ENGINEERING APPENDIX A

APPENDIX 2

HYDRAULIC ENGINEERING APPENDIX - COLORADO RIVER FLOODGATES

Hydrodynamic Evaluation of Proposed Navigation Improvements at the Colorado River Intersection with the Gulf Intra-Coastal Waterway

Maxwell E. Agnew, USACE New Orleans District

November 2018

Preface

As part of the continuing studies of the Mouth of Colorado River Project, TX, the US Army Engineer District, Galveston (SWG), requested the New Orleans District (MVN) to perform a numerical model study of hydrodynamics, including currents, salinity, and sediment changes, associated with the plan to improve navigation through the intersection of the Gulf Inter-Coastal Waterway (GIWW) and the Colorado River. The purpose of the numerical model study was to evaluate the impacts to currents, sediment, and salinity associated with a proposed alternative involving removal of the existing Colorado River Locks.

The Galveston District provided funding for this study. Max Agnew (MVN H&H) served as principal investigator of the project, while a team from the US Army Engineer Research and Development Center (ERDC), composed of Gary Brown, Tate McAlpin and Dr. David Young provided technical support and review.

Contents

Introduction

Background and Problem Statement

In the early 1990's the mouth of the Colorado River was moved from the Gulf of Mexico to West Matagorda Bay in an effort to enhance seafood productivity of the bay, reduce flood damage potential along the lower Colorado River, and reduce navigation hazards as well as channel maintenance costs (USACE 1981). Since the river was diverted, a substantial increase in currents at the intersection of the GIWW with the Colorado River has been observed. The currents adversely affect navigation through the intersection, especially during higher flows. Tripping, or the practice of towing only one barge at a time, has become a necessity when currents reach 3 ft/s. When velocities exceed 5ft/s, the locks are completely shut down at considerable cost to the navigation industry (USACE 2003). Figure 1 displays the location of the Colorado River, Bypass Channel, Colorado River Delta, GIWW, East and West Matagorda Bays.

Figure 1 Colorado River Locks Project Site

One proposal to remedy the navigation issues at the intersection is complete removal of the locks, creating an open channel through the intersection. Complete removal of the lock carries many potential risks including increased sedimentation in the GIWW, changes to the salinity in both East and West Matagorda Bays, increased velocities in the GIWW, and other problems. The effects of any proposed alternative can be evaluated through hydrodynamic modeling.

Objective and Approach

This report details a numerical modeling study of the Colorado River Locks using the AdH Adaptive Hydraulics model. Developed at ERDC-CHL, the AdH model solves all relevant hydrodynamic processes, including water levels, velocity, discharge, salinity and sedimentation. The following steps were taken to develop the AdH model of the Colorado River.

a. Field Data Collection.
   - Assembly of all relevant water level, velocity, discharge, and salinity measurements from various sources including USGS, USACE, NOAA.
   - Acquire bathymetric elevation surveys of all relevant channels in the project vicinity.
   - Acquire sediment samples in the project vicinity.

b. Hydrodynamic Model Development
   -Development of AdH finite element mesh for the Colorado River, East and West Matagorda Bays, and the GIWW.
   -Development of necessary boundary conditions including water levels, discharges, precipitation, evaporation, wind, sediment concentrations.
   -Simulation of existing conditions for the floods occurring in 2001, 2015 and 2016.

c. Hydrodynamic Model Validation
   -Comparison of model results to observations.

d. Evaluation of the Proposed Alternative
   -Comparison of existing condition and the lock-removed scenario.
   -Evaluation of the impacts to currents, sedimentation and salinity associated with removal of the locks.

Numerical Model Description

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 module 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.

Field Data

In 2001, ERDC completed a hydrodynamic study of the Colorado River locks. Extensive field measurements were conducted including deployment of 12 water level gages, 2 velocity gages for a 6-month time frame. In addition, on July 20th 2001, 7 25-hr discharge time-series measurements were taken at various locations using Acoustic Doppler Current Profiling (ADCP). Figure 2 displays the location of the 12 water level and velocity gages deployed for the 2001 study (gages 1 to 12). Gages 14 through 18 at the Colorado River locks are operated permanently by the USGS. Figure 3 displays the location of the 7 ADCP transects taken for the 2001 study. The 2001 field data collection has been described previously in a memo titled "Field Data Collection at the Colorado River and Gulf Inter-coastal Waterway, Matagorda, TX" dated January 2002. Although 16 years have passed, the 2001 field data provided a valuable resource for development of the AdH model.

The modeling required more recent measurements to better evaluate existing conditions. Water level, velocity and sediment data was collected from various sources including USGS, USACE and NOAA for the more recent time period. Bed sediment samples were taken at 17 locations, as pictured in Figure 4. A summary of the sediment measurements in provided in the appendix. Additionally, a bathymetric survey was conducted by USACE in May of 2017. The bathymetric survey transects are pictures in Figure 5. Table 1 contains a summary of the gages presented in Figure 2.

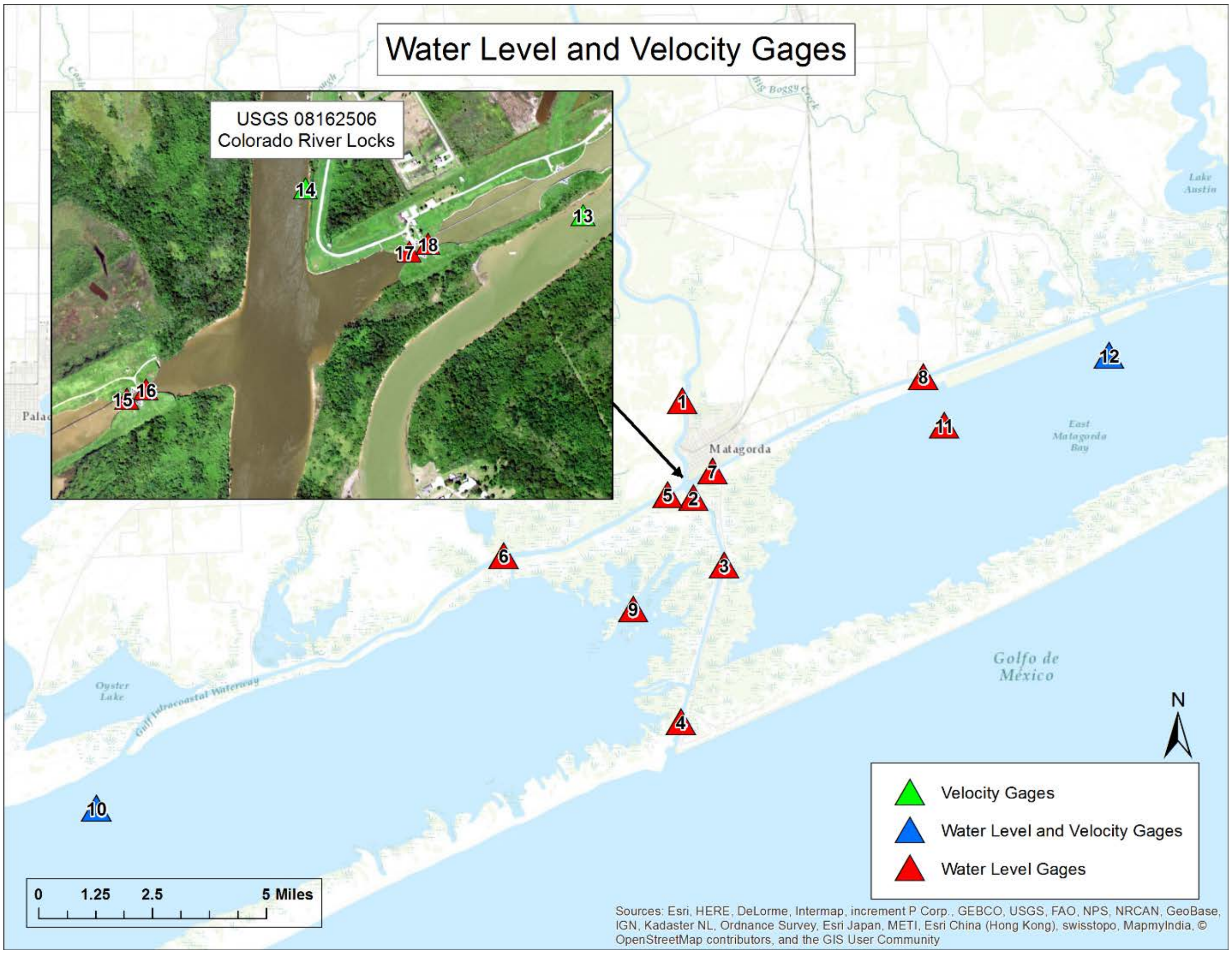

Figure 2 Location of Water Level and Velocity Gages

Figure 3 ADCP Transect Locations from 2001 Study

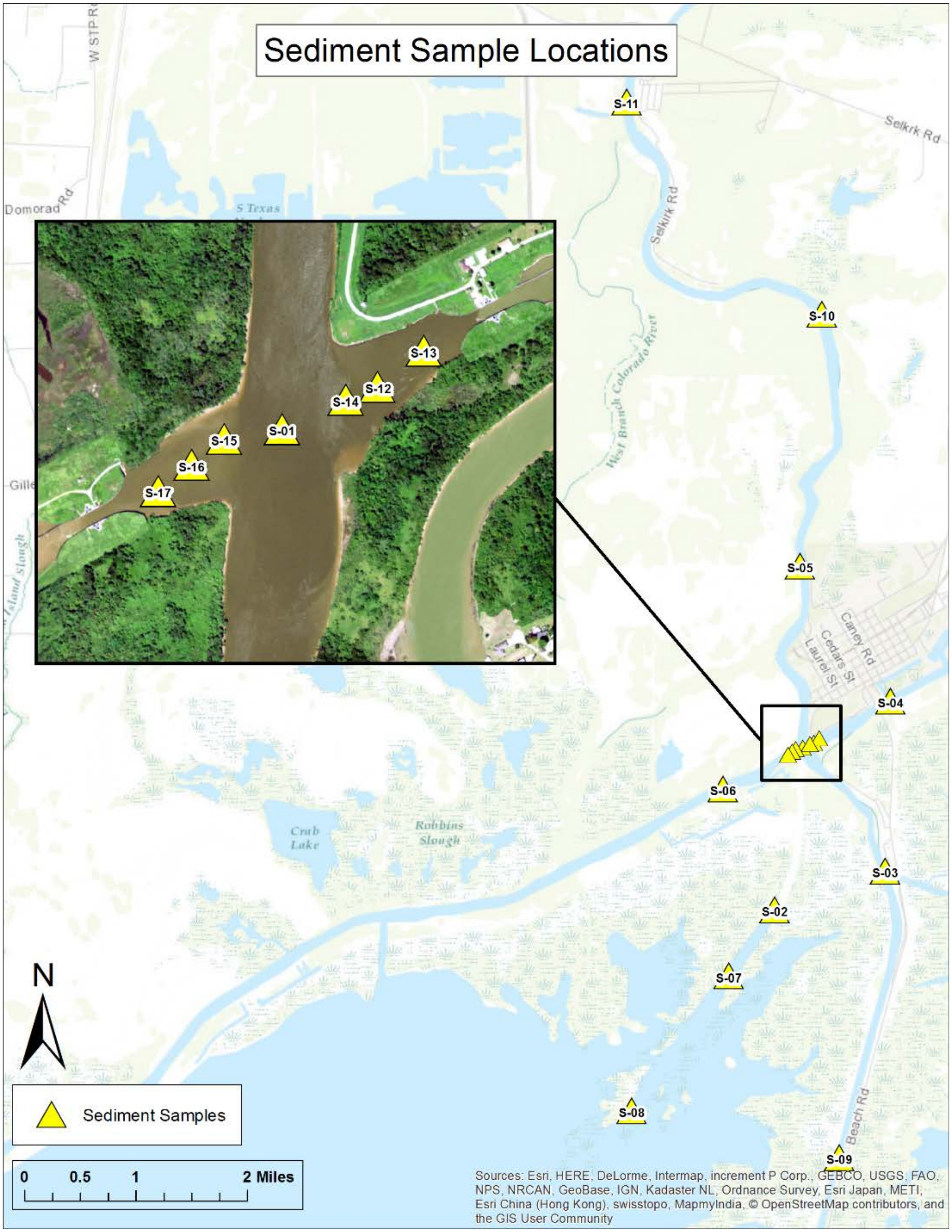

Figure 4   2017 Sediment Sample Locations

Figure 5   2016 Bathymetric Survey Extents of the Colorado River, GIWW, and Bypass Channel.

Id	Source	Long	Lat	Location	Parameter	Data Availability
1	USACE/ERDC	-95.98	28.71	Colorado River	Salinity, Water Level	2001
2	USACE/ERDC	-95.97	28.68	Bypass Channel	Salinity, Water Level	2001
3	USACE/ERDC	-95.96	28.66	Bypass Channel	Salinity, Water Level	2001
4	USACE/ERDC	-95.98	28.61	Bypass Channel	Salinity, Water Level	2001
5	USACE/ERDC	-95.98	28.68	West Lock	Salinity, Water Level	2001
6	USACE/ERDC	-96.04	28.66	West GIWW	Salinity, Water Level	2001
7	USACE/ERDC	-95.97	28.69	East GIWW	Salinity, Water Level	2001
8	USACE/ERDC	-95.89	28.72	East GIWW	Salinity, Water Level	2001
9	USACE/ERDC	-96.00	28.64	Colorado River Delta	Salinity, Water Level	2001
10	USACE/ERDC	-96.19	28.58	West Matagorda Bay	Salinity, Water Level, Velocity	2001
11	USACE/ERDC	-95.88	28.70	East Matagorda Bay	Salinity, Water Level	2001
12	USACE/ERDC	-95.82	28.72	East Matagorda Bay	Salinity, Water Level, Velocity	2001
13	USGS	-95.97	28.68	Bypass Channel	Velocity	2012 to Present
14	USGS	-95.98	28.68	Colorado River	Velocity	2012 to Present
15	USGS	-95.98	28.68	West Lock Chamber	Water Level	2012 to Present
16	USGS	-95.98	28.68	West River	Water Level	2012 to Present
17	USGS	-95.97	28.68	East River	Water Level	2012 to Present
18	USGS	-95.97	28.68	East Lock Chamber	Water Level	2012 to Present

Table 1 Summary of Gages in Project Vicinity

Hydrodynamic, Salinity, and Sediment Model

Computational Mesh

An AdH mesh was developed using the Surfacewater Modeling System (SMS) software. The AdH mesh includes the West and East Matagorda Bays, the GIWW and the Colorado River and Bypass Channels. The majority of the mesh bathymetry was adapted from a high resolution ADCIRC mesh of Texas. The complete model domain and bathymetry is pictured in Figure 6. Model resolution varies 1000m near the gulf boundary to 4m near the project sire. Figure 7 displays a zoomed in view of the AdH mesh showing the East and West Matagorda Bays, the GIWW, the Colorado River and Bypass Channel. Figure 8 displays the 4m resolution at the intersection of the GIWW and Colorado River. 7 different material types were assigned to the AdH computational mesh. Figure 9 displays the material types assigned to the computational mesh. All material types were given a Manning's n value of 0.02, except for the main river channel, the bypass channel and the GIWW, which were assigned an n value of 0.015. The Manning's n values came from direct calibration. Material 6 was set up as a supply reach for the model with a 100m layer thickness. The supply reach allows the river to suspend material from the bottom without changing the bed elevation. The supply reach serves as the primary source of fine grain sand into the model domain. All other materials were assigned a very small initial layer thickness of 0.01m, and thus do function as a source of sediment.

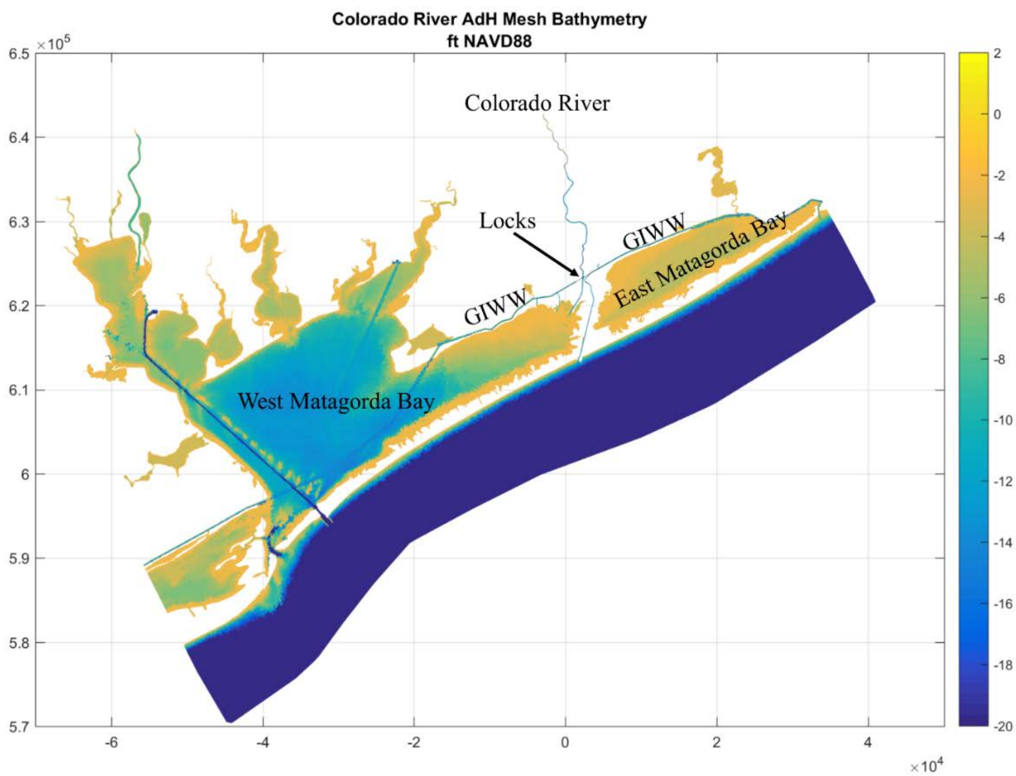

Figure 6 AdH Computational Mesh Extents and Bathymetry

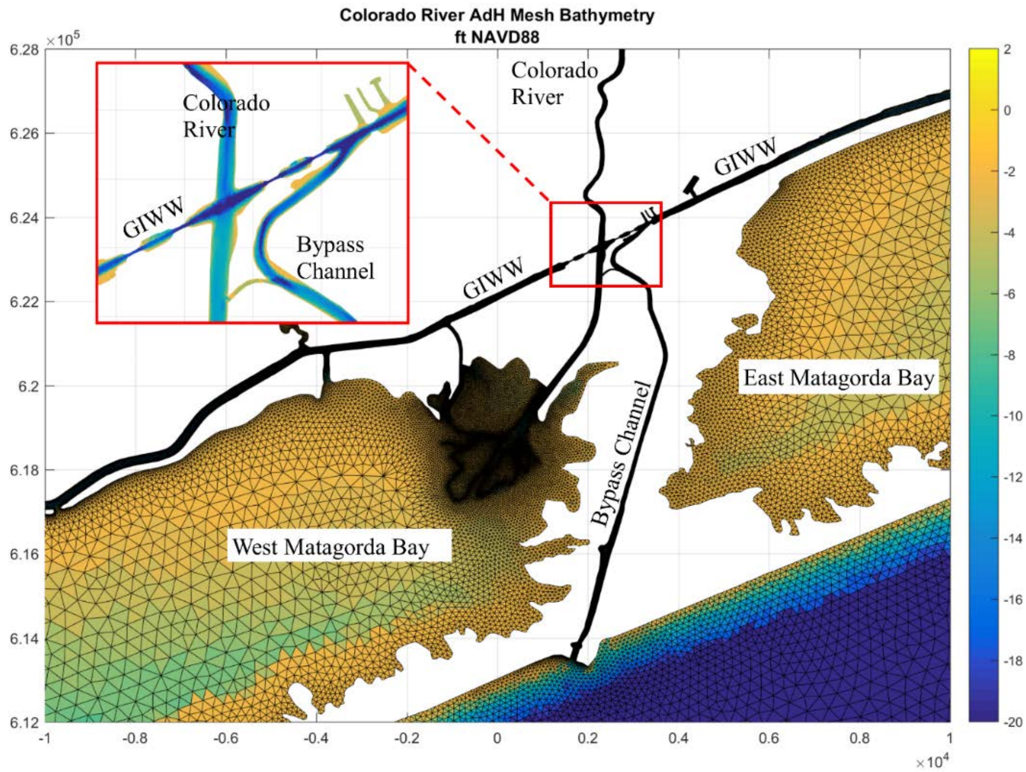

Figure 7 AdH Computational Mesh

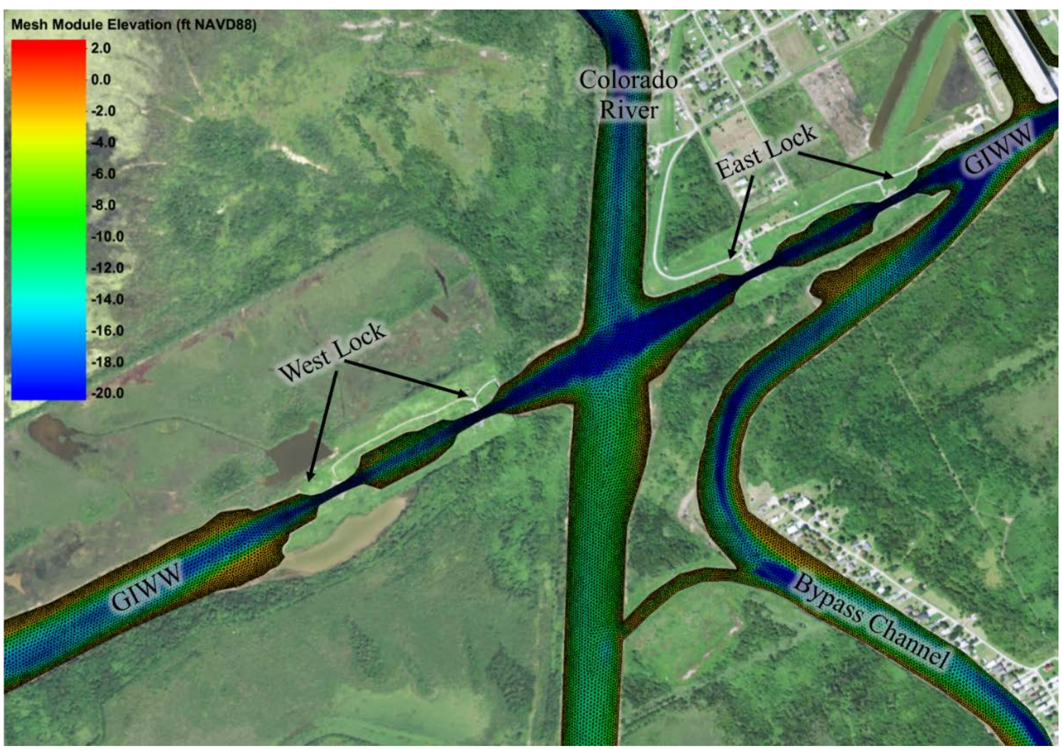

Figure 8 AdH Computational Mesh – View at Intersection of GIWW and Colorado River

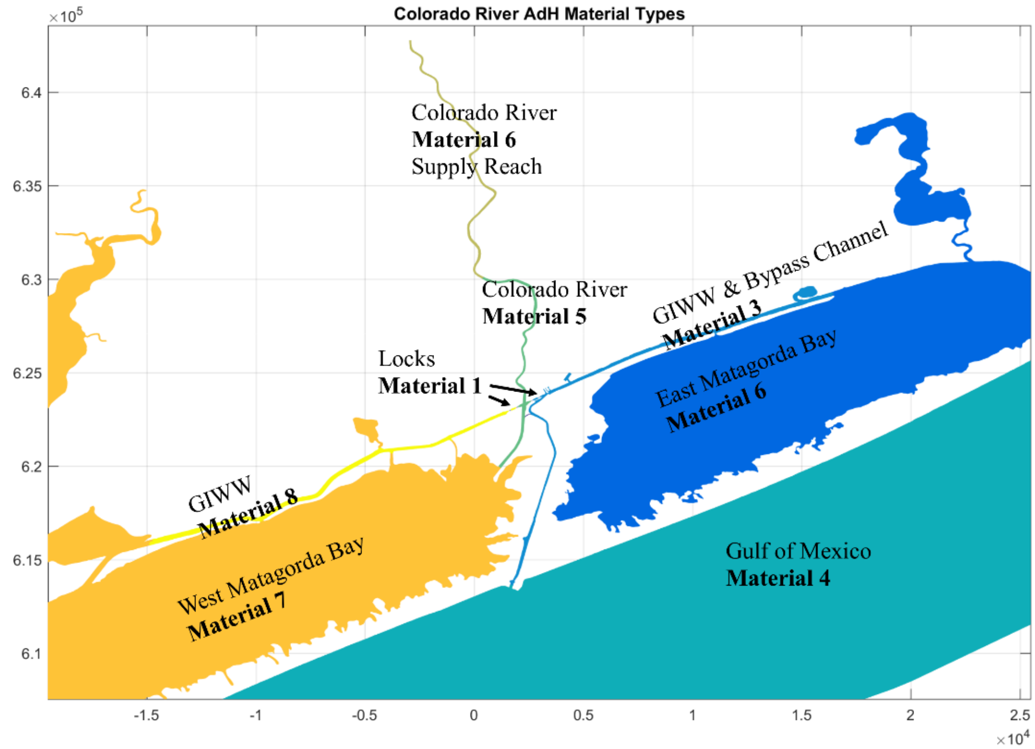

Figure 9 Material types on the AdH mesh

Boundary Conditions and Initial Conditions

Discharge

A discharge boundary was assigned at the upstream end of the Colorado River. Flows measured at the USGS gage near Bay City, TX were assigned at the boundary. The USGS gage near Bay City records both stage and flow. Figure 10 displays the complete discharge time-series from 1948 to present. Figure 10 also displays the annual peak discharge with a linear trendline fit. The trend shows a slight increase in peak annual discharge through time. Figure 11 plots the total discharge volume for each year. In some cases the discharge was not reported, but a stage was reported. Figure 12 displays the discharge-rating curve developed by USACE from the available data. The rating curve was used to populate missing discharge measurements. The discharge measurements that were missing typically happened during low stages of less than 5ft. During low stages, tidal influences become dominant and the rating curve loses accuracy, which is probably why the USGS does not report discharges for low stages. Since the majority of sediment transport occurs during high flows, the inaccuracy of the rating curve at low flows is not an issue for the current study. 2001 was a relatively dry year, 2015 and 2016 were relatively wet years. Figure 13 displays the discharge time-series applied in the 2001 simulations. In the 2001 simulation period, one small flood occurred in September. Figure 14 displays the discharges used in the 2015 simulation. In 2015, multiple floods occurred, including one with a peak of approximately 50,000cfs. Figure 14 displays the discharge time-series applied in the 2016 simulation. 2016 had two back to back extreme floods, each approaching a maximum discharge of approximately 65,000cfs. In terms of flood volume, the 2016 was the ranked as 4th wettest year on record. The three years 2001, 2015 and 2016 provide a reasonable range of severity of flood events.

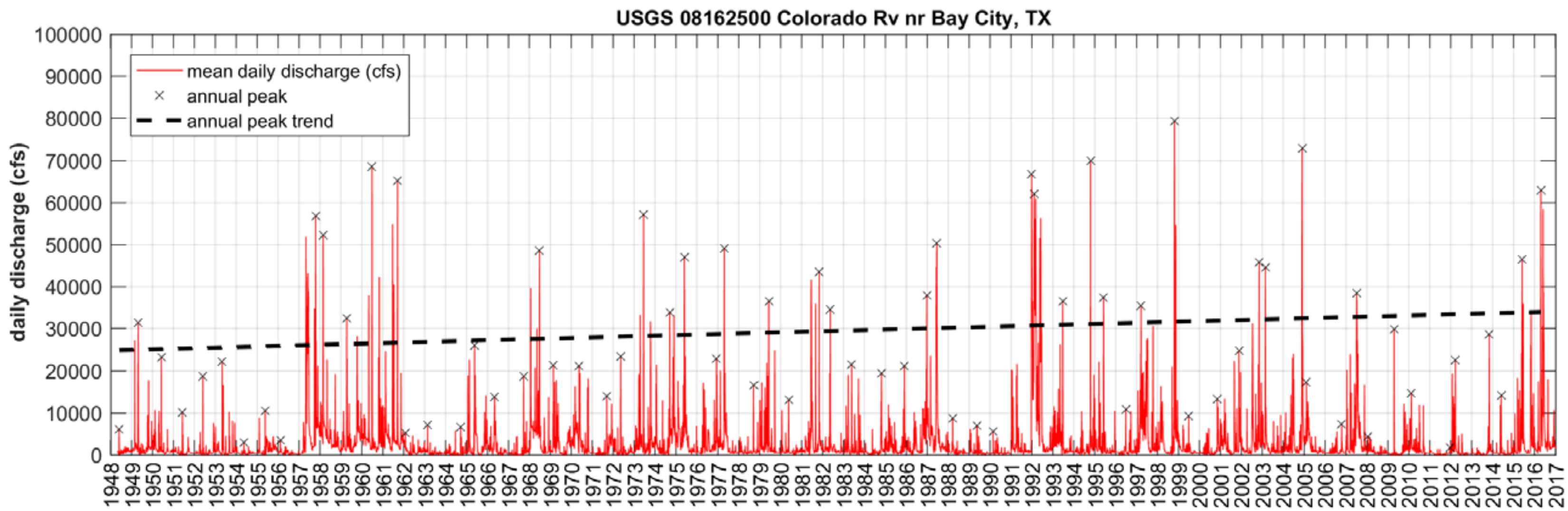

Figure 10 1948 to 2016 Discharge Measurements at USGS 08162500 Colorado River near Bay City, TX

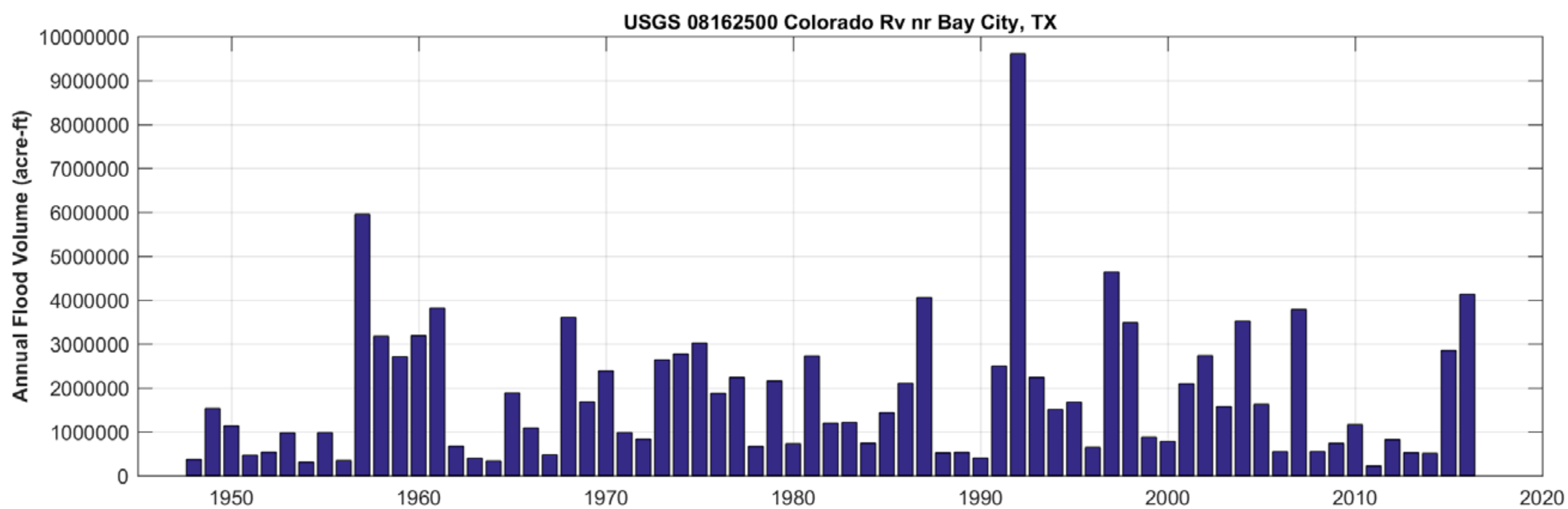

Figure 11 1948 to 2016 Discharge Volume Measurements at USGS 08162500 Colorado River near Bay City, TX

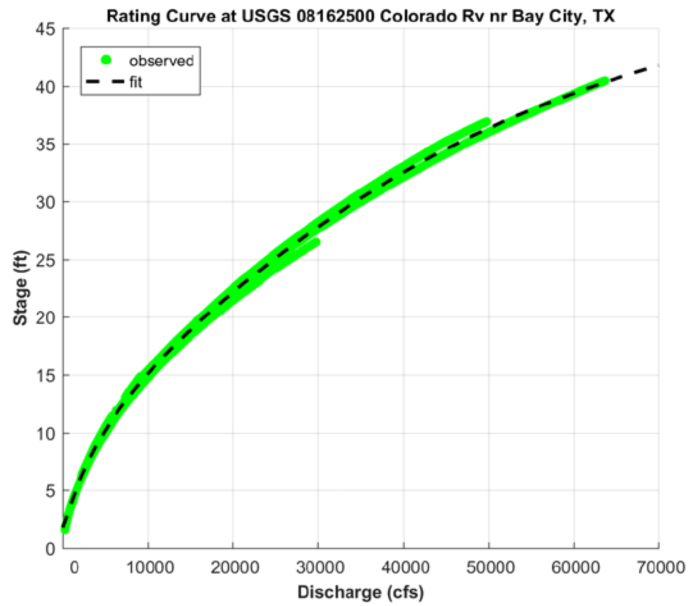

Figure 12 Stage-Discharge Rating Curve at USGS site near Bay City, TX

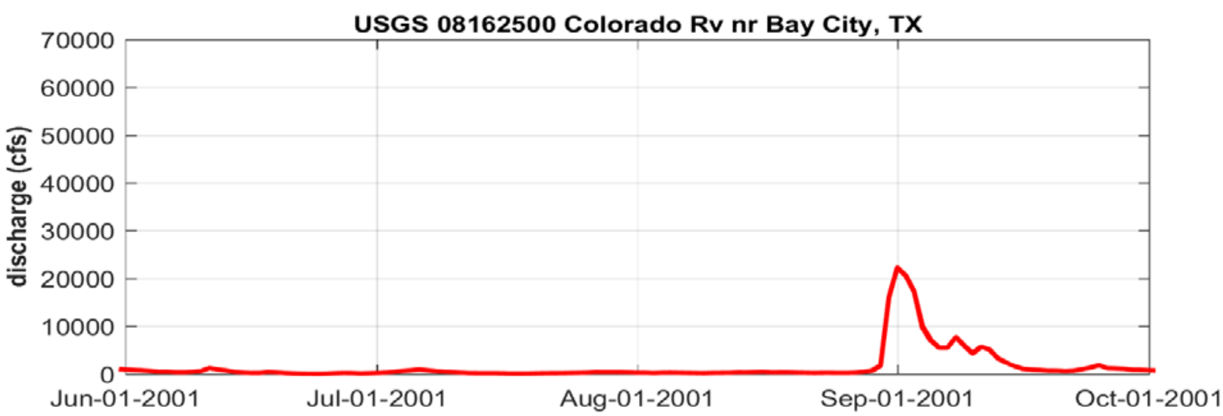

Figure 13 2001 Simulation Period Discharge Measurements at USGS 08162500 Colorado River near Bay City, TX

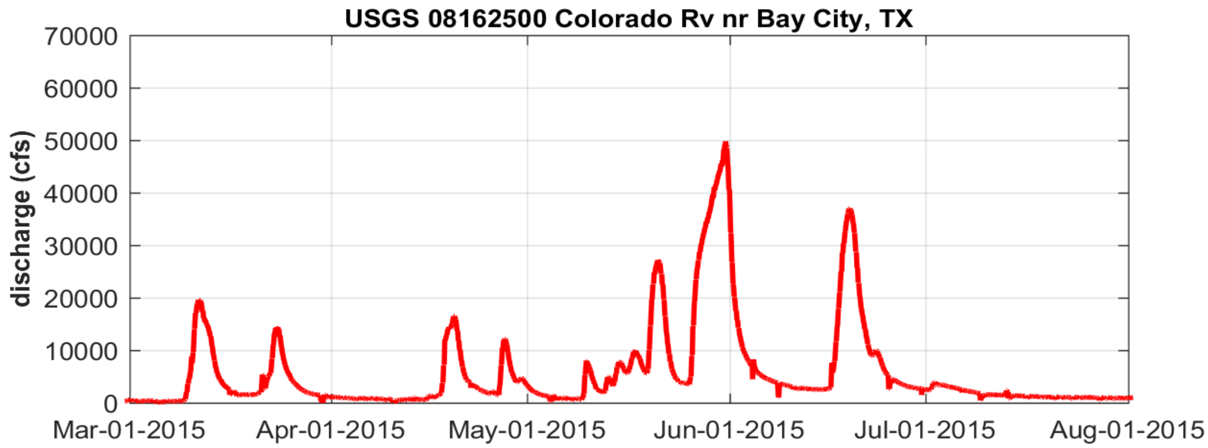

Figure 14 2015 Simulation Period Discharge Measurements at USGS 08162500 Colorado River near Bay City, TX

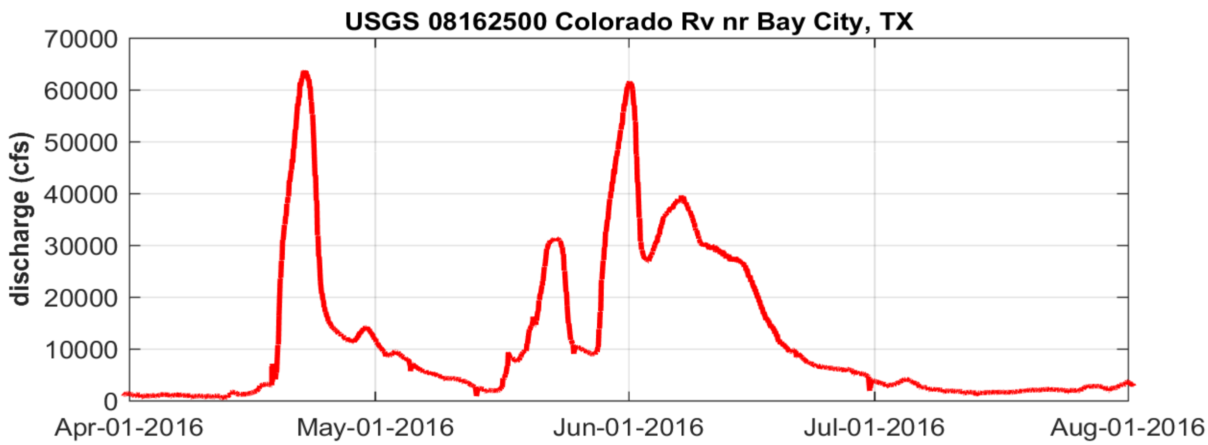

Figure 15 2015 Simulation Period Discharge Measurements at USGS 08162500 Colorado River near Bay City, TX

Stage

A tidal stage time-series was assigned at the gulf boundary. The boundary condition for the 2001 simulation was developed using gage measurements at the TCOON "Bait Shop" gage which was located in the bypass channel (ERDC 2003). A phase shift and amplitude shift was applied to the time-series to get a reasonable stage at the gulf boundary, which is approximately 7 miles offshore from the mouth of the bypass channel. Figure 16 displays the water level time-series applied to the gulf boundary for the 2001 simulation. For the 2015 and 2016 simulations, the "Bait Shop" gage was out of commission. Instead, the tidal time-series at NOAA's Matagorda Bay Entrance Channel, TX gage was used as a boundary condition. The predicted water level time-series was applied at the boundary with a phase and amplitude shift. Figure 17 and Figure 18 displays the water level time-series applied to the gulf boundary for the 2015 and 2016 simulations.

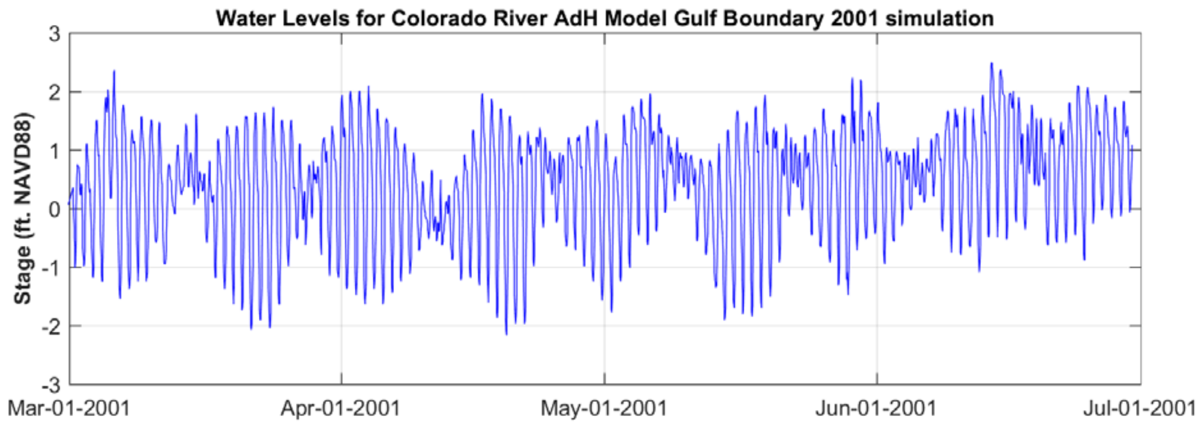

Figure 16 Water level time-series applied to AdH gulf boundary for 2001 simulation

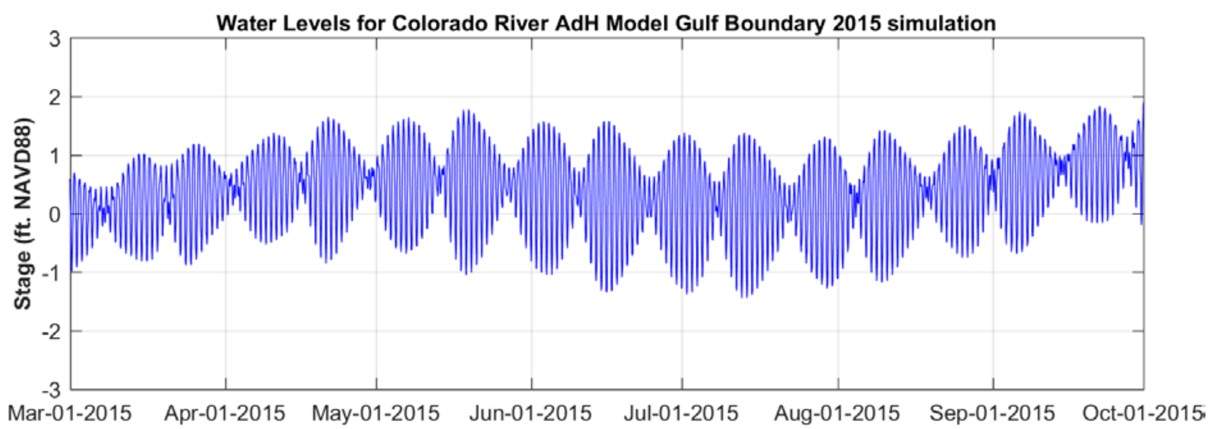

Figure 17 Water level time-series applied to AdH gulf boundary for 2015 simulation

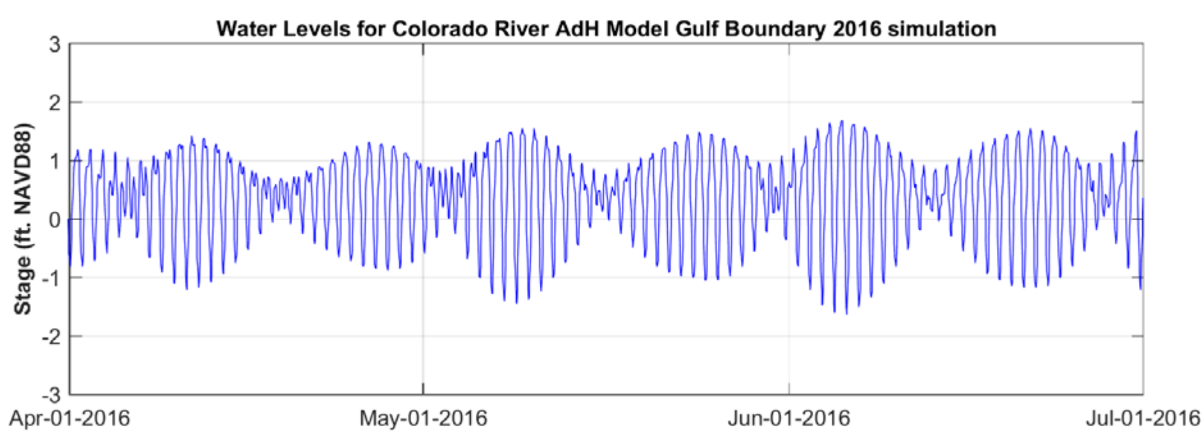

Figure 18 Water level time-series applied to AdH gulf boundary for 2016 simulation

Sediment

The sedimentation model required an inflow of sediment concentrations for silts and clays at the northern Colorado River boundary. USGS records sediment data during floods at a gage located 8 miles upriver from the intersection of the GIWW and Colorado River. Observations recorded by the USGS near Wadsworth, TX include total suspended sediment load (tons/day) as well as the measured concentration of suspended sediments (mg/L), distributions of suspended material, and distributions of bed material. The discharges at Bay City and the sediment measurements at Wadsworth were used to create a sediment rating curve. Figure 19 displays the discharge vs suspended concentration rating curve. The arrows plotting on each point represent a rising or falling hydrograph. In theory, the rising limb of the hydrograph should have higher sediment concentrations than the descending limb. An effort was made to apply a time shift to the discharge measurements to account for lag time, as the gages are located roughly 16 miles apart, but no noticeable improvement in the curve was observed. The rating curve was used in conjunction with the discharge time-series to develop fine-grain suspended sediment inflow at the AdH boundary. Figure 20 displays the rating curve developed for total suspended load in tons/day. This rating curve was not used for a boundary condition, but is included in the report for information purposes only. There is significant uncertainty in the suspended sediment rating curve. However, the application of a rating curve based on observed data will give more confidence of the actual volumes of material in suspension, and confidence in the amount of material being suspended from the supply reach. Figure 22, Figure 23, and Figure 24 display the time-series of suspended sediment concentrations applied to the boundary for the 2001, 2015 and 2016 simulations. The USGS suspended sediment concentration observations are also plotted in Figure 22, Figure 23, and Figure 24.

The measured suspended loads include all grainsizes. Because of this, it was necessary to separate a time-series for fine grain material only. The USGS provides grain size distributions of the suspended load at the Wadsworth gage. Figure 21 displays the measured percent of fines vs flow at the Wadsworth gage. During higher flows, a higher percentage of sand become suspended, while during lower flow, mostly fine material is suspended. In the AdH model, sand is not included as a transported constituent at the inflow boundary. Instead, the sand becomes suspended from the supply reach. The supply reach acts as an infinite source of material. It was necessary to reduce the suspended load concentration time-series presented in Figure 22, Figure 23, and Figure 24. The time-series were reduced based on the flow vs percent-fines relationship established in Figure 21, effectively removing the sand from the suspended load. The parameters of the supply reach were adjusted until the total suspended sediment concentrations were close to observations. Furthermore, based on grab sample results, the suspended material at the boundary was divided as 50% silt and 50% clay. Overall, the distribution of sand, silt, and clay depends on the discharge. The average of 12 grab samples taken in 2017 in the Colorado River at the intersection of the GIWW and Colorado River consists of 24% fine sand, 36% silts, and 40% clays. Overall, the model is set up to provide reasonable estimates of the volume and distribution of the material being transported down the Colorado River.

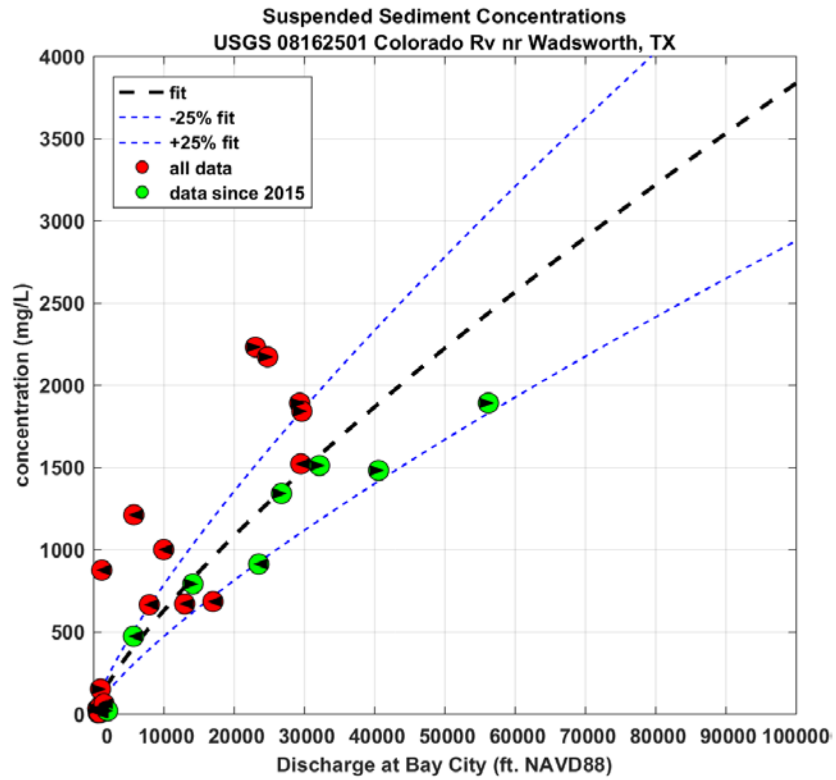

Figure 19   Suspended Sediment Concentration Rating Curve at USGS site near Wadsworth, TX

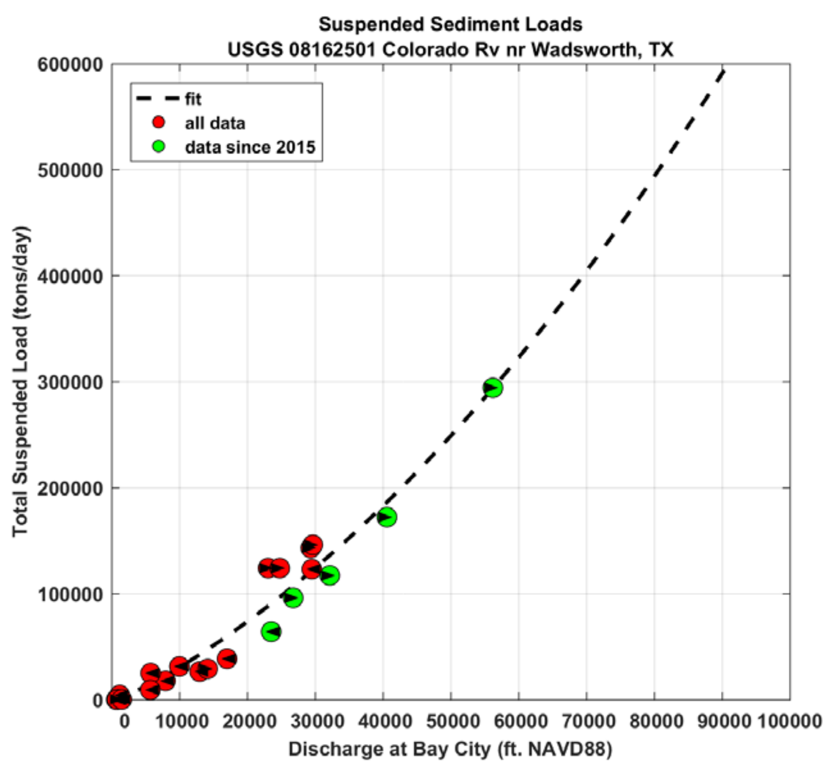

Figure 20   Suspended Sediment Load Rating Curve at USGS site near Wadsworth, TX

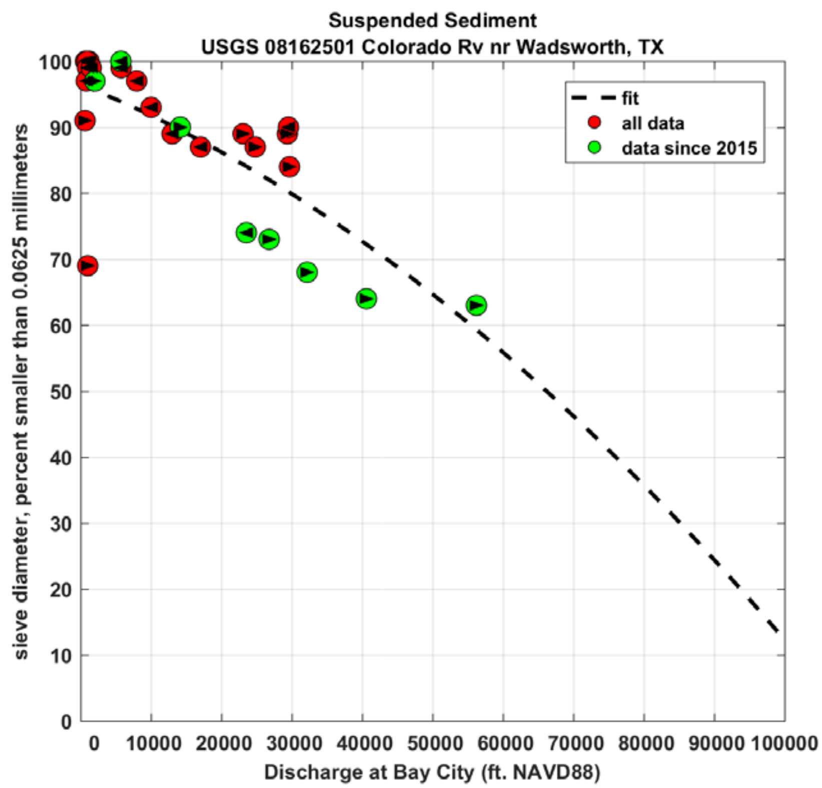

Figure 21   Percent fine grain material in suspended sediment vs flow in Colorado River near Wadsworth, TX

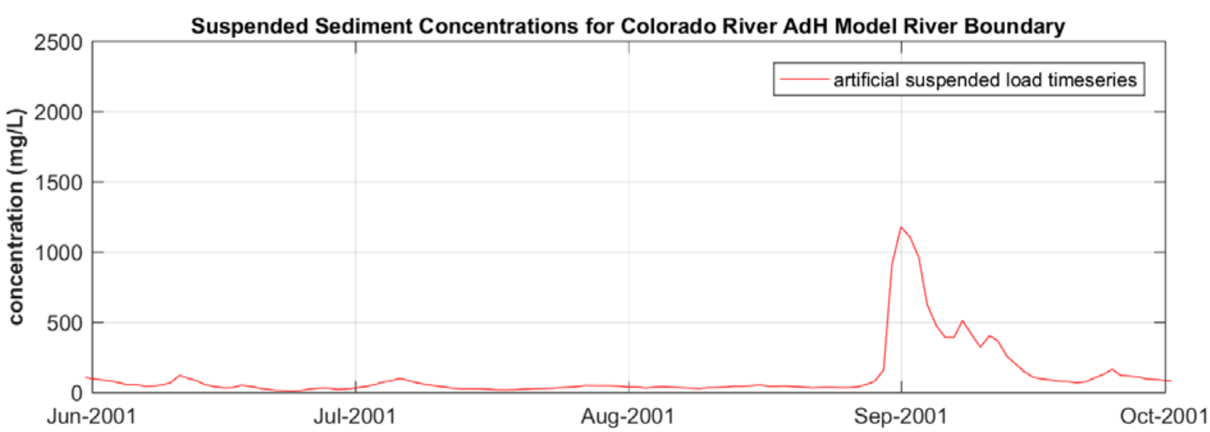

Figure 22   Artificial sediment concentration time-series for boundary condition for 2001 AdH Simulation

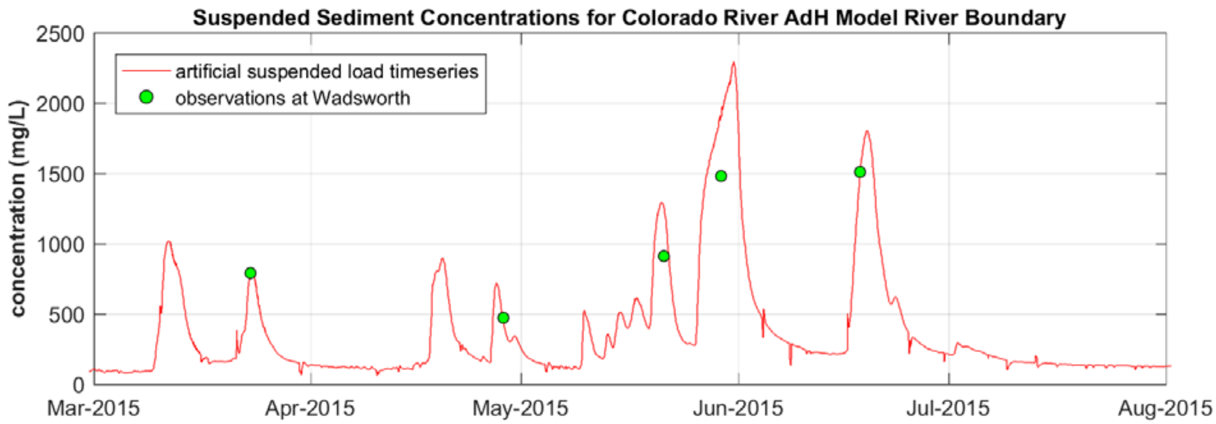

Figure 23   Artificial sediment concentration time-series for boundary condition for 2015 AdH Simulation

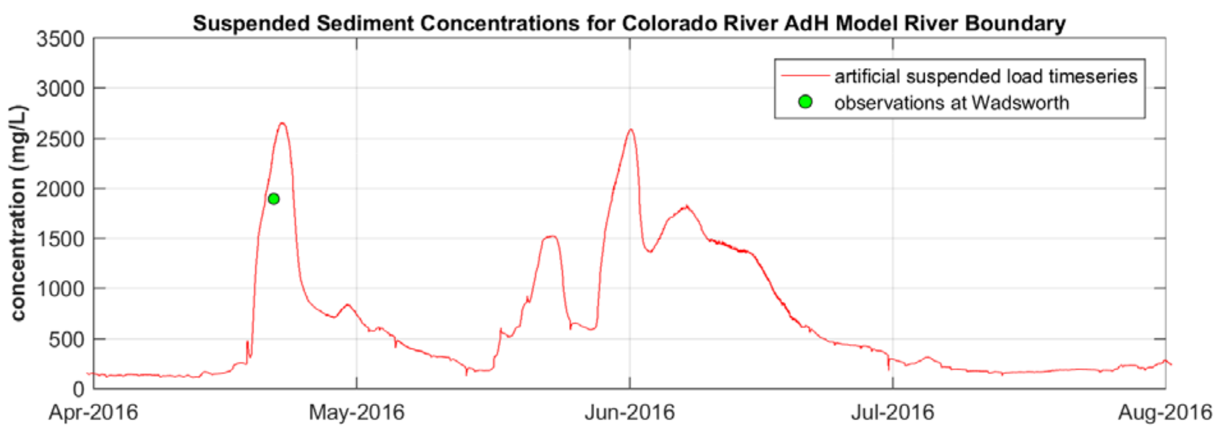

Figure 24   Artificial sediment concentration time-series for boundary condition for 2016 AdH Simulation

Wind

For the 2001 simulation, wind time-series were taken from the 2001 study data and applied to the entire domain. For the 2015 and 2016 simulation, wind was taken from the at the NOAA gage at Port O'Connor. The wind data at this site is recorded is at a 5-minute interval. To increase model stability, the wind was averaged over 2-hour increments. Figure 25 displays the raw observed 5-minute data, and the 2-hour averaged windspeed data for the 2015 simulation period.

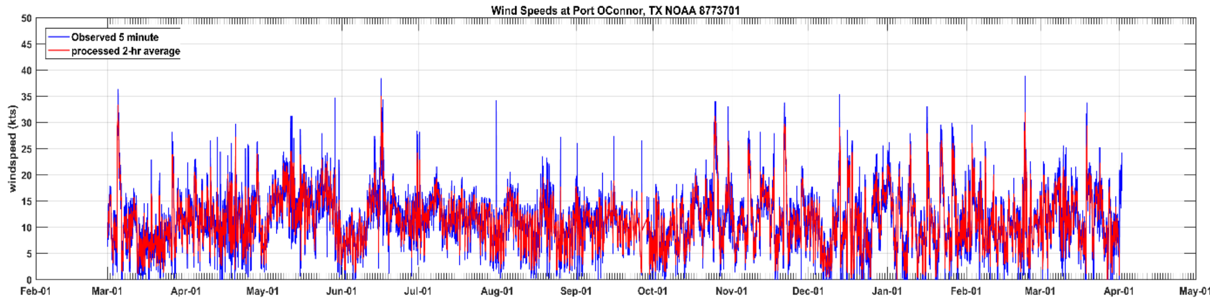

Figure 25   Wind time series 2015 simulation

Precipitation and Evaporation

For the 2001 simulation, net precipitation (evaporation + precipitation) time-series were taken from the 2001 study data and applied to the entire domain (ERDC 2003). For the 2015 and 2016 simulations, hourly precipitation was downloaded from the from National Weather Service website:

http://www.srh.noaa.gov/ridge2/RFC_Precip/

Monthly average evaporation data for the 2015 and 2016 simulations was downloaded from the Texas Water Development Board's website:

http://www.twdb.texas.gov/surfacewater/conditions/evaporation/

AdH requires a net precipitation plus evaporation time-series. To accomplish this, the monthly average evaporation rates were concerted to hourly evaporation rates and added to the hourly rainfall.

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.

Locks

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 2001, 2015, and 2016 simulations. To develop the time-series of gate closures, the velocity at the gage 14 was analyzed to see when it exceed 2 ft/s. This time-series was applied in the modeling to mimic the gate operations occurring in reality.

Calibration and Validation

Three time periods were simulated with AdH.

Simulation	From	To	Purpose
2001	6/1/2001	10/1/2001	Calibration
2015	3/1/2015	7/1/2015	Validation
2016	4/1/2016	7/1/2016	Validation

Model Calibration 2001 Simulation

The AdH hindcast of the 2001 simulation (6/1/2001 to 10/1/2001) agrees very well with the water level observations at the 12 deployed gates. An example is provided at Gage 1 in Figure 26. Water level plots for all 12 locations are provided in the appendix. The AdH model also validated well with the observed discharge measurements taken in 2001. Figure 27 displays the modeled vs observed discharges at transect 6, which is located in the bypass channel. Figure 28 displays the modeled vs observed velocity at gage 14, which in the USGS gage in the bypass channel. The model tends to agree with the measurements, although there seems to be an issue with the sensor during beginning of the plotted time-period. Figure 29 displays the modeled vs observed salinity. The salinity is more difficult to predict than other parameters, although for a 2D model, the results are reasonable. The primary adjustments involved in the calibration effort involved adjusting of Manning's n values and artificially deepening some of the shallow nodes along the banks of the channels. Table 2 contains water level error statistics are the 12 deployed gages for the 2001 simulation.

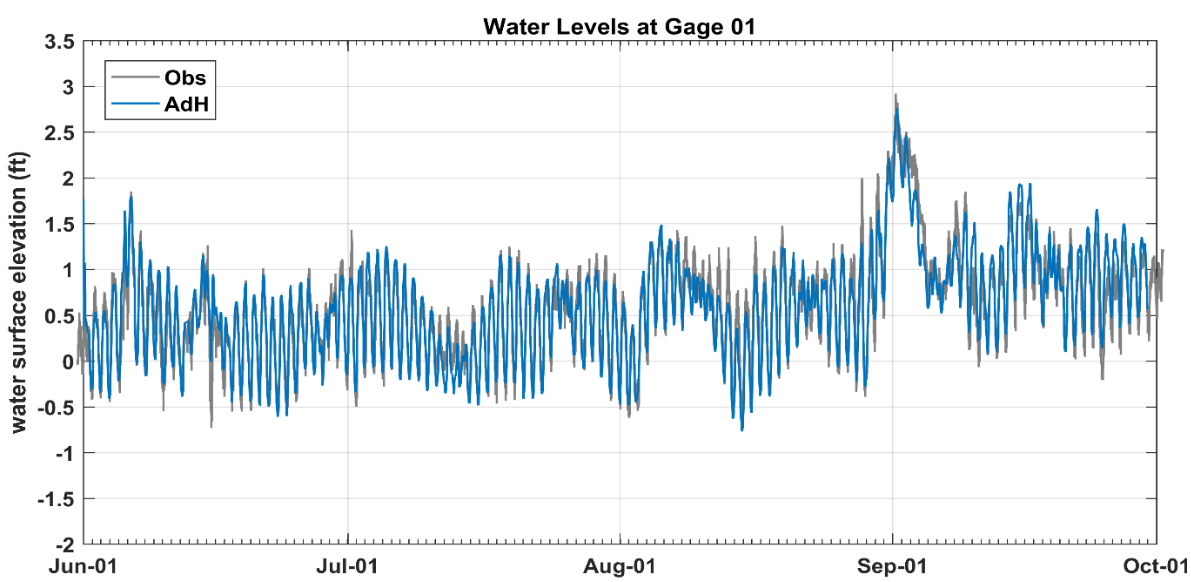

Figure 26 Modeled vs. Observed water level time-series at Gage 01.

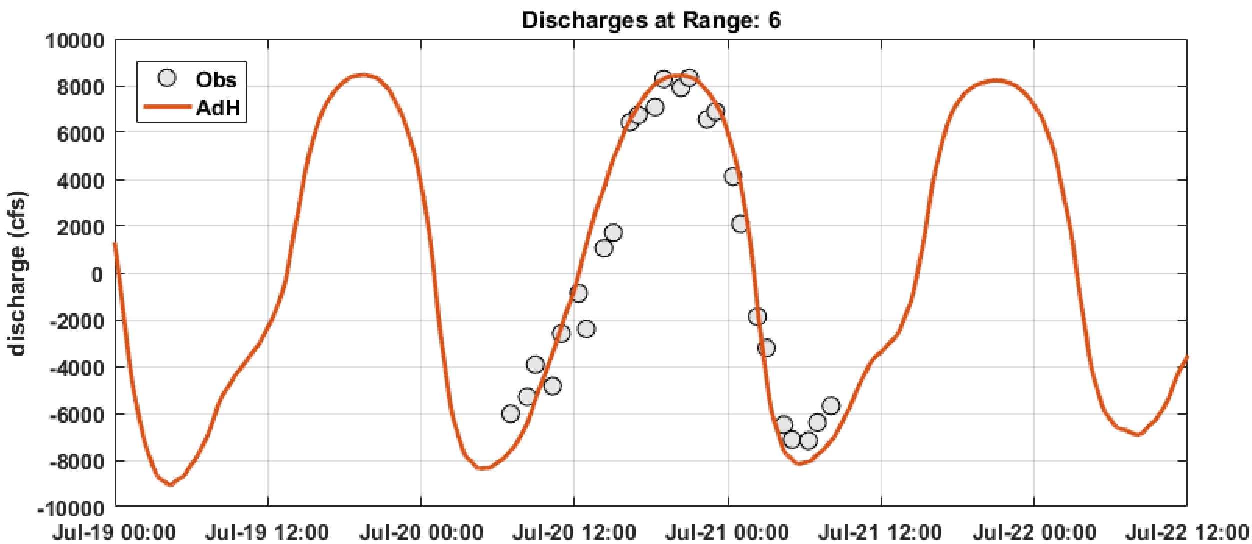

Figure 27 Modeled vs Observed discharges at the USGS gage in the Colorado River Bypass Channel for the 2001 simulation

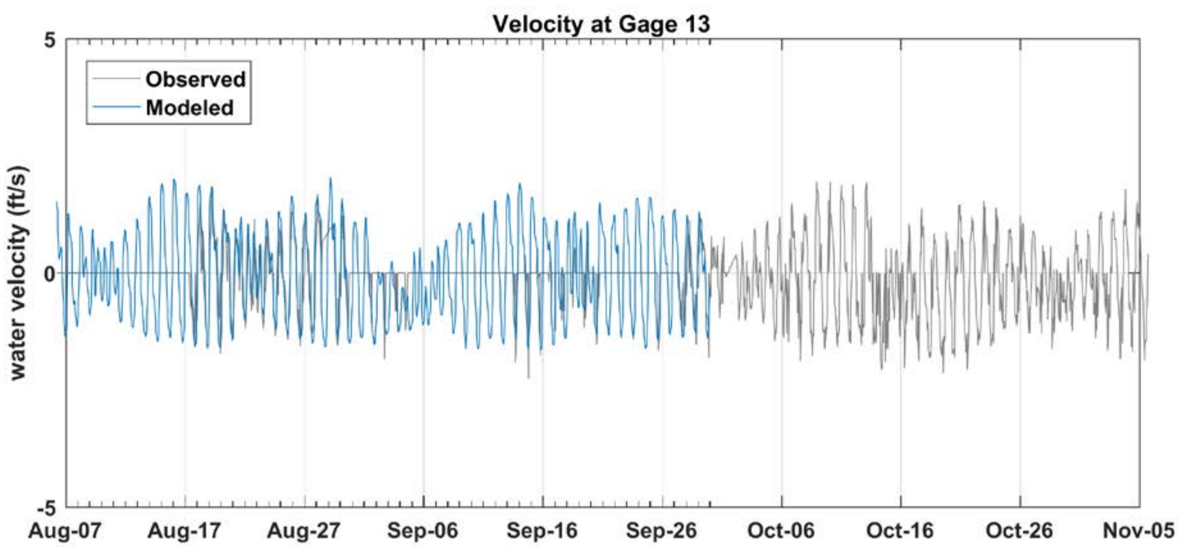

Figure 28 Modeled vs Observed velocities at the USGS gage in the Colorado River Bypass Channel for the 2001 simulation

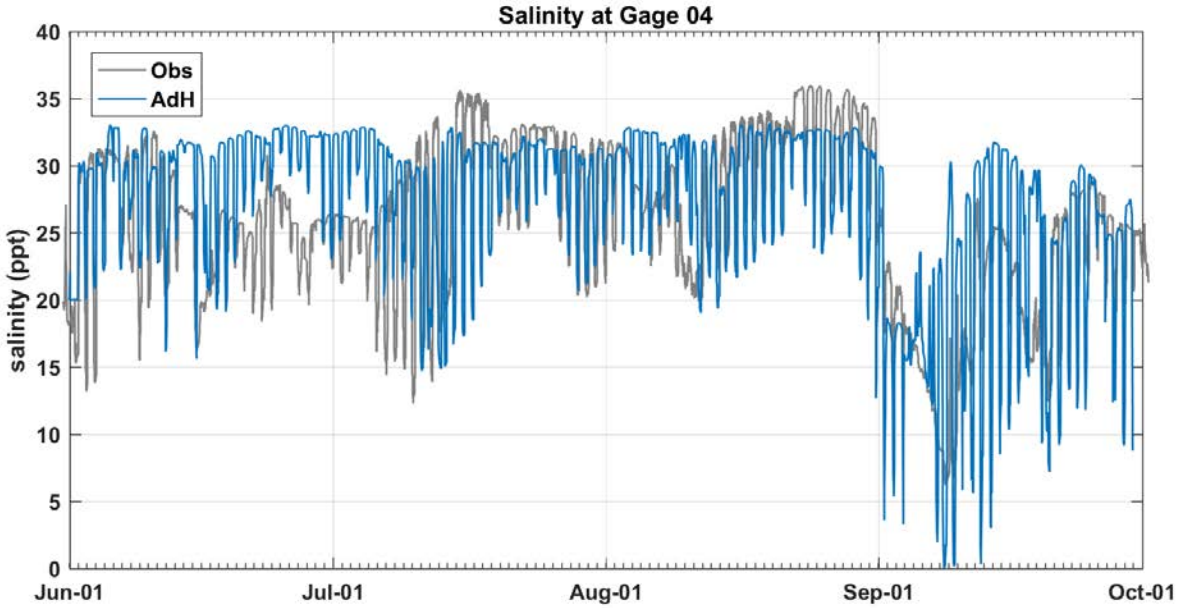

Figure 29 Modeled vs Observed salinities at Gage 4 for the 2001 simulation

Gage Number	Mean Absolute Error MAE (ft)	Root Mean Square Error RMS (ft)	Index of Agreement (d)
1	0.13	0.18	0.95
2	0.17	0.22	0.92
3	0.16	0.20	0.95
4	0.18	0.22	0.97
5	0.13	0.18	0.96
6	0.12	0.16	0.97
7	0.21	0.27	0.88
8	0.12	0.16	0.91
9	0.13	0.17	0.96
10	0.14	0.18	0.96
11	0.09	0.11	0.87
12	0.07	0.09	0.91

Table 2 Water Level Error Statistics for 2001 Simulation

Model Validation 2015 Simulation

The 2015 time period was simulated and compared to measurements. Seven distinct floods occur during this time period. Figure 30 displays the modeled vs observed water-levels in the Colorado River near the project site. The model matches measurements very well, especially at the peaks of the two largest floods in late May and late June. The plot also shows the time series of gate operations. The locks close and open many times during the simulation, allowing the model to match the measured water levels. Figure 31 displays the modeled vs observed velocity at the gage in the river near the project site. The model predicts the velocities at this gage very well for this time period. There is some discrepancy between the model and observations for the flood in late June. Figure 32 displays the modeled vs observed suspended sediment concentration and total suspended sediment load. The model is in agreement with the measurements, primarily because the concentrations for fine grain material are forced at the boundary. However, the model does predict a reasonable amount of suspended fine grain sand from the supply reach, both in terms of concentration and total suspended load. Figure 32 also plots the total bed load for the 2015 simulation. Model output at all locations is provided in the appendix.

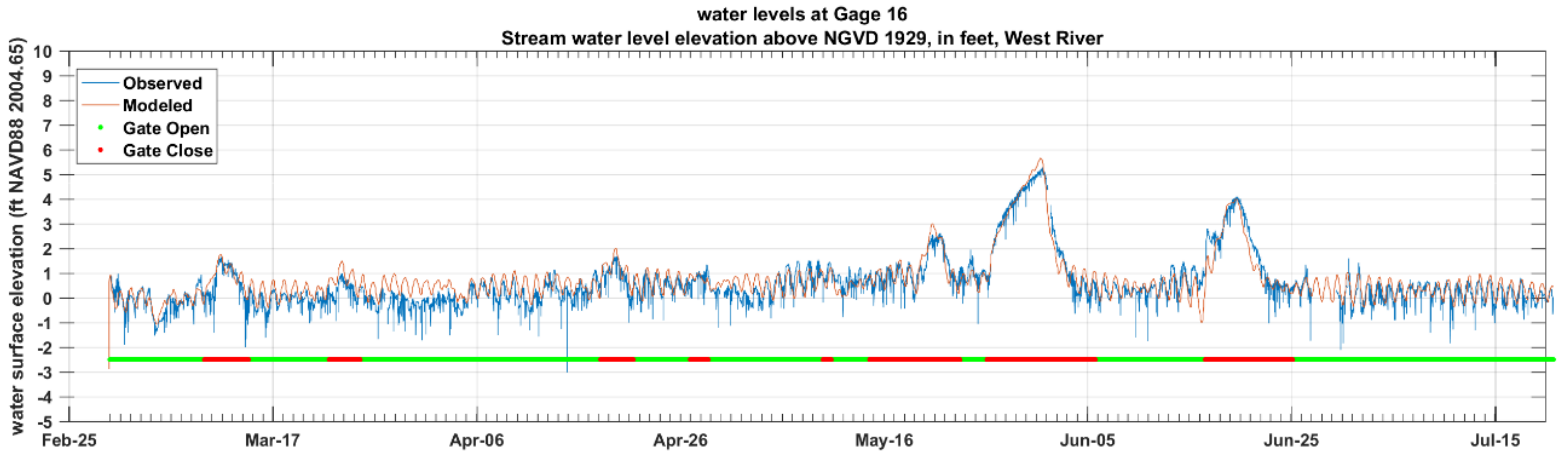

Figure 30 Modeled vs Observed water-levels at Gage 16 for the 2015 simulation

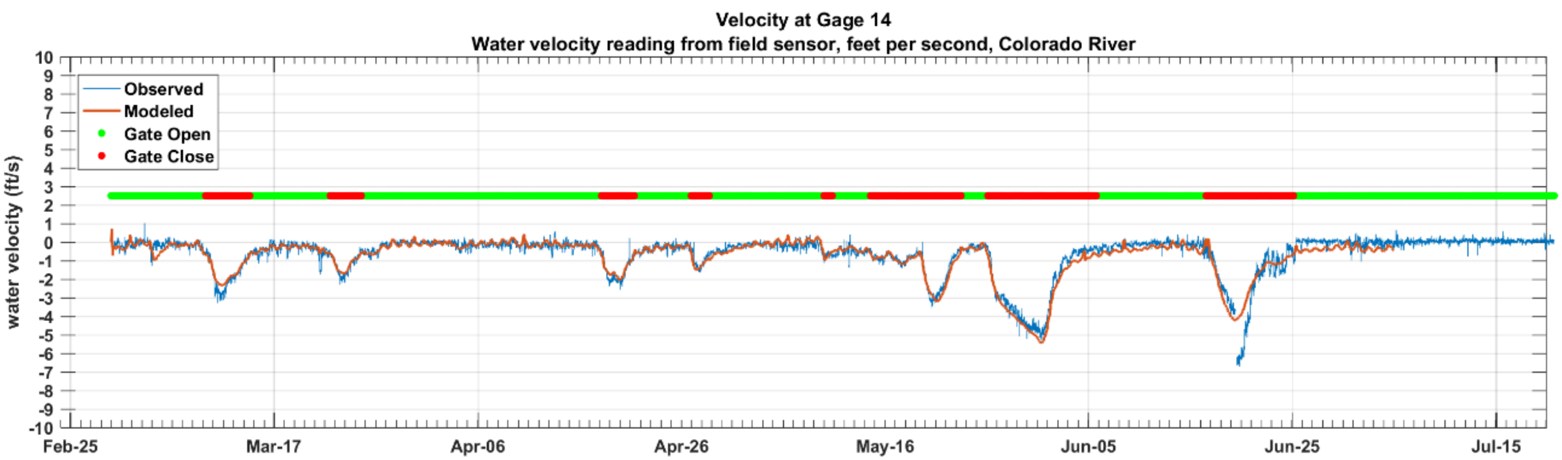

Figure 31 Modeled vs Observed velocities at Gage 14 for the 2015 simulation

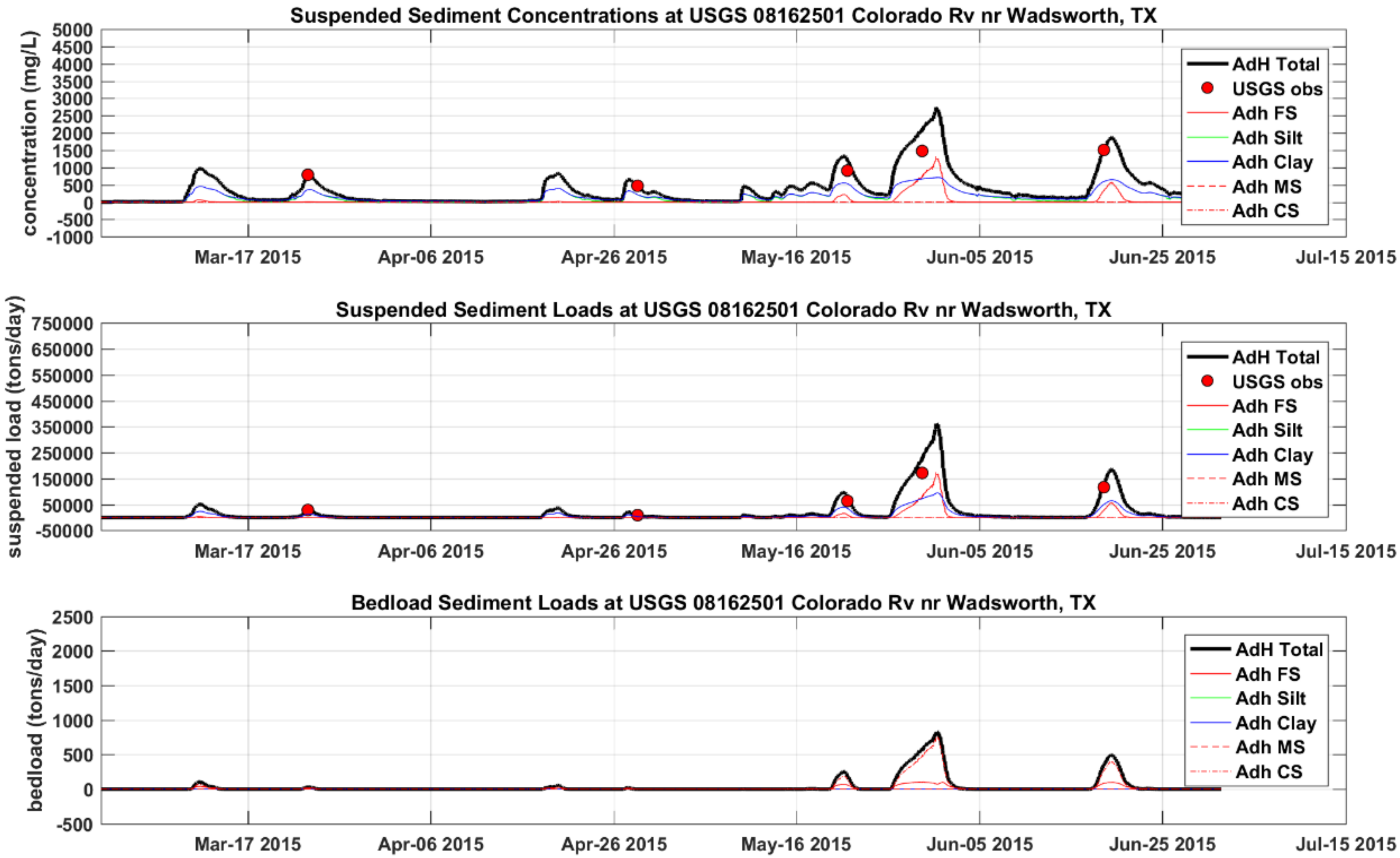

Figure 32 Modeled vs Observed suspended sediment concentrations and total suspended loads for 2015 simulation

Model Validation 2016 Simulation

The 2016 time period was simulated and compared to measurements. Two large back to back floods occur during this time period. Figure 33 displays the modeled vs observed water-levels in the Colorado River near the project site. The model matches measurements, but tends to over-predict the peak of the flood by roughly 1 foot. The plot also shows the time series of gate operations. Figure 34 displays the modeled vs observed velocities at the gage in the river near the project site. The model predicts the velocities fairly well, especially during the floods. There is some over-prediction of velocities on the descending limb of the hydrograph. Figure 35 displays the modeled vs observed suspended sediment concentration and total suspended sediment load. The model is in agreement with the measurements, primarily because the concentrations for fine grain material are forced at the boundary. However, the model does predict a reasonable amount of suspended fine grain sand from the supply reach, both in terms of concentration and total suspended load. Figure 35 also plots the total bed load for the 2016 simulation. Model output at all locations is provided in the appendix.

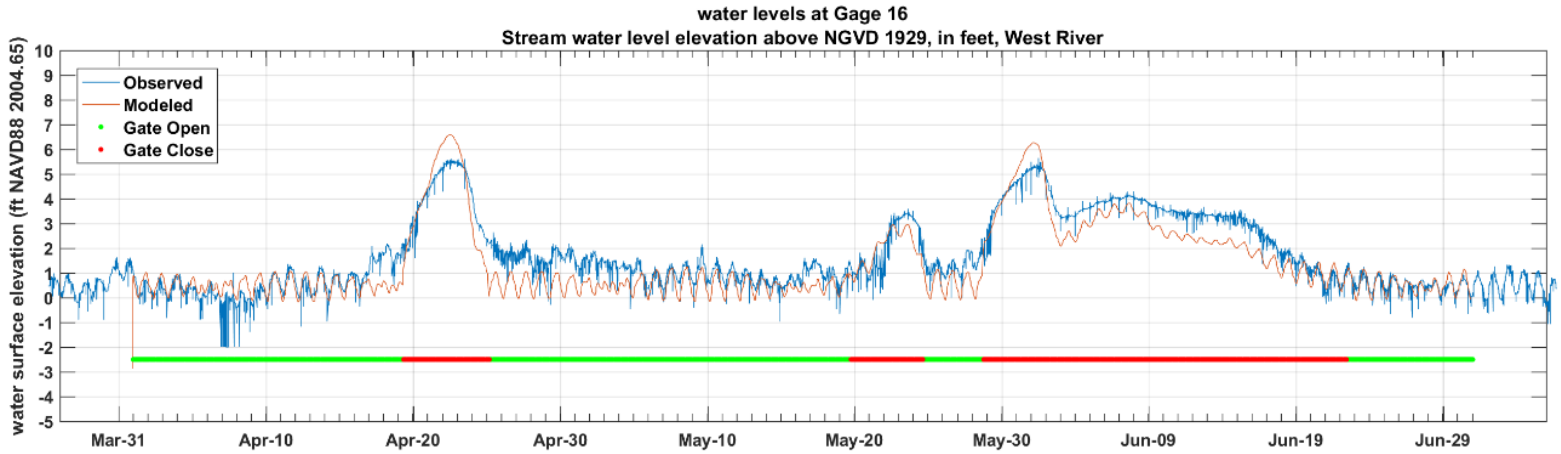

Figure 33 Modeled vs Observed water-levels at Gage 16 for the 2016 simulation

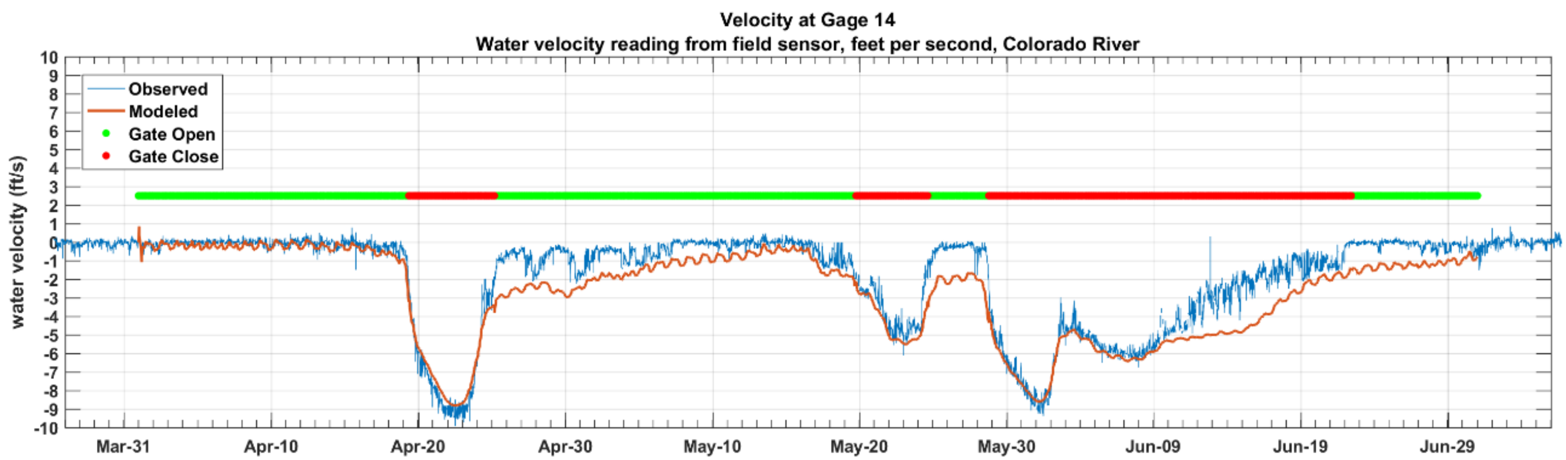

Figure 34 Modeled vs Observed velocities at Gage 14 for the 2016 simulation

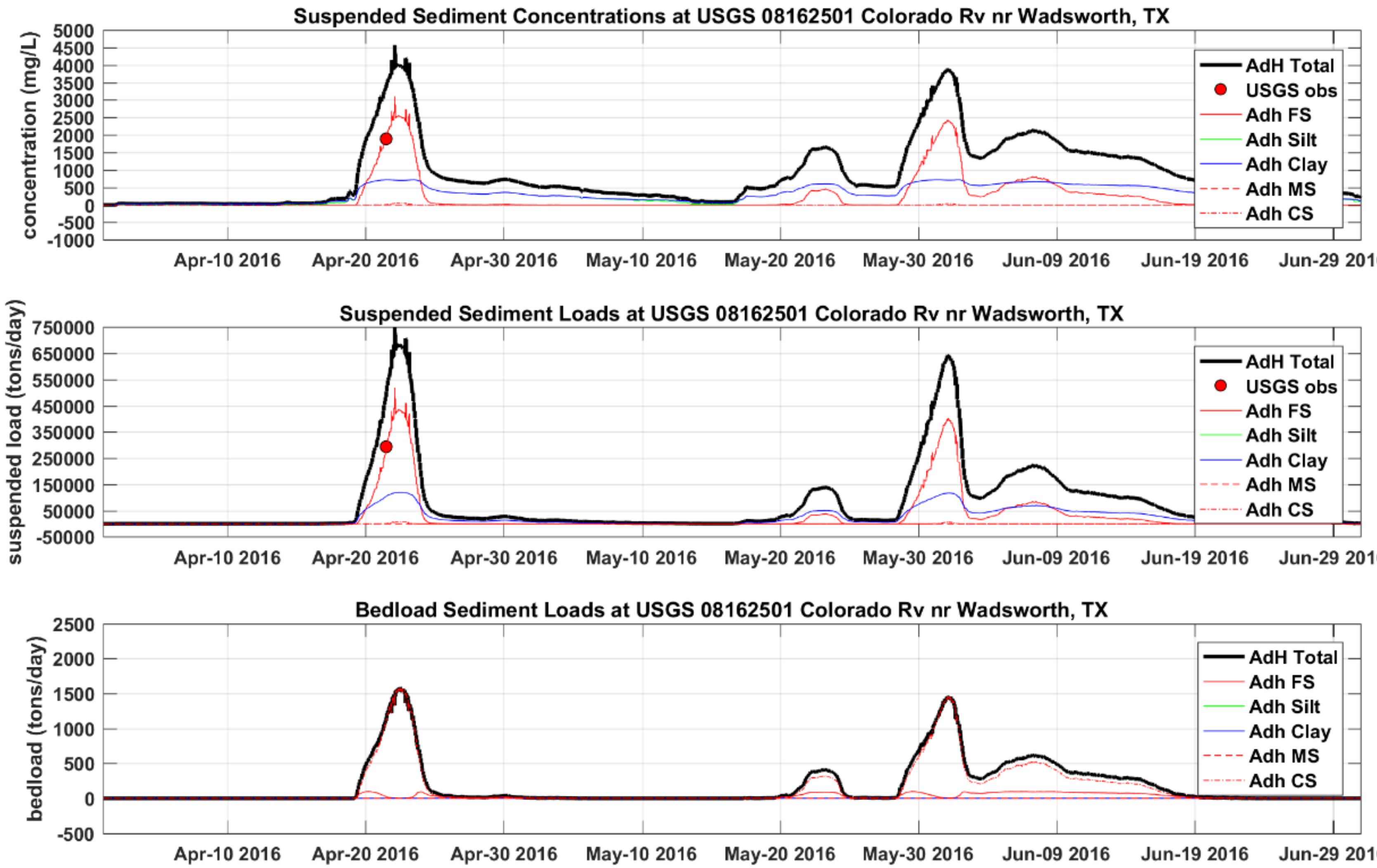

Figure 35 Modeled vs Observed suspended sediment concentrations and total suspended loads for 2016 simulation

Model Validation - Harvey Simulation

During the course of this study, Hurricane Harvey impacted the project area with extreme rainfall amounts. The resulting discharge set records on the Colorado River. AdH was used to hindcast the time period from 8/24/2017 to 9/19/2017. Boundary conditions, including the gulf stage, rainfall, and discharge were assigned in a similar way as the previous simulations. The simulation of Hurricane Harvey shows a tremendous volume of material, especially in the west lost forebay. In terms of deposition volume, the simulation of hurricane Harvey shows approximately 90,300 cubic yards of material in both east and west forebays. Pre and post flood surveys show a similar volume of approximately 103,000 cubic yards in the Colorado River Crossing (Sta. 806+400 to Sta. 808+440). Figure 36 displays the total bed change at the end of the Hurricane Harvey simulation.

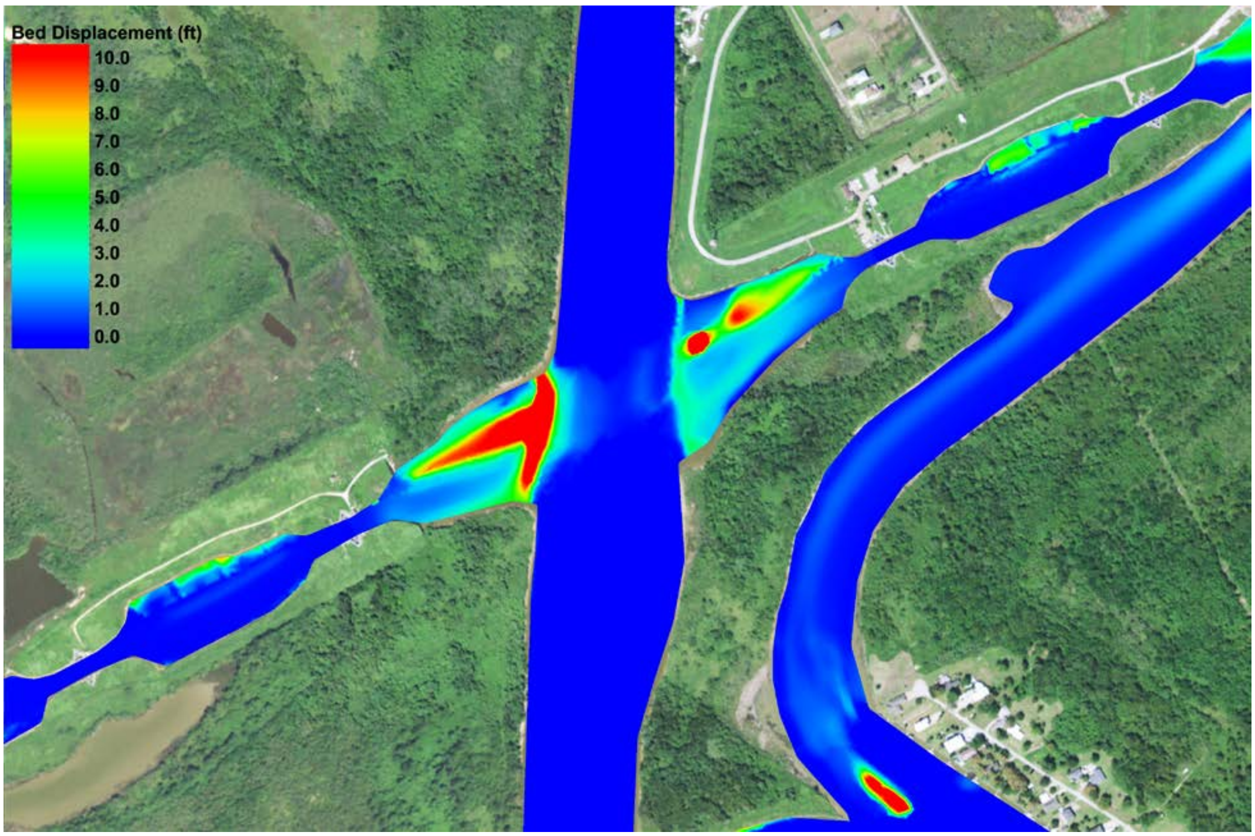

Figure 36 Bed Change at end of Hurricane Harvey Simulation

Model Scenario Runs

For this analysis, one alternative was proposed which was removal of the Colorado Locks. The existing condition mesh, pictured in Figure 37, was modified to represent a condition with the locks removed. The channel was widened at the location of the locks by simply adding elements to the base condition mesh. By adding new elements, the existing mesh node numbering remained intact, allowing use of the base condition boundary condition file with limited modification. A Matlab script was developed to append the new elements to the existing condition mesh. The widened channel is similar to the adjacent GIWW in terms of channel shape, width and depth. Figure 38 shows the AdH mesh with the locks removed. The hotstart file for the existing condition was also modified to account for the Open Channel scenario. The only modification in the boundary condition file was deactivation of the breach card which controls the opening and closing of the locks. The model was set up to evaluate what would happen to water levels, velocities, sediment, and salinity if the Colorado River locks were removed. For the model run scenarios, both the 2015 and 2016 simulations were conducted for all alternatives.

The primary goals of the scenario runs are as follow:

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

Currents

Figure 39 displays a snapshot of the modeled velocities at the peak of the April 2016 flood. The modeled velocity for existing conditions is approximately 9 ft/sec in the channel immediately upstream from the intersection, which agrees well with the observations. Figure 40 displays the modeled velocity with the locks are removed. Removing the locks causes a significant increase in velocities in the main river channel extended well above the GIWW intersection. The peak velocity increases to approximately 12.0 ft/sec when the locks are removed. The removal of the locks simply provides a more efficient route to the open water of East and West Matagorda Bays. As a result, the velocities in the River and GIWW increase significantly when the locks are removed. As the velocity increases, the depths become much less as the river outlet is more efficient. Figure 41 displays a time-series of velocities at gage 14, which is the location of the USGS gage upstream of the intersection. 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 Figure 10, 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.

Water levels drop significantly in the river channel when the locks are removed. Figure 42 displays the water levels upstream of the intersection at gage 1 for existing and open-channel conditions. Figure 43 displays the water levels for existing and open-channel alternatives at gage 14, which is just upstream from the intersection.

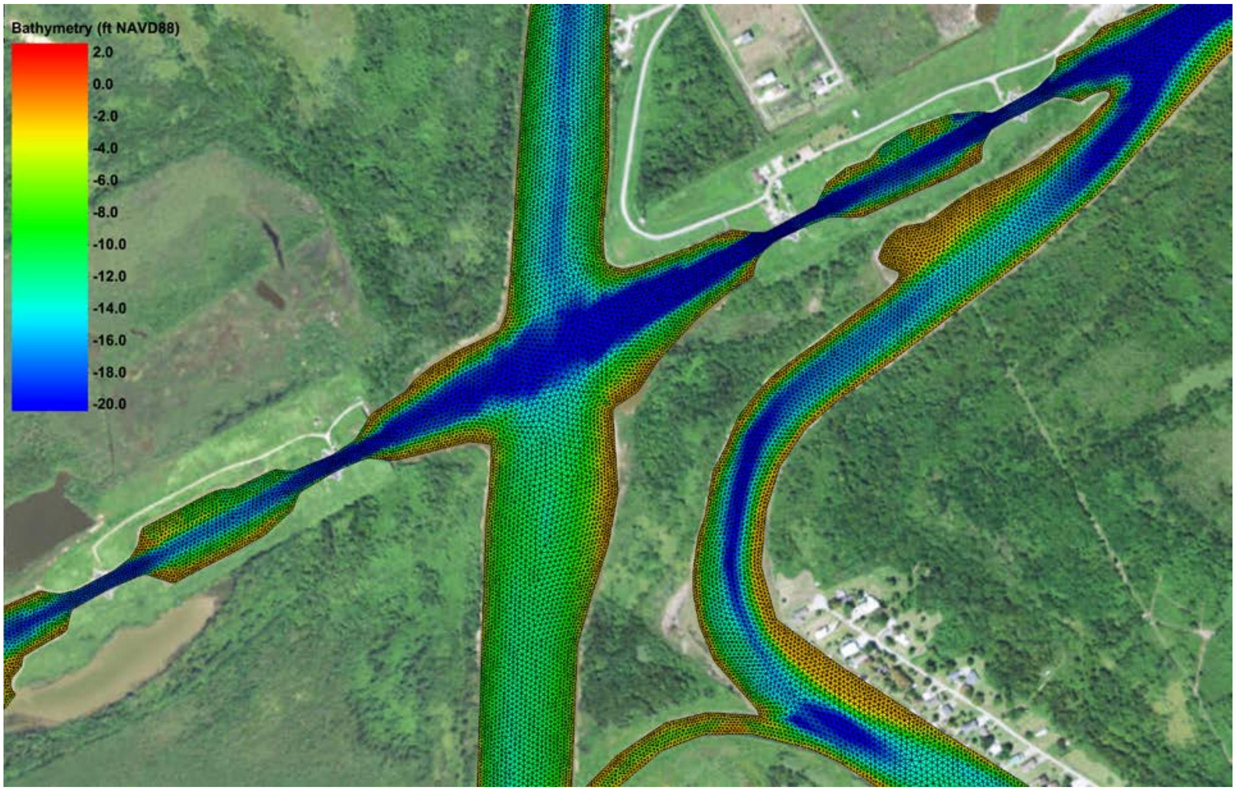

Figure 37   Existing condition AdH mesh

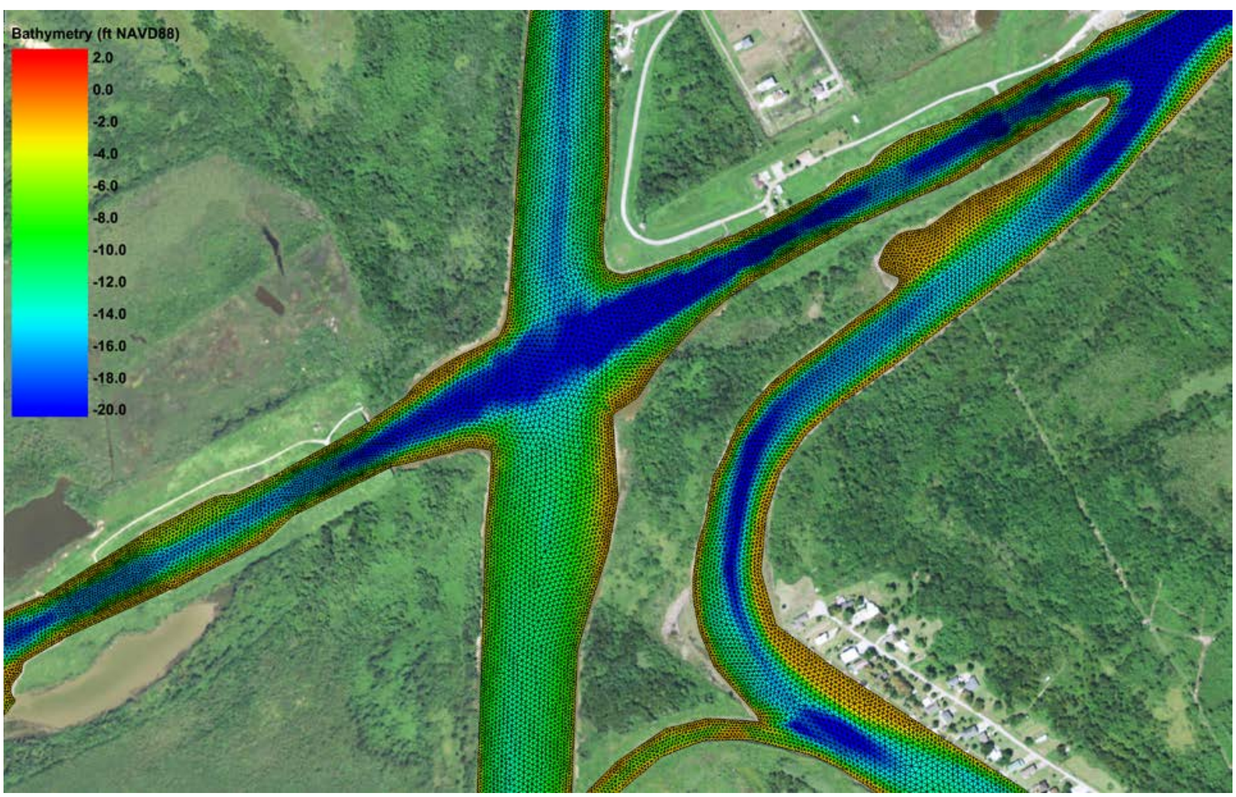

Figure 38   AdH mesh for Open-Channel Alternative

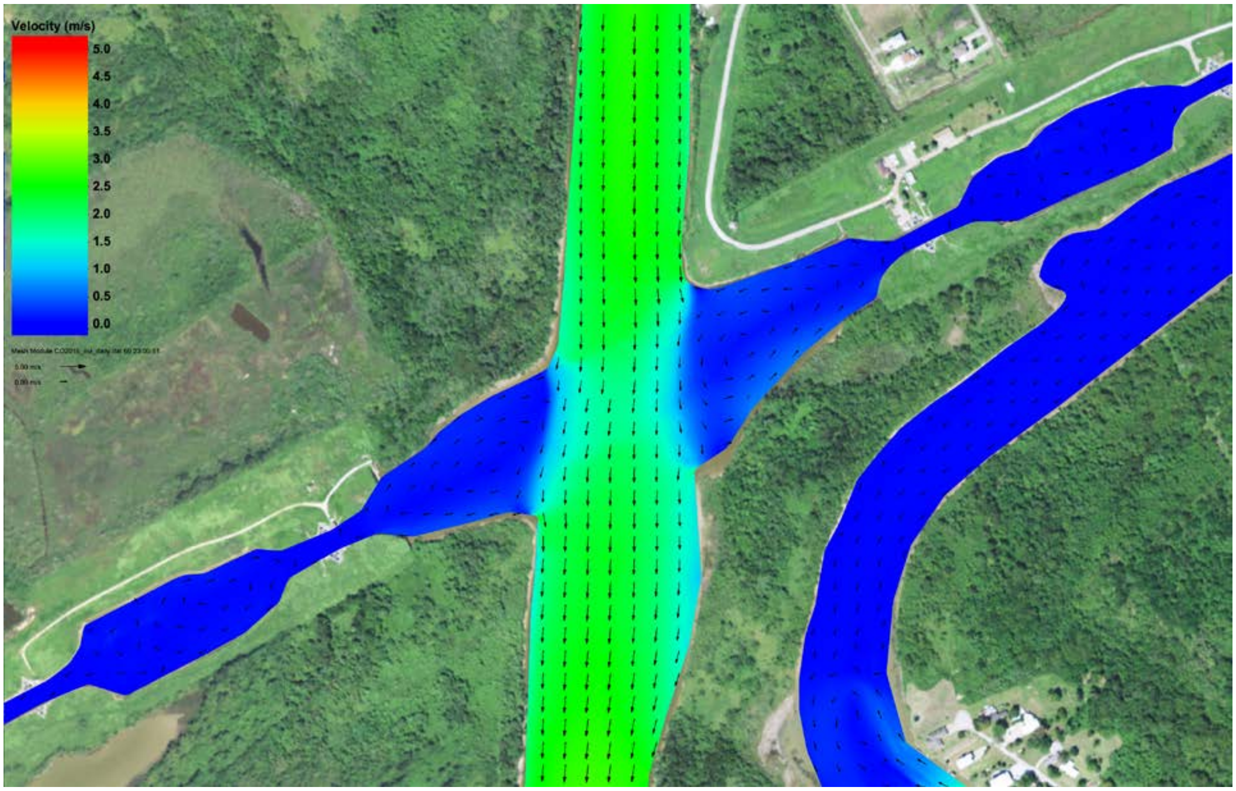

Figure 39   Velocity at peak of April 2016 Flood Event for Existing Conditions

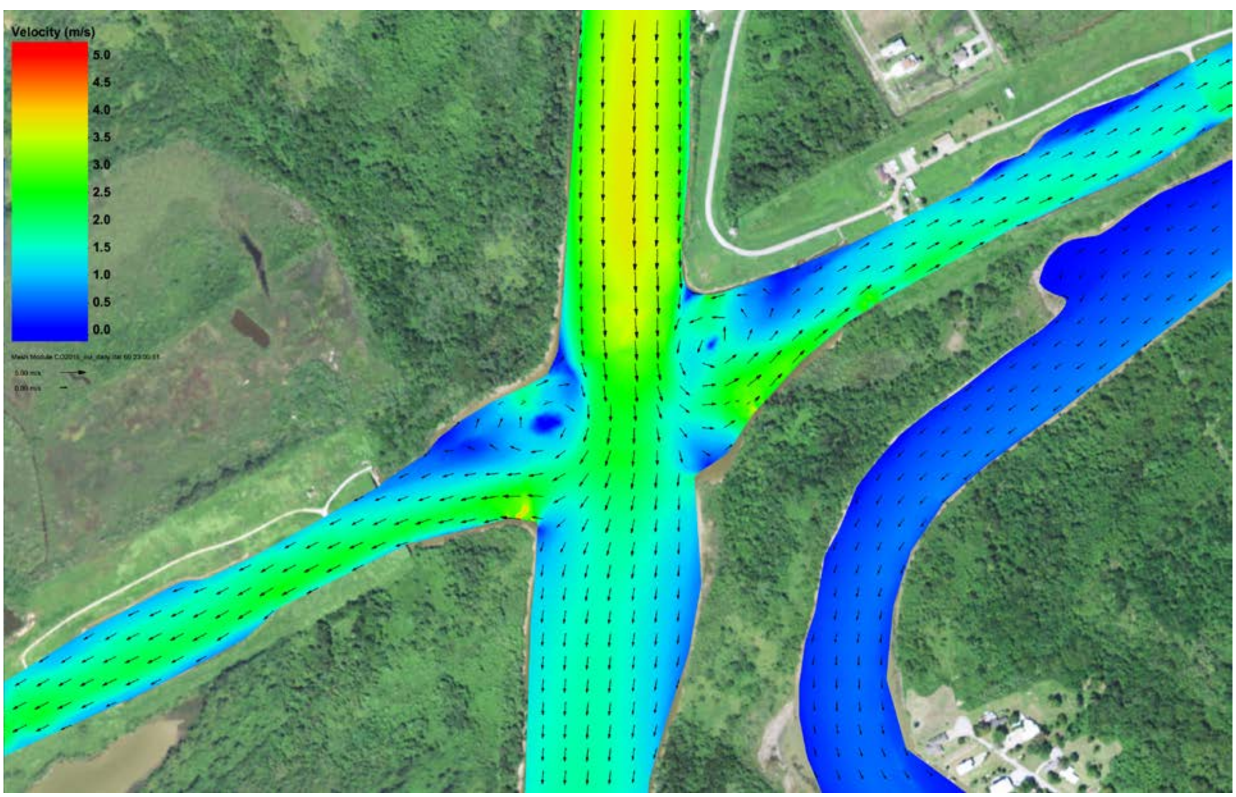

Figure 40   Velocity at peak of April 2016 Flood Event for the Open Channel Alternative

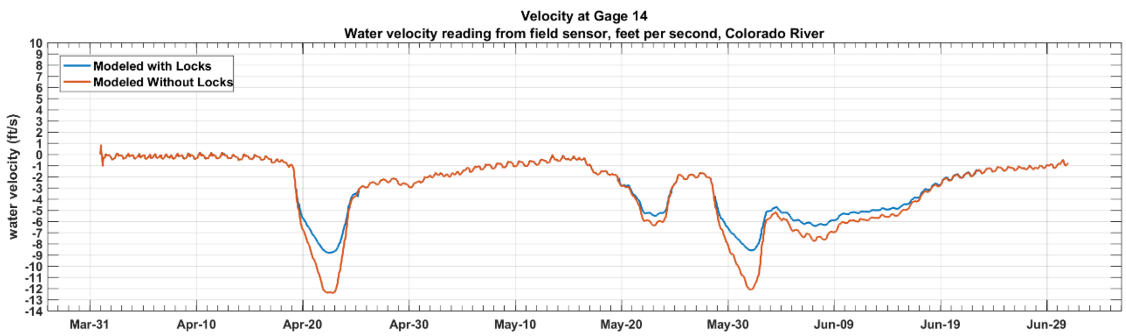

Figure 41 Comparison of Open-Channel and Existing Condition Velocities for 2016 Simulation Period at Gage 14

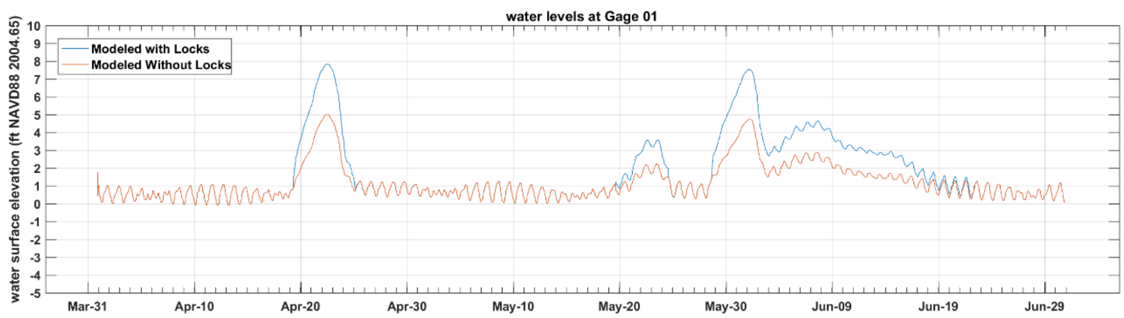

Figure 42 Comparison of Open-Channel and Existing Condition Water Levels for 2016 Simulation Period at Gage 1

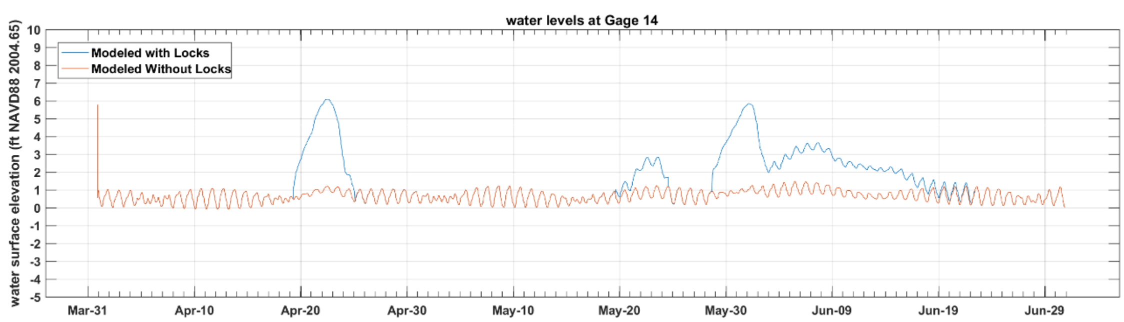

Figure 43 Comparison of Open-Channel and Existing Condition Water Levels for 2016 Simulation Period at Gage 14

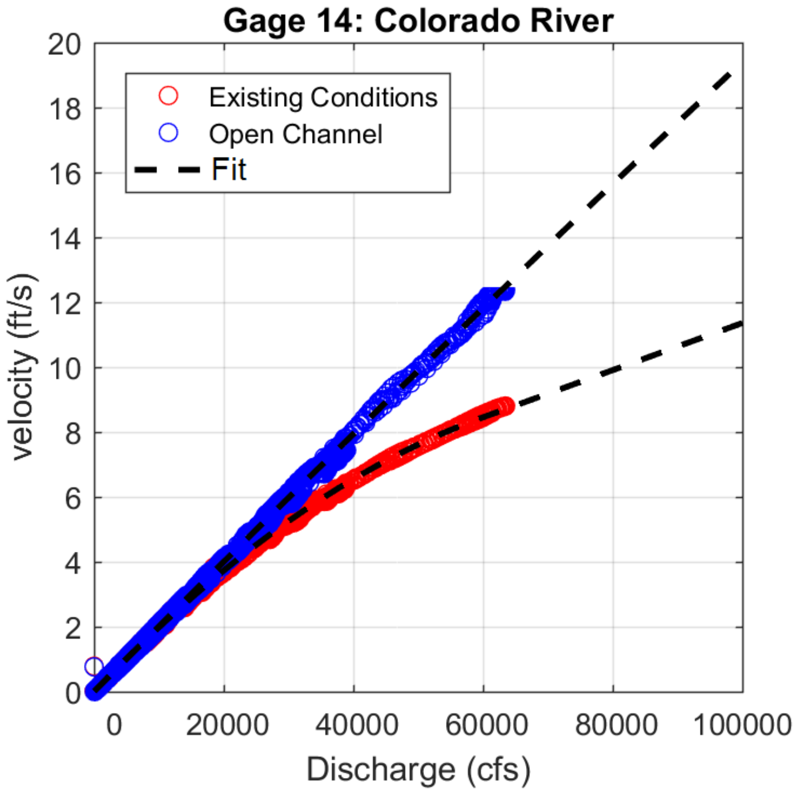

Figure 44 Discharge vs Velocity Rating Curve at Gage 14

Salinity

Figure 45 displays the average salinity for the 2016 simulation for existing condition. Figure 46 displays the average salinity for the open channel alternative. The results show that the average salinity increases slightly in West Matagorda Bay and decreases significantly in East Matagorda Bay. Figure 47 displays the salinity time-series at gage 10, which is located in West Matagorda Bay. Figure 48 displays the salinity time-series at gage 12, which is located in East Matagorda Bay. The modeled salinities at gage 12 are shown to decrease significantly with the inflow of fresh water into East Matagorda Bay associated with removal of the locks.

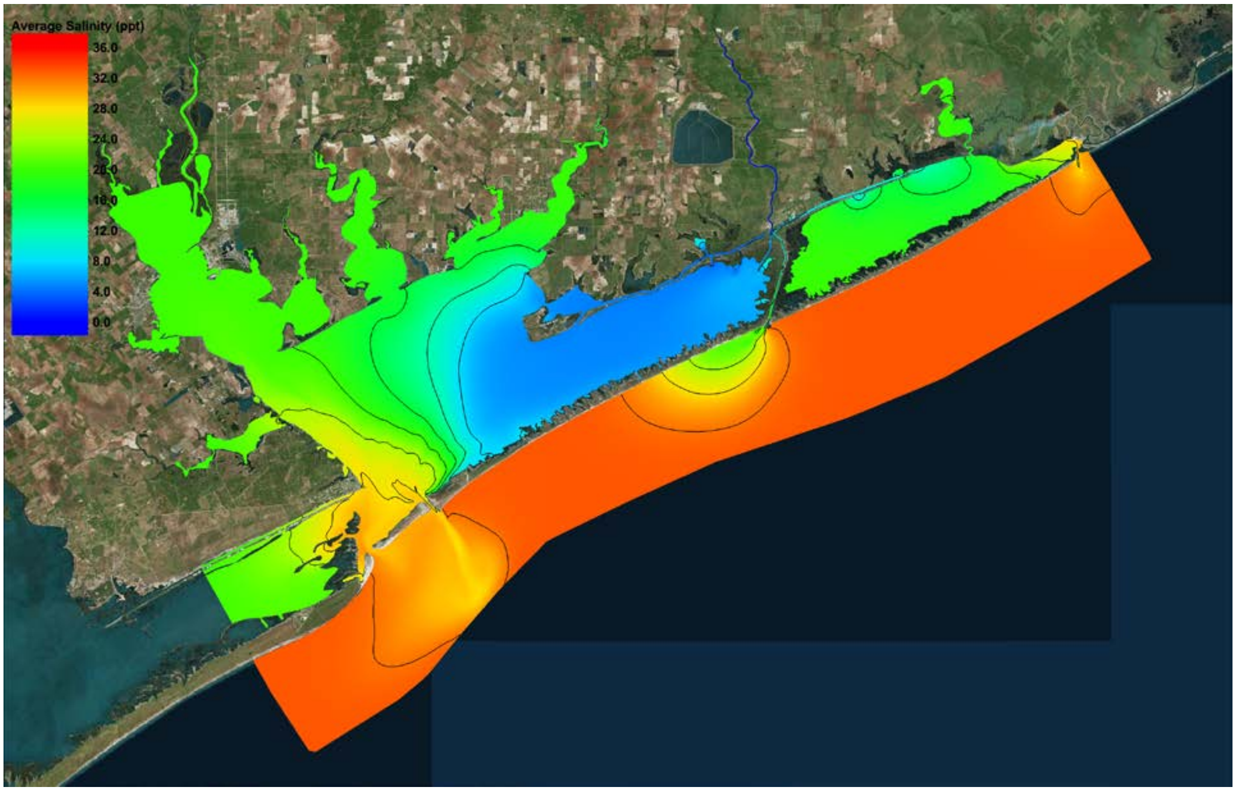

Figure 45 Average Salinity of 2016 Simulation for Existiing Conditions

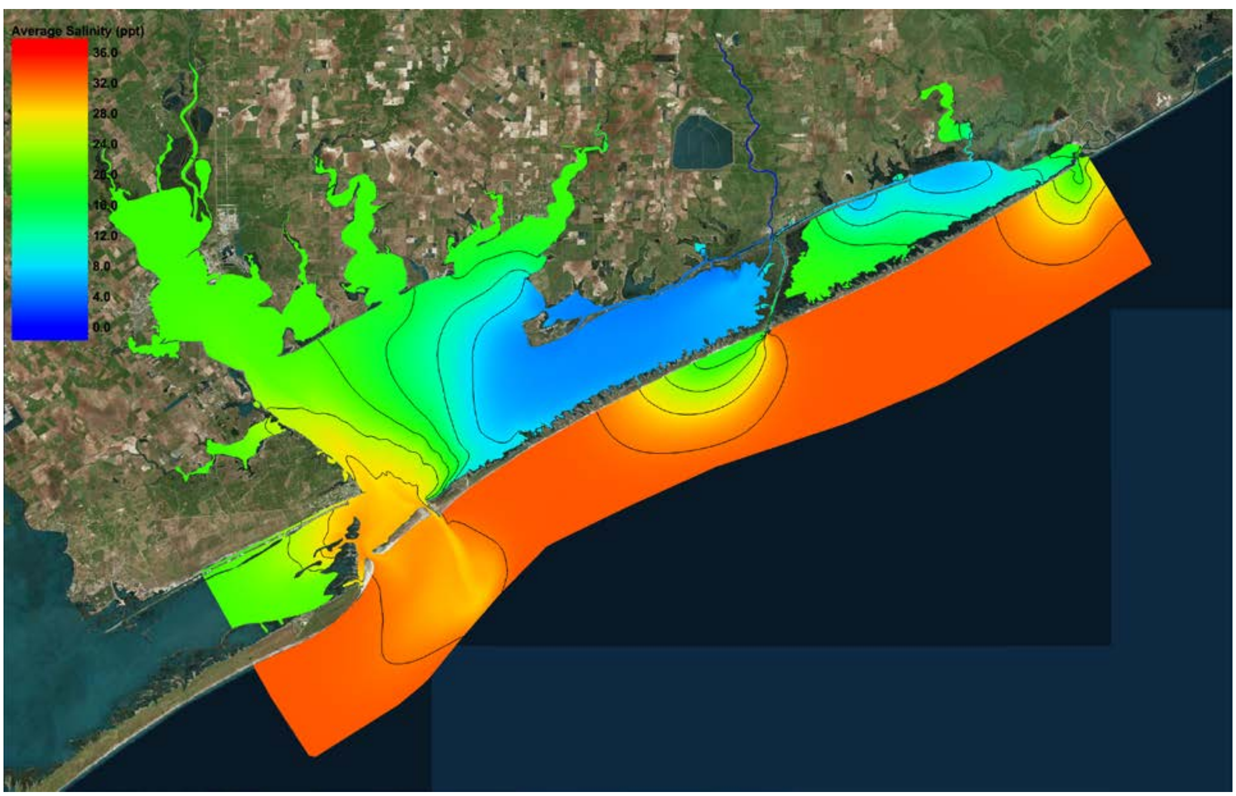

Figure 46 Average Salinity of 2016 Simulation for Open-Channel Alternative

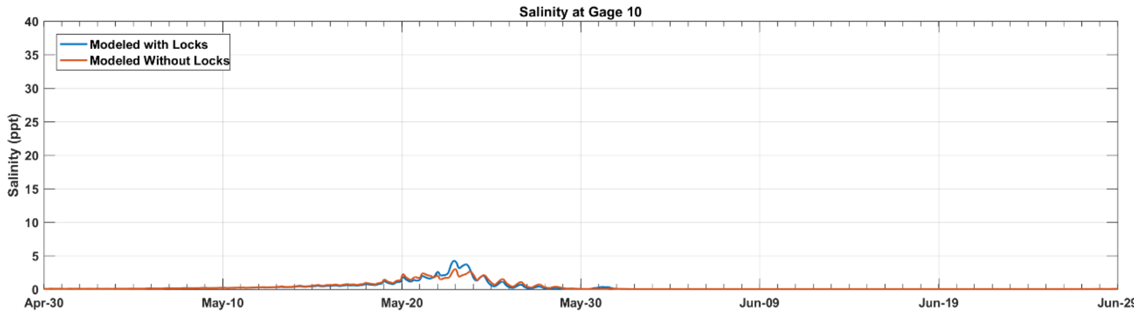

Figure 47 Comparison of Open-Channel and Existing Condition Salinity for 2016 Simulation Period at Gage 10

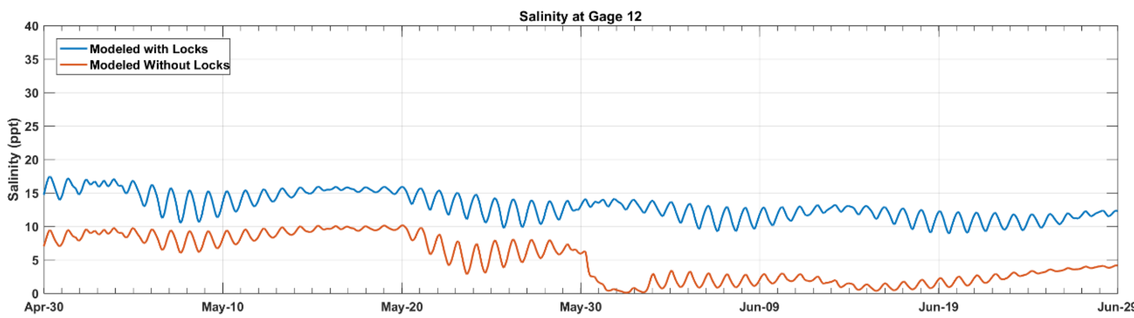

Figure 48 Comparison of Open-Channel and Existing Condition Salinity for 2016 Simulation Period at Gage 12

Sediment

Figure 49 and Figure 51 display the resulting bed-change for existing conditions for the 2016 simulation. The resulting bed-change is significant, especially at the intersection and the Colorado River Delta in West Matagorda Bay. Figure 50 and Figure 52 display the bed-change for the open-channel alternative. With the locks removed, the sediment budget changes significantly. As expected, a significant amount of deposition occurs in the east and west GIWW with the open-channel alternative.

AdH allows the user to specify internal boundaries that record the sediment flux at each time-step. To better assess the sediment budget, 4 sediment flux boundaries were drawn at the 4-way intersection. The four flux boundaries are displayed in Figure 53. The sediment flux at each boundary is dependent on many variables, especially the discharge in the Colorado River. A regression analysis was performed on discharges and sediment fluxes for each flux boundary. Figure 54 displays the results of the regression analysis for the 4-way intersection. For existing conditions, the sediment stays within the Colorado River and continues to the delta in West Matagorda Bay. For the open channel alternative, about 25% of the sediment enters the West GIWW, and about 25% enters the East GIWW, and 50% continues down the Colorado River to the delta in West Matagorda Bay. The sediment flux analysis shows a tremendous change in the basic transport of materials.

To further analyze the fate of the sediment, a deposition analysis was performed. A series of polygons were drawn to delineate specific areas. Figure 55 displays the polygons used in the deposition analysis. For each simulation, the total deposition in cubic yards was determined for both existing and open-channel alternatives. Table 3 contains the total deposition quantities for both existing and open-channel alternatives. The table also provides a percent difference between the existing and open channel alternatives. The open channel alternative drastically changes the existing sediment budget. For example, for the East GIWW, the estimated deposition increases from 110,957 to 362,795 cubic yards with removal of the locks for the 2016 simulation period. For the open-channel alternative, a significant increase in shoaling within the East and West GIWW would be expected. For other areas, such as Delta 3, the sedimentation rates decrease. With the open channel alternative, about 25% of the sediment flux enters the East GIWW, therefore some reduction in sedimentation is expected in West Matagorda Bay. The open channel alternative is expected to slow down the formation of the delta in West Matagorda Bay. The simulations of the 2015 and 2016 time periods provide useful information for a reasonable range of expected events. 2015 is closer to an average flood year, while 2016 is a wet year.

In order to better assess the long term impacts to sedimentation, a regression analysis was performed to determine average annual deposition rates for select areas. The sedimentation rate (cubic yards/day) at each hour of the simulation was determined for each polygon displayed in Figure 55. The sedimentation rate was plotted against the discharge upstream of the crossing. A linear trend line was plotted through resulting data. The sedimentation rate vs discharge linear trend was established for select polygon areas for both existing and open channel alternatives. Figure 56, Figure 57, and Figure 58 display the regression analysis data for the GIWW East, GIWW West and Delta 3 locations. The linear trend lines were used to convert long term daily discharge measurements presented in Figure 10 into long term deposition rates. Once the long term daily rates were determined, the average annual deposition volumes were calculated for select areas. For some areas, a reasonable trend could not be determined. Table 4 contains the estimated annual average deposition volumes for the select areas of interest. One set of average annual volumes was determined from the 2015 simulation, and one was determined from the 2016 simulation. The two sets of values provide reasonable range of results. The overall uncertainty of the regression analysis results is considerable. Additionally, dredging frequency estimates, based on the estimated average annual deposition volumes, were also provided. Table 5 contains dredging frequency estimates for existing and open channel conditions.

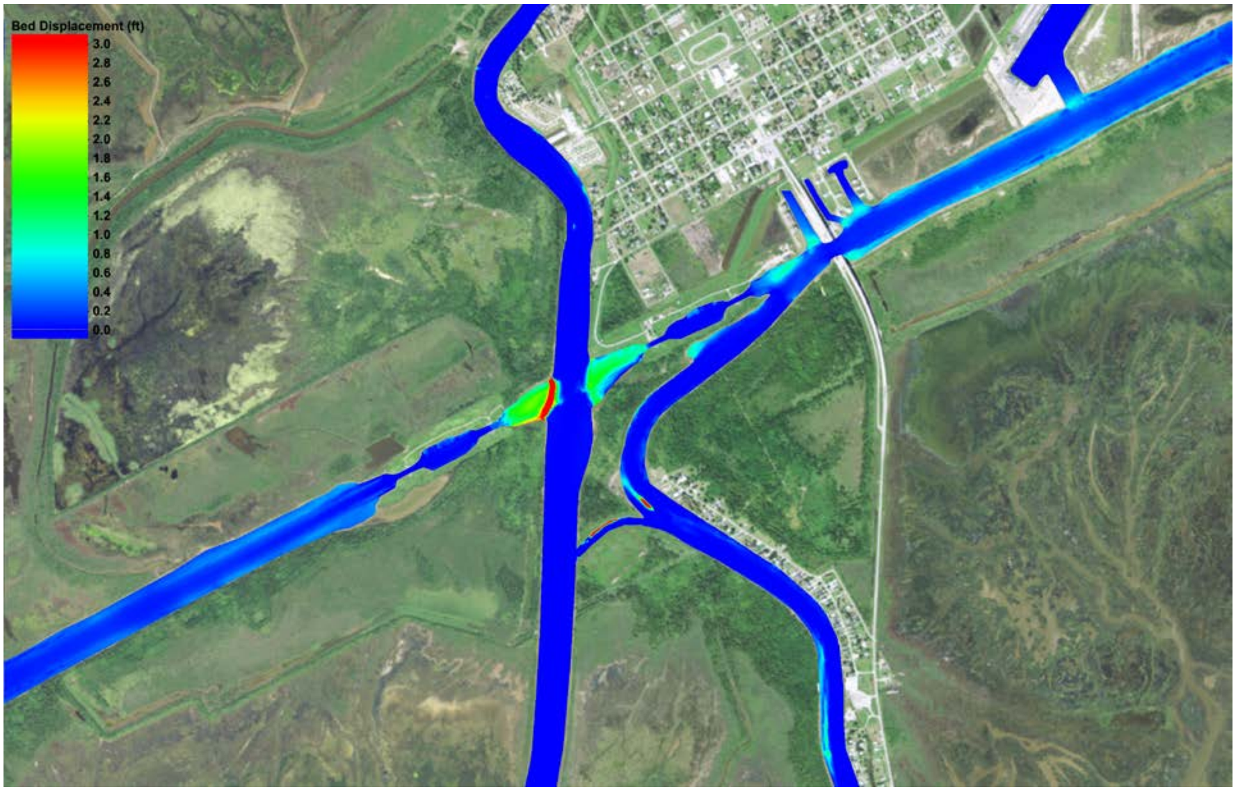

Figure 49 Bed Change at end of 2016 Simulation for Existiing Conditions

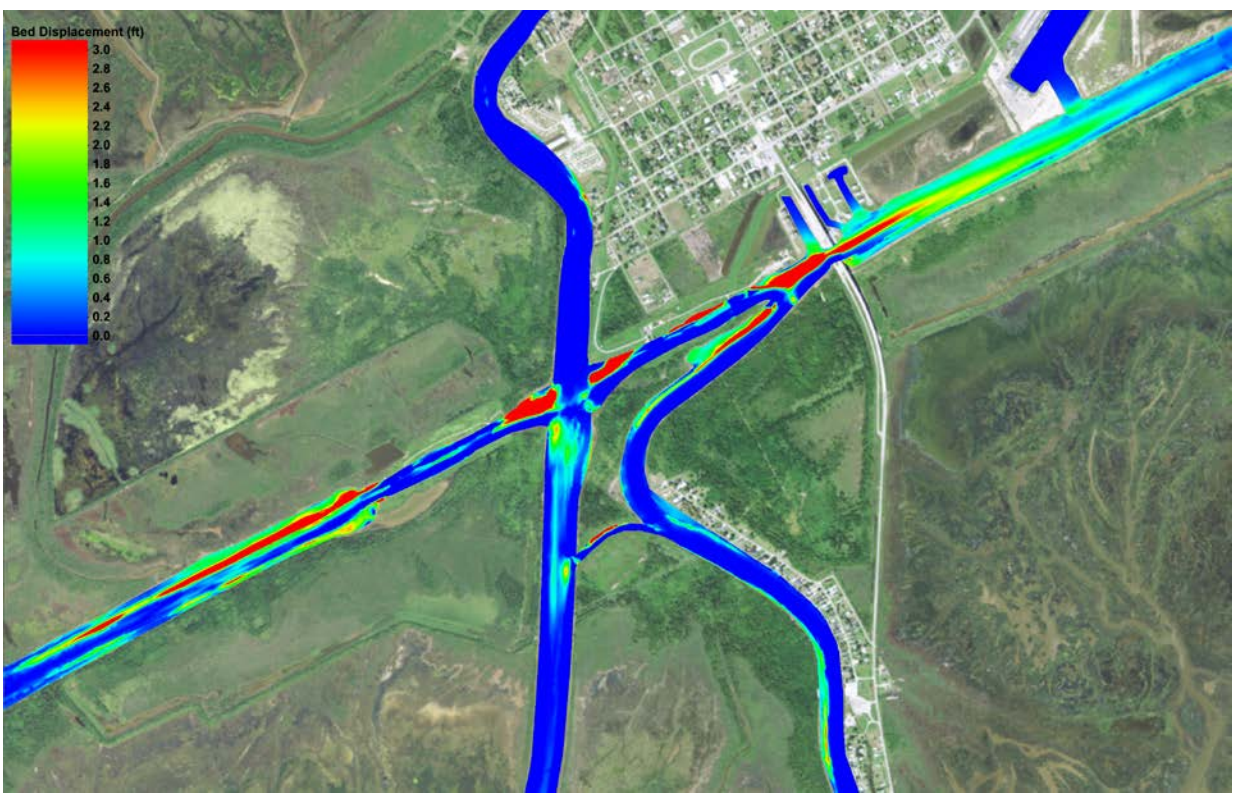

Figure 50 Bed Change at end of 2016 Simulation for Open-Channel Alternative

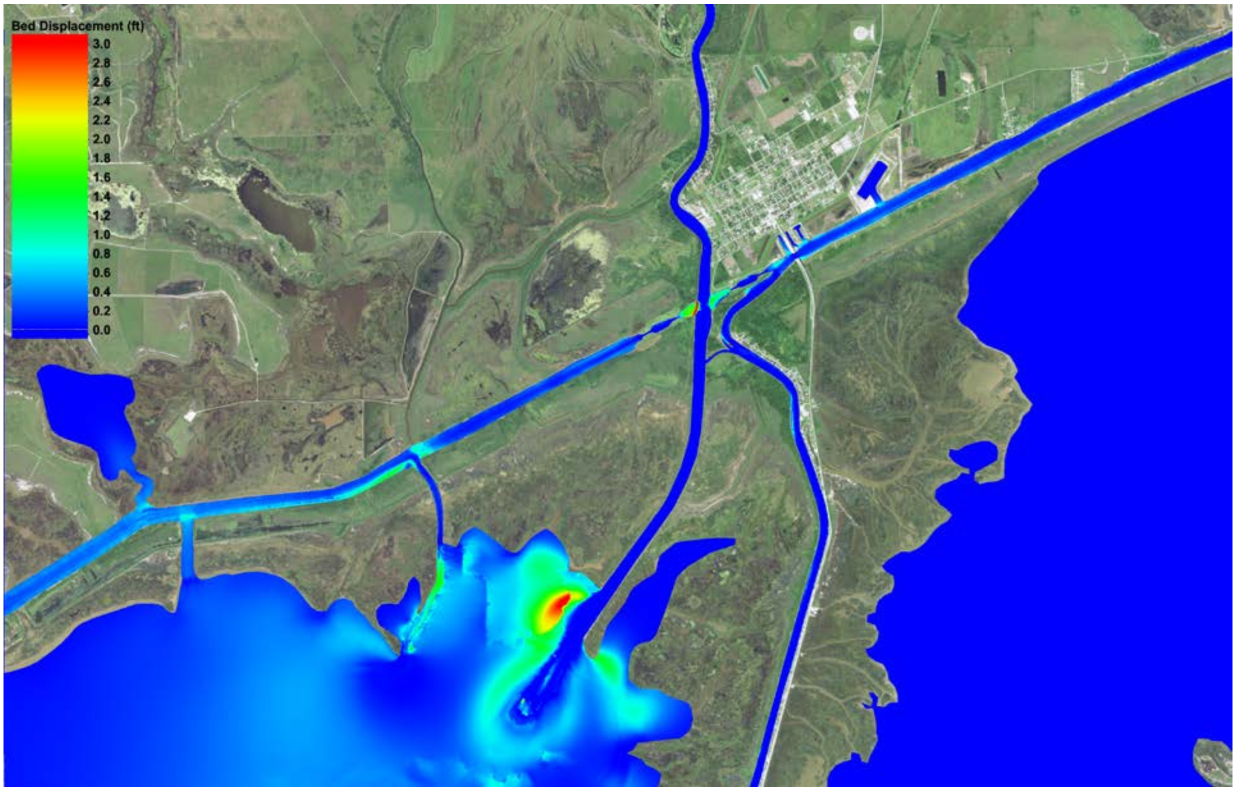

Figure 51   Bed Change at end of 2016 Simulation for Existiing Conditions

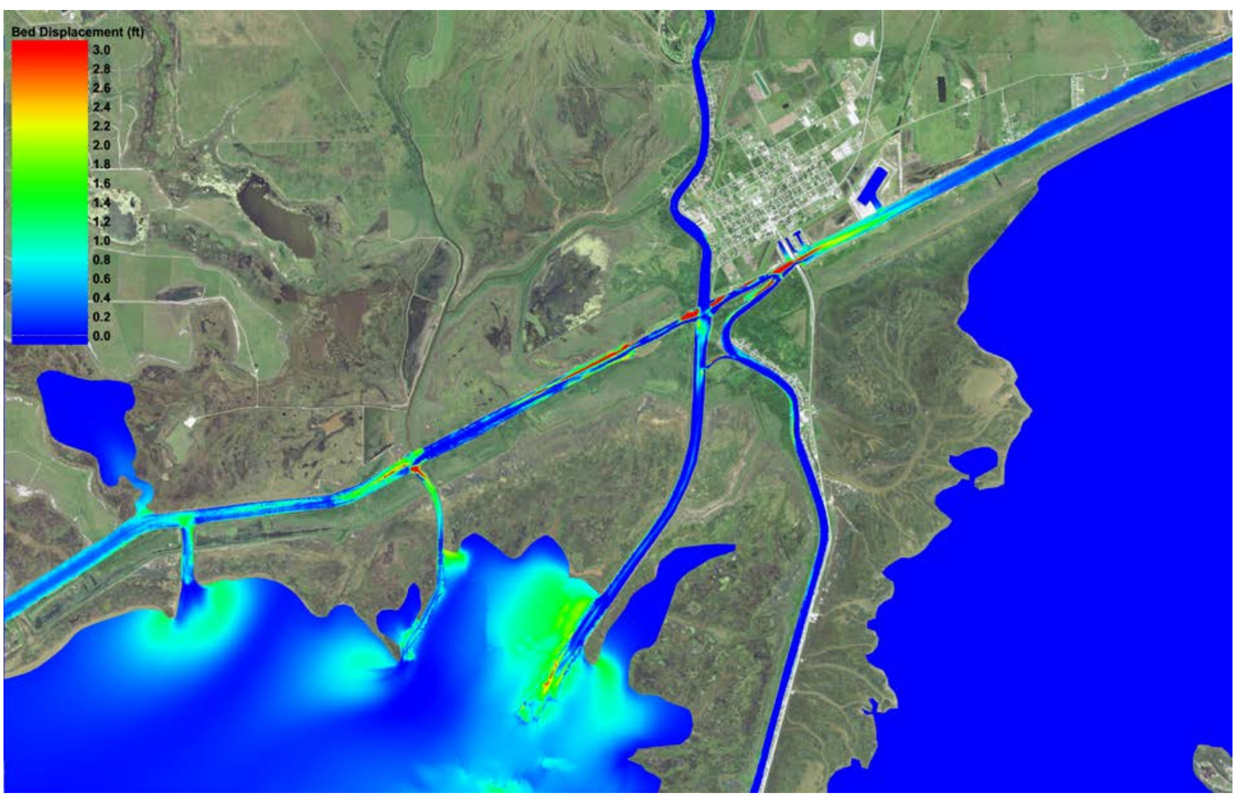

Figure 52   Bed Change at end of 2016 Simulation for Open-Channel Alternative

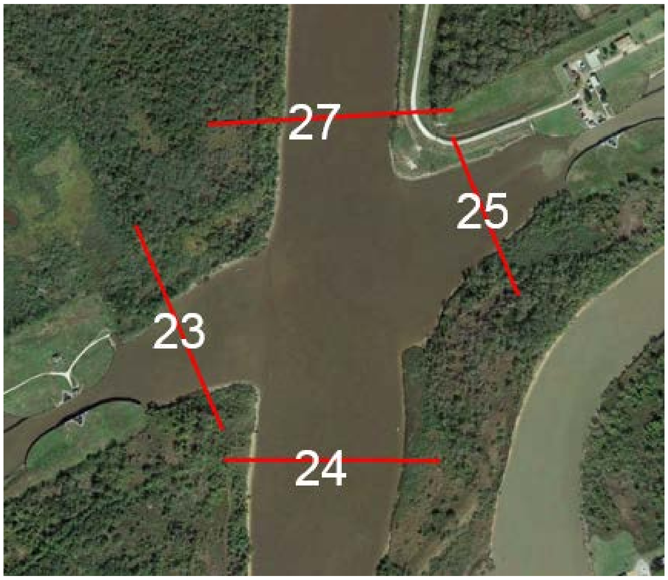

Figure 53 Sediment Flux Boundaries

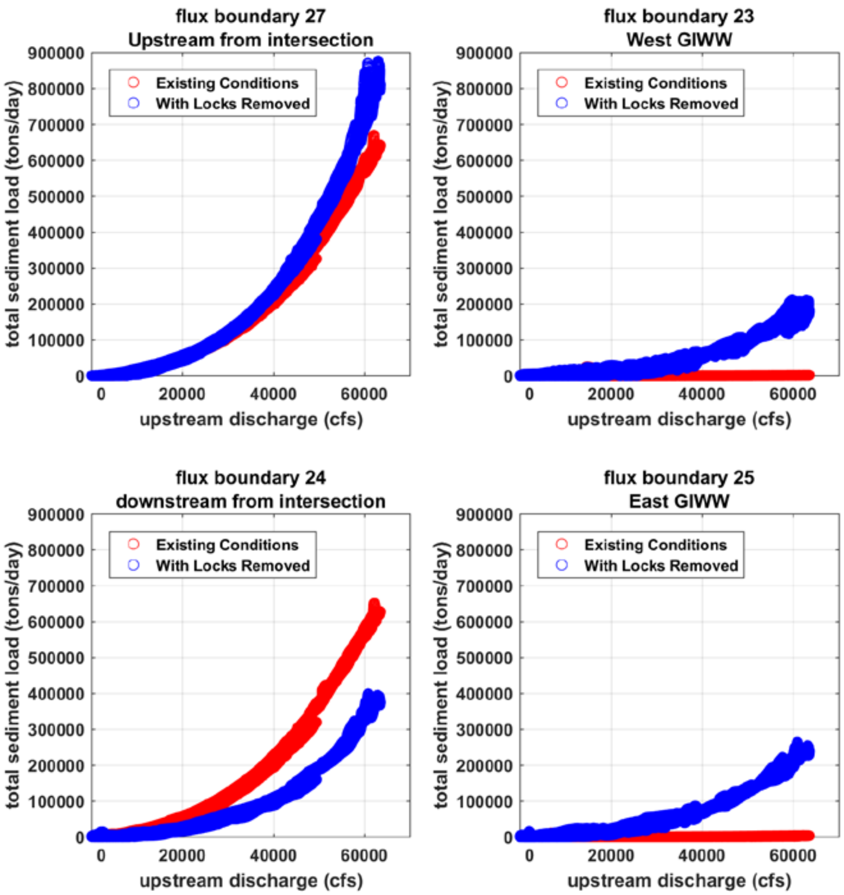

Figure 54 Discharge vs Sediment Flux for existing and open channel alternatives at 4-Way Intersection of the Colorado River and the GIWW

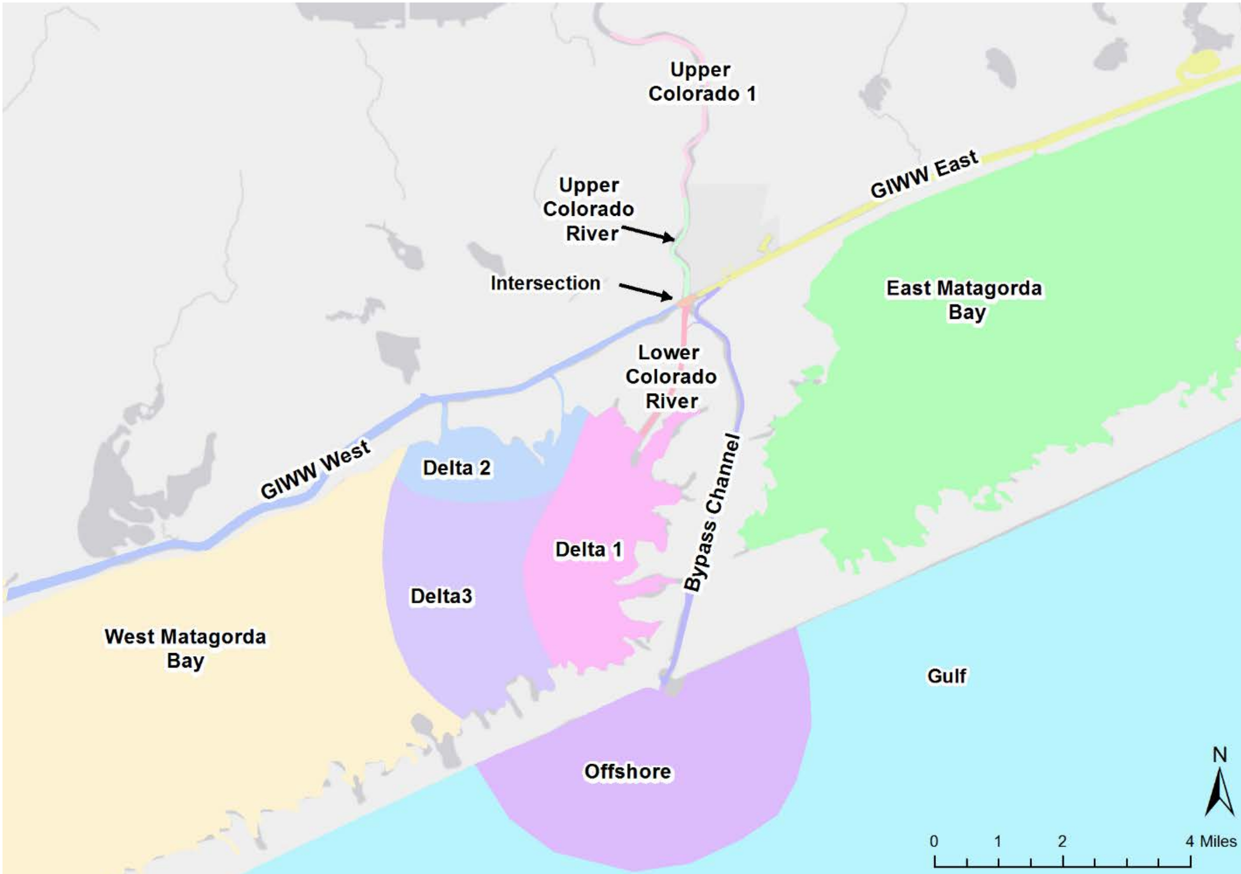

Figure 55 Map Showing the Location of the Assigned Sediment Deposition Areas

Area of Interest	2015 Simulation total deposition Existing (cubic yards)	2015 Simulation total deposition Open Channel (cubic yards)	% difference	2016 Simulation total deposition Existing (cubic yards)	2016 Simulation total deposition Open Channel (cubic yards)	% difference
West Matagorda Bay	598,039	427,436	-29	2,630,555	1,471,820	-44
Gulf	69,261	132,310	91	91,676	209,760	129
East Matagorda Bay	8,288	173,005	1987	63,996	788,097	1131
Upper Colorado 1	27,027	41,971	55	175,582	324,379	85
GIWW East	26,940	134,120	398	138,165	562,192	307
GIWW West	143,619	434,721	203	427,467	1,060,309	148
Bypass Channel	14,803	32,577	120	57,430	156,787	173
Intersection	19,948	40,400	103	49,375	125,569	154
Lower Colorado River	-1,544	17,504	1234	4,276	88,329	1966
Upper Colorado River	-977	499	151	-891	2,523	383
Delta 1	1,508,711	1,296,412	-14	3,193,778	2,942,016	-8
Delta 2	444,065	597,870	35	893,679	1,071,119	20
Delta 3	858,720	329,028	-62	1,822,269	867,789	-52
Offshore	191,529	397,176	107	561,599	1,119,848	99
TOTAL	3,908,429	4,055,029	4%	10,108,956	10,790,537	7%

Table 3 Total Modeled Deposition for 2015 and 2016 Simulations for Existing and Open Channel Scenarios

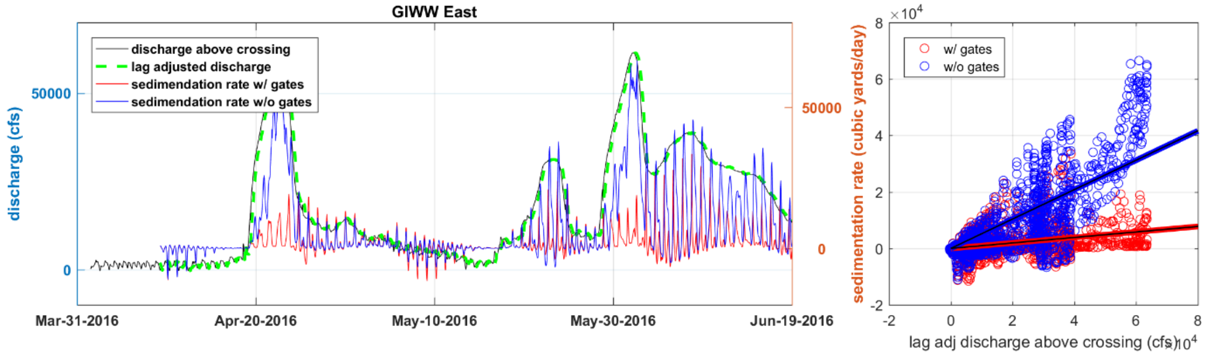

Figure 56   Sedimentation Rate Regression Analysis for GIWW East

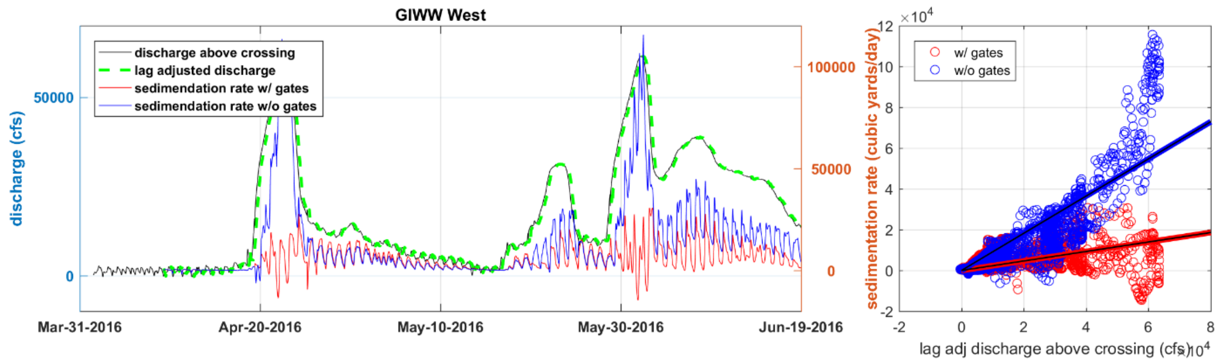

Figure 57   Sedimentation Rate Regression Analysis for GIWW West

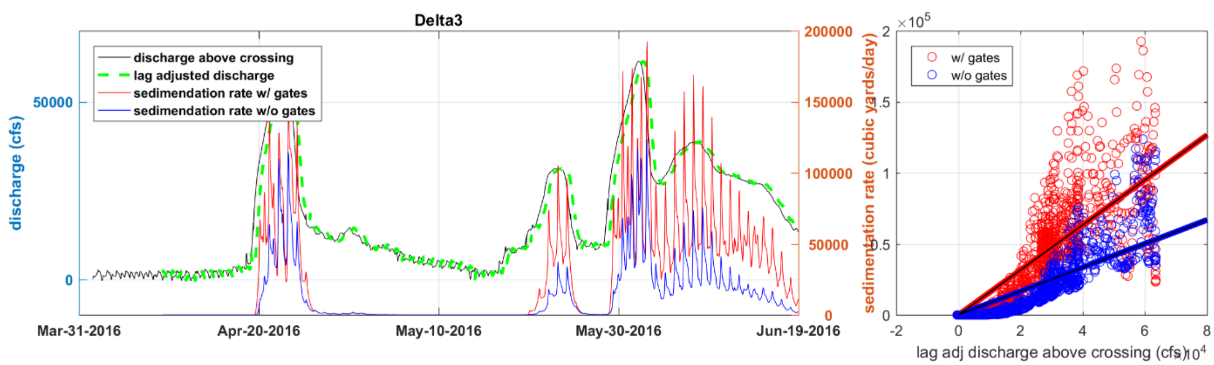

Figure 58   Sedimentation Rate Regression Analysis for Delta 3

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	88,921	476,787	**436**	59,260	279,816	**372**
GIWW West	212,956	834,907	**292**	184,303	501,183	**172**
Bypass Channel	70,519	171,101	**143**	39,786	78,744	**98**
Intersection	11,789	30,017	**155**	19,122	34,374	**80**
Delta 1	2,432,825	2,206,549	**-9**	1,784,570	1,789,594	**0**
Delta 2	651,095	791,945	**22**	668,469	842,056	**26**
Delta 3	1,450,778	765,962	**-47**	1,480,637	574,349	**-61**
Offshore	360,739	799,477	**122**	270,035	606,075	**124**

Table 4 Average Annual Deposition Simulations for Existing and Open Channel Scenarios based on 2015 and 2016 Simulation Results

	Based on 2016 Simulation		Based on 2015 Simulation	
	Existing	**Open Channel**	**Existing**	**Open Channel**
AdH mesh node	27,845	27,912	27,846	27,977
bottom Elevation (ft NAVD88)	-19	-19	-19	-19
deposition height (ft)	17	22	5	16
deposition volume (cubic ft)	1,333,125	3,390,363	538,596	1,090,800
mean water surface elevation (ft NAVD88)	0	0	0	0
depth trigger (ft)	10	10	10	10
average annual deposition (cubic ft/year)	318,303	810,459	318,303	810,459
dredging frequency (years)	**2.1**	**1.6**	**2.9**	**0.7**

Table 5 Dredging frequency estimates based on 2015 and 2016 AdH simulation results

Future Conditions

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. The 2015 simulation was selected for evaluation of future conditions because 2015 is a better approximation of average annual conditions.

Average annual sedimentation rates for future conditions were determined using the same methodology as existing conditions. Table 6 contains the average annual deposition volumes for the existing and open channel alternatives with 1.0ft of RSLR applied to the model. The table also contains the % difference from the respective existing conditions simulation. For example, a 14% increase in sedimentation within the GIWW East can be attributed to 1.0ft of RSLR for existing conditions. Table 7 contains the average annual deposition volumes for the existing and open channel alternatives with 2.0ft of RSLR applied to the model. In summary, the changes to sedimentation rates due to RLSR are relatively minor and well within the overall uncertainty of the model. Intuitively, RLSR has a dual effect. Firstly, RSLR increases the tailwater condition which lowers velocities in the river and bays thus increasing sedimentation. Secondly, lower velocities decrease the scour and transport of material. These two effects seem to counter each other, so the net result of RLSR on sedimentation could be relatively minor. RSLR increases depths, which could possibly improve navigability though the project area.

Area of Interest	Results Based on 1.0ft of RSLR			
	Average Annual deposition Existing (cubic yards)	% difference from Project Start Date	Average Annual deposition Open Channel (cubic yards)	% difference from Project Start Date
GIWW East	67,448	14%	272,607	-3%
GIWW West	147,500	-20%	610,537	22%
Bypass Channel	35,516	-11%	67,713	-14%
Intersection	18,465	-3%	31,008	-10%
Delta 1	2,319,951	30%	1,915,209	7%
Delta 2	715,695	7%	957,369	14%
Delta 3	1,445,948	-2%	553,344	-4%
Offshore	286,223	6%	548,650	-9%

Table 6 Average Annual Deposition Simulations for Existing and Open Channel Scenarios based on 2015 and 2016 Simulation Results with 1.0ft of RSLR

Area of Interest	Results Based on 2.0ft of RSLR			
	Average Annual deposition Existing (cubic yards)	% difference from Project Start Date	Average Annual deposition Open Channel (cubic yards)	% difference from Project Start Date
GIWW East	73,228	24%	257,541	-8%
GIWW West	101,080	-45%	678,515	35%
Bypass Channel	32,513	-18%	54,969	-30%
Intersection	18,165	-5%	26,751	-22%
Delta 1	2,622,112	47%	1,957,265	9%
Delta 2	733,720	10%	1,031,450	22%
Delta 3	1,398,036	-6%	553,031	-4%
Offshore	305,599	13%	501,671	-17%

Table 7 Average Annual Deposition Simulations for Existing and Open Channel Scenarios based on 2015 and 2016 Simulation Results with 2.0ft of RSLR

Velocities at the intersection of the Colorado River and the GIWW were evaluated for 1.0 and 2.0ft RSLR. Discharge – velocity rating curves were developed for existing and open-channel for 0.0ft, 1.0ft and 2.0ft RLSR. Figure 59 displays a comparison of the discharge-velocity rating curves for 0.0ft and 2.0ft RSLR for the open-channel condition. The effect of RSLR on velocity at the intersection is relatively minor. For example, for open-channel conditions, 2.0ft or RSLR reduces velocity by roughly 12.6%. Table 8 contains the percentage difference in velocity due to RSLR for all scenarios evaluated. The velocity data for future conditions was supplied to the economics team for evaluation.

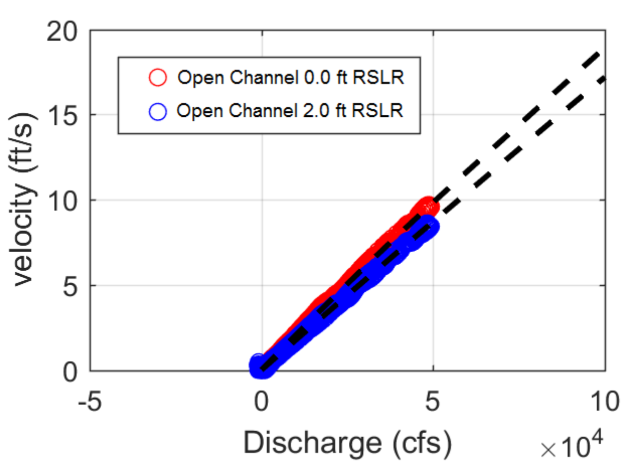

Figure 59 Comparison of Open Channel Velocities for RSLR=0.0ft and RSLR=2.0ft

	RSLR 0.0 ft	RSLR 1.0ft	RSLR 2.0ft
Existing Conditions	0%	-1.5%	-3.1%
Open Channel	0%	-5.6%	-12.6%

Table 8 Percent difference in velocity from RSLR = 0.0ft

Average changes to salinity were also evaluated for future conditions for both with-locks and open-channel alternatives. Table 9 contains the mean salinity values for the present day with and without project, and future condition with and without project. The results show very modest changes to average salinity within each of the specific geographic areas. 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.

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 9 Mean Salinity values for 2015 Simulation at specific areas of interest

Additional Alternative – Removal of Riverside Floodgates

An additional alternative was proposed late in the project study. The alternative includes removal of the river side floodgates, effectively turning the lock system into a flood gate system. The 2016 AdH simulation was re-run without the river side floodgates. To model this scenario, the open channel mesh was used with gates added at the location of the GIWW side locks, as pictured in Figure 60. The results of the simulation show nearly identical sedimentation patterns and volumes as the existing condition. It seems that most of the sediment settles in the forebays, regardless of whether or not the river side floodgates are in place. However, if the forebay is expanded, a larger area would require dredging. The increase in area where sediment can fall out of suspension results in an approximate 20% increase in sediment volume. A major downside of this alternative is the loss of ability to lock across the river during high flows. Given existing information about lock operations, the crossing would be closed when a head differential of 1.8 ft exist across the floodgate, or when the river velocity exceeds 4.5 ft/s. Long term analysis of water levels at the locks reveal a slight increase with time as the existing delta becomes more restrictive. Figure 61 displays the observed discharge and stage data for two datasets, one from 1999 to 2008 and the other from 2008 to 2018. For higher flow events, the stages are approximately 0.2 to 0.6 ft higher for the more recent data. The ongoing sedimentation in the lower delta will continue to increase head differences at the lock, making a single 75ft gate more challenging to navigate. Dredging the lower delta may reduce water levels at the lock. In summary, there are little expected changes to sedimentation, salinity and water levels associated with removal of the river side locks, but there will be a tremendous effect on navigation during high flows, especially given the long term trends in water levels. This information was provided to the economics team for evaluation.

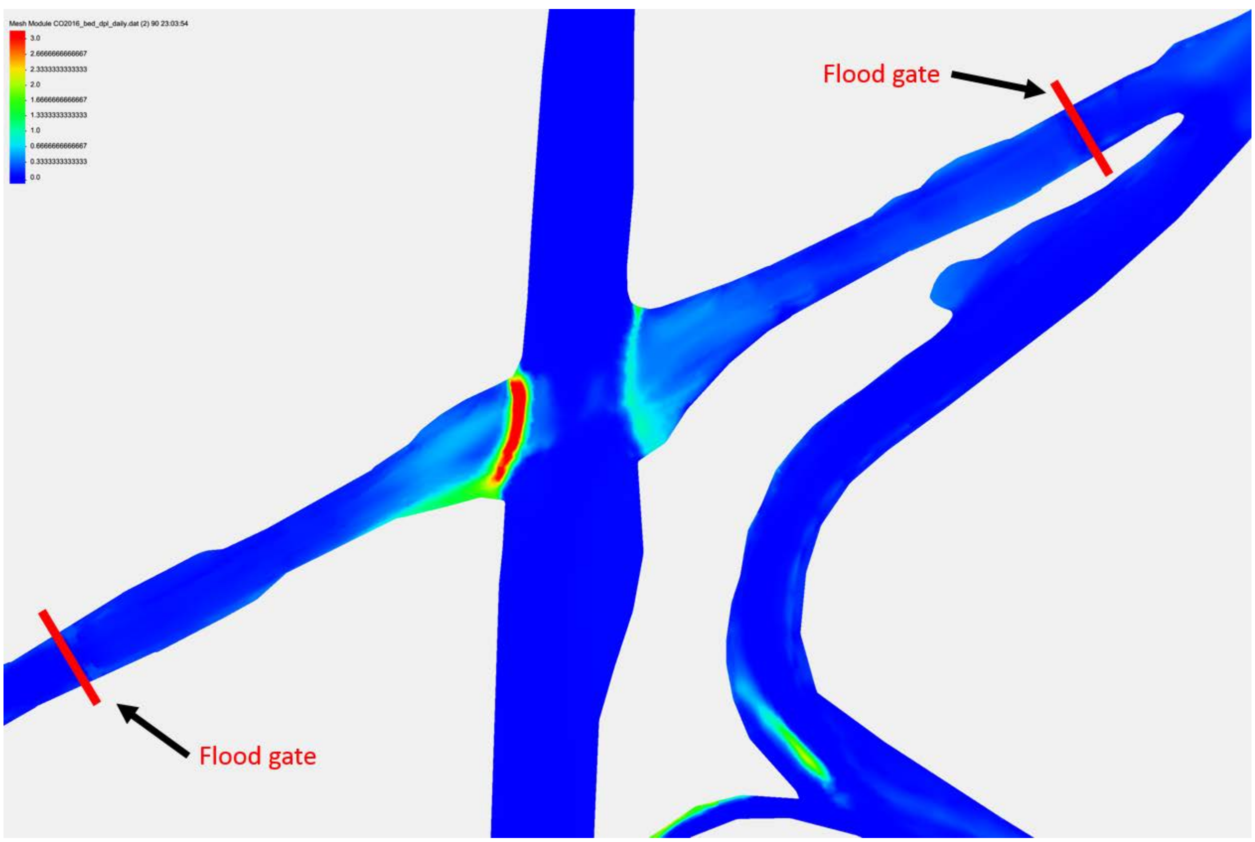

Figure 60 Additional alternative bed displacement and gate locations

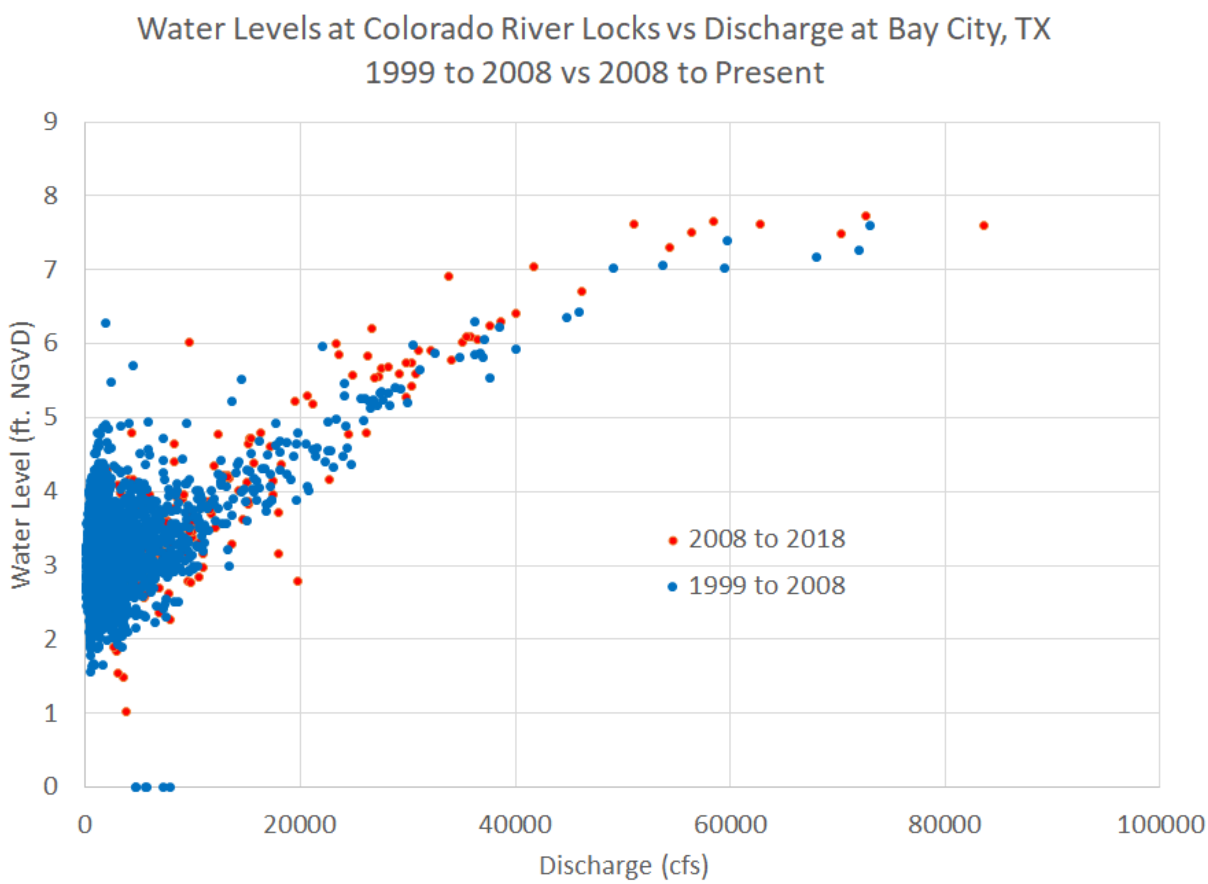

Figure 61 Water levels at Colorado River Locks vs discharge

Additional Alternative – 125ft Single Gate

An additional alternative which proposed removal of the existing lock structure and replacing each side with a single 125ft gate was evaluated. The AdH mesh was set up to evaluate this scenario by modifying the mesh to include a 125ft opening on each side of the GIWW. Figure 62 and Figure 63 display the AdH mesh bathymetry for the existing 75ft lock and the 125 ft single gate setup, respectively. The 125ft floodgates are operated in the model to prevent flow from entering the GIWW during periods of high discharge. The simulation of the single 125ft gate results in a significant reduction in velocity through the gate structures, which may improve navigability. Figure 64 and Figure 65 show the velocity during ebb tide for the existing 75ft locks and 125ft single gates. The velocity through the gate drops significantly with a wider opening, while the velocity in the main river channel does not change noticeably. Velocities for each scenario at the gate structures are plotted in Figure 68. The data shows that velocities through the structure will be significantly reduced with the 125ft single gate. Figure 66 and Figure 67 show the sedimentation for the existing 75ft locks and 125ft gate scenarios. The sedimentation patterns stay similar, although with the 125ft gate, a longer forebay traps about 20% more sediment. Mean annual sedimentation rates for the existing 75ft locks and proposed 125ft gates are provided in Table 10. The mean annual sedimentation rates and velocity information was provided to the economics team for evaluation.

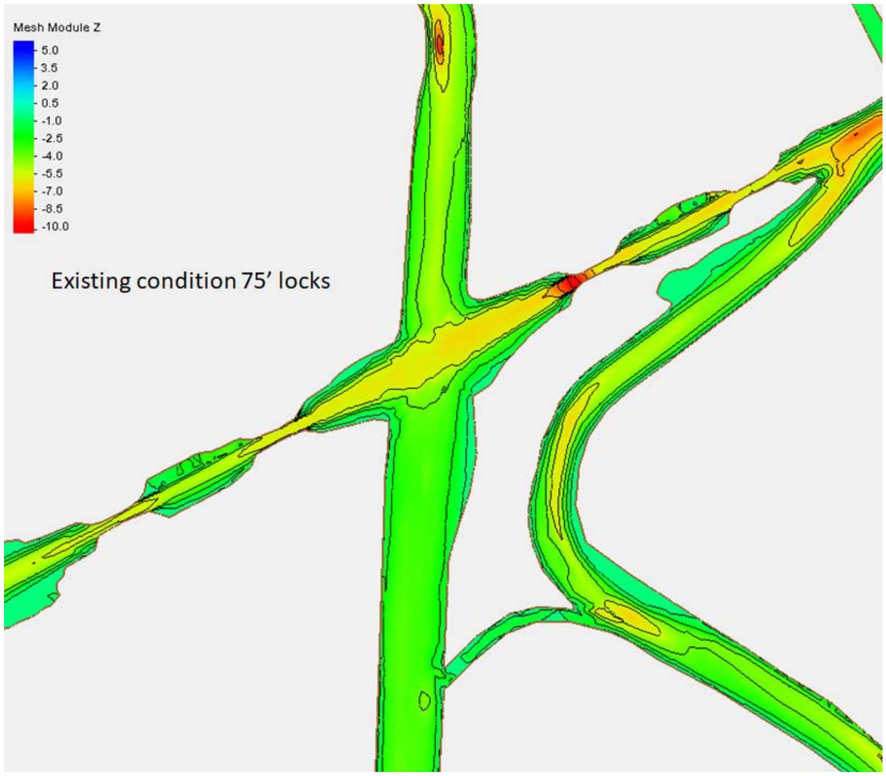

Figure 62 AdH mesh bathymetry for existing condition AdH mesh with 75ft lock system

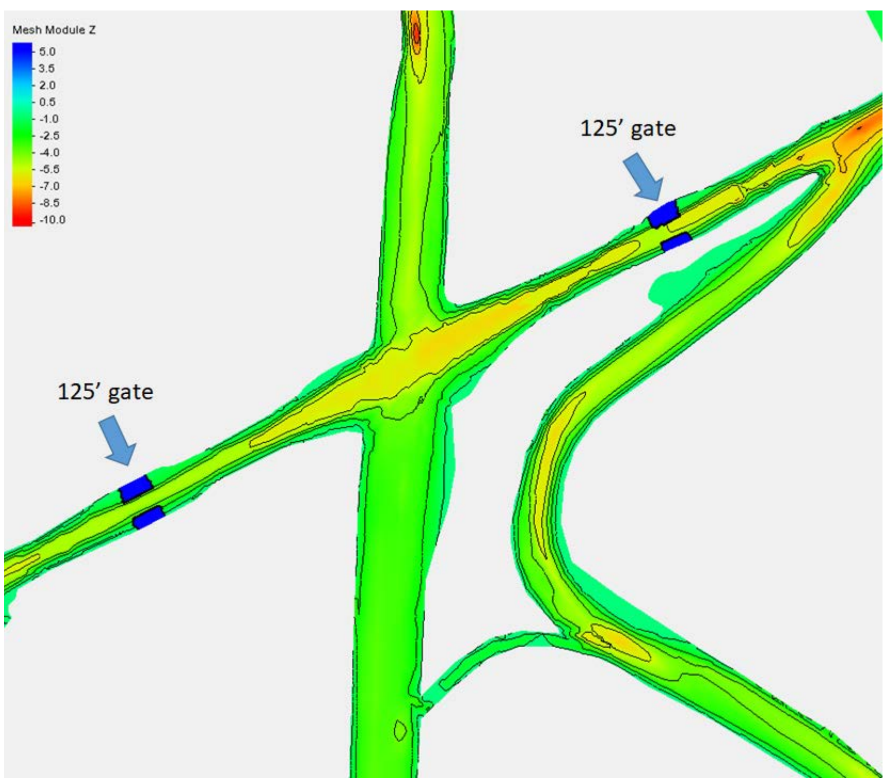

Figure 63 . AdH mesh bathymetry for with-project condition AdH mesh with 125ft single gate system

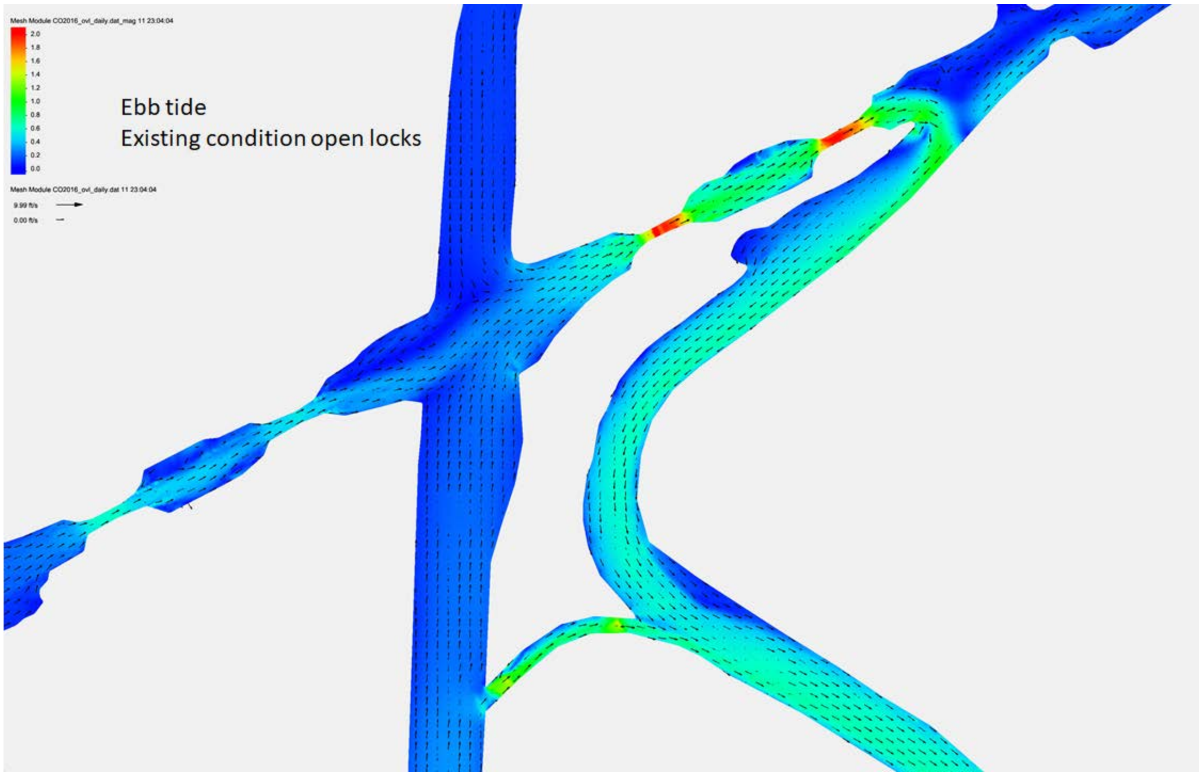

Figure 64 Velocity for existing 75ft locks during strong ebb tide

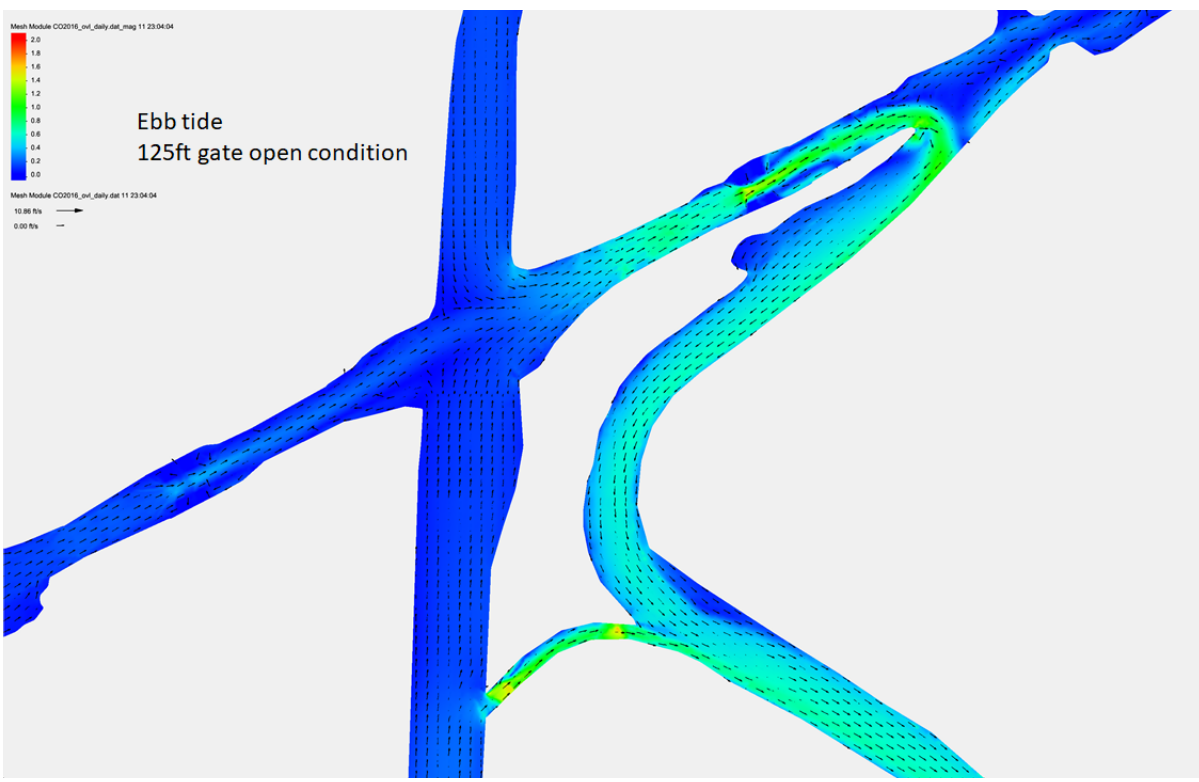

Figure 65   Velocity for 125ft gates during strong ebb tide

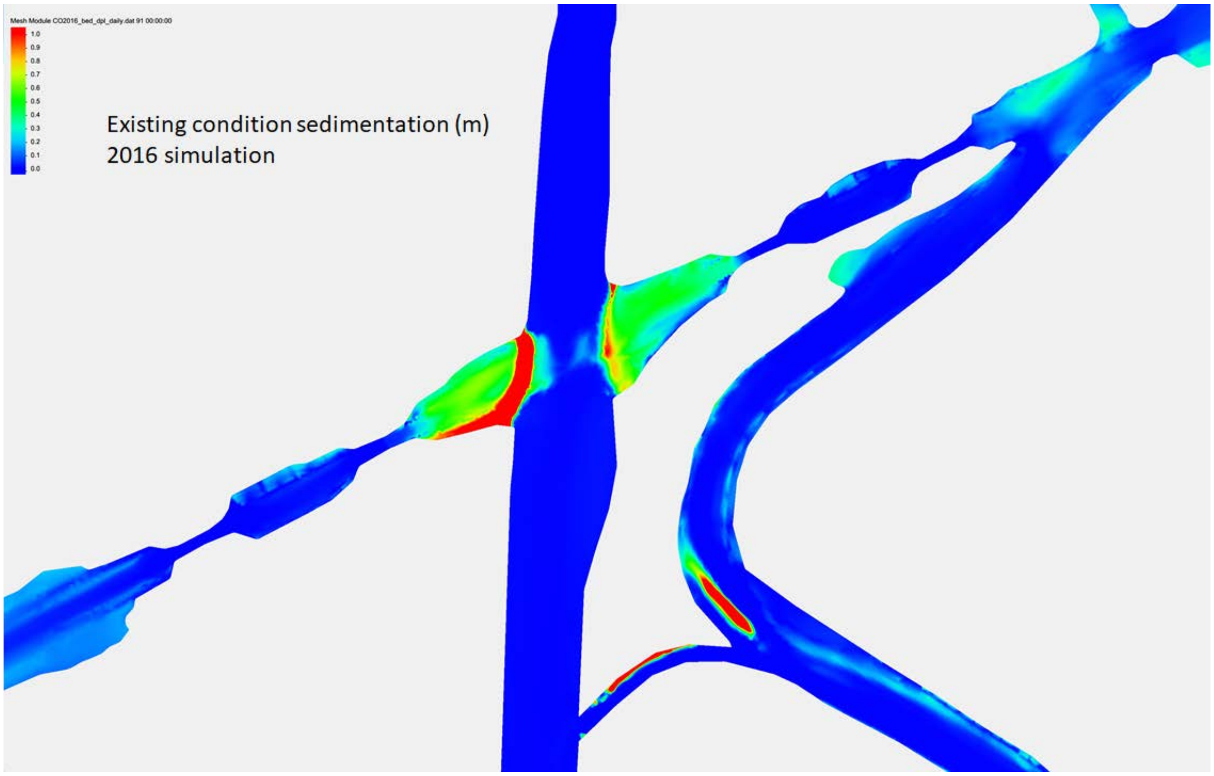

Figure 66 Sedimentation for existing 75ft locks from 2016 simulation

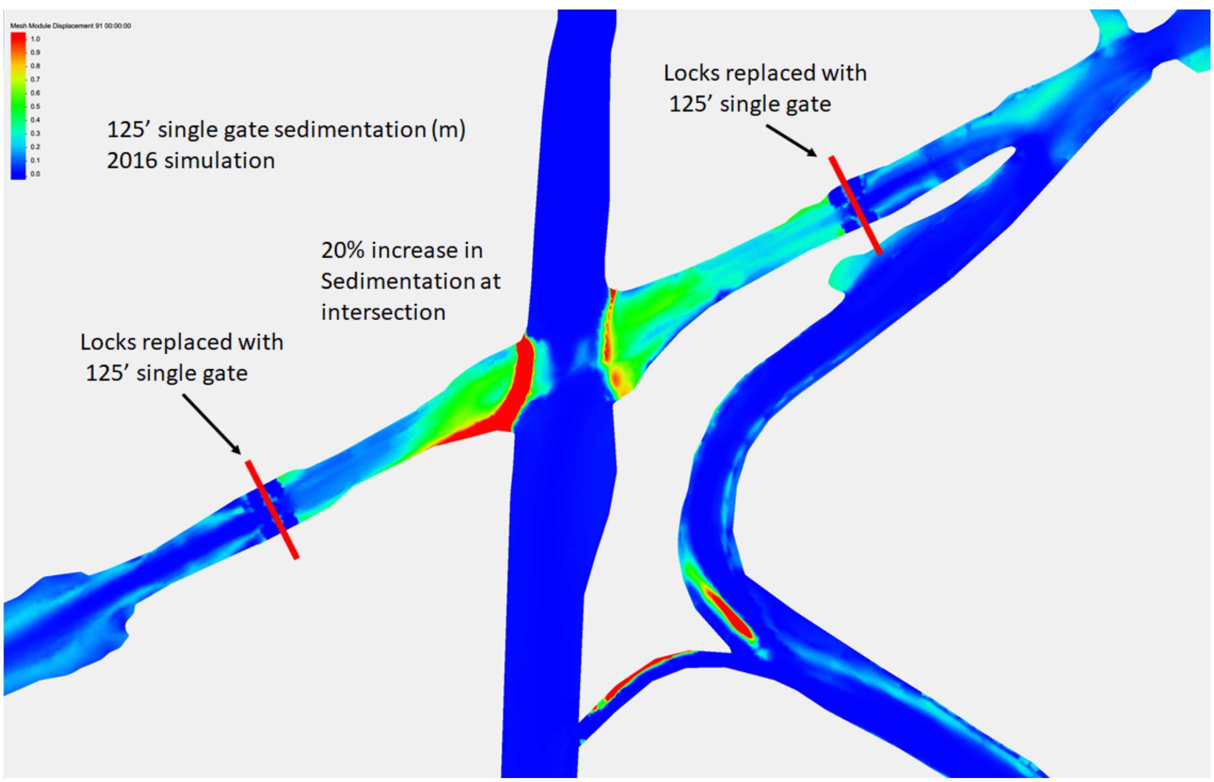

Figure 67 Sedimentation for 125ft gates from 2016 simulation

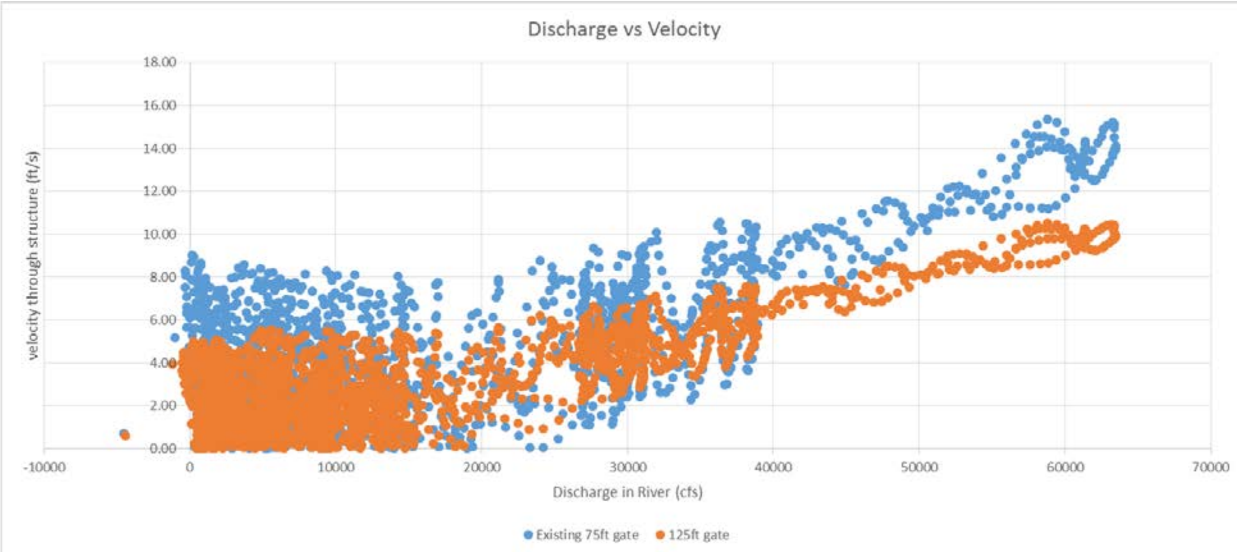

Figure 68 Discharge in Colorado River vs velocity through open 75ft locks and open 125ft single gate.

Area of Interest	Results Based on 2016 Simulation Regression Analysis		
	Average Annual deposition with 75 ft Locks (cubic yards)	Average Annual deposition with single 125 ft gate	% difference
GIWW East	88,921	83,387	**-6.22%**
GIWW West	212,956	206,952	**-2.82%**
Bypass Channel	70,519	72,813	**3.25%**
Intersection	11,789	14,695	**24.65%**
Delta 1	2,432,825	2,523,478	**3.73%**
Delta 2	651,095	648,468	**-0.40%**
Delta 3	1,450,778	1,453,523	**0.19%**
Offshore	360,739	359,459	**-0.35%**

Table 10 Average annual deposition for existing 75ft lock and 125ft gate scenarios based on the 2016 Simulation Results

The recommended plan 4b.1 is different than the configuration of in modeling. The change between the modeled 125ft single gate alternative and the recommended plan 4b.1 is a shift in channel/gate location to the south. Based on our engineering judgment and familiarity with the model, the differences between the modeled scenario and plan 4b.1 are not significant enough to change the overall expected sediment deposition or velocity patterns in the river, or through the gates. The flow and sediment volume through the open 125ft gate is expected to be similar regardless of a shift in geometry, since the controlling factor is primarily the flow area of the gate and orientation of the gate relative to the river, which is equivalent for both the modeled scenario and plan 4b.1.

Uncertainty Assessment

Numerical modeling of complex hydrodynamics is inherently uncertain. Sediment transport and salinity modeling are even more uncertain. While the Colorado River AdH model does a sufficient job at predicting water levels, velocities, salinities, and sediment transport, there remains a large uncertainty, especially when considering all sources of error. When projecting 50 years into the future, the uncertainty bands grow even larger. Uncertainty estimates are provided for various output parameters of this study in Table 11. When conducting economic analysis using the values provided by this analysis, these uncertainty estimates should be considered.

Parameter	Units	Estimated Uncertainty
Water Levels	ft. NAVD88	+/- 10%
Velocities	ft/s	+/- 15%
Average Annual Sedimentation	cubic yards/ year	+/- 50%
Average Salinity	Ppt	+/- 50%

Table 11 Uncertainty estimates for various Colorado River analysis outputs

To reduce uncertainty in the hydraulic modeling, a full scale test could be done to further validate the modeling. Pre and post flood surveys could be compared to the hydraulic modeling. In the case of the Colorado River, the inner floodgates could be left open during a major flood. In this real world full scale test, we could observe the sedimentation that occurs. This would give us insight into the effects completely removing the inner flood gates and further validate the hydraulic analysis. In the case of the Brazos River, the construction bypass could be left open as a first order of work. If a flood event were to occur with the open bypass, the sedimentation that occurs would be closely monitored and compared to the AdH model. In summary, full scale testing might provide additional confidence in overall TSP selection.

Conclusions and Recommendations

- The Colorado River AdH model provides a realistic hindcast of water-levels, velocities, salinity and sediment transport for the 2001, 2015 and 2016 time periods. The model also validates well for Hurricane Harvey.

- The model was developed to determine impacts to currents, salinity and sedimentation associated with the open channel alternative.

- Average annual sedimentation rates as well as river velocity data were provided to the economics team to help evaluate impacts to navigation and determine project feasibility.

- If the Colorado River Locks are removed, drastic changes to the existing sediment budget can be expected. For example, sedimentation rates might increase by approximately 372% to 436% in the GIWW East, and increase by approximately 172% to 292% in the GIWW West.

- Removal of the Colorado locks will also slow down the rate of growth of the Colorado River delta in West Matagorda Bay.

- Removal of the locks would significantly increase velocities in the main river channel and in the GIWW during floods. During extreme floods, the navigation through the GIWW might still be impaired even with implementation of the open channel alternative.

- Removal of the locks will decrease salinity in the East Matagorda Bay significantly, and decrease salinity in West Matagorda Bay slightly. The open channel alternative seems to move more fresh water to East Matagorda Bay, and less to West Matagorda Bay.

- Changes to sedimentation due to RSLR are expected to be moderate. RSLR seems to have a two-fold effect on sedimentation rates, as the increased tailwater lowers velocities and decreases scour and re-suspension, yet facilitates particles to fall out of suspension sooner. The net effect could be considered neutral, or within the overall uncertainty of the sediment modeling (+/- 50%)

- RSLR is expected to modestly increase salinities globally for both existing and open channel alternatives.

- Numerical modeling of complex hydrodynamics including sediment and salinity transport is inherently uncertain. Uncertainty estimates of study outputs were provided.

- The AdH model can be used for a variety of other future purposes, including future studies of the project area.

References

U. S. Army Engineer District, Galveston (1981) “Mouth of Colorado River, Texas, Phase I:
General Design Memorandum and Environmental Impact statement (Diversion Features)”

Brown, G.L., Sarruff, M. S., Fagerburg, T. L., Raphelt, N. (2003). “Numerical Model Study of Proposed Navigation Improvements at the Colorado River Intersection with the Gulf Intra-Coastal Waterway, TX.” Technical Report, U.S. Army Corps of Engineer Waterways Experiment Station, Vicksburg, MS.

Fagerburg, T.L. (2001). “Memorandum for Record, Subject: Field Data Collection at the Colorado River and Gulf Intercoastal Waterway, Matagorda, TX.

(FEMA) flood insurance study (FIS) of the Texas coastline (USACE 2011).