 125 foot by-pass channel would be provided to the south of the existing alignment while the existing locks were removed. This allows navigation to pass through the existing alignment while the new open channel is under construction. Demolition includes the removal of sector gates, vertical masonry walls, buildings, and anchored sheet pile guide walls. The existing base slabs are to remain in place. Once structure removal is complete, the bypass channel would be filled in as necessary to prevent flow with the original material that was stockpiled nearby.

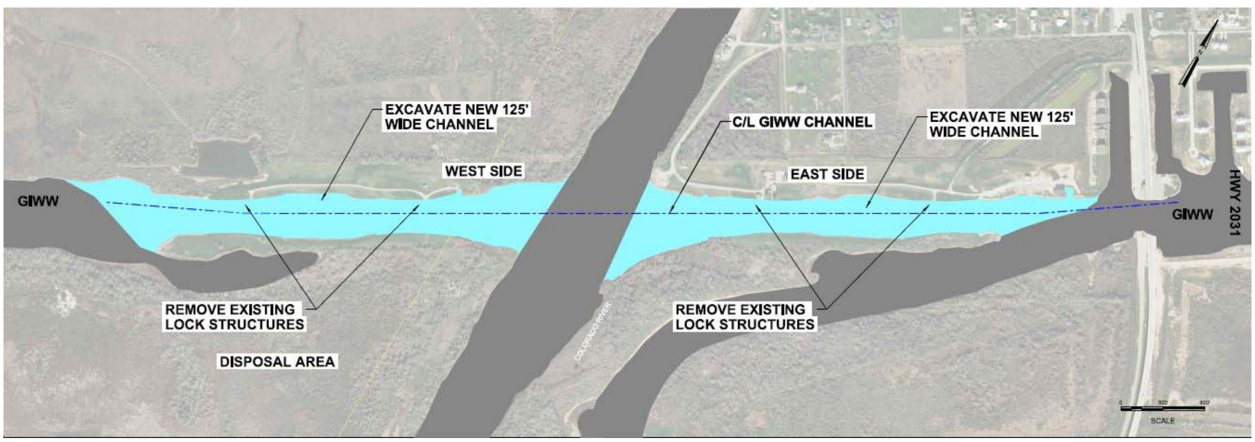

Figure 7 Colorado River Crossing – Alt 3b

1.3.2.3 Alternative 4b.1 – Riverside Gate Removal

Key Features	• Demolish lock gates closest to river • Construct 125 ft channel from original forebay to the remaining gates • Update remaining gate machinery • Install new machinery house, control house, and equipment buildings

This alternative consists of the removal of the existing river side sector gate structures (See Figure 8). The existing 75 foot lock complex on both sides of the river cause considerable delays in barge traffic due to the proximity of the river side gate structures to the river. Substantial benefits of decreased tripping delays and additional fore bay before the river crossing are realized with the removal of the river side gates on both sides. The removal would include the removal of the anchored sheet pile guide walls, vertical structure walls, sector gates, control houses, and equipment buildings. The land area behind the anchored sheet pile retaining walls would be excavated in order to accommodate a new 125 channel up to the remaining sector gate structure on the GIWW side of the lock. The interior guide wall in the lock chamber would also be removed. Because of the increased demand on the remaining GIWW side sector gate structures because of the reduction in delays, similar rehabilitation would be performed on the remaining sector gates as described in Alternative 2B above to accommodate the greater demand on the features to remain for this alternative. Additionally, this alternative reduces the redundancy of having 2 sets of gates to prevent sediment transport into the GIWW. In the current FWOP condition, if one sets of gates becomes inoperable, the other set of gates can still pass navigation traffic and prevent significant sediment transport into the GIWW, Rehabilitation of the remaining set of gates is necessary to maintain reliability to open and close when needed to limit sediment transport into the GIWW,

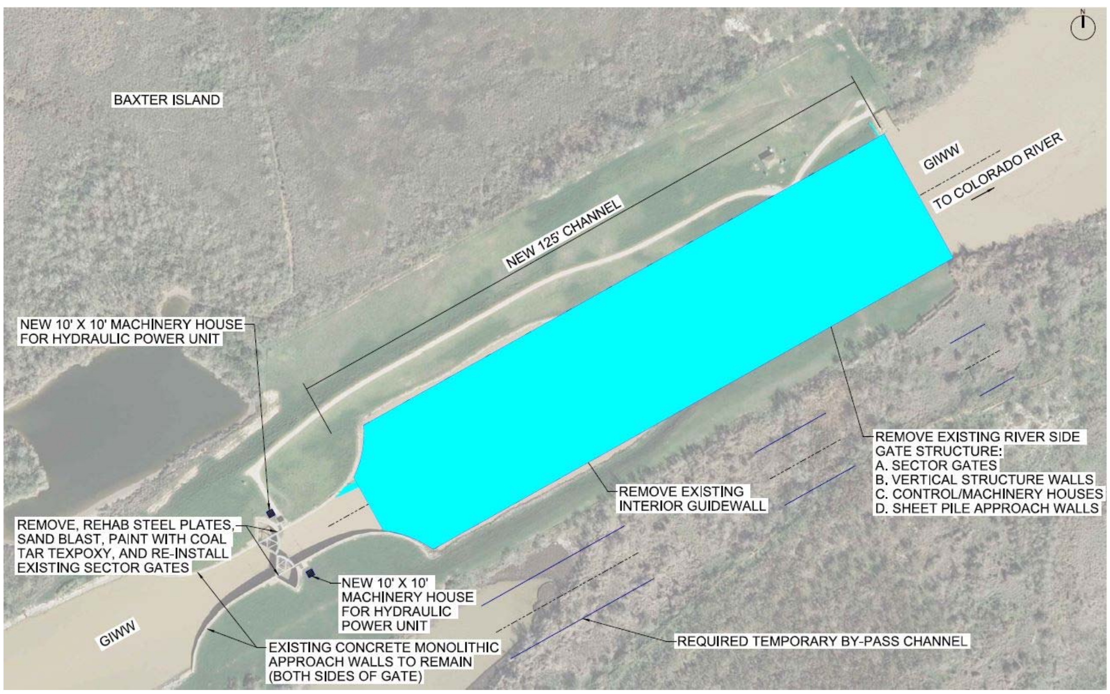

Figure 8 Colorado River Crossing – Alt 4b.1

1.4 SELECTED TSP ALTERNATIVES

Based on the economic analysis and cost estimates developed (Described in Paragraph 5 below), the highest net benefits were found in Alternative 9a at Brazos and Alternative 4b.1 at Colorado.

Potential risk and uncertainty of environmental, navigation, and system impacts led to the selection of Alternative 3a.1 at Brazos and Alternative 4b.1 at Colorado as the TSP. Risks are discussed in Paragraph X below.

1.5 POST-TSP REFINEMENTS

For both river crossings, small scale measures will be investigated post-TSP, aimed at reducing sediment deposits at the crossings and improving safety of the crossings. Items such as dikes to move the sediment deposits downstream of the crossings and adjustments to the approaches to the structures to reduce accident risks will be investigated.

1.5.1 Brazos Alternative 3a.1

1.5.1.1 Crossing Geometry

Refinements to the crossing will be investigated, such as straightening out the crossing slightly to the north instead of maintaining the existing 60 degree crossing geometry. The addition of river training structures such us chevrons, spur dikes, or similar training structures to reduce sediment flow into the GIWW will also be investigated. This may require ship simulation or pilot consultation and could result in a different ultimate alignment than the plan shown.

1.5.1.2 Brazos West

On the west side of the Brazos River for this alternative, consideration will be given to using the bypass channel as the permanent new channel, creating cost savings from not performing demolition on the sector gate structure and no backfilling of the temporary bypass channel. The new channel alignment will also permit a phased construction approach where the performance of the open channel on the west side of the Brazos can be assessed prior to demolition of the existing gate structure. Impacts to the San Bernard and flooding in its watershed will be evaluated and documented further.

1.5.1.3 Support Facilities

Impacts to support facilities such as the administrative building, boathouse, flammable storage building, emergency generator and building and storage area will be further investigated. Replacement facilities, if necessary, will be included in the final plan.

1.5.2 Colorado Alternative 4b.1

1.5.2.1 Demolition/Channel Configuration

The location of the 125' forebay will be further refined. The north side of the existing river side gate structure and lock chamber guidewall may be retained as the edge of the new 125 foot channel to reduce demolition costs and provide a guide into the existing 75' gates.

1.5.2.2 Support Facilities

Impacts to support facilities such as the administrative building and boat dock will be further investigated. Replacement facilities, if necessary, will be included in the final plan.

1.5.2.3 Spare Gates

Rehabilitation of one set of steel sector gates pulled from the river side gate monoliths to be demolished will be considered. A spare set of gates would reduce closures and navigation impacts during major rehabilitation, as freshly refurbished gates could be swapped out with the existing gates in a few days. The spare set of gates will also provide increased reliability of the system in the event of damage/failure of the in-place gates.

1.5.2.4 Lower Hinge Replacement

The presence of a temporary bypass in this alternative provides an opportunity to have a longer duration available to rehabilitate the gate structure because of minimal impacts to navigation while the bypass is operating. Taking advantage of this once in a lifetime opportunity to thoroughly rehabilitate and modernize the sector gates, a replacement/retrofit of the lower hinge of the sector gates will be investigated.

2 CLIMATOLOGY, HYDROLOGY, HYDRAULICS, AND WATER QUALITY

2.1 BACKGROUND

The engineering team performed a numerical model study of hydrodynamics, including currents, salinity, and sediment changes, associated with the proposed alternatives aimed at improving navigation through the intersection of the Gulf Intracoastal Waterway (GIWW) and the Colorado River and the intersection of the GIWW with the Brazos River. One team, consisting of engineers from Mott Macdonald, was responsible for analysis of the Brazos River, while another team from the New Orleans District (MVN), were responsible for analysis of the Colorado River. The two teams worked closely together to ensure a consistent methodology was followed for both analyses. The purpose of the numerical model study was to evaluate the impacts to currents, water levels, sediment, and salinity associated with proposed alternatives aimed at improving navigations, as well evaluate the potential effects of climate and sea level change. The following chapter describes the various inputs and outputs of the numerical modeling. Further information concerning the hydraulic analysis can be found in the H&H Appendix.

2.2 AdH MODELING

2.2.1 General

Adaptive Hydrology/Hydraulics (AdH) is a modular, parallel, adaptive finite-element model for one-, two- and three-dimensional flow and transport. AdH is a module of the Department of Defense (DoD) Surface-Water Modeling System and Ground-Water Modeling System. AdH simulates groundwater flow, internal flow and open channel flow. The AdH model was developed in the Engineer Research and Development Center's Coastal and Hydraulics Laboratory and is a product of the System-Wide Water Resources Program. AdH was developed to address the environmental concerns of the DoD in estuaries, coastal regions, river basins, reservoirs and groundwater. The general features in AdH that benefit the modeler include:

•Adaptation: The user needs only to generate a general mesh to capture the geometry of the problem. AdH will automatically refine it to provide accurate solutions and more stable and less expensive simulations.

•Portability: AdH can run efficiently on a wide variety of platforms ranging from standard PCs to high-end supercomputers.

2.2.2 GIS and Field Data

GIS data needed for the development of the hydraulic models included bathymetric surveys, pre and post dredge contract bathymetric surveys, land cover surveys, aerial imagery, and levee alignment shapefiles. The channel bathymetry in the project area is highly dynamic due to dredging and floods that remove or deposit sediment. A comprehensive bathymetric survey of the area of interest, including both Colorado and Brazos Rivers and the GIWW was completed in March 2017, providing an estimate of the channel geometry that could be applied to the AdH model for existing conditions.

A large effort was made to collect and process all available gage data, including water levels, velocities, sediment concentrations, salinities, sediment properties. Gages in the area are operated by USACE, NOAA and USGS. All available gage data was downloaded and processed to assist in the assignment of model boundary conditions, and to help assist in the calibration and validation of the models. The gage data is absolutely imperative to ensure the quality and robustness of the hydraulic model results.

In March of 2017, sediment samples were taken at various locations of interest. The properties of the sediment, including the grain size distribution and bulk density, were applied to the AdH model. The sediment data was critical for the modelers to achieve a calibrated model.

2.2.3 Boundary/Initial Parameters

2.2.3.1 Discharge

For the Colorado River, a long term USGS gage near Bay City, TX provided discharges that were used as a boundary condition for the model.
For the Brazos River, a USGS gage near Rosharon, TX was used for boundary condition flows. A USGS gage at Boling, TX was also used for boundary condition flows for the Brazos River crossing.

2.2.3.2 Stage

A stage boundary condition was assigned at the gulf boundary. The stage hydrograph includes tides. The gulf boundary was assigned sufficiently far from the influence of the river.

2.2.3.3 Sediment

Sediment concentrations are measured by USGS. For the Colorado River, a sediment rating curve was developed based on measurements of sediment concentration and discharge. The rating curve was used to develop sediment concentration time-series that were applied at the river boundary. For the Brazos River, a sediment rating curve was developed for the San Bernard and Brazos River gages and applied at the respective river boundaries.

2.2.3.4 Wind

Wind was applied to the models based on measurements taken at nearby gages. Wind contributes to the circulation of water in the modeling domain.

2.2.3.5 Precipitation and Evaporation

Precipitation and evaporation were also assigned to the model based on measurements at local gages.

2.2.3.6 Salinity

A constant salinity time-series of 33 parts per thousand was applied at the gulf boundary and a constant salinity of 0.01 was applied to all freshwater inflows. The initial salinity of the gulf was set to 33, and the initial salinity everywhere else was set to 20, based on observations.

2.2.3.7 Locks/Gates Operation

Locks were simulated using the breach card in AdH. This method effectively raises or lowers the bathymetry during the simulation using a user specified time-series. A time-series of gate operations was developed for the Brazos River floodgates and Colorado River locks.

2.2.3.8 Sea Level Change

Future conditions were modeled by adjusting the boundary conditions and re-running the AdH simulations for the open channel and existing alternatives. Given the uncertainty in projected sea level rise and subsidence, a range of relative sea-level rise (RSLR) scenarios was evaluated. For this project, a 1.0ft and 2.0ft RSLR were evaluated. The RSLR amounts of 1.0ft and 2.0ft were applied to the Gulf boundary condition. No other adjustments were made to the model input files.

2.2.4 Calibration and Validation

The models were simulated for floods occurring in 2015, 2016 and 2017. In general, AdH output compared well with observations at USGS, USACE and NOAA gages. Figure 9 displays an example of the modeled water levels compared to the observed water levels at the Colorado River locks. **Error! Reference source not found.** shows an example of the modeled water levels compared to the observed water levels at three gage locations within the Brazos River Floodgates model. The purpose of calibration and validation is to improve the models predictive skill. A calibrated and validated model provides more confidence in the evaluation of project alternatives.

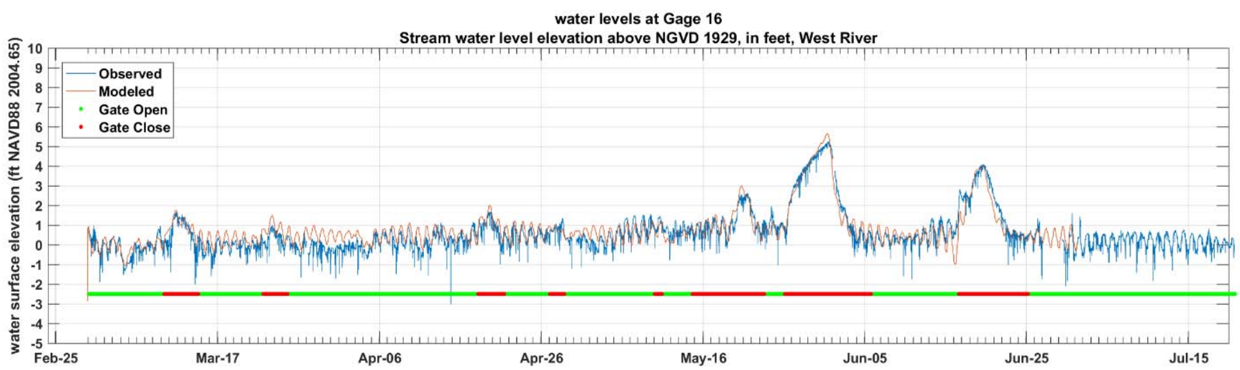

Figure 9 Colorado River Crossing – Gage 16

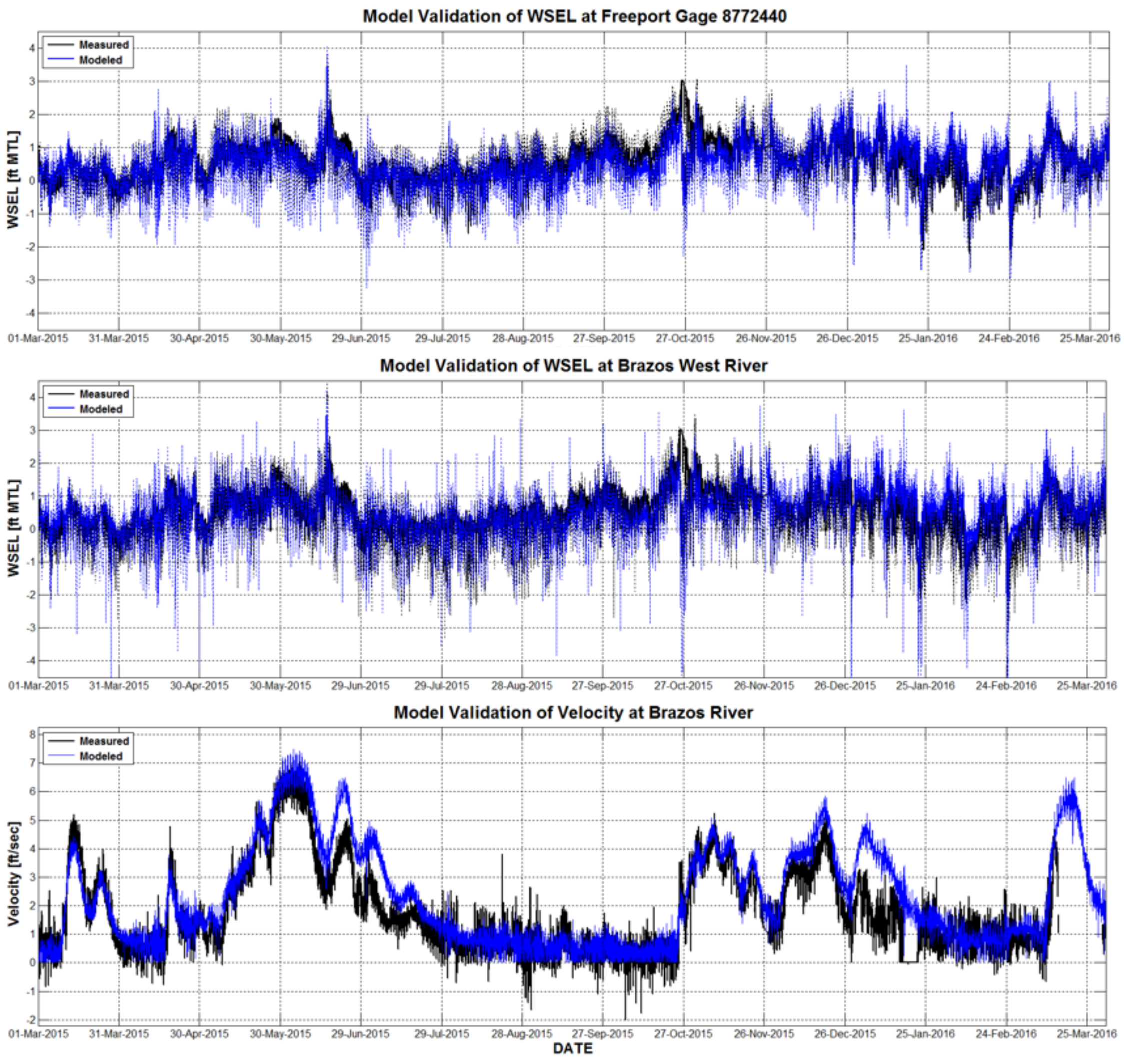

Figure 10 Model Validation of water surface elevations for Brazos model.

During the course of the investigation, Hurricane Harvey made landfall near the project site. The rainfall associated with the storm produced near record discharges for the Colorado River, and record discharges for the Brazos River. The event provided a very beneficial data point for the calibration and validation of the hydraulic models.

2.2.5 Currents, Water Levels, Salinity and Sediment

AdH was used to evaluate project alternatives in terms of impacts to currents, salinity and sediment. The primary goals of the modeling included:

1. Estimate changes to water levels, velocities and discharges near the project site and within the GIWW

2. Estimate the expected changes to salinity in the project vicinity.

3. Estimate changes to the sediment budget, and changes to deposition patterns in specific areas of interest.

An example of the output from the AdH model is provided in the following figures. Figure 11 **Map Showing the Location of the Assigned Sediment Deposition Areas** and 12 display the sediment deposition areas that were delineated in the post-processing of model results. Table 3 and 4 contains the average annual sedimentation volumes that were summarized in each of the distinct areas based on the results of the simulations of the 2015 and 2016 floods. For the Colorado River Crossing with the open-channel alternative, the sedimentation rates in the GIWW increase from approximately 150% in the GIWW West, to 300% in the GIWW East. Changes to the sedimentation were also evaluate for future conditions for with and without project. Changes in the sedimentation rates for the proposed Brazos River alternatives are summarized in **Error! Reference source not found.**. Additional information on the sedimentation analysis can be found in Appendices 1 and 2.

The AdH model was also used to evaluate impacts to salinity for the various areas of interest displayed in Figure **11 Map Showing the Location of the Assigned Sediment Deposition Areas** 11 and 12. Table 5 and 6 contains the mean salinity values for existing condition and open-channel, and future condition existing condition and open-channel. The results show very modest changes to average salinity within each of the specific geographic areas. For the Colorado River Crossing with the open-channel alternative, salinities are expected to decrease in East Matagorda Bay, and increase slightly in West Matagorda Bay. Both GIWW East and West are expected to have decreased salinities with the open channel alternative. For the Brazos River Crossing minor decreases in salinity are expected in the west GIWW and east GIWW for all alternatives. The only exception is a slight potential increase in salinity in the east GIWW for alternative 3a.1. Additional information on the salinity analysis can be found in Appendices 1 and 2.

For the Colorado River Crossing, a velocity rating curve was developed for the existing and open channel alternatives at the location of gage 14. Using the rating curve, and long term daily discharges presented in **Error! Reference source not found.**13, long term daily velocities were produced for the period 1948 to present for both existing and open channel alternatives. The velocity time-series were provided to the economics team for the navigation analysis.

For the Brazos River Crossing, a hindcast of velocities and head differentials for all alternatives was developed. The hindcast was developed to predict head differentials and velocities at each gate from 1980-2016. The head differential and velocity time-series was provided to the economics team for navigation analysis.

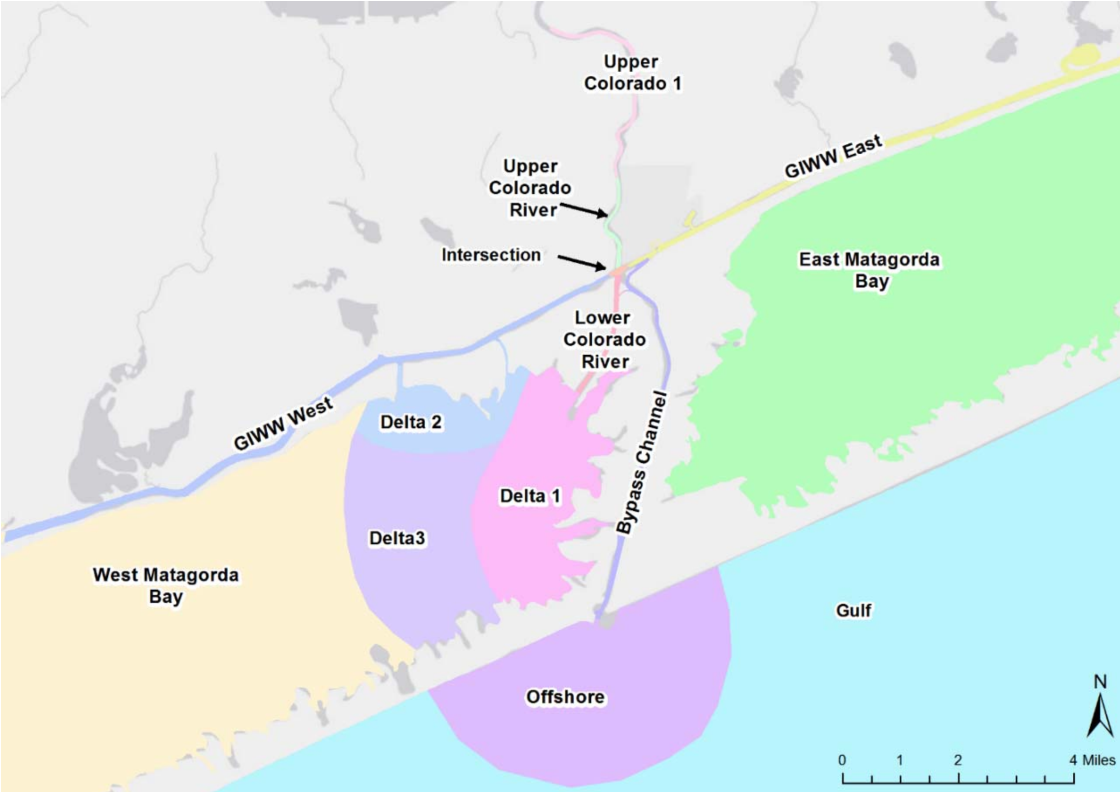

Figure 11 Map Showing the Location of the Assigned Sediment Deposition Areas – Colorado River Crossing

Figure 12 Map Showing the Location of the Assigned Sediment Deposition Areas – Brazos River Crossing

Area of Interest	Results Based on 2016 Simulation Regression Analysis	Results Based on 2015 Simulation Regression Analysis

	Average Annual deposition Existing (cubic yards)	Average Annual deposition Open Channel (cubic yards)	% difference	Average Annual deposition Existing (cubic yards)	Average Annual deposition Open Channel (cubic yards)	% difference
GIWW East	75,124	285,606	**280**	49,331	193,940	**293**
GIWW West	199,974	492,967	**147**	147,801	324,766	**120**
Bypass Channel	42,509	81,952	**93**	27,290	50,678	**86**
Intersection	7,766	18,207	**134**	12,905	17,053	**32**
Delta 1	1,651,540	1,780,622	**8**	1,409,626	1,533,274	**9**
Delta 2	611,284	723,660	**18**	583,908	728,329	**25**
Delta 3	1,374,640	771,110	**-44**	1,302,189	497,307	**-62**
Offshore	346,021	732,546	**112**	235,308	527,348	**124**

Table 3 Average Annual Deposition Simulations for Existing and Open Channel Scenarios based on 2015 and 2016 Simulation Results – Colorado River Crossing

Alternative	**West GIWW**	**Brazos Basin**	**East GIWW**	**Freeport Channel**	**Brazos Delta**	**Freeport Offshore**	**Total in Zones Requiring Maintenance**
Existing/2a	554,769	48,000	890,769	295,385	44,382,462	208,726	1,788,923
3a	493,846	59,077	902,769	316,615	44,332,615	190,864	1,772,307
	(-11%)	23%	1%	7%	0%	(-8%)	(-0.1%)
3a.1	653,130	58,332	902,653	326,420	44,000,887	196,239	1,940,535
	18%	22%	1%	11%	(-1%)	(-6%)	8%
9a	781,846	92,308	1,079,077	978,462	42,026,769	854,614	2,931,693
	41%	92%	21%	231%	(-5%)	309%	64%
9b	780,923	96,923	1,044,000	550,154	43,232,308	396,989	2,472,000
	41%	102%	17%	86%	(-3%)	90%	38%
9c	781,846	107,077	1,044,000	550,154	43,218,462	395,887	2,483,077
	41%	123%	17%	86%	(-3%)	90%	39%

Table 4 Average Annual Deposition Simulations for Existing and Alternative Scenarios based on Simulation Results – Brazos River Crossing

Location	Average Salinity Existing RSLR=0 (ppt)	Average Salinity Existing RSLR=1 (ppt)	Average Salinity Existing RSLR=2 (ppt)	Average Salinity Open-Channel RSLR=0 (ppt)	Average Salinity Open-Channel RSLR=1 (ppt)	Average Salinity Open-Channel RSLR=2 (ppt)
West Matagorda Bay	18.0	18.6	19.1	18.2	18.7	19.3
Gulf	32.0	32.1	32.1	31.9	32.0	32.0
East Matagorda Bay	25.2	25.2	25.6	22.3	22.9	23.8
Upper Colorado 1	0.3	0.3	0.4	0.3	0.3	0.4
GIWW East	17.2	17.9	18.8	14.1	15.1	16.1
GIWW West	10.2	11.2	12.1	9.1	10.0	10.9
Bypass Channel	18.3	19.2	20.0	16.4	17.6	18.4
Intersection	7.4	8.6	9.3	7.3	8.2	9.0
Lower Colorado River	11.2	12.0	12.7	11.1	12.1	12.9
Upper Colorado River	0.5	0.6	0.7	0.5	0.6	0.7
Delta 1	11.0	11.4	12.0	11.6	12.4	13.3
Delta 2	10.2	11.0	11.8	10.3	11.3	12.3
Delta3	9.4	9.9	10.5	10.4	11.3	12.3
Offshore	30.1	30.3	30.4	29.7	30.0	30.2

Table 5 Mean Salinity values for 2015 Simulation at specific areas of interest – Colorado River Crossing

Alternative	West GIWW	Brazos Basin	East GIWW	Freeport Channel
Existing	5.6	1.7	5.0	15.6
3a	6.0 (0.4)	2.2 (0.5)	3.9 (-1.1)	15.2 (-0.4)
3a.1	3.8 (-1.8)	2.7 (1.0)	5.8 (0.8)	13.6 (-2.0)
9a	3.7 (-1.9)	2.3 (0.6)	4.0 (-1)	10.3 (-5.3)
9b	4.2 (-1.4)	1.9 (0.2)	3.7 (-1.3)	13.4 (-2.2)
9c	4.0 (-1.6)	2.0 (0.3)	3.5 (-1.5)	13.3 (-2.3)

Table 6 Mean Salinity values at specific areas of interest – Brazos River Crossing

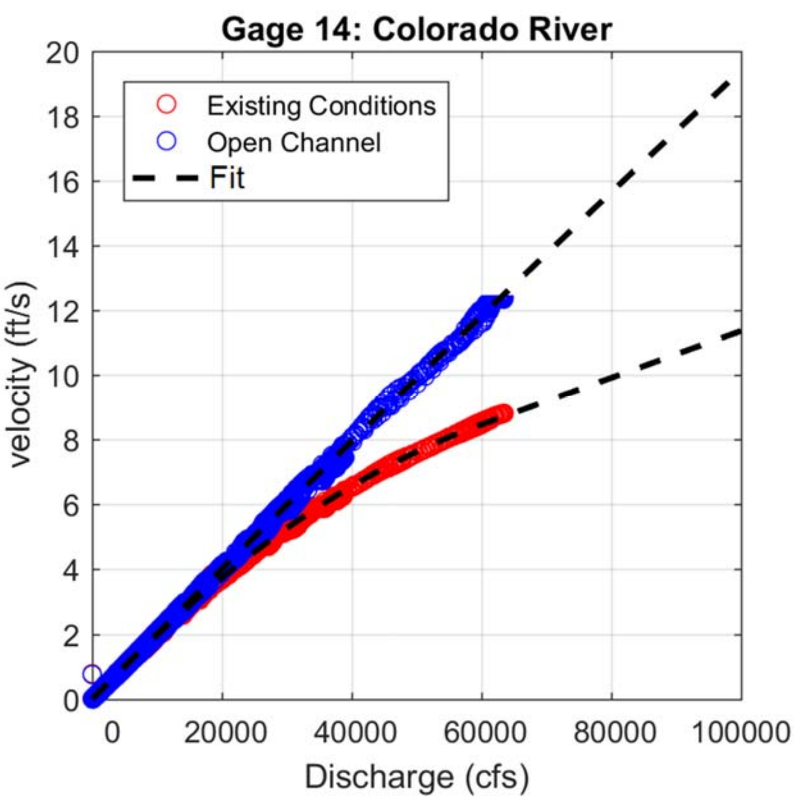

Figure 13 Discharge vs Velocity Rating Curve at Gage 14

3 GEOTECHNICAL

Geotechnical information is a key component of design details that impacts cost. There was no new field data collected for this study, and therefore no new lab testing to determine soil profiles and no geotechnical analyses performed. There is no detailed soils testing data in the area in order to classify the foundation as well defined and use lower factors of safety in design. Without any new soil boring and testing data beneath the footprint of any proposed structures that would be constructed as part of the TSP, higher safety factors will be used, resulting in more conservative designs, for the feasibility level design following TSP. The PDT has elected to tolerate the risk(s) associated with the lack of geotechnical data and proceed.

4 CIVIL/STRUCTURE DESIGN

4.1 Civil/Structural Project Features

This section summarizes the work that was performed to develop sufficient quantities for the civil/structural features of the various alternatives investigated following the AMM milestone. No design was performed to develop the cost estimates. Drawings shown are based on similar existing systems. Rather, existing data was used and quantities pro-rated to arrive at the quantities that were used to develop the cost estimate.

4.2 Alternative Quantity Take-Offs for TSP Selection

Each alternative consists of various features of work that were quantified to support the cost estimate.

4.2.1 Quantity Take-Offs for Rehab Alternatives

For the Rehabilitation alternatives, historical documents were reviewed to determine specifics of the original structures. These historical documents consisted of the original drawings of the two projects and previous rehabilitation contracts that were completed prior to this study. Features such as wall dimensions, sector gate dimensions, foundation dimensions, anchored sheet pile guide walls, concrete guide walls, interior chamber guide walls, machinery, and electrical system were shown in the historical documents. The previous rehabilitation contracts also assisted in pro-rating the cost of gate removal, damaged plate replacement, sand blasting, painting, and re-installation costs.

Anchored sheet pile limits were identified in the original construction drawings in order to determine the quantities for the UHMW (Ultra High Molecular Weight Polyethylene) backed by steel plating proposed to be installed on the river side of the anchored sheet pile guide walls. CADD was utilized to lay out a typical composite UHMW panel size with a steel backing plate to cover the sheet pile area exposed to navigation impacts. A nominal panel size of 4 foot by 4 foot was selected as the main size and a smaller 4 foot by 1 foot, 8 inch panel was to fill in smaller sections. The number of panels, bolts, and steel backing plate surface area was quantified.

For CRL, a Hagglund Viking 63 Series was used for the cost based on machinery used for previous sector gates of this size in the Southeast Louisiana area. The sized motor led to the sizing of a new Hydraulic Power Unit (HPU). Cost data for both the HPU(s) and machinery house(s) was based on similar configurations on sector gate structures in the Southeast Louisiana area. For BRFG, the decision based on discussion with the operators to relocate the existing machinery. The machinery pits are approximately 4 feet lower than the Colorado Locks and experiences frequent flooding. The plan is to raise the operating machinery even with the top of protection height. To accomplish this, a bracket is to be fabricated on the gate to raise the gear rack to accommodate the new machinery height. Additionally the control houses are to be raised 4 feet higher as they are subject to frequent rubbing and scraping by vessels transiting through. New concrete column like piers are to be constructed with a new floor slab on top. The building with controls are to be relocated on top. The concrete and steel for these additions were quantified by the ton. Additionally for Brazos, two 5 pile dolphin structures are to be located on each side of the river to act as a guide into the intersecting GIWW alignment. A typical dolphin consists of 24 inch steel pipe piles with a lower steel bracket for stiffening and a concrete cap at the top. The materials were quantified; cost data was accessible as these are common sector gate features in the recent south Louisiana hurricane protection work.

4.2.2 Quantity Take-Offs for New Structures

For the Brazos alternatives that include a new structure replacement, a 125 foot opening sector gate was quantified. Features of the sector gate structure include sand/gravel bedding, concrete stabilization slab, reinforced concrete foundation slab, reinforced concrete vertical walls, vertical and battered spiral welded pipe piles, steel sheet piling, steel tension connectors, pre-engineered machinery and control houses, miscellaneous metal ladders, railing, corner protection, seal plates steel dewatering bulkheads, hydraulic motors, hydraulic power units, and electrical power/controls. Sector Gate features consist of steel pipe, hinge and pintle, composite protection members, seals, cathodic protection, walkway grating, hand rails, and paint system. All concrete features were measured by the cubic yard along with bedding material. Piling both vertical and battered was measured by the linear foot. Steel cut off sheet piling was measured by the square foot. Steel tension connectors that install on top of selected piles were measured by each. Miscellaneous metal seal plates, walkway rails, corner protection, and ladders was measured by the linear foot. The steel members of the sector gate and dewatering bulkheads were measured by the ton while gate features such as hinge, pintle, seals, and cathodic protection was grouped as lump sum cost. Composite timbers on the gate the fender system was quantified by linear foot. The dewatering storage platform consisting of steel frame work and support piling was measured by the ton and linear foot respectively. All quantities were developed through pro-rating of existing sector gate structures.

The placement of the new structure requires excavation of the existing channel and placement of a temporary retaining structure (TRS). The area excavated was quantified by the cubic yard. A portion of the excavated quantity will be re-used to grade out a new vessel channel and to fill in the temporary by-pass channel once construction is complete. The remaining material is to be placed in adjacent disposal areas south of the GIWW at both projects. The TRS is to be a braced excavation with sheet pile, whale members, and struts. It also utilizes king post piling and support piling. The sheet pile was quantified by the square foot. Steel members were measured by the ton and piling by the linear foot respectively. Costs were also added for a dewatering system and TRS removal.

Additional new structure work includes an anchored sheet pile guidewall system that will be protected by the UHMW Panel system. The existing anchor wall design was used as the basis of the new design and to develop quantities. The guidewall sheet pile was quantified by the square foot with anchor hardware measured by the ton. The UHMW panels were quantified by the number panels over exposed surface area above the normal water line. Steel backing plate corresponds to this surface area.

BRFG Alternative 9c includes the addition of a flow control structure to regulate the San Bernard River contribution into the GIWW. It is to be placed in the existing west side channel on the river side of the demolished structure. The quantities and cost were based on cost estimate prepared for a similar sluice gate structures designed for the Morganza to the Gulf of Mexico PAC. Piling was quantified by linear foot. Concrete foundation, vertical towers, and horizontal slabs was measured by the cubic foot.

4.2.3 Quantity Take-Offs for Demolition

Demolition of the existing 75 foot wide sector gate structure is required on open channel and new structure replacement alternatives at Brazos. This also includes the riverside gates removal alternative 4b.1 at Colorado. The scope involves the removal of the vertical walls, gates, control house, machinery, and anchored sheet pile guidewall. The tonnage of the gates were calculated for removal costs. All concrete demolition was calculated by the cubic yard. Existing construction plans were used to develop the quantities.

4.3 O&M Dredging Assumptions

Anecdotal O&M data was supplied by SWG Operations Division personnel based on historical data including yearly maintenance costs on the structures, major maintenance cost and frequency on the structures, average yearly dredge quantities along the GIWW, estimated dredging costs based on recent dredging contracts, and remaining capacity of the existing disposal sites. Remaining capacities of the disposal sites was based on prior geotechnical analysis conducted for determining current and remaining maximum capacities for GIWW Placement Areas. Nos. 29 through 88. The placement areas considered for capacity for this study were Placement Areas 86/87, 88, 89, 90, 92, 106, 108, 108A, 109, and 110. Estimated dike elevations from the prior geotechnical analysis conducted and past dredging/construction contracts for placement areas not covered by the prior geotechnical analysis were used to calculate future volumes for the placement areas based on 3 foot incremental lifts until the estimated maximum dike elevation was reached.

A comparison of the historical dredge quantities was made versus the sediment deposition predicted by the AdH models. Because the AdH models output total of channel deposition included quantities from top of bank to top of bank and does not account for the consolidation that may occur in the deposited material, the yearly historical dredge quantities were less than those predicted by the AdH model. Therefore, the O&M dredging costs for the various alternatives was developed by pro-rating the quantities predicted by the AdH model by the ratio of the AdH predicted sediment values for the existing condition to the actual historical dredge quantities.

4.3.1 Brazos River Crossing

For dredging costs for Freeport, all dredging was assumed to be disposed offshore as that is the current mode of disposal for dredging in the Freeport Channel. Mobilization and unit costs were assumed for the dredge disposal in this area (costs escalated over 50 year project life). The existing dredge frequency of 8 months provided by OD was assumed to stay constant. It was assumed that the volume of dredging in each event would increase based on changes to sedimentation rates computed by the modeling.

For dredging costs for the GIWW from the east gate to the Freeport Harbor, a remaining adjacent disposal quantity of 7,500,000 CY was assumed. After that capacity was exceeded, offshore disposal was assumed. For adjacent disposal, a mobilization and unit cost were assumed for the dredge disposal. A levee raise was assumed every two years for the FWOP while the adjacent disposal was still being utilized. For offshore disposal, a separate mobilization and unit cost were assumed for the dredge disposal.

For dredging costs for the GIWW from the west gate to the San Bernard River, a remaining adjacent disposal quantity of 3,000,000 CY was assumed. After that capacity was exceeded, offshore disposal was assumed. For adjacent disposal, a mobilization and unit cost were assumed for the dredge disposal. A levee raise was assumed every three years for the FWOP while the adjacent disposal was still being utilized.
For offshore disposal, a separate mobilization and unit cost were assumed for the dredge disposal.

For dredging costs for the GIWW crossing at the Brazos Floodgates, a remaining adjacent disposal quantity of 8,000,000 CY was assumed. After that capacity was exceeded, offshore disposal was assumed. For adjacent disposal, a mobilization and unit cost were assumed for the dredge disposal. A levee raise was assumed every three years for the FWOP while the adjacent disposal was still being utilized. For offshore disposal, a separate mobilization and unit cost were assumed for the dredge disposal.

For all alternatives for dredging at the GIWW and at the river crossing, the levee raise cost was pro-rated based on the ratio of sedimentation associated with the alternative for that particular dredging area to the sedimentation in the FWOP condition. This accounts for the increased cost to raise the levees from the FWOP for the increased quantities of dredged material that will be deposited in the disposal areas. The existing dredge frequency of 2 years was provided by OD for the FWOP. The GIWW and Brazos dredging frequencies and associated mobilization costs were scaled from existing O&M frequency based on changes to sedimentation rates computed by the AdH modeling. A cost of $200,000 was assumed every 5 years to complete the permit process to utilize offshore disposal areas once offshore disposal was needed.

4.3.2 Colorado River Crossing

For dredging costs for the GIWW east of the locks, a remaining adjacent disposal quantity of 12,500,000 CY was assumed. After that capacity was exceeded, offshore disposal was assumed. For adjacent disposal, a mobilization and unit cost were assumed for the dredge disposal. A levee raise was assumed every ten years for the FWOP while the adjacent disposal was still being utilized. For offshore disposal, a separate mobilization and unit cost were assumed for the dredge disposal. While there are currently no offshore disposal sites available near the crossing, this study assumes that they will be approved and available.

For dredging costs for the GIWW west of the locks, a remaining adjacent disposal quantity of 10,500,000 CY was assumed. After that capacity was exceeded, offshore disposal was assumed. For adjacent disposal, a mobilization and unit cost were assumed for the dredge disposal. A levee raise was assumed every ten years for the FWOP while the adjacent disposal was still being utilized. For offshore disposal, a separate mobilization and unit cost were assumed for the dredge disposal

For dredging costs for the GIWW crossing at the Colorado River, a remaining adjacent disposal quantity of 4,000,000 CY was assumed. After that capacity was exceeded, offshore disposal was assumed. For adjacent disposal, a mobilization and unit cost were assumed for the dredge disposal. A levee raise was assumed every ten years for the FWOP while the adjacent disposal was still being utilized. For offshore disposal, a separate mobilization and unit cost were assumed for the dredge disposal

For all alternatives for dredging at the GIWW and at the river crossing, the levee raise cost was pro-rated based on the ratio of sedimentation associated with the alternative for that particular dredging area to the sedimentation in the FWOP condition. This accounts for the increased cost to raise the levees from the FWOP for the increased quantities of dredged material that will be deposited in the disposal areas. The existing dredge frequency of 2 years was provided by OD for the FWOP. The GIWW and Brazos dredging frequencies and associated mobilization costs were scaled from existing O&M frequency based on changes to sedimentation rates computed by the AdH modeling. A cost of $200,000 was assumed every 5 years to complete the permit process to utilize offshore disposal areas once offshore disposal was needed.

5 COST

5.1 Brazos River Floodgates and Colorado River Locks Systems

5.1.1 General

5.1.1.1 Cost estimate development

The project cost estimate was developed in the latest TRACES MII cost estimating software and used the standard approaches for a feasibility estimate structure regarding labor, equipment, materials, crews, unit prices, quotes, sub- and prime contractor markups. This philosophy was taken wherever practical within the time constraints. It was supplemented with estimating information from other sources where necessary such as quotes, bid data, and A-E estimates. The intent was to provide or convey a “fair and reasonable” estimate that which depicts the local market conditions. The estimates assume a typical application of tiering subcontractors. All of the construction work (e.g., sector gate structures, dredging, excavation, dewatering, pilings, rock, etc.) is common to the gulf coast region. The construction sites are accessible from land and water. Access is easily provided from the Gulf of Mexico, GIWW, or various local highways.

5.1.1.2 Estimate Structure

The estimates are structured to reflect the projects performed. The estimates have been subdivided by alternative and USACE feature codes.

5.1.1.3 Bid Competition

It is assumed that there will not be an economically saturated market and that bidding competition will be present.

5.1.2 Contract Acquisition Strategy

There is no declared contract acquisition plan/types at this time. It is assumed that the contract acquisition strategy will be similar to past projects with large, unrestricted design/bid/build contracts.

5.1.3 Labor Shortages

It is assumed there will be a normal labor market.

5.1.4 Labor Rates

Local labor market wages are above the local Davis-Bacon Wage Determination and actual rates have been used. Local payroll information was not available, therefore regional gulf coast information was used from the New Orleans District Construction Representatives and estimators with experiences in past years.

5.1.5 Materials

Cost quotes are used on major construction items when available. Recent quotes may include concrete, steel and concrete piling, rock, gravel and sand. The assumption is that materials will be purchased as part of the construction contract. The estimate does not anticipate government furnished materials. Prices include delivery of materials.

5.1.6 Quantities

Quantities provided for Colorado River Locks by MVN Structures Branch and for Brazos River Floodgates by TXDOT.

5.1.7 Equipment

Rates used are based from the latest USACE EP-1110-1-8, Region VI. Adjustments are made for fuel and facility capital cost of money (FCCM). Judicious use of owned verses rental rates was considered based on typical contractor usage and local equipment availability. Only a few select pieces of marine \ marsh equipment are considered rental. Full FCCM/Cost of Money rate is latest available; Mii program takes EP recommended discount, no other adjustments have been made to the FCCM.
Equipment was chosen based on historical knowledge of similar projects.

5.1.8 Severe Rates

Severe equipment rates were used for various pieces of equipment in the hydraulic dredging crews where they may come in contact with a saltwater environment.
Rental Rates

Rental rates were used for various pieces of marine and marsh equipment where rental is typical such as marsh backhoes.

5.1.9 Fuels

Fuels (gasoline, on and off-road diesel) were based on local market averages for on-road and off-road for the Gulf Coast area. The Team found that fuels fluctuate irrationally; thus, used an average.

5.1.10 Crews

Major crew and productivity rates were developed and studied by senior USACE estimators familiar with the type of work. All of the work is typical to the gulf coast area and New Orleans District cost engineers. The crews and productivities were checked by local MVN estimators, discussions with contractors and comparisons with historical cost data. Major crews include haul, earthwork, piling, concrete, and hydraulic dredging.

Most crew work hours are assumed to be 10 hrs 6 days/wk which is typical to the area. Marine based bucket excavation/dredging operations are assumed to work 2-12 hours shifts 7 days / week.

A 10% "markup on labor for weather delay" is selectively applied to the labor in major earthwork placing detail items and associated items that would be affected by small amounts of weather making it unsafe or difficult to place (trying to run dump trucks on a wet levee) or be detrimental/non-compliant to the work being done (trying to place/compact material in the rain). The 10% markup is to cover the common practice of paying for labor "showing up" to the job site and then being sent home due to minor weather which is part of known average weather impacts as reflected within the standard contract specifications. The markup was not applied to small quantities where this can be scheduled around.

5.1.11 Unit Prices

The unit prices found within the various project estimates will fluctuate within a range between similar construction units such as floodwall concrete, earthwork, and piling. Variances are a result of differing haul distances (trucked or barged), small or large business markups, subcontracted items, designs and estimates by others.

5.1.12 Relocation Costs

Relocation costs are defined as the relocation of public roads, bridges, railroads, and utilities required for project purposes. In cases where potential significant impacts were known, costs were included within the cost estimate.

5.1.13 Mobilization

Contractor mobilization and demobilization are based on the assumption that most of the contractors will be coming from within the gulf coast/southern region. Mob/demob costs are based on historical studies of detailed Government estimate mob/demob which are in the range of 5% of the construction costs. With undefined acquisition strategies and assumed individual project limits, the estimate utilizes a slightly more comprehensive approx. 6% value (min) applied at each contract rather than risking minimizing mob/demob costs by detailing costs based on an assumed number of contracts. This value also matches well with values previously prescribed by Walla Walla District, which has studied historical rates.

5.1.14 Field Office Overhead

The estimate used a field office overhead rate of 12% for the prime contractors at budget level development. Based on historical studies and experience, Walla Walla District has recommended typical rates ranging from 9% to 11% for large civil works projects; however, the 9-11% rate does not consider possible incentives such as camps, allowances, travel trailers, meals, etc. which have been used previously to facilitate large or remote projects. With undefined acquisition strategies and assumed individual project limits, the estimate utilizes a more comprehensive percentage based approach applied at each contract rather than risking minimizing overhead costs by detailing costs based on an assumed number of contracts. The applied rates were previously discussed among numerous USACE District cost engineers including Walla Walla, Vicksburg, Norfolk, Huntington, St. Paul and New Orleans.

5.1.15 Overhead Assumptions

Overhead assumptions may include superintendent, office manager, pickups, periodic travel, costs, communications, temporary offices (contractor and government), office furniture, office supplies, computers and software, as-built drawings and minor designs, tool trailers, staging setup, camp/facility/kitchen maintenance and utilities, utility service, toilets, safety equipment, security and fencing, small hand and power tools, project signs, traffic control, surveys, temp fuel tank station, generators, compressors, lighting, and minor miscellaneous.

5.1.16 Home Office Overhead

Estimate percentages range based upon consideration of 8(a), small business and unrestricted prime contractors. The rates are based upon estimating and negotiating experience, and consultation with local construction representatives. Different percents are used when considering the contract acquisition strategy regarding small business 8(a), competitive small business and large business, high to low respectively. The applied rates were previously discussed among numerous USACE District cost engineers including Walla Walla, Vicksburg, Norfolk, Huntington, St. Paul and New Orleans.

5.1.17 Taxes

Local taxes will be applied based on the counties that contain the work. Reference the tax rate website for Texas: http://www.salestaxstates.com.

5.1.18 Bond

Bond is assumed 1% applied against the prime contractor, assuming large contracts. No differentiation was made between large and small businesses.

5.1.19 Planning, Engineering & Design (PED)

The PED cost includes such costs as project management, engineering, planning, designs, investigations, studies, reviews, value engineering and engineering during construction (EDC). Historically a rate of approximately 12% for E&D plus small percentages for other support features is applied against the estimated construction costs. Other USACE civil works districts such as St. Paul, Memphis, and St. Louis have reported values ranging from 10-15% for E&D. Additional support features might include project management, engineering, planning, designs, investigations, studies, reviews, and value engineering.

5.1.20 Supervision & Administration (S&A)

Historically a range from 5% to 15% depending on project size and type applied against the estimated construction costs. Other USACE civil works districts such as St. Paul, Memphis, and St. Louis report values ranging from 7.5-10%. Consideration includes that a portion of the S&A effort could be performed by contractors. S&A costs are percentage based.

5.1.21 Contingencies

Contingencies were developed using the USACE Abbreviated Cost Risk Analysis (ARA) program based on cost risks determined by the PDT. A separate ARA was prepared for each alternative to help differentiate between the alternatives.

5.1.22 Escalation

Escalation used is based upon the latest version of the US Army Corps of Engineers Engineering Manual (EM) 1110-2-1304 Civil Works Construction Cost Index System (CWCCIS).

5.1.23 HTRW

The estimate does not include costs for any potential Hazardous, Toxic, and Radioactive Waste (HTRW) due to lack of any concerns.

5.1.24 Schedule

The project schedule for each alternative was developed based on the construction line items for each feature of work.

Alternative	Construction Duration (year)
Brazos Alt 2a - Rehab	1.25
Brazos Alt 3a - Move gates back	2.25
Brazos Alt 3a.1 - Move gate back East + Open channel West	2.00
Brazos Alt 9a - Open channel	1.00
Brazos Alt 9b - New gates Align C w/o Sediment Control	2.25
Brazos Alt 9c - New gates Align C with Sediment Control	3.00
Colorado Alt 4b.1 Hybrid - Rehab Inland gate + Remove Riverside gate	1.25
Colorado Alt 2b - Rehab w/ Guidewall	1.50
Colorado Alt 2b1 - Rehab w/ NO Guidewall	1.25
Colorado Alt 3 - Open channel	1.00

Table 7 Summary of Construction Durations

5.2 Baseline Project Cost for Each Alternative

Error! Reference source not found. through 16 show the baseline project cost for each alternative. This information is taken from the Total Project Cost Sheet (TPCS).

Table 8 Brazos River – Alt 2a Rehab

Feature	Cost	Contingency	Total
01 Lands & Damages	$28,000	$6,000	$33,000
02 Relocations			
05 Locks			
06 Fish & Wildlife Facilities			
11 Levees & Floodwalls			
15 Fldwy Control & Div Str	$24,038,000	$10,096,000	$34,134,000
30 PED	$4,895,000	$2,056,000	$6,950,000

31 Construction Management	$2,692,000	$1,131,000	$3,823,000
TOTAL	$31,652,000	$13,288,000	$44,940,000

Table 9 Brazos River – Alt 3a

Feature	Cost	Contingency	Total
01 Lands & Damages	$28,000	$6,000	$33,000
02 Relocations			
05 Locks			
06 Fish & Wildlife Facilities	$311,000	$131,000	$442,000
11 Levees & Floodwalls			
15 Fldwy Control & Div Str	$142,506,000	$59,853,000	$202,358,000
30 PED	$29,071,000	$12,210,000	$41,281,000
31 Construction Management	$15,989,000	$6,715,000	$22,704,000
TOTAL	$187,905,000	$78,914,000	$266,819,000

Table 10 Brazos River – Alt 3a.1

Feature	Cost	Contingency	Total
01 Lands & Damages	$28,000	$6,000	$33,000
02 Relocations			
05 Locks			
06 Fish & Wildlife Facilities	$306,000	$122,000	$429,000
11 Levees & Floodwalls			
15 Fldwy Control & Div Str	$79,939,000	$31,975,000	$111,914,000
30 PED	$16,332,000	$6,533,000	$22,865,000
31 Construction Management	$8,984,000	$3,593,000	$12,577,000
TOTAL	$105,588,000	$42,230,000	$147,818,000

Table 11 Brazos River – Alt 9a

Feature	Cost	Contingency	Total
01 Lands & Damages	$1,803,000	$448,000	$2,251,000
02 Relocations			
05 Locks			
06 Fish & Wildlife Facilities	$1,556,000	$576,000	$2,132,000

09 Channels & Canals	$13,452,000	$4,977,000	$18,429,000
15 Fldwy Control & Div Str			
30 PED	$3,056,000	$1,131,000	$4,187,000
31 Construction Management	$1,681,000	$622,000	$2,304,000
TOTAL	$21,549,000	$7,754,000	$29,303,000

Table 12 Brazos River – Alt 9b

Feature	Cost	Contingency	Total
01 Lands & Damages	$1,803,000	$448,000	$2,251,000
02 Relocations			
05 Locks			
06 Fish & Wildlife Facilities	$1,454,000	$582,000	$2,036,000
11 Levees & Floodwalls			
15 Fldwy Control & Div Str	$137,458,000	$54,983,000	$192,441,000
30 PED	$28,276,000	$11,310,000	$39,586,000
31 Construction Management	$15,552,000	$6,221,000	$21,773,000
TOTAL	$184,543,000	$73,544,000	$258,087,000

Table 13 Brazos River – Alt 9c

Feature	Cost	Contingency	Total
01 Lands & Damages	$1,803,000	$448,000	$2,251,000
02 Relocations			
05 Locks			
06 Fish & Wildlife Facilities	$1,454,000	$596,000	$2,050,000
15 Fldwy Control & Div Str	$136,152,000	$55,822,000	$191,974,000
15 Fldwy Control & Div Str	$7,946,000	$3,258,000	$11,204,000
30 PED	$29,626,000	$12,147,000	$41,772,000
31 Construction Management	$16,294,000	$6,681,000	$22,974,000
TOTAL	$193,275,000	$78,951,000	$272,226,000

Table 14 Colorado River – Alt 2b1 Rehab

Feature	Cost	Contingency	Total
01 Lands & Damages	$16,000	$3,000	$20,000
02 Relocations			
05 Locks	$25,724,000	$11,061,000	$36,785,000
06 Fish & Wildlife Facilities			
11 Levees & Floodwalls			
15 Fldwy Control & Div Str			
30 PED	$5,235,000	$2,251,000	$7,487,000
31 Construction Management	$2,880,000	$1,238,000	$4,118,000

TOTAL	$33,855,000	$14,554,000	$48,409,000

Table 15 Colorado River – Alt 3b Open Channel

Feature	Cost	Contingency	Total
01 Lands & Damages	$16,000	$3,000	$20,000
02 Relocations			
05 Locks			
06 Fish & Wildlife Facilities			
09 Channels & Canals	$11,351,000	$4,994,000	$16,345,000
15 Fldwy Control & Div Str			
30 PED	$2,319,000	$1,020,000	$3,340,000
31 Construction Management	$1,275,000	$561,000	$1,837,000
TOTAL	$14,997,000	$6,595,000	$21,592,000

Table 16 Colorado River – Alt 4b.1

Feature	Cost	Contingency	Total
01 Lands & Damages	$16,000	$3,000	$20,000
02 Relocations			
05 Locks	$19,053,000	$8,955,000	$28,008,000
06 Fish & Wildlife Facilities			
11 Levees & Floodwalls			
15 Fldwy Control & Div Str			
30 PED	$3,878,000	$1,823,000	$5,701,000
31 Construction Management	$2,132,000	$1,002,000	$3,134,000
TOTAL	$25,079,000	$11,783,000	$36,862,000

DRAFT

ENGINEERING APPENDIX A

APPENDIX 1

HYDRAULIC ENGINEERING APPENDIX – BRAZOS RIVER FLOODGATES

MOTT MACDONALD

Hydraulic Engineering Appendix

Brazos River Floodgates

February 8th, 2018

Texas Department of Transportation (TXDOT)

Mott MacDonald
10415 Morado Circle
Building One
Suite 300
Austin TX 78759
United States of America

T +1 (512) 342 9516
F +1 (512) 342 9708
mottmac.com

Texas Department of
Transportation (TXDOT)

Hydraulic Engineering Appendix

Brazos River Floodgates

For Inclusion in Feasibility Report

February 8th, 2018

Texas Department of Transportation (TXDOT)

Issue and revision record

Revision	Date	Originator	Checker	Approver	Description
0	9/1/17	P. McLaughlin C. Harter	J. Carter	J. Carter	Engineering Appendix, first draft
1	1/3/18	P. McLaughlin C. Harter	J. Carter	J. Carter	Engineering Appendix, second draft
2	2/2/18	P. McLaughlin C. Harter	J. Carter	J. Carter	Engineering Appendix, third draft
3	2/8/18	P. McLaughlin C. Harter	J. Carter	J. Carter	Engineering Appendix, fourth draft

Document reference: 357463 | A | 0

Information class: Standard

Contents

Tables

Figures

1 Introduction

This report describes the hydraulic modeling and analysis conducted at the Brazos River Floodgates to support the US Army Corps of Engineers Feasibility Study. Hydraulic modeling was conducted for existing conditions to simulate the system hydraulics, salinity, and sedimentation. The models were calibrated to available measured data. These models were then used to simulate hydraulics, salinity, and sedimentation for the proposed Alternatives 2a, 3a, 9a, and 9c. Alternative 2a involves major rehabilitation of the existing floodgates. Alternative 3a involves setting the floodgates farther back along the existing alignment and widening the chamber wall opening to 125 feet. Alternative 9a involves an open channel north of the existing alignment. Alternative 9b involves construction of 125-foot-wide floodgates along the same alignment as 9a and closing off the existing alignment. Finally, Alternative 9c involves construction of 125-foot-wide floodgates with a flow control sluice gate constructed at the existing west gate. Note that Alternative 2a involves major rehabilitation of existing gate structures, but is assumed to not change the guide wall orientation, gate operations, or bathymetry and therefore the hydraulics and resulting salinity and sedimentation are assumed to be identical to existing conditions. Throughout this document, results for Alternative 2a will not be presented separately but will instead be considered the same as exiting conditions results.

The hydraulic modeling was also used to understand changes to the navigation of the system, and evaluated the changes to the navigation restrictions and closures due do to system hydraulics.

2 Data Collection & Project Site Conditions

The Brazos River Floodgates are located at the intersection of the Gulf Intracoastal Waterway (GIWW) and the Brazos River in Brazoria County, TX (Figure 1). The drainage area of the Brazos River is approximately 45,560 sq mi. The Brazos River is the only significant source of sediment for the central Texas coast. In 1929, the Brazos River was diverted 8 miles south of its mouth at Freeport by the Galveston District to reduce flooding and shoaling in the Port of Freeport (USACE, 2002). The intent for the relocation was for the Brazos River Diversion Channel (BRDC) to divert the sediment load of the Brazos River from the Freeport Ship Channel. The GIWW crosses the BRDC 7,000 ft upstream from its mouth. Tidal and fluvial flows into the GIWW are controlled by the Brazos River Floodgates constructed and controlled by the Corps of Engineers in 1943 (USACE, 1988).

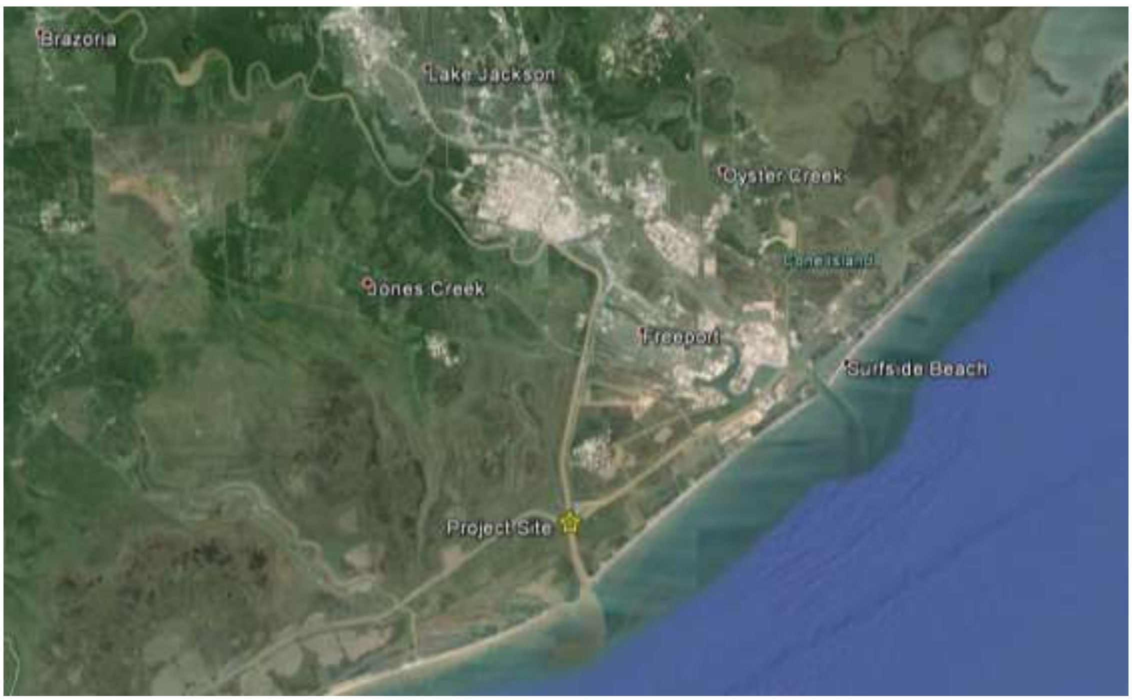

Figure 1. Brazos River Floodgates location map.

The floodgates serve to control flood flows from the Brazos River to the GIWW, improve navigation safety by controlling traffic flow and currents at the intersection of the Brazos River's connection with the GIWW and to control sand and silt deposition from the Brazos River into the GIWW. The total commercial tonnage traversing the Brazos River Floodgates is 45 million tons with an estimated value of $4.5 billion in cargo per year. When the floodgates were built in 1943, barges were typically 26 ft to 35 ft wide. The floodgate chamber is 75 ft wide, and the maximum width of the barge it can accommodate is 55 ft. Today, it is common for towboat operators to push two 35-ft dry cargo barges side by side, for a total width of 70 ft. A typical tank barge measures 54 ft across, so tank barges must transit singly. The necessity to break the tow to pass individual barges through the Floodgates causes time delays (George, 2016).

Frequent accidents occur when tows strike the facilities while trying to line up to enter the floodgates after crossing the Brazos River. The floodgates are only approximately 600 ft from the river. When crossing the river, towboat operators do not have enough time to recover their course after struggling with the river currents. As a result, an average of 36 accidents occurs per year, causing damages worth approximately $800,000 annually to the facility and to the barges (TXDOT, 2015). When these accidents involve tank barges, there is also a risk for hazardous material spills. Navigation traffic delay costs are estimated to exceed $10 million annually (TXDOT, 2015).

Due to the navigation hazards at the BRFG, navigation restrictions have been included in the Code of Federal Regulations (33 CFR 207.187). The restrictions are summarized in Table 1.

Table 1. Navigation restrictions at the BRFG

Restriction	Velocity [ft/s]	Head Difference [ft]
Unlimited passage	< 2.0	< 0.7
Limited passage	2.0 – 5.0	0.7 – 1.8
Gate closure	> 5.0	> 1.8

2.1.1 River Hydraulics and Basin Hydrology

Hydrology and hydraulic data such as rainfall-runoff and river discharge are required for hydraulic engineering analysis as well as numerical modeling of existing conditions and any proposed alternatives of Brazos River Floodgates. Historical rainfall and river discharge data are used to derive river statistics, namely for design and navigation purposes. Simultaneous discharge measurements at different locations within the Brazos River, GIWW, and San Bernard River network are used develop an understanding of the local hydraulics and to calibrate numerical hydrodynamic models.

2.1.1.1 River Hydraulics

Publicly available data from USGS stream gaging stations are available. The available existing hydraulic data for the Brazos River and San Bernard River have been acquired and analyzed. USGS gages are shown on Figure 2 and Table 2 (USGS, 2015) (Jeffery, 2015).

Figure 2. (left) USGS Gaging Stations used in the hydrodynamic processes analysis near Brazos River Floodgates, and (right) detailed view of USGS gaging stations used in the hydrodynamic processes analysis near Brazos River Floodgates, see Table 2 for legend.

Table 2. USGS gaging station map legend.

USGS gage ID	Gage location
08114000	Brazos River at Richmond, TX
08116650	Brazos River at Rosharon, TX
08117300	Brazos River at GIWW Flood Gates near Freeport, TX
08117290	Brazos River at Freeport, TX
08117500	San Bernard River near Boling, TX
08117730	San Bernard River Upstream of GIWW near Freeport, TX
08117740	San Bernard River Downstream of GIWW near Freeport, TX
285217095263001	GIWW East of the San Bernard River, near Freeport, TX

Various statistical parameters were computed for Brazos River and San Bernard River from the available daily mean discharge as a way of summarizing the large dataset. Table 3 provides the long-term daily discharge statistics for Brazos River at Rosharon and San Bernard River at Boling (see Figure 2). It is evident Brazos River discharge is an order of magnitude larger than San Bernard River which is associated with the size of the catchment, 43,339 sq mi and 727 sq mi, respectively. Extreme value statistics on long-term daily discharge data from Brazos River at Rosharon and San Bernard River at Boling were also performed and are shown on Table 3.

Table 3. Long-term daily USGS stations discharge statistics for Brazos River at Rosharon (1903-2015) and San Bernard River at Boling (1954-2015).

Discharge	Brazos River at Rosharon Q [cfs]	San Bernard River at Boling Q [cfs]
Contributing drainage area	45,339 sq mi	727 sq mi
Maximum	123,000	31,300
Minimum	35	0.4
Mean	7,392	519
Standard deviation	11,846	1,389

Table 4. Long-term daily USGS stations discharge extremal analysis by annual maximum for Brazos River at Rosharon (1903-2015) and San Bernard River at Boling (1954-2015).

Return Period [yrs]	Brazos River at Rosharon Q [cfs]	San Bernard River at Boling Q [cfs]
1	56,997	5,971
2	64,887	9,057
5	72,988	13,536
10	78,207	17,108
20	82,927	20,798
25	84,363	22,006
50	88,615	25,818
75	90,974	28,084
100	92,599	29,707
250	97,537	34,949
500	101,067	38,984

Figure 3 provides the long-term monthly mean discharge at Brazos River Richmond gage (upstream) for the period 1940-2016, Brazos River Rosharon gage (downstream) for the period 1967-2016 and San Bernard River at Boling for the period 1954-2016. Brazos River at Richmond monthly discharge distribution is seemingly unimodal having one evident monthly peak discharge in May. The unimodal quality fades downstream at Rosharon since two local maximum discharge are observed in the moths of March and June as opposed to a single maximum in May.

The comparison of these data shows that over the entire period of record, the monthly mean peak discharge attenuates in the downstream direction. The maximum monthly mean discharge drops from 14,200 cfs to 12,400 cfs in May. Such attenuation is expected in the lower sections of the Brazos River, “as elevated flows enter storage in the low elevation terrain and are released over longer time periods” (USGS, undated). Conversely the lower flows seen during November, December, January, February, March, April, June, July, April, and September increase in the downstream reach.

Differences are observed when comparing the Brazos (at Rosharon) and San Bernard (at Boling) monthly mean discharges. As shown on Figure 3, the San Bernard River at Boling distribution is multimodal having three local maximum discharges – October, February, and June. Opposite behaviors are observed in October and March when the high flows on San Bernard match the low flows of Brazos and vice versa. In June, however, the highest monthly average discharge occurs for both the San Bernard and Brazos River.

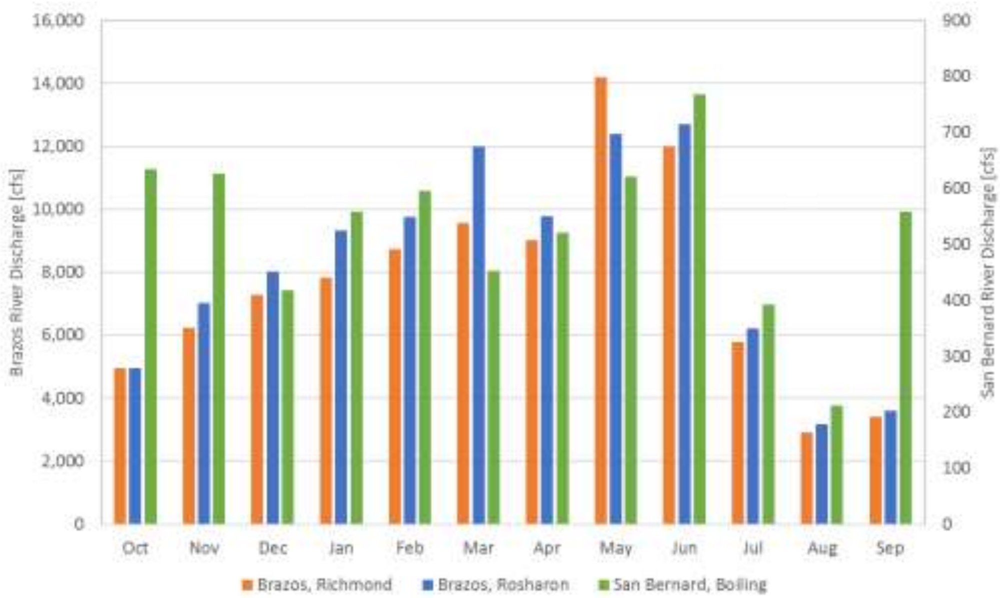

Figure 3. Long-term monthly mean streamflow discharge at USGS stations Brazos River near Richmond (upstream in blue), Brazos River near Rosharon (downstream in red) and San Bernard River near Boling. Data is shown in water year from October 1st to September 30th.

As shown in Figure 4, attenuation is also present in the San Bernard River. Peak flows in the San Bernard River are attenuated from the USGS Boling station to the intersection with the GIWW in the lower sections of River due to elevated flows storage (USGS, undated), which is similar to the trend observed for Brazos River. The high flows at San Bernard in October are associated with local precipitation events that do not reach the headwaters of Brazos River; such high precipitation-discharge events are related to the hurricane/storm season in the Gulf Coast.

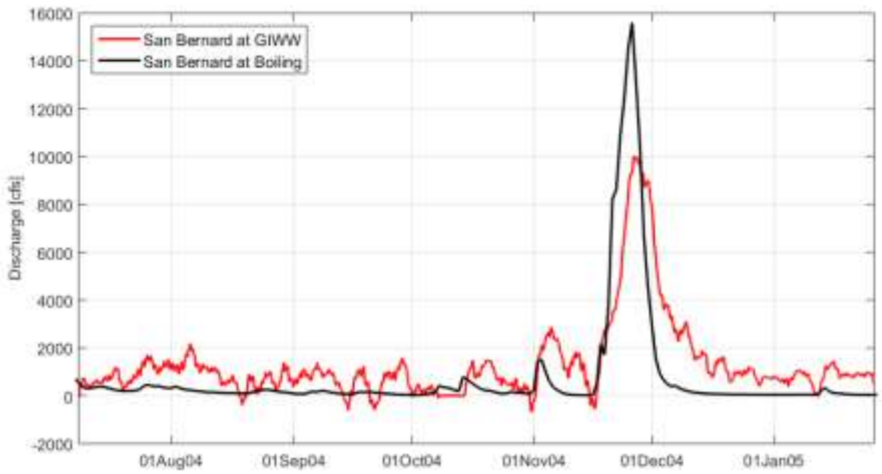

Figure 4. Streamflow discharge at USGS station Bernard River near Boling and detrended discharge data at USGS station San Bernard River upstream of the GIWW July 2004 to February 2005 (USGS, undated).

The undated USGS report on the discharge at the intersection of the San Bernard River and the GIWW, the data show the vast majority of water flowing in the San Bernard River immediately upstream of the GIWW intersection (08117730 on Figure 2) flows east into the GIWW (285217095263001 on Figure 2). In addition, the data indicates the magnitude of discharge in the San Bernard River downstream of the GIWW is much less than flow upstream of the GIWW (USGS, undated). Hence, it can be concluded that the majority of the peak discharge in the San Bernard River flows east into the GIWW.

2.1.1.2 Hydraulics at the Brazos Crossing

Several data measurements are available in the vicinity of the GIWW crossing of the Brazos River. USGS station 08117300 is located at the project site and consists of water level gages on either side of both the East and West Gates (4 total). Station 08117300 also includes velocity gages on the river side of both the East and West Gates as well as one velocity gage in the Brazos River approximately 400 feet upstream of the GIWW. The USGS gage locations are shown in Figure 5 and a summary of available data is shown in Table 5.

Figure 5: Station 8117300 gage locations

These gages have recorded historical hourly stage and velocity since 2008. Starting in 2014, these gages recorded stage and velocity at 15 minute intervals. A summary of the available data at the gauges shown is described in Table 5 (USGS, 2017). The gages adjacent to the gates (East Lock, East River, West Lock, West River) are strongly influenced by the opening and closings which cause large, rapid fluctuations in the stage and velocity.

The sampling intervals of the measured gage data (hourly before 2014, 15 mins after 2014) are such that these opening/closing events, which take between 2 and 5 minutes, cannot be captured and fully resolved. This relatively coarse sampling interval long with the very close location of the gages to the gates result in very noisy data with little apparent discernable meaningful signal. It is difficult to interpret head differentials at the gates using the gage data.

The Brazos River velocity gage provides a good record of the river velocity. However, the gage is located close to the river bank and does not capture the representative velocities in the River. The Lockmaster stated they do not base decisions to restrict navigation based on measurements from this gage because of this fact (George, 2016).

Table 5. GIWW Brazos Crossing Data Stations Summary

Data Station	Data Available	Recording Period	Sampling Interval
USGS 08117300 - East Lock	Stage	1/1/2008 - 9/30/2011, 2/1/2014 - Present	Hourly (Velocity, Stage until 9/30/2011), 15-minute (Stage starting 2/1/14)
USGS 08117300 - East River	Velocity, Stage	1/1/2008 - 9/30/2011, 2/1/2014 - Present	Hourly (Velocity, Stage until 9/30/2011), 15-minute (Stage starting 2/1/14
USGS 08117300 - West Lock	Stage	1/1/2008 - 9/30/2011, 2/1/2014 - Present	Hourly (Velocity, Stage until 9/30/2011), 15-minute (Stage starting 2/1/14
USGS 08117300 - West River	Velocity, Stage	1/1/2008 - 9/30/2011, 2/1/2014 - Present	Hourly (Velocity, Stage until 9/30/2011), 15-minute (Stage starting 2/1/14
USGS 08117300 – Brazos River Upstream	Velocity	1/1/2008 - 9/30/2011, 2/1/2014 - Present	Hourly Velocity until 9/30/2011 15-minute (Stage starting 2/1/14

2.1.1.3 Basin Hydrology

Existing hydrology data in the project vicinity were compiled. The following hydrology data corresponds to the hydrology studies completed by the Texas Water Development Board for Brazos River (Figure 6) and San Bernard River (Figure 7) (Texas Water Development Board, 2011):

- Brazos River Estuary Hydrology Study; covers period from 1977 to 2009
- San Bernard River Estuary Hydrology Study; covers period from 1977 to 2009

Hydrology analysis results provide a volumetric runoff balance in acre-ft which includes the following contributions:

$$\textit{Balance} = \textit{gaged} + \textit{modeled} - \textit{diversion} + \textit{return} - \textit{evaporation} + \textit{precipitation}$$

Where gaged flows are obtained from USGS gages, modeled are rainfall-runoff values estimated using TxRR model, diversions and returns are flows associated with water rights and holders of discharge permits, and evaporation and precipitation include at contribution from each process on the bay surface area exclusively (Texas Water Development Board, 2011).

Figure 6 shows over the study period, gaged inflow from the USGS station at Brazos River near Rosharon accounted for approximately 86 percent of combined inflow, while modeled flows (rainfall-runoff) accounted for almost 3 percent of the balance. Hence, the river discharge at the

Brazos River Floodgates is significantly dominated by upstream riverine processes rather than precipitation-induced discharges in the coastal plain. Therefore, precipitation processes can be ignored in the analysis. Such behavior is expected due large drainage area.

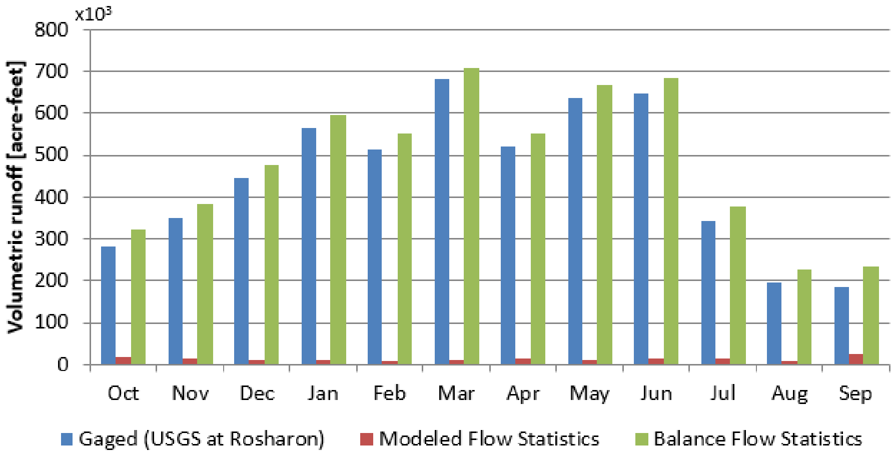

Figure 6. Brazos River long-term monthly mean freshwater inflow hydrology data over the period from 1977 to 2009. Data is shown in water year from October 1st to September 30th (Texas Water Development Board, 2011).

Conversely, Figure 7 shows that over the study period gaged inflows from the USGS gage station at San Bernard River near Boling accounted for approximately 64 percent of the combined inflows, while ungaged flows (modeled rainfall-runoff) accounted for approximately 40 percent of the balance (balance= gaged + modeled - diversion + return - evaporation + precipitation). Therefore, the San Bernard river discharge at the intersection with the GIWW is heavily influenced by precipitation-induced discharge in addition to upstream riverine processes. The rainfall-runoff for San Bernard River (Figure 7) overall trend agrees with the trend overserved at the Boling station, where high flows are observed in September/October and June.

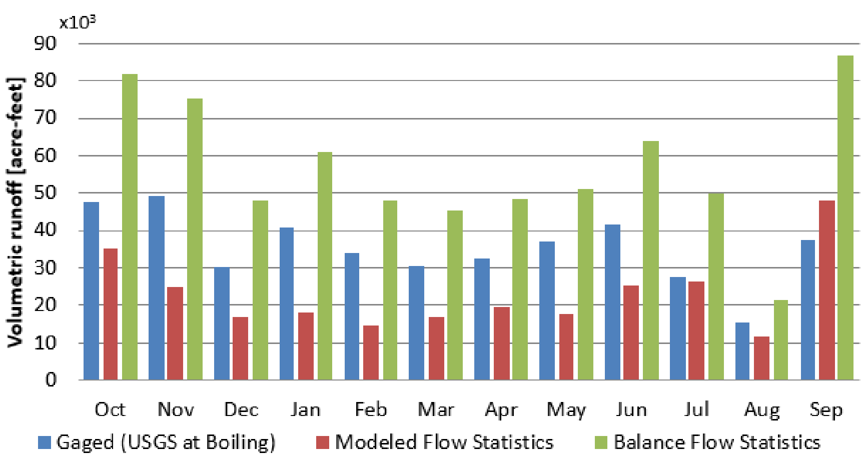

Figure 7. San Bernard River long-term monthly mean freshwater inflow hydrology data over the period from 1977 to 2009. Data is shown in water year from October 1st to September 30th (Texas Water Development Board, 2011).

Table 6 presents a qualitative summary of the data analysis of hydrologic process in Brazos and San Bernard Rivers.

Table 6. Brazos River and San Bernard River qualitative summary of hydrologic process.

River	High Discharge	Driving Mechanism	Peak Attenuation
Brazos (at Rosharon)	March June	Headwater processes	From Richmond to Rosharon Flood plain storage
San Bernard (at Boling)	October February June	Headwater processes Local rainfall-runoff	From Boling to GIWW Flood plain storage

2.1.2 Bathymetric and Topographic Data

Available bathymetric and topographic data sets were used to build the bathymetric surface to be used for wave and current modeling described in later Sections. Multibeam bathymetric surveys of the Brazos Locks and Basin from 2012 – 2016 were collected. Single beam surveys of the GIWW approximately twice a year from 2012 – 2016 between Freeport and the San Bernard River were collected. Transects of the single beam surveys are spaced at approximately 200 ft. In addition to survey data, this analysis includes data from the Coastal Relief Model, and EC2012 ADCIRC Tidal Database Mesh. The bathymetry sets used to create the modeling surface are further described in Section 3.1.

2.1.3 Tidal Elevations

Tidal elevations at the project site were extracted from NOAA Station 8772447 in Freeport, TX approximately 6 miles northeast of the project site. The tidal elevations used for this study are shown below in Table 7. Tide levels relative to NAVD88 were found using VDatum (Parker et al. 2003).

Table 7. Tidal Datums at NOAA Station 8772447.

Tide Level	Description	MLLW (Epoch 1983-2001) [ft]
MHHW	Mean Higher-High Water	1.80
MSL	Mean Sea Level	0.97
MLLW	Mean Lower-Low Water	0.00
NAVD88	North-American Vertical Datum, 1988	-0.04

2.1.4 Relative Sea Level Rise

The Brazos River Floodgates are located in the coastal zone. The existing system as well as any proposed alternatives have the potential to be affected by relative sea level rise. Therefore, it is important to document the robustness of the project alternative selections to climate change, and how the hydraulics and hydrology analysis will change with the changing climate.

The project start date is assumed to be 2020. Since the project life was assumed to be 50 years, the future extent of sea level change was determined using the USACE climate change website http://corpsclimate.us/ccaceslcurves.cfm. Data was obtained using the web tool from the closest available gage which was 8772440 at Freeport which is located approximately 6 miles from the project site. The data was extracted 100 years from the project start date of 2020, to show the extent of sea level change beyond the project life of 50 years. Figure 8 shows the resulting relative sea level change over the project life (until 2070) and 100 years from the project start date (2120).

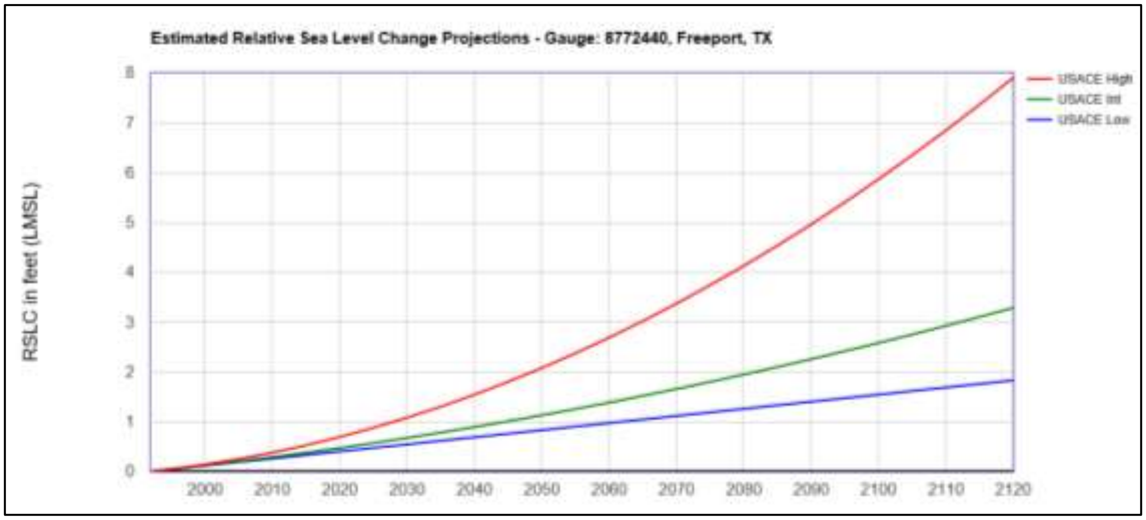

Figure 8. USACE projected sea level change from 1992 to 2120 at NOAA gage 8772440, Freeport TX.

2.1.4.1 Analysis of Flow Gage Data Trends

To evaluate the long-term trends of climate change on river discharge, a trend analysis was conducted on the annual peak discharges at the Rosharon, Texas USGS gage for the Brazos River and at the Boling, Texas USGS gage for the San Bernard River. A trendline was fit to the annual peak discharges at each site. Figures showing the peak annual discharges, along with linear trendlines are shown below in Figure 9 and Figure 10 for the Brazos and San Bernard Rivers, respectively.

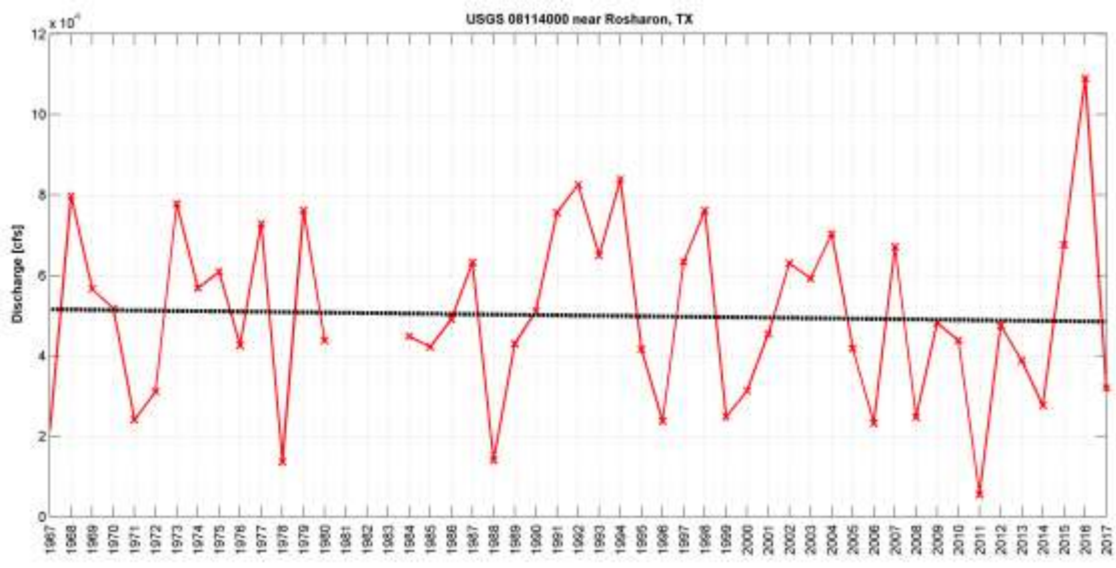

Figure 9. Annual peak discharges on the Brazos River near Rosharon, TX.

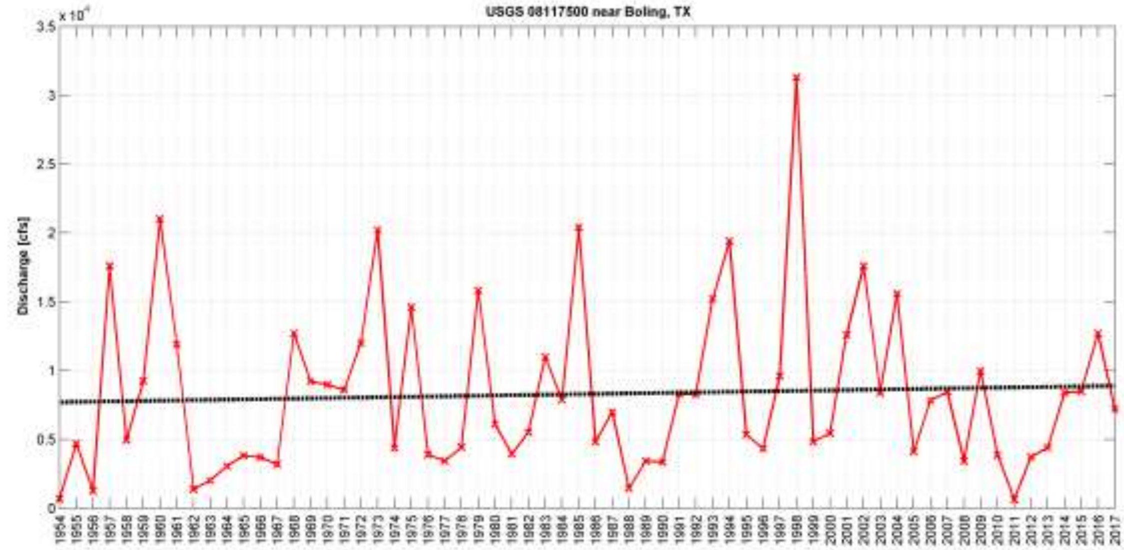

Figure 10. Annual peak discharges on the San Bernard River near Boling, TX.

The trendline fitted to the Brazos River data shows a slight decrease from 1967-2017. The trendline fitted to the San Bernard River data shows a slight increase from 1954-2017. The discrepancy between the two datasets could be attributed to very low flow years in the early 1960's which are present in the San Bernard dataset, but absent from the Brazos River dataset. Changes in discharge rate are expected to result in changes in the sedimentation, however the amount of increased sedimentation due to increased discharge is assumed to be relatively small compared to the uncertainty associated with the sediment rating curve. The analysis conducted above is based on annual trends at the Brazos River was compared to the peak discharge trends produced by the USACE Climate hydrology assessment tool (see Figure 11). The trends developed by the USACE also show a slight decrease in peak annual discharge. However, the climate hydrology tool does not include data from 2016 and 2017, which were relatively wet years. As a result, the trendline developed by the USACE climate hydrology tool shows a steeper decrease in peak flow, while the revised analysis shown in Figure 9 shows a more gradual decrease in peak flow rates.

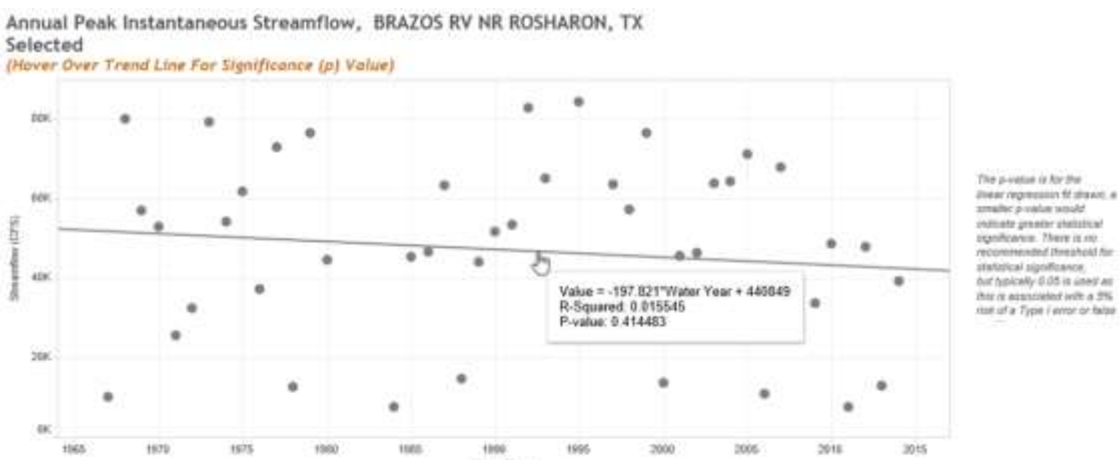

Figure 11. Annual peak instantaneous flow trends at the Brazos River near Rosharon, TX pulled from USACE Climate Hydrology Assessment Tool.

Further discussion of the sedimentation modeling, including modeling of sedimentation with sea level rise, is conducted in Section 3.

2.1.4.2 Climate Change Literature Review

As part of Responses to Climate Change Program, the Region 12 (Texas-Gulf Region) of the USACE climate change report were reviewed. The Region 12 report is located here: http://www.corpsclimate.us/rccciareport.cfm (USACE, 2015). This report describes applicable climate change and hydrology literature for the project area. First, precipitation projections were reviewed to qualitatively analyze the effects on the project site. According to USACE 2015, precipitation in the southeastern United States may be expected to decrease slightly in a warmer climate, though intense rainfall events may increase in frequency (USACE, 2015). This means that mean rainfall may decrease while variance increases. See Figure 12 (extracted from USACE, 2015) showing the projected changes in seasonal precipitation in 2085 relative to a 30-year period (1971-2000) centered at 1985 (USACE, 2015).

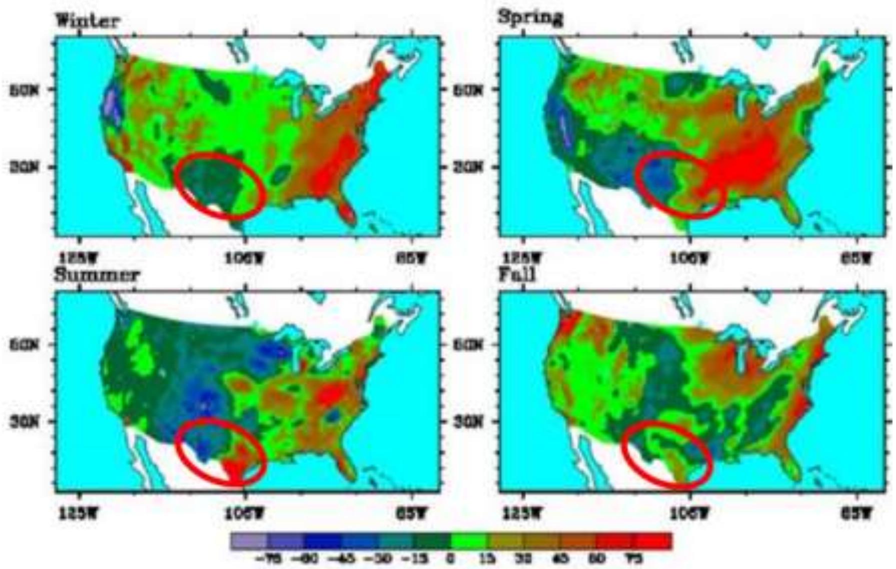

Figure 12. Projected changes in seasonal precipitation, 2085 vs. 1985 mm (from USACE, 2015). Texas region circled with red oval.

Although Figure 12 shows a slight decrease in precipitation at the project site, projections of future precipitation change are especially uncertain in this region because it is located in a transition zone between projected drier conditions to the south and projected wetter conditions to the north, which could have mixed effects on flows at the project site. Due to these uncertainties, the assumption that future precipitation in the project area will be roughly similar to past precipitation appears to be justified.

The USACE watershed vulnerability tool was used to examine the vulnerability of the project area to flooding under future conditions. For the Brazos River Watershed (HUC 1207), the projected future risk to navigation is expected to be low for the dry scenario, and moderate for the wet scenario. Figure 13 shows the vulnerability of the Brazos River watershed for 2050 and 2085 conditions.

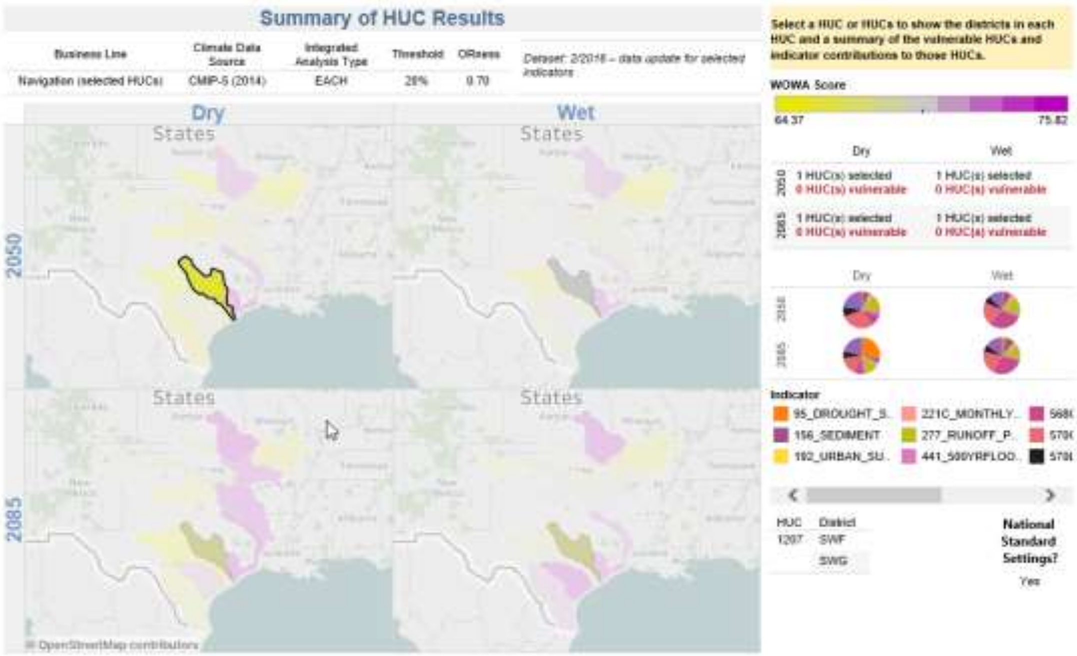

Figure 13. Watershed vulnerability for the Brazos River watershed (HUC 1207) from the USACE watershed vulnerability tool.

The climate hydrology assessment tool was also used to assess the predicted trends of the peak annual discharge for the Brazos River. Figure 14 shows the trends in projected peak annual flowrate, which represent the mean of 93 climate change hydrology models for the Brazos River watershed (HUC-1207). The projected annual maximum monthly streamflow for the Brazos River is expected to remain relatively constant, with the potential for a very small increase in flow rates in the future based on the climate hydrology model results shown in Figure 14.

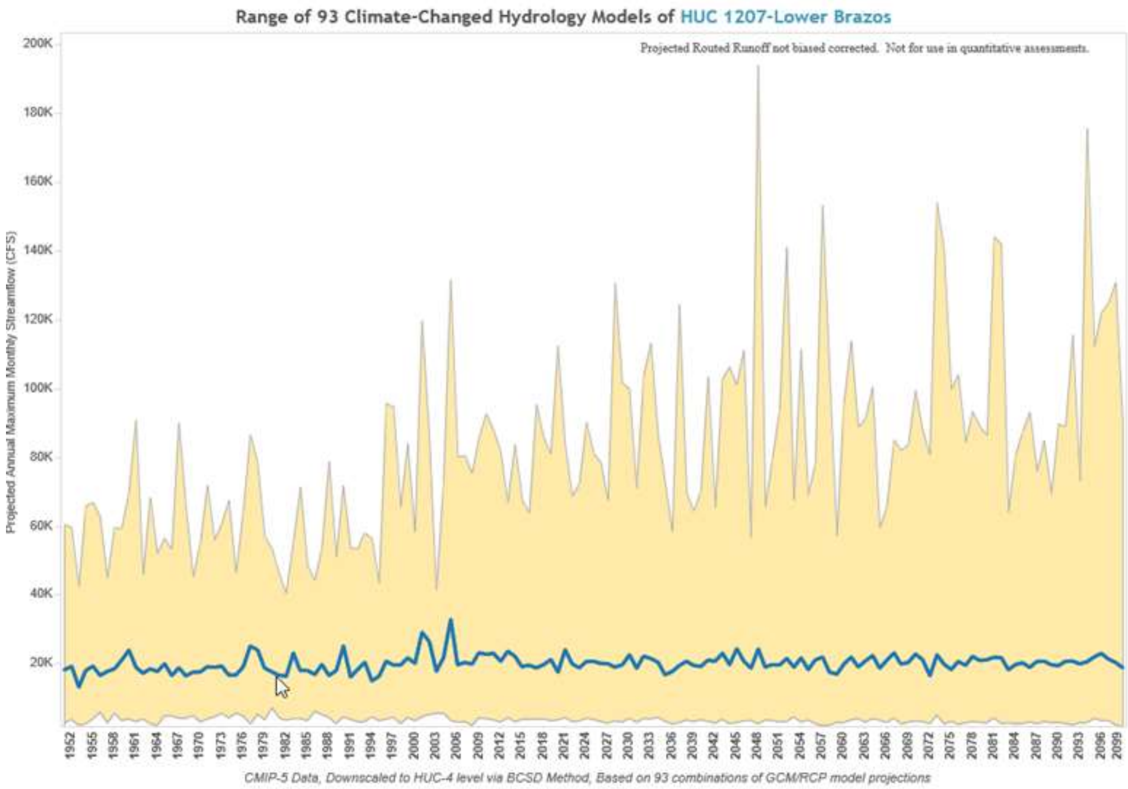

Figure 14. Trends in mean modeled annual maximum streamflow. The mean (blue line) is the average of 93 Climate-Change Hydrology Models of HUC 1207

The consensus in the recent literature points toward mild increases in annual precipitation and streamflow in the Texas-Gulf Region over the past century. In some studies, and some locations, statistically significant trends have been quantified however the trends at the Brazos project site remain insignificant or unclear. However, the discussion above should be used for qualitative analysis of the impacts of climate change on the project site.

2.1.4.3 Quantification of Climate Change Impacts on the proposed projects.

Relative sea level rise trends were analyzed from the USACE projections at Freeport gage 8772440. These relative sea level rise trends include water level changes, as well as general subsidence estimates for the Freeport gage. The projected changes in relative sea level rise were analyzed in the hydraulic modeling described in Sections 3-5 of this report. The impacts of sea level rise to velocities in the Brazos River, sedimentation, and salinity are further described in Sections 3-5 of this report

2.1.5 Winds

There are several wind data stations in the vicinity of the project. The wind stations available consisted of two onshore stations and three offshore stations. While the onshore stations give representation winds at the project site, the collected wind data at the offshore stations are more useful for the purpose of wind-wave generation modeling. The offshore wind data is available as Wave Information Studies (WIS) hindcast data at WIS stations 73060, 73062, and 73064, shown in Figure 15. WIS 73062 was chosen for wind data due to its location directly offshore of the project site.

Figure 15. WIS hindcast data stations near Brazos River Floodgates.

Statistics and extremal analysis of the wind data was calculated in order to characterize the winds just offshore of the project site. Rose plots were developed for the wind data at WIS 73062. Rose plots illustrate the frequency of occurrence of event over different directional bins for various magnitudes. Figure 16 shows the wind rose for all of the wind data at WIS 73062.This wind rose shows that the majority of the winds are from south-southeast to south east direction with wind speeds of 0 to 25 mph. The majority of the highest winds speeds (over 30 mph) tend to come from the north. Additionally, the seasonal variation in the winds was explored by plotting the wave roses for summer (April to September) and winter (October to March) months. Summer winds are characterized primarily of low magnitude winds coming from south-southeast to southeast directions, whereas winter season experiences much stronger cold fronts coming dominantly from northern directions as shown in Figure 16.

The Gulf shoreline fronting the Brazos River Outlet is subject to extratropical storms (cold fronts), tropical storms, and hurricanes. The summary of hurricanes and tropical storms that made landfall within a 60 nautical mile radius near the project site in the last 50 years is listed in Table 8. A total of 19 storms have made landfall in the vicinity of the project site since 1959.

Toro et al. (2010) recommends against using point gauge data for extreme value analysis when the primary extreme events are tropical storms. In order to provide a more comprehensive analysis of wind speed, MM used an extreme value of wind based on methodology of the National Hurricane Center Risk Analysis Program (HURISK) (NOAA, 1987). The average Saffir-Simpson Hurricane Wind Scale velocity was used in combination with the NHC study to calculate the return period winds for these larger events. An extreme value distribution was fit to these max wind speeds; results are shown in Table 9.

Lower return period wind speeds, such as the 1, 2, and 5-year events are not accurately represented by the NHC methodology due to the infrequent nature of hurricanes making the landfall. These events are better represented by cold fronts and other extratropical storms that affect the project area. In order to form a complete extremal wind dataset, the wind data from WIS 73062 was used to generate extremal winds for the 1, 2 and 5-yr return period events while the NHC methodology was used to generate extremal winds for the 10-yr and greater return period events.

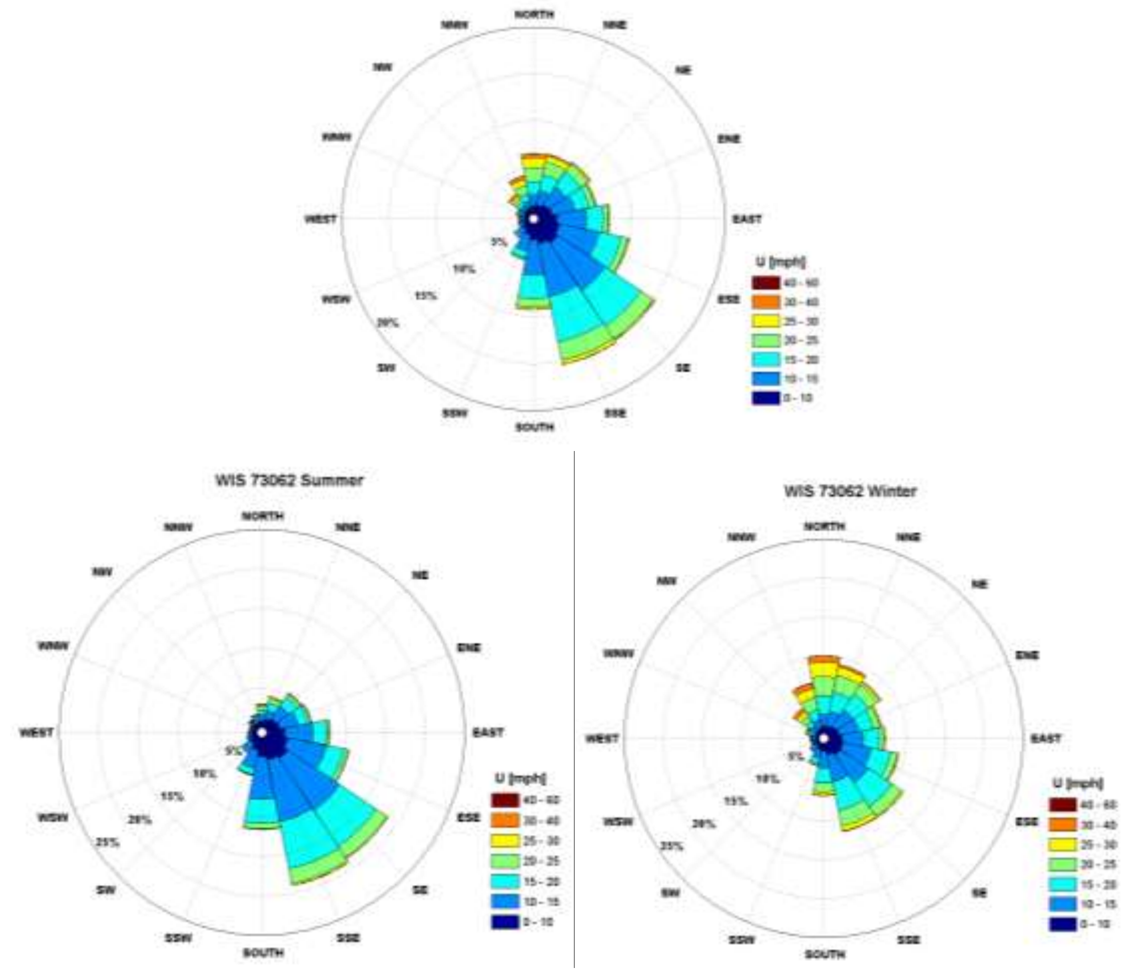

Figure 16. Wind Rose at WIS 73062 for overall (top), summer (left) and winter (right) months.

Table 8. Summary of storms that have made landfall near the project site.

Name	Year	Landfall location [mi from project site]	Landfall Pressure [mb]	Landfall Wind Speed [kts]	Landfall Intensity	Landfall Wind Speed [MPH]
Debra	1959	22	984	70	H1	81
Abby	1964	26	1000	55	TS	63
Fern	1971	80	979	60	TS	69
Edith	1979	160	978	85	H2	98
Delia	1973	8	N/A	50	TS	58
Elana	1979	29	1008	35	TS	40
Danielle	1980	53	1004	40	TS	46
Alicia	1983	24	962	100	H3	115
Jnnamed	1987	68	1009	40	TS	46
Allison	1989	23	1001	45	TS	52
Jerry	1989	31	983	75	H1	86
Dean	1995	21	999	40	TS	46
Allison	2001	4	1003	45	TS	52
Fay	2002	61	999	50	TS	58
Claudette	2003	70	979	80	H1	92
Grace	2003	25	1007	35	TS	40
Humberto	2007	80	985	80	H1	92
Ike	2008	52	950	95	H2	109
Harvey	2017	127	938	113	H3	130

Table 9. Return period of extreme winds.

Return Period [yrs]	Wind Speed [mph]
1	39
2	42
5	47
10	91 (Cat 1)
15	112 (Cat 3)
20	120 (Cat 3)
25	129 (Cat 3)
50	141 (Cat 4)
75	146 (Cat 4)
100	150 (Cat 4)

2.1.6 Waves

In addition to wind data, the WIS station also contains hindcast wave data. As described in Section 2.1.5, the location of WIS 73062 (shown in Figure 15) is closest in relation to the project site being directly offshore. Wave statistics and extreme values were calculated to gain perspective of the wave conditions within the project vicinity. Similar to the wind rose, Figure 17 shows the wave rose for WIS station 73062 identifying a predominant wave direction from the south east. This wave direction correlates to shore normal direction as the shoreline near the project site runs approximately from the north east to the south west. Seasonality of the waves was also analyzed by plotting wave roses for the summer and winter months, shown in Figure 17. During the summer months, a majority of the waves come from the south-south east to south east direction. Wave directions during the winter months are more equally distributed from south to north east directions, influenced by the winter cold fronts from the north as described in Section 2.1.5.

Wave statistics were developed for WIS Station 73062, which is shown in Table 10. Waves are generally from southeast with a mean wave height and period of 2.9 ft and 5.5 seconds respectively. Table 11 shows the percent occurrence of wave height and wave period and demonstrates that 90% of the waves are less than 7 ft and 99.5% are less than 9 ft in height.

Table 12 contains the extreme wave height and peak wave period for the wave data at WIS station 73062 and gives the associated return period. The wave height values were developed using the peak over threshold method. The peak wave period was approximated using a calculated linear relationship between the wave heights and associated wave periods at the WIS station 73062.

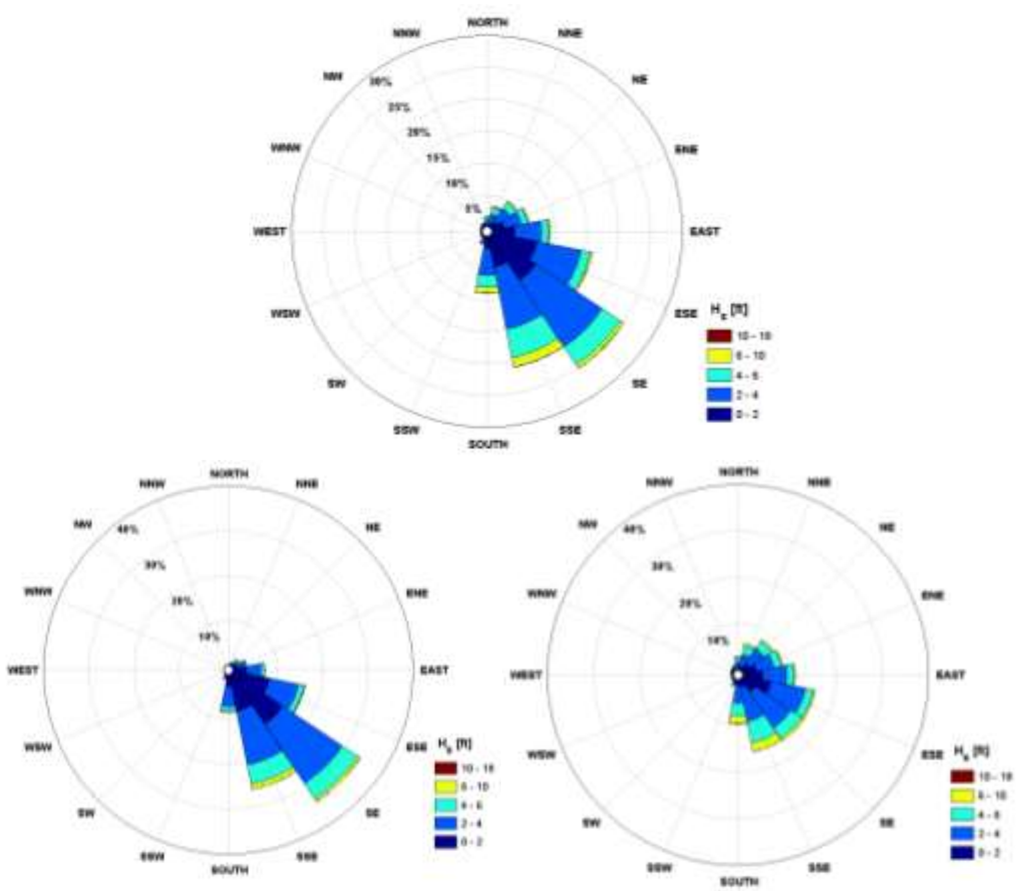

Figure 17. Wave Rose as WIS 73062 for overall (top), summer (left) and winter (right) months.

Table 10. General statistics computed for WIS Station 73062 from 1980-2013.

Parameter	Max	Mean	Std
Depth (ft)	--	66	--
H_s (ft)	19.4	2.9	1.6
T_p (sec)	16.4	5.5	1.4
W_θ (TN)	--	126	52

Table 11. Percent occurrence of wave height and wave period at WIS station 73062.

Tp [s]	2 - 4	4.1 - 5	5.1 - 6	6.1 - 7	7.1 - 8	8.1 - 9	9.1 - 10	10.1 - 12	12.1 - 14	14.1 - 16	Sum
Hs [ft]											
0.0 - 1	2.8	2.0	1.2	1.2	0.4	0.2	0.1	0.2	0.02	0.006	**8.2**
1.1 - 2	6.3	7.5	7.7	2.7	0.4	0.2	0.05	0.04	0.02	0.001	**24.7**
2.1 - 3	3.3	8.2	8.6	5.6	0.7	0.2	0.08	0.06	0.04	0.003	**26.8**
3.1 - 4	0.4	5.0	7.2	5.2	1.1	0.3	0.1	0.06	0.03	0.007	**19.5**
4.1 - 5	0.0	1.4	4.2	3.5	0.9	0.3	0.1	0.05	0.02	0.012	**10.6**
5.1 - 6	0.0	0.3	1.6	2.7	0.7	0.3	0.05	0.03	0.01	0.009	**5.7**
6.1 - 8		0.02	0.6	1.6	0.8	0.4	0.1	0.06	0.01	0.009	**3.6**
8.1 - 12			0.03	0.2	0.3	0.3	0.1	0.02	0.01	0.004	**0.9**
12.1 - 16				0.001	0.002	0.003	0.008	0.01	0.00	0.002	**0.03**
Sum	**12.8**	**24.5**	**31.1**	**22.6**	**5.2**	**2.3**	**0.7**	**0.5**	**0.2**	**0.1**	**100**

Table 12. Extreme Values of Wave Heights at WIS 73062.

Return Period [yrs]	Wave Height [ft]	Peak Wave Period [s]
1	10.3	9.7
2	11.6	10.5
5	13.6	11.7
7.5	14.6	12.3
10	15.4	12.7
15	16.5	13.4
20	17.3	13.9
25	17.9	14.2
50	19.9	15.5
75	21.2	16.2
100	22.1	16.7

3 Hydrodynamic Analysis

3.1 Hydrodynamic Processes Modeling

The combined influences of tidal circulation and river hydraulics was simulated in the project vicinity to evaluate the influence of tidal currents and the Brazos and San Bernard River discharges on flow velocities and water surface elevations at the Brazos River Floodgates. Following the guidance on quality assurance for engineering models contained on ER 1110-2-1150 (USACE, 1999), the modeling was conducted using an adaptive two-dimensional finite-element model of flow and transport Adaptive Hydraulics (ADH) (USACE, 2014). The model domain development and calibration are discussed in the following sections.

3.1.1 Model Description

The Adaptive Hydraulics Model (ADH) is a modular, parallel, adaptive finite-element model for one-, two- and three-dimensional flow and transport developed by the Engineering Research and Development Center Coastal and Hydraulics Laboratory (ERDC-CHL). ADH has several integrated modules to supplement the shallow water wave module including SEDLIB (a multiple grain size mixed sediment library), and a sediment transport module for dynamically coupling sediment transport with hydrodynamics. One unique function of ADH is mesh adaption, where the model will automatically refine the mesh resolution in areas where higher resolution is required. This allows for the original mesh to be much coarser, leading ultimately to better computation efficiency. ADH also uses an implicit adaptive time step which can be automatically calculated to control stability and convergence.

3.1.2 Mesh & Bathymetric Surface Development

The computational grid for the ADH circulation model is shown on Figure 18. The area around Brazos River Floodgates was refined to 5 m (16 ft) resolution to better capture the flows; the resolution decreases to 3500 m (11,500 ft) in the offshore. Based on prior experience in modeling this region, the mesh was created to include both Galveston Bay and the eastern Matagorda Bay. The Brazos River was extended approximately 50 miles upstream to the USGS Gage at Rosharon (08116650) and the San Bernard River was extended about 50 miles upstream to the USGS Gage at Boling (08117500) to ensure accurate boundary conditions at the river boundaries. Smaller tributaries and estuaries that are connected to the GIWW were also included in the mesh, as retention of water in these estuaries has an influence on circulation locally within the GIWW.

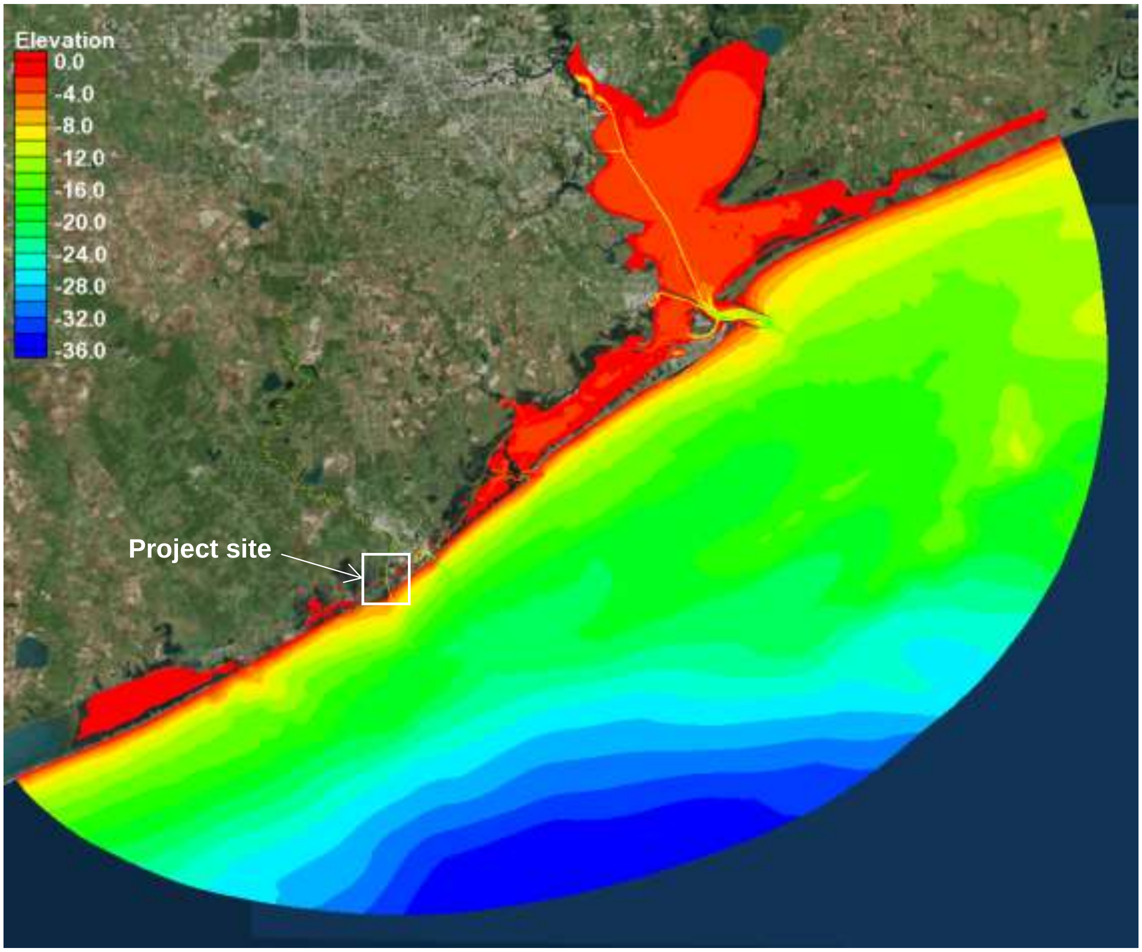

Figure 18. Brazos River Floodgates ADH circulation model mesh.

The base of the model bathymetry was taken from previous models that Mott MacDonald constructed in the region, with bathymetry sourced from the NOAA Coastal Relief Model, local and USACE surveys. The bathymetry in the GIWW and the Brazos Locks was updated using more recent bathymetric surveys where appropriate, as discussed in Section 2.1.2.

Bathymetric survey transects of the Brazos River were taken in April, 2017 at 400-ft increments for approximately 2.5 miles upstream of the Brazos River inlet to the Gulf, and at 0.5-mile increments for approximately 50 miles upstream to Rosharon, TX. In the absence of available survey data, the depth of the San Bernard River was assumed to be constant at -10.5 ft MLLW, with side slopes of 8H:1V.

The bathymetry of the Brazos River between the Gulf of Mexico and the BRFG was artificially lowered to -18 ft NAVD88 (Figure 19). This was required since the hydrodynamic model does not have a way to account for intermittent erosion and accretion of the due to flood and drought events, as was evident through model calibration (Section 3.1.4). As shown in Figure 63, the Brazos River can experience significant event-driven bed change, which in turn would affect the hydrodynamics. It was found through sensitivity testing that a bed level of -18 ft NAVD88 significantly improved the model validation.

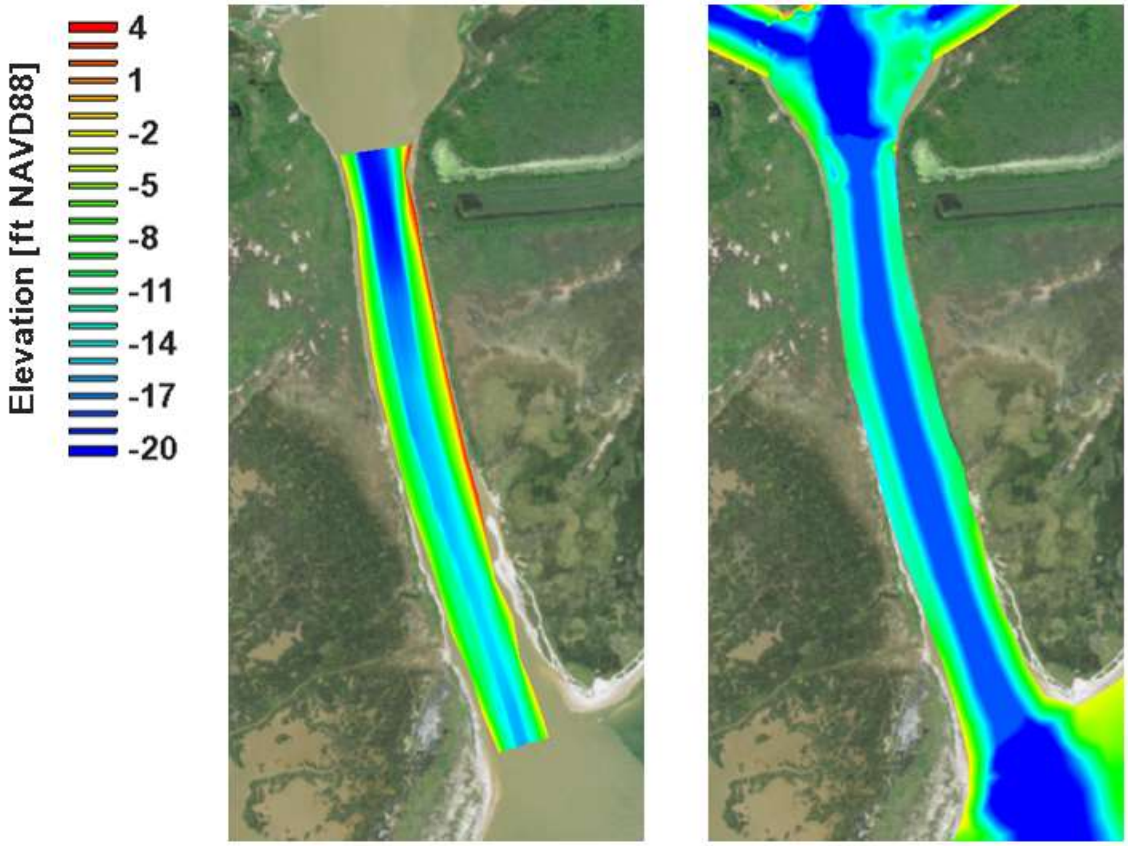

Figure 19. Bathymetry correction between the BRFG and the Gulf of Mexico.

3.1.3 Hydrodynamic Model Setup

The offshore model boundary is a natural boundary condition forced by a uniform time series of water surface elevation extracted from the Tidal Model Driver (TMD), a product of the Earth and Space Research Institute (ESR). The harmonic tides were then adjusted based on the difference between predicted and measured tide at the Freeport tide gage (8772447) to account for meteorological effects. The river boundaries are natural boundary conditions forced by a measured time series of discharge extracted from the Rosharon Gage (08116550) and the Boling Gage (08117500) for the Brazos River boundary and the San Bernard River boundary respectively.

3.1.4 Sensitivity Testing and Calibration

The data analysis in Section 2.1.1 indicates the USGS gaging stations have an overlapping time period between July 2004 and January 2005 (Table 13). Within that window, a two-week calibration period of July 20 – Aug 2 was selected due to the moderate flow rate in the Brazos River and good agreement between predicted and recorded tide elevation at the Freeport Gage (8772440), meaning that meteorological forces potentially influencing hydrodynamics is negligible.

Table 13. Available overlapping data between July 2004 and January 2005 among all USGS stations to be used in calibration and validation.

USGS Gage	Discharge	Stage	Velocity
San Bernard Upstream of GIWW	✓	✓	✓
GIWW at San Bernard	✓	✓	✓
San Bernard Downstream at GIWW	✓	✓	✓
San Bernard at Boling	✓	✓	N/A
Brazos at Richmond	✓	✓	N/A
Brazos at Rosharon	✓	✓	N/A
Brazos at GIWW	N/A	✓	✓

The hydrodynamics and hydraulics were simulated during this period using the default parameters to create a base case. The overall modeling required assessment of a variety of parameters as site specific data was not available, including detailed gate operations and bathymetry at the San Bernard river and river outlet. Therefore, the following parameters were modified and compared to the base case to determine sensitivity of the model to each parameter:

- Friction coefficient
- River discharge rate
- Gate operations
- Opening of the San Bernard River inlet.

As sector gate function is not explicitly included in the ADH model, the gate operations were simulated by rapidly raising and lowering the bed elevation of an assigned set of gate nodes to allow and restrict flow. No record of actual gate opening and closing is available from the Brazos Floodgates (George, 2016). Therefore, an artificial gate operational scheme was developed based on input from the lockmaster. The frequency of gate operations was based on an assumed 50 openings and closings a day, an opening time of 5 minutes, a closing time of 2 minutes and an open gate duration of 15 minutes. This gate operation was cycled at uniformly spaced events to produce 50 operations a day. Model sensitivity was analyzed at the San Bernard Upstream Gage (08117730) since this gage presented the most reliable data at a high sampling frequency. Figure 20 shows the results of the sensitivity analysis on water surface elevation at this gage. The model was found to be sensitive to gate operations and the opening of the San Bernard River inlet.

The sensitivity analysis concluded that the model friction coefficient over a reasonable range of values and a 20% variation in river discharge does not significantly influence velocities at the intersection of the San Bernard and the GIWW. However, the gate operations have a large influence in the hydraulics in the GIWW, and when combined with an approximated San Bernard connection with the Gulf of Mexico (which was present during the calibration time period) the model was able to reasonably represent the hydraulics in the system. Important conclusions from this sensitivity testing is that the hydraulics are very sensitive to the gate operations, and the exact gate operations (exact timing and duration of opening and closing) are unknown. Therefore, there will always exist some inaccuracies in the model results as it is impossible to simulate correct hydraulics without operational data. Results match well using the artificial scheme, but further model refinement is not warranted with the lack of this data set.

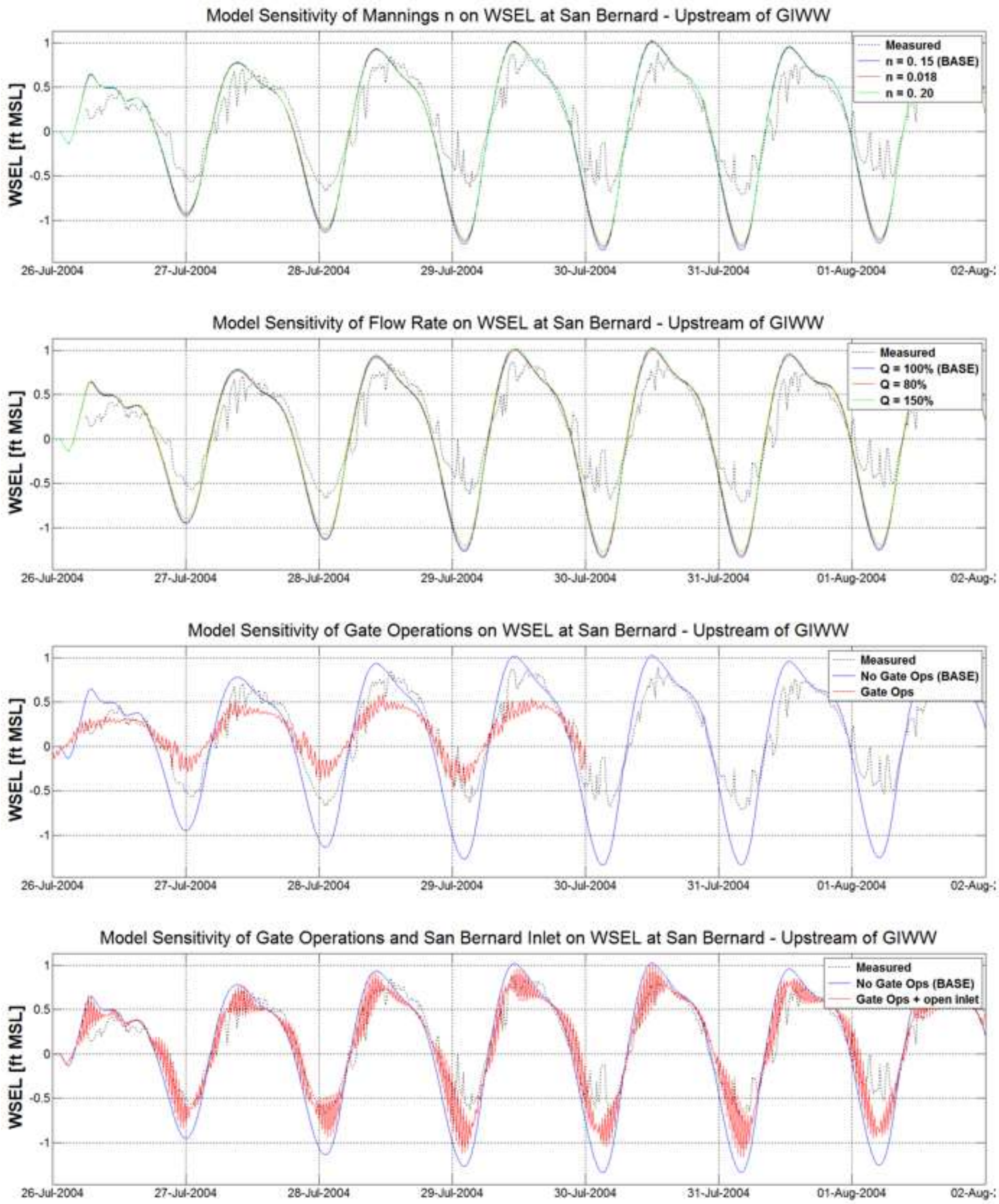

Figure 20. Time series of water surface elevation showing the model sensitivity to friction coefficient (top), river flow rate (mid-top), gate operations (mid-bottom) and the combined effect of gate operations and an open San Bernard River inlet (bottom).

3.1.5 Validation of Calibrated Model

The calibrated model was validated using a 13-month period between March 1, 2015 and April 1, 2016. This period is a relatively high-flow year and covers a large range of high and low flow conditions, with the following hydrodynamic and hydraulic conditions:

- An approximately 4-year flood event in the Brazos river
- An approximately 5-year flood event in the San Bernard River

- 186 days with reported limited navigation and 23 days of reported restricted navigation
- 3 flood events in the Brazos River greater than the 1-year event
- 4 flood events in the San Bernard River greater than the 1- year event
- An approximately 2-month period having low river flows in both rivers

The time series of river discharge for the Brazos and San Bernard Rivers is shown in Figure 21.

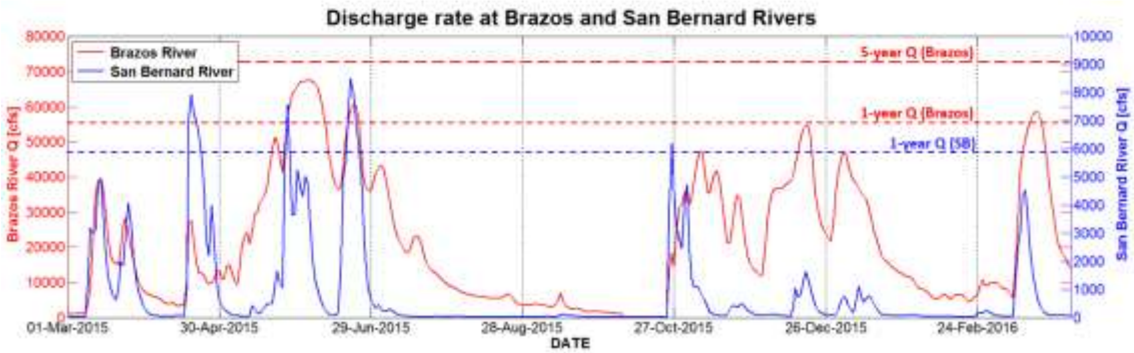

Figure 21: River discharges during the model validation period.

A comparison time series of modeled vs. measured water surface elevations and velocities is shown in Figure 22. As discussed in Section 2.1.1.2, water level and velocity data are available immediately adjacent to each gate. Gate operations cause high frequency oscillations in the water surface and velocity signals in both the measured and modeled data. Model data can be extracted at frequency to resolve the gate operations and their influence, but the measured data does not. Therefore, for validating the model, these high frequency signals were filtered using a low-pass filter with a frequency cutoff of 3-hours in an attempt to extract a meaningful signal. The 3-hr cutoff was determined through sensitivity testing of the modeled data sampled at the same sampling interval as the measured data to produce as close to a real signal without the noise of gate opening and closing, however, as previously discussed, the real gate operations are at a random, inconsistent frequency while modeled gate operations are at a set, cyclical frequency, and therefore it is not possible to know how well the filtered data represents actual measured conditions. Given these limitations, model results shown in Figure 22 match the measured data with reasonable accuracy.

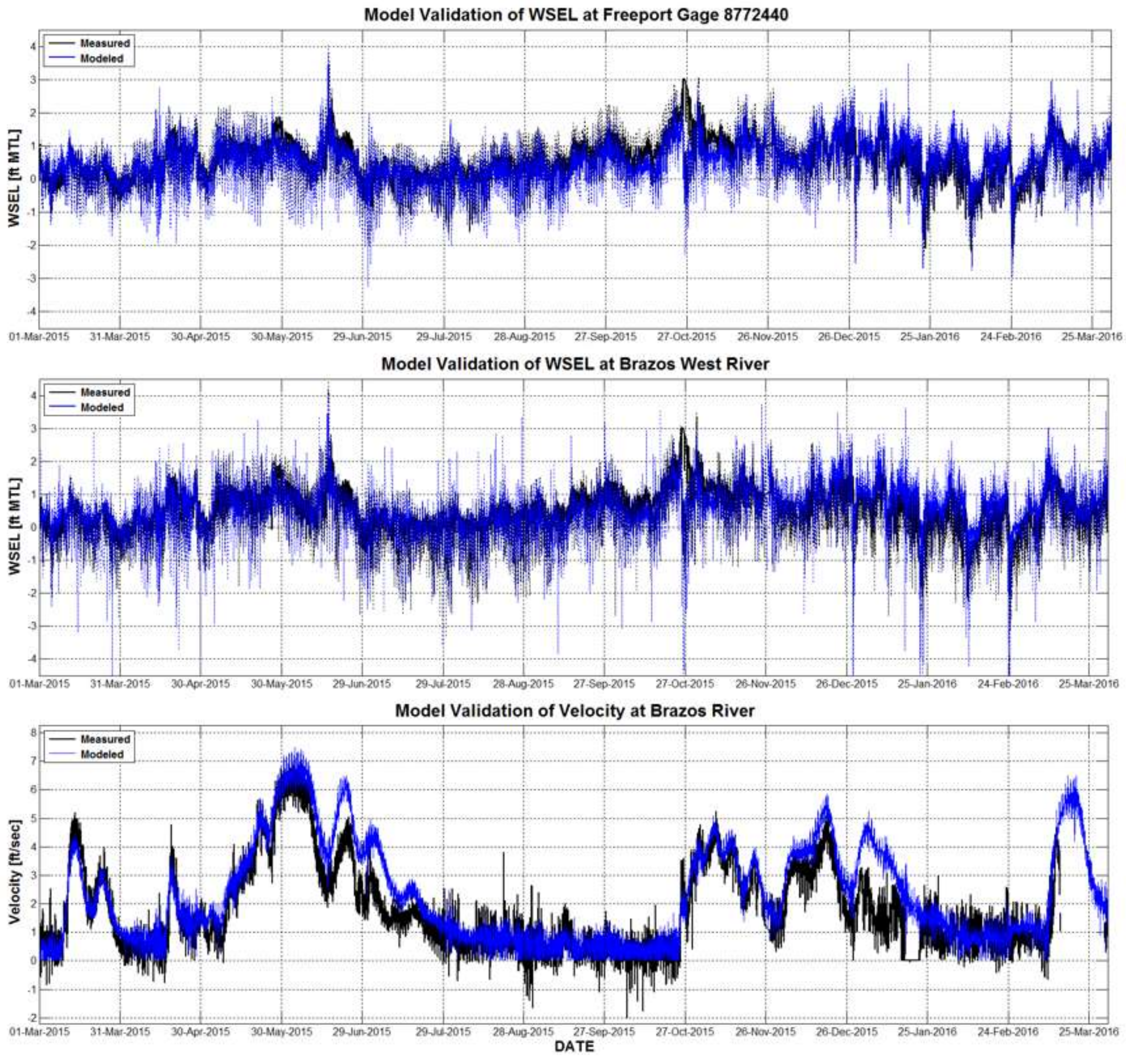

Figure 22: Time series comparison of water surface elevation at the Freeport Gage (top) and the river side of the West Gate (middle) and of velocity at the Brazos River Gage (bottom)

Figure 23 shows a scatter plot of the measured vs. modeled water surface elevation of every time step at every available gage in the model domain. Using these data, the model index of agreement (IA) was calculated based on the following equation (Willmott *et al.* 1985):

$$IA = 1 - \frac{\langle (x_c - x_m)^2 \rangle}{\langle (|x_c - \langle x_m \rangle| + |x_m - \langle x_m \rangle|)^2 \rangle}$$

Where x_m represents the measured values and x_c represents the calculated values. An IA equal to 1 represents perfect agreement, and an IA of 0 indicates no agreement. For the purposes of this study, an IA greater than 0.9 is considered good agreement.

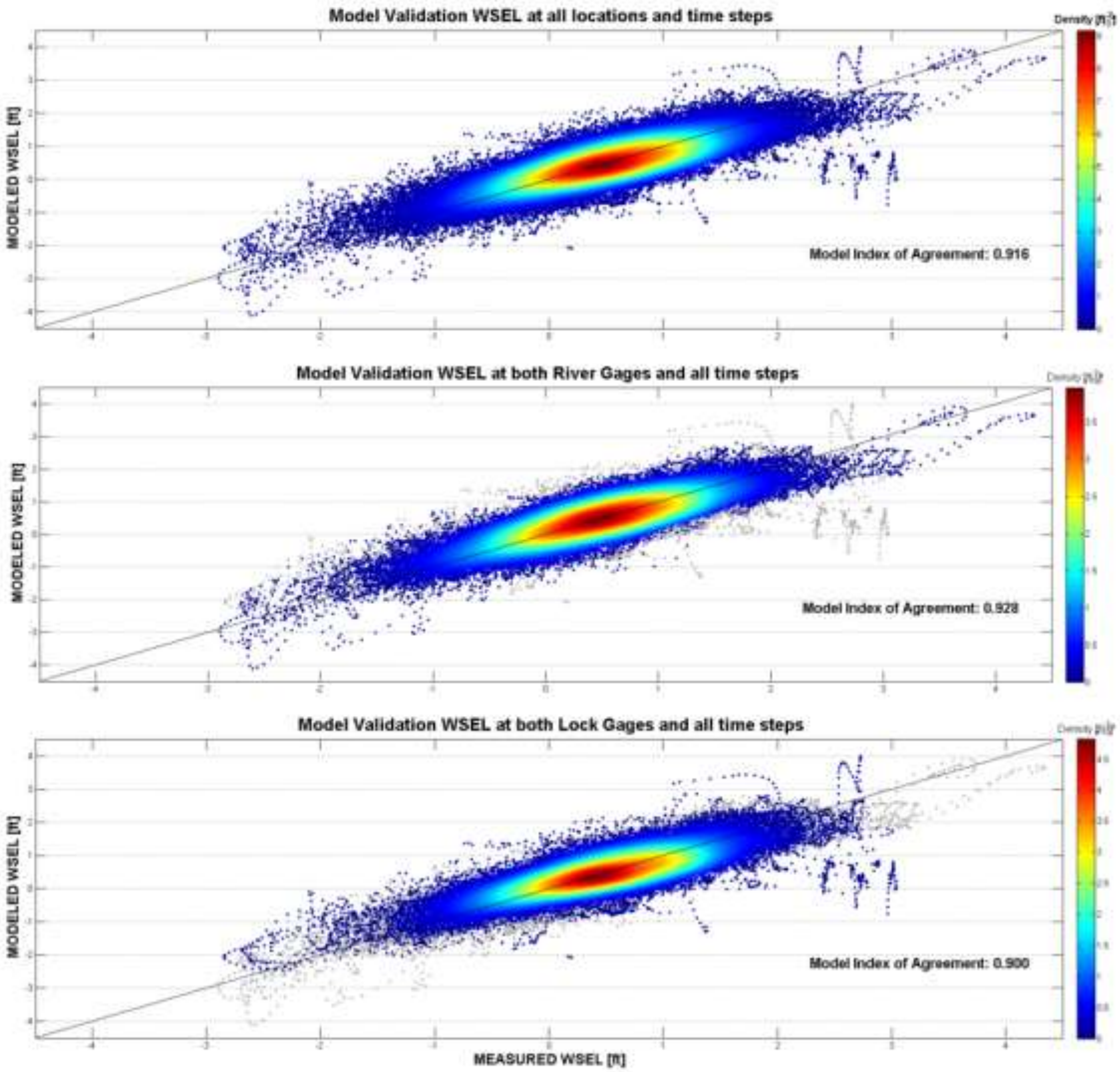

Figure 23: (top) measured vs. modeled water surface elevation at every gage in the domain and for every time step in the model period. (Middle) measured vs. modeled water surface elevation at the east and west river gages for every time step in the model period. (Bottom) measured vs. modeled water surface elevation at the east and west lock gages for every time step in the model period. Color bar indicates point density calculated as the number of points within a 0.25 ft radius of the point specified.

The hydrodynamic model validated well with observed conditions at six tide stations and one velocity station as shown in Figures Figure 22 and Figure 23, with a combined index of agreement of 0.916. The model performs slightly better on the river-side of the gates, which is expected since the direct connection to the Gulf makes the water level less sensitive to gate operations.

River velocity was accurately simulated on the leading edge of the flood hydrograph, however it tended to over-estimate velocities on the trailing edge. Since model boundary condition discharges are based on daily rates from USGS gages, the tendency to over-estimate velocities on the trailing edge of a flood could be attributed to the loop effect. Based on these results, the model is considered validated and can adequately represent the system’s hydraulics to conclude meaningful results.

3.2 Hydrodynamic Alternatives Analysis

The proposed alternatives were modeled using the same 13-month period as the validation period described in Section 3.1.5. For analysis of alternatives performance, the project region was separated into five zones of influence: West GIWW, Brazos Basin, East GIWW, Freeport, Brazos Delta, and Freeport Offshore as shown in Figure 24. These zones of influence were used to identify relative changes as discussed in Section 4 and Section 5.

Figure 24. Project zones of influence.

For Alternative 2a, or the “no-build” alternative, no changes were made to the existing mesh or bathymetry. This alternative is henceforth referred to as “Existing Conditions.” The model alignment and bathymetry for Existing Conditions is shown in Figure 26. This alternative represents the standard by which the other alternatives are analyzed. Figure 25 shows the model mesh resolution and populated bathymetry for each TSP alternative.

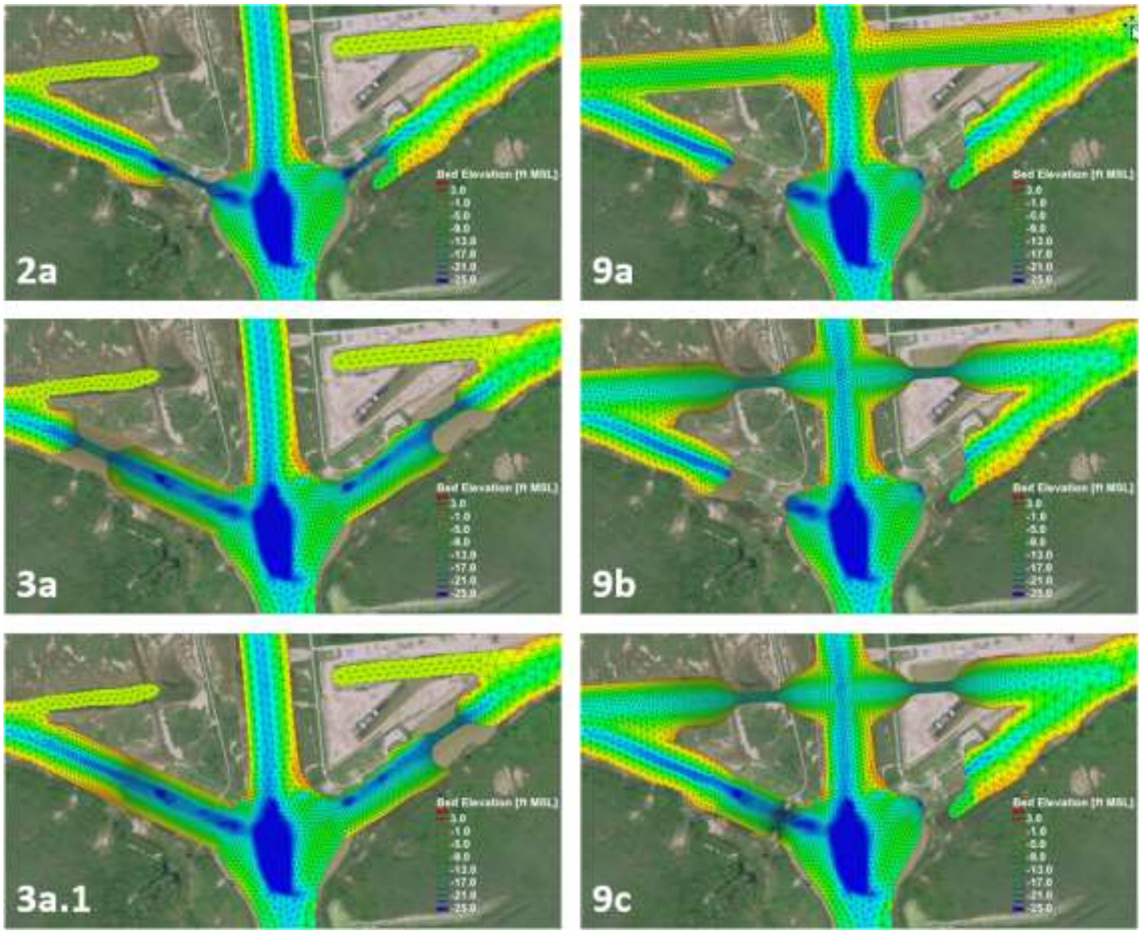

Figure 25. Model mesh resolution and bathymetry for all proposed TSP alternatives

A snapshot of velocity during peak ebb conditions (combination of tide and river discharge) and peak flood conditions is shown in Figure 27. The peak ebb velocity reaches a maximum of about 12 ft/s just north of the Brazos Basin, and eddying is observed on either side of the Brazos River channel. During flood tide, the velocity through the west gate is often more than double that through the east gate.

Figure 26. Existing conditions model alignment and bathymetry.

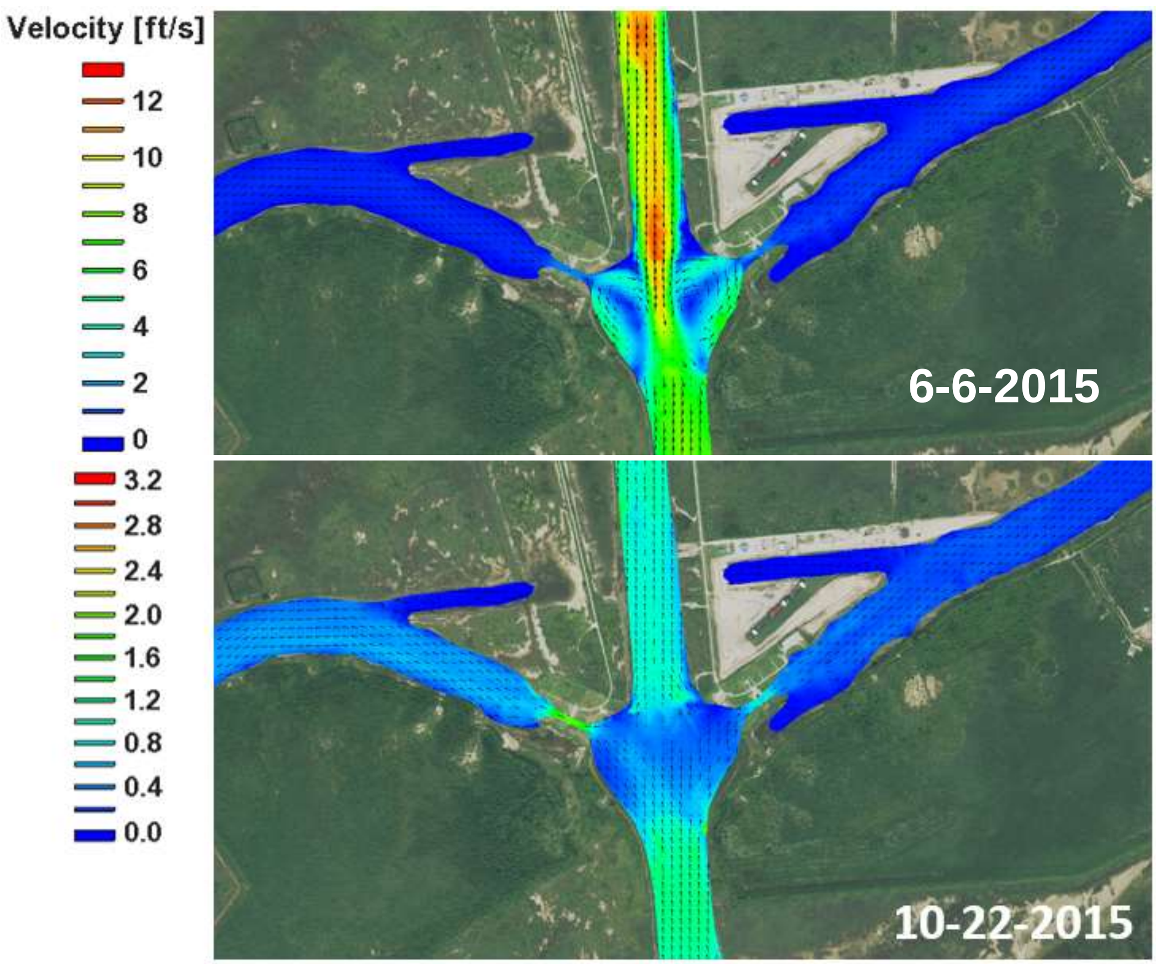

Figure 27. Existing Conditions peak ebb velocity (top) and flood velocity (bottom) at the Brazos River - GIWW intersection.

For Alternative 3a, the flood gates are moved back from the Brazos River by approximately 1,300 ft and the gates are widened from 75 ft to 125 ft, while maintaining the same channel alignment (Figure 28). The land surrounding the existing gates is removed to create a straight GIWW alignment approximately 500 ft wide. While the depth of the channel near the existing gates has been scoured to approximately -21 ft NAVD88, the elevation of the new gates will be limited to -16 ft NAVD88. A snapshot of velocity during peak ebb conditions (combination of tide and river discharge) and peak flood conditions is shown in Figure 29. The peak ebb velocity reaches a maximum of about 12 ft/s, and no significant difference in velocity from Existing Conditions is evident. The eddies on either side of the Brazos Basin are approximately the same scale as Existing Conditions. During flood, the velocity through both gates is reduced, likely because of the gate widening.

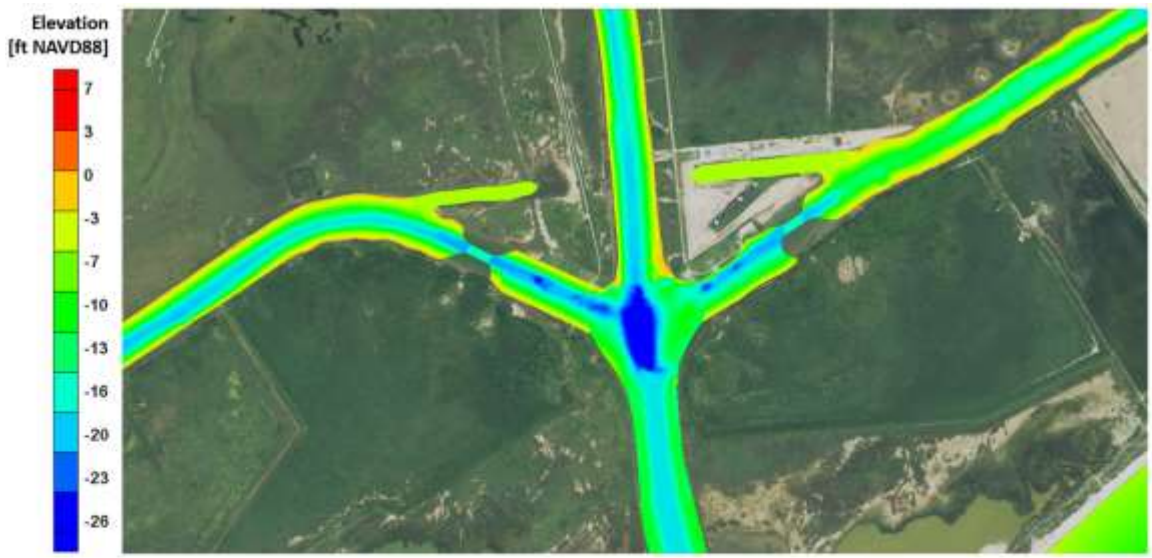

Figure 28. Alternative 3a model alignment and bathymetry.

Alternative 3a.1 has the same gate alignment as Alternative 3a on the East side and an open channel along the existing alignment on the west side (Figure 30). A snapshot of velocity during peak ebb conditions (combination of tide and river discharge) and peak flood conditions is shown in Figure 31. The peak ebb velocity reaches a maximum of about 12 ft/s in the Brazos River channel. The eddy on the east side of the Brazos Basin is approximately the same scale as Existing Conditions, while on the west side of the Brazos Basin, the eddy has reduced in magnitude. During peak ebb, the velocities in both the East and West GIWW are slightly increased, while during peak flood, the velocity in the West GIWW is significantly increased to about 2 to 3 ft/sec.

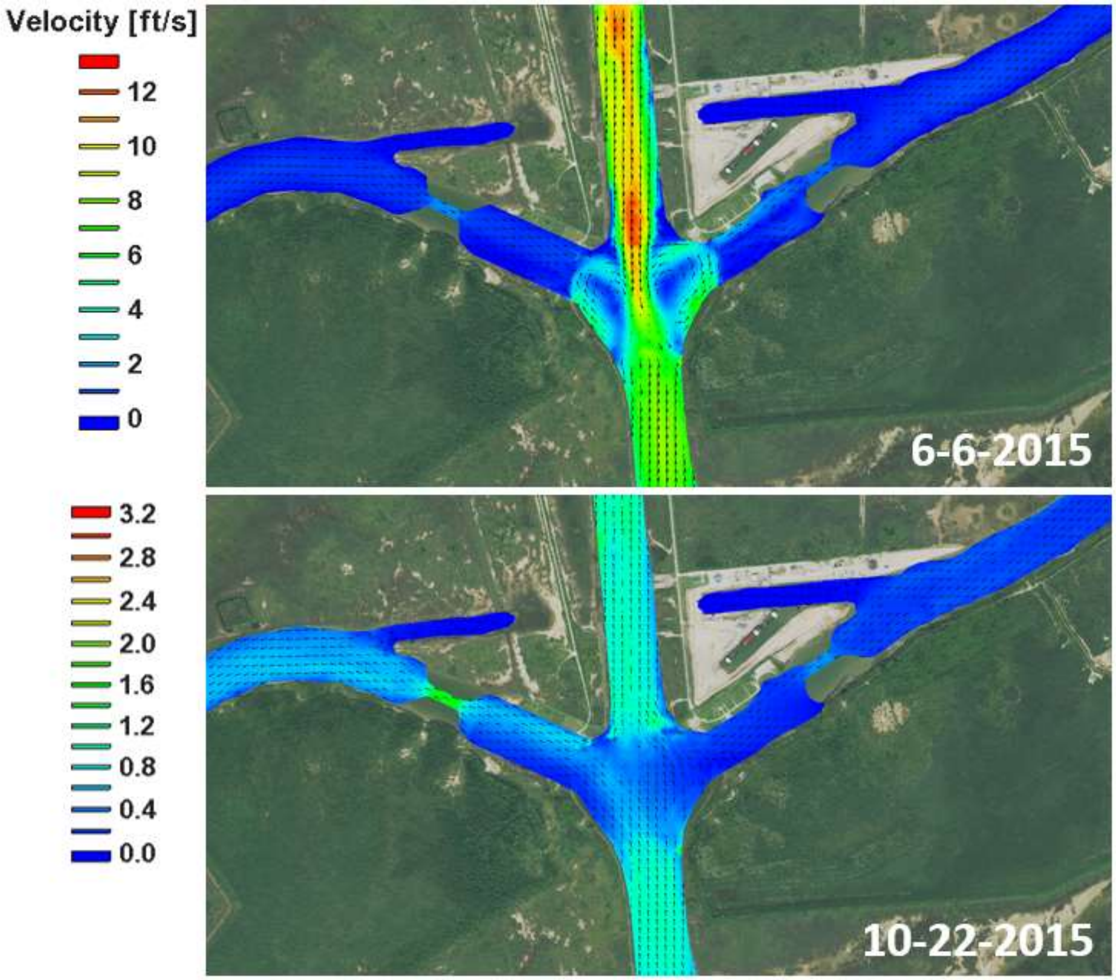

Figure 29. Alternative 3a peak ebb velocity (top) and flood velocity (bottom) at the Brazos River - GIWW intersection.

Figure 30. Alternative 3a.1 model alignment and bathymetry.

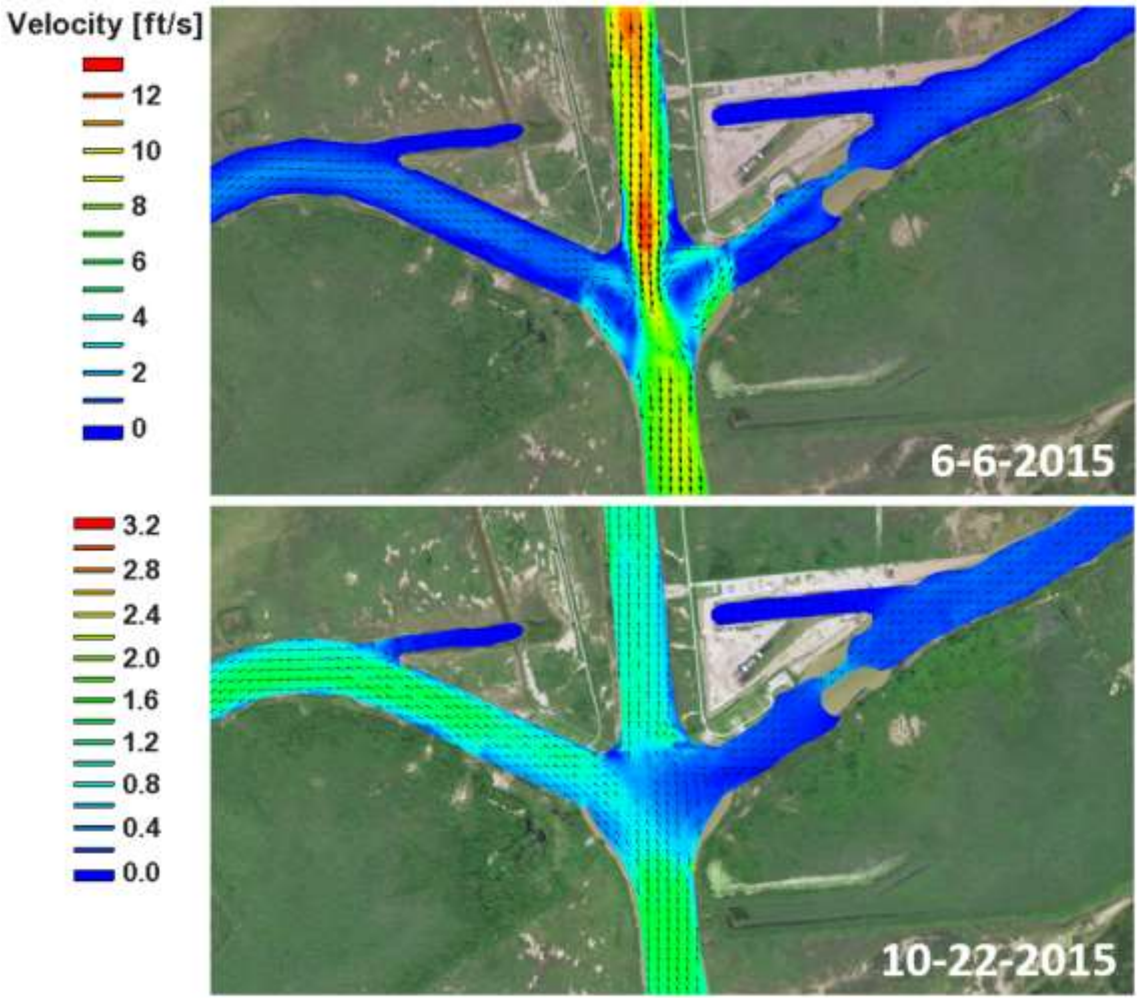

Figure 31. Alternative 3a.1 peak ebb velocity (top) and flood velocity (bottom) at the Brazos River - GIWW intersection.

Alternative 9a is defined by a straight, open channel whose alignment roughly reflects a straight line between GIWW Stations 588+000 and 597+000 (Figure 32). The new channel has a depth of -12 ft NAVD88 and a bank-to-bank width of approximately 500 ft. There are no gates controlling flow between the Brazos River and the GIWW. The site of the existing gates has been infilled on both the east and west sides to prevent flow. A snapshot of velocity during peak ebb conditions (combination of tide and river discharge) and peak flood conditions is shown in Figure 33. The peak ebb velocity reaches a maximum of nearly 14 ft/s, on the north side of the Brazos River – GIWW intersection. Interestingly, there's also a strong eastward current on the south side of the east channel connection, and a return current on the north side of the east channel connection. There is also a very high velocity of about 12 ft/s south of the Brazos River – GIWW intersection and eddying in the previous Brazos Basin consistent with Existing Conditions and Alternative 3a. During flood, the velocity in both the West and East GIWW has increased, possibly because of the new channel alignment and shallower channel depth.

Figure 32. Alternative 9a model alignment and bathymetry.

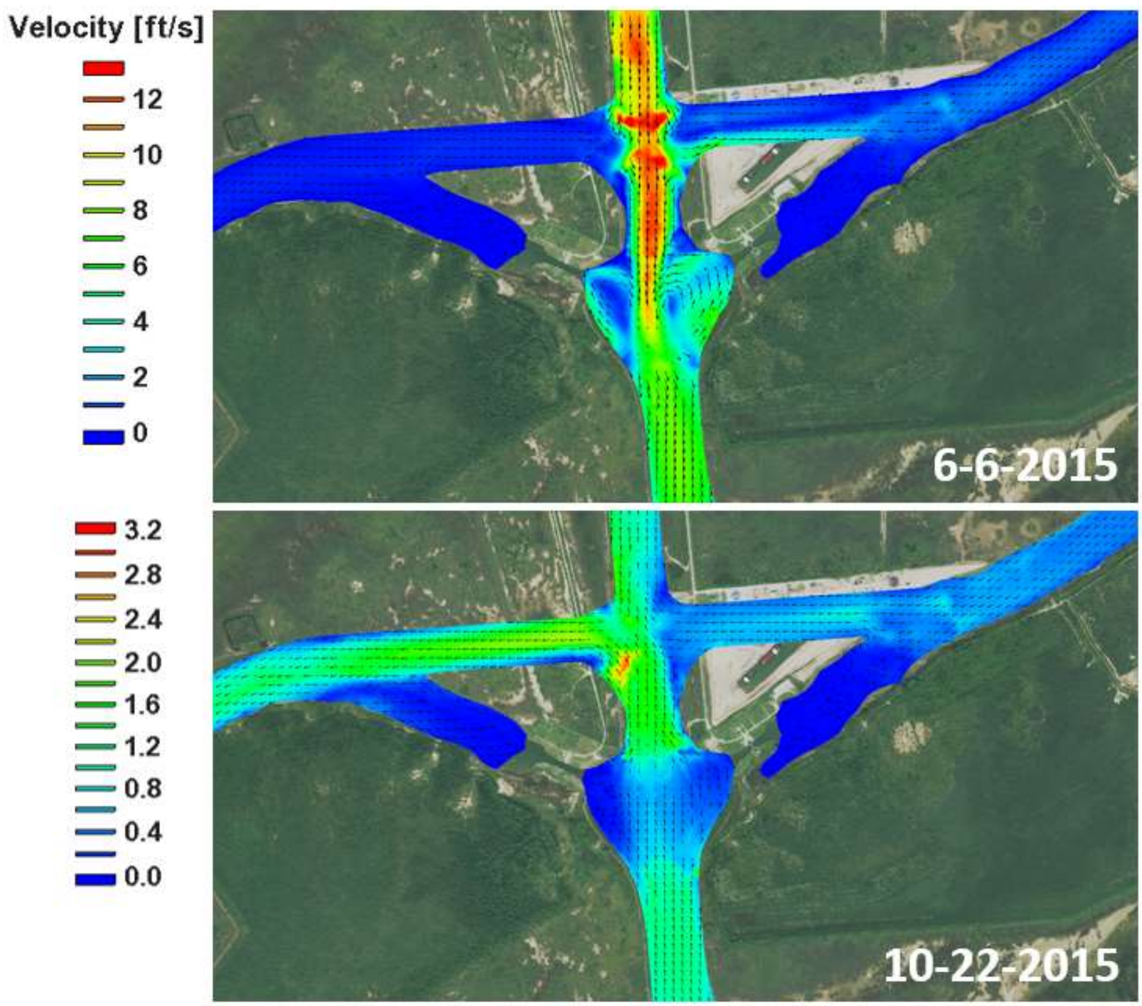

Figure 33. Alternative 9a peak ebb velocity (top) and flood velocity (bottom) at the Brazos River - GIWW intersection.

Alternative 9b has the same channel alignment as Alternative 9a, but with 125 ft wide flood gates set back about 800 ft from the Brazos River (Figure 34). For this alternative, the new channel alignment has a constant depth of -16 ft NAVD88. A snapshot of velocity during peak ebb conditions (combination of tide and river discharge) and peak flood conditions is shown in Figure 35. The peak ebb velocity reaches a maximum of about 12.5 ft/s both north and south of the Brazos River – GIWW intersection. A similar return flow pattern seen in Alternative 9a can also occurs in 9b, however is it restricted in size by the gate. Minimal eddying occurs on the west side of the new Brazos basin, while eddying still occurs on both sides of the previous Brazos Basin. During flood, the velocity in the West GIWW is slightly lower than for Alternative 9a at the gates, but significantly lower west of the gates.

Figure 34. Alternative 9b model alignment and bathymetry.

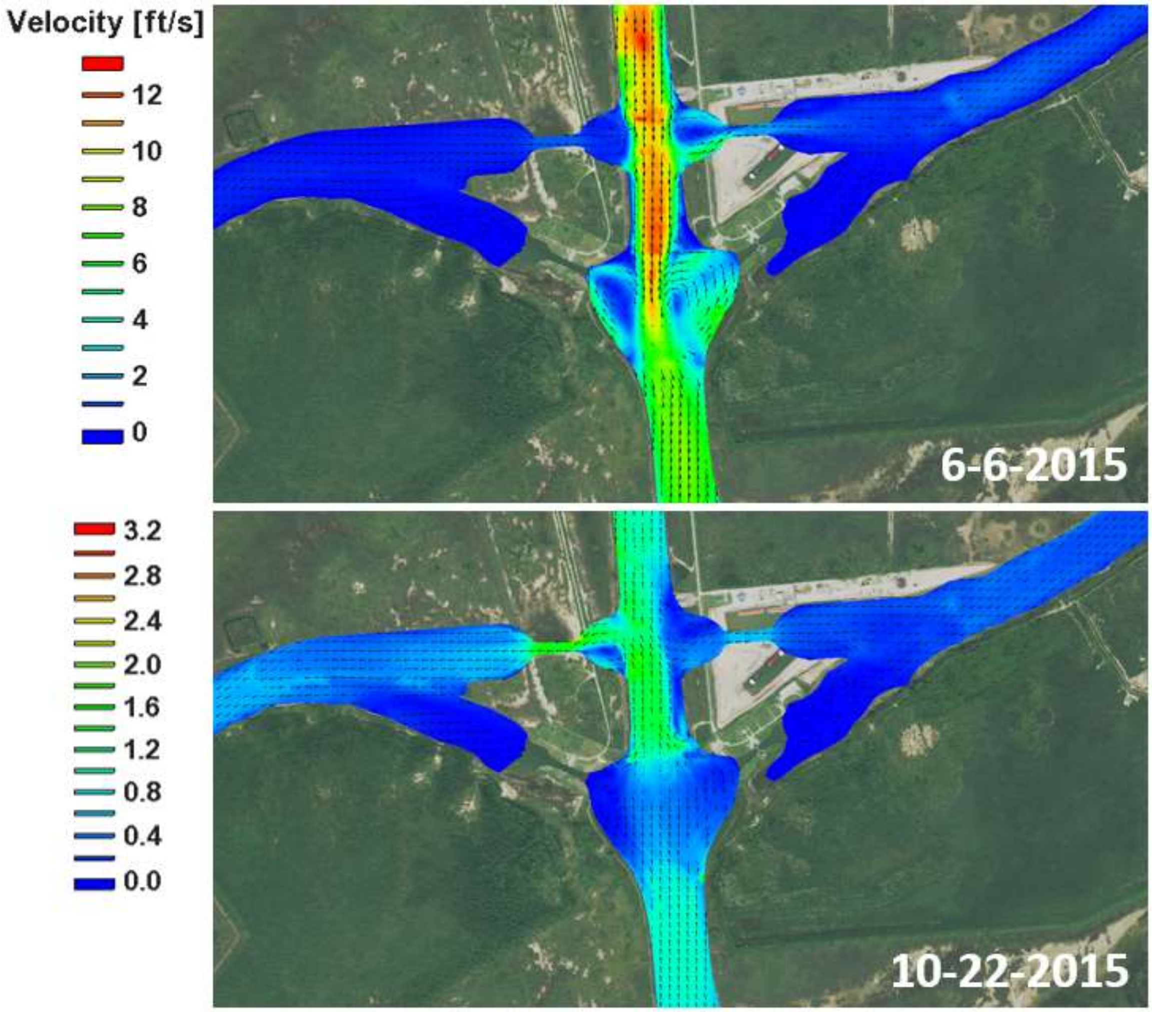

Figure 35. Alternative 9b peak ebb velocity (top) and flood velocity (bottom) at the Brazos River - GIWW intersection.

Alternative 9c is identical to Alternative 9b, but instead of completely filling in the existing channel alignment, flow was restricted through the west side of the existing channel via a sluice gate (Figure 36). The goal of this sluice gate feature is to allow for head relief when the head difference across the west gate restricts safe navigation. The sluice gate was modeled by the same concept of raising and lowering the bed elevation at the gate to allow and restrict flow. The sluice gate operations were determined based on the head differences from the Alternative 9b simulation. A snapshot of velocity during peak ebb conditions (combination of tide and river discharge) and peak flood conditions is shown in Figure 37. There are no distinguishable differences from Alternative 9b in the peak flood or ebb flow pattern, as the sluice gates are not open during these times.

Figure 36. Alternative 9c model alignment and bathymetry.

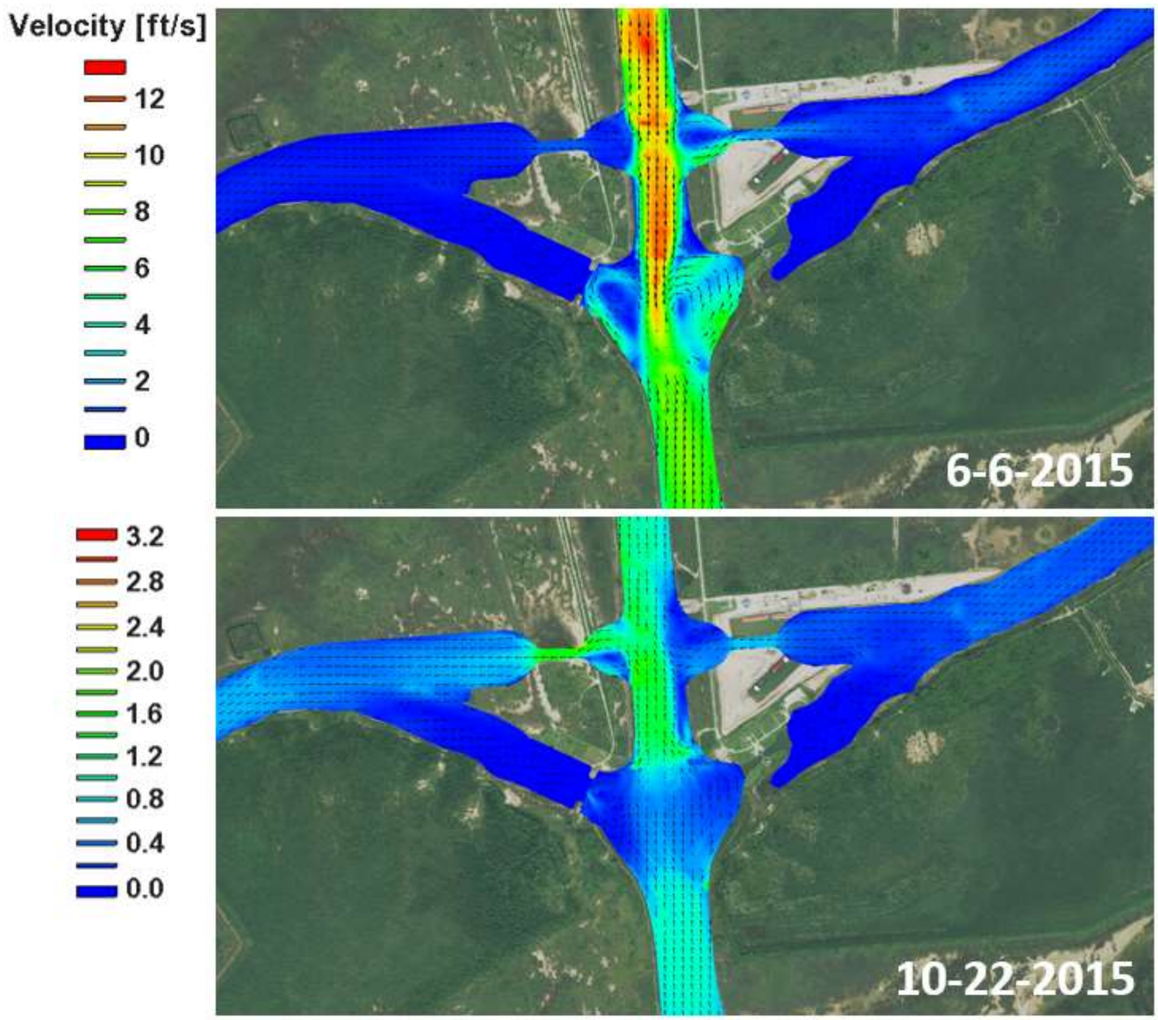

Figure 37. Alternative 9c peak ebb velocity (top) and flood velocity (bottom) at the Brazos River - GIWW intersection.

Since the West GIWW does not have an alternate nearby connection to the Gulf other than through the west gate, there was some concern that the alternate alignment could lead to elevated water levels in the GIWW during high river flow events, causing a risk of flooding the adjacent land areas. Time series of water levels in the West GIWW were analyzed at an approximately 1/3 mile spacing between the Brazos River and the San Bernard River for each alternative. The probability of water level non-exceedance for each extraction point was computed and compared to existing conditions. Figure 38 through Figure 41 show the probability of non-exceedance curves for all alternatives compared with the Existing Conditions (Alternative 2a); the color blending on these curves show the general change in water level along the West GIWW.

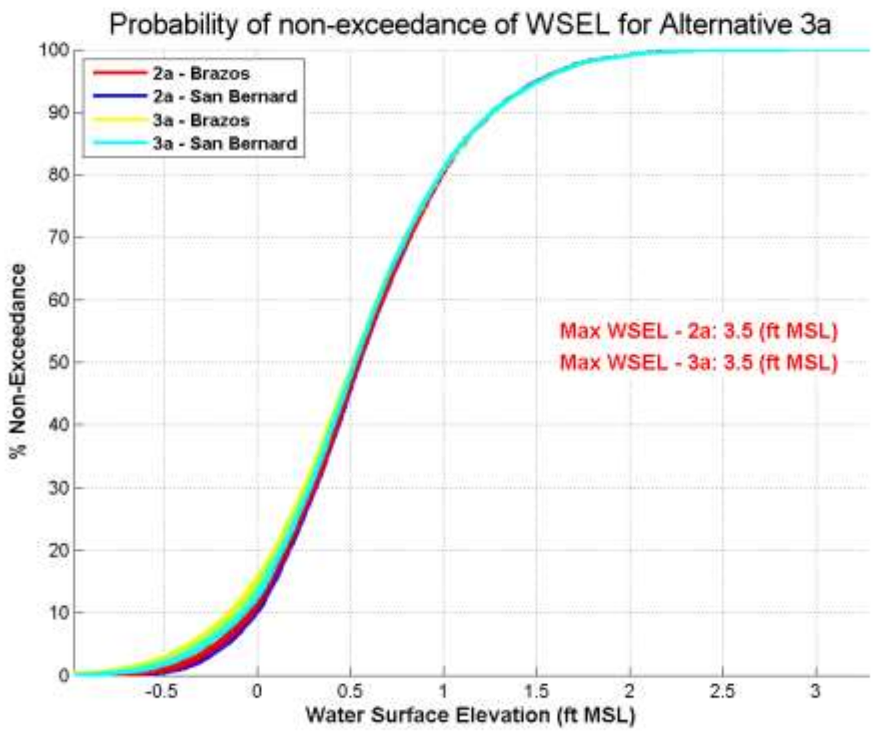

Figure 38. Probability of water level non-exceedance in West GIWW for Alternative 3a.

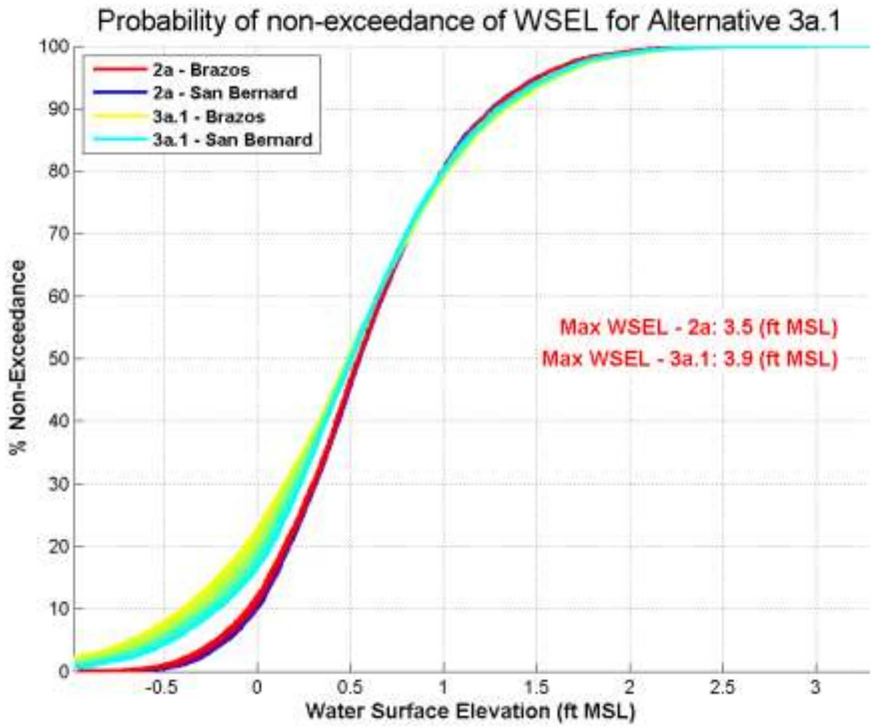

Figure 39. Probability of water level non-exceedance in West GIWW for Alternative 3a.1.

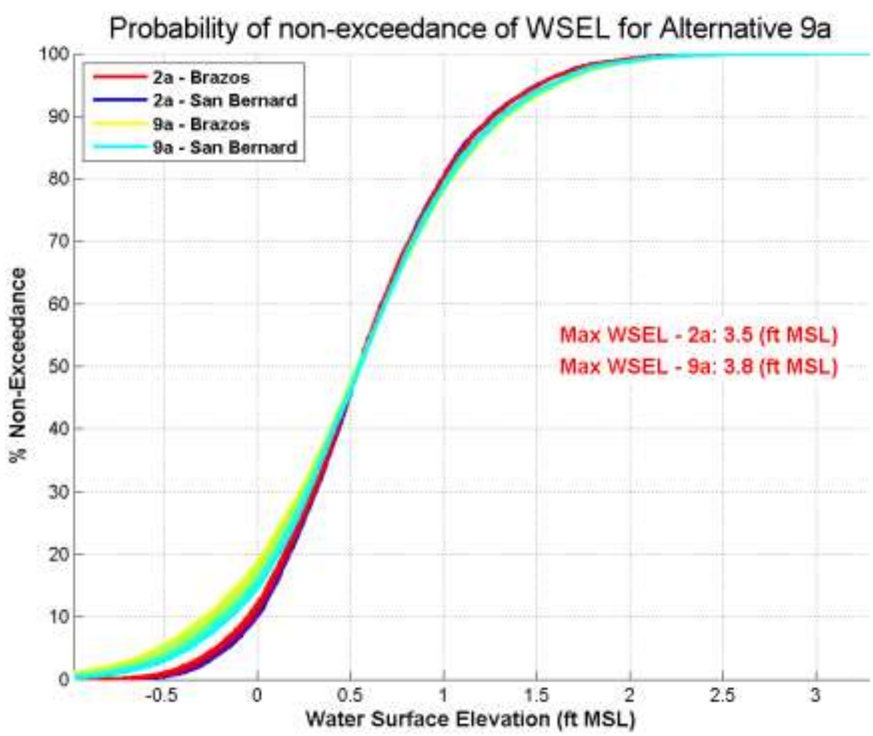

Figure 40. Probability of water level non-exceedance in West GIWW for Alternative 9a.

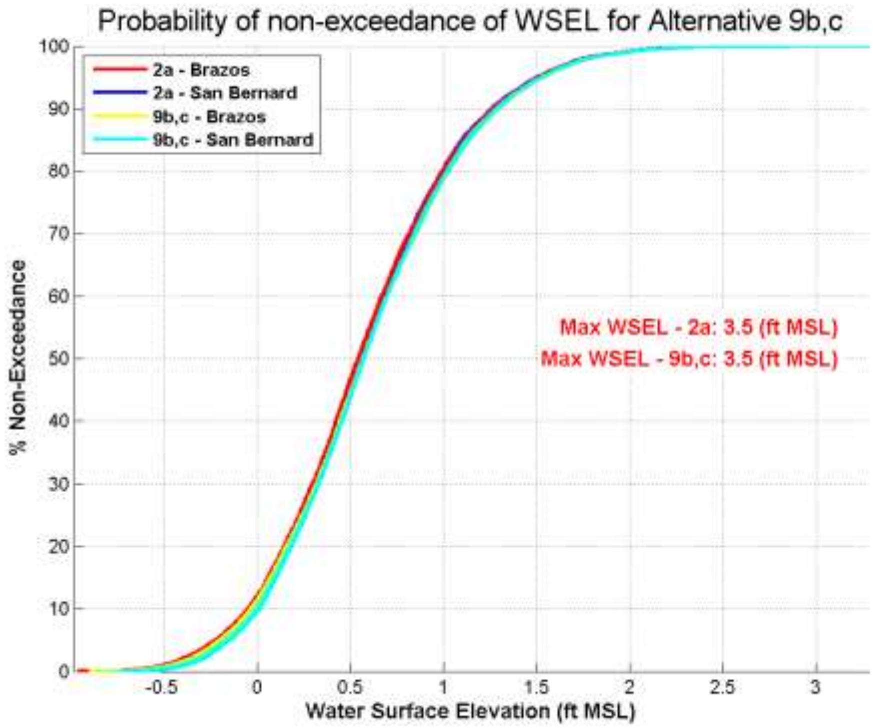

Figure 41. Probability of water level non-exceedance in West GIWW for Alternatives 9b and 9c (negligible difference).

For alternatives that have an open channel connection to the Brazos River at the West GIWW (Alternative 3a.1 and Alternative 9a), the low water levels in the West GIWW are raised while high water levels are slightly reduced. Despite the slight reduction in the highest 10% of water levels, the absolute peak water level for both these alternatives is slightly increased by 0.3-0.4 ft. Furthermore, these open channel alignments tend to cause an increased attenuation of low water levels from east to west as shown by the thickness of the non-exceedance curve. For Alternatives 3a, 9b, and 9c, the change in water level non-exceedance from Existing Conditions is negligible, and the absolute peak water level is unchanged. LiDAR data was examined along the west GIWW to determine whether this change could result in additional overtopping of the banks of the GIWW Bank elevations ranged from 3.5-4.0 ft NAVD88, so the minor increase in peak water level is not expected increase overtopping of the GIWW banks.

There was additional concern that the open connection between the west GIWW and the Brazos River (i.e. Alternatives 9a and 3a.1) could cause elevated water levels in communities along the San Bernard River. Water levels were extracted near the communities of Lands End and Sanders Road, which are approximately 1 mile and 5 miles upstream of the GIWW San Bernard River intersection respectively. Figure 42 and Figure 43 show the probability of non-exceedance curves for Alternative 3.a.1 and Alternative 9a compared with the Existing Conditions.

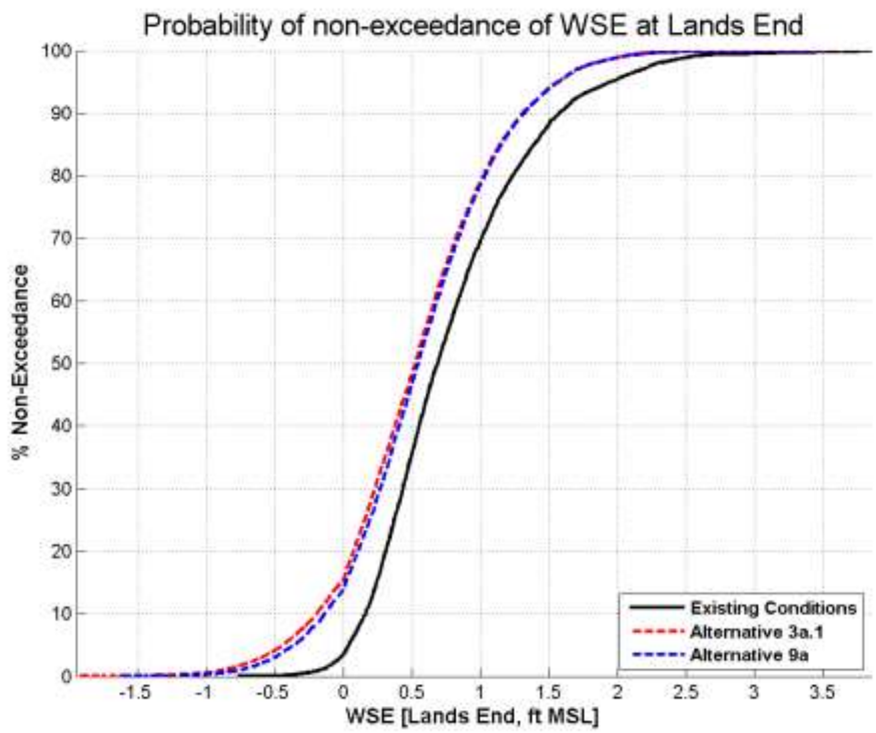

Figure 42. Probability of Non-Exceedance (PNE) for WSE [ft MSL] at Lands End.

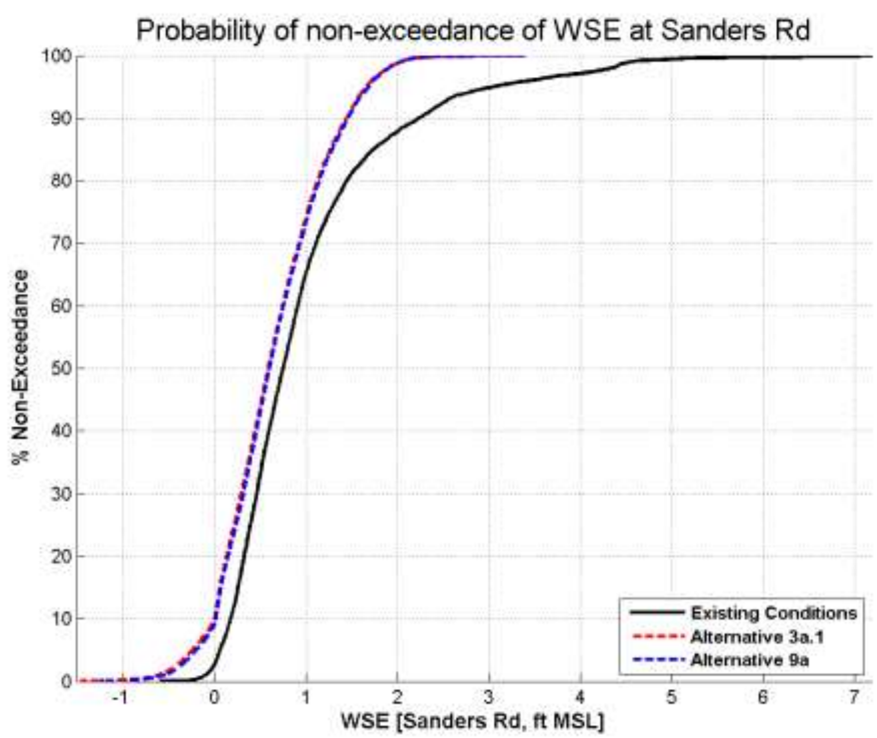

Figure 43. Probability of Non-Exceedance (PNE) for WSE [ft MSL] at Sanders Rd.

Figure 42 and Figure 43 show reduced water surface elevations at both communities along the San Bernard River. The San Bernard Rivers connection to the Gulf has silted in in recent years. The reduction of water surface elevations observed for Alternatives 3a.1 and 9a along the San Bernard River likely occurs due to the proposed open channel at the intersection of the west GIWW and Brazos River, which allows increased drainage of San Bernard flows, thereby reducing water surface elevations along the San Bernard. FEMA DFIRMS were also investigated to determine the base flood elevations of communities along the San Bernard River. DFIRMS indicate the areas of River's End and other communities up the river several miles are in the AE zone with Base Flood Elevations ranging from 12 to 14 ft NAVDD88. Based on the above analysis, it is unlikely that Alternatives 3a.1 or 9a would have any adverse impacts to flooding, and may to improve mitigate along the San Bernard River from fluvial events. It should be cautioned that the AdH circulation model was not calibrated or developed as a flood model, and the modeling was not conducted to determine flooding impacts.

3.2.1 Impacts on Relative Sea Level Rise on River Velocity

The impacts of Relative Sea Level Rise (RSLR) on river velocity are important to consider when analyzing the performance of the proposed alternatives. As later discussed in Section 6, the river velocity impacts navigability across the Brazos River and high river velocities can result in closures of the Brazos River Floodgates system. Therefore, the velocity for all alternatives for a RSLR scenario of +1.00 and +2.00 feet from existing conditions was extracted from the model results. Figure 44 shows probability of non-exceedance curves for river velocity in ft/s for all proposed alternatives. All alternatives show similar trends for the RSLR scenarios, with reduced velocities compared to existing conditions. Since the changes in river velocity appear to be uniform across all alternatives, it is unlikely that the outcome of a TSP selection will change based on RSLR.

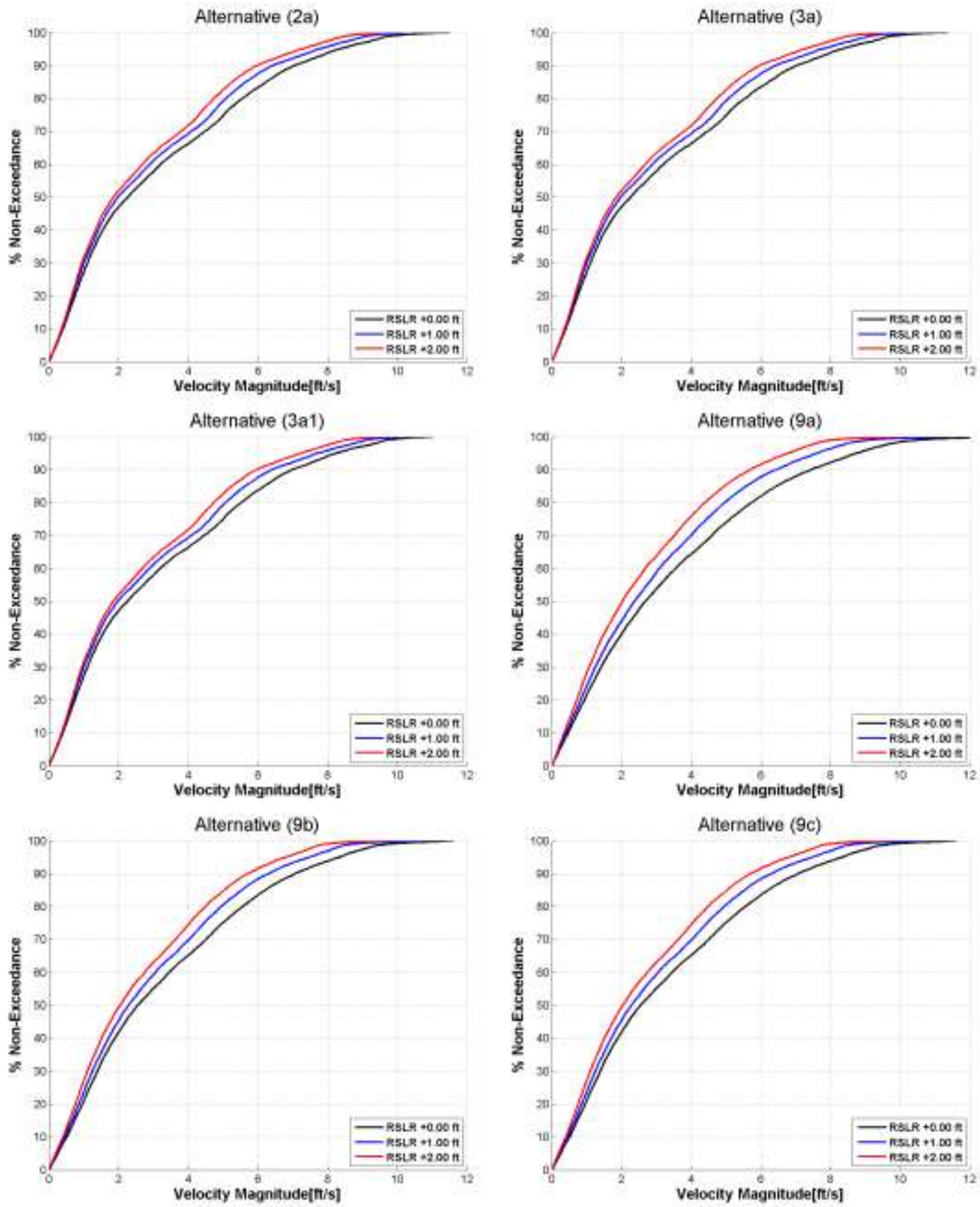

Figure 44. PNE of velocities extracted just north of the Brazos River Crossing for Existing Conditions/2a (top left) and all proposed alternatives for existing conditions, +1.0 ft RSLR and +2.0ft RSLR.

4 Salinity Analysis

4.1 Introduction

Salinity was modeled for Existing Conditions all alternatives to assess potential impacts of the project on the possible changes to salinity in the system resulting from the proposed alternatives. Salinity was modeled using ADH for the same 13-month validation period described in Section 3.1.5.

4.2 Data Collection

Salinity is recorded at a 15-minute frequency at a location east of the east gate at USGS Station 08117300. These measured data were used to validate the salinity model.

4.3 Model Setup

A 1-year spinup simulation was run to determine the initial salinity distribution for the 13-month simulation. The spinup run was initiated with a salinity concentration of 0 ppt in the Brazos and San Bernard Rivers, 20 ppt in the GIWW and attached estuaries, and 33 ppt in the Gulf. The salinity distribution at the end of the spinup run is shown in Figure 45, and this distribution was used as an initial condition for the 13-month simulation.

The model was run with a boundary concentration of 0 ppt at both river boundaries and 33 ppt at the offshore boundary.

Figure 45. Initial salinity concentration in the model domain.

4.4 Results

The salinity model was validated with the measured data at USGS Gage 08117300 (Figure 46). The model captures the trends associated with the flow rates in the Brazos River (e.g. Salinity drops abruptly during a flood event and gradually recovers during low flow conditions). Inaccuracies in the salinity model are likely due to assumptions in modeling gate operations, which controls the flow of fresh water into the GIWW from the Brazos River. The model is considered validated to sufficiently explain salinity variations in the system.

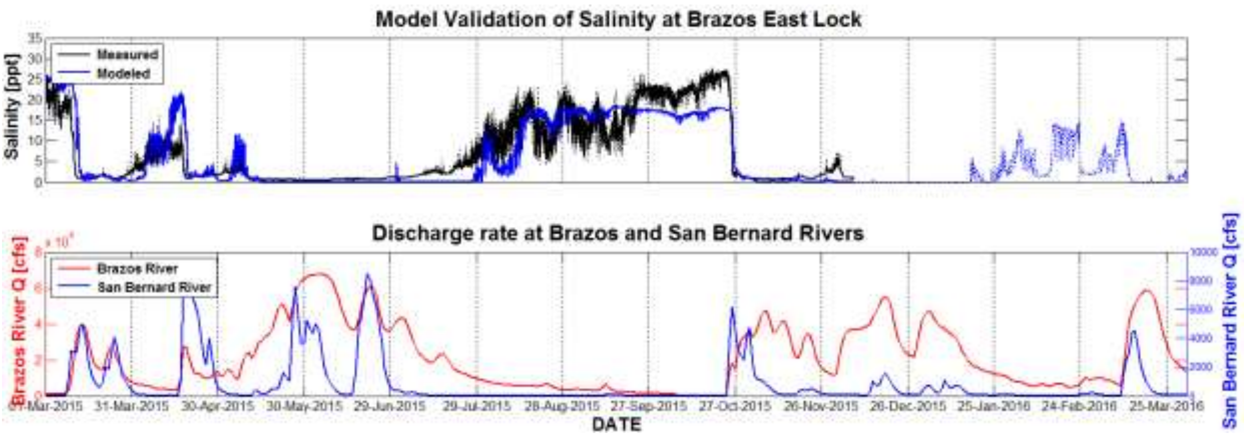

Figure 46. Validation of Salinity at USGS gage 08117300 (top) and flow rates in the Brazos and San Bernard Rivers (bottom).

Table 14 and Table 15 show the average salinity in each of the impact zones for low freshwater flow (summer: June – August) and high freshwater flow (late fall: October – December) respectively. In general, Alternatives 3a.1, 9a, 9b, and 9c tend to reduce the salinity in all zones of influence, while alternative 3a causes minimal changes to salinity. Figure 47 through Figure 51 show the difference in mean salinity between Existing Conditions and Alternatives 3a, 3a.1, 9a, 9b and 9c respectively for both summer and late fall time periods. This is due to larger gates (or lack of gates for Alt 9a) which leads to greater exchange from the Brazos River into the GIWW.

Table 14. Mean salinity (and change for alt-existing) [ppt], October – December

Alternative	West GIWW	Brazos Basin	East GIWW	Freeport Channel
Existing	5.6	1.7	5.0	15.6
3a	6.0 (0.4)	2.2 (0.5)	3.9 (-1.1)	15.2 (-0.4)
3a.1	3.8 (-1.8)	2.7 (1.0)	5.8 (0.8)	13.6 (-2.0)
9a	3.7 (-1.9)	2.3 (0.6)	4.0 (-1)	10.3 (-5.3)
9b	4.2 (-1.4)	1.9 (0.2)	3.7 (-1.3)	13.4 (-2.2)
9c	4.0 (-1.6)	2.0 (0.3)	3.5 (-1.5)	13.3 (-2.3)

Table 15. Mean salinity (and change for alt-existing), June – August.

Alternative	West GIWW	Brazos Basin	East GIWW	Freeport Channel
Existing	3.0	0.4	3.5	17.5
3a	3.0 (0)	0.6 (0.2)	2.7 (-0.8)	17.1 (-0.4)
3a.1	0.9 (-2.1)	0.3 (-0.1)	3.3 (-0.2)	13.7 (-3.8)
9a	1.7 (-1.3)	0.3 (-0.1)	1.5 (-2.0)	11.4 (-6.1)
9b	2.2 (-0.8)	0.3 (-0.1)	2.0 (-1.5)	14.4 (-3.1)
9c	2.1 (-0.9)	0.5 (0.1)	2.0 (-1.5)	14.5 (-3.0)

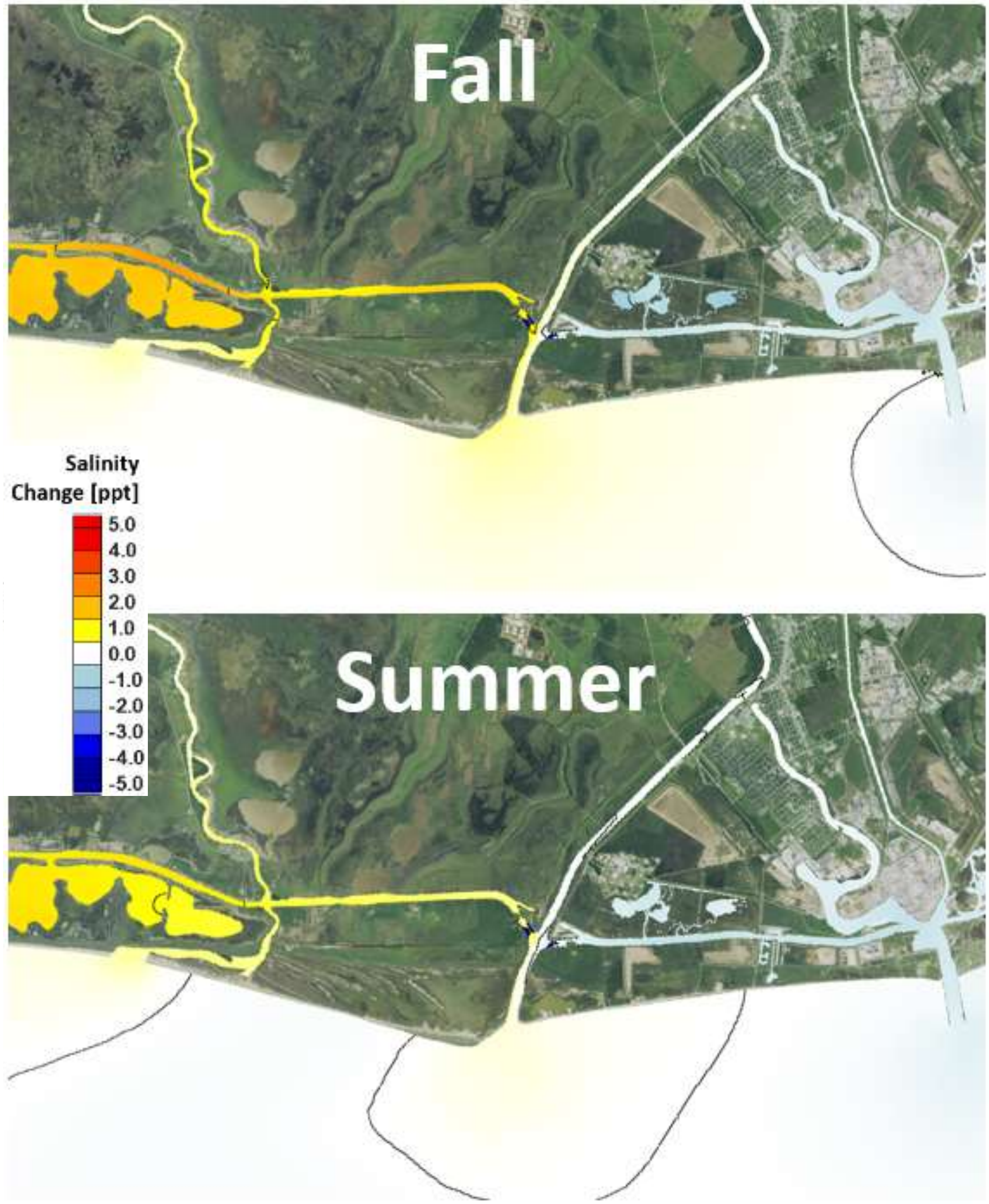

Figure 47. Change in mean salinity for summer and late-fall between Existing Conditions and Alternative 3a.

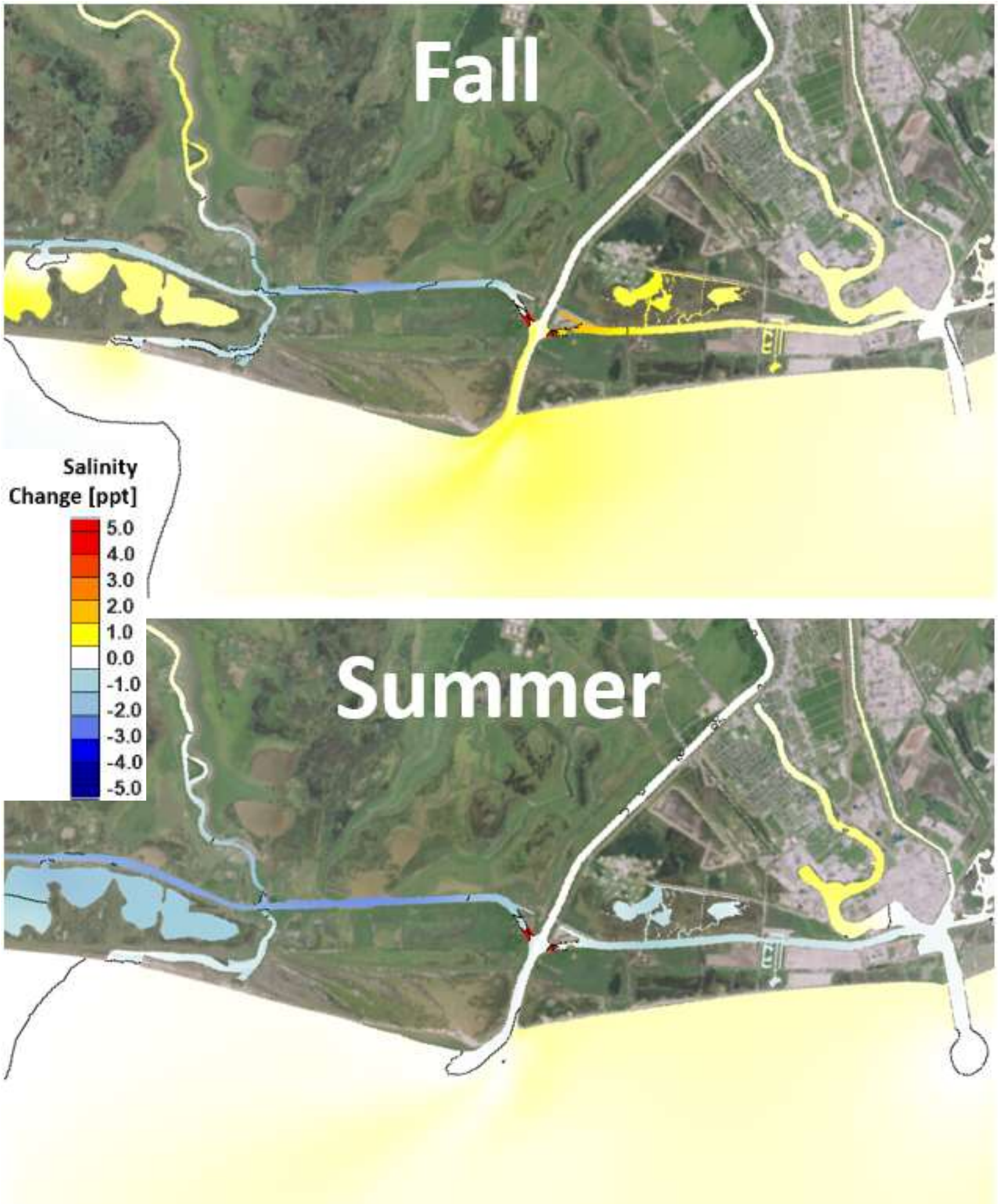

Figure 48. Change in mean salinity for summer and late-fall between Existing Conditions and Alternative 3a.1.

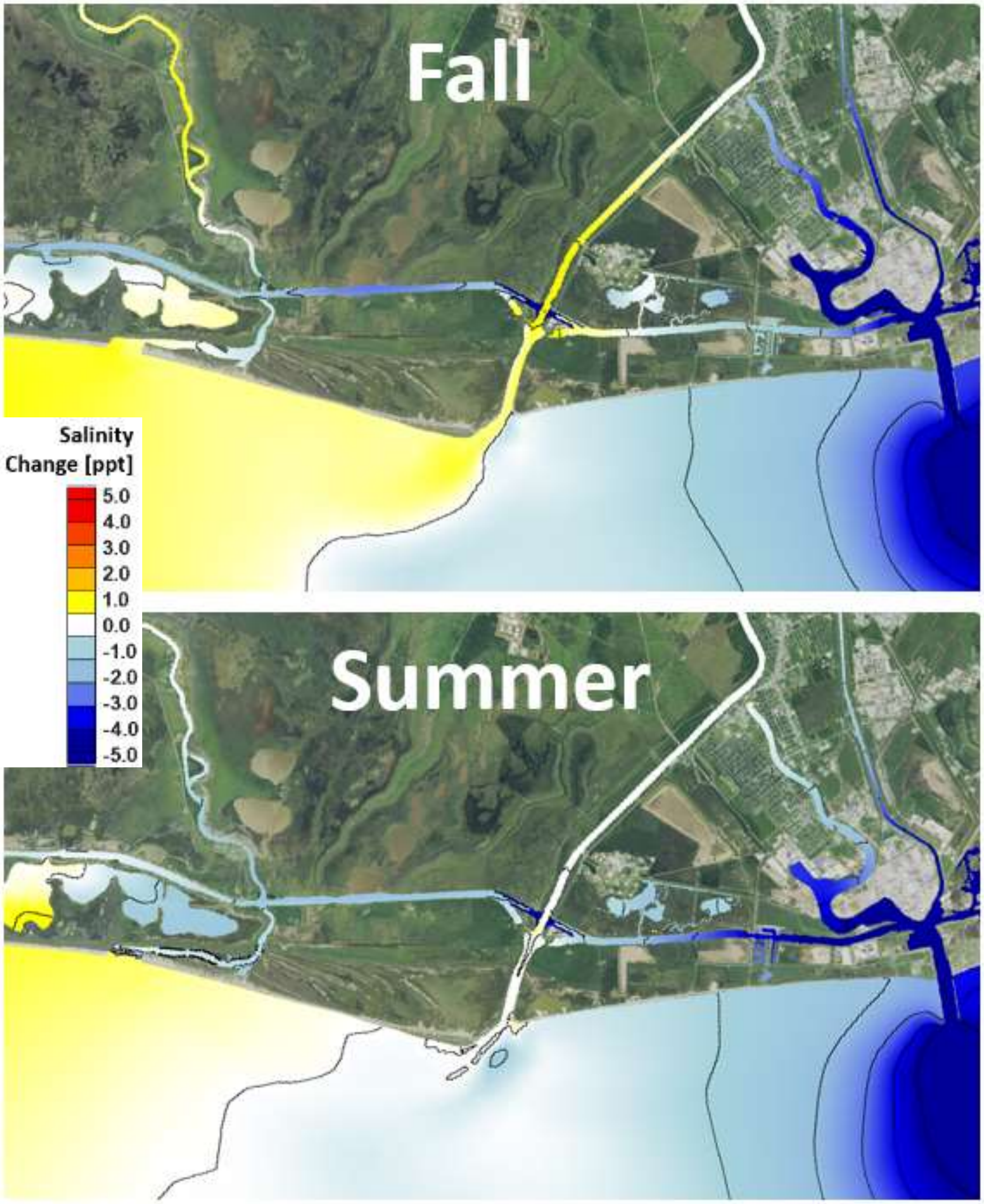

Figure 49. Change in mean salinity for summer and late-fall between Existing Conditions and Alternative 9a.

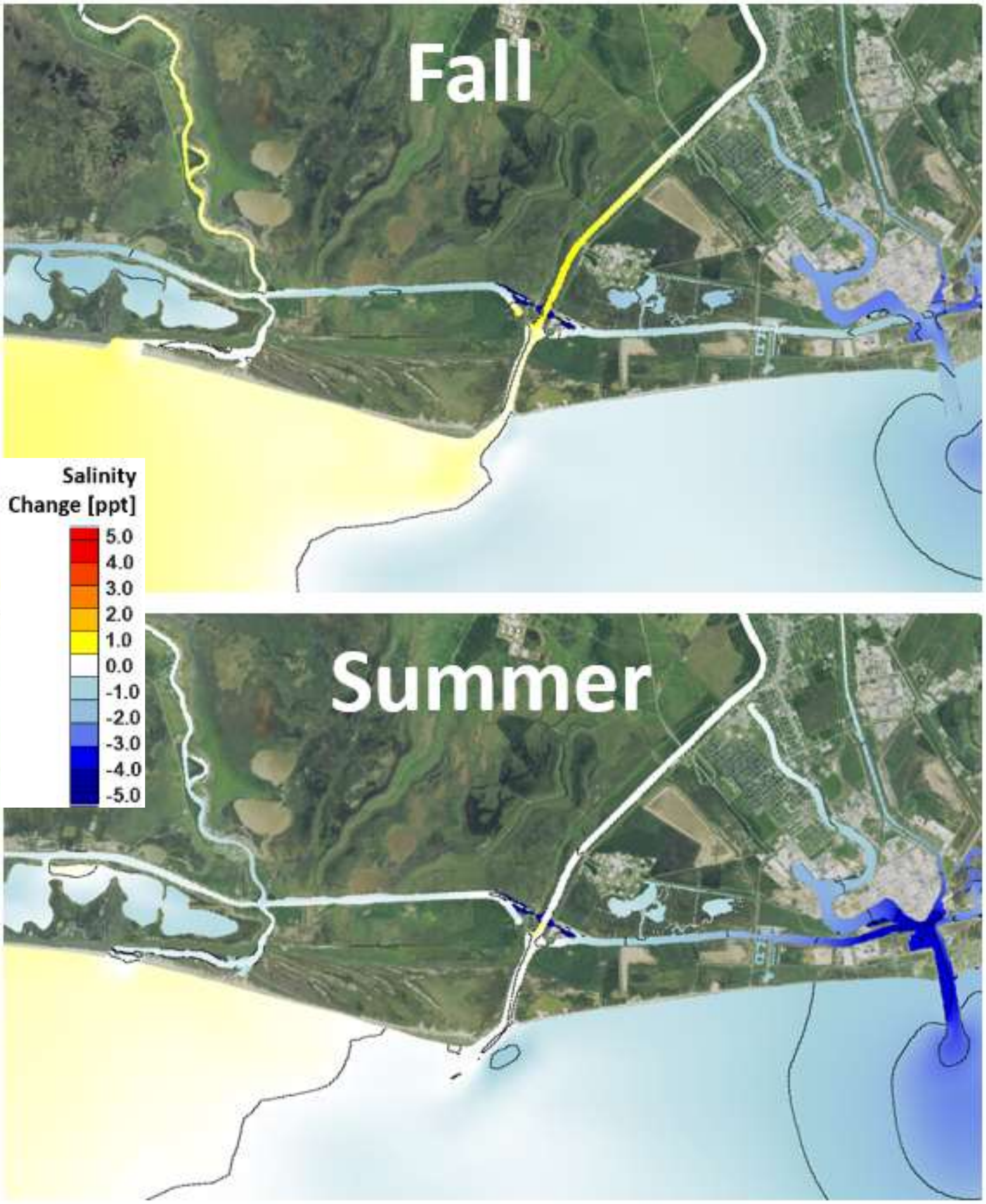

Figure 50. Change in mean salinity for summer and late-fall between Existing Conditions and Alternative 9b.

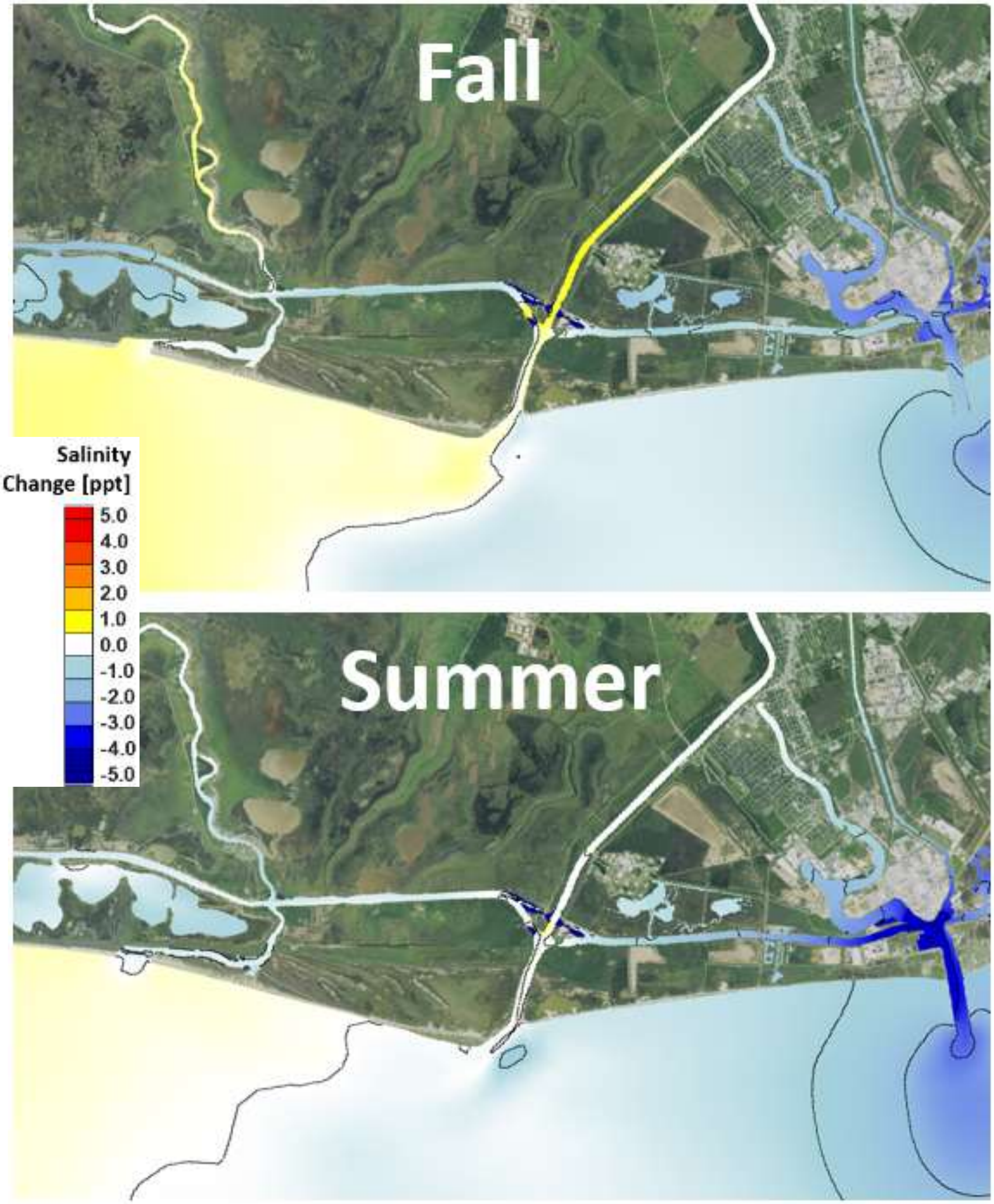

Figure 51. Change in mean salinity for summer and late-fall between Existing Conditions and Alternative 9c.

5 Sedimentation Analysis

To determine the potential impacts of the project on sedimentation patterns and volumes in the GIWW, a thorough sedimentation study was carried out. This study included review of available surveys and dredge records, analyzing sediment grab samples, generating suspended sediment rating curves from available measured data, and developing a calibrated sedimentation model.

5.1 Site Conditions

5.1.1 Sediment Sampling

Sediment grab samples were collected and analyzed at ten locations near the project site, identified as BR-01 – BR-10 in Figure 52. The grab sample locations span from approximately 4.5 miles west of the San Bernard River – GIWW intersection to the intersection of the GIWW with the Freeport Harbor. The grab samples were analyzed for grain size distribution and liquid/plastic limits. The average sediment class distributions, as well as the median grain size diameter is shows in Table 16.

Figure 52. Locations of sediment grab samples.

Table 16. Grab sample sediment class distributions and median grain size.

Sample	% Silt	% Clay	% Sand	D50 [mm]
BR-01	37.9	60.1	2.1	0.0021
BR-02	36.0	60.0	4.0	0.0028
BR-03	42.9	51.1	6.0	0.0046
BR-04	51.1	43.2	5.8	0.0089
BR-05	55.0	29.4	15.7	0.0347
BR-06	71.4	21.3	7.4	0.0369
BR-07	62.3	31.5	6.2	0.0234
BR-08	64.0	26.9	9.1	0.0345
BR-09	50.7	44.3	5.1	0.0077
BR-10	49.6	47.1	3.3	0.0061

As shown in Figure 53, the fraction of clay in the grab sample tends to increase farther away from the Brazos River. This is logical, as clay particles have a lower settling velocity, and thus can travel farther from the source (the Brazos River) before depositing. By the same reasoning, the fraction of sand is greatest near the Brazos River – GIWW intersection, and peaks at 15% just to the west of the west gate. Most of the sediment in the GIWW contains less than 7% sand

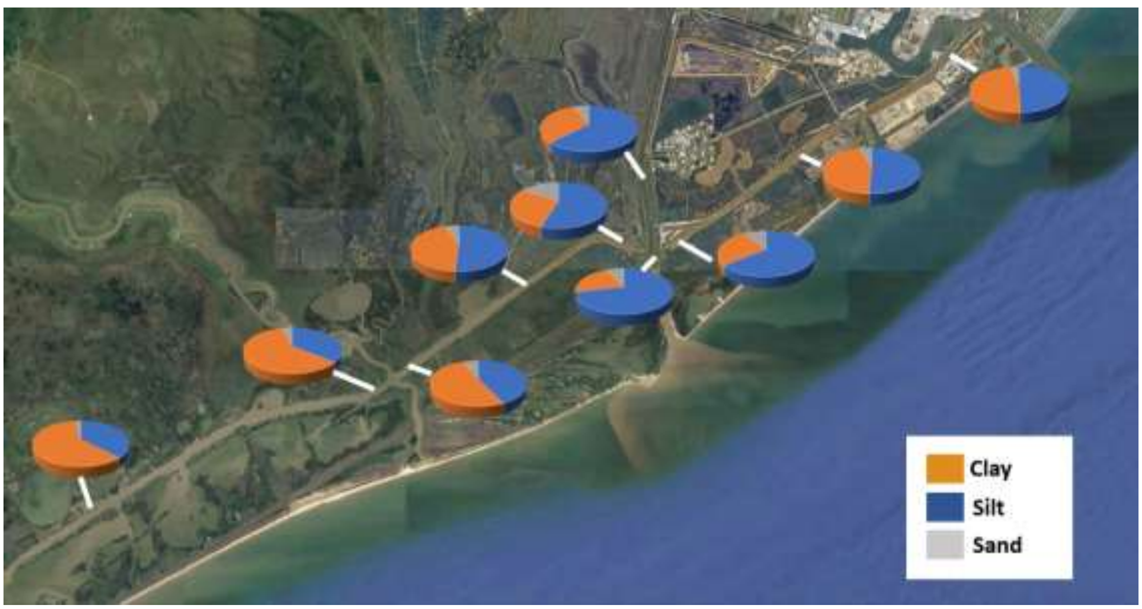

Figure 53. Grab sample sediment class distributions.

5.1.2 Suspended Sediment Concentrations

Historical suspended sediment concentration (SSC) was recorded in the Brazos River at USGS Station 08116650 at an approximately monthly frequency between 1973 and 1981, and again between 2008 and 2015. Historical SSC was also recorded in the San Bernard River at USGS Station 08117500 at approximately the same frequency between 1978 and 1987. Each measured sediment concentration was compared with its corresponding average river discharge, and the data were fit to an exponential regression curve. Figure 54 and Figure 55, show the sediment load curves for the Brazos and San Bernard Rivers respectively. These curves were used to determine suspended sediment concentrations at the model boundary in Section 5.1.5. Note the scatter in the data spans at least an order of magnitude in concentration.

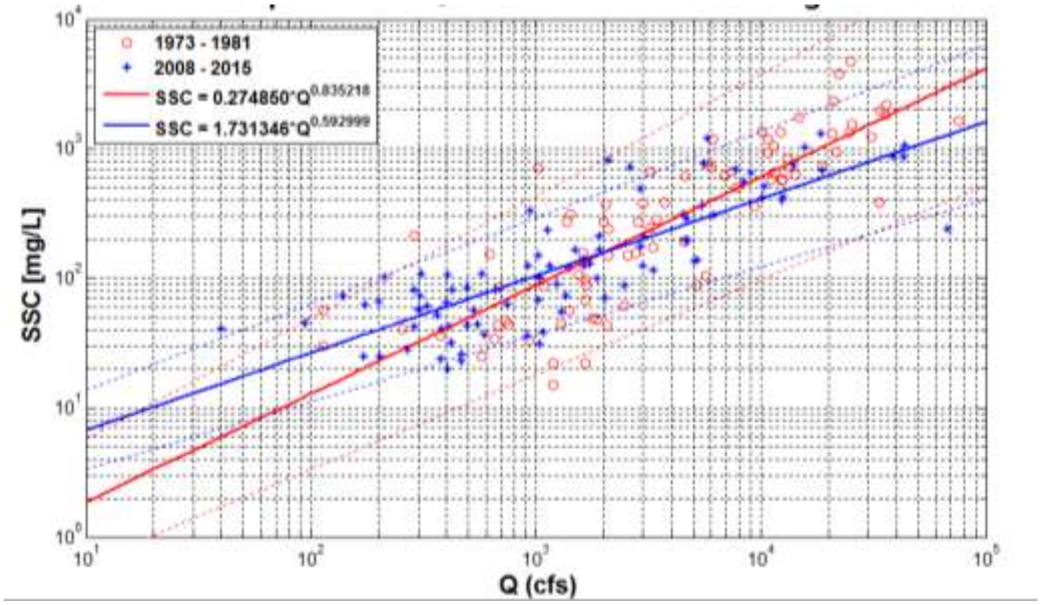

Figure 54. Sediment load curve at Brazos River, Rosharon gage based on measured data. 95% confidence intervals shown as dotted lines.

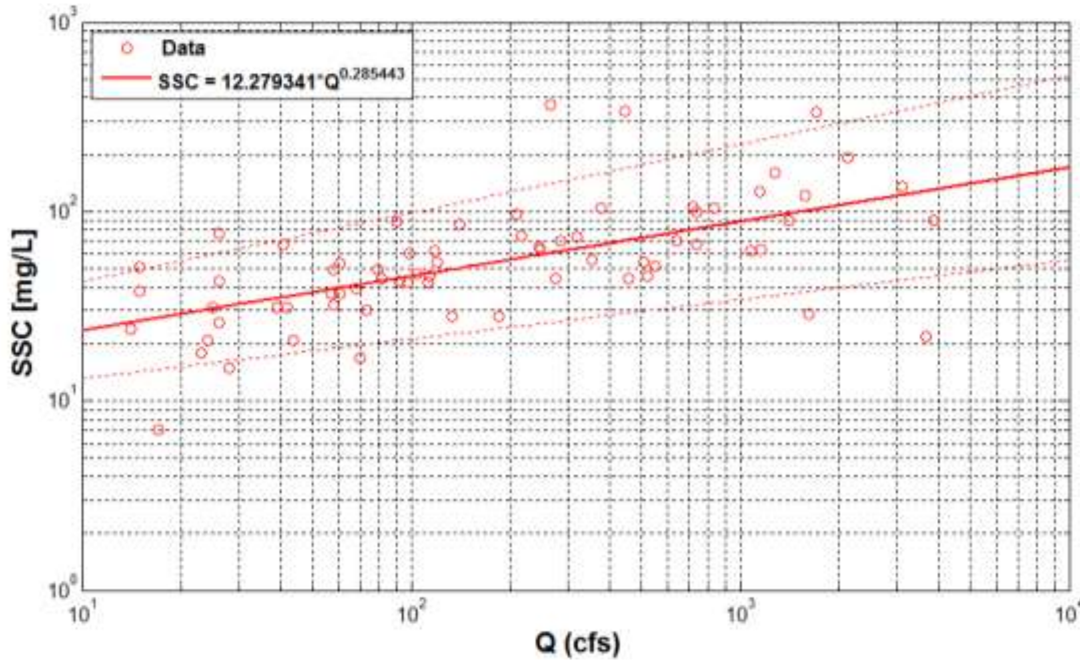

Figure 55. Sediment load curve at San Bernard Boling gage based on measured data. 95% confidence intervals shown as dotted lines.

5.1.3 Dredging History

To develop an understanding of sedimentation in the project vicinity, both historical bathymetric surveys and corresponding dredging history is required. Bathymetric surveys of the GIWW channel were obtained from the USACE within the project area (USACE, 2016). The surveys provided by the USACE document either existing (EX) conditions, before dredging (BD) conditions, or after dredging (AD) conditions. Thus, dredging activities within the GIWW channel occurred during the duration between each BD and AD survey sets. Sedimentation rate can be inferred by comparing surveys where no dredging occurred between them (for example, comparing the BD survey to the preceding AD survey). The survey data from 2012 through 2016 was investigated along the stretch of the GIWW extending from Station 566+000 to Station 615+000. See Figure 56 for the location of these Stations. Figure 57 displays the temporal and spatial coverage of all documented surveys within this section of the GIWW. In Figure 57, blue indicates EX surveys, green indicates BD surveys, and red indicates AD surveys. Most dredging activities within this section of the GIWW occurred during August – November in 2012, with localized dredging in 2015 and 2016. Based on these data sets provided by the USACE, it is assumed that no dredging was conducted from December 2012 to August 2016, except for a small dredging event in August 2015 between Station 587+500 and 588+500.

Figure 56. Station numbers along the GIWW channel alignment; survey and dredging data was investigated for the reach of channel extending from Station 566+000 to Station 615+000.

Figure 57. Summary of surveys and dredging activities from 2012 through 2016 along the reach of the GIWW channel from Station 566+000 to Station 615+000. Blue indicates surveys documenting existing conditions (EX); red indicates surveys documenting post-dredging conditions (AD); and green indicates surveys documenting pre-dredging conditions (BD).

5.1.4 Historical Sedimentation Analysis

To estimate the sedimentation rates within the project area, a preliminary analysis of historical sedimentation within the GIWW was performed using the available channel surveys documented in above. The most accurate sedimentation rates can be estimated by comparing AD surveys to their next consecutive BD surveys, as this comparison captures sedimentation that occurs after the channel is dredged to a known and measured dimension. However, due to the limited available AD to BD survey comparisons, consecutive AD to EX and EX to EX surveys were compared as well. Based on the available dredging history and discussions with the USACE Galveston District, it is assumed that no dredging activities occurred between consecutive EX surveys.

From Station 566+000 through Station 615+000, sedimentation rates were estimated in 1,000 LF segments, except in the region of the Brazos River Locks, between Stations 590+000 and 596+000, where the rates were estimated in 500 LF segments. Figure 58 displays a plot of the calculated average sedimentation rates along each Station, and the second column in Table 17 provides the sedimentation rate values. The third column in Table 17 shows sedimentation rates over a specified one-year period from March 2015 to April 2016; these sedimentation rates were used in the model calibration.

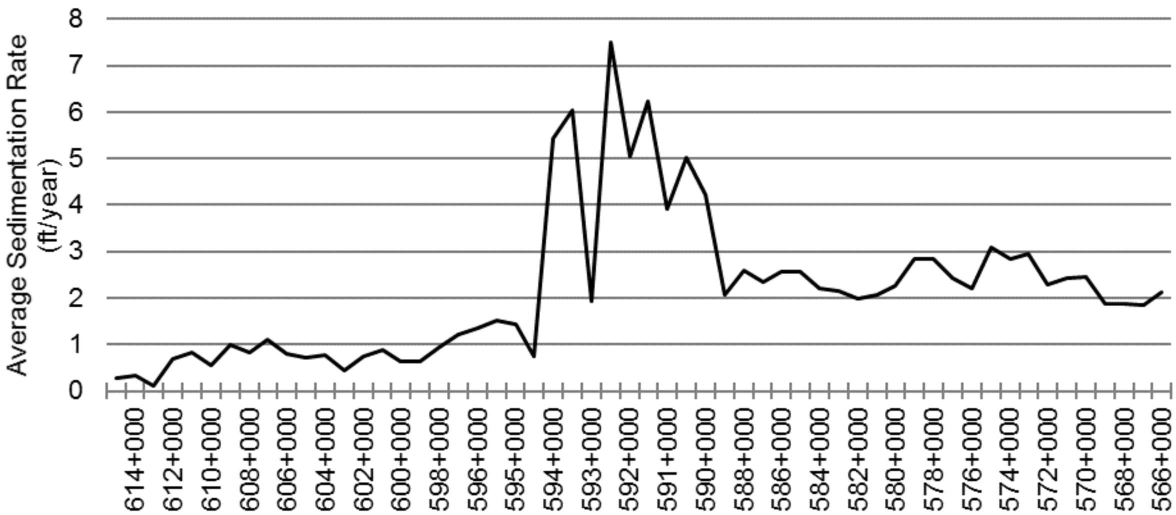

Figure 58. Sedimentation rates within the GIWW from Station 566+000 to Station 615+000 based on surveys from 2012 to 2016.

Table 17. Average sedimentation rates from Station 566+000 to Station 615+000 using survey data from 2012 through 2016. Note that cells stating No Data indicate areas where there were no consecutive surveys for the specified time period.

Start Station	2012 to 2016: Average Sedimentation Rate (ft/year)	March 2015 to April 2016: Average Sedimentation Rate (ft/year)
566+000	2.1	3
567+000	1.8	2.5
568+000	1.9	2.8
569+000	1.9	2.9
570+000	2.5	3.2
571+000	2.4	3.1
572+000	2.3	2.9
573+000	3	3.3
574+000	2.8	2.9
575+000	3.1	2.7
576+000	2.2	2.5
577+000	2.4	2.4
578+000	2.8	2.6
579+000	2.8	2.5
580+000	2.3	2.6
581+000	2.1	1.9
582+000	2	2.5
583+000	2.1	2.7
584+000	2.2	2.4
585+000	2.6	2.2
586+000	2.6	2.4
587+000	2.3	2.6
588+000	2.6	No Data
589+000	2.1	4.1
590+000	4.2	No Data
590+500	5	2.1
591+000	3.9	0.1
591+500	6.2	3.6
592+000	5	2.1
592+500	7.5	-5.6
593+000	1.9	2.8
593+500	6	1.9
594+000	5.4	0.6
594+500	0.8	2.9
595+000	1.4	4.2
595+500	1.5	3.6
596+000	1.4	2.7
597+000	1.2	2.3
598+000	1	2.3
599+000	0.6	1.7
600+000	0.7	1.9
601+000	0.9	1.3
602+000	0.8	0.8
603+000	0.5	0.3
604+000	0.8	0.3
605+000	0.7	0.5
606+000	0.8	0.1
607+000	1.1	0.6
608+000	0.8	0
609+000	1	-0.1
610+000	0.6	0.5
611+000	0.8	0.3
612+000	0.7	0
613+000	0.1	No Data
614+000	0.3	No Data
615+000	0.3	No Data

5.1.5 Hurricane Harvey

Hurricane Harvey made landfall in southern Texas on August 25, 2017 and then stalled inland of Matagorda for two days dumping heavy rainfall into the Brazos River floodplain. On August 29, the flow rate in the Brazos River reached 133,000 cfs at Rosharon, TX, the highest ever recorded at that location. Multibeam bathymetric surveys were made on June-1 2017, and post-storm surveys were made on September-29, 2017. Sedimentation volumes were calculated based on the overlapping area of these two surveys, and are summarized in Table 18.

Table 18. Calculated sedimentation volumes based on pre- and post-storm surveys.

W-GIWW	Erosion Volume [cu.yd.]	Sedimentation Volume [cu.yd.]	Average Sedimentation Depth [ft]
W-GIWW	0	150,000	1.0
Brazos Basin	-174,000	71,000	4.2*
E-GIWW	0	344,000	1.7
Total	**-174,000**	**565,000**	1.5

* Average sedimentation depth includes only the shoal on the east Brazos Basin forebay and does not include the eroded Brazos River Channel.

The sedimentation patterns for the West GIWW, Brazos Basin and East GIWW are shown in Figure 59 to Figure 61. Figure 60 shows the Sedimentation pattern at the Brazos Basin, where the most pronounced erosion and sedimentation occurs. The Brazos River channel has been scoured by about 6.9 ft, and a large shoal has been created in the forebay of the East Gate. Sedimentation in the West GIWW is less severe than in the East GIWW, which is consistent with the observations made in Section 5.1.4.

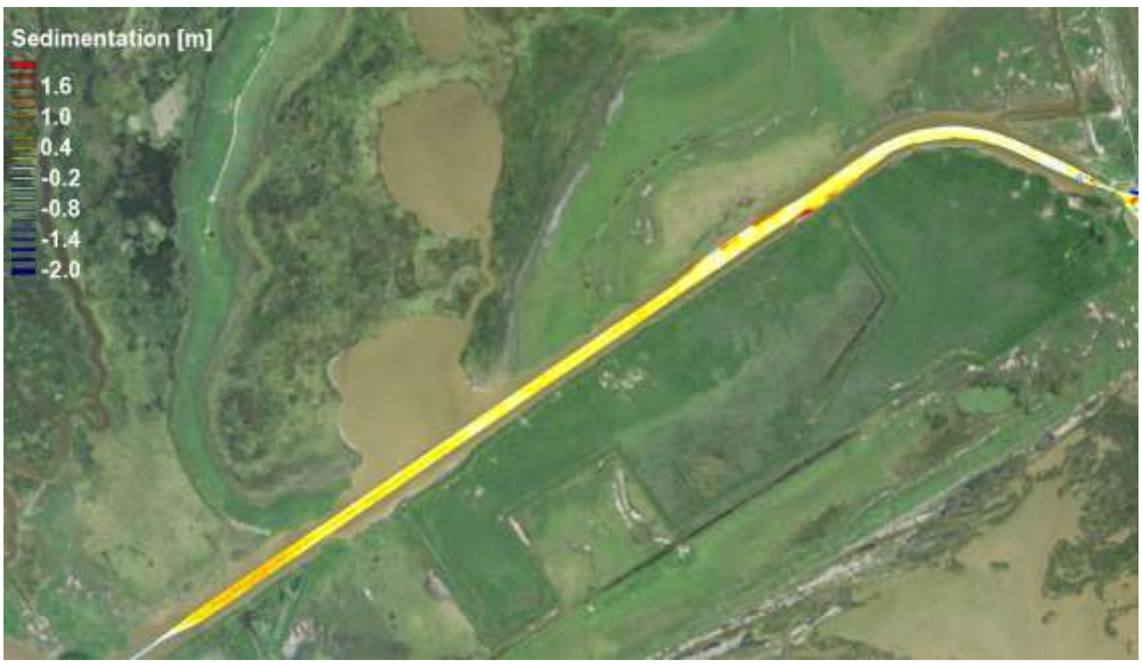

Figure 59. Sedimentation pattern in the W-GIWW due to Hurricane Harvey.

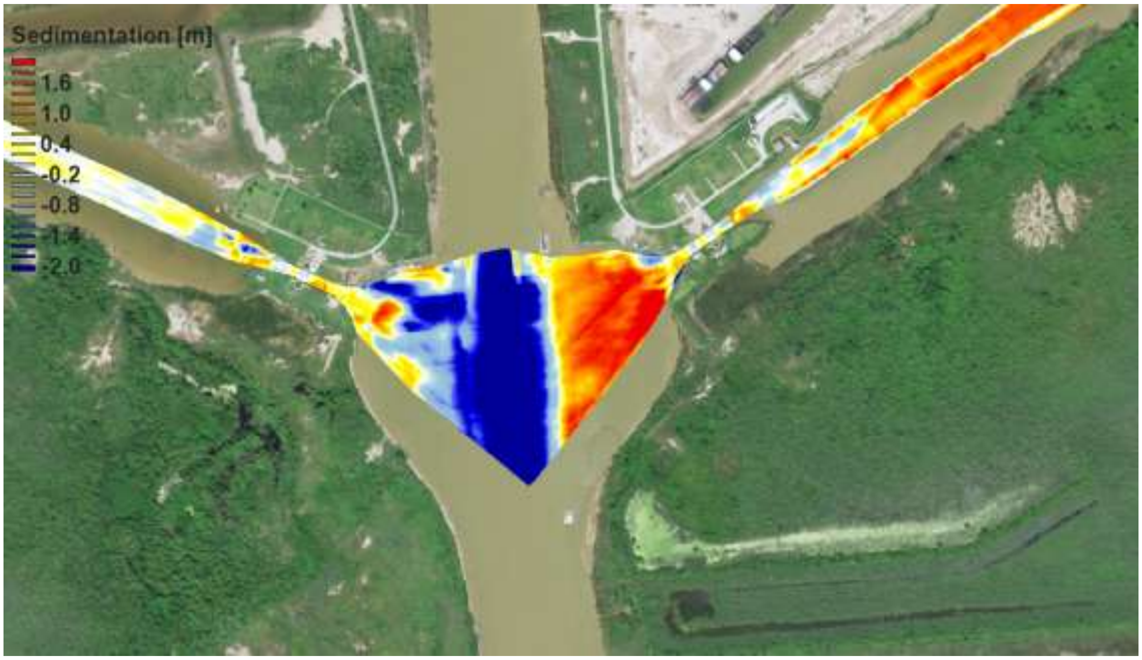

Figure 60. Sedimentation pattern in the Brazos Basin due to Hurricane Harvey.

Figure 61. Sedimentation pattern in the E-GIWW due to Hurricane Harvey.

Post-storm sediment samples were collected from the shoal at the east forebay, as well as on either side of the East and West Gate. The post-storm sediment composition in the shoal consists primarily of very fine silt with some sand, with the samples nearest to the south and north banks having a higher proportion of very fine sand, and the sample closer to the channel consisting primarily of fine silt and clay. The samples on either side of the East and West Gates were primarily very fine silt and clay. These post-storm sediment samples are consistent with the samples collected under typical conditions (Section 5.1.1) with a slightly higher proportion of sand in the Brazos Basin.

5.2 Sedimentation Modeling

To simulate the changes in sedimentation patterns and volumes associated with the proposed alternatives, a calibrated sediment transport and sedimentation model was required. Sedimentation was modeled using ADH for the same 13-month validation period described in Section 3.1.5.

5.2.1 Model setup

The sedimentation model was built using the same mesh and hydrodynamic forcing conditions as the hydrodynamic and salinity models. Sediment boundary conditions were determined using the sediment rating curves shown in Figure 54 and Figure 55 based on the boundary flow rates shown in Figure 21. Based on the sediment class distribution shown in Table 16, the boundary sediment was assumed to be 50% Silt and 50% Clay. Sediment parameters are shown in

Table 19. Sedimentation model sediment parameters.

Parameter	Silt	Clay
Median Grain Diameter [mm]	3.0E-5	5.0E-6
Specific Gravity [-]	2.72	2.72
Bulk Density [kg/m3]	1400	1200
Critical Shear of Erosion [kPa]	0.67	0.1
Erodibility Factor [-]	1.6E-4	1.6E-4
Critical Shear of Deposition [kPa]	0.1	0.05
Settling velocity [m/s]	2.2E-4	5.0E-5

Like the salinity model, a 1-year spinup simulation was run to determine the initial conditions for the 13-month simulation. The spinup simulation was initiated with zero bed layer thickness and zero sediment concentration in the entire domain and boundary sediments were introduced and allowed to circulate and deposit naturally within the domain. For the spinup simulation, bed updating was disabled, so only the initial distribution of bed layer thickness (i.e. a local source of sediment) was created. One drawback to this method is that high currents in the spinup simulation prevented sediment from naturally settling and developing an erodible layer in the Brazos River, which ultimately restricted the erosion of the Brazos River during the 13-month simulation and resulted in showing no erosion of the river bed.

5.2.2 Calibration & Validation

The sedimentation model was validated by comparing sedimentation rates in each of the zones of influence to calculated sedimentation rates from available surveys. GIWW surveys used to determine the volumetric sedimentation rates in Table 17 were interpolated onto a high-resolution point swath for the West GIWW, Brazos Basin and East-GIWW. The model results were also interpolated onto the same point swath, and the average sedimentation rates for each were compared (Figure 62 and Figure 64). Note in Figure 63, that the model did not capture the erosion of the Brazos River. This is because of the absence of a bed layer thickness in the Brazos River due to the spinup simulation.

Figure 62. Comparison of measured (top) and modeled (bottom) sedimentation rates in the West GIWW.

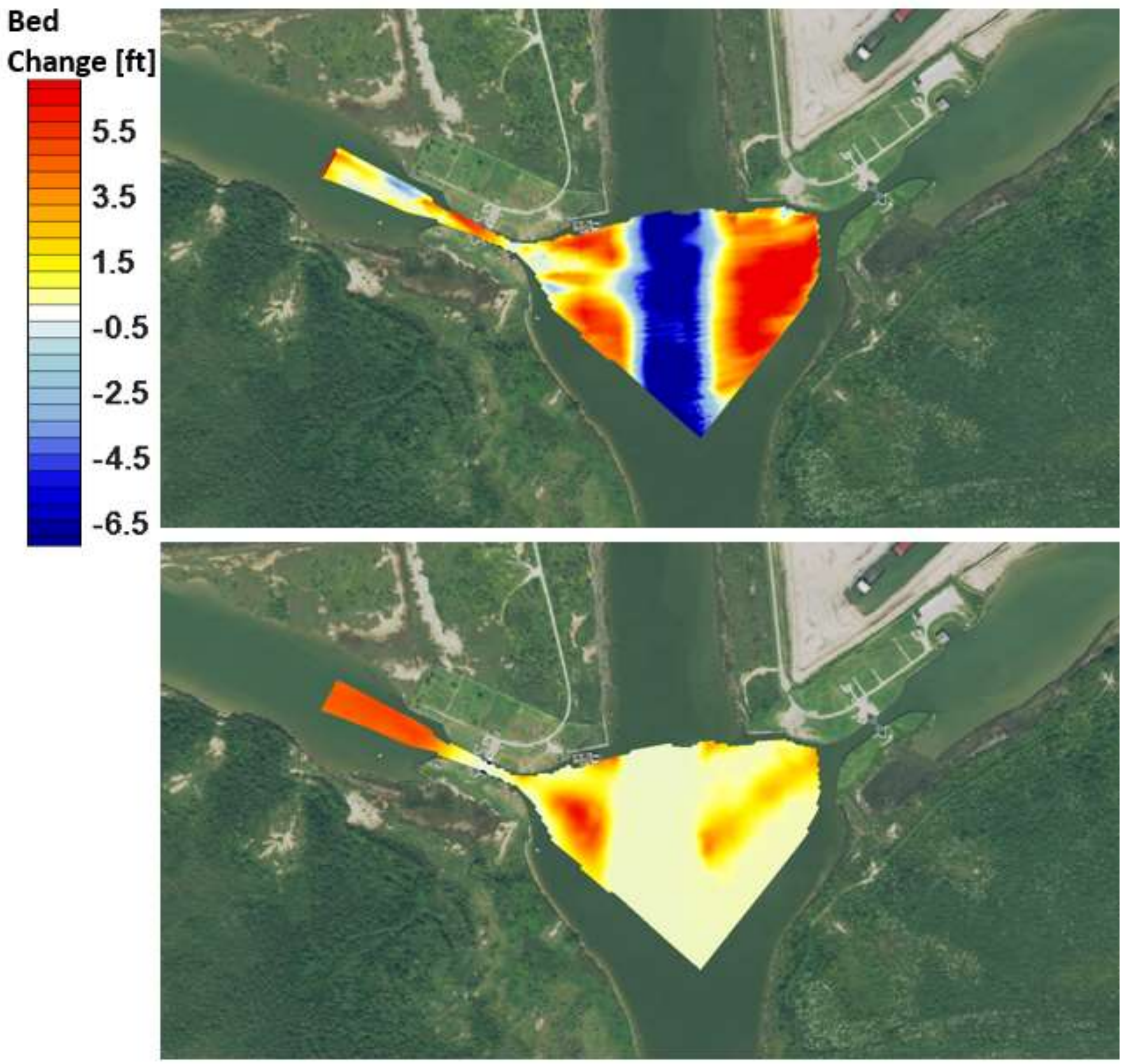

Figure 63. Comparison of measured (top) and modeled (bottom) sedimentation rates in the Brazos Basin.

Figure 64. Comparison of measured (top) and modeled (bottom) sedimentation rates in the East GIWW.

Table 20 shows the comparison of volumetric sedimentation rate for the West GIWW, Brazos Basin, and East GIWW. The measured volume in the Brazos Basin was calculated as only the accreted volume, and erosion of the Brazos River channel as seen in Figure 63 was not included in this volume calculation as it was not simulated. While the model skews the distribution of sedimentation volume towards the west, the total sedimentation volume was underpredicted by about 10%, shown reasonable agreement in the sedimentation in the system overall.

Table 20. Validation of volumetric sedimentation rates in the West GIWW, Brazos Basin, and East GIWW.

	West GIWW	Brazos Basin	East GIWW	Total
Measured	1,502,919	1,076,581	4,232,713	6,812,214
Modeled	2,145,144	454,710	3,563,866	6,163,720
Relative error	43%	-58%	-16%	-10%

Figure 66 shows modeled and measured sedimentation depth compared along the channel centerline (Figure 65). The model does a good job of predicting the sedimentation depth and distribution in the West GIWW (Stations 595+000 – 612+000). In the Brazos Basin (Stations 590+000 – 595+000) the model does not predict the erosion of the Brazos River channel because a lack of sediment layer thickness in the model prevented it, the model does a good job predicting the general sedimentation pattern (accretion in the forebays). In the East GIWW (Stations 567+000 – 590+000), the model predicts sedimentation depth near the East Gate well, but underestimates sedimentation rate farther east towards Freeport. There are a number of factors that could attribute to this, including the influence of vessel traffic on the GIWW on sediment settlement and resuspension, and potential sediment contribution from Oyster Creek east of Freeport. As the goal of sedimentation modeling is to identify potential changes in sedimentation rates and patterns due to project implementation and not to perfectly capture sediment transport dynamics resultant of all possible influences, the model is deemed appropriately calibrated to quantify changes to sedimentation within the system as influenced by the Brazos Floodgates.

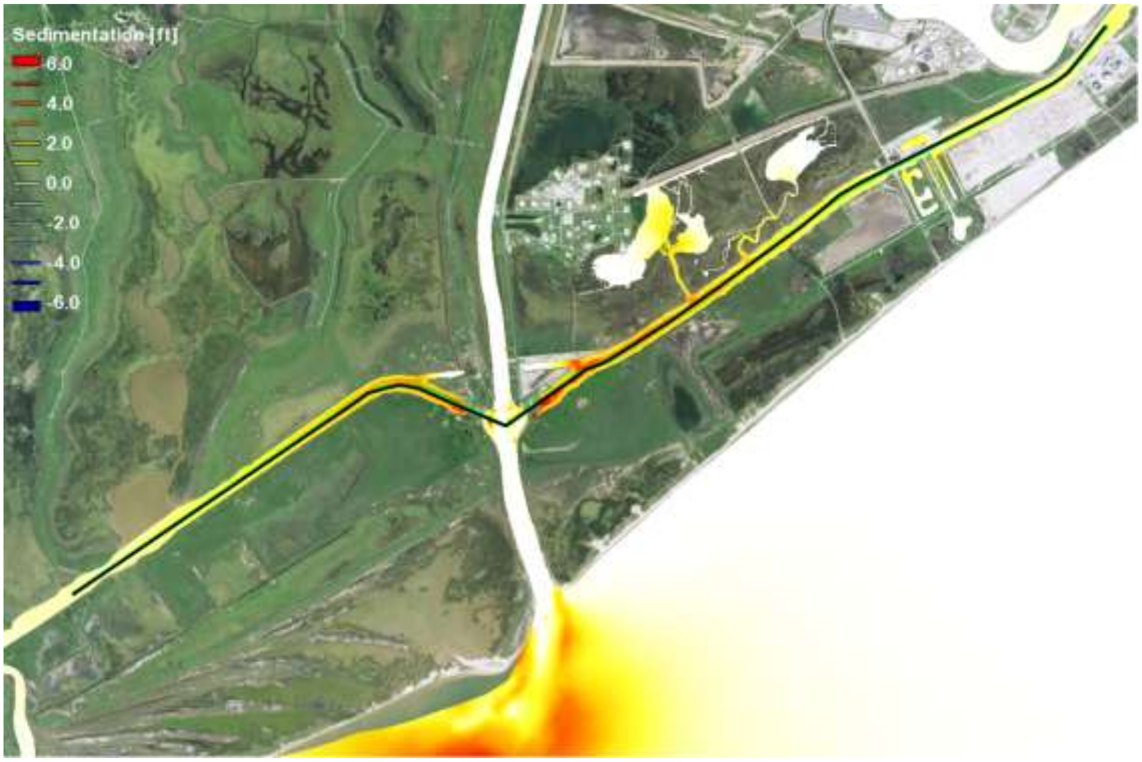

Figure 65. Channel centerline for comparison of modeled vs. measured sedimentation depth between the Freeport Harbor and the San Bernard River.

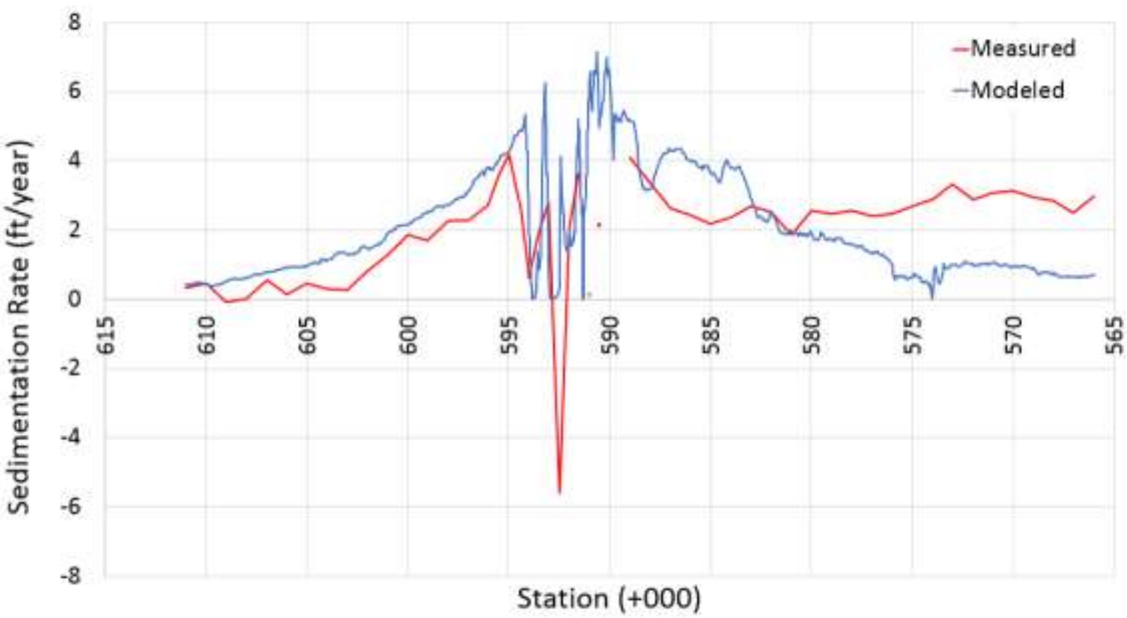

Figure 66. Comparison of measured vs. modeled sedimentation depth along the GIWW channel centerline between the Freeport Harbor and the San Bernard River.

5.2.3 Model Sensitivity to Sand Load

Based on the sediment distributions in Section 5.1.1 and the sediment sampling after Hurricane Harvey, sand was excluded from the sedimentation model since there is a high degree of uncertainty in the boundary sand load and because sand does not penetrate the GIWW and thus will not have a large impact on the resulting sedimentation volumes. While the existing alignment may not be sensitive to sand load, it is possible that the open channel alternatives may be. Thus, a sensitivity simulation was run with a boundary sand load of 20% the total sediment load (i.e. the total sediment load in increased by 20%). The sediment parameters for the sensitivity simulation are outlined in Table 21.

Table 21. Model sensitivity simulation to sand load sediment parameters.

Parameter	Sand	Silt	Clay
Median Grain Diameter [mm]	2.5E-4	3.0E-5	5.0E-6
Specific Gravity [-]	2.65	2.72	2.72
Bulk Density [kg/m3]	-	1400	1200
Critical Shear of Erosion [kPa]	-	0.67	0.1
Erodibility Factor [-]	-	1.6E-4	1.6E-4
Critical Shear of Deposition [kPa]	-	0.1	0.05
Settling velocity [m/s]	-	2.2E-4	5.0E-5
Total Fraction [%]	16%	42%	42%

The resulting sediment volume in each of the zones of influence was compared to the simulation results without a sand load (Table 22). Based on these results, a 20% sand load leads to a disproportionate increase in sedimentation volume in the Brazos Basin (61% increase), while increasing the sedimentation rate in the other GIWW zones by 10% or less. Thus, if the sediment load of fine sediments was reduced in place of a proportional addition of sand load, the sedimentation volumes would be skewed towards higher sedimentation in the Brazos Basin which is an order of magnitude less than sedimentation in the East GIWW, and towards the Brazos Delta which does not require dredging, thus simulating a less conservative solution.

Table 22. Sedimentation volumes in zones of influence for sensitivity simulations with and without 20% sand load.

	West GIWW	Brazos Basin	East GIWW	Freeport Channel	Brazos Delta	Total
9a [cy./yr.]	775,897	96,903	1,135,209	883,064	37,421,241	40,312,314
9a w/ 20% Sand [cy./yr.]	836,567	155,704	1,251,008	948,638	41,935,363	45,127,279
% increase	8%	61%	10%	7%	12%	12%

Three additional sensitivity simulations were run for Existing Conditions with boundary sediments of 5%, 10% and 20%. The resulting volume increase was evaluated at sediment sample locations BR-05, BR-06, and BR-08 (Figure 52) where measured sand fractions are greatest. A simple linear transfer function was developed for each sample location to relate the boundary sand fraction to the sand fraction at each sample location.

Table 23. Changes in deposition rates based on sand load.

	No Sand	5% Sand (yd.^{3})	10% Sand (yd.^{3})	20% Sand (yd.^{3})	Measured	Target Boundary Sand Fraction
BR-05	7,043 ()	7,454 (6%)	7,880 (12%)	8,885 (26%)	(16%)	(13%)
BR-06	16,470 ()	19,379 (18%)	24,314 (48%)	35,746 (117%)	(7%)	(2%)
BR-08	33,353 ()	35,957 (8%)	38,068 (14%)	42,937 (29%)	(9%)	(6%)

Based on this analysis, the most conservative estimate of boundary sand load would be 13% (at BR-05), meaning that the results of the sensitivity test for Alternative 9a using a 20% boundary sand load would be doubly conservative.

Since there is so much uncertainty in the boundary sand load, and since adjusting the boundary sediment fractions to include sand lead to a less conservative solution, the sedimentation simulations excluding sand load are determined to be acceptable.

5.3 Alternatives Analysis

For all alternatives, a series of sediment load curves were developed to describe the sediment budget around the Brazos Basin. For these load curves, positive values indicate sediment flux into the Brazos Basin and negative values indicate sediment flux out of the Brazos Basin. Similarly, daily sedimentation rating curves were also developed for each of the impact zones.

Figure 67 shows the sediment flux rating curves for Alternative 3a. The sediment flux rating curves show a slight decrease in sediment load into the Brazos Basin at higher flow rates and a comparable decrease in sediment load towards the Gulf. While sediment flux into the West GIWW appears unchanged, the sediment flux into the East GIWW shows a slight decrease at high flow rates. Figure 68 shows the daily sedimentation rating curves for the zones of influence requiring maintenance for Alternative 3a. Based on this figure, there is no noticeable change in sedimentation rates for Alternative 3a.

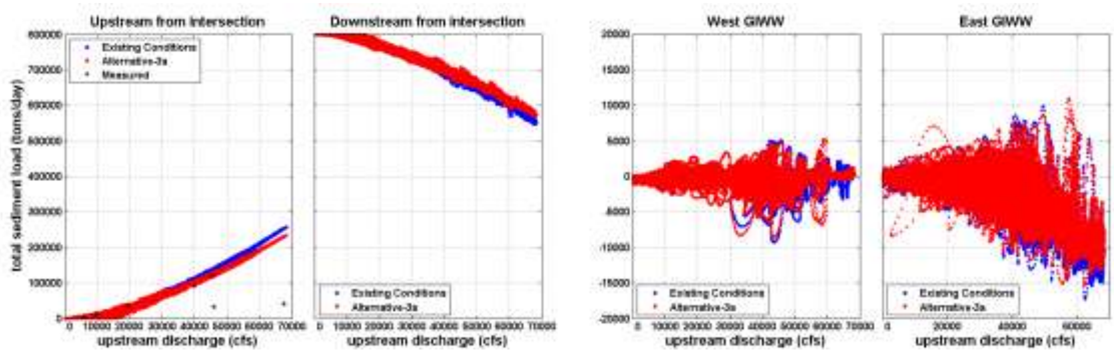

Figure 67. Sediment load vs river discharge for existing conditions and Alt 3a.

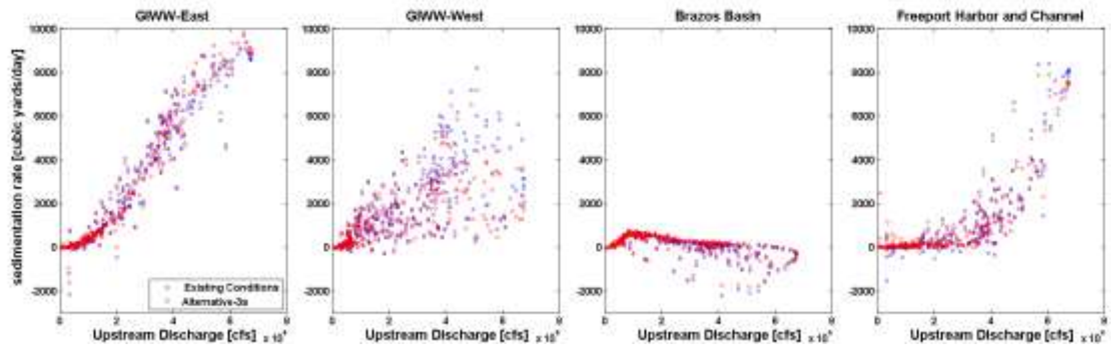

Figure 68. Sedimentation rate vs river discharge for existing conditions and Alt 3a.

Figure 69 shows the sediment flux rating curves for Alternative 3a.1. As with Alternative 3a, there is a noticeable decrease in upstream flux into and downstream flux out of the Brazos Basin at higher flow rates as well as a slight decrease in flux into the East GIWW at high flow rates. However, sediment fluxes both into and out of the West GIWW are increased in magnitude as the absence of the West Gate means there is less damping of tidal flows, which dominates flows and sediment fluxes into the West GIWW. Figure 70 shows the daily sedimentation rating curves for the zones of influence requiring maintenance for Alternative 3a.1. There is no noticeable change in sedimentation rates in the East GIWW, Brazos Basin or Freeport Harbor, however there is a slight increase in sedimentation rate in the West GIWW due to the open channel.

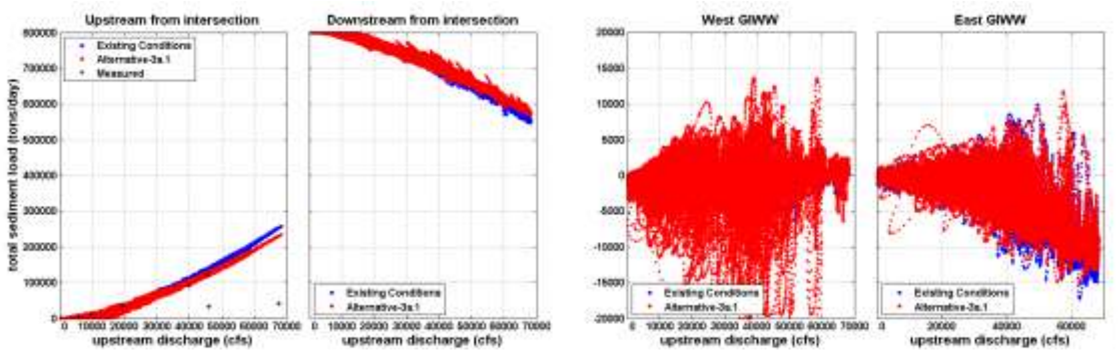

Figure 69. Sediment load vs river discharge for existing conditions and Alt 3a.1.

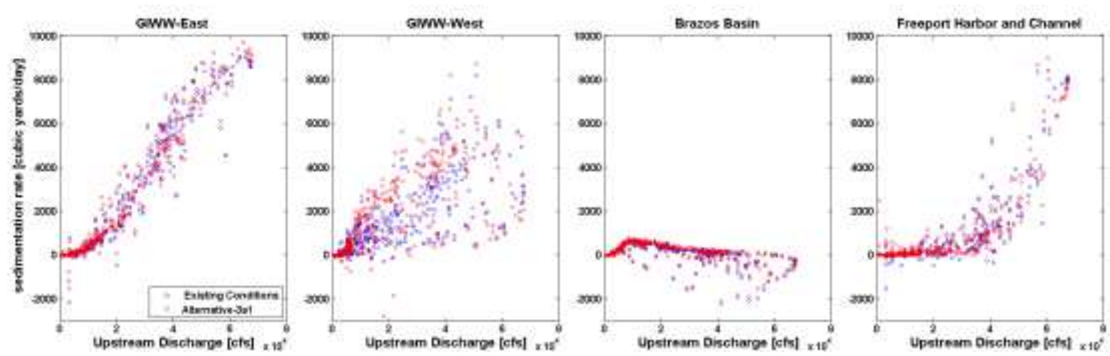

Figure 70. Sedimentation rate vs river discharge for existing conditions and Alt 3a.1.

Figure 71 shows the sediment flux rating curves for Alternative 9a. As with Alternative 3a, there is a noticeable decrease in upstream flux into and downstream flux out of the Brazos Basin at higher flow rates. There is a noticeable increase in sediment flux into the East GIWW at high flow rates, and sediment fluxes both into and out of the West GIWW are increased in magnitude as the absence of gates means there is less damping of tidal flows, which dominates flows and sediment fluxes into the West GIWW.

Figure 72 shows the daily sedimentation rating curves for the zones of influence requiring maintenance for Alternative 9a. Sedimentation rate in the East GIWW seems to increase at flow rates lower than 4,000 cfs, but decreases at high flow rates when sediment loads are more dramatic. This is intuitive as above a certain flow rate, velocities in the East GIWW will be too high to allow sediment to settle. This observation can be further corroborated by the sedimentation rate in the Freeport Harbor, where flows above 4,000 cfs cause significantly increased sedimentation from Existing Conditions, and lower flows cause negligible sedimentation. The Brazos Basin experiences a noticeable increase in sedimentation rate for flows greater than 1,000 cfs. This can be explained by sediments settling out on the north side of the GIWW just east of the Brazos River – GIWW intersection where higher flows cause a large eddy (as seen in Figure 33). Sedimentation rates in the West GIWW show a slight increase with no real correlation to flow rate.

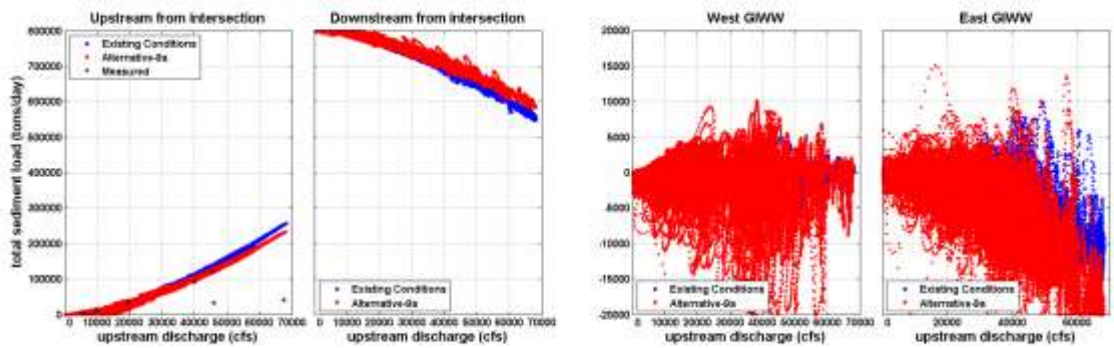

Figure 71. Sediment load vs river discharge for existing conditions and Alt 9a.

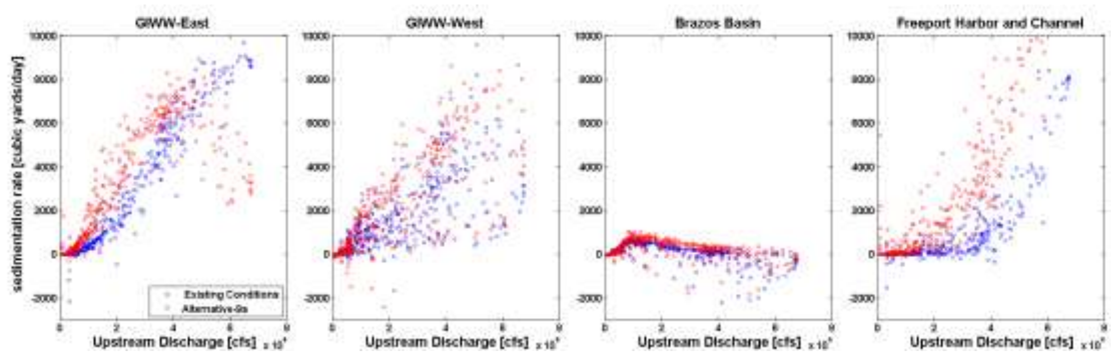

Figure 72. Sedimentation rate vs river discharge for existing conditions and Alt 9a.

Figure 73 shows the sediment flux rating curves for Alternative 9b. As with Alternatives 3a and 9a, there is a decrease in upstream flux into and downstream flux out of the Brazos Basin at higher flow rates. Sediment flux into and out of the west GIWW are increased in magnitude from Existing Conditions, especially at flow rates less than 3,000 cfs. Sediment flux into the East GIWW is increased slightly, especially at high flow rates. Figure 74 shows the daily sedimentation rating curves for the zones of influence requiring maintenance for Alternative 9b. All zones experience an increase in sedimentation rate for flow rates above 2,000 cfs. Like Alternative 9a, at very high flow rates, there is a slight reduction in sedimentation rate in the East GIWW with an accompanying increase in sedimentation in the Freeport Harbor.

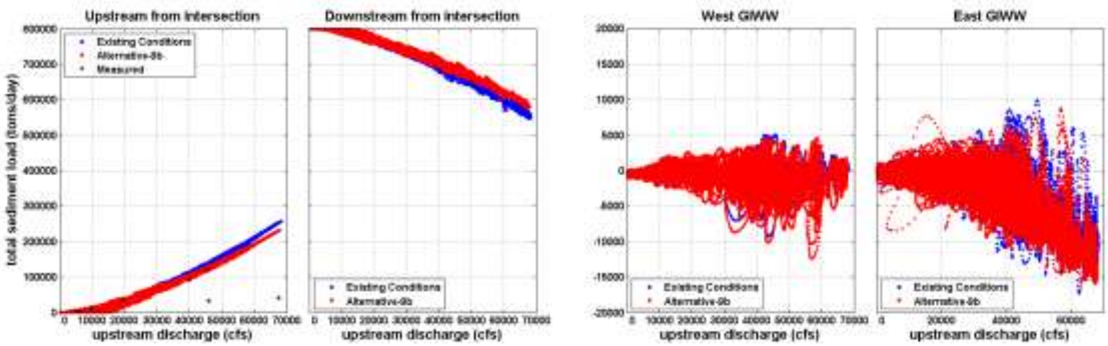

Figure 73. Sediment load vs river discharge for existing conditions and Alt 9b.

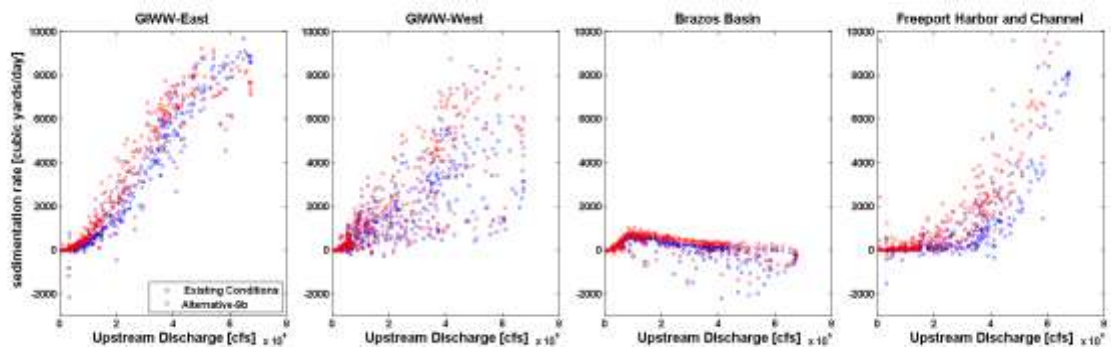

Figure 74. Sedimentation rate vs river discharge for existing conditions and Alt 9b.

Figure 75 shows the sediment flux rating curves for Alternative 9c. The sediment fluxes are virtually identical to Alternative 9b. This is understandable as the only difference between the two alternatives is the sluice gate which is seldom opened and intended to primarily aid in navigation, not to prevent sedimentation.

Figure 76 shows the daily sedimentation rating curves for the zones of influence requiring maintenance for Alternative 9c. As with sediment fluxes, sedimentation rates are very similar to Alternative 9b. The only noticeable difference is that sedimentation rates in the Brazos Basin are slightly for flow rates between 2,000 cfs and 6,000 cfs, which is most likely due to a slight increase in area of the basin near the sluice gate.

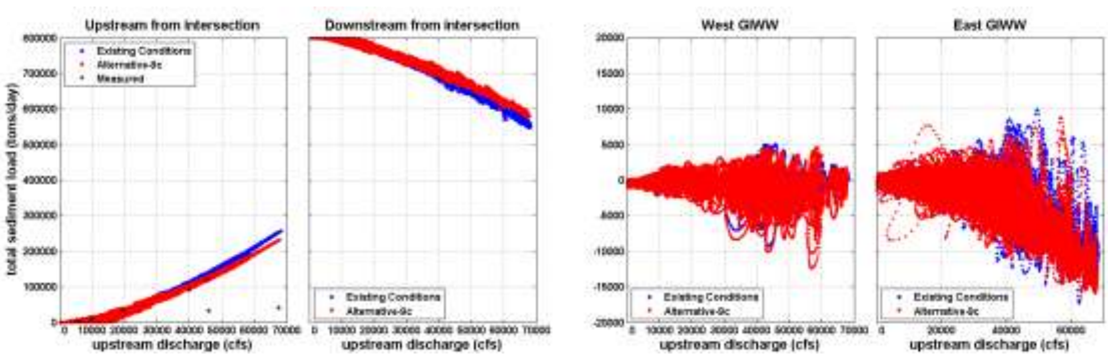

Figure 75. Sediment load vs river discharge for existing conditions and Alt 9c.

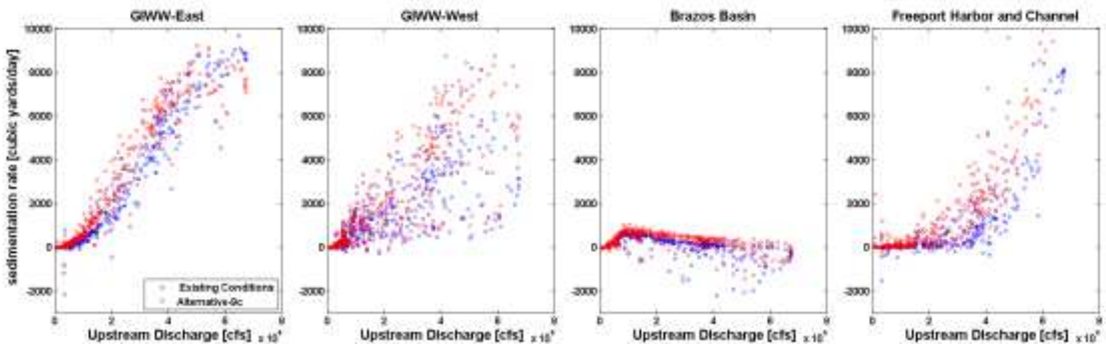

Figure 76. Sedimentation rate vs river discharge for existing conditions and Alt 9c.

Some general trends can be observed for all alternatives. For example, the sediment fluxes upstream, downstream and east of the Brazos Basin generally show an exponential relationship with upstream flow rate, where an increasing flow rate is accompanied by an increase in sediment flux. However, west of the Brazos Basin, there is no apparent relationship between sediment flux and river flow rate. Thus, flow and sediment flux through the west gate seems to be mostly tide-dominated.

Furthermore, based on the sedimentation rating curves, sedimentation rates in the East GIWW increase rapidly between flow rates of 2,000 cfs and 5,000 cfs, and tend to reduce slightly at flow rates greater than 6,000 cfs. In the West GIWW, the relationship is quite scattered. While there is some general increase in sedimentation with increase in flow rate, the large scatter likely indicates that either the tide dominates, or that the San Bernard River influences sedimentation in some way. In the Brazos basin, sedimentation rates increase with and peak at a flow rate of approximately 1,000 cfs at which point they begin to decrease. Negative sedimentation rates indicate erosion of a previously deposited sediment.

In the Freeport harbor, sedimentation rates are negligible for flows less than 2,000 cfs and increase dramatically with flow rates greater than 5,000 cfs. This is intuitive since at low flow rates, sediments heading towards Freeport will instead settle in the East GIWW, and at very high flow rates, sediments are not able to settle in the East GIWW and will instead settle in Freeport.

Table 24 summarizes annualized sedimentation volumes computed in each of the zones of influence. The percent change in total sediment volume in all six zones of influence is less than 1.1% for all alternatives, indicating that the total sediment budget is conserved and local sources of sediment in the model domain are negligible.

Table 25 summarizes the changes in sedimentation volume relative to Existing Conditions for all project alternatives and zones of influence requiring maintenance.

Alternative 3a shows relatively modest changes in sedimentation. There is a small decrease in sediment to the west GIWW and a modest increase to other zones, with an overall slight (negligible) decrease in total sedimentation in zones requiring maintenance dredging. Alternative 3a.1 is very similar to Alternative 3a in the Brazos Basin, East GIWW and Freeport Harbor, in the West GIWW, there is a significant increase in sedimentation rate due to absence of the West Gate.

Alternative 9a had the largest changes in sedimentation both in the GIWW east and west, and had a dramatic increase in sedimentation in the Freeport Channel (231%), and had an overall increase in total sedimentation that requires maintenance of about 64%. In addition, this alternative reduces the sediment to the Brazos Delta, but only by a 5% reduction.

Alternatives 9a and 9b performed nearly identically, with patterns similar to alternative 9a with slightly smaller magnitudes, and an overall increase in sedimentation to be maintained of about 38%. The only substantial difference between 9b and 9c is a slight increase in sedimentation in the Brazos Basin in 9c at the location of the sluice gate. It is hypothesized that the sluice gate allows additional sediment into the basin, possibly recirculated from the western gate around the GIWW and back into the Brazos through the sluice gate.

Table 24. Summary of sedimentation volumes in cubic yards for a one year period for each alternative and all zones of influence.

	West GIWW	Brazos Basin	East GIWW	Freeport Channel	Brazos Delta	Freeport Offshore	Total	% Change
Existing	554,769	48,000	890,769	295,385	44,382,462	208,726	46,379,628	0.0%
3a	493,846	59,077	902,769	316,615	44,332,615	190,864	46,295,289	-0.2%
3a.1	653,130	58,332	902,653	326,420	44,000,887	196,239	46,137,661	-0.5%
9a	781,846	92,308	1,079,077	978,462	42,026,769	854,614	45,813,556	-1.2%
9b	780,923	96,923	1,044,000	550,154	43,232,308	396,989	46,102,044	-0.6%
9c	781,846	107,077	1,044,000	550,154	43,218,462	395,887	46,097,646	-0.6%

Table 25. Summary of sedimentation volume change from existing conditions in cubic yards (and percent) for each alternative and all zones of influence.

	West GIWW	Brazos Basin	East GIWW	Freeport Channel	Brazos Delta	Freeport Offshore	Total Change in Zones Requiring maintenance
3a	-61,000 (-11%)	11,000 (23%)	12,000 (1%)	21,000 (7%)	-50,000 (0%)	-18,000 (-8%)	-17,000 (-0.1%)
3a.1	98,000 (18%)	10,000 (22%)	12,000 (1%)	31,000 (11%)	-381,000 (-1%)	12,000 (-6%)	151,000 (8%)
9a	227,000 (41%)	44,000 (92%)	188,000 (21%)	683,000 (231%)	-2,356,000 (-5%)	646,000 (309%)	1,143,000 (64%)
9b	226,000 (41%)	49,000 (102%)	153,000 (17%)	255,000 (86%)	-1,150,000 (-3%)	188,000 (90%)	683,000 (38%)
9c	227,000 (41%)	59,000 (123%)	153,000 (17%)	255,000 (86%)	-1,150,000 (-3%)	187,000 (90%)	794,000 (39%)

Figure 78 to Figure 81 show a comparison of the modeled sedimentation patterns at the West GIWW, Brazos Basin, East GIWW, and Freeport Harbor respectively. Figure 77 shows the alignment and bounds of each of these figures.

As shown in Figure 78, the most noticeable changes in sedimentation occur near the Brazos River – GIWW intersection. While Alternative 3a experiences a small net decrease in sedimentation volume (Table 25), the volume of sedimentation between the Brazos River and the East Gate has increased dramatically. Thus, while the overall dredge volume required may be decreased, the dredge frequency will increase for that small region.

Figure 79 and Figure 80 show that while the sedimentation near in the GIWW near the Brazos River hasn't changed much for Alternative 9a, while sedimentation father from the Brazos River has increased significantly, particularly in the Freeport Harbor (Figure 81)

Alternatives 9b and 9c show a similar trend to Alternative 9a, but not as pronounced. Also, similar to Alternative 3a, there is significant increase in sedimentation locally just east of the east gate, indicating that dredge frequency in this area would need to be increased.

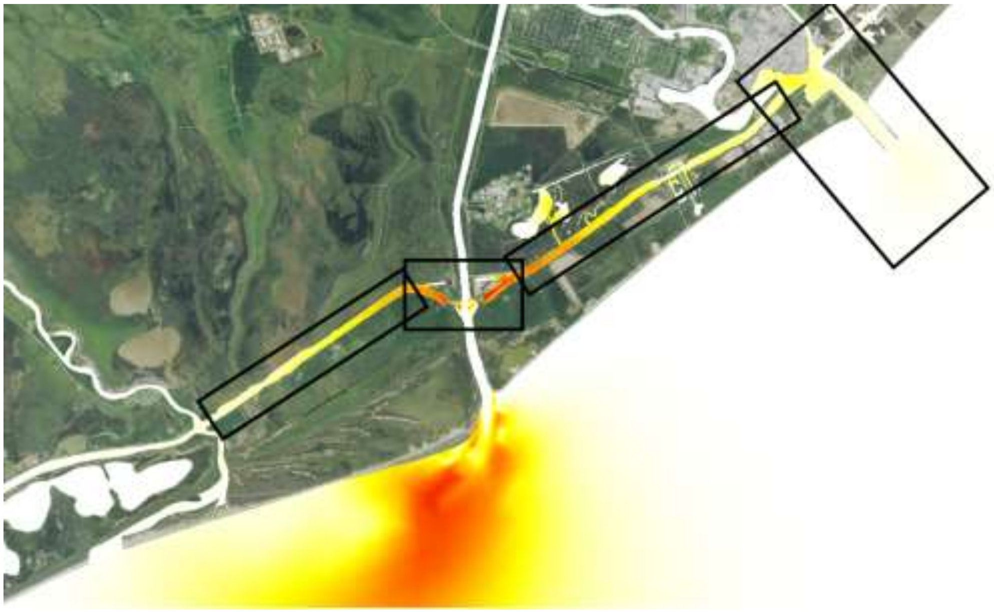

Figure 77. Sedimentation pattern zones master figure.

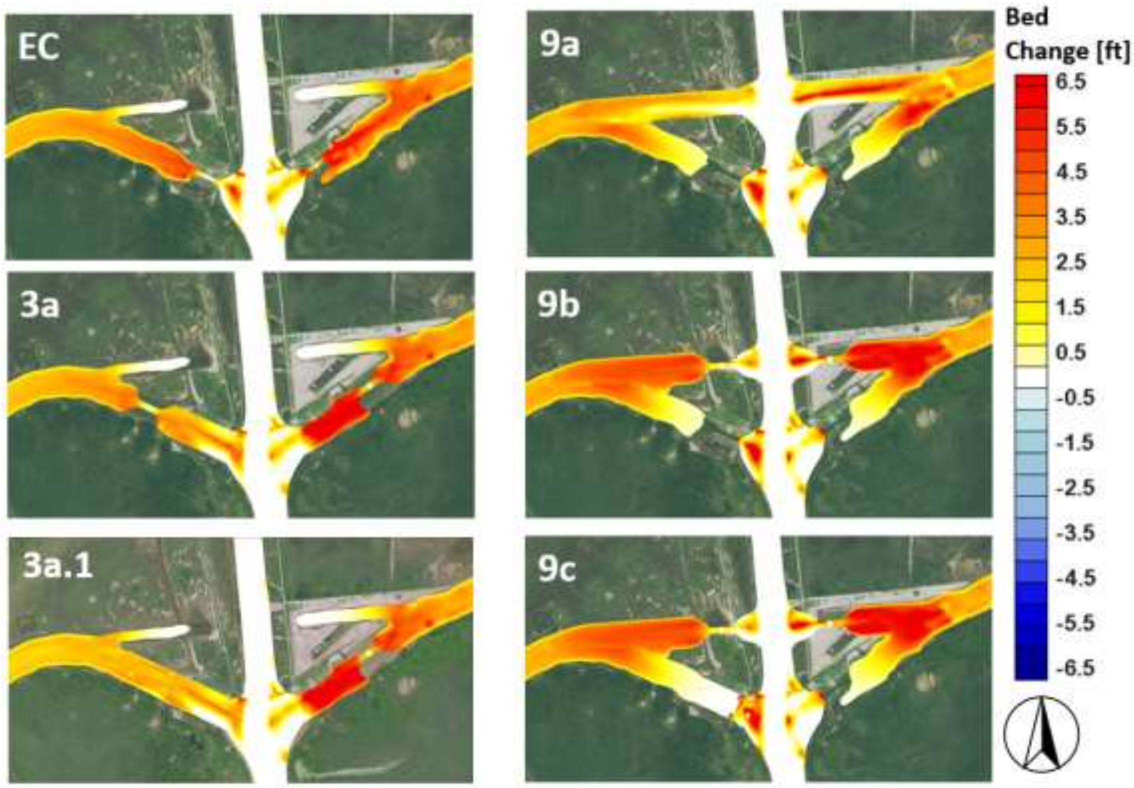

Figure 78. Sedimentation pattern at the Brazos River - GIWW intersection for all alternatives.

Figure 79. Sedimentation pattern in the West GIWW for all alternatives.

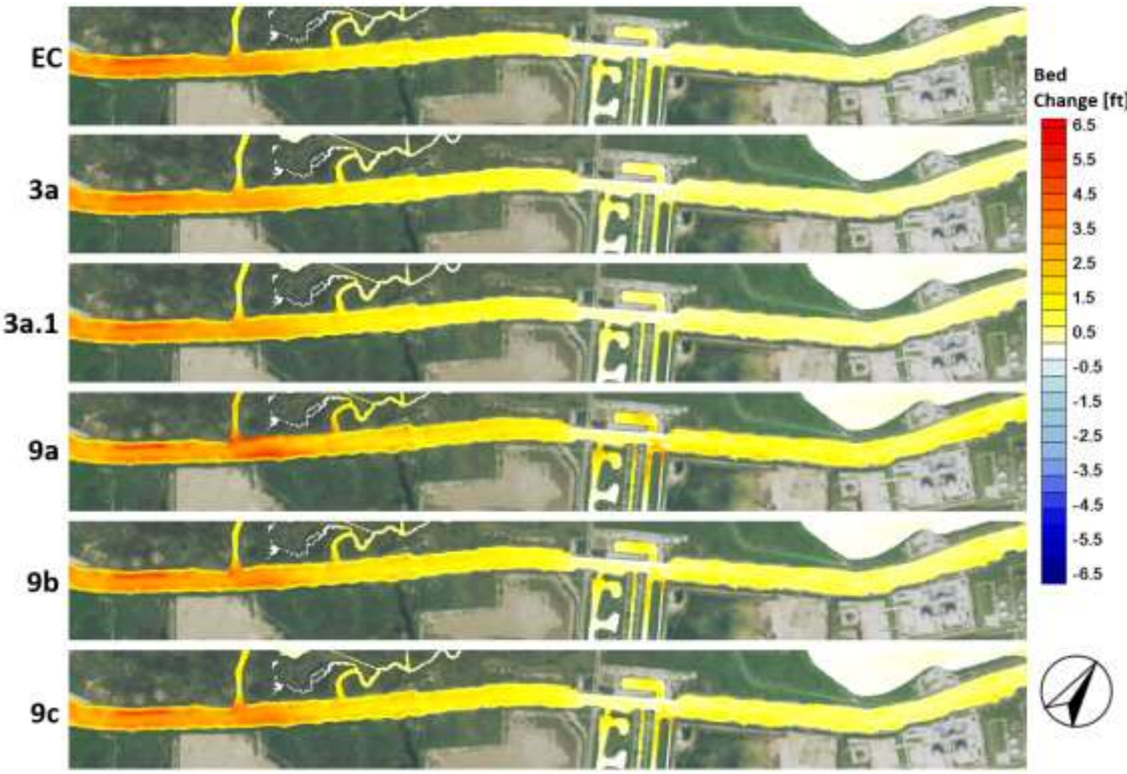

Figure 80. Sedimentation pattern in the East GIWW for all alternatives.

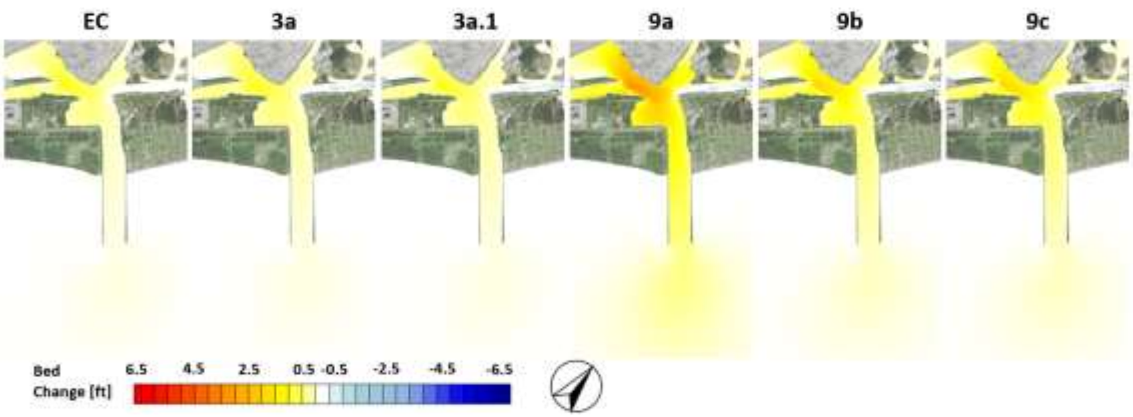

Figure 81. Sedimentation pattern in the Freeport Harbor and channel.

5.3.1 Scaling of Sedimentation Rates

Actual dredging rates for each zone of influence were obtained from the USACE operations department. The annual dredging rates obtained from the USACE operations personnel are provided in Table 26.

Table 26. Scale ratio for East GIWW, Brazos Basin and West GIWW for Existing Conditions to account for the difference between sedimentation volume and dredge volume.

	USACE operations [cu.yd./yr.]	ADH Model [cu.yd./yr.]	Scale Ratio [-]
East GIWW	395,000	890,769	0.44
Brazos Basin	110,000	48,000	2.29
West GIWW	360,000	554,769	0.65

Since the modeled sedimentation rates account for all material deposited within each zone (ie, bank to bank sedimentation) while the USACE operations measure the amount dredged from the channel boundaries only, the modeled sedimentation rates were scaled to match the actual dredging quantities provided by USACE operations. The annual dredging volumes were used to scale the modeled sedimentation rates for existing conditions. The scaling ratio developed for existing conditions was applied to the modeled alternative results. A separate scaling ratio was developed for the East GIWW, Brazos Channel, and West GIWW as shown in Table 26. The sedimentation rates within the Freeport Channel area were not scaled due to limited detailed dredging data in this area. A summary of the sedimentation scaling is shown below in Table 27.

Table 27. Summary of modeled and scaled annual sedimentation rates in cubic yards

	West GIWW		Brazos Channel & Basin		East GIWW			
	Modeled	**Scaled**	Modeled	**Scaled**	Modeled	**Scaled**	**Freeport Channel**	**Total[1]**
Existing	554,769	**360,000**	48,000	**110,000**	890,769	**395,000**	**295,385**	**1,160,385**
3a	493,846	**320,466**	59,077	**135,385**	902,769	**400,321**	**316,615**	**1,172,787**
3a.1	653,130	**423,828**	58,332	**133,678**	902,653	**400,270**	**326,420**	**1,284,196**
9a	781,846	**507,355**	92,308	**211,539**	1,079,077	**478,503**	**978,462**	**2,175,858**
9b	780,923	**506,756**	96,923	**222,115**	1,044,000	**462,948**	**550,154**	**1,741,973**
9c	781,846	**507,355**	107,077	**245,385**	1,044,000	**462,948**	**550,154**	**1,765,842**

The scaled sedimentation rates were used by the economic team to analyze project costs and net benefits.

5.3.2 Impact of Sea Level Rise on Sedimentation Rate

To bolster posterity of the TSP selection, the sedimentation model was run with a hypothetical relative sea level rise (RSLR) of 1 ft. and 2 ft. Table 28 shows a summary of sedimentation volumes in each zone of influence for all alternatives and relative sea level rise conditions. These data are presented graphically in Figure 82 through Figure 85. Alternative 9c was excluded from this analysis because it assumed to have nearly identical values to Alternative 9b.

Table 28. Summary of sedimentation volumes and percent change from the base condition for all alternatives and RSLR conditions. Percent changes, in parentheses are relative to the base condition for each zone of influence.

	West GIWW			Brazos Basin			East GIWW			Freeport Channel		
	Existing	**+1ft.**	**+2ft**	**Existing**	**+1ft.**	**+2ft**	**Existing**	**+1ft.**	**+2ft**	**Existing**	**+1ft.**	**+2ft**
2a	554,769 (-)	701,987 (+27%)	771,263 (+39%)	48,000 (-)	57,366 (+20%)	62,006 (+29%)	890,769 (-)	924,755 (+4%)	986,214 (+11%)	295,385 (-)	239,774 (-19%)	193,047 (-35%)
3a	493,846 (-11%)	655,834 (+18%)	687,736 (+24%)	59,077 (+23%)	71,184 (+48%)	79,948 (+67%)	902,769 (+1%)	1,030,745 (+16%)	1,133,765 (+27%)	316,615 (+7%)	386,029 (+31%)	337,209 (+14%)
3a.1	653,130 (+18%)	820,267 (+48%)	905,365 (+63%)	58,332 (+22%)	69,693 (+45%)	78,301 (+63%)	902,653 (+1%)	943,599 (+6%)	1,018,189 (+14%)	326,420 (+11%)	278,102 (-6%)	239,442 (-19%)
9a	781,846 (+41%)	1,019,896 (+84%)	1,206,746 (+118%)	92,308 (+92%)	111,199 (+132%)	128,972 (+169%)	1,079,077 (+21%)	1,231,424 (+38%)	1,399,920 (+57%)	978,462 (+231%)	948,741 (+221%)	900,053 (+205%)
9b	780,923 (+41%)	1,025,001 (+85%)	1,241,545 (+124%)	96,923 (+102%)	105,580 (+120%)	119,645 (149%)	1,044,000 (+17%)	1,133,113 (+27%)	1,239,575 (+39%)	550,154 (+86%)	473,473 (+60%)	418,966 (+42%)

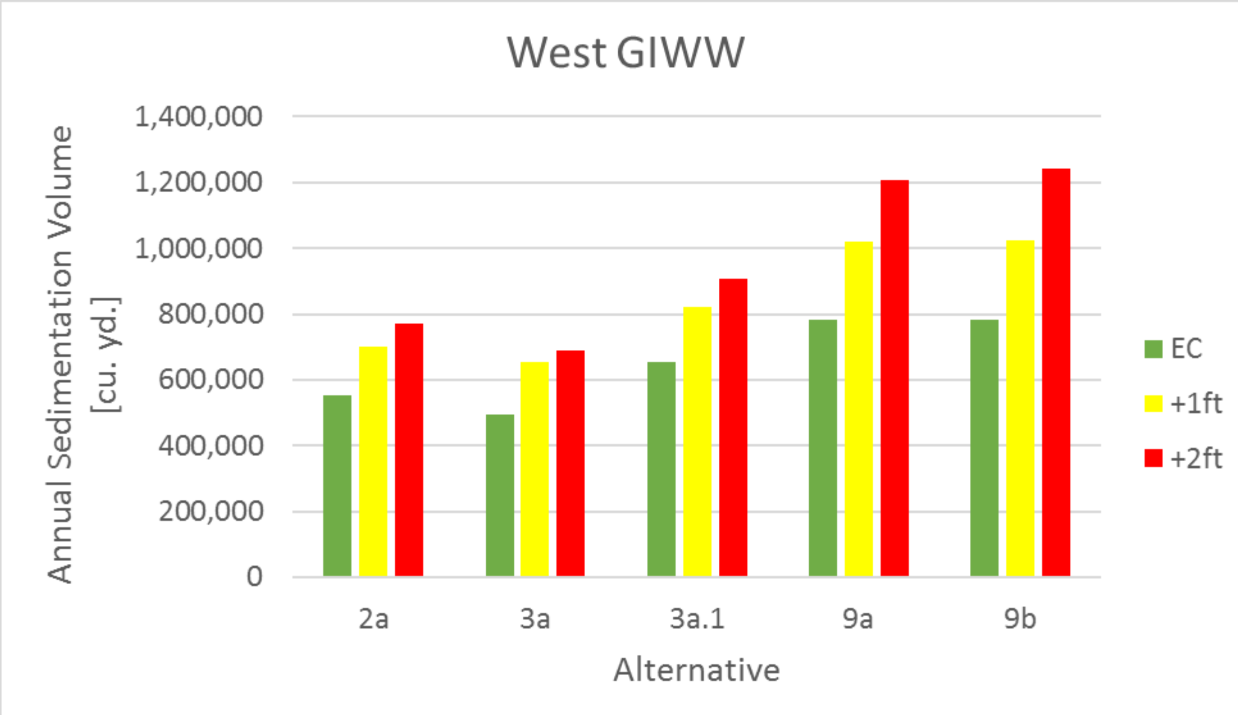

Figure 82. Sedimentation volume in the West GIWW for all alternatives and sea-level conditions.

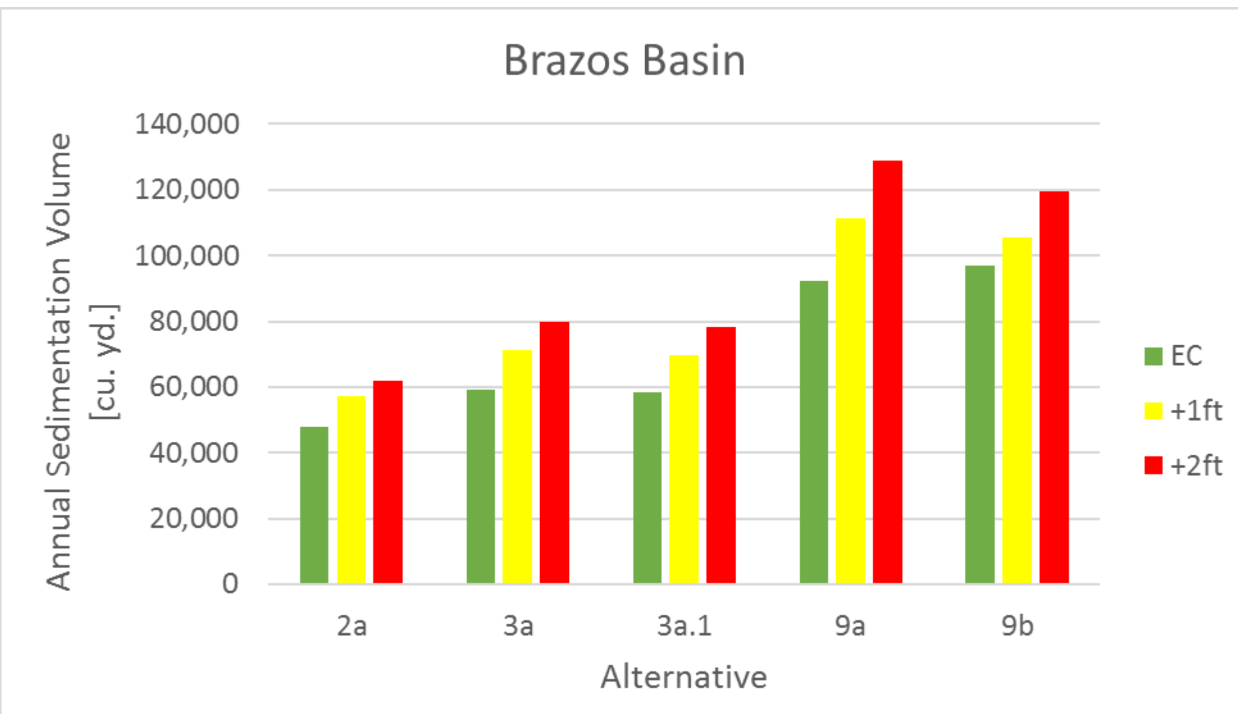

Figure 83. Sedimentation volume in the Brazos Basin for all alternatives and sea-level conditions.

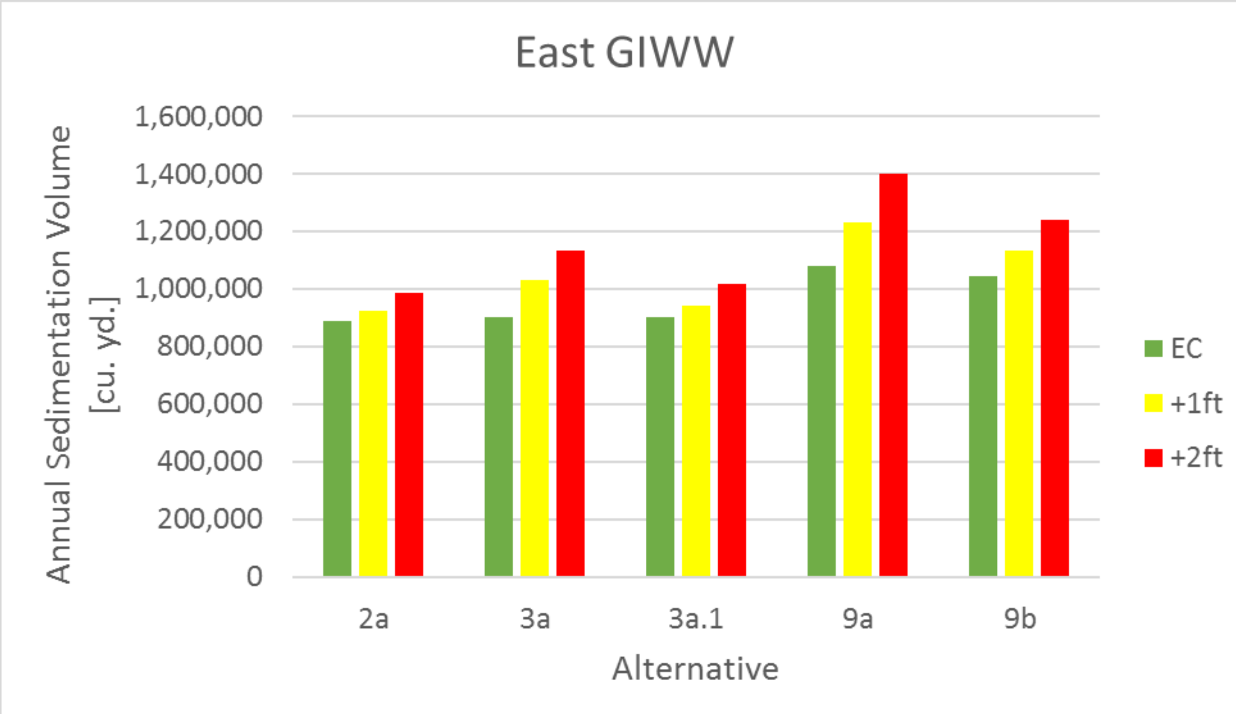

Figure 84. Sedimentation volume in the East GIWW for all alternatives and sea-level conditions.

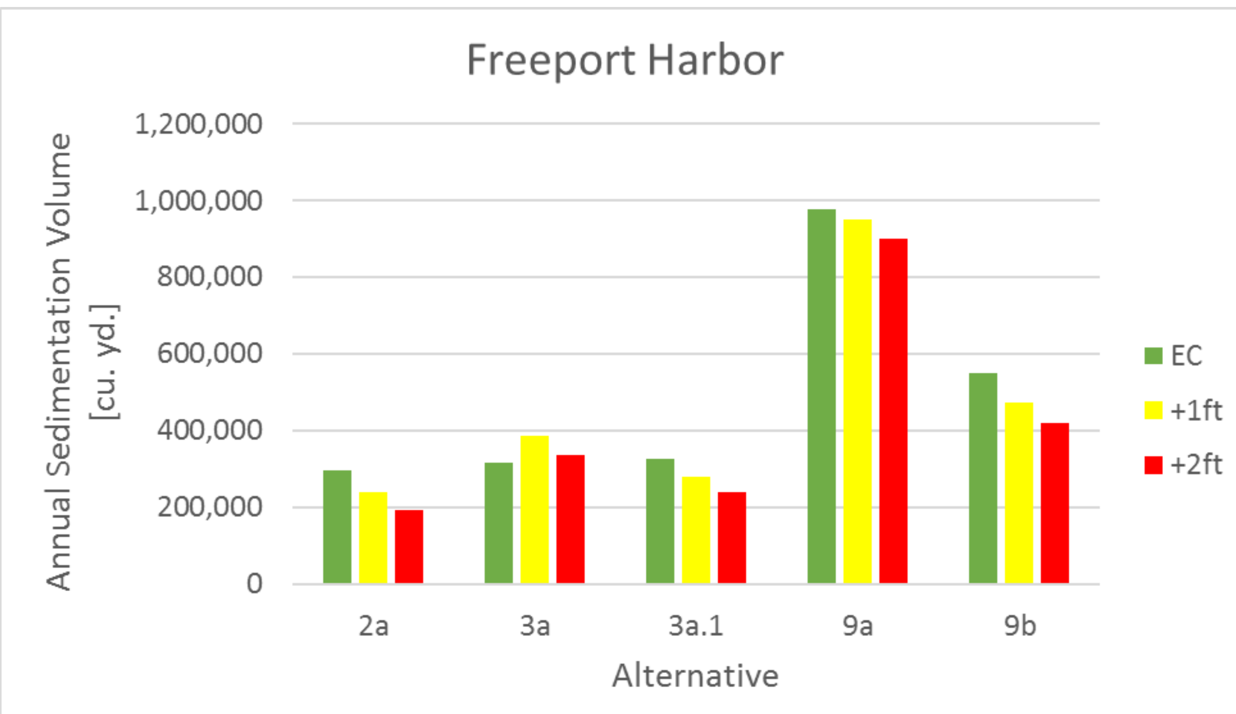

Figure 85. Sedimentation volume in the Freeport Harbor for all alternatives and sea-level conditions.

All alternatives show an almost linear increase in sedimentation volume with RSLR in the East GIWW, West GIWW and Brazos Basin, with a corresponding decrease in sedimentation volume in the Freeport Harbor. This is expected, as the higher sea level would correspond to a lower velocity in the GIWW which would cause more sediment to fall out of suspension before reaching the Freeport Harbor. The effects of sea level rise are most dramatic in the West GIWW for Alternatives 9a and 9b, where the sedimentation volume increases by nearly 500 thousand cubic yards (about 120% increase from the base condition). Comparatively, Alternative 3a.1 which has an open channel connection to the West GIWW only increases in sedimentation volume by less than 250 thousand cubic yards, indicating that a straight channel is more sensitive to RSLR than a channel along the existing alignment.

While not explicitly included in Table 28, the sedimentation volumes in the Brazos Delta and the Freeport Offshore both tend to decrease with increasing sea level, further compensating for the sedimentation increase in the GIWW. All model scenarios have less than a 2% net change in total sedimentation volume from the base case, so any changes in sedimentation cannot be attributed to a change in the sediment budget of the model. Since the changes in sedimentation volumes appear to be uniform across all alternatives, it is unlikely that the outcome of a TSP selection will change based on RSLR.

6 Navigation Analysis

6.1 Introduction

Closures and delays at the Brazos River floodgates are often caused by hydraulic conditions. This Section of the report quantifies these closure and delay conditions for existing conditions, and uses the results of the hydraulic model to quantify those conditions for the proposed alternatives. The following sub-sections examine project site conditions, provide an assessment of existing navigation regulations, provide a methodology for analyzing the hydraulic model results, calibrate the model for existing conditions, and perform an analysis of the navigation conditions for all proposed alternatives.

6.2 Project Site Conditions

This Section examines existing conditions at the Brazos River Floodgates (BRFG). In this Section, closure and delay criteria are described and a summary of the available data is provided.

6.2.1 Existing Closure & Delay Criteria

Delay conditions at the Brazos River Floodgates are caused by numerous factors including high velocities in the Brazos River, head differential between the river and GIWW side of the gate structure, and accidents. This memorandum investigates closures due to river velocity and head difference. Closures due to accidents are included in economic analysis and models developed under task 100.3 – Economics. The closure criteria guidelines for hydraulic conditions as listed in 33 CFR 207.187 are shown in Table 29 (USACE, 1969). Note that the closure criteria for river velocities is based upon the High Water Operations Policy Memorandum CESWG-OD-O (11-2-240a) (USACE2016).

Table 29. Closure criteria.

Condition	Description	River Conditions
Unlimited passage	No restrictions on passage.	River current below 2 mph and head differential is less than 0.7 feet.
Limited Passage	Passage allowed for single vessels with a single loaded barge or two empty barges	River current between 2-5 mph (daylight) or 2-7 mph (night) or the head differential is between 0.7-1.8 feet.
Gate Closures	Closed to navigation.	River current exceeds 7 mph (daylight) or 5 mph (night). Head differential exceeds 1.8 feet.

6.2.2 Available Data for Navigation Analysis

Each of the Brazos floodgates were individually removed for maintenance between 2009 and 2013. Thus, the gages were analyzed in the period between March 2015 and April 2016 to determine typical hydrodynamic conditions at the Brazos gates.

6.3 Navigation Assessment

This Section assesses the navigation standards to characterize the safe inland waterway navigation criteria through the Brazos River Floodgates. The goal of this section is to understand how the navigation threshold criteria are set relative to the standards in order to understand how they may change with future alternative conditions.

Currently the GIWW is maintained to a bottom width of 125 feet. Depths along the GIWW are maintained at a project depth of 12 feet mean low water. As shown in Table 29, there are regulations on the operations of the floodgates that fall into three categories. Proposed alternatives include a 125-foot-wide gate structure, which is 50 feet wider than the existing alignment. It is possible that the closure conditions may change under the proposed wider gate alignment. For the purposes of this analysis, closure and limited passage conditions were assumed to remain the same for all alternatives. Shipping industry members were consulted during a Project Delivery Team (PDT) meeting held on October 5th, 2017. Industry members were consulted regarding closure restrictions for the with-project conditions. Industry members present at the October 5th meeting recommended maintaining the current restriction and closure criteria for all with project alternatives.

6.4 Navigation Analysis Methodology

The goal of this analysis is to determine delays at the Brazos River floodgates for the existing configuration due to conditions exceeding the limitations stated in 33 CFR207.187. Closure data during the model simulation period was obtained from the USACE and used to calibrate the navigation analysis (USACE, 2017).

Modeling of hydrodynamic processes at the project site was conducted using the ADH model as described in Section 3.1. The modeled flow conditions were analyzed for delay events and compared to the measured closures. The following methodology is proposed to compare the recorded closures to the modeled closures.

- Outlier processing was conducted to remove unrealistically high or low spikes in modeled data. Closure or limited passage events less than a 30-minute duration were removed from the modeled dataset. Events with less than a 45-minute time between them were grouped into a singular event.
- The modeled data was processed through a low pass to remove the higher frequency fluctuations due to gate operations, discussed in Section 2.1.1.2.
- Recorded closure data due to head differential and river velocity was obtained from the USACE. The filter scheme that provided the highest correlation between the modeled and recorded closures and limited passage conditions was selected.
- A comparison between the recorded and modeled closure data was conducted to determine the percent error of modeled closures when compared to recorded closures.

6.5 Existing Condition Results

This Section discusses the analysis conducted to determine closures of the existing BRFG system. The goal of the analysis of existing conditions analysis are to develop understanding of hydrodynamic conditions causing closures of the BRFG system crossing during a variety of conditions. This methodology will be used to quantify closures for proposed array of alternatives

6.5.1 Measured Data Delays

6.5.1.1 Limited Passage & Closure Data

As shown in Table 29, limited passage due to river velocity occurs when the river velocity is between 2 mph and 5 mph during nighttime hours, or between 2 mph and 7 mph during daylight hours. Limited passage due to head differential occurs when the head differential at the gates is between 0.7 and 1.8 feet. Limited passage requires "… passage afforded only for single vessels or towboats with single loaded barges or two empty barges. When two barges are rigidly assembled abreast of each other and the combined width is 55 feet or less, they are considered a single barge". Limited passage requires additional tripping of barges, and is therefore a key variable when determining the delays related to the hydrodynamics at the BRFG system.

Complete closure of the gates due to river velocity occurs when the river velocity is greater than 5 mph during nighttime hours, or above 7 mph during daylight hours. Closures due to head differential occur when the head differential at the gates is greater than 1.8 feet. Recorded closures and limited passage conditions were analyzed for the model simulation period of March 1, 2015 to April 1, 2016 (USACE, 2017). A summary of the recorded limited passage conditions and closure during the model simulation period of March 1, 2015 to March 31st, 2016 (396 days) is shown below in Table 30.

Table 30. Recorded limited passage delays and closure conditions between March 2015 and April 2016 when the threshold head difference and velocity for limited passage was exceeded.

Condition	Number of days with Delay	% of total time delay occurs
Limited Passage	186	43%
Closures	23	2%
Total	209	45%

Note that the number of days shown in column one of Table 30 represent the number of days over the evaluated time period (396 days occur between 3/1/15 and 3/31/16) when at least one instance of limited passage or closure conditions occur. The percent of total time with a delay column shown in Table 30 represent the percent of total time where a given delay condition was met. The results show that approximately 45% of the time limited passage or closure conditions occur at the Brazos River Floodgates.

6.5.2 Modeled Delays

Output results for existing conditions were extracted from the hydraulic model to determine the modeled downtime due to head differential (>1.8 feet) and river velocity (> 5 mph during daylight or >7mph during nighttime). Statistics on limited passage due to head differential (>0.7 feet) and river velocity (2-7 mph during daylight or 2-5mph during nighttime) were also developed. The extraction points used for delay calculations are shown in Figure 86. To determine river velocity criteria, the velocity used was derived from the total flow divided by the flooded area of the river cross section rather than a singular point extraction. This better represents the overall velocity of the river. The point data shown in Figure 86 represent a singular point along the flow extraction line.

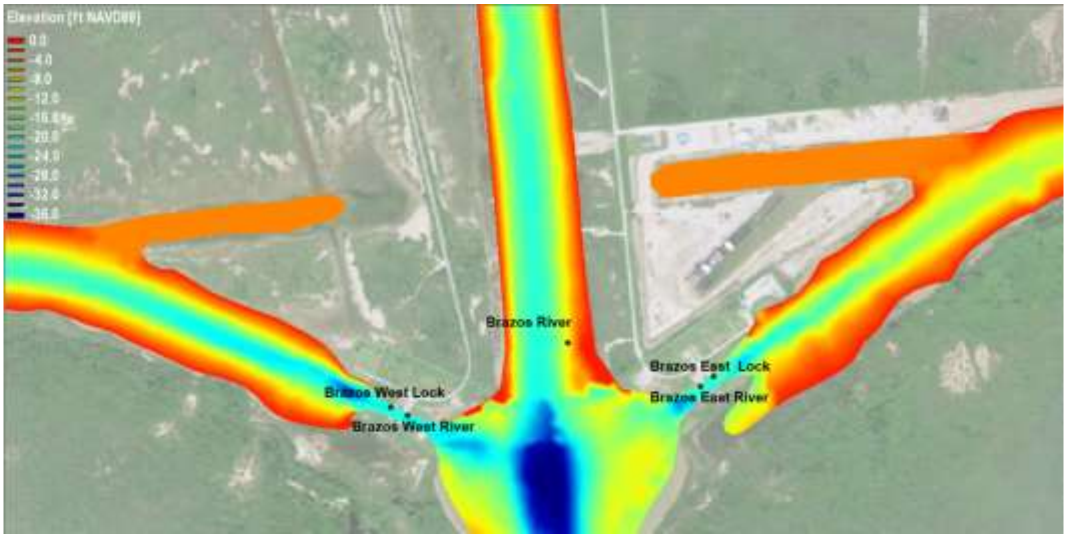

Figure 86. Existing condition model bathymetry and extraction points for navigation analysis.

An example of the raw modeled water surface elevation data and the filtered data is shown in Figure 87. A 3-hour moving average window was used to filter the data shown in Figure 87. Note the large spikes in the raw data. Several filtering schemes were tested and the selected scheme was chosen based on agreement with the recorded closure data. The filtered data was used to calculate the modeled delays and compare them to the known delays as recorded by the USACE. The selected filtering scheme (a moving average window of 3 hours) was able to predict 100% of the limited passage events, and 31% of the closure events. While the closure event prediction rate is fair, the model was able to identify these known closure times as at least limited passage. So, while the closure was not identified for 69% of events, all these events were identified as limited passage (i.e., some navigation impact). The recorded restricted navigation events occur for 45% of the time; the model predicts restricted navigation 48%. Overall the methodology captures the major trends in the navigation restrictions. The results of the modeled closure analysis for limited passage and closure conditions using a 3-hour moving average filter are shown in Table 31 and Table 32, respectively.

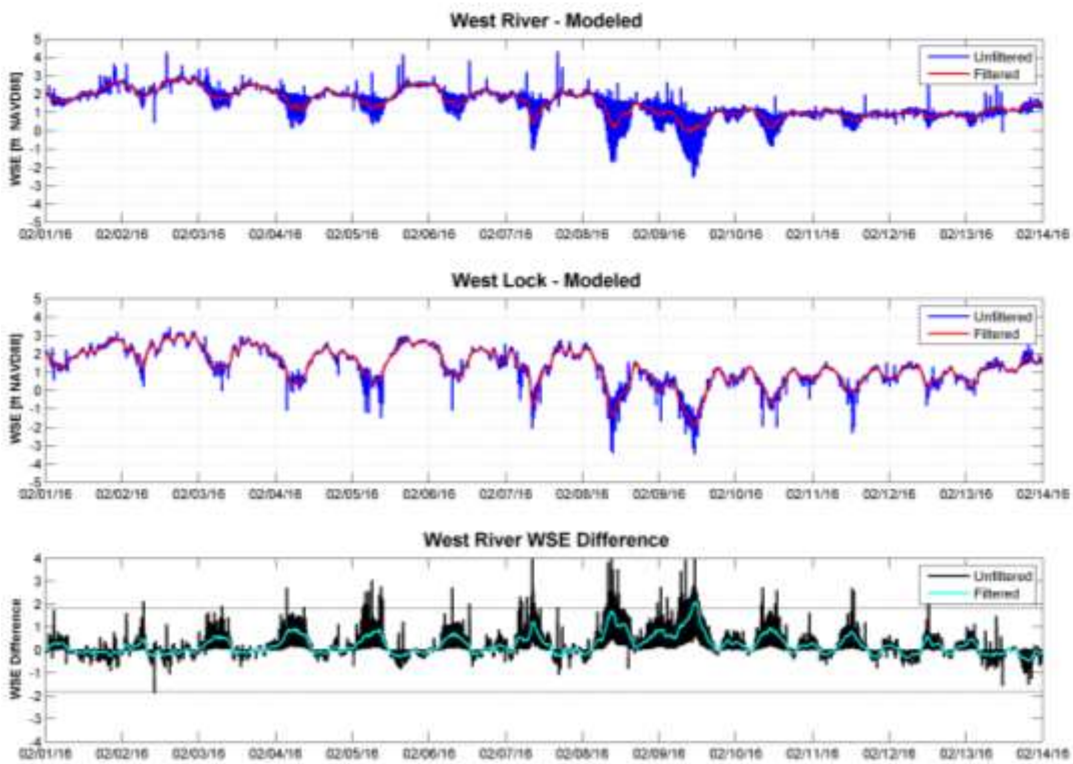

Figure 87. Filtering results for west river extraction point (top), west lock extraction point (middle), and the water surface elevation difference (west river – west lock) between the two gages (bottom).

Table 31. Comparison of what causes modeled limited passage conditions.

Condition	Number of days with delay	% of total time delay occurs
West Gate >0.7ft and <1.8ft on river side	200	5.2%
West Gate >0.7ft and <1.8ft on GIWW side	9	0.03%
East Gate >0.7ft and <1.8ft on river side	11	0.05%
East Gate >0.7ft and <1.8ft on GIWW side	3	0.04%
River Velocity >=2mph	185	41.1%

Table 32. Comparison of what causes modeled closures.

Condition	Number of days with closure	% of total time closure occurs
West Gate >= 1.8 ft on river side	5	0.1%
West Gate >= 1.8 ft on GIWW side	0	0.0%
East Gate >= 1.8 ft on river side	0	0.0%
East Gate >= 1.8 ft on GIWW side	0	0.0%
River Velocity >=5mph	37	3.5%

The results shown in Table 31 and Table 32 illustrate that limited passage and closures conditions are controlled by head differential at the west gate and velocity in the river. The majority of closures and limited passage conditions are due to the river velocity being above the specified thresholds. The second most common cause of both closure and limited passage conditions is the water surface elevation of the river being higher than the water surface elevation of the GIWW at the west gate. Potential causes of these delay conditions are examined later in this Section. A comparison of the modeled closure and limited passage conditions is shown in Figure 88.

Modeled limited passage conditions (light blue) show significant overlap with recorded limited passage conditions (dark blue). Modeled closure conditions (red) show less overlap with recorded closures (pink). The largest discrepancy between recorded and modeled closure conditions occurs in mid-June to early July. There is a modeled closure condition during this time due to high river velocity, while the recorded closure data showed limited passage during this time. Despite this discrepancy, when you combine closure and limited passage conditions, the modeled results show 100% overlap with the recorded results. The model results do show several brief limited passage events from July to November and from February to March that are not in the recorded data; this may be due to the high temporal resolution of the model compared to the manual measurement and implementation of actual limited passage criteria on the ground. Figure 89 shows the modeled head differential at both gates, as well as modeled river velocity plotted against the recorded closure and limited passage conditions obtained from the USACE. Note that the head differential at each gate is calculated by subtracting the river elevation from the GIWW elevation resulting in positive values indicating the GIWW is higher than the river.

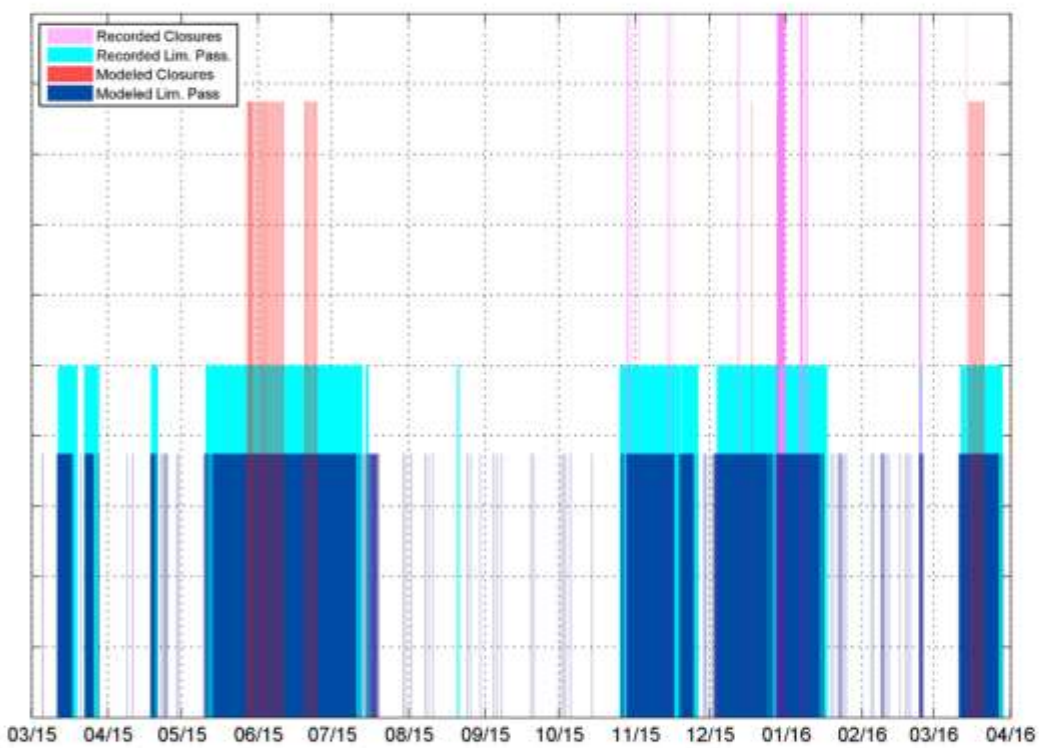

Figure 88. Comparison of recorded and modeled close and limited passage events.

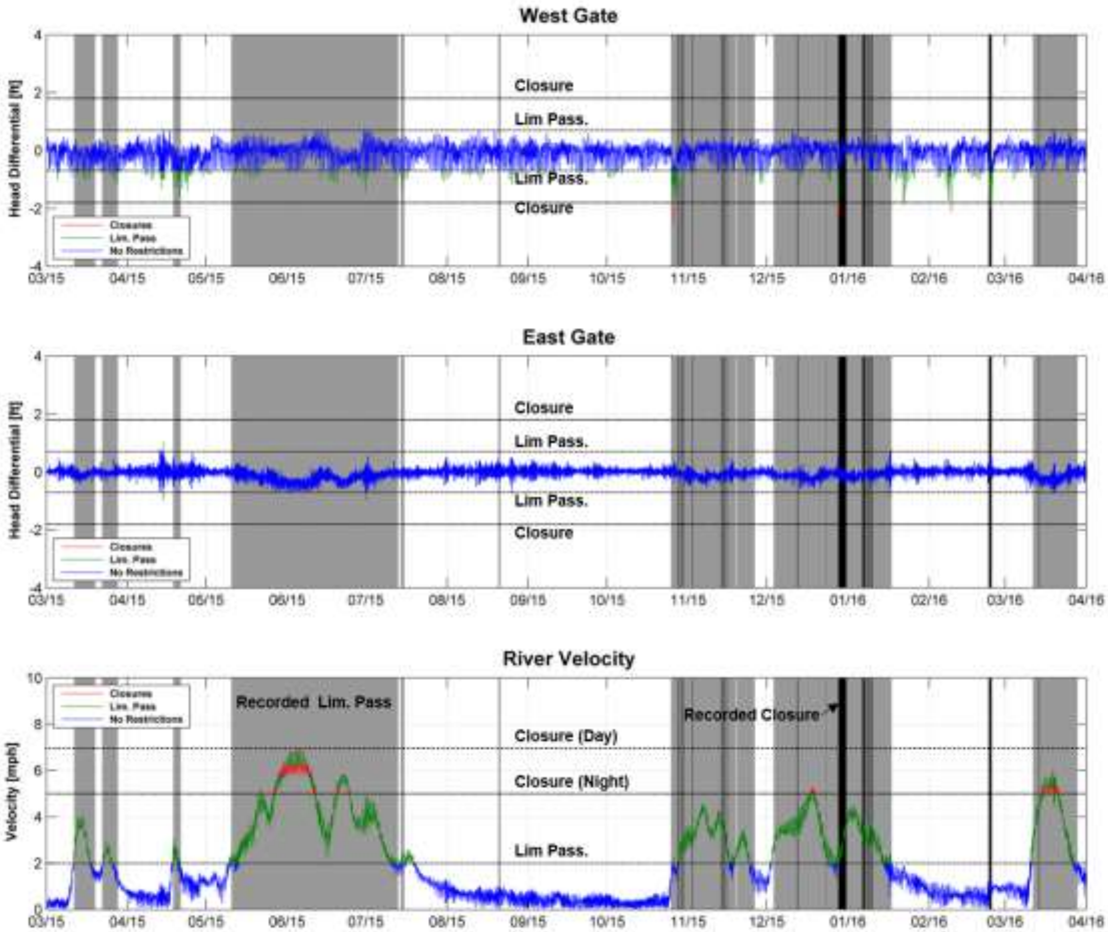

Figure 89. Modeled head differential (River – GIWW) at west gate (top), east gate (middle), and modeled river velocity. Grey shaded areas represent recorded limited passage conditions, while black shaded areas represent recorded periods of closure.

These results show limited modeled closure conditions due to head differential. The only modeled closure events due to head differential occur at the west gate, when the Brazos River is at a higher elevation than the GIWW.

Closure and limited passage events were compared to river conditions to examine the relationship between different types of river events and river flow to quantify any patterns. Figure 90 shows the relationship between days on which a modeled gate closure condition occurs and the time series of flow rates in the Brazos River and San Bernard River and the observed tidal elevation. This figure also shows the relationship between the combined flow rates in the Brazos River and the San Bernard River on days when a gate closure condition occurred.

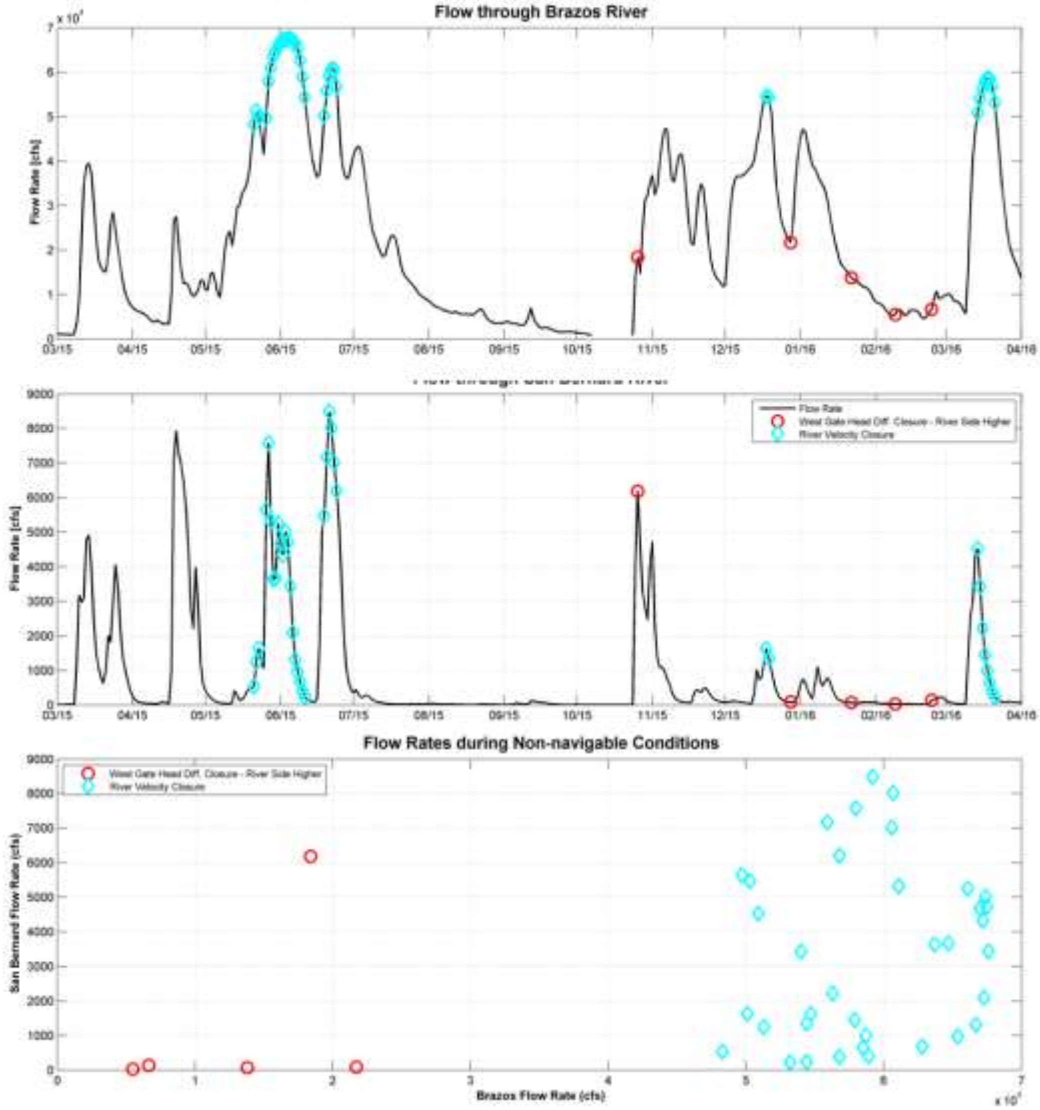

Figure 90. Relationship between modeled gate closure conditions and flow rate in the Brazos River (top), flow rate in the San Bernard River (middle), and the combined flows in both rivers (bottom).

Based on Figure 90, the following can be observed about the relationship between the river flows and what condition caused the closure during the model simulation period:

- **Condition 1) Brazos River head exceeds GIWW head at the West Gate:** The majority of these closures tend to occur during times when the flow in the San Bernard River is low relative the flow in the Brazos River. This closure condition seems more dependent on very low flows in the San Bernard River than very high flows in the Brazos River.
- **Condition 2) River Velocity exceeds threshold:** Closures due to high river are solely dependent on high flows in the Brazos River. It appears that when the input flow into the modeling grid at Rosharon, TX is approximately above 50,000 cfs that the river velocity at the gates meets the closure condition.

Limited passage conditions and river flow velocities were also investigated. The results of the limited passage analysis are shown below in Figure 91.

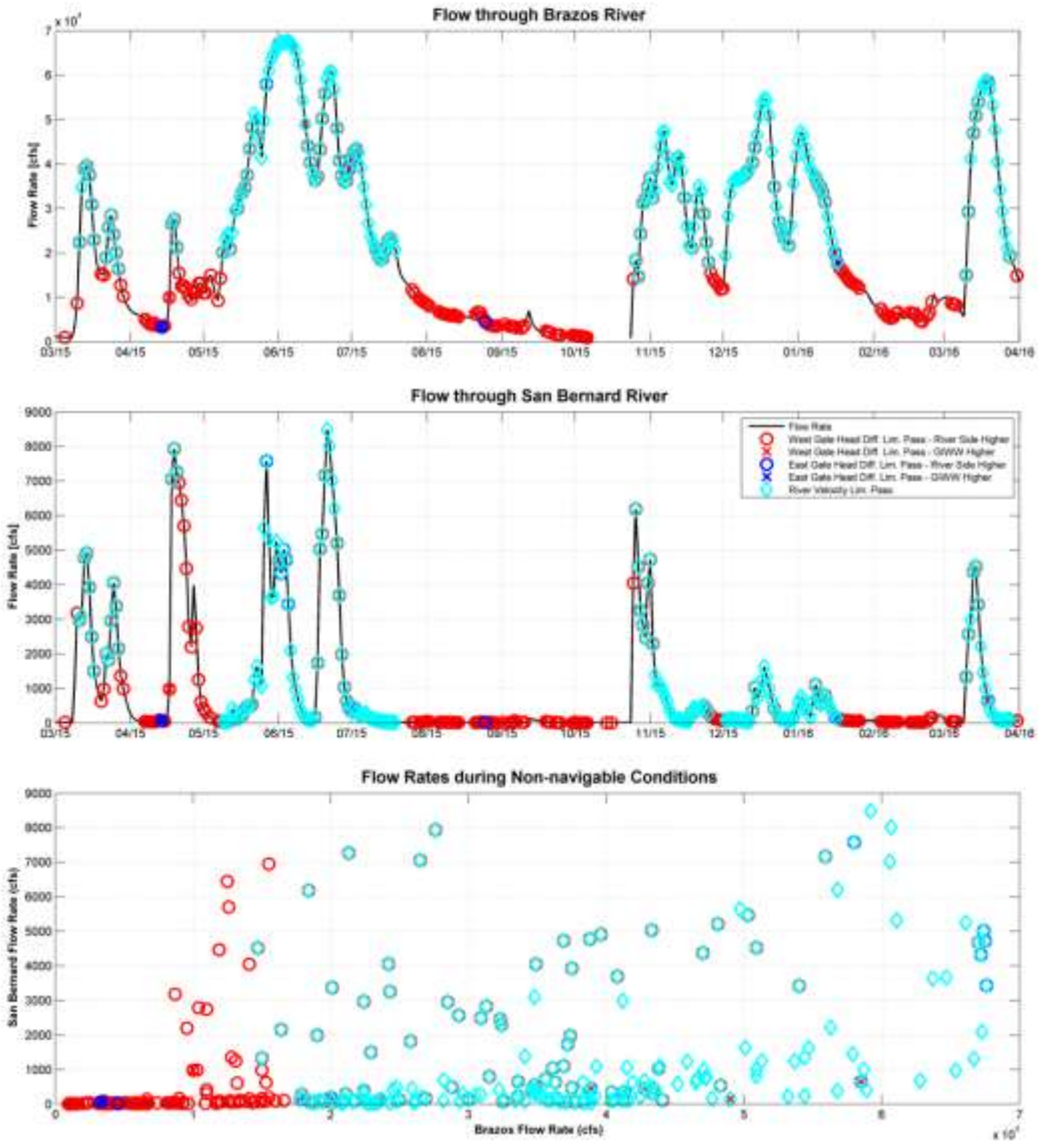

Figure 91. Relationship between modeled limited passage conditions and flow rate in the Brazos River (top), flow rate in the San Bernard River (middle), and the combined flows in both rivers (bottom).

Based on Figure 91, the following can be observed about the relationship between the river flows and what condition caused the limited passage event during the model simulation period:

- **Condition 1) Brazos River head exceeds GIWW head at the West Gate:** Similar to the closure analysis, the majority of these closures tend to occur during times when the flow in the San Bernard River is low relative the flow in the Brazos River. During high flow events, this condition seems to coincide with the river velocity condition.
- **Condition 2) River Velocity exceeds threshold:** Limited passage events due to high river are solely dependent on high flows in the Brazos River. It appears that when the input flow into the modeling grid at Rosharon, TX is approximately above 15,000-20,000 cubic feet per second (cfs) that the river velocity at the gates meets the limited passage condition. At higher flow rates in the Brazos, this condition has large amounts of overlap with limited passage events due to the Brazos head exceeding the GIWW head at the west gate.

- **Condition 3) Brazos River exceeds GIWW head at the East Gate:** Limited passage events due to the Brazos exceeding the GIWW at the east gate are rare, however they seem to occur only when the flow in the Brazos is extremely high. The flow in the San Bernard river does not appear to influence these events.

The model is well suited for prediction of limited passage, but poor in prediction of closures. We hypothesize that much of the lack of skill in the prediction of closures is due to at least three factors. One factor is no knowledge of actual gate operations; instead we use only a schematized approach. Gate operations impact hydraulics. In the runup to an event, if the gates are actually closed more than are being simulated, this may result in an increase in head difference which results in closure that may not have occurred if the gates were operating at regular intervals as they are in the model. The opposite is true as well: in the runup to an event if the gates were operating more frequently than simulated, this may reduce head difference compared to the model. Second, we have only very noisy measured hydraulic data resulting from gages sampling too infrequently and located too close to the gates that provides little insight into the actual hydraulics at closures. Finally, the recording of events has a coarse temporal resolution. In other words, the declaration of events is based on human sampling of the head and velocity, and is updated at unknown frequency, is recorded at an unknown time relative to onset of the event, and ends at an unknown time relative to the actual end of the event. Given these challenges, the model’s ability to predict restricted navigation is reasonable for comparison purposes. However, we recommend improving these limitations after a Tentatively Selected Plan (TSP) is selected for a more quantifiable comparison of delay events.

6.6 Navigation Hindcasting

An Artificial Neural Network (ANN) was developed to hindcasting head differentials at each gate and river velocity from 1980-2016. An ANN is a machine learning technique that uses a series of input data to perform “training examples”. The training examples are organized into layers of nodes, that are calibrated to the training dataset. Once trained, the ANN can be used to predict results outside of the training set. At the BRFG, the modeled head differential at each gate and the river velocity were used to train the ANN. The input conditions fed into the ANN during the training period are the wind velocity, Brazos River flowrate, San Bernard River Flowrate, change rate of the harmonic tide, and harmonic tidal elevations. Using these variables as input conditions and the modeled head differential or velocity as output, the ANN was trained for the model simulation period of March 2015 to April 2016. Once trained, the ANN was used to hindcast river velocity and the head differential at each gate Figure 92 shows the results of the neural network training for head differential at each gate and river velocity. River velocity shows the greatest correlation with modeled results, with an index of agreement of 1.00. The index of agreement between hindcast and modeled head differential is 0.94 at the west gate and 0.81 at the east gate. The lower index of agreement at the east gate suggests that head differentials are less correlated with the training parameters than the river velocity and west gate head differential. Model results show that delays are mostly caused by head differential at the west gate and river velocity, with little impact from the east gate head differential. Therefore, the lower index of agreement between the modeled and hindcast results at the east gate is not expected to greatly affect the hindcast accuracy.

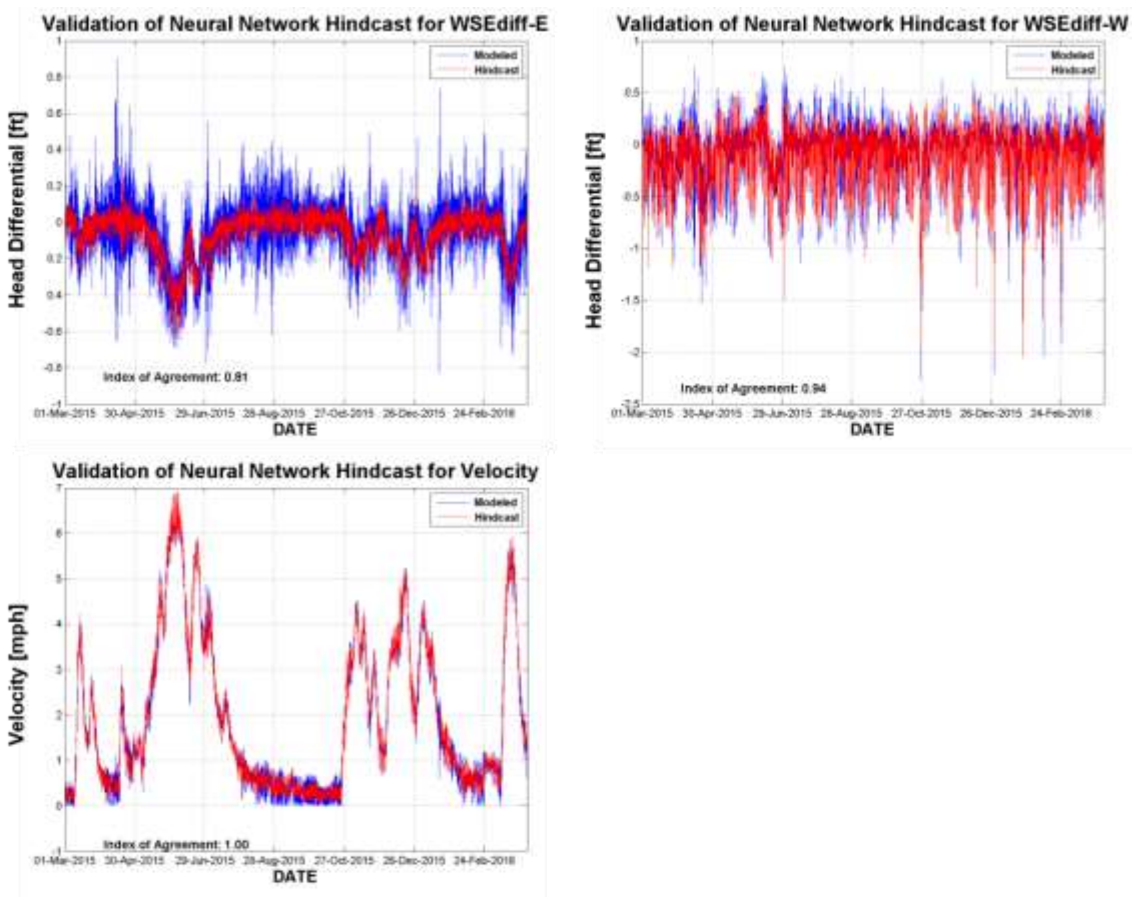

Figure 92. Existing condition hindcast training results.

Once validated, the trained neural network was used to hindcast river velocity and head differentials at each gate from 1980-2016. The hindcast results from this 36-year period were then used to form closure and limited passage statistics for existing conditions. A comparison of the delay statistics for the hindcast (1980-2016) and modeled (2015-2016) results is shown in Table 33.

Table 33. Comparison between modeled and hindcast delay statistics.

Method	Limited Passage	Closure	Total
Model 2015-2016	44%	4%	48%
Hindcast 1980-2016	24%	4%	27%

Note that the hindcast delays for existing conditions are significantly less than the modeled delays. This is likely explained by the fact that the modeled year (March 2015-April 2016) was an unusually wet year, with 3 flood events greater than the 1-year event in the Brazos and 4 such events in the San Bernard.

6.7 Alternatives Analysis

The hydraulic conditions were extracted from the alternatives and filtered using the same methodology as existing conditions. The results of the alternatives analysis are described in the following Section.

Alternatives were analyzed for closure and limited passage delay events. The proposed alternatives were simulated using the hydrodynamic model results. All alternatives were filtered using the same methodology stated in the previous section. The filtered results for each alternative were then passed through the neural network, which was trained separately for each alternative. The trained neural network was then used to hindcast the gate head differentials and river velocities from 1980-2016. Figure 93 shows the extraction points used for navigation analysis as well as the bathymetry used to model each alternative.

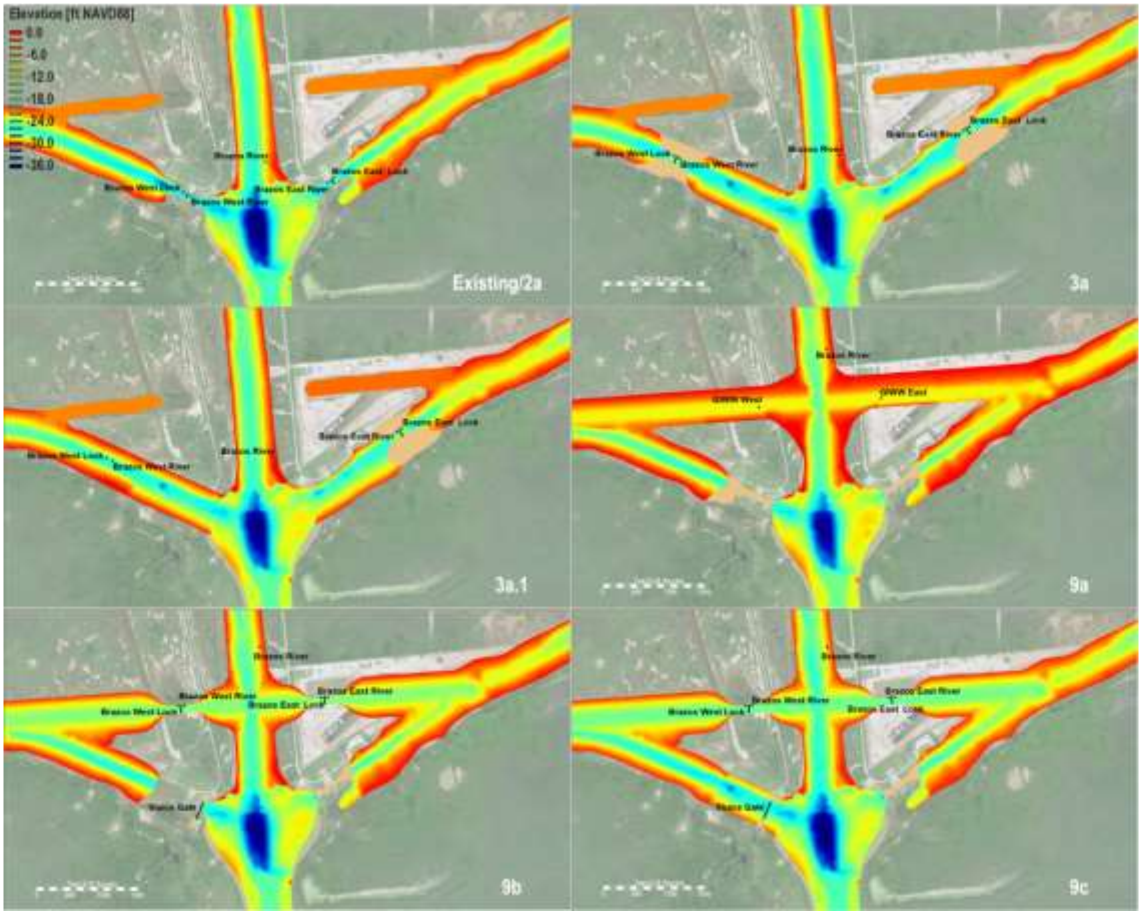

Figure 93. Alternatives modeled and extraction points for navigation analysis.

A summary of the closure conditions during the hindcast period (1980-2016) due to head differential, velocity and total closures is shown in Table 34. A summary of the limited passage occurrence rate during the simulation period due to head differential, velocity, and total is shown in Table 35. Note that the total closure and limited passage columns in each table employ the filters described earlier in this Section and only count the instances when head differential and velocity delays occur simultaneously as one event.

Table 34. Summary of closure condition causes and total closure % for alternatives.

Alternative	Closure % Head Differential	Closure % Velocity	Total %
Existing/2a	3.1%	1.0%	3.8%
3a	0.0%	0.7%	0.6%
3a.1	0.0%	0.9%	0.9%
9a	0.0%	1.8%	1.7%
9b	0.3%	1.7%	1.8%
9c	0.2%	1.6%	1.6%

Table 35. Summary of limited passage conditions and % of time under limited passage restrictions for alternatives.

Alternative	Limited Passage % Head Differential	Limited Passage % Velocity	Total %
Existing/2a	14.5%	10.6%	23.5%
3a	7.5%	10.0%	16.6%
3a.1	0.2%	9.7%	9.8%
9a	0.0%	12.3%	12.2%
9b	7.5%	12.5%	18.9%
9c	6.2%	12.6%	17.4%

Based on the hindcast results shown in Table 34, all proposed alternatives are expected to significantly reduce closures due to head differential. Changes in closure conditions due to river velocity remain relatively unchanged, except for Alternative 9a, 9b, and 9c. Increased closures due to velocity are noted for these alternatives, however overall closure rates are lower than existing conditions. Note that for Alternative 9a there is a potential for higher velocities through the GIWW due to the lack of gates. This is investigated later in this Section.

Limited passage occurrences due to head differential are also decreased with all proposed alternatives as show in Table 35. Limited passages due to velocity follows similar trends to the closure statistics. Alternatives along the existing alignment (Alternative 3a and 3a.1) show little change, while Alternatives 9a, 9b, and 9c show an increase in velocity closures. The total percent of the model simulation where limited passage or closure conditions occur is shown in Table 36.

Table 36. Summary of limited passage conditions, closure conditions, and total event conditions as a percentage of the model simulation period.

Alternative	Limited Passage %	Closure %	Total %	% Change from Existing
Existing/2a	23.5%	3.8%	27.3%	--
3a	16.6%	0.6%	17.2%	-10.0%
3a.1	9.8%	0.9%	10.7%	-16.6%
9a	12.2%	1.7%	13.9%	-13.3%
9b	18.9%	1.8%	20.7%	-6.5%
9c	17.4%	1.6%	19.1%	-8.2%

Based on the results shown in Table 36, Alternative 3a.1 provides the greatest reduction in total events (16.6% reduction), followed by Alternative 9a (13.3% reduction).

Head differentials at the gates were analyzed and are shown in the form of cumulative distribution function (CDF), with probability of non-exceedance for the range of water surface elevations in Figure 94. The CDF curves for head differential were based on the hindcast results. The CDF curves developed during this analysis show the probability of non-exceedance at various head differentials. The alternatives show reduction in head differential at the west gate from existing conditions, while all alternatives with a gate on the east side of the Brazos show similar results to existing conditions.

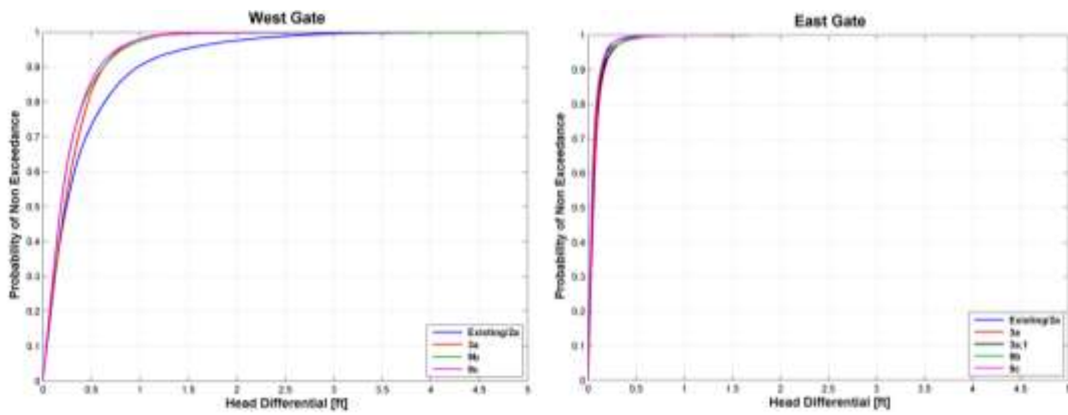

Figure 94. Probability of Non-Exceedance for head differential at west gate (top) and east gate (bottom).

The CDF curves were also developed for velocities at the intersection of the GIWW and the Brazos River. Hindcasting was not performed on these velocities due to a due to a lack of measured data for calibration of the model results. The CDF velocity curves shown in Figure 95 were developed using model output. The CDF curves for velocities at the GIWW and Brazos intersection were extracted riverward of the gates for Alternatives 2a, 3a, 3a.1 east, 9b, and 9c. The velocities were extracted near the intersection of the GIWW and Brazos for Alternatives 3a.1 west and 9a since there are no gate structures. The results of the CDF curves at the intersection of the Brazos River and GIWW are shown in Figure 95. Alternative 3a.1 west shows slightly decreased velocities at the intersection under daily conditions, even when compared to the open channel alternative. This is likely due to the lack of a gate constriction causing increased velocities. In addition, Alternative 3a.1 shows lower velocities in the west GIWW immediately adjacent to the Brazos River when compared to Alternative 9a. This reduction in velocity is hypothesized to be directly related to the angled intersection with the Brazos. The angled intersection reduces the amount of flow that can enter the GIWW, resulting in the lower velocities seen for Alternative 3a.1 (west side) when compared to Alternative 9a (west side).

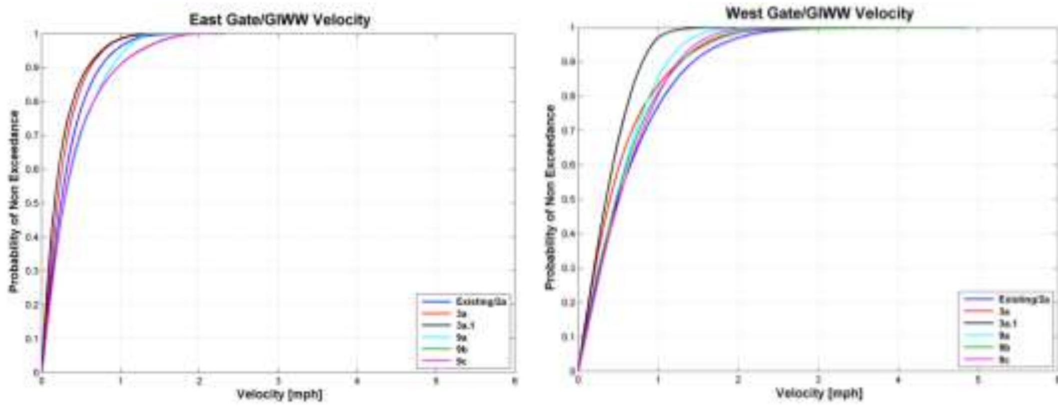

Figure 95. Probability of Non-Exceedance of velocity at gate locations (Existing/2a,3a,3a.1 east, 9b, 9c), and open GIWW (3a.1 west, 9a).

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