

Restoration of Hydrology along Upper Mobile Bay Causeway

Feasibility Investigation Report

Prepared For

Alabama Department of Conservation and Natural Resources,
State Lands Division
31115 Five Rivers Blvd.
Spanish Fort, AL 36527

December 2015



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December 2015

The funding for this report was provided by the U.S. Fish and Wildlife Service, Department of the Interior through the Coastal Impact Assistance Program (CIAP). The CIAP is funded by qualified outer continental shelf oil and gas revenues.



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ACRONYMS AND ABBREVIATIONS

ACHP	Advisory Council on Historic Preservation
ADCNR	Alabama Department of Conservation and Natural Resources
ADEM	Alabama Department of Environmental Management
AHC	Alabama Historic Commission
ALDOT	Alabama Department of Transportation
ALAMAP-C	Alabama Monitoring and Assessment Program - Coastal
APHA	American Public Health Association
ASTM	American Society of Testing and Materials
Bottom	lower profile
Calscience	Calscience Environmental Laboratories, Inc.
CB	Choccolatta Bay
CIAP	Coastal Impact Assistance Program
COC	chemical of concern
CWA	Clean Water Act
CZMA	Coastal Zone Management Act
DISL	Dauphin Island Sea Lab
DDT	dichlorodiphenyltrichloroethane
DO	dissolved oxygen
ERL	Effects Range Low
ERM	Effects Range Median
ESA	Endangered Species Act
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
GPS	Global Positioning System
GSA	Geological Survey of Alabama
HASP	Health and Safety Plan
HDPE	high-density polyethylene pipe
I-10	Interstate 10
ID	identification
JB	Justins Bay
LPTM	Lagrangian Particle Tracking Model
MAWSS	Mobile Area Water and Sewer System
MBNEP	Mobile Bay National Estuary Program
MBTA	Migratory Bird Treaty Act
MLLW	mean lower low water
MMPA	Marine Mammal Protection Act
NAIP	National Agriculture Imagery Program
NCA	National Coastal Assessment
NHPA	National Historic Preservation Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
pH	hydrogen ion concentration
PEL	probable effects level
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control

ACRONYMS AND ABBREVIATIONS

RAGS	Risk Assessment Guidance for Superfund
RHA	Rivers and Harbors Act
SAV	Submerged aquatic vegetation
SCE	South Coast Engineers
SHPO	State Historic Preservation Officer
SLD	State Lands Division
SM	standard methods
SOP	standard operating procedure
SR	Shellbank River
SVOC	semivolatile organic compound
TEL	threshold effects level
TOC	total organic carbon
TOP	upper profile
Tr	residence time
Tr'	change in residence time
TWP	Technical Work Plan
USACE	United States Army Corps of Engineers
USCS	Unified Soil Classification System
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
WAS GPS	Wide Area Augmentation-enabled Global Positioning System
WESTON	Weston Solutions, Inc.
WGS 84	World Geodetic System 1984

UNITS OF MEASURE

cm	centimeter(s)
cm/s	centimeter(s) per second
ft	foot or feet
in	inch(es)
kg/m ³	kilogram(s) per cubic meter
km	kilometer
μg/kg	microgram per kilogram
m	meter(s)
m ²	square meter
m ³ /s	cubic meter(s) per second
mg/kg	milligram per kilogram
%	percent

EXECUTIVE SUMMARY

The report has been prepared for the Alabama Department of Conservation and Natural Resources (ADCNR) and funded with qualified outer continental shelf oil and gas revenues by the Coastal Impact Assistance Program (CIAP), U.S. Fish and Wildlife Service, Department of the Interior for the purposes of detailing the results of the primary tasks performed under CIAP Grant F12AF01457 (AL-12) that included the following:

- Data compilation.
- Sediment core collection and analysis.
- Ecosystems field surveys and mapping.
- Identification of upper Mobile Bay hydrologic restoration alternatives.
- Analysis of upper Mobile Bay hydrologic restoration alternatives.
- Compilation of this Feasibility Investigation Report.

The tasks were performed in the regions north and south of the Mobile Bay Causeway (Causeway) with a focus in areas where conceptual causeway restoration projects may be located in the future. These locations of focus included Choccolatta Bay, Justins Bay, and Shellbank River.

Data Compilation

A historical data review was performed from previous studies to determine potential areas of concern and data gaps. This review encompassed over 50 documents covering studies that had been performed in the investigation area. Potentially relevant sediment data results gathered from the historical review were entered into a Geographic Information System (GIS) and mapped. The resulting map was then used to determine which locations were relevant to the study area. The compiled data from within the study area were compared to ecotoxicological benchmarks. These benchmarks assisted in understanding the potential effects to biota from the chemical concentrations reported from the sediment samples. Exceedances of benchmark values from the literature review were found within the investigation area for mercury, nickel, chromium, copper, lead, zinc, dichlorodiphenyltrichloroethane (DDT) compounds, and acenaphthene.

Sediment Core Collection and Analysis

This investigation task included a comprehensive analysis of sediment contaminant concentrations in sediments located in areas just north and south of the Causeway at Choccolatta Bay, Justins Bay, and Shellbank River. This task was performed to supplement prior investigations by providing physical data (grain size and total organic carbon (TOC)) to support modeling efforts and chemical data (metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), phenyls, phthalates, and chlorinated pesticides) to assess the pre-existing potential ecotoxicological risks associated with the three sites. At each of the 29 site locations, upper and lower sediment samples were collected, and results were compared against ecotoxicological benchmarks to identify chemicals of potential ecological concern.

In general, contaminants of potential concern were detected above ecotoxicological benchmarks in sediments from stations located both north and south of the Causeway in each of the three potential restoration locations. The contaminants occurred in both Top sediment (0 – 15 inches [in] to depth) and Bottom sediment (below 15 in to depth). Among the three restoration area alternatives, the Shellbank River study area had more exceedances of ecotoxicological benchmarks than the Choccolatta Bay or Justins Bay study areas.

In Choccolatta Bay, 4,4'-DDT concentrations exceeded probable effects level (PEL) values at three stations: two located north of the Causeway and one located south of the Causeway. Other DDT compounds also exceeded threshold effects level (TEL) values both above and below the Causeway, and in Top and Bottom sediment layers. PAH concentrations exceeded TEL values at three stations: 2 located north of the Causeway and one located south of the Causeway.

Results from Justins Bay indicated that nickel was the only metal that exceeded benchmark values (detected in Top sediment north of the Causeway). DDT compound concentrations exceeded Risk Assessment Guidance For Superfund (RAGS) values at seven stations but did not exceed PEL values. Of these, one station was located north of the Causeway, whereas six were located south of the Causeway. PAH concentrations in Justins Bay exceeded TEL values at five stations: three located north of the Causeway and two located south of the Causeway.

In Shellbank River, concentrations of arsenic, cadmium, copper, lead, mercury, nickel, and zinc were measured above TEL benchmarks. Metal exceedances occurred at four of six stations, whereas DDT compound concentrations were above ecotoxicological benchmarks at all Shellbank River sites. The PAH benzo(a)pyrene exceeded the TEL value at one station (located north of the Causeway).

Based on the distributions and concentrations of contaminants detected in the three investigation areas, at this time, there does not appear to be sufficient reason to completely rule out any of the potential restoration locations. Further study may be needed to better delineate the spatial extent of contaminants in the areas of concern.

Ecosystems Field Surveys and Mapping

Re-establishment of hydrology through bridge construction at Choccolatta Bay, Justins Bay, and Shellbank River is expected to result in a variety of ecological impacts, including both beneficial and detrimental effects to the natural communities of upper Mobile Bay and the lower delta. Effects would occur primarily through habitat alteration and re-established tidal exchange at these sites.

Wetlands and submerged aquatic vegetation (SAV) distributions were mapped, with a focus on those areas in proximity to the potential restoration locations. A desktop estimation of wetland and SAV boundaries was performed prior to field surveys at the scale of 1:1800 (1 in = 150 feet [ft]) in ArcGIS. 2013 National Agriculture Imagery Program (NAIP) imagery was observed in ArcView GIS, and feature boundaries were digitally delineated on a computer screen display. Field surveys were performed on 19, 24, and 25 June 2014 with emphasis on validating the estimated boundaries of wetlands and SAV beds near the potential restoration locations. A list of plant species was generated for each potential restoration location.

Wetlands occur at all three of the alternative sites, both north and south of the Causeway. The opening at Justins Bay would affect the largest wetland area at 9.4 acres, followed by Choccolatta Bay (2.8 acres) and Shellbank River (0.4 acre). Wetland avoidance may be possible at Choccolatta Bay. The combined alternatives would also directly affect a total of 19 acres of subtidal habitat, including areas with SAV. The areas affected comprise a small portion of the SAV acreage that occurs during most years in the immediate vicinity of the three sites. Reductions in tidal exchange and sediment transport rates predicted at Pass Picada, Interstate-10 (I-10) Cut, and Sardine Pass could result in water quality changes and sediment deposition over time, potentially resulting in gradual habitat changes at those locations.

With constructed openings that increase tidal flushing and reduce retention time, episodic hypoxia and anoxia in the bays and waterways north of the Causeway may be less frequent during warm seasons compared to the current condition. Tidal exchange would tend to equalize salinities in the areas of influence north and south of the Causeway during periods of low river flow. During high flow conditions, freshwater dominates the delta and is likely to mask tidal exchange effects at Causeway openings. Salinity changes due to potential openings may not result in measureable differences in the distributions of the predominant flora and fauna of the study area since these groups tend to have wide salinity tolerances and generally occur north and south of the Causeway.

In general, the Causeway impedes faunal migration and has altered natural food web interactions in its immediate vicinity. The construction of openings would restore some level of natural function to the adjacent areas.

Potential impacts to the endangered Alabama red-bellied turtle habitat may require additional investigation prior to any potential project implementation at Justins Bay. Project planning for any potential opening at Shellbank River would require more detailed consideration of sediment contamination issues. A Shellbank River opening has potential to complement ongoing restoration efforts to reduce the effects of sediment loading in D'Olive Bay, south of the Causeway.

Identification of Restoration Alternatives

Conceptual level designs were created to show areas along the Causeway that could be modified to allow for water movement between water bodies located north and south of the Causeway. The areas designated for potential openings occur between Mobile Bay and Choccolatta Bay; John's Bend and Justins Bay; and Shellbank River above and below the Causeway. The basis of design for locating and sizing the openings included analyzing the existing topography north and south of the Causeway and providing connections that attempt to mimic the natural terrain of nearby areas. Cost estimates were prepared for each design alternative primarily based on the major construction materials (e.g., excavations of earth and reinforced concrete bridge components). Cost estimates were compared to historic costs for bridges of similar design, and in general the estimated costs correspond to the range of historic costs. Rudimentary estimates of construction periods were prepared for each design alternative, which principally correspond to the length of the bridge (roughly 20 weeks for initial and final phases plus 2 weeks per 60-foot span).

Hydrodynamic Modeling of Restoration Alternatives

Hydrodynamic modeling of the existing conditions and hypothetical design alternatives were performed to evaluate the effects that constructed openings through the Mobile Causeway may have on the tidal exchange between Mobile Bay and water bodies north of the Causeway. Four specific objectives were used to frame simulation results and included assessments of (1) increased tidal communication; (2) increased tidal prisms; (3) decreased tidal phase lags with Mobile Bay; and (4) increased flushing within each system. Specific performance measures for each objective were used to quantify the degree to which an objective is met.

Field data collection was completed in support of model setup during the 2-week period from 27 March 2014 to 4 April 2014, with ship-based surveys of velocity and bathymetry conducted on 3 April 2014. Data collection included the measurement of water levels (i.e., tides) in Choccolatta Bay, Ducker Bay, and Sardine Pass during the period as well as mapping of velocity, discharge, bathymetry, and standard water characteristics (e.g., temperature and salinity) at I-10 Cut, the box culverts, Pass Picada, Apalachee River, Sardine Pass, Duck Skiff Pass, and Blakeley River. These data were used to develop the unstructured mesh for the hydrodynamic model and to validate the model through comparisons of predicted and measured water levels and velocities.

The Advanced Circulation (ADCIRC) model was applied to a hindcast simulation of the period 27 March 2014 to 4 April 2014. Forcing included predicted tides, observed discharge for the Mobile and Tensaw Rivers, and observed meteorology (i.e., winds and pressure). Model-data comparisons were generally good within the study area, capturing the range and phase of tides as well as the magnitudes and directions of flows. Predicted errors for water levels were 20% (~10 centimeter [cm]) or less over the entire simulation. Predicted velocity errors were 30% (~5 centimeters per second [cm/s]) or less over the entire simulation.

The ADCIRC model was used to simulate unique restoration alternative scenarios under representative tidal forcing and river discharge for present and future sea levels. Five restoration scenarios were simulated with typical summer (July) river discharge (~470 cubic meters per second [m^3/s]) on present-day sea levels. Those same forcing conditions were used to simulate the five restoration scenarios with an elevated sea level that was 30 cm higher than present-day levels. The restoration alternative with openings at Choccolatta Bay, Justins Bay and Shellbank River were simulated with high (wet season) river discharge (~1950 m^3/s) on present-day sea levels. A corresponding simulation of existing conditions within the study area (i.e., no openings) was performed for each of the three forcing conditions, resulting in 14 total model simulations.

Restoration scenario results are generally expressed in terms of changes, increases or decreases, relative to existing conditions. A summary of the major conclusions, relative to the objectives stated above, are listed below:

- The restoration scenarios at Choccolatta and Justins Bay would measurably increase all aspects of tidal communication between those bays and Mobile Bay.

- Model predictions suggest that the potential restoration alternatives would, overall, experience an 80% increase in tidal exchange (volume of water entering the water body) for Choccolatta Bay and a 120% increase for Justins Bay.
- Constructed openings would generally eliminate all existing tidal phase lags in Choccolatta and Justins Bays. In other words, the high tide would occur at the same time as it does in northern Mobile Bay.
- Tidal prisms in Choccolatta and Justins Bays would increase by 8% and 64%, respectively.
- Flushing of Choccolatta and Justins Bays would be improved under the restoration alternatives considered.
- The existing man-made tidal channels that were built north of the Causeway (Pass Picada and the I-10 Cut) that govern the tidal exchange of Choccolatta Bay under existing conditions would experience 90% reductions in tidal exchange as a result of the constructed openings evaluated here as restoration alternatives. Optimizing the size of the hypothetical opening through the Causeway could moderate such reductions.
- Reductions in tidal exchange in Pass Picada, I-10 Cut, and Sardine Pass may alter the characteristics of those systems, including changes to water quality and possible sediment deposition over time. These uncertainties could be addressed in future studies.
- The restoration alternatives mostly act independent of one another with only small changes (<1%) noted between scenarios.
- Tidal exchange would be reduced at higher river discharge due to a general reduction of tidal forcing.
- Most effects of the constructed openings evaluated as restoration alternatives would be within the immediate vicinity of the Causeway, Choccolatta Bay, Justins Bay, and Shellbank River.
- The effects of these hypothetical openings on wave action in Choccolatta and Justins Bays was not considered here, but could be evaluated in future studies.

1.0 INTRODUCTION

1.1 Investigation Purpose

The overall purpose of this investigation was to determine if restoring the hydrology along the Mobile Bay Causeway would be feasible considering the potential major constraints and opportunities along the Mobile Bay Causeway (Causeway). The potential major constraints include the existing sediment characteristics, biology, and constructability (costs). The potential major opportunities include modifications to circulation and water exchange in the bodies of water north of the Causeway. The scope included tasks related to the collection and evaluation of data related to each of these major constraints and opportunities, progress and coordination meetings, and the preparation of this Investigation Report.

1.2 Investigation Team

The Investigation Team consisted of environmental consultants (both engineers and scientists) coordinating with the Alabama Department of Conservation and Natural Resources (ADCNR), State Lands Division staff. The overall process included the consultants first preparing work plans that were provided to ADCNR staff for review. Meetings were conducted to provide progress status, answer questions, and discuss upcoming tasks to be performed. Fieldwork and modeling tasks were performed, and the results were presented to the ADCNR staff via reports and meeting presentation. Input provided by ADCNR staff were incorporated into this report. The members of the investigation team are provided in Table 1.

Table 1. Investigation Team

ADCNR Staff (in alphabetical order of last name)	
Terry Boyd	
Will Brantley	
Carl Ferraro	
Jeremiah Kolb	
Patti Powell	

Consulting Staff (in alphabetical order of last name)	Firm
Chris Blackwood	South Coast Engineers
Beau Buhring	South Coast Engineers
Anthony Cotts, P.E.	Weston Solutions, Inc.
Scott Douglass, Ph.D., P.E. D.CE	South Coast Engineers
Philip Lebednik, Ph.D.	Weston Solutions, Inc.
Amy Margolis	Weston Solutions, Inc.
Daniel McCoy	Weston Solutions, Inc.
Scott Slocum	Weston Solutions, Inc.
Tim Thibaut	Barry A. Vittor & Associates, Inc.
Barry A. Vittor, Ph.D.	Barry A. Vittor & Associates, Inc.
Bret Webb, Ph.D., P.E.	South Coast Engineers
Cheryl Ulrich, P.E.	Weston Solutions, Inc.
Christopher Warn	Weston Solutions, Inc.

1.3 Background and History

The Mobile Bay Causeway (U.S. Highway 90/98) was constructed in 1927 to link Baldwin County to Mobile County in southwest Alabama. The Causeway is located at the transition of the five river Mobile-Tensaw Delta to the expansive Mobile Bay. At the time the Causeway was constructed, filling the marsh areas was preferred over the construction of an elevated roadway due to technological and funding limitations. Large areas of open water/marsh habitat were filled with dredged material in certain locations in order to provide a base for the roadway. As a result, the constructed land acts to impede flow between areas north and south of the Causeway and has interrupted natural processes of the delta system and estuary. This has created a barrier between the Delta and Mobile Bay with the exception of four narrow channel openings.

Several studies have investigated general opportunities to restore some of the land crossings through the construction of bridges. Specifically, the U.S. Army Corps of Engineers (USACE) published the *Upper Mobile Ecosystem Restoration Project – Proposed Modification to U.S. Highway 90 (Causeway)* in 2001 and the *Preliminary Restoration Plan* in 2003 (USACE, 2001 and 2003, respectively). The *Preliminary Restoration Plan* identified four areas where increased flow exchange could be beneficial to the environment without the total removal of the Causeway. These locations included Choccolatta Bay, Justins Bay, Sardine Pass, and Shellbank River.

The Alabama Department of Conservation and Natural Resources (ADCNR), State Lands Division (SLD) is leading the current Investigation of Restoration of Hydrology on Mobile Bay Causeway through a Coastal Impact Assistance Program (CIAP) grant. This study includes regions north and south of the Mobile Bay Causeway, with focus towards conceptual Causeway restoration locations (Figure 1). These locations included Choccolatta Bay, Justins Bay, Ducker Bay, and Shellbank River. Early in the investigation, coordination during meetings resulted in Ducker Bay being eliminated as a possible restoration site due to potential easement/ownership issues. The remaining restoration locations included Choccolatta Bay, Justins Bay, and Shellbank River.

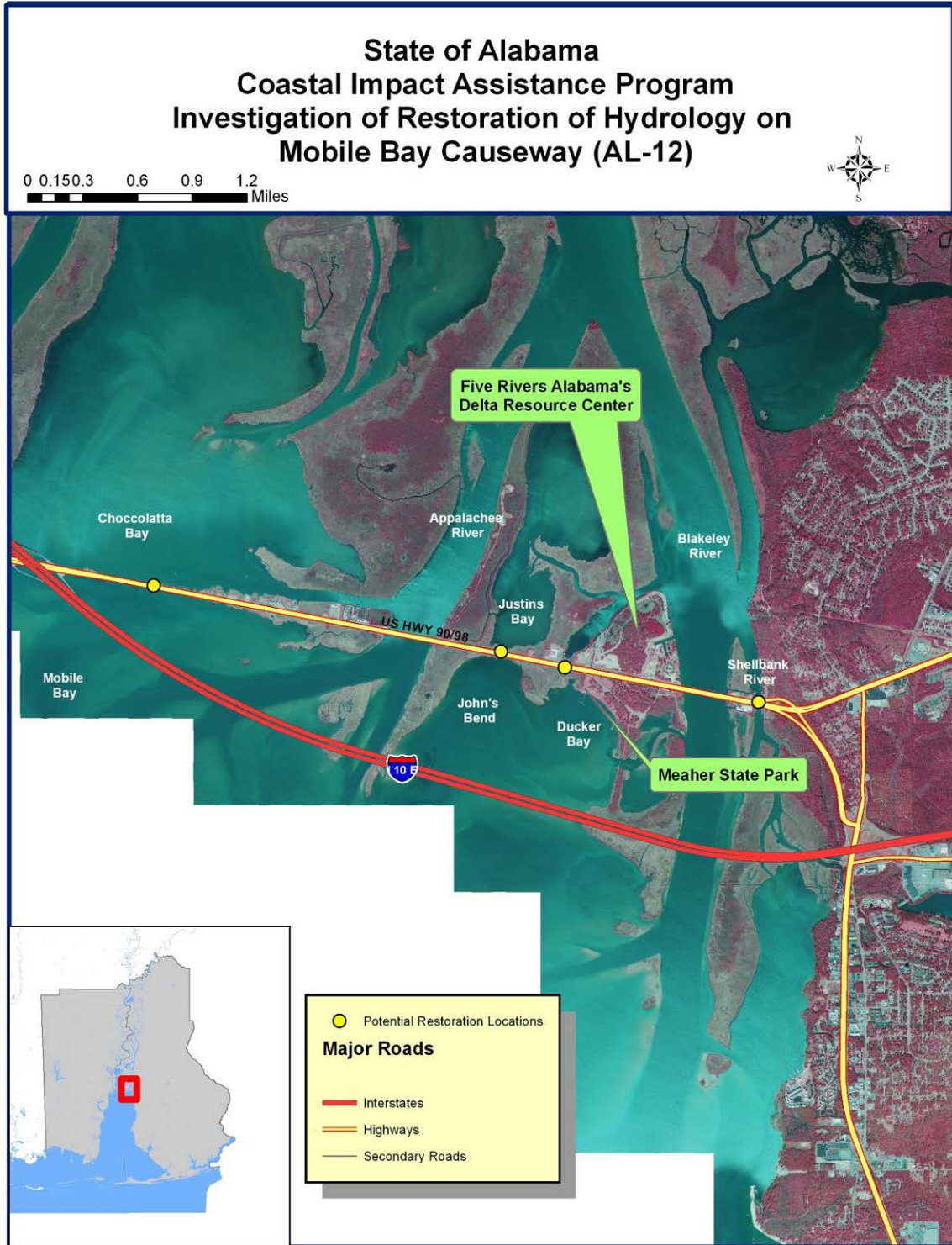


Figure 1. Mobile Bay Causeway Investigation Area

1.4 CIAP AL-12 Investigation Scope

In addition to the preparation of this report, the scope for the overall CIAP AL-12 investigation included several tasks that were performed in support of fulfilling the primary purpose to investigate the feasibility of restoring the hydrology along the Mobile Bay Causeway. The primary tasks are summarized below:

Data Compilation and Comprehensive Report

- Define Investigation Area Conditions and Planning Constraints
 - Compile and review existing sediment contamination data.
 - Compile and review prior studies relating to hydrological, ecological and sediment characteristics of the study area.
 - Define ecological and physical site parameters critical for investigation design such as tidal prism, flow velocity, salinity regime, tidal footprint, freshwater inflows (surface and ground), surface elevation (topography and bathymetry), plant communities, species composition, soil characteristics, climate, and adjacent lands (land cover, use and ownership).
 - Identify key ecological and physical resources that could be affected (adversely or beneficially) by restoration measures.
 - Create site base-map that highlights habitat types, tidal streams, adjacent land uses, infrastructure, real estate ownership and other key physical parameters.
- Preparation of the feasibility investigation report, planning constraints, goals, objectives and performance measures.

Identification of Restoration Alternatives

- Selection of five alternative design scenarios.
- Preparation of alternative design conceptual design sheets.
- Preparation of alternative design conceptual cost estimate calculations.
- Preparation of preliminary conceptual construction schedules.

Sediment Core Collection and Analysis

- Preparation of a Technical Work Plan (TWP) that provided the recommendations along with the rationale for the sampling and analytical program that included:
 - Points of contact, proposed schedule, and scope/objectives;
 - Sampling design, locations, equipment, materials, methods, collection/handling procedures, and field measurements; and
 - Site Health and Safety Plan (HASP).
- Preparation of a Quality Assurance Project Plan (QAPP): that provided a detailed description of proposed sampling and analytical methodologies and quality assurance/ quality control (QA/QC) procedure to be employed to ensure the validity of the data obtained.
- Collection of shallow sediment cores at strategic locations along the Causeway to be chemically analyzed to determine the existence of potential contaminants of concerns (COCs).

- Document results of sediment core collection and analysis (Sediment Report, included in its entirety as Appendix A of this report with portions incorporated into this report).

Ecosystem Field Surveys and Mapping

- Mapping of Submerged Aquatic Vegetation (SAV) within approximately 100 m of the Causeway (north and south) to encompass areas that could be directly affected by modifications associated with the alternative designs.
- Mapping of terrestrial/wetland vegetation within areas where physical alterations could be made to reestablish flow through the Causeway, resulting in excavation/removal of wetland habitat.
- Evaluation of finfish and macro-invertebrates assemblages that could be affected by potential future projects (described through synthesis of existing information rather than through field surveys).
- Evaluation of protected species (especially Alabama red-bellied turtle and manatee) occurrence in the Causeway study area (described on the basis of existing information as well as through habitat mapping).

Hydrodynamic Modeling of Restoration Alternatives

- Development of a hydrodynamic model to simulate potential breaches through the Mobile Bay Causeway. The model was developed to accurately represent the following:
 - Simulate flow and transport through potential Causeway breaches in the study area under typical tidal situations.
 - Simulate relevant hydrodynamic parameters.
 - Provide estimates of sediment resuspension, transport, and deposition.
 - Simulate flow conditions and water levels to aid in the estimation of residence times.
 - Simulate temporal and spatial variation of water, salinity and other relevant hydrodynamic parameters.
- Field data collection included limited bathymetry and short-term collection of water level and coincident current measurements for model development and validation/calibration.
- Numerical grid/mesh development. The grid was developed to allow for appropriate driving boundary conditions for estimating the effects of the breaches on the typical tidal flow patterns.
- Validation runs of hydrodynamic model. The model was tested under existing conditions to verify its ability to model the flow velocities and patterns in the vicinity of the existing opening in the Causeway in Choccolatta Bay.
- Development of an agreement on metrics for model runs.
- Evaluation of the five alternative design scenarios using the hydrodynamic model under representative tidal and flow forcing. The results were quantitative estimates of the impacts of the openings on tidal flows with specific emphasis on the tidal communications between the water bodies north of the Causeway and those south of the Causeway.
- Address sea level rise in five alternative scenarios for potential secondary effects on the tidal hydrodynamics.
- Documentation of the results of the modeling. A written summary of the model and model runs was produced with specific emphasis on presenting the overall aspects of the model and

results to the client for the purposes of decision making at the conceptual, or feasibility stage, including descriptions of the general abilities and limitations of the model (Hydrodynamic Modeling Report, included in its entirety as Appendix E of this report with portions incorporated into this report).

Comprehensive Report

- Preparation of this Draft Feasibility Investigation Report that provides the results of the primary tasks performed under this contract. Brief summaries of task activities and methodologies, if applicable, are also included in this report for purposes of providing background information related to the determination and limitations the results.

2.0 GOALS, OBJECTIVES, AND PERFORMANCE MEASURES

Goals, objectives, and performance measures provide the base for potential restoration projects. Clearly stating these measures provide the investigation team with the guidelines necessary to implement the study successfully.

The goal of this project is to investigate restoration opportunities in the coastal area of Alabama, specifically, to initiate, design, and answer research questions relating to restoring the historical flow of water around the Mobile Bay Causeway. Such research will assist decision-makers in determining infrastructure needs associated with this roadway by evaluating the potential impacts of altering flows in this estuary.

The objectives are derived from the goal statement and define the specific, measurable targets. There are four main objectives for this investigation:

Objective 1 - Increase the tidal communication between Mobile Bay and areas north of the Causeway.

Objective 2 - Increase the tidal prism in water bodies north of the Causeway.

Objective 3 - Decrease the tidal phase lag between Mobile Bay and areas north of the Causeway.

Objective 4 - Increase the flushing of water bodies north of the Causeway.

2.1 Performance Measures

Performance measurements are a means of quantifying the effectiveness of the objectives. Performance measures are presented below for each of the investigation objectives based on hydrodynamic modeling.

Objective 1:

- Estimate the volume flux of water per tidal cycle and compare to existing conditions.
- Estimate the subtidal exchange flows and rates and compare to existing conditions.
- Estimate tidal current velocity in study area and compare to existing conditions.
- Estimate/identify the potential for sediment resuspension, transport rates, and depositional areas relative to existing conditions.
- Estimate the effects of removal of emergent wetland and upland habitat for aquatic fauna and wildlife.
- Estimate the effects of removal of SAV habitat on aquatic fauna and wildlife.
- Estimate the effects of erosion, redistribution, and deposition of sediments, nutrients, or contaminants on habitats and aquatic fauna.
- Estimate the effects of new migratory corridors and habitat access for aquatic fauna.
- Estimate the effects of hydrodynamic alteration on habitats, aquatic fauna, and wildlife.
- Estimate the effects of hydrologic alteration on habitats, aquatic fauna, and wildlife.

Objective 2:

- Estimate water levels in the study area and compare to existing conditions.
- Estimate the tide range in the affected water bodies and compare to existing conditions.
- Estimate the tidal prism of affected water bodies and compare to existing conditions.

Objective 3:

- Estimate the tidal stage inside and outside of the study area and compare to existing conditions.
- Estimate the tidal phase lag in affected water bodies and compare to existing conditions.

Objective 4:

- Estimate the flushing times of affected water bodies using a tidal prism method and compare to existing conditions.
- Estimate the improvement of flushing time, per tidal day, in affected water bodies relative to existing conditions.

3.0 EXISTING SEDIMENT CONDITIONS

The Mobile Bay Causeway (U.S. Highway 90/98), located at the transition of the five river Mobile-Tensaw Delta in Upper Mobile Bay, was constructed in 1927 to link Baldwin County to Mobile County. At the time the Causeway was constructed, filling the marsh areas was preferred over the construction of an elevated roadway due to technological and funding limitations. Large areas of open water/marsh habitat were filled with dredged material in order to provide a base for the 7-mile long roadway. As a result, the constructed land acts to impede flow between areas north and south of the Causeway and has interrupted natural processes of the delta system and estuary.

This section on existing sediment conditions summarizes the potential for restoring natural tidal flushing to the Upper Bay by creating channel openings along the Causeway at four locations. The goal of this sediment study was to determine the spatial extent and magnitude of contaminated sediment within the project area that may be mobilized if hydrological restoration project was undertaken in the future.

The four potential locations were areas that were recommended in a USACE report that investigated opportunities to restore some of the land crossings through the construction of bridges. The USACE report *Preliminary Restoration Plan - Upper Mobile Ecosystem Restoration Project*, published in 2003, identified four areas where increased flow exchange could be beneficial to the environment without the total removal of the Causeway. These locations occur along the Causeway at Choccolatta Bay, Justins Bay, Sardine Pass, and Shellbank River.

Figure 1 on page 3 depicts an overview of the project area and the potential hydrological restoration locations.

3.1 Historical Data Review

Initially, a historical data review was performed from previous studies to determine potential areas of concern and data gaps and was used as a basis for the development of a Technical Work Plan (TWP) and an accompanying Quality Assurance Project Plan (QAPP). This review encompassed over 50 documents covering studies that had been performed in the project area. Potentially relevant sediment data results gathered from the historical review were entered into a GIS and mapped. The resulting map was then used to determine which locations were relevant to the study area and project. The compiled data from within the study area were compared to ecotoxicological benchmarks. These benchmarks assisted in understanding the potential effects to biota from the chemical concentrations reported from the sediment samples. Exceedances of benchmark values from the literature review were found within the project area for mercury, nickel, chromium, copper, lead, zinc, DDT compounds, and acenaphthene. Maps of the locations where benchmark exceedances were documented in the data review are provided in the full Sediment Report in Appendix A.

3.2 Sediment Deposition

Fearn et al. (2004) reported that the construction of the Causeway altered the hydrology of the delta by reducing and impeding water exchange between Mobile Bay and the smaller bays north of the Causeway, which has resulted in reduced sedimentation rates. According to Fearn et al. (2014) about 40 centimeters of sediment has accumulated in Choccolatta Bay since the mid-1920s. The Byrnes et al. (2013) report to the Mobile Bay National Estuary Program (MBNEP) provides detailed information about historical sediment deposition in the area and provides a sediment budget for the Mobile Bay area.

Isphording and Enright (1997) have also conducted extensive research related to sediment characteristics in the delta area from the 1970s to late 1990s. They reported that approximately one million tons of sediment is carried into the delta each year and the bulk of this material transits the delta and is discharged into Mobile Bay. However, they did not establish how much entrapment occurs at the Causeway boundary or how this discharge is released further down channel to the south.

Additionally, the D'Olive Creek Watershed Management Plan (Thompson Engineering, 2010) discussed the increase in urbanization in that watershed and the resulting impacts to sedimentation. Streams within that watershed are on the 303(d) list of impaired water bodies due to the excessive sedimentation from urban development. Along with upland drainage from the D'Olive Watershed, the Blakeley River and Mobile Bay influence sedimentation patterns within D'Olive Bay.

Based on the findings of the historical data review and consultation with ADCNR personnel, a comprehensive sampling and analysis study was formulated. The overall goal of the sediment sampling and analysis study was to provide a screening analysis of chemical concentrations in sediments near the Causeway. This study was undertaken to supplement prior investigations to provide physical sediment parameters to support modeling efforts and to assess sediment chemical concentrations and their potential to contribute to ecological impacts from any potential restoration alternatives. The study included regions north and south of the Mobile Bay Causeway, with focus towards conceptual Causeway restoration locations that have the highest potential for success, as identified in the USACE report (2001). These potential restoration locations include Choccolatta Bay, Justins Bay, and Shellbank River. This study included the collection of shallow sediment cores at strategic locations north and south of the Causeway to be analyzed to determine the existence of potential COCs.

3.3 Investigation- Methods

The sampling program was developed based on consultation with ADCNR and on the results of the data review that identified locations of primary COCs and data gaps. A proposed sampling program consisting of 29 sampling locations was developed from this information and was approved by ADCNR. Samples were collected from each of the sites shown in Figure 2 (12 sites in Choccolatta Bay, 11 sites in Justins Bay, and 6 sites in Shellbank River) using a push core device operated from a small sampling vessel (Figure 3). The target core depth included two depth profiles – an upper profile (Top) and lower profile (Bottom). The first profile was from 0 to 15 inches in depth and the second depth profile was from 15 to 30 inches in depth. In some

instances, penetration to 30 inches in depth was not attainable. In those cases, the lower profile ranged from 15 inches to refusal depth (less than 30 inches). Upper and lower sediment profiles were analyzed for percent solids, total organic carbon (TOC), particle size, trace metals, mercury, and organochlorine pesticides. In addition, upper sediment profiles were also analyzed for polychlorinated biphenyl (PCB) congeners, polycyclic aromatic hydrocarbons (PAHs), phenols, and phthalates. Analysis methods, detection limits, reporting limits, and sample handling procedures are provided in the full Sediment Report in Appendix A. A calibrated YSI datasonde was used to collect water quality measurements on site. The YSI was used to measure hydrogen ion concentration (pH), dissolved oxygen (DO), turbidity, temperature, conductivity, and salinity.

Physical and chemical analysis was performed to provide physical sediment parameters to support modeling efforts and to assess sediment chemical concentrations and their potential to contribute to ecological impacts from any potential restoration alternatives. All analytical methods used to obtain chemical concentrations followed United States Environmental Protection Agency (USEPA) methods or Standard Methods (SM) provided by American Public Health Association (APHA, 1998). Quality assurance objectives for chemical analysis conducted by the participating analytical laboratory are detailed in the full Sediment Report provided in Appendix A.

All data were reviewed and verified by participating team laboratories to determine whether all data quality objectives were met, and that appropriate corrective actions were taken, when necessary. The WESTON QA Officer was responsible for the final review of all data generated.

Data analysis consisted of tabulation and comparison to established ecotoxicological benchmarks. These benchmarks included USEPA Risk Assessment Guidance for Superfund (RAGS), TEL, and PEL values. Results for each study area were mapped by constituent and exceedances of benchmarks were identified at the respective stations. Exceedances were compiled and analytical results were mapped to show average chemical concentrations in both the upper and lower sediment profiled for each study area.



Figure 2. Sediment Sampling Locations in Upper Mobile Bay

The ecological risk benchmarks considered in this report are:

- **USEPA RAGS** – USEPA Region 4 RAGS sediment screening values. These benchmarks indicate chemical concentrations associated with a low probability of unacceptable risks to ecological receptors (USEPA 2001).
- **ER-L** – Effects Range–Low (ER-L) sediment quality benchmarks are derived from synoptic studies and represent the concentration at the lower 10th percentile effect concentration (i.e., the concentration below which effects are infrequently observed or predicted) (Long et al., 1990). These are more conservative benchmarks than ER-Ms.
- **ER-M** – Effects Range–Median (ER-M) sediment quality benchmarks are derived from the same synoptic studies as the ER-Ls but represent the median effect concentration (i.e., the concentration at which effects are frequently observed or predicted) (Long et al., 1990).
- **TEL** –TEL represents the concentration below which adverse effects are expected to occur only rarely (MacDonald et al., 1996). These are more conservative benchmarks than PELs.
- **PEL** – PEL represents the concentration above which adverse effects are frequently expected (MacDonald et al., 1996).



Figure 3. Pushcore Sediment Sampling and Processing in Justins Bay

3.4 Investigation- Constraints

During the sediment collection field event there was concern that not all of the Technical Work Plan approved sampling locations would be accessible due to shallow water conditions. To address this constraint, a shallow draft sampling vessel was used to allow for maximum access in areas where the minimum water depth was a concern. Additionally, sampling attempts for shallow depth areas were coordinated to occur around periods of high tide. As a result, sediment was successfully collected from all pre-plotted sampling locations.

3.5 Investigation- Results

The historical data were few and provided limited insight regarding COC presence, distribution, and/or ecological risk. Mercury data indicated that there were exceedances of the most conservative benchmark in some locations upstream and exceedances of less conservative benchmarks in some locations on both sides of the Causeway. Nickel data indicated that there were exceedances of the most conservative benchmark in some locations on both sides of the Causeway. Data for DDT and acenaphthene (a PAH) were few and revealed one exceedance in each of the review areas. However, the paucity of data available for these compounds in the study area prevented conclusions from being drawn. Overall, beyond indicating the presence of certain contaminants, the historical review provided little insight into potential ecological risk in the area with the possible exception of an indication of mercury risk north of the Shellbank River location. Most of the exceedances in the historical data occurred in locations outside the

conceptual restoration alternative area footprints. For this reason, sediment sampling stations were located throughout the project area rather than concentrated around previously investigated areas.

Field samples were collected during the week of 12 May 2014. COC data were obtained by collection of shallow sediment cores (separated into 0-15 in and 15-30 in profiles) at several locations north and south of the Causeway at each of the three potential restoration alternative locations (Chocolatta Bay, Justins Bay, and Shellbank River). Field samples were labeled Top or Bottom to identify which depth profile was sampled, the upper profile (Top) or lower profile (Bottom).

3.5.1 Chocolatta Bay Study Area Results

There were twelve sampling locations in Chocolatta Bay, eight north of the Causeway and four south of the Causeway. Samples were collected at both the upper and lower depth horizons at all sites with the exception of site CB-N-06. Physical and general chemistry results are provided in Table 2. Top sediments located north and south of the Causeway consisted predominantly of sand with silt and lesser amounts of clay. Bottom sediments north of the Causeway were similar in grain size to Top sediments, while Bottom sediments south of the Causeway were slightly coarser in size than Top sediments from the same stations. TOC concentrations north and south of the Causeway were similar among Top sediments and were slightly higher than Bottom TOC concentrations, both north and south of the Causeway.

Table 2. Average Grain Size and TOC Results from Chocolatta Bay Stations

Parameter	CB North Top (%)			CB North Bottom (%)			CB South Top (%)			CB South Bottom (%)		
	Ave. ± Std. Dev.	Min	Max	Ave. ± Std. Dev.	Min	Max	Ave. ± Std. Dev.	Min	Max	Ave. ± Std. Dev.	Min	Max
Sand	64.4 ± 8.2	52.3	73.5	69.8 ± 16.2	40.0	90.0	45.4 ± 31.0	0.0	67.4	56.2 ± 39.5	0.0	87.9
Silt	28.7 ± 6.7	20.5	37.7	24.8 ± 13.0	8.3	48.6	41.8 ± 23.4	25.6	75.5	28.6 ± 21.8	10.0	59.1
Clay	6.8 ± 1.7	4.4	10.0	5.4 ± 3.2	1.7	11.4	12.8 ± 8.0	7.1	24.5	15.2 ± 17.7	2.1	40.9
TOC	1.04 ± 0.4	0.54	1.70	0.82 ± 0.2	0.40	1.20	1.05 ± 0.38	0.74	1.60	0.76 ± 0.40	0.40	1.20

There were no metal exceedances north or south of the Causeway in the Chocolatta Bay study area. In general, the majority of metal concentrations in both Top and Bottom sediments were 50% or more below RAGS benchmark values. Several DDT compounds were measured above RAG, TEL, and PEL benchmark concentrations in the Chocolatta Bay study area. Chlorinated pesticide concentrations above ecotoxicological benchmarks occurred in both Top and Bottom sediment layers and at sites located both north and south of the Causeway (Figure 4). With the exception of CB-N-08, pesticide concentrations were higher in Top sediments than in Bottom sediments. No chlorinated pesticides other than DDTs were detected in either Top or Bottom sediments.

Three sites in the Chocolatta Bay study area had concentrations of PAHs above RAGS and TEL benchmark values; two were located north of the Causeway and one was located south of the

Causeway. However, total PAH concentrations at each site were below the RAGS benchmark. There were no PCBs detected in surficial sediments from the Choccolatta Bay study area. Benzoic acid and bis (2-ethylhexyl) phthalate were the only semivolatile organic compounds detected, and both were below RAGS and TEL benchmarks.

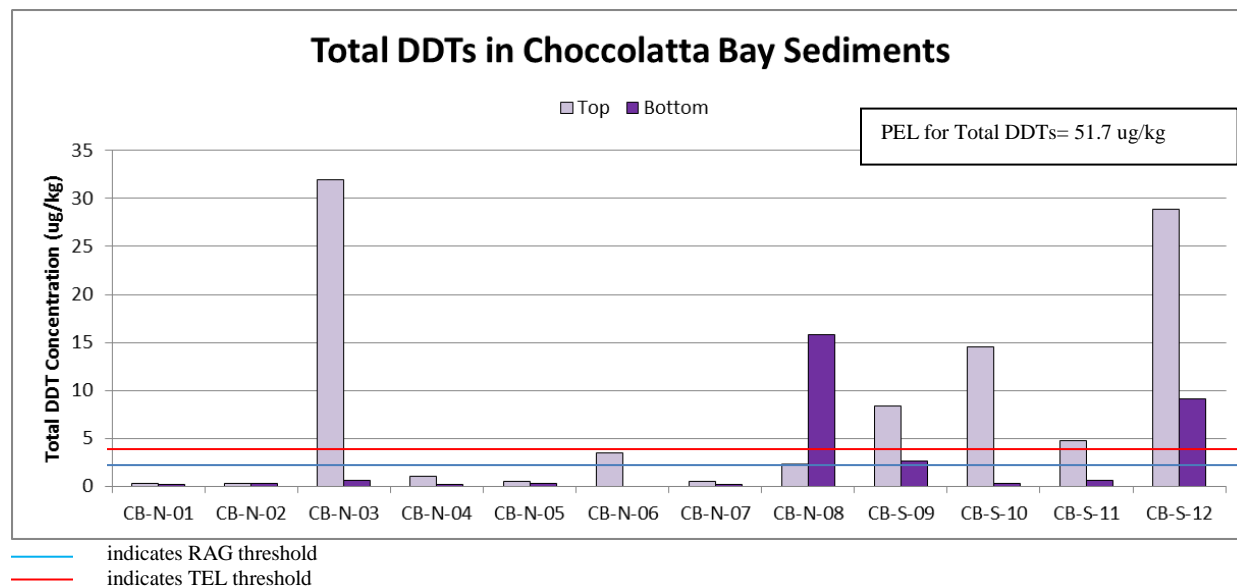


Figure 4. Total DDTs in Choccolatta Bay Top and Bottom Sediments

3.5.2 Justins Bay Study Area Results

There were eleven sampling locations in the Justins Bay study area, four north of the Causeway and seven south of the Causeway. Samples were collected at both the upper and lower depth horizons at all sites. Physical and general chemistry results are provided in Table 3. Top sediments collected south of the Causeway in general were comprised of slightly coarser grains on average than Top sediments collected from stations north of the Causeway. Bottom sediments from stations south of the Causeway were coarser in size than Bottom sediments north of the Causeway and Top and Bottom sediment TOC concentrations were higher north of the Causeway than south of the Causeway.

Table 3. Average Grain Size and TOC Results from Justins Bay Stations

Parameter	JB North Top (%)			JB North Bottom (%)			JB South Top (%)			JB South Bottom (%)		
	Ave. ± Std. Dev.	Min	Max	Ave. ± Std. Dev.	Min	Max	Ave. ± Std. Dev.	Min	Max	Ave. ± Std. Dev.	Min	Max
Sand	52.1 ± 24.9	17.2	73.1	57.8 ± 7.3	47.7	86.4	66.4 ± 12.9	40.9	80.7	79.4 ± 7.3	64.8	86.4
Silt	39.2 ± 19.2	22.4	65.7	34.6 ± 5.8	29.8	26.4	28.0 ± 11.3	16.0	50.8	16.6 ± 5.1	11.4	26.4
Clay	8.7 ± 5.8	4.5	17.6	7.5 ± 1.7	6.2	8.8	5.6 ± 1.6	3.3	8.3	4.0 ± 2.2	2.2	8.8
TOC	1.94 ± 1.0	0.55	2.80	1.03 ± 0.5	0.51	0.96	0.96 ± 0.4	0.57	1.60	0.58 ± 0.2	0.26	0.96

Nickel was the only metals exceedance for the Justins Bay study area and was measured above RAG and TEL benchmarks in Top sediments at site JB-N-03. Several DDT compounds were

also measured above RAG and TEL benchmark concentrations in the Justins Bay study area (Figure 5). Aside from DDTs, no other chlorinated pesticides were detected in Top or Bottom sediments in Justins Bay. PAH concentrations at five sites (three north of the Causeway and two south of the Causeway) were above RAGS and TEL benchmark values. No PCBs, phthalate, or phenols were detected above benchmark concentrations.

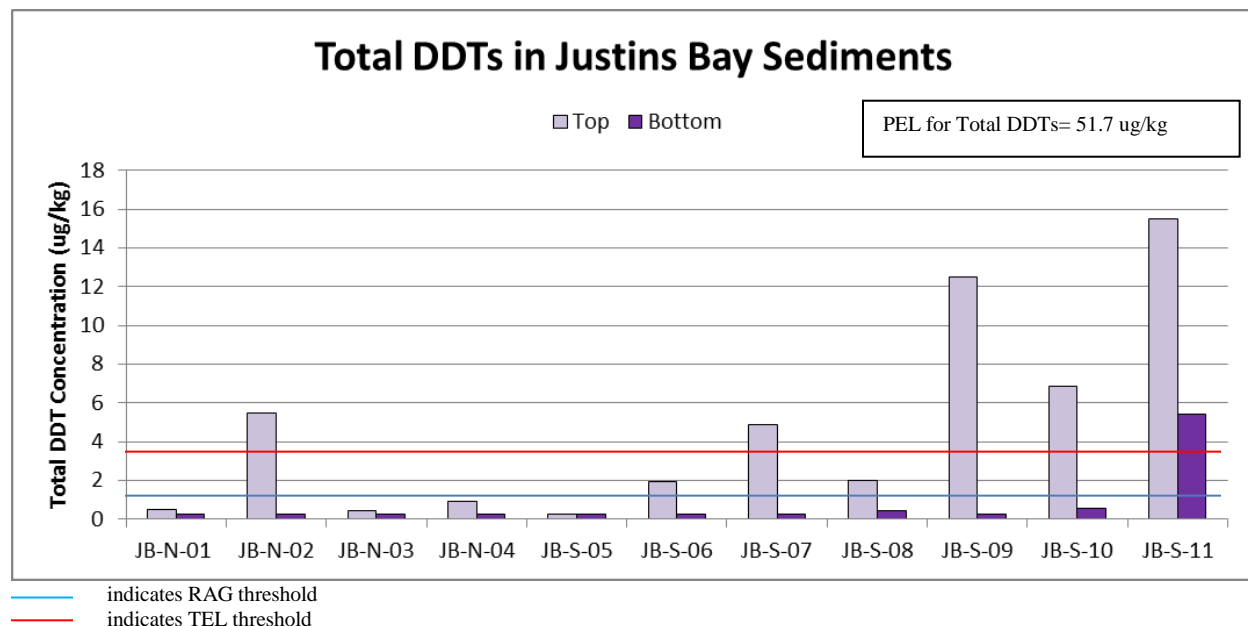


Figure 5. Total DDTs in Top and Bottom Sediments at Justins Bay Stations

3.5.3 Shellbank River Study Area Results

There were six sampling locations in Shellbank River study area, three located north of the Causeway and three located south of the Causeway. Physical and general chemistry results are provided in Table 4. Samples were collected at upper and lower depth horizons at all sites. Top and Bottom sediments located north of the Causeway in the Shellbank River study area consisted predominantly of silt with sand and clay. Top and Bottom sediments from stations south of the Causeway, were slightly coarser with higher percentages of sand than stations located north of the Causeway. Top sediment TOC concentrations were higher south of the Causeway than north of the Causeway, while Bottom sediment TOC concentrations were similar both north and south of the Causeway.

Table 4. Physical and General Chemistry Results from Shellbank River Stations

Parameter	SR North Top (%)			SR North Bottom (%)			SR South Top (%)			SR South Bottom (%)		
	Ave. ± Std. Dev.	Min	Max	Ave. ± Std. Dev.	Min	Max	Ave. ± Std. Dev.	Min	Max	Ave. ± Std. Dev.	Min	Max
Sand	11.5 ± 3.1	8.0	13.4	10.1 ± 11.2	1.1	22.6	19.3 ± 12.6	9.7	33.5	34.1 ± 48.3	0.0	89.4
Silt	74.1 ± 3.8	70.1	77.6	70.6 ± 11.0	58.0	78.6	69.3 ± 13.1	54.2	78.3	53.6 ± 40.6	7.5	84.0
Clay	14.3 ± 2.2	12.1	16.4	19.3 ± 1.0	18.2	20.2	11.4 ± 1.2	10.0	12.2	12.3 ± 8.0	3.1	17.7
TOC	2.23 ± 0.6	1.6	2.6	1.57 ± 0.50	1.1	2.1	2.90 ± 1.47	1.3	4.2	1.53 ± 1.30	0.2	2.8

Concentrations of arsenic, cadmium, copper, lead, mercury, nickel, and zinc were measured above ecotoxicological benchmarks in sediments collected from the Shellbank River study area (Table 5). Elevated metals concentrations occurred in sites located north and south of the Causeway and in Top and Bottom sediment profiles. In many instances metal concentrations that exceeded benchmarks in the upper sediment profile at a given site also exceeded benchmarks in the lower sediment profile at that site. Copper, nickel, and zinc concentrations were above the TEL at four of the six sample locations. Average metal concentrations were generally higher in both Top and Bottom sediments located north of the Causeway.

Table 5. Metals Exceedances in Shellbank River Study Area

	Arsenic mg/kg	Cadmium mg/kg	Copper mg/kg	Lead mg/kg	Mercury mg/kg	Nickel mg/kg	Zinc mg/kg
RAG/ Reg4	7.24	0.676	18.7	30.2	0.13	15.9	124
TEL	7.24	0.67	18.7	30.2	0.13	15.9	124
PEL	41.6	4.21	108	112	0.7	42.8	271
SR-N-02 TOP			26.2			17	
SR-N-02 BOTTOM			19.6		0.156	18.3	154
SR-N-03 TOP	8.03	0.825	29.3	74.4		19.6	205
SR-N-03 BOTTOM			21.2	39	0.157		154
SR-S-04 TOP			23.9			18.5	128
SR-S-05 TOP	7.53	0.677	22.5			18.9	
SR-S-05 BOTTOM	7.89		22.4			20.7	158

Blank cell indicates result below benchmarks.

Bolded text indicates result above TEL.

Chlorinated pesticide concentrations above ecotoxicological benchmarks occurred across all Shellbank River sites, and were found in both Top and Bottom sediments located both north and south of the Causeway. PEL exceedances of DDT compounds occurred in Top sediments at stations SR-S-06 and in Bottom sediments at SR-N-01, SR-N-02, and SR-N-03 (Figure 6). Aside from DDTs, no other chlorinated pesticides were detected in Top or Bottom sediments in Shellbank River. The PAH benzo(a)pyrene was above the TEL benchmark at Station SR-N-01. All sites were well below threshold levels for Total PAHs. There were no exceedances for PCBs, phenols, or phthalates in the Shellbank River study area.

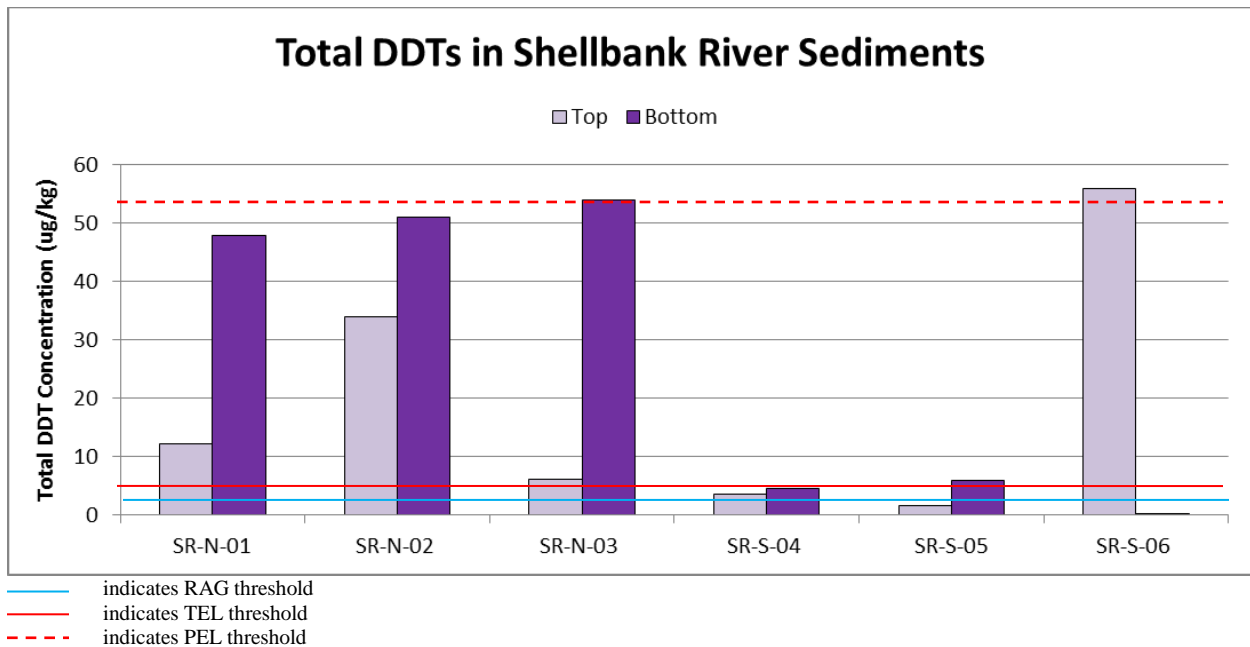


Figure 6. Total DDTs at Shellbank River Stations

3.5.4 Sediment Results Maps

The following pages present sediment exceedance maps for select chemical constituents. Figure 7 through Figure 10 present the metal constituent results for copper, mercury, nickel, and zinc. Figure 11 presents the chlorinated pesticide results for Total DDTs and Figure 12 presents the PAH results for benzo(a)pyrene. Each upper profile sampling location is designated by a small circle. A concentric ring around the small circle indicates the lower profile sample result. Each ring is color coded to indicate the respective ecotoxicological benchmark exceedance:

- green indicates the result is below the RAG,
- yellow indicates the result exceeds the RAGS,
- orange indicates the result exceeds the TEL, and
- magenta indicates the result exceeds the PEL.
- The blue lines in each of the study areas indicate the general boundary of conceptual restoration locations.

The full table of analytical results and all of the sediment results maps are presented in the full report in Appendix A.

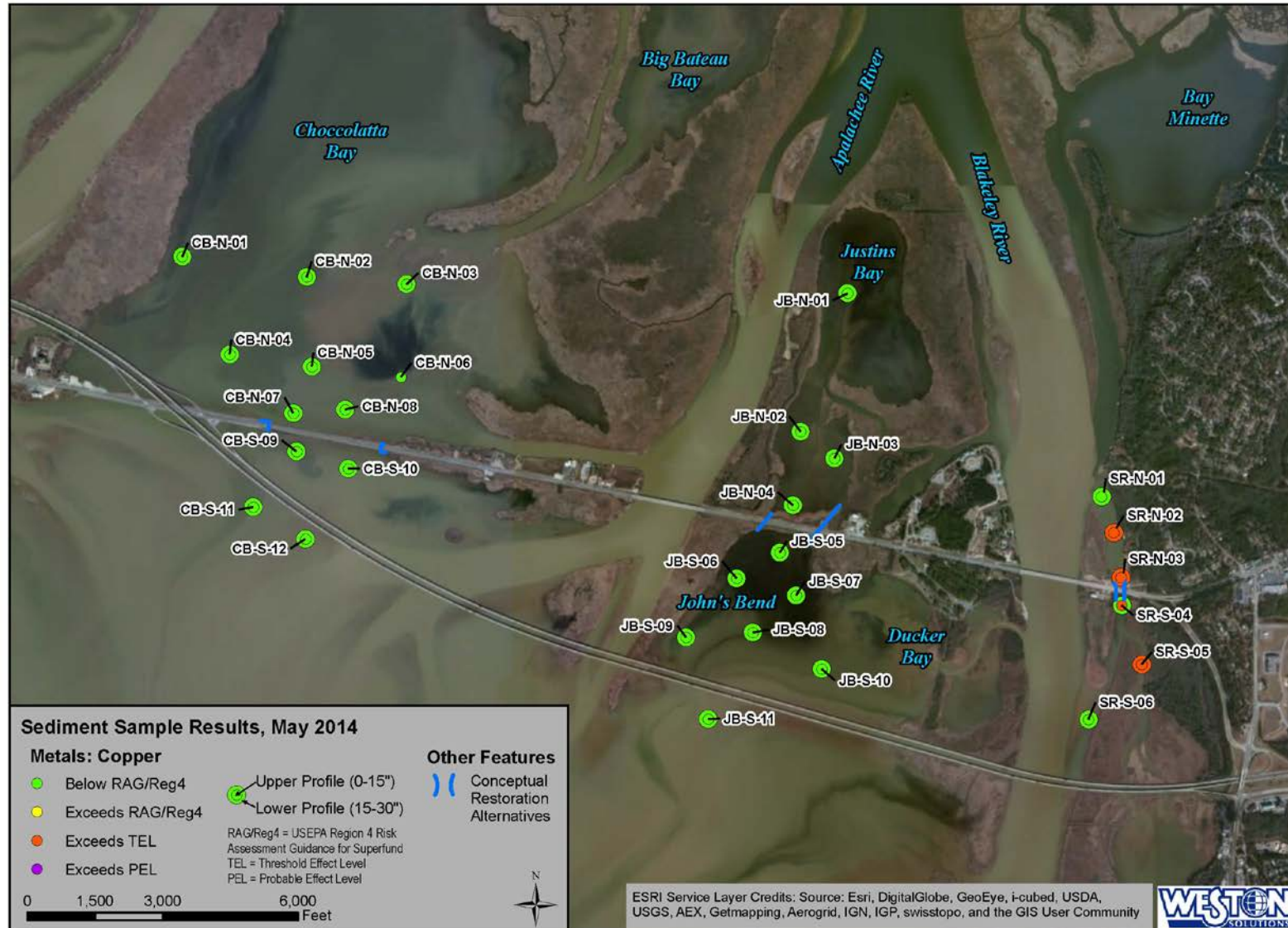


Figure 7. Sediment Sample Results for Copper

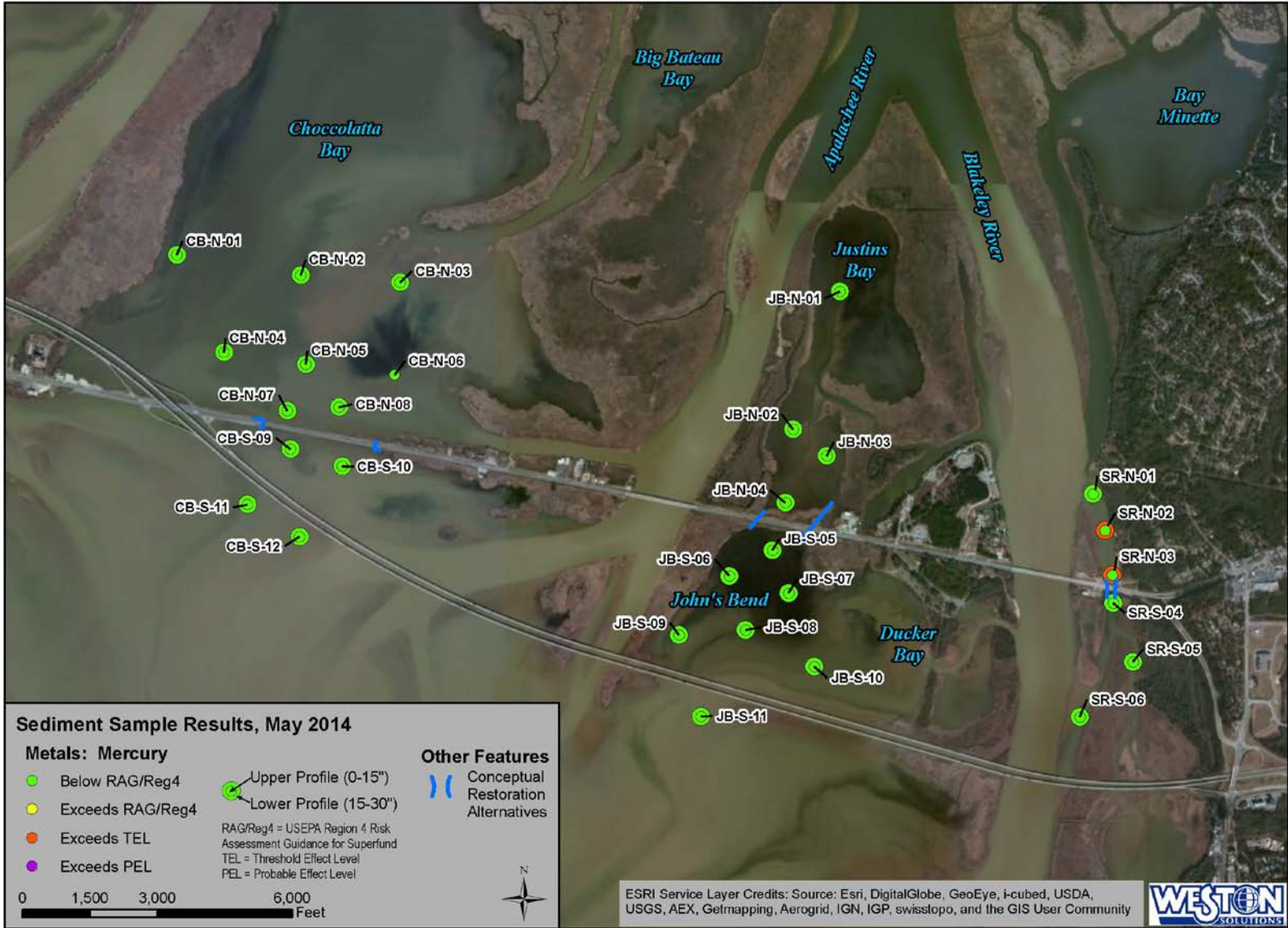


Figure 8. Sediment Sample Results for Mercury

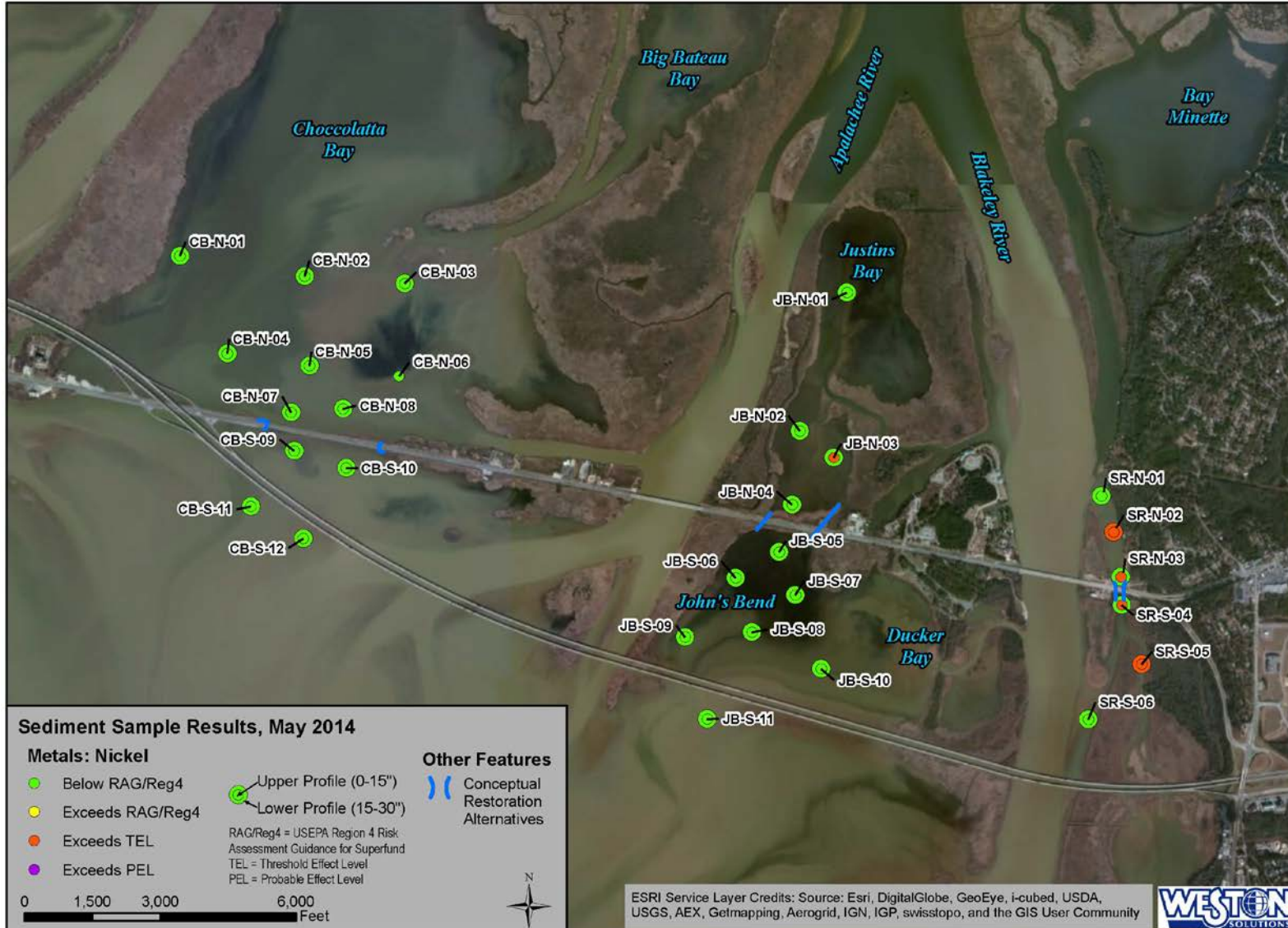


Figure 9. Sediment Sample Results for Nickel

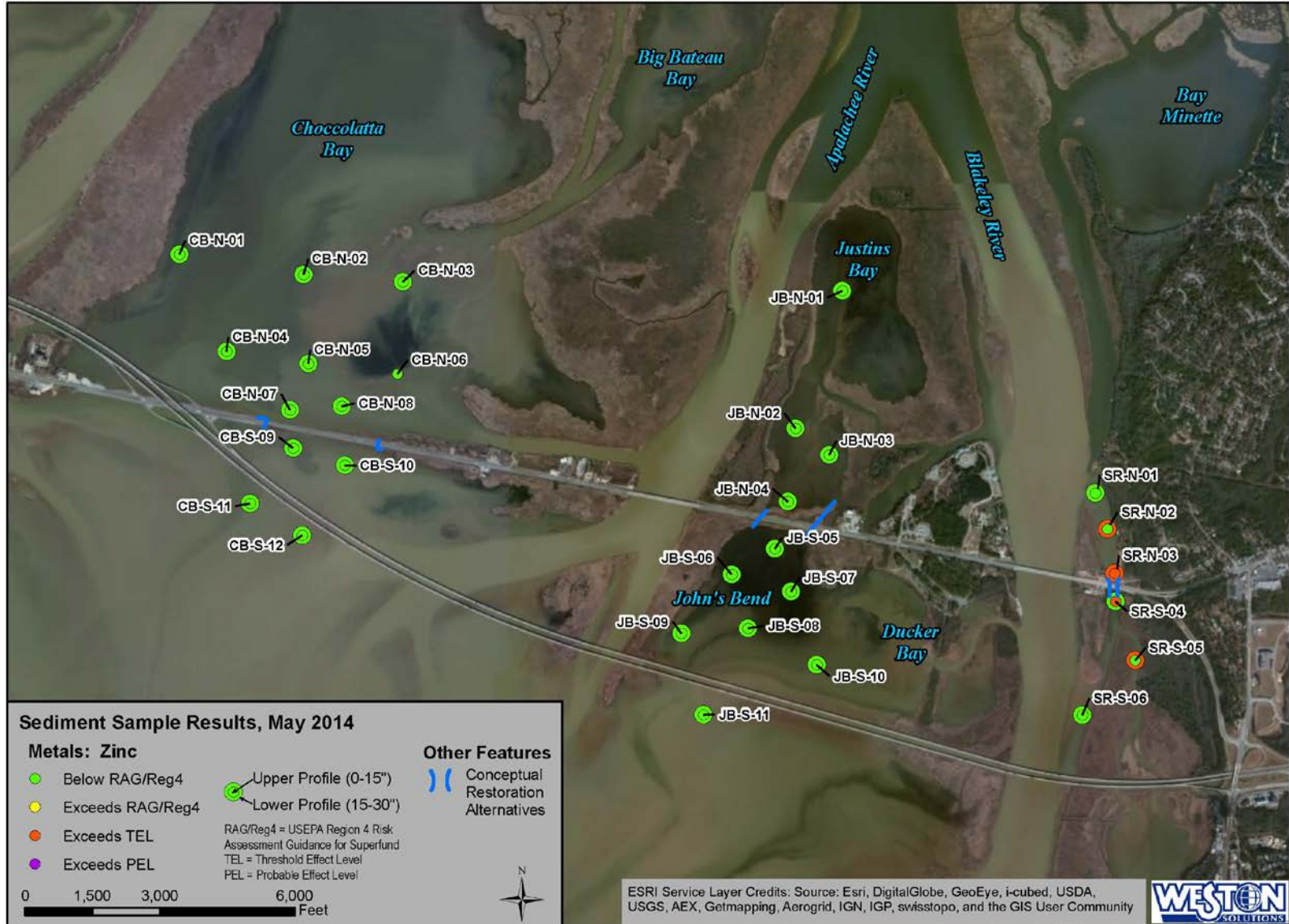


Figure 10. Sediment Sample Results for Zinc



Figure 11. Sediment Sample Results for Total DDTs

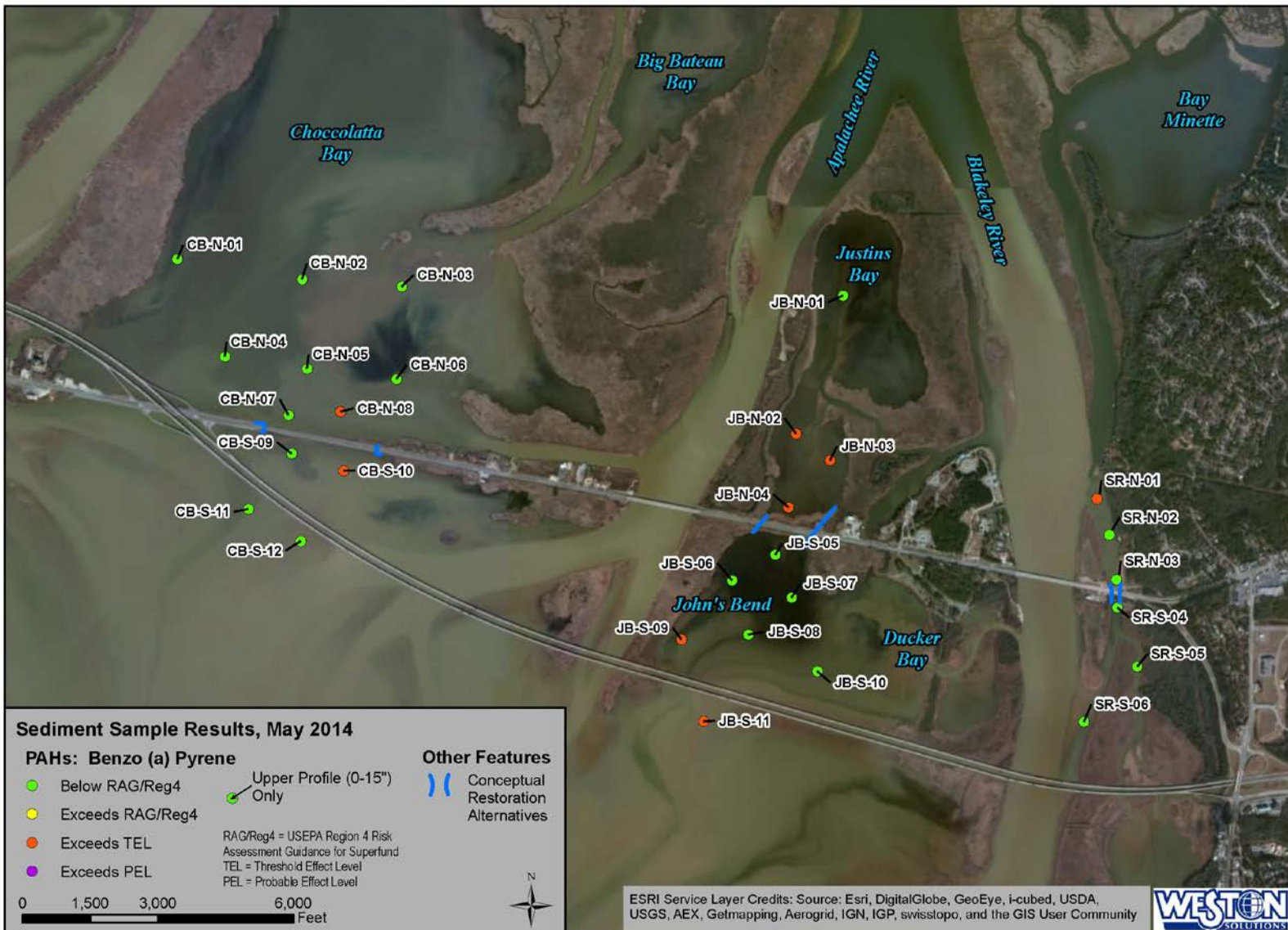


Figure 12. Sediment Sample Results for Benzo(a)pyrene

4.0 BIOLOGICAL RESOURCES

Existing biological resources occurring within upper Mobile Bay and the lower delta may be impacted by potential alterations to existing hydrological conditions, modifications to existing structures, and installation of new structures should hydrological restorative actions move forward at one or more of the potential breach locations. Potential disturbances, which may be either temporary or permanent, include increased turbidity and siltation, burial, changes in water quality, mobilization of COCs, and removal and alteration of existing habitat. For these reasons, it was important to document the existing biological resources within the study area to aid in the investigation as to the feasibility of any potential restoration planning and to assess potential impacts to these resources.

Wetlands and SAV distributions were mapped in the study area (Figure 1). Field surveys were performed on 19, 24, and 25 June 2014 with emphasis on validating the estimated boundaries of wetlands and SAV beds in the vicinity of the four alternative restoration locations. A list of plant species found at each of these locations was generated by field biologists, who utilized a Trimble® Ranger Global Positioning System (GPS) to collect and store the field data. Over the course of the 3-day survey, a total of 105 field locations were logged.

The collected data were imported to ArcGIS to map and characterize the habitats and to refine the mapped features and boundaries of the wetlands and SAV. The 2013 National Agriculture Imagery Program (NAIP) aerial imagery for Baldwin County was used as a base map. A desktop estimation of wetland and SAV boundaries was performed prior to field surveys at the scale of 1:1800 (1 foot = 150 feet) in ArcGIS. The NAIP imagery was observed in ArcView GIS, and feature boundaries were digitally delineated on a computer screen display.

Habitat maps for each of the restoration alternative locations are presented in Figure 13 through Figure 16. Species listed on the maps are the dominant species located within each mapped feature and do not represent all of the species that were observed. Vegetation species lists for each alternative location are presented in Appendix B. Vegetation species are discussed in the following text based on the areas in which they occur, along the Causeway right-of-way or in the wetland.

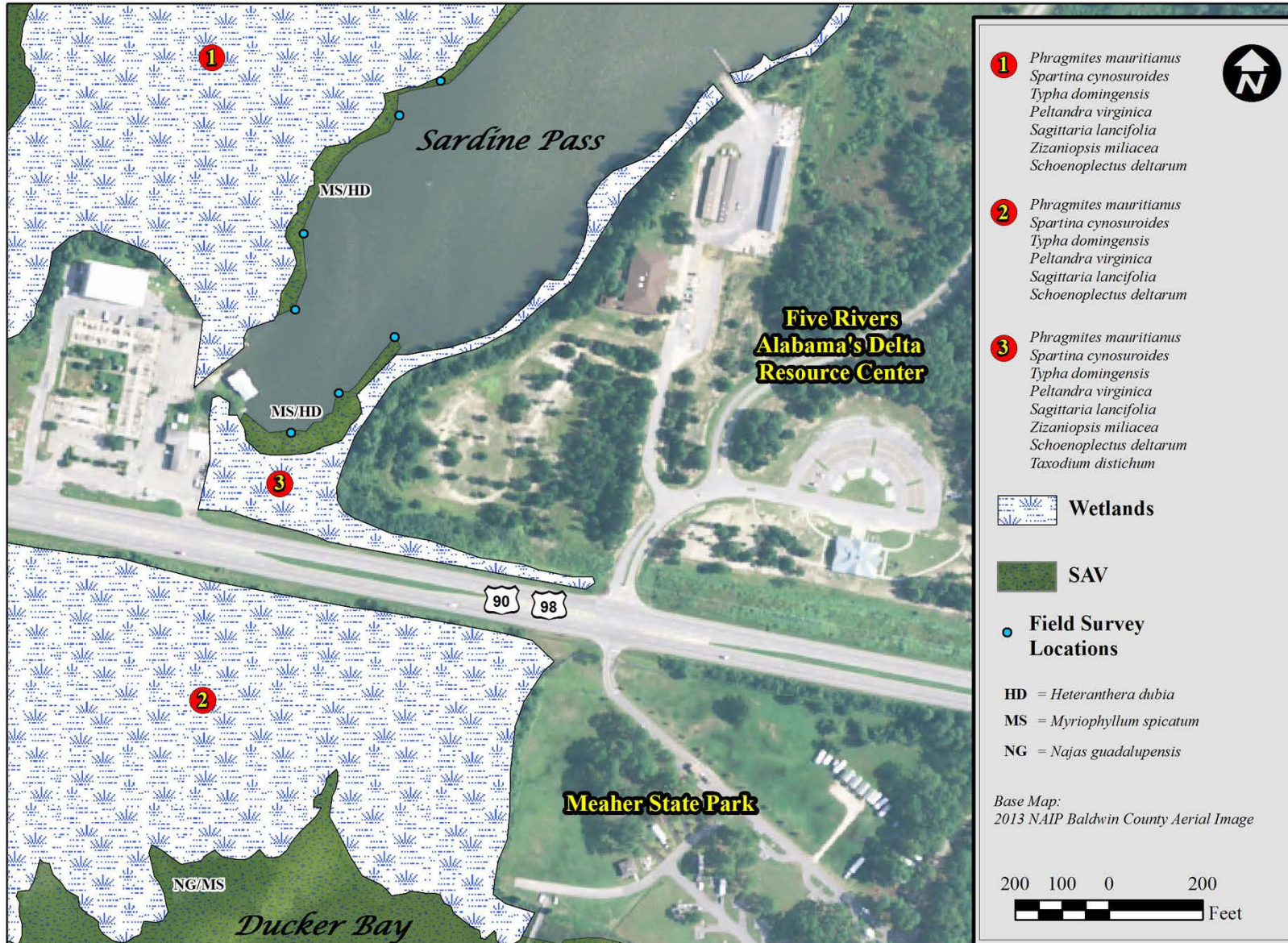


Figure 14. Habitat Map for East Justins Bay and Vicinity

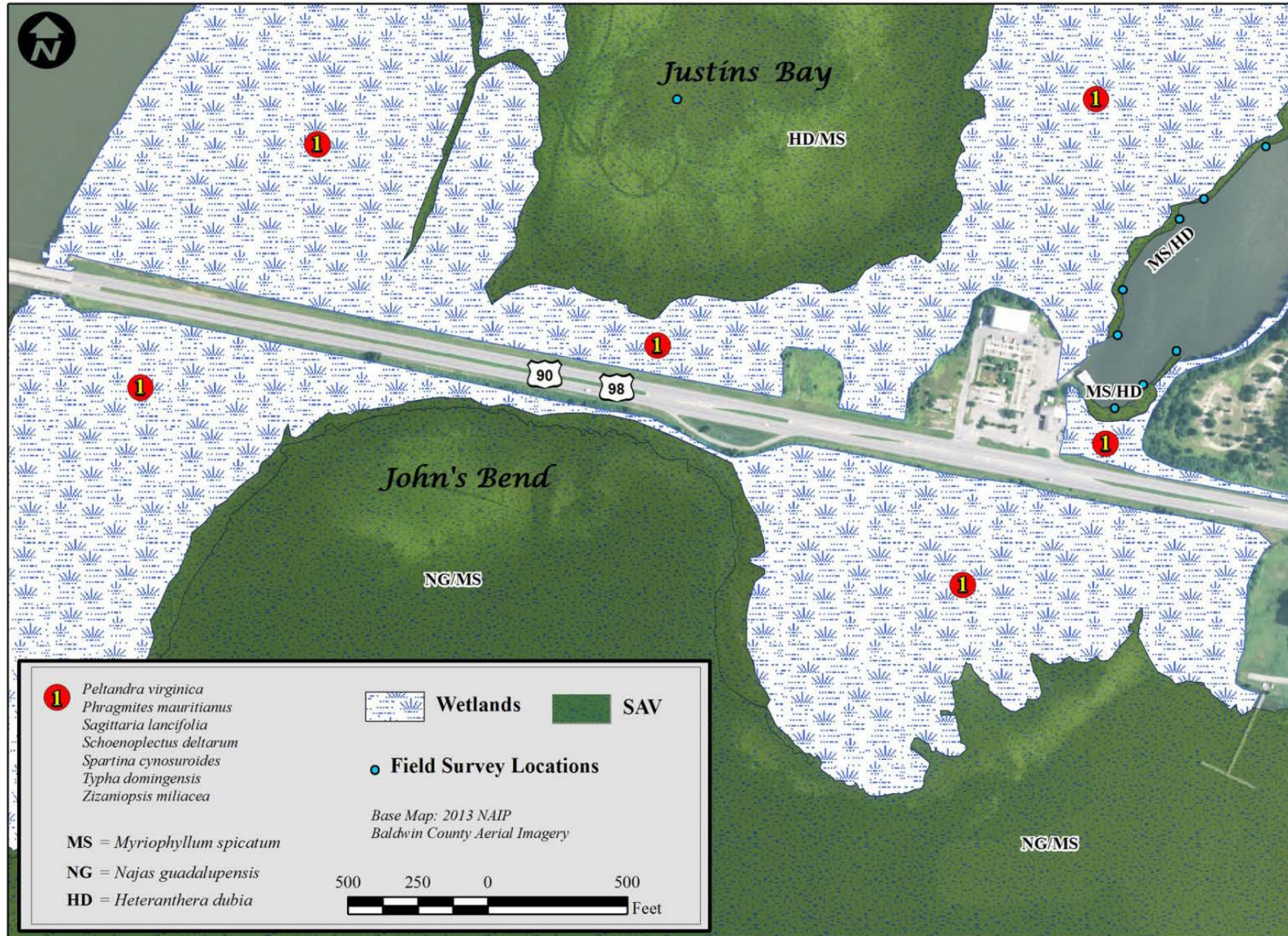


Figure 15. Habitat Map for Justins Bay and Vicinity

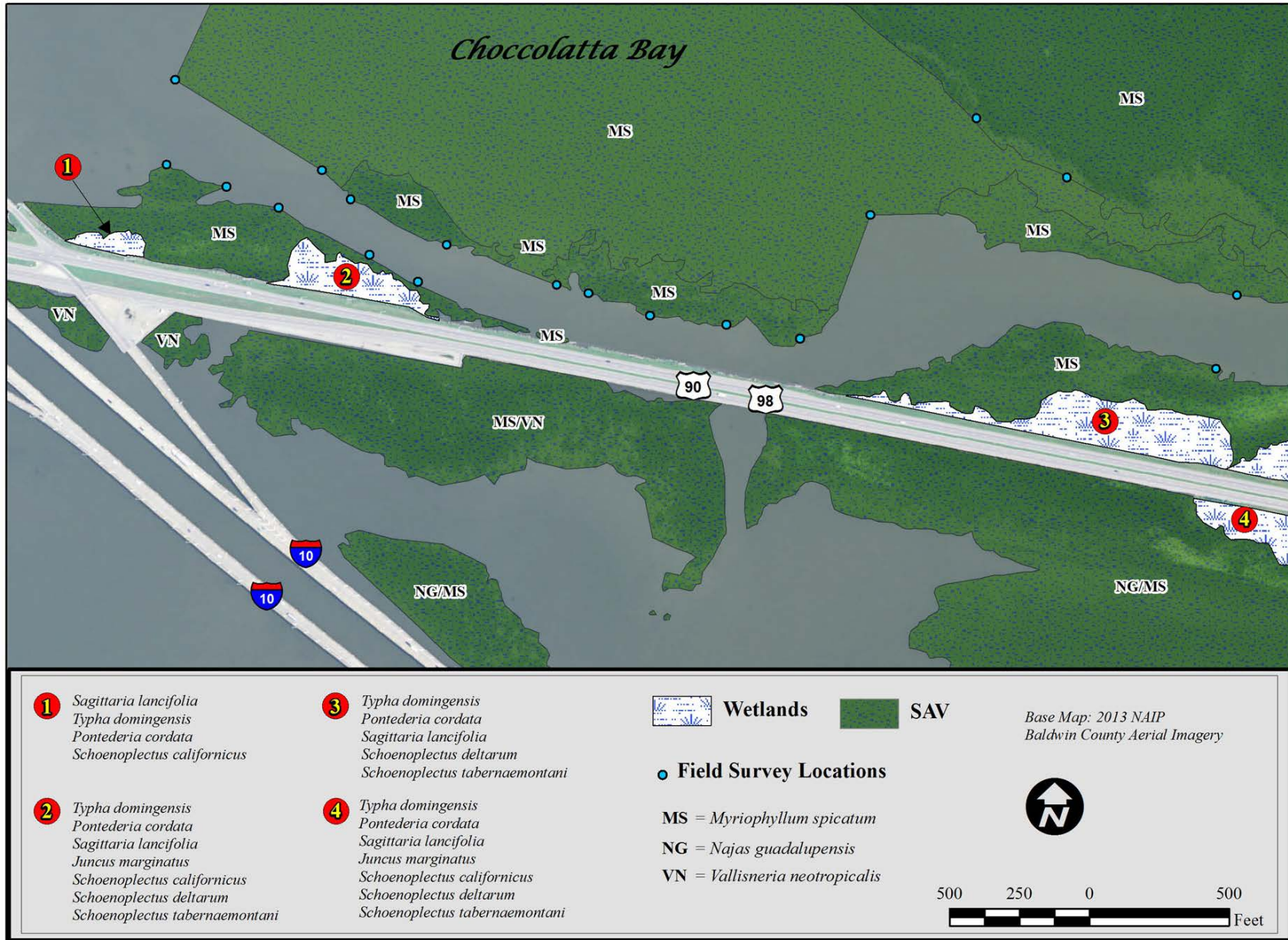


Figure 16. Habitat Map for Choccolatta Bay and Vicinity

4.1 Causeway Right-of-way

The maintained right-of-ways adjacent to the Causeway are dominated by numerous weedy species characteristic of disturbed habitats. Grasses (Poaceae) are particularly common and many species are non-native taxa specifically introduced as roadside plantings including Bermudagrass (*Cynodon dactylon*), Bahiagrass (*Paspalum notatum*), perennial ryegrass (*Lolium perenne*), centipedegrass (*Eremochloa ophiuroides*), and St. Augustine grass (*Stenotaphrum secundatum*). Other weedy, native herbaceous plants include Virginia pepperweed (*Lepidium virginicum*), buttonweed (*Diodia virginiana*), frogfruit (*Phyla nodiflora*), and Carolina pony's foot (*Dichondra carolinensis*).

The invasive Torpedograss (*Panicum repens*) is particularly widespread in lower elevational areas with wet soils. Other non-native grasses present along the Causeway include little quaking grass (*Briza minor*), Vasey's grass (*Paspalum urvillei*), annual rabbit's foot grass (*Polypogon monspeliensis*), Indian goosefoot grass (*Eleusine indica*), and Johnsongrass (*Sorghum halepense*). Although its native status is not currently well understood along the northern Gulf Coast, common reed (*Phragmites mauritianus*) forms extensive monotypic stands along the disturbed edges of the right-of-ways and extend outward into the adjacent natural marshes.

4.2 Wetlands

Terminal portions of the Mobile and Tensaw Rivers branch into a series of distributary channels, emergent delta lobes, levees, and interdistributary bays with shallow depths (Crance, 1971). Low marshes occupy shallow flats surrounding the bays and watercourses of the study area. Sedges, grasses, and rushes are typically the dominant vegetation of these marshes, and scattered shrubs and small trees occur in higher spots or ridges (Stout et al., 1982).

The 2014 distribution of wetlands is presented in Figure 13 through Figure 15, along with the dominant species occurring in these areas. Wetlands occur at all three alternative study sites, north and south of the Causeway. These wetlands are predominantly herbaceous, low marsh habitats.

Marsh vegetation is predominantly comprised of green arrow-aram (*Peltandra virginica*), pickerelweed (*Pontederia cordata*), common reed (*Phragmites mauritianus*), bulltongue (*Sagittaria lancifolia*), bulrush (*Schoenoplectus* spp.), big cordgrass (*Spartina cynosuroides*), cattail (*Typha domingensis*), and southern wild-rice (*Zizaniopsis miliacea*).

A forested wetland occurs on the south side of Shellbank River. This area has woody species such as black willow (*Salix nigra*), Chinese tallowtree (*Triadica sebifera*), loblolly pine (*Pinus taeda*), saw greenbrier (*Smilax bona-nox*), wax myrtle (*Morella cerifera*), and yaupon (*Ilex vomitoria*).

4.3 Submerged Aquatic Vegetation (SAV)

SAV is found throughout the lower delta and upper bay in shallow bays and flats, small tributaries, and along river margins (Baldwin 1957, Stout et al. 1982, Barry A. Vittor and

Associates 2010). Approximately 20 species are known to occur in the study area, often in mixtures of several species. Eurasian watermilfoil (*Myriophyllum spicatum*), wild celery (*Vallisneria neotropicalis*), southern naiad (*Najas guadelupensis*), water stargrass (*Heteranthera dubia*), and coon's tail (*Ceratophyllum demersum*) are typically the most prevalent species. Their distributions vary from year to year and seasonally. The Causeway may function as a breakwater that has facilitated the spread of the exotic Eurasian watermilfoil on its north side (Martin and Valentine, 2012).

SAV was found to occur within the wetlands at all four study sites, both north and south of the Causeway. During the vegetation survey, a total of seven SAV species were identified, with each species occurring both north and south of the Causeway. The invasive species Eurasian watermilfoil is the most prevalent species across the study area. Wild celery is more prevalent on the south side of the Causeway.

4.4 Resident Fauna

A literature review was performed to assess distributions of animal species of concern in upper Mobile Bay and the lower delta, including benthic and epibenthic invertebrates, fish, reptiles and amphibians, and mammals. Benthic invertebrates include infauna and epifauna that are adapted to burrow into and through soft sediments or crawl across sediment surfaces or other habitats such as detritus, algae, and plants. Benthic invertebrates are ecologically important, providing a trophic link to higher order consumers such as fish and birds. Benthic populations in the lower delta and upper bay are dominated by species adapted to the fluctuating physical environment. Due to variable hydrology, sedimentation, and currents, community structure in soft sediments is spatially and temporally patchy. Abundant benthic invertebrates in the study area include segmented worms, clams, snails, and insect larvae (Valentine and Sklenar, 2006). The Mobile-Tensaw Delta Hydrological Impacts Study (Valentine and Sklenar, 2006) found that higher salinity locations south of the Causeway had greater species richness and invertebrate density than sites north of the Causeway.

Studies evaluating motile invertebrates and fishes of coastal Alabama and the study area include Swingle and Bland (1974), Shipp (1979), Valentine and Sklenar (2006), Rozas et al. (2013), and others. Assemblages include estuarine and freshwater fishes and invertebrates, with assemblages changing seasonally due to salinity and other factors. Abundant invertebrates include grass shrimp (*Palaemonetes* spp.), blue crab (*Callinectes sapidus*), brown shrimp (*Farfantepenaeus aztecus*), and white shrimp (*Litopenaeus setiferus*). Abundant fishes include Gulf menhaden (*Brevoortia patronus*), Atlantic croaker (*Micropogonias undulatus*), bay anchovy (*Anchoa mitchilli*), spot (*Leiostomus xanthurus*), tidewater silverside (*Menidia beryllina*), and rainwater killifish (*Lucania parva*). The Alabama shad (*Alosa alabamae*) is the only anadromous clupeid species in Alabama. Adults live in salt water but migrate upstream into free-flowing rivers to spawn. In the past, Alabama shad inhabited most Gulf Coast drainages from the Mississippi River east to the Suwannee River in Florida. During the last 20 years, inland distribution and abundance have greatly declined due to the construction of dams, which block annual spawning runs, and to water pollution and habitat alteration. The largest remaining population is in the Apalachicola River system below Jim Woodruff Dam. Each year, shad still enter the Choctawhatchee and Conecuh river systems in southeastern Alabama to spawn. Recent Mobile

basin records are limited to collections of single adults in the Alabama River below Claiborne (1993) and Millers Ferry (1995) locks and dams (Mettee et al., 1996). This species is under consideration for listing as threatened under the Endangered Species Act (Steven J. Rider, personal communications, October 2015).

Many of the most abundant nekton consist of important forage and fishery species. Strong patterns of seasonality of nekton assemblages in the study area coincide with seasonal recruitment of juveniles into the estuary. Rozas et al. (2013) found that recruitment by transient fishery species appear to drive the nekton assemblage below the Causeway and in lower delta areas with hydrologic connection to the upper Mobile Bay, whereas estuarine-resident species dominated the nekton assemblage at Choccolatta Bay. Breaching the Causeway to create direct access to Choccolatta Bay and other areas on the north side of the roadway is likely to increase the use of nursery habitats by estuarine-dependent, transient fishery populations (Rozas et al., 2013).

In addition to impeding migration of larval, juvenile, and adult stages of benthos and nekton, the Causeway may have altered natural production and nutrient exchange between the delta and the upper bay. Goecker et al. (2009) found differences in stable isotope signatures comparing locations north and south of the Causeway, suggesting that natural energy transference and trophic function have been altered since construction of the roadway.

Three federally protected species occur in the study area. The Alabama red-bellied turtle (*Pseudemys alabamensis*) and West Indian manatee (*Trichechus manatus*) are endangered, and the Gulf sturgeon (*Acipenser oxyrinchus desotoi*) is listed as threatened.

Alabama red-bellied turtles in the delta represent a single population with concentrations of individuals around Graving Island and along the Causeway near Meaher State Park (Nelson and Turner, 2004). The species is primarily an inhabitant of freshwater and brackish streams, rivers, and shallow bays. The turtles forage on SAV, which comprises a majority of the adult diet. Red-bellied turtles nest on sand banks along the Causeway, and a large number of the turtles are killed each year by vehicular traffic (Nelson et al., 2009).

West Indian manatee sightings in Alabama have been increasing in recent years as they extend their presence farther west of Florida in the warmer months. Manatees are opportunistic herbivores, consuming SAV in marine, estuarine, and freshwater systems. Manatees occur in the vicinity of the Causeway in surrounding bays and waterways. Recent sightings in the project area are shown in Figure 17.

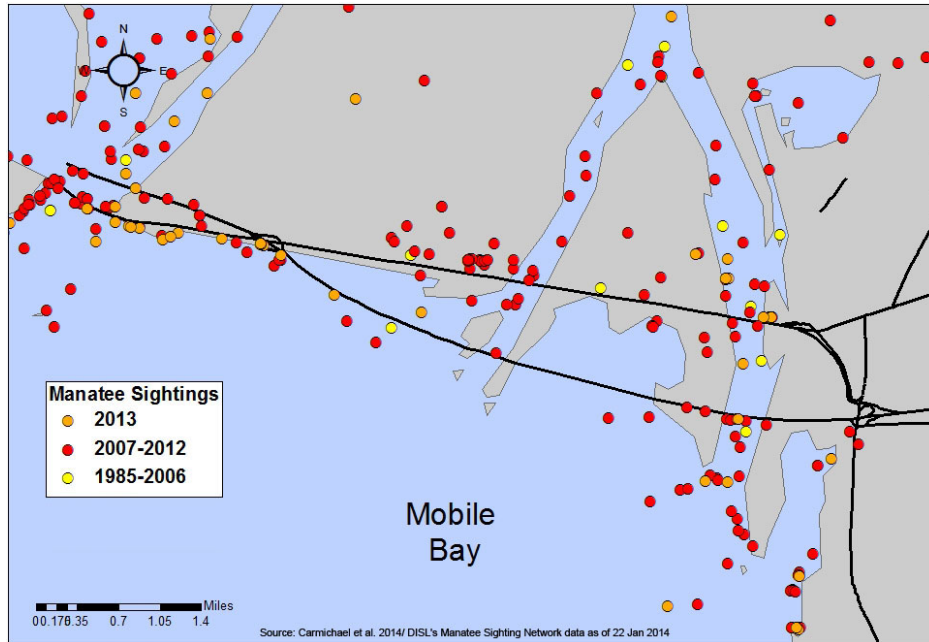


Figure 17. Manatee Sightings in Upper Mobile Bay

The Gulf sturgeon is an anadromous fish, with reproduction occurring in fresh water. Sturgeons are thought to return to breed in the river system in which they hatched. The fish initiate migration out of river drainages in the fall. Most sturgeon feeding takes place in the Gulf and its estuaries, where active foraging replaces depleted energy reserves. Gulf sturgeons feed on a variety of benthic food organisms, including isopods, amphipods, lancelets, mollusks, crabs, grass shrimp, and marine worms (Mason and Clugston, 1993). Adult sturgeons over the age of 5 or 6 years overwinter in marine waters. Juveniles may remain in the estuary during winter to feed (Fox and Hightower, 1998). Genetically distinct subunits of Gulf sturgeon have been identified throughout the Gulf of Mexico (Stabile et al., 1996). The Pascagoula and Pearl Rivers support a western group, distinct from the eastern assemblages of the Escambia, Yellow, Choctawhatchee, and Apalachicola river drainages (Dugo et al., 2004). While Gulf sturgeon may be present in Mobile Bay and the rivers of the Mobile-Tensaw Delta, the Mobile River basin is not known to support a breeding sub-population and is not designated as Gulf Sturgeon Critical Habitat. However, since the species is present in the Mobile River, Gulf sturgeon would need to be considered during consultations due to its status as threatened under the Endangered Species Act.

5.0 IDENTIFICATION OF ALTERNATIVES

5.1 Purpose

The potential design alternatives to restore the hydrology along the Mobile Bay Causeway included preparing conceptual level designs showing areas of the Causeway that could be modified to allow for water movement (opened) between Mobile Bay and Choccolatta Bay, Justins Bay, and Shellbank River. During the construction of the Causeway, in order to create the roadway embankment, materials were dredged from the north side of the Causeway and placed as fill materials along the roadway alignment. In general, the basis of design for locating and sizing the openings included analyzing the existing topography north and south of the Causeway and providing connections that mimic the natural terrain in nearby areas.

5.2 Design Limitations

The intent of this study was to provide basic design alternatives that could be used to coordinate modeling of proposed conditions, define biological impact areas, and estimate costs for each alternative. Through a process that includes several iterations of design, modeling, and impact analysis, the design alternatives could be modified to provide a balance between restoring hydrology, understanding biology impacts, developing construction costs, and other key goals that could be determined through further analysis.

This study was limited to preparing the initial design alternatives, associated hydrology analysis (modeling), and a general biology evaluation. The study did not optimize the designs. The design alternatives should be considered preliminary concepts only. Additional iterations are required to refine the design and will need to be performed for areas where projects may be implemented.

During the process of preparing the alternative designs, a cursory review of the available record drawings was performed to determine major utilities within the Causeway right-of-way. This did not include using utility location services. Additional studies and planning shall include research into what utilities are located within the project areas, locations, and the best solution to relocate each.

The alternative designs formulation did not include performing a geotechnical evaluation. The materials underlying the design locations are assumed to be suitable for the construction of bridge structure foundations based on the existence of similar structures previously constructed nearby (e.g., Causeway bridges and I-10). The length of foundation piers has been assumed to be 62 feet; however, actual required depths may be much deeper.

5.3 Restoration Constraints

A number of planning constraints need to be considered for any future implementation of hydrological restoration along the Causeway. The majority of these constraints fall into the following broad categories: land ownership, utilities, structural engineering, and permitting. Several project constraints may be encountered if it is decided to move forward with

hydrological restoration along the Mobile Bay Causeway. These constraints include, but are not limited to, public and private land ownership, utility infrastructure, structural engineering of culverts and bridges, and permitting.

5.3.1 Land Ownership

Ownership of the potential restoration locations will have direct impacts on the ultimate feasibility of any of the potential restoration locations, as potential hydrologic restoration may not be compatible with adjacent or regional land uses. Management plans for publicly owned land should be reviewed to determine opportunities and restrictions of potential restoration locations. Privately owned land may require negotiations for purchase of land or may require a conservation easement.

5.3.2 Utilities

With regard to utilities, there is not a central source of utility infrastructure information along the Causeway. The lack of accessible information is a constraint that will need to be addressed in looking at potential alternatives, as numerous agencies and entities may currently have their own infrastructure. This being said, the following limited information has been compiled based on telephone and email communications with local agencies:

- Alabama Power: The right-of-way along the north side of the Causeway contains raised, high voltage electrical transmission lines from Alabama Power.
- Mobile Area Water and Sewer System (MAWSS): Provides sewer service to the portion of the Causeway west of the Interstate-10 (I-10) interchange, however hookup to the sewer service is not mandatory under local codes. East of the interchange is currently serviced exclusively by septic systems and individual sewage packing plants. MAWSS has historically provided water service to the area of the Causeway west of the I-10 interchange.
- Spanish Fort Water System: Has historically served the area east of the interchange. However, in an agreement finalized in 2001, MAWSS began laying a water main the entire length of the Causeway to Spanish Fort to supplement the Spanish Fort water supply (USACE, 2001).
- The City of Spanish Fort: Has no utilities located along the Causeway.
- Alabama Department of Transportation (ALDOT): Does not have a GIS system or maps of existing utilities along the State Right-of-Way.
- Alabama One Call Location Center: Will send someone to locate utilities in a specific location when excavation work is to occur.
- Baldwin County Sewer Service: Provides a PDF map of service area on their website, but the information is not in a useable format for geographic information system (GIS).
- Fairhope Utilities: Does not have utilities along the Causeway.
- Other Utilities: Riviera Utilities, Mobile Gas, ATT Transmission, Daphne Utilities, Interstate Fibernet, Level 3 Communications, MCI Communications, Madison River Communications, Quest Communications, and Southern Light LLC have been contacted. At the time of this writing, no information regarding the utilities along the Causeway has been provided.

5.3.3 Structural Engineering

It should be noted that an independent structural engineering investigation was not performed as part of this study. The information collected from the 2001 USACE report presented below represents the opinions, assumptions, computations, and conclusions made at that time by the USACE. These opinions, assumptions, computations, and conclusions should be reassessed for projects that are advanced beyond the feasibility study phase.

The USACE (2001) report presented construction options including constructing bridges and/or culverts at selected locations along the Causeway. During their formulation process, they discussed whether to construct bridges or a series of culverts (similar to those constructed by the ALDOT in the 1980s). However, in subsequent discussions between the USACE and ALDOT, it was determined that it is impractical to construct a series of culverts due to difficulty in establishing a suitable foundation; therefore, the USACE dropped culverts from consideration in the 2001 report.

The USACE report describes the Corps Engineering Division computations to establish a 6-ft deep channel in the four alternative areas and costs to construct bridges over these channels. ALDOT indicated that the bridges would need to have low clearance in order to keep construction costs down and to meet approach grade requirements. Therefore, there may be some restrictions to the size of the vessels that could navigate under these bridges.

Bridges were selected to be evaluated at the alternative locations as part of this project. For a given roadway length, bridges with piers every 60 feet provide significantly more cross sectional area for the flow of water in comparison to culverts with walls every 14 feet (typical width of large culverts). Bridges having a greater amount of cross sectional area would provide for better exchange of water between the water bodies when all other conditions remain the same (e.g., roadway length, difference in water surface elevations, etc.).

5.3.4 Permitting

The key agencies participating in the permitting process should be identified as early as possible. Engaging these agencies at the start of a restoration project will be beneficial and likely critical to the project's success. A summary of the permits and clearances that may be required for a restoration project along the Causeway is provided in Table 6. These permits and clearances are general requirements that should be considered. Some of the listed items may not be applicable. Additional requirements relating to the listed permits may be identified during the planning phase through coordination with the resource agencies (e.g., additional studies).

Table 6. Potential Environmental Permits and Clearances for Mobile Bay Causeway Restoration Projects

Agency	Permit / Clearance	Phase	Schedule	General Comments
Federal				
Advisory Council on Historic Preservation (ACHP)	National Historic Preservation Act (NHPA)	--	--	Delegated authority to Alabama Historic Commission (AHC).
USEPA - Region 4	Section 401/404, Clean Water Act (CWA)	--	--	USEPA has delegated the authority to the USACE and Alabama Department of Environmental Management (ADEM) for CWA; but retains veto power for issued permits.
	Coastal Zone Management Act (CZMA)	--	--	Delegated authority to the ADEM.
National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) - Southeast Region	Section 7, Endangered Species Act (ESA)	Pre-Construction	30 to 60 days	Review is done in conjunction with USACE permitting. Previous consultation with NMFS can assist with USACE permitting review and may include a survey or assessment submitted as part of consultation.
	Marine Mammal Protection Act (MMPA)			
USACE - Mobile District	Section 404 CWA - Individual Permit	Pre-Construction	8 to 12 Months	For activities involving impact to wetlands or Waters of the United States an Individual Permit is required. It is anticipated that these project would not qualify for neither a Nationwide permit nor a General Permit, due to the levee of activities and dredge removal. The Individual Permit also includes a 30-day public comment period and multiple agency consultations/coordination. A mitigation plan would need to be submitted as part of the permit application.
	Section 10 Rivers and Harbors Act (RHA) - Individual Permit	Pre-Construction	8 to 12 Months	Required due to dredging, construction and filling of navigable waters of the United States; Section 10 review would be done in conjunction with the Individual Permit for Section 404 and only one permit would be issued.
United States Coast Guard	Section 10 Rivers and Harbors Act (RHA) - Individual Permit	Pre-Construction	8 to 12 Months	Coordinating Agency on USACE permit. Will be brought in as commenter and for review by USACE.
United States Fish and Wildlife Service (USFWS)- Southeast Region	Section 7, ESA, Federally Protected Species	Pre-Construction	60 to 90 days	Review is done in conjunction with USACE permitting. Previous consultation with USFWS can assist with USACE permitting review and may include a survey or assessment submitted as part of consultation. Due to the likely presence of the endangered Alabama red-bellied turtle, coordination may be longer if species specific surveys are necessary. Additionally, monitoring may also be requested.
	Migratory Bird Treaty Act (MBTA)			
	Fish and Wildlife Coordination Act			

Table 6. Potential Environmental Permits and Clearances for Mobile Bay Causeway Restoration Projects

Agency	Permit / Clearance	Phase	Schedule	General Comments
	Golden and Bald Eagle Protection Act			
State				
Alabama Department of Environmental Management (ADEM)	Section 401 Water Quality Certification	Pre-Construction	30 to 60 days	ADEM is a coordinating agency with USACE permit; and certification is done concurrently with USACE Permit.
	Coastal Section Office, Individual Coastal Use Permit or Coastal Use Consistency Statement	Pre-Construction	8 to 12 Months	For activities involving impact to wetlands or water resources within the Coastal Zone Management Area a coastal use permit is reviewed in conjunction with the USACE permit. The coastal use permit is submitted to ADEM, with copies to USACE. ADEM typically takes the lead on the project and review for coastal use consistency is done concurrently with the Section 401/404/10 permit. May also include coordination with ADCNR.
ADCNR	Individual Coastal Use Permit or Coastal Use Consistency Statement	Pre-Construction	8 to 12 Months	ADCNR (State Lands Division, Coast Section, Alabama Coastal Area Management Program Office) may request to be a coordinating agency with ADEM on the Coastal Use Permit. If engaged, coordination occurs concurrently with ADEM permit review.
	Section 7, ESA (State Protected Species)	Pre-Construction	30 to 60 days	Review is done in conjunction with USACE permitting. Previous consultation with ADCNR can assist with USACE permitting review and may include a survey or assessment submitted as part of consultation.
AHC	Section 106 of the NHPA	Pre-Construction	30 to 60 days	Review is done in conjunction with USACE permitting; Previous consultation with AHC and State Historic Preservation Officer (SHPO) can assist with USACE permitting review and may include a cultural resource survey or assessment submitted as part of consultation.

5.4 Alternatives Formulation Results

For a given length, bridges allow for more hydraulic conductivity compared to culverts, and thus bridge structures were selected at the potential openings for the purposes of design layout, cost estimations, and hydrology analysis. For this study, the design of the bridges was assumed to be very similar to that of the existing bridge located where the Causeway crosses the Apalachee River, which consists of two bridges, one for each direction of traffic. The foundation of each bridge consists of three piers that support a main reinforced concrete beam. These foundation elements are spaced approximately 60 feet on center along the length of bridge. Five precast-prestressed concrete girders rest on a foundation main beam and span the 60 feet between each foundation. A cast-in-place reinforced decking slab with guard rails (traffic barrier) rest on top of the girders.

The potential design alternatives include transition areas adjacent to the beginning and end of the bridge structures for each direction of the travel at the Choccolatta Bay and Justins Bay locations. Each potential transition is 400 feet in length and consists of an earthen embankment designed to create vertical curves and a 3% incline that results in a roadway elevation change of 12 feet. At the toe of the potential embankment, a maintenance access road is included to allow for access to beneath the roadway deck.

5.4.1 Choccolatta Bay

The Choccolatta Bay design alternative (or hypothetical opening) includes providing an open water connection between Mobile Bay and Choccolatta Bay along a length of 2,508 feet. The Choccolatta design alternative is shown on Figure 18. (Appendix C includes higher resolution alternative design sheets). The west edge of this design begins east of the existing seawall approximately 1,000 feet east of the westbound U.S. Highway 98 (Causeway) onramp to the westbound I-10. The design area extends east approximately 3,400 feet. The design requires the removal of the existing concrete culverts, consisting of six box structures that are each 6 feet wide and 8 feet high. Per The Board of Water and Sewer Commissioners of the City of Mobile, Alabama MCW Project No. M5712-2028 Spanish Fort Water Interconnection record drawings, an existing 20-inch high-density polyethylene pipe (HDPE) is located approximately 63 feet north of the north edge of pavement at a depth of approximately 45 feet below mean lower low water (MLLW); therefore, project construction within the assumed design area would most likely not impact the water line (relocation would not be required). There are fiber optic conduits located various distances (approximately 5 to 15 feet) north of the existing edge of pavement at depths assumed to be shallow. The fiber optical lines would require relocations to be supported by hangers attached to the bridge structures. Also located north of the existing roadway are overhead power lines and associated poles. The poles would need to be replaced or enhanced to withstand the open water conditions.

5.4.2 Justins Bay

The Justins Bay design alternative includes providing an opening of approximately 1,164 feet between John's Bend and Justins Bay. The Justins Bay design alternative is shown on Figure 19 (Appendix C includes higher resolution alternative design sheets). The aforementioned Spanish Fort Water Interconnection record drawings indicated that the 18-inch waterline located in this

design area is 32 feet north of the edge of pavement at a shallow depth of about 4 feet (constructed using open cut method). Similar to Choccolatta Bay design alternative, this area has fiber optic conduits that require relocation and overhead power lines that require upgraded poles. No information was found in the review of record drawing relating to force main sewer pipes; however, this type of utility may be located in the design area and require relocation. Based on the aforementioned Spanish Fort Water Interconnection record drawings, a privately owned parcel (RP 413 PG. 923) with an area of 1.01 acres is located along the eastern limits of the design alternative area (Station 483+00).

5.4.3 Shellbank River

The existing conditions at the Shellbank River design alternative area differs from the Choccolatta Bay and Justins Bay design alternatives. The Shellbank River design area is occupied by a connecting on-ramp and residential access road in addition to the Causeway. The design alternative includes providing an opening of approximately 154 feet connecting the Shellbank River on the north side of the Causeway to the Shellbank River on the south side of the Causeway. The Shellbank River design alternative is shown on Figure 20 (Appendix C includes higher resolution alternative design sheets). The design includes the elimination of the access road and three bridge structures; two for the Causeway and one for the west bound on-ramp to the Causeway. Similar to the Justins Bay design alternative, various utilities would require relocation including the waterline main, fiber optic conduits, force main sewer, and overhead power line poles.

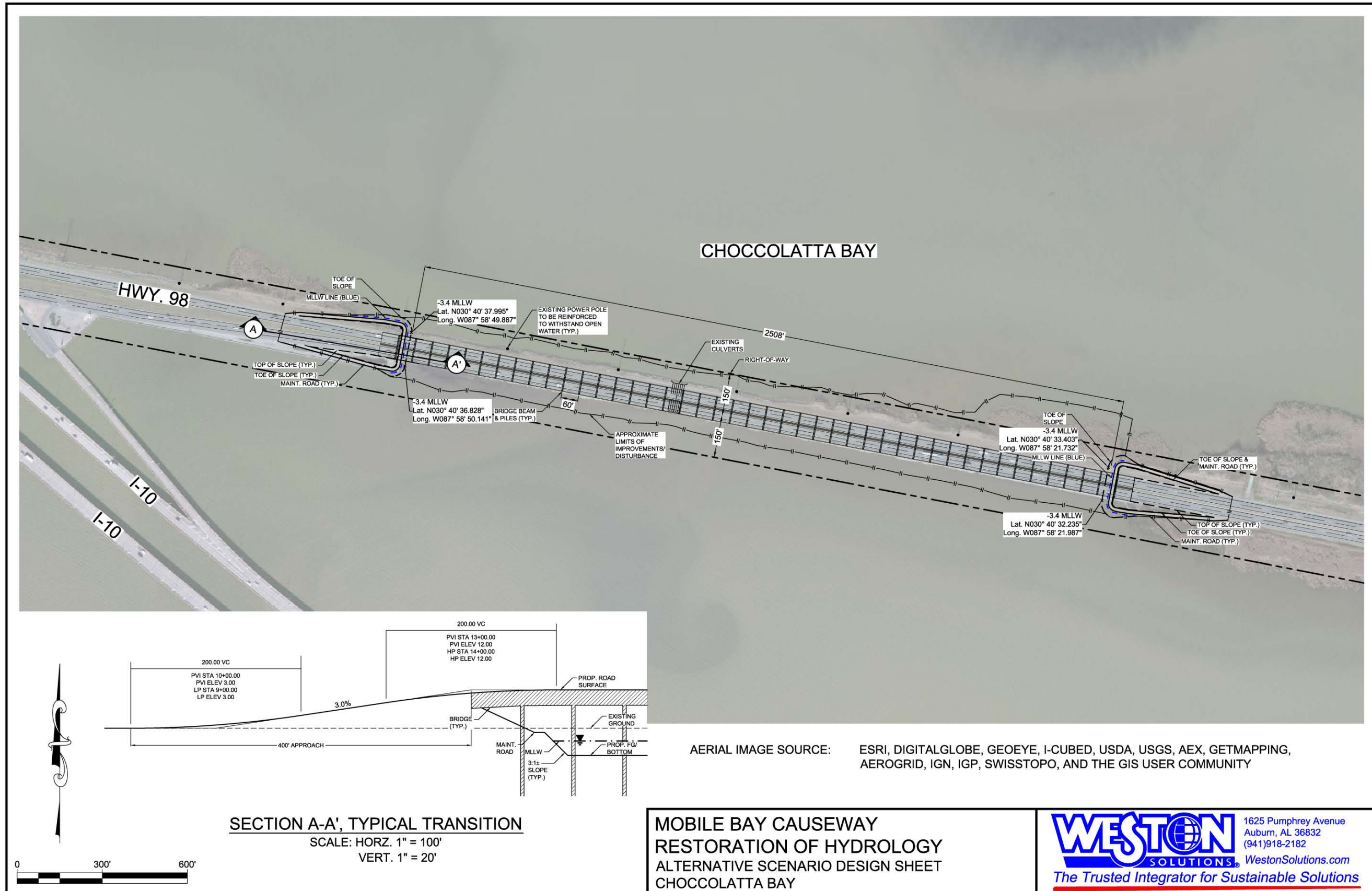


Figure 18. Alternative Design – Choccolatta Bay

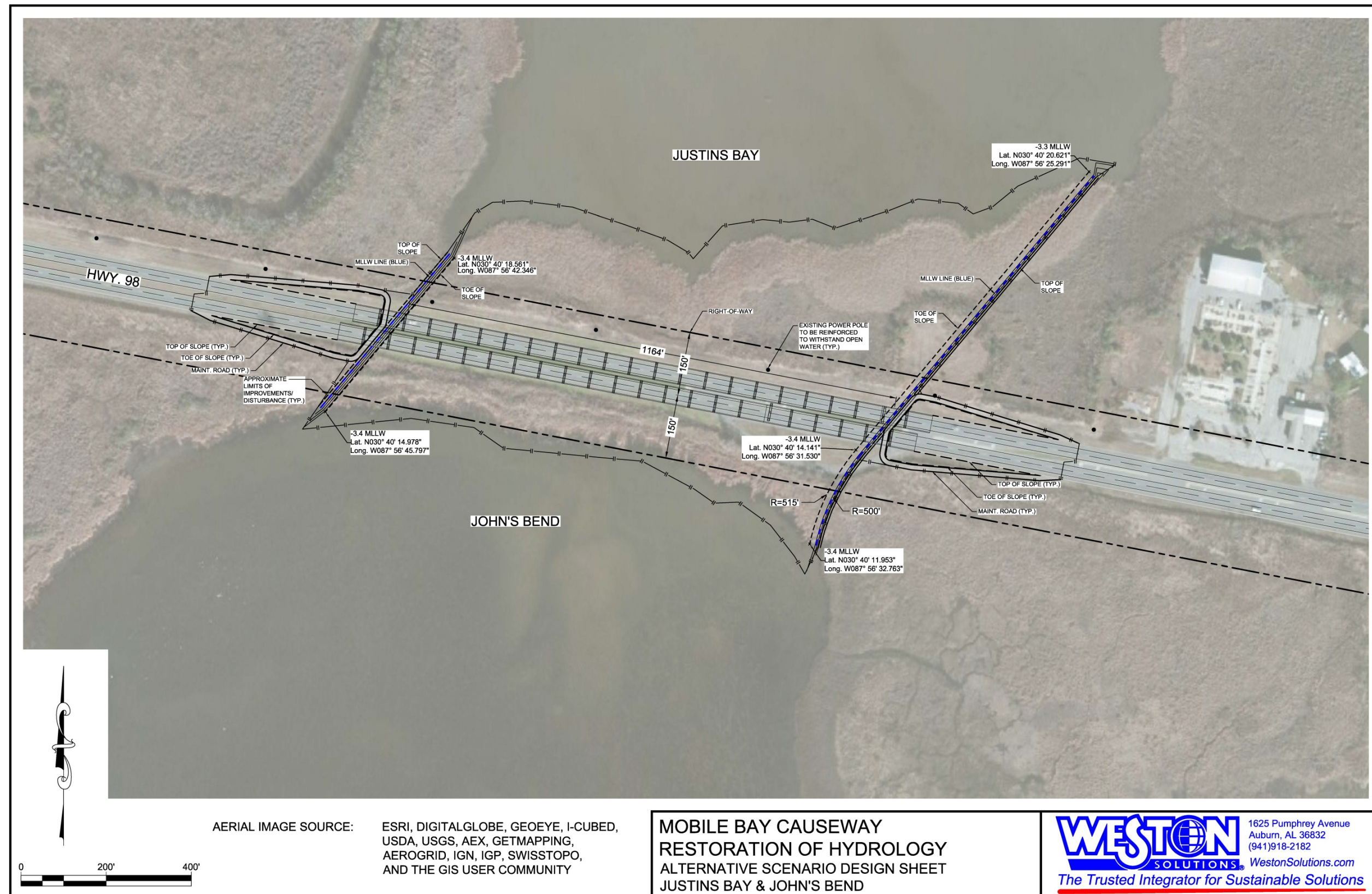


Figure 19. Alternative Design – Justins Bay

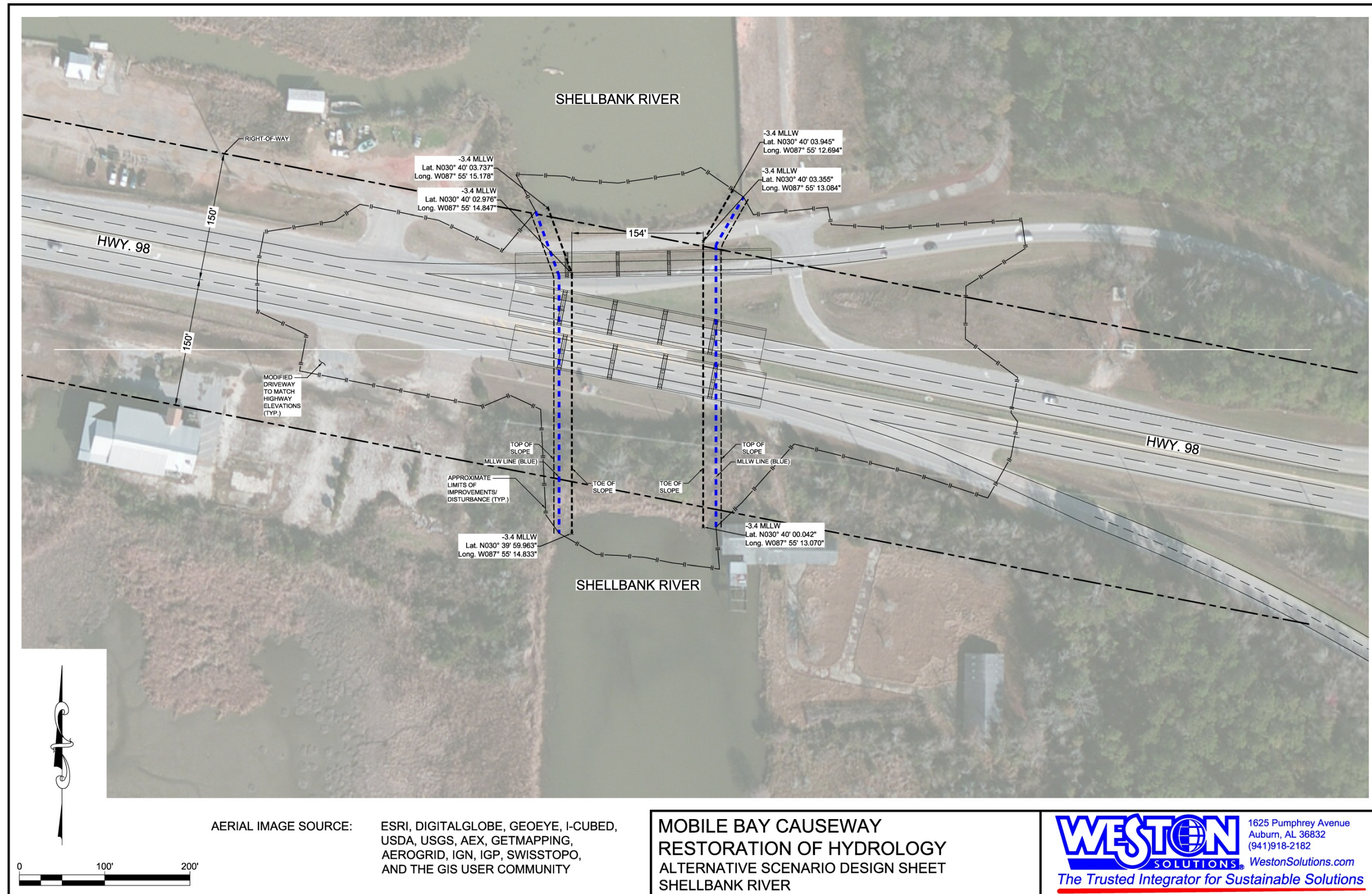


Figure 20. Alternative Design – Shellbank River

5.5 Cost Estimates

Cost estimates were prepared for each design alternative primarily based on the estimated quantities of construction materials and associated estimated unit costs. The design alternatives were prepared using computer-aided drafting and design (CADD) software that allows the user to accurately measure lengths, areas, and volumes. The unit costs are based on research construction cost reports, reasonable time and materials costs to perform work (e.g., earthwork excavation), and best professional judgment leaning toward being conservative (more costs rather than less). The costs associated with concrete were estimated using the Florida Department of Transportation (FDOT) report entitled *Structural Design Guidelines, Chapter 11 Bridge Development Report Cost Estimating* (FDOT, 2012). Additional costs for miscellaneous items such as mobilization, demobilization, traffic control, and erosion control were estimated based on the general scope of each and the associated reasonable costs to perform each. The cost estimates were compared to historic costs (per square foot) as a means to verify the cost was reasonably estimated.

The quantities of concrete required to construct the bridges associated with the design alternatives were the major portion of the overall estimated construction costs. The structural design of the bridges in this study was based on assuming a similar design for each as that of the Causeway structure located at the crossing of the Apalachee River. Field reconnaissance was performed to collect data on the configuration and component sizes of the existing bridge, and those data were incorporated into the layout of the design alternatives. The design alternative bridge cross-sections were accurately sketched using CADD software (Figure 21). The software was used to calculate the area of each component. By knowing the area and length, the volume of each member could be calculated (converted to cubic yards). The numbers of members required for each bridge component (e.g. bridge substructure and decking per span) were tallied to determine volume of concrete for each component. These data were extrapolated to estimate volumes and costs associated with the bridge concrete construction for each location.

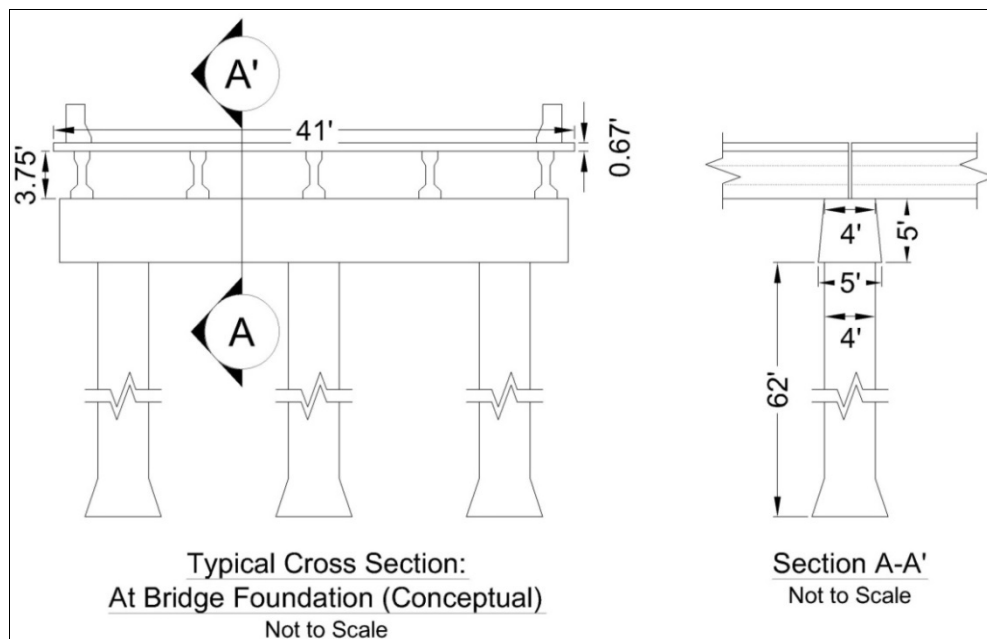


Figure 21. Alternatives Design Bridge Cross Section (Conceptual)

The quantity of earthwork materials associated with the excavation of the openings was another major item of the estimated construction costs associated with the design alternatives. The quantities of earthwork were calculated by using CADD software to prepare three-dimensional models of the existing and proposed conditions, in which the software compares the two models to accurately determine the volume difference. A small fraction of the excavation spoils will be used to construct the transition embankments (cut and fill), and the majority of the excavation spoils would be hauled off-site (cut and export).

The process of preparing the alternative designs and the associated cost estimates revealed that projects designed to provide connections across the Causeway could be constructed most efficiently, considering both costs and time, by closing both lanes of traffic in the construction area, as compared to diverting traffic to one side of the Causeway while the other is being constructed (i.e., single lane of travel in each direction in the construction area). However, the benefit of leaving the Causeway open for traffic to travel through the construction area, albeit at a reduced capacity, may outweigh the impact of the additional construction costs and duration. The determination of which method would be better is beyond the scope of this project. Geotechnical considerations may require that both lanes of travel be closed. The cost estimations were prepared for both scenarios, and summaries of costs are provided in the Table 7. More details of the cost estimate calculations, including quantities and units costs, are provided in Appendix D.

Table 7. Alternative Design Cost Estimates Summary

Location	Construction Costs	
	Scenario 1, No Through Traffic	Scenario 2, Single Lane of Traffic in Each Direction
Chocolatta Bay	\$24,656,000	\$28,967,000
Justins Bay	\$17,325,000	\$19,644,000
Shellbank River	\$3,900,000	\$4,558,000

The bridge construction costs make up the majority of the overall costs associated with opening the Causeway. To verify that the cost estimates prepared for the bridges were reasonable, comparisons to historical bridge construction costs were performed. Historical values for similar types of bridges (concrete deck/pre-stressed girder – simple span) range in costs from \$90 to \$145 per square foot (FDOT, 2014). The cost estimates prepared for the alternative designs were converted to costs per square foot, and a summary is provided in the Table 8. Both total cost per square foot and bridge only cost per square foot are shown with the bridge only cost per square foot excluding the costs not required with typical bridge construction, including earthwork, utility relocation, and property acquisition. The low cost shown in Table 7 is associated with construction with no through traffic in the construction, and the high is associated with keeping a single lane of traffic in each direction open during construction.

Table 8. Cost Comparison to Historic Values

Location	Historic Cost ¹ (per ft ²)	Total Project Cost (per ft ²)	Bridge Only Cost ² (per ft ²)
Chocolatta Bay	\$90 to \$145	\$109 to \$128	\$86 to \$100
Justins Bay	\$90 to \$145	\$149 to \$169	\$99 to \$119
Shellbank River	\$90 to \$145	\$114 to \$133	\$93 to \$112

Note 1: Source: FDOT, 2014

Note 2: Bridge only costs include all cost except earthwork, utility relocation, and property acquisition, as applicable.

The bridge only costs aligned with the lower end of the historic values. The major bridge component costs are from the concrete piers, and for this study, piers were assumed to be drilled on land with casing salvages. This may be accomplished by drilling piers prior to the excavation of the Causeway embankment. This on land method has significantly less costs in comparison to drilling over water with casing salvaged or drilling in water with permanent casings (\$600 per cubic yard compared to \$650 per cubic yard and \$1,000 per cubic yard, respectively). The total project costs align well with the historic values, with the exception of the Justins Bay alternative, which is slightly higher. The major construction item that resulted in the Justins Bay alternative to have a higher cost than the other locations is the additional excavation required per liner foot, and thus per square footage (wide area of upland area compared to other sites).

Based on the results of the comparison to historic values, the estimated costs prepared for this study appear to be reasonable for the stated assumptions and designs presented. Optimization of the design may be performed in the future, and doing so may affect the width of causeway openings (e.g., opening of half the size shown in this report may be 80 percent as effective and thus selected), which in turn may affect the bridge length and costs. During the planning and design phase of potential projects, additional details on the existing utilities and the relocation costs may differ from assumptions made in this study. The estimates do not include costs associated with on-site or off-site mitigation that may be required as part of the project implementation.

5.6 Construction Schedule

Included in this study was a preliminary, conceptual evaluation of the potential construction schedules associated with the hypothetical openings along the Causeway. The construction schedules presented here are based on the approximate time required to perform the key construction steps (e.g., pre-construction item, excavation (cut/fill) associated with approaches, excavation (cut/export) associated with dredging, and concrete work associated with the piers, substructures, and decking). In reality, project construction schedules may depend on many other factors not considered here, such as funding distribution, availability of materials, selected construction techniques, environmental permitting constraints, inclement weather, and other factors.

The earthwork (excavation/export) and the various concrete work will be the construction tasks that take a long period of time to complete. The other construction tasks could be performed in a relatively short time at the beginning/ending of construction project or concurrently with the construction of the earthwork and concrete. Prior to the construction of the bridge components, the construction contractor will perform the following: set up traffic control; mobilization;

associated demolition of existing roadway; and rerouting of existing wet and dry utilities, if applicable.

The assumed selected construction technique to construct the bridge components includes performing as much work as possible associated with the bridge construction prior to excavating the earth materials to open the Causeway. One crew would work on constructing the piers, and a second team would work on constructing the substructure beams above the piers starting at one end of the potential project location and working across the site. This includes first drilling and constructing the concrete piers from land. The pier crew would move to the next pier location and repeat the process while the second team constructed the associated substructure beam. The substructure beam crew would move to the next pier location and repeat the process, and the process would continue until all piers and substructure beams were completed. After the first two pier locations had adequate time to set up (typically 30 days), the materials around the piers would be excavated, to a depth of approximately 3.5 feet, and materials hauled off-site. A third crew (decking crew) would follow behind and set the precast concrete girders and construct the concrete decking. The precast, prestressed concrete girders would be placed to span the distance between the substructure beams (accessible from the land side opposite of the progression direction of the piers being constructed). The final structural component associated with the first bridge span would be the decking, which includes placing sheet metal down first to support a reinforced concrete slab (roadway). The road deck crew would then move onto the next span and repeat the process.

The assumed durations were used to estimate the total construction duration for each potential location based on the number of spans and whether or not both roadways directions would be constructed concurrently. Based on the assumptions regarding per task durations, the tasks performed to construct various components of the bridge require the longest duration (2 weeks per deck span). In order to estimate the total construction duration for the closed to all traffic scenario, the number of spans were multiplied by 2 weeks and combined with the preconstruction duration, the duration to construct two piers and substructures, and the final construction phase duration.

For the scenario of allowing a single lane of traffic to travel in each direction, the estimated construction duration is first doubled and then 4 weeks is added to allow time for an adequate, temporary retaining wall to be constructed. The summary of the estimated conceptual construction durations is presented in the Table 9.

Table 9. Construction Durations Summary

Potential Location	Construction Durations	
	Scenario 1*, No Through Traffic	Scenario 2*, Single Lane of Traffic in Each Direction
Chocolatta Bay	108 weeks	220 weeks
Justins Bay	65 weeks	134 weeks
Shellbank River	30 weeks	64 weeks

*Construction schedule conservatively assumes that work will be segmented to single spans (see the above-mentioned assumptions). It may be possible to segment work to multiple spans (e.g., pour decking concrete for two spans at once instead of one span) and significantly reduce the construction time frame (complete in approximately half the time).

6.0 EVALUATION OF POTENTIAL RESTORATION ALTERNATIVES

6.1 Hydrodynamic Modeling Effort Overview

Hydrodynamic modeling included in this study was performed by South Coast Engineers (SCE). The modeling included the preparation of a detailed report entitled, *Hydrodynamic Modeling Report, Restoration of Hydrology of Mobile Bay Causeway, Alabama*, and dated 7 October 2014 (Hydrodynamic Modeling Report) (SCE, 2014). The Hydrodynamic Modeling Report is provided as Appendix E and describes the hydrodynamic modeling activities completed as part of the CIAP AL-12 project aimed at investigating hypothetical restoration strategies for the Mobile Bay Causeway in Alabama.

The Hydrodynamic Modeling Report documents the steps taken to develop and validate a tidal circulation model for the study area, including field data collection and model hindcasting of the data collection period. The Hydrodynamic Modeling Report also provides an overview of the five restoration simulated alternative scenarios, their conditions and parameters, and their pertinent results. Simulation results are presented in a manner that addresses project goals, objectives, and performance measures identified in the project plan formulation.

Sections of the Hydrodynamic Modeling Report have been included in the main text of this report for the purpose of describing the hydrodynamics of existing conditions as well as the hypothetical openings under normal circumstances. For a more detailed explanation of the modeling related approach, methodology, scope, and results along with additional modeling scenarios of high river flow and sea level rise, see the Hydrodynamic Modeling Report provided in the Appendix E.

6.1.1 Hydrodynamic Modeling Study Area

The study area for this project is shown in Figure 22, which provides names of relevant roadways, rivers, water bodies, tributaries, and creeks. Specific points of interest include the I-10 Cut, Choccolatta Bay, the existing box culverts under the Causeway, Pass Picada, Justins Bay, Sardine Pass, John's Bend, Ducker Bay, and Shellbank River. The study area for the hydrodynamic modeling is focused on the features depicted in Figure 22, but the model domain is more comprehensive.

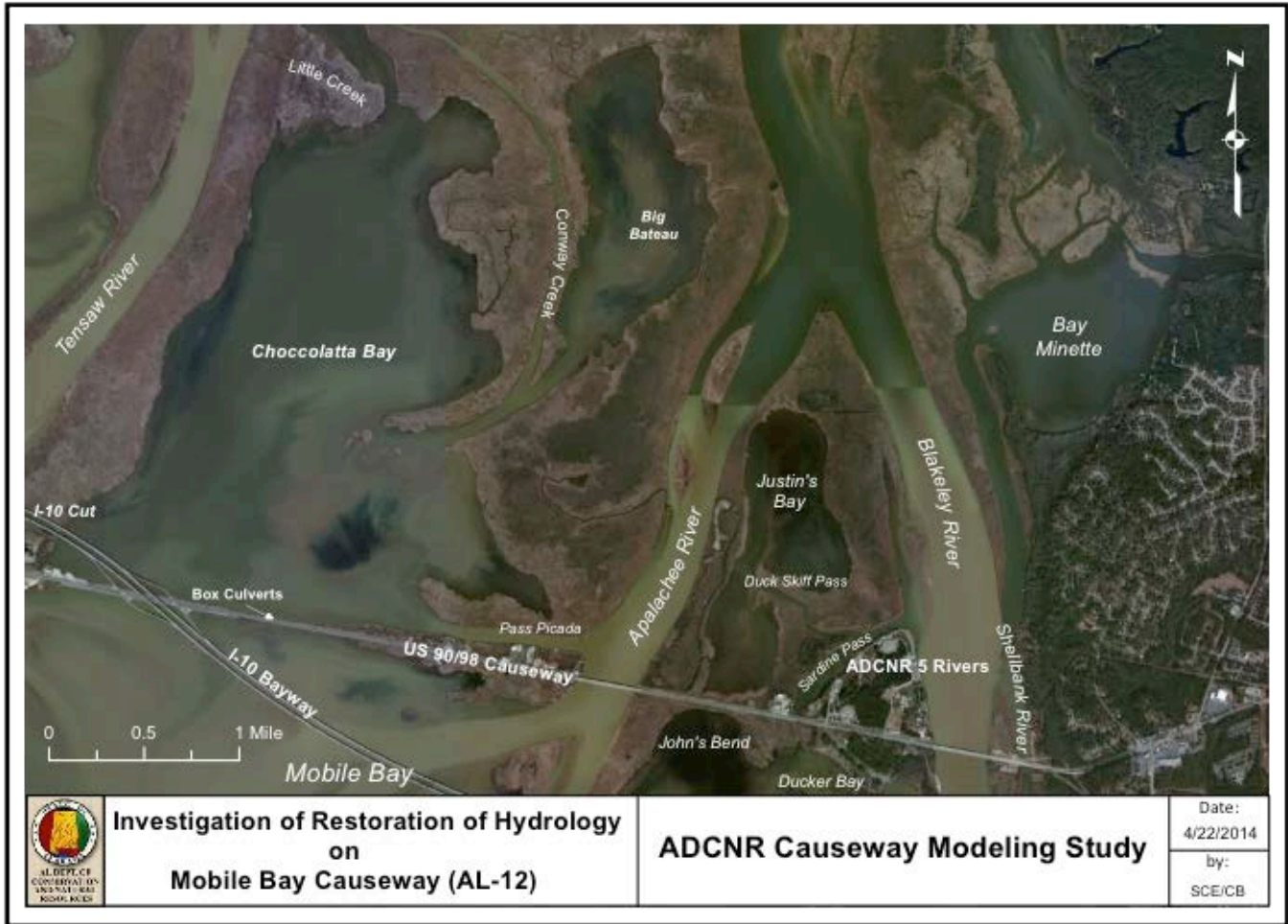


Figure 22. Study Area Map for Hydrodynamic Model Investigation

6.1.2 Field Data Collection In Support of Model Development

Limited field data were collected as part of the hydrodynamic modeling task of this study over the period 27 March 2014 to 9 April 2014. The Hydrodynamic Modeling Report (Appendix E) describes the objectives of the field data collection, sampling locations, conditions during the sampling period, measured water levels and velocities, and bathymetric sampling. South Coast Engineers (SCE) and the University of South Alabama Civil Engineering Department collected the field data.

6.2 Model Set Up and Validation

The hydrodynamic model was used to simulate circulation, flows, and water levels within the study area and is provided in this section. More detailed information regarding the model, including model calibration, is provided in the Hydrodynamic Modeling Report in Appendix E, which includes a summary of the model validation conditions and results with a focus on measured water levels and the underwater velocity profiling.

6.2.1 Model Description

The ADvanced CIRCulation (ADCIRC) model, described in Luettich et al. (1992) and Westerink et al. (1994), was selected for use in this hydrodynamic model investigation of hypothetical restoration alternatives along the Mobile Bay Causeway. The ADCIRC model is actually a suite of hydrodynamic models used for simulating tidal circulation and water levels in estuaries and open seas. The ADCIRC model has been successfully applied to a variety of studies ranging from larval transport to storm surge. It is used exclusively by Federal Emergency Management Agency (FEMA) for mapping flood risk in coastal areas and is used by additional federal agencies such as NOAA, USACE, and the U.S. Geological Survey (USGS).

The model is typically forced by representative tidal constituents along an open ocean boundary, as is the case in this study. The implementation of ADCIRC includes non-periodic inflow boundary conditions to simulate riverine flows upstream of the study area. The locations roughly correspond to Bucks, Alabama, on the Mobile River and Mount Vernon, Alabama, on the Tensaw River. USGS monitoring stations near those locations provide the discharge measurements required to specify the boundary conditions. Note that in this two-dimensional implementation of the ADCIRC model, the water is assumed to be completely mixed and homogeneous in nature.

6.2.2 Model Mesh

The underlying structure of the hydrodynamic model is the mesh (grid) of information that is referenced when performing numerical calculations of flows through space and time. The ADCIRC model is a finite element model built upon an unstructured mesh consisting of triangular elements. A distinct advantage of an unstructured mesh consisting of triangular elements is its ability to resolve complex shoreline geometries by alternatively shrinking or expanding the size of each element as needed.

The basic geometry of the ADCIRC mesh used for this study was adapted from a mesh developed by SCE for a previous hydrodynamic study in southwest Mobile Bay. The essential nodal attributes were updated using a 2011 NOAA 1/3rd arc-second DEM of Mobile Bay. The nodal elevations were referenced to the North American Vertical Datum of 1988 (NAVD88). Refinement of the underlying mesh was performed throughout much of the study area using recent aerial imagery and the bathymetric data collected in April 2014. Specific areas of refinement included the I-10 Cut, Choccolatta Bay, Big Bateau, Pass Picada, Justins Bay, Duck Skiff Pass, Sardine Pass, and Shellbank River.

The completed ADCIRC mesh consists of 45,294 nodes and 84,225 elements. The spatial extents of the mesh cover an area approximately 40 kilometer (km) south of Mobile Pass to over 20 km north of the Causeway. The mesh extents, triangular elements, and corresponding nodal elevations (depths) are shown in Figure 23 and Figure 24. Nodal spacing ranges from 1000s of meters along the tidal forcing boundary in the Gulf of Mexico to as little as 5 m in complex areas, like the box culverts, with typical nodal spacing throughout the study area varying from 10 m to 150 m.

Efforts were made to capture and resolve all tidal connections within the study area; however, some channels were omitted either due to their very small size and shallow depth, or their

predicted inability to significantly alter tidal exchange. A few examples of the former are found around Choccolatta Bay and Bay Minette. Another example is the very narrow and hydraulically inefficient channel that connects the Blakeley River to North Shellbank River on the north side of the Causeway. The head, or water level, difference between the two ends of this channel is negligible owing to the nature of the system; therefore, the channel would support very little flow.

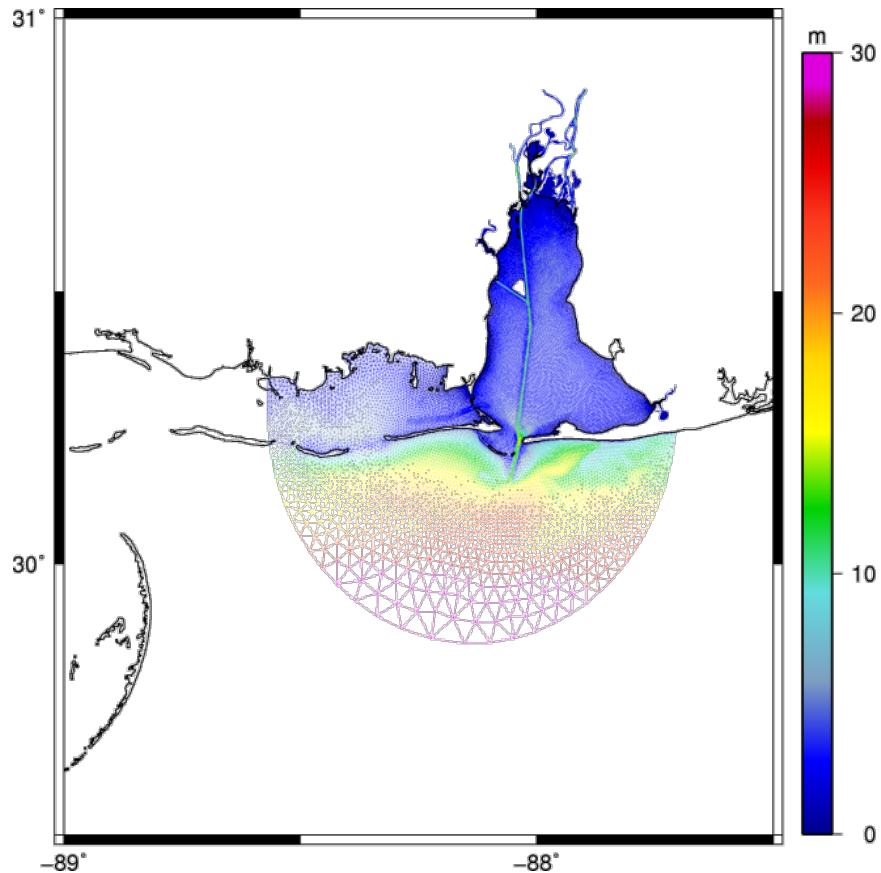


Figure 23. Spatial Extents of the ADCIRC Mesh Showing the Distribution and Size of Triangular Mesh Elements, and Their Corresponding Nodal Elevation (Depth) Relative to the Color Scale. Depths are in Meters Below NAVD88

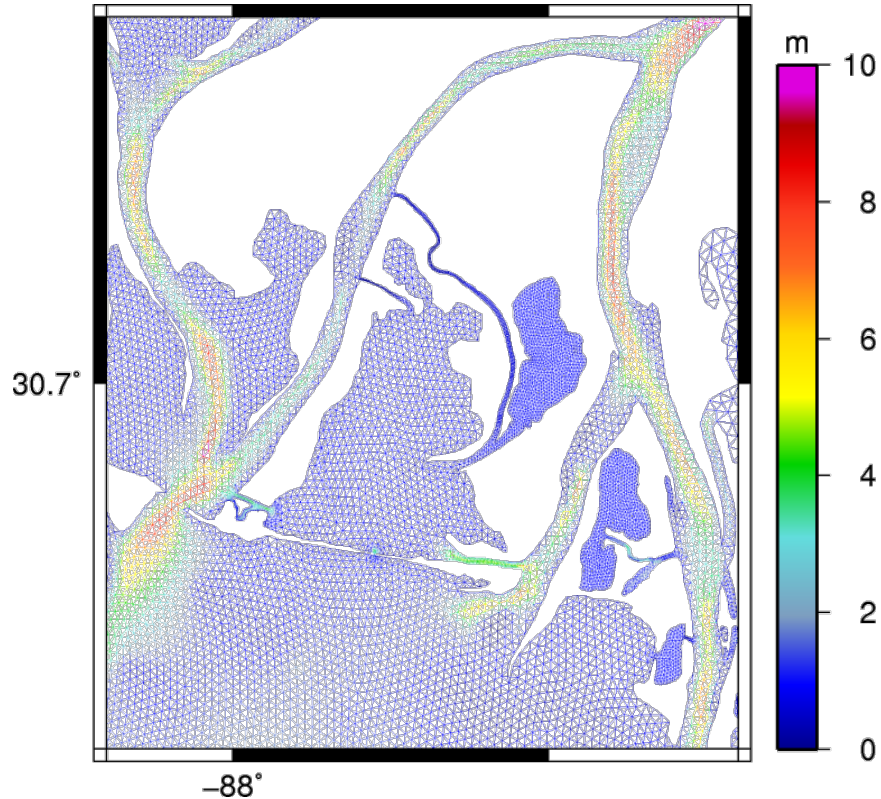


Figure 24. Distribution of Triangular Elements and Corresponding Depths of the ADCIRC Mesh Within the Study Area. Depths Correspond to the Color Scale and Are in Meters Below NAVD88

6.2.3 Mesh Boundary Conditions

In addition to the essential nodal attributes of the unstructured finite element mesh, the ADCIRC model requires specified boundary conditions for forcing and numerical calculations. This model mesh consists of a tidal forcing boundary condition in the Gulf of Mexico, non-periodic inflow boundary conditions on the Mobile and Tensaw Rivers, and a combination of mainland and island boundary conditions that define the shorelines. The locations of these boundary conditions are shown in Figure 25.

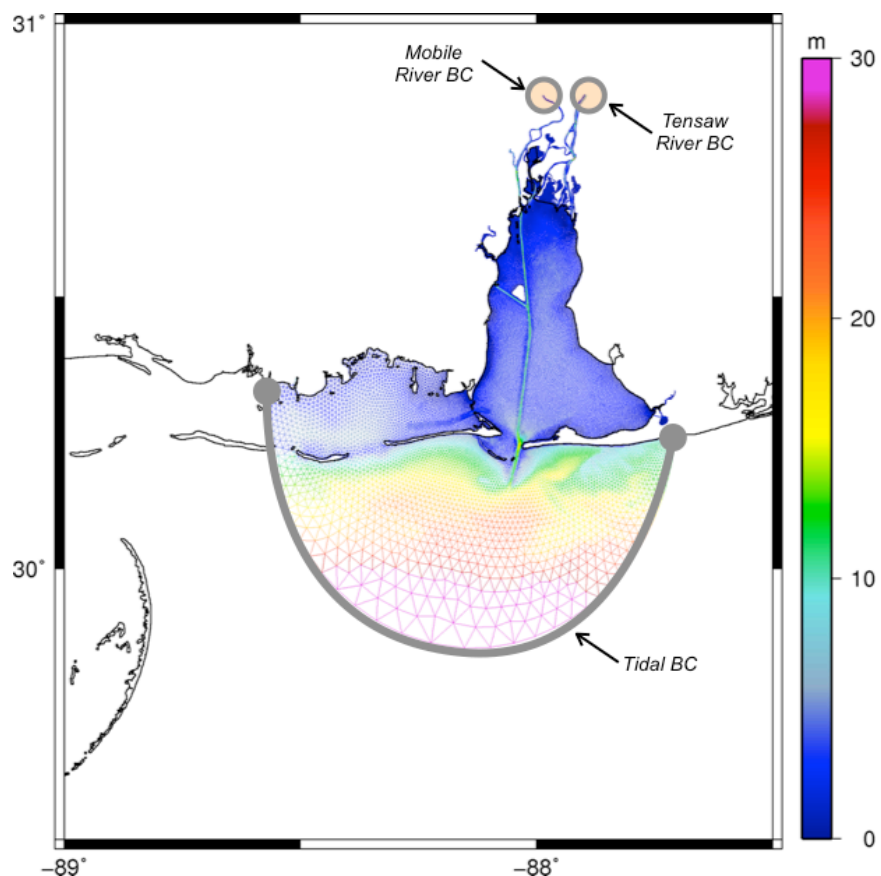


Figure 25. Location of Essential ADCIRC Boundary Conditions for Model Simulations in Mobile Bay

6.2.4 Validation Period and Conditions

The hydrodynamic model of the study area was validated by simulating conditions during the field data collection period of 27 March 2014 to 9 April 2014. This process is called "hindcasting" as the process involves recreating, or re-simulating, the conditions as they existed at a previous time. By supplying representative tide, river, and wind forcing for the hindcast period, the model predictions of water levels and velocities can then be compared to physical measurements.

The field data collection period captured nearly 2 weeks of tidal elevations. Velocity sampling was performed over an 8-hour period on a single day in that 2-week period. The specific hindcast period for model validation was 30 March 2014 to 5 April 2014. This period was selected to allow the model predictions to stabilize over a three-day period prior to the day on which velocity sampling was conducted. This period allowed the water levels and velocities to adjust to the tidal, river, and wind forcing.

In addition to the tidal constituent and river discharge forcing supplied over the hindcast period, meteorological forcing was supplied to the ADCIRC model using observed wind speed, direction and atmospheric pressure at 16 locations throughout the north central Gulf Coast. The

observations were extracted from NOAA National Data Buoy Center station records having 6- or 30-minute recording intervals. All observations were interpolated to a consistent six-minute interval in time, and to a rectangular grid of 0.25-degree spacing covering the extents of the ADCIRC mesh. The ADCIRC model then interpolated those wind and pressure measurements to match the model time step (~5 s) and to each node location in the mesh.

6.2.5 Validation Results

The model validation results corresponding to the hindcast simulation period of 30 March 2014 to 5 April 2014 are provided in the Hydrodynamic Modeling Report. Model validation consists of direct comparisons between model predictions of water levels and velocities and measurements of water levels and velocities obtained during that same period. The validation comparisons mostly focused on water levels and velocities within the study area. The Hydrodynamic Modeling Report shows graphical comparisons of modeled water levels and measured water levels as well as model velocities and measured velocities at five locations within the modeled study area.

6.2.5.1 Water Levels

Hindcast water level predictions were compared against measured water levels at Dauphin Island, Mobile State Docks, Lap's on the Causeway, Meaher State Park, and Five Rivers Delta Resource Center. The water level time-series comparisons for each location are shown in the Hydrodynamic Modeling Report (Appendix E). The ADCIRC model was able to reasonably predict the phase, range, and high water levels during the hindcast period. The model predictions also demonstrated the increase in mean tidal position over the hindcast period, at the northern locations, due to the increased river discharge during that time. This increased staging of water levels in the northern portion of Mobile Bay was captured by the temporary tide gages.

A quantitative assessment of model-data error was developed for each tide gage over the hindcast period 1 April 2014 to 5 April 2014. Errors associated with predicted water levels were 20% or less within the study area. Errors were calculated by considering the square root of the mean square difference (RMS difference) between measurements and predictions. The resulting "mean" errors are presented in Table 10 as heights and as a percentage of the tide range at the corresponding tide gage.

Table 10. Root Mean Square Difference (Error) Assessment for Predicted and Measured Water Levels at Five Tide Gages

Location	Mean Height Error (cm)	% of Tide Range
Dauphin Island	7.3	17.0
Mobile State Docks	11.6	21.0
Chocolatta Bay (Lap's)	9.7	17.8
Ducker Bay (Meaher)	9.0	16.4
Sardine Pass (5 Rivers)	10.3	20.0

6.2.5.2 Velocity

Hindcast water velocity predictions were compared against measured water velocities at the I-10 Cut, box culverts, Pass Picada, Apalachee River, and Blakeley River. The water velocity time-series comparisons for each potential location are shown in Hydrodynamic Modeling Report (Appendix E). Since the ADCIRC model predicts depth-averaged water velocity, the measured

velocities were averaged over depth for the purpose of model-data comparisons. The model was able to faithfully reproduce the flow direction and magnitude at most locations.

A quantitative assessment of model-data error for direct comparisons of predicted and measured water velocity is provided in Table 11. As was done with water levels, the mean difference between predicted and measured water velocity was determined and is reported as an average error velocity and also as a percentage of the average velocity measured over the data collection period. With the exception of flow through the I-10 Cut, the velocity errors were less than 5 cm/s or 30% of measured values. The model overestimated the magnitude of water velocity early in the data collection period, likely due to a slight phase lead in the tidal stage as compared to observed values. The model predictions and measured data at I-10 Cut come into better agreement later in the day.

Table 11. Assessment of Model-Data Errors for Depth-Averaged Water Velocity During the Data Collection Period

Location	Velocity Error (cm/s)	% of Average Velocity
I-10 Cut	5.8	60.1
Box Culverts	4.4	30.7
Pass Picada	4.2	17.4
Apalachee River	0.6	2.2
Blakeley River	3.4	5.8

6.3 Hydrodynamic Modeling Simulation Setup

This ADCIRC model tool was used to assess the hydrodynamic characteristics of the existing conditions and five restoration alternative scenarios under various conditions. A brief overview of the restoration alternatives is followed by a description of the naming conventions used to identify each simulation, as well as information about the model characteristics and forcing conditions. This subsection concludes with a description of the analysis methodology applied to address the performance measures described previously.

6.3.1 Overview

The ADCIRC model was used to evaluate five hypothetical restoration alternative scenarios for constructed openings along the Mobile Bay Causeway. In addition to the five restoration alternative simulations, a corresponding simulation of the existing site conditions was performed for the purpose of comparative analysis. Simulations were performed under: (1) representative tidal and flow forcing for present day sea levels; (2) representative tidal and high flow forcing (high river discharge) for present day sea levels; and (3) representative tidal and flow forcing for future, higher sea levels (year 2100). Additional brief details regarding forcing conditions are provided in the following subsection with more details provided in the Hydrodynamic Modeling Report (Appendix E).

The potential restoration locations included Choccolatta Bay, Justins Bay, and Shellbank River. The simulations included each restoration alternatives simulated in isolation (3 scenarios), with all of them open simultaneously (1 scenario), and with only Choccolatta and Justins Bay open (1 scenario) for a total of five possible restoration alternative scenarios.

For the purposes of this hydrodynamic model study, the hypothetical restoration alternatives were assumed to be openings through the Causeway having depths equal to surrounding conditions. Culverts were not explicitly included in the hydrodynamic model.

6.3.2 Naming Conventions

Each scenario has a three-digit identifier. The first digit (0, 1, 2, 3, 4, 5) represents the scenario considered, where 0 corresponds to existing conditions and numbers 1 - 5 correspond to each of the five hypothetical restoration scenarios considered. The second digit (0, 1) represents the sea level scenario, with "0" corresponding to present-day levels and "1" representing the future sea level condition. The third digit (2, 3) corresponds to the river forcing where "2" represents the average July (low) flows, and "3" corresponds to the average wet season (high) flows. The naming convention and general characteristics of all hydrodynamic model simulations performed for this study is provided in Table 12. These conventions will be used throughout the remaining sections of the report.

Table 12. Naming Convention and General Conditions for all Simulated Restoration Alternative Scenarios

Name	Restoration Scenario	Flow Conditions	Sea Level
Case 002	Existing Conditions	Average Summer	Present Day
Case 102	Choccolatta Bay		
Case 202	Justins Bay		
Case 302	Shellbank River		
Case 402	All Open		
Case 502*	Choccolatta + Justins		
Case 003*	Existing Conditions	Average Wet Season	
Case 403*	All Open		
Case 012*	Existing Conditions	Average Summer	Year 2100
Case 112*	Choccolatta Bay		
Case 212*	Justins Bay		
Case 312*	Shellbank River		
Case 412*	All Open		
Case 512*	Choccolatta + Justins		
*Case not presented in main text of this report. See Hydrodynamic Modeling Report (Appendix E) for information on this scenario.			

6.3.3 Model Simulations Setup

The ADCIRC model parameters and characteristics were held constant across all restoration alternative simulations. For a particular forcing condition and sea level scenario, the only thing altered was the unstructured mesh. Additional nodes and elements were added or subtracted, as needed, to incorporate each of the hypothetical openings. Mesh properties are listed in Table 13. Images of the existing and altered meshes are provided in Figure 26.

Table 13. Existing and Altered Mesh Properties

Case Name	Number of Nodes	Number of Elements
002, 003, 012	45294	84225
102, 112	45239	84151
202, 212	45320	84286
302, 312	45304	84242
402, 403, 412	45275	84229
502, 512	45265	84212

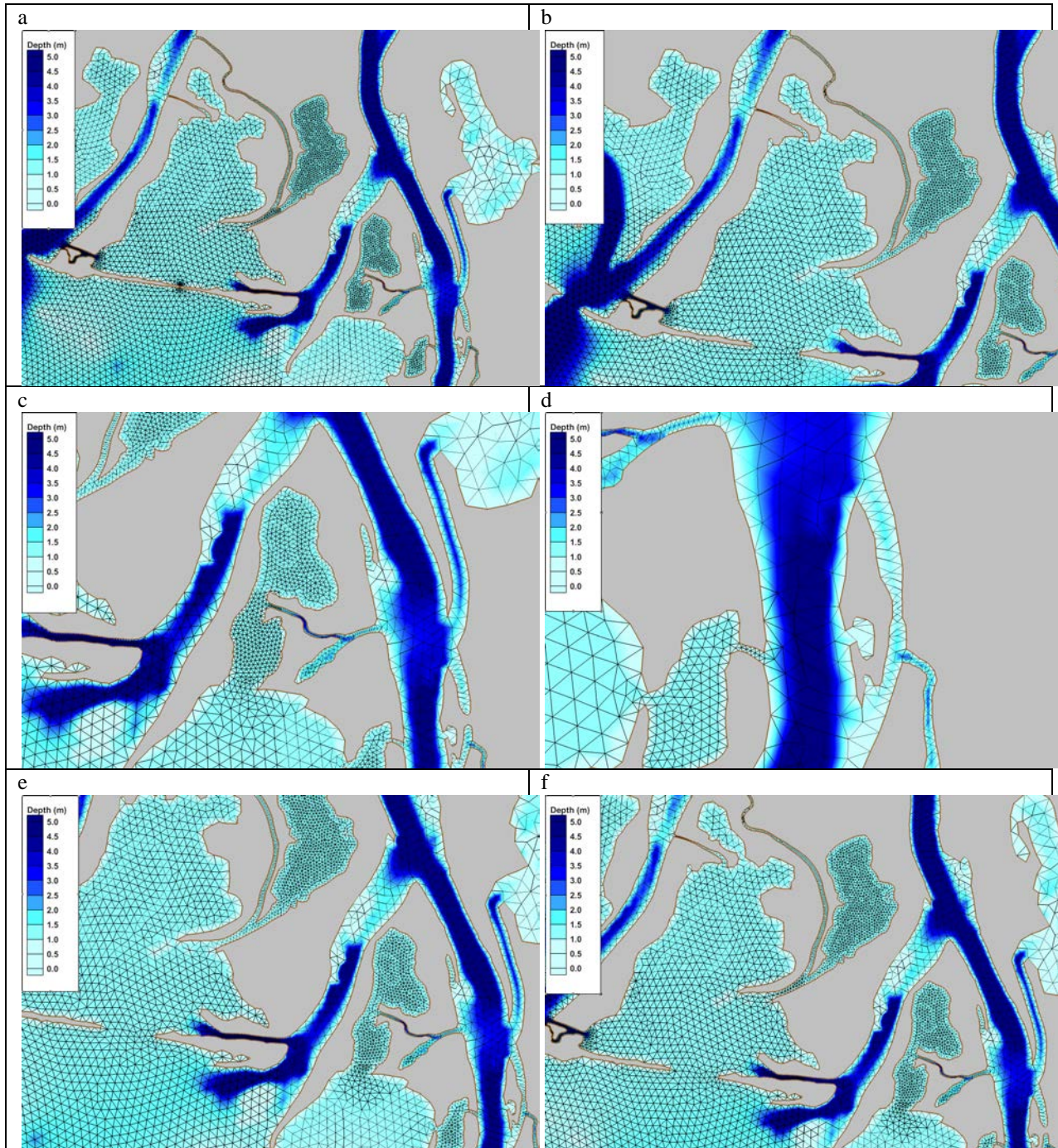


Figure 26. Images of the ADCIRC Mesh for (a) Existing Conditions, (b) Chocolatta Bay Opening, (c) Justins Bay Opening, (d) Shellbank River Opening, (e) All Aites Open, and (f) Chocolatta + Justins Bay Openings. The Distribution of Triangular Elements is Shown, and the Colors Correspond to Depths in Meters below NAVD88

6.3.4 Simulation Conditions

Each simulation included tidal and flow forcing representative of the study area. All model simulations covered a period of ten days beginning 16 July 2014. In this case, the date is only relevant for determining the stage and phase of the tide. The period of time simulated included the end of a neap (equatorial) tide cycle and most of the seven-day spring (tropic) tidal cycle.

For the initial set of the simulation, discharge values supplied to the Mobile and Tensaw River boundaries were assumed to be representative of average inflow conditions for the month of July over the years 2008 to 2012. Discharge statistics were computed from measured flows at USGS gages located on the Mobile and Tensaw Rivers upstream of the mesh boundaries. More information is provided on these data in the Hydrodynamic Modeling Report (Appendix E).

Two additional simulations (Case 003 and Case 403) were conducted to determine the effects of high river discharge on sediment transport potential within the study area. The discharge values for those simulations were determined by considering an average "wet season" value for the months December through May over the years 2010 to 2014. The discharge values were obtained from the same USGS gages on the Mobile and Tensaw Rivers. More information on these scenarios including the model results are provided in the Hydrodynamic Modeling Report (Appendix E).

The final suite of restoration alternative simulations were conducted to determine the effects of elevated future sea levels on hydrodynamic characteristics within the study area. These simulations were prepared by incorporating an additional nodal attribute to account for the sea level offset relative to the existing nodal elevations. More information on the estimation of the assumed year 2100 sea level elevation and the modeling results are provided in Hydrodynamic Modeling Report (Appendix E).

For reference, the tidal, flow, and sea level parameters used for each model simulation are summarized in Table 14.

Table 14. Summary of Tidal, Flow, and Sea Level Characteristics Applied to Each ADCIRC Simulation

Name	Tidal Constituents	Average Discharge (cfs)		Sea Level Offset (m)
		Mobile River	Tensaw River	
Case 002	K1, O1, P1, Q1, M2, S2, N2	8,900	7,700	+0.0
Case 102				
Case 202				
Case 302				
Case 402				
Case 502*				
Case 003*		37,587	31,283	+0.3
Case 403*				
Case 012*		8,900	7,700	
Case 202*				
Case 302*				
Case 402*				
Case 502*				

*Case not presented in main text of this report. See Hydrodynamic Modeling Report (Appendix E) for information

on this scenario.

6.3.5 Analysis Methodology

The simulation results were analyzed to specifically address hydrodynamic performance measures tied to the four study objectives mentioned previously. The analysis of each simulation required an assessment of tide ranges; tidal prisms and volume fluxes; tidal phase lags; residence times; subtidal¹ velocities; and sediment transport potential.

Tide ranges were determined by considering the range between high and low water throughout the study area. Tidal prisms and volume fluxes were calculated by considering the cumulative discharge across defined transects between subsequent high and low water conditions throughout the study area. Tidal phase lags were determined by considering the time of high water inside and immediately outside of affected water bodies. Residence times were calculated using a Lagrangian Particle Tracking Model (LPTM) to simulate the removal of passive particles from defined water bodies in the study area (see Dietrich et al., 2012 and Marr, 2013). Subtidal velocities were calculated by averaging all predicted tidal velocities over the simulation period.

The LPTM analysis of residence times was accomplished by passing the predicted water velocities to an ADCIRC sub-model that tracks the movement of passive particles from their initial position. Particle displacements were controlled by the predicted water velocity without dispersion. The LPTM results were used to determine how long it took for a specific particle to exit a water body of interest for the first time. This corresponds to the most widely accepted definition of the residence time.

A total of 1,677 passive particles were initialized in the Choccolatta Bay system, which includes Big Bateau, Little Creek, and Conway Creek. A total of 579 passive particles were initialized in the Justins Bay system, which also includes Duck Skiff Pass and Sardine Pass. A figure showing the distribution and initial positions of passive particles is provided in Figure 27. These particles were tracked over the last nine days of the ADCIRC simulations and the results summarized in terms of residence times, exposure times, and percentage of particles removed under each scenario. The exposure time is defined as the total amount of time a particle spends within a region of interest, recognizing that tidal action may return a particle to a water body escaped on a previous tide.

Since only Choccolatta Bay and Justins Bay are nearly enclosed with defined exit boundaries, they were considered in the LPTM analysis and Shellbank River was excluded. (Shellbank River has a narrow connection to Blakeley River; however it is considered hydraulically inefficient [see Section 6.2.2].) The exit boundaries for the existing conditions for Choccolatta Bay were assumed to be I-10 Cut, Pass Picada, Little Creek, Conway Creek, and the existing culverts. For the existing conditions, the exit boundaries for Justins Bay were assumed to be Sardine Pass.

Sediment transport, resuspension, and deposition potential were determined using established models available in the published literature. Namely, bedload sediment transport rates and sediment resuspension rates were calculated using the methods of Meyer-Peter and Müller

¹ Subtidal refers to the non-periodic component of circulation, which could be a combination of river forcing and/or non-linear tidal forcing within the study area.

(1948) and van Rijn (1984). These methods and their application to hydrodynamic modeling are more fully described in Webb (2008), Webb and Slinn (2006), Webb and Slinn (2008), and Zedler and Street (2001). Application of these equations to coastal sediment transport is also described in Nielsen (1992).

These methods are based on exceedance of a critical sediment stress (e.g., Shields' stress), which is a function of sediment diameter and specific gravity (van Rijn, 1993). The fluid stress is a function of the square of the ADCIRC predicted water velocity at each nodal location, the density of fluid (1000 kg/m^3), and a typical friction coefficient (0.0025). The transport and resuspension rates have dimensions of volume rate of bed material exchange per unit area (e.g., $\text{m}^3/\text{s}/\text{m}^2$).

Sediment characteristics were obtained from the CalScience Environmental Laboratories, Inc. (CalScience) sediment analysis reports (No. 14-05-1270; No. 14-05-1271; and No. 14-05-1383), which were based on data collected of this study. These data reports provided average particle diameters and gradation characteristics for each sediment core collected in the study area. These particle diameters were then mapped to the hydrodynamic model mesh nodes using inverse distance weighted interpolation.

Sediment deposition potential was modeled by considering the balance between horizontal momentum imparted by the predicted water velocity, the gravitational force acting on the particle, and the vertical momentum due to the particle's mass and fall velocity (van Rijn, 1984). Once the particle had fallen a distance equivalent to the surrounding water depths it was assumed to settle on the bed. These areas were flagged during the simulations as depositional.

It should be noted that sediment transport modeling has a large margin of error. All sediment transport modeling should be evaluated through a lens of conservatism and changes in magnitudes should be considered in a relative, or comparative, sense. Therefore, the qualitative changes in sediment transport and resuspension rates between scenarios should be weighed more heavily than any specific quantity predicted by the sediment transport models.

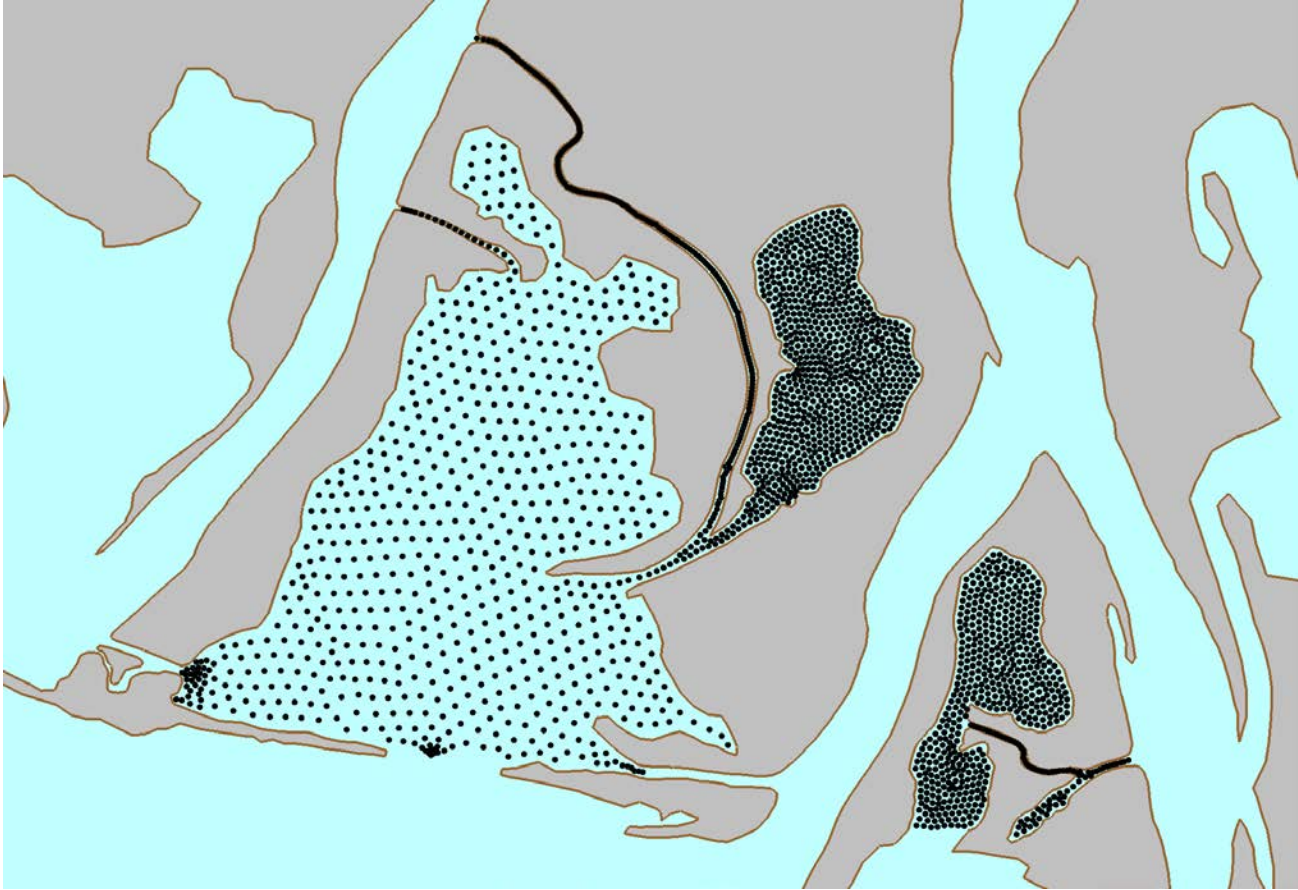


Figure 27. Distribution and Initial Position of Passive Particles used in LPTM Simulations (Black Dots). The Distribution and initial Position of Particles was the Same for each Simulation. The Mesh Corresponding to Case 412 (all open) is Shown for Reference

6.4 Existing Conditions Simulation Results

The simulation results reflect predictions of the hydrodynamic conditions associated with the scenario within the study area. The forcing conditions consist of representative tides and average summer river discharge under present day sea levels. The results of the simulations are presented with a discussion of four quantifiable hydrologic parameters that include:

- Water Levels
- Flows
- Sediment Transport Potential
- Flushing

6.4.1 Water Levels

The predicted maximum water levels in Choccolatta Bay were approximately 2 to 4 cm lower than areas south of the Causeway, while maximum water levels in Justins Bay were 10 cm lower than other areas. Due to their highly constricted nature, these systems experience substantially less tidal forcing as compared to other parts of Mobile Bay. These results are shown in Figure 28 and are reinforced by the predicted maximum tide ranges listed in Table 15. Predicted tide ranges

in Choccolatta and Justins Bays were 6% and 40%, respectively, less than the tide range at a location immediately south of the Causeway in Mobile Bay.

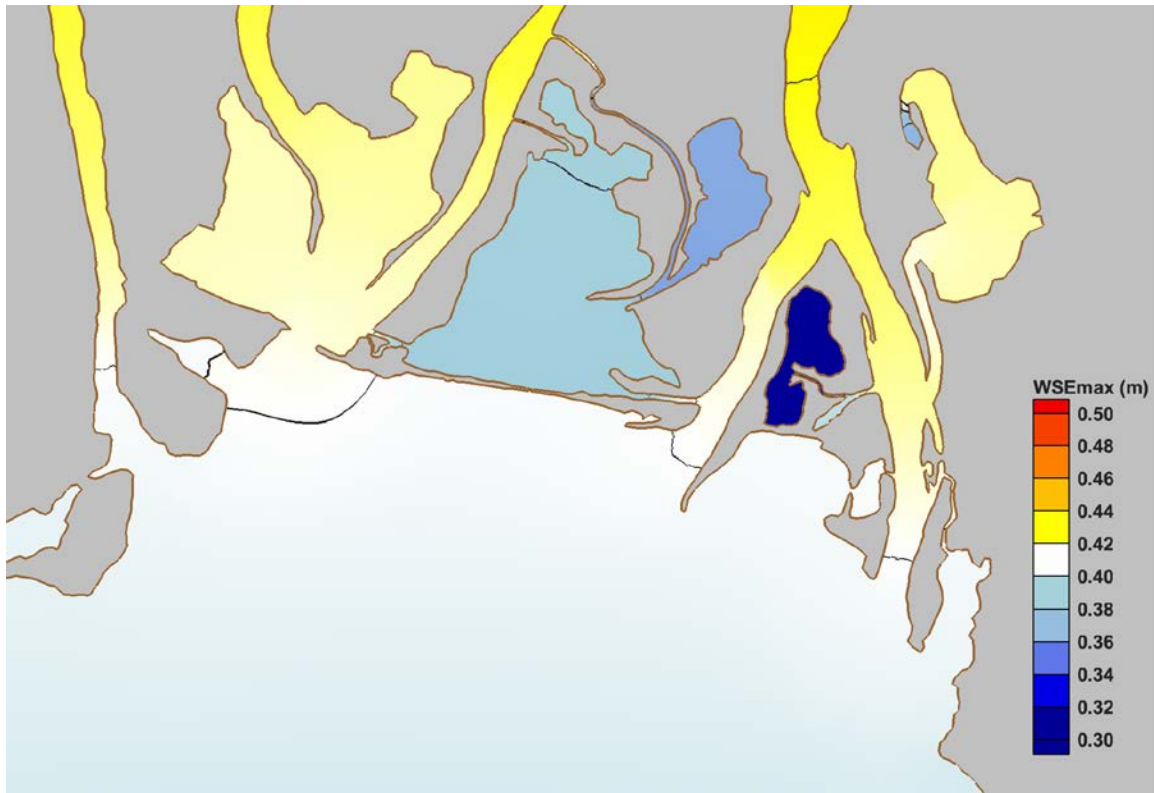


Figure 28. Distribution of Maximum Water Levels (Meters Relative to NAVD88) for Case 002

Table 15. Tide Range at Selected Locations Within the Study Area for Case 002

Location	Tide Range (m)
Choccolatta Bay	0.675
North Mobile Bay	0.720
Justins Bay	0.441
Ducker Bay	0.718
Shellbank River North	0.721
Shellbank River South	0.719

6.4.2 Flows

The largest velocity values were predicted to occur in the rivers, tributaries, and some constricted tidal channels. For example, note the large values at the confluence of Conway Creek and the channel from Big Bateau, in I-10 Cut, and also in Pass Picada for Choccolatta Bay. The discharge magnitude going through these channels is high relative to their area, resulting in high velocities. The magnitude of maximum depth-averaged water velocities throughout the study area is shown in Figure 29.

Because of their poor flushing and limited tidal communication with Mobile Bay, Choccolatta Bay, Big Bateau, Justins Bay, and Shellbank River experience very little subtidal flow. Subtidal velocities were calculated as the average of velocities at each node over the last nine days of model simulation. The subtidal velocity magnitude and direction are shown in Figure 30.

In Choccolatta Bay, a majority of the tidal volume exchanged with Mobile Bay enters through I-10 Cut (40%), Pass Picada (41%), and the existing box culverts (17%); and exits through Little Creek and Conway Creek. Pass Picada and I-10 Cut served as the primary conduits of tidal communication under existing conditions (~80% of total exchange). The distributions and directions of tidal volume exchange under existing conditions are shown graphically for Choccolatta Bay in Figure 31.

For Justins Bay, 100% of the tidal exchange occurred through Sardine Pass (and Duck Skiff Pass), as it was the only opening for the system under existing conditions. Tidal exchange was calculated from model results by tracking the cumulative discharge across specific transects between successive low and high water events for the maximum flood tide. The cumulative tidal exchange volumes for Choccolatta Bay and Justins Bay are provided in Table 16.

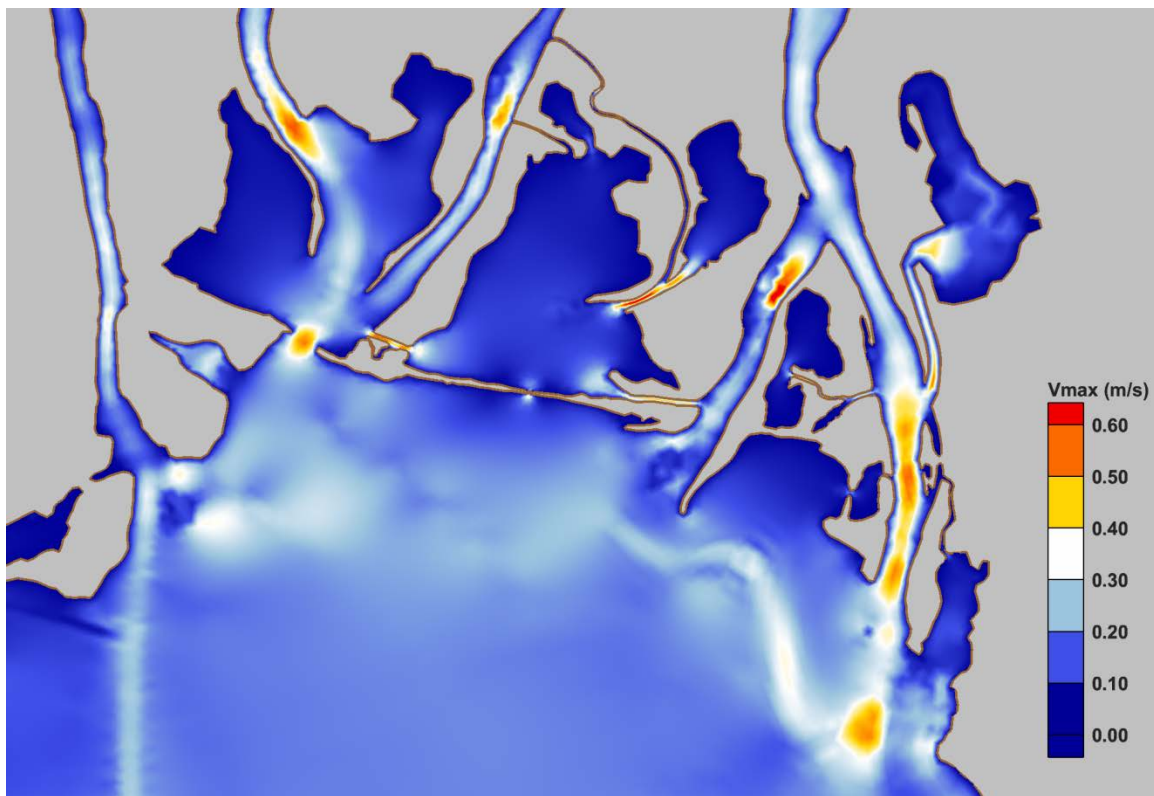


Figure 29. Magnitude of Maximum Depth-averaged Velocity (Meters per Second) for Case 002

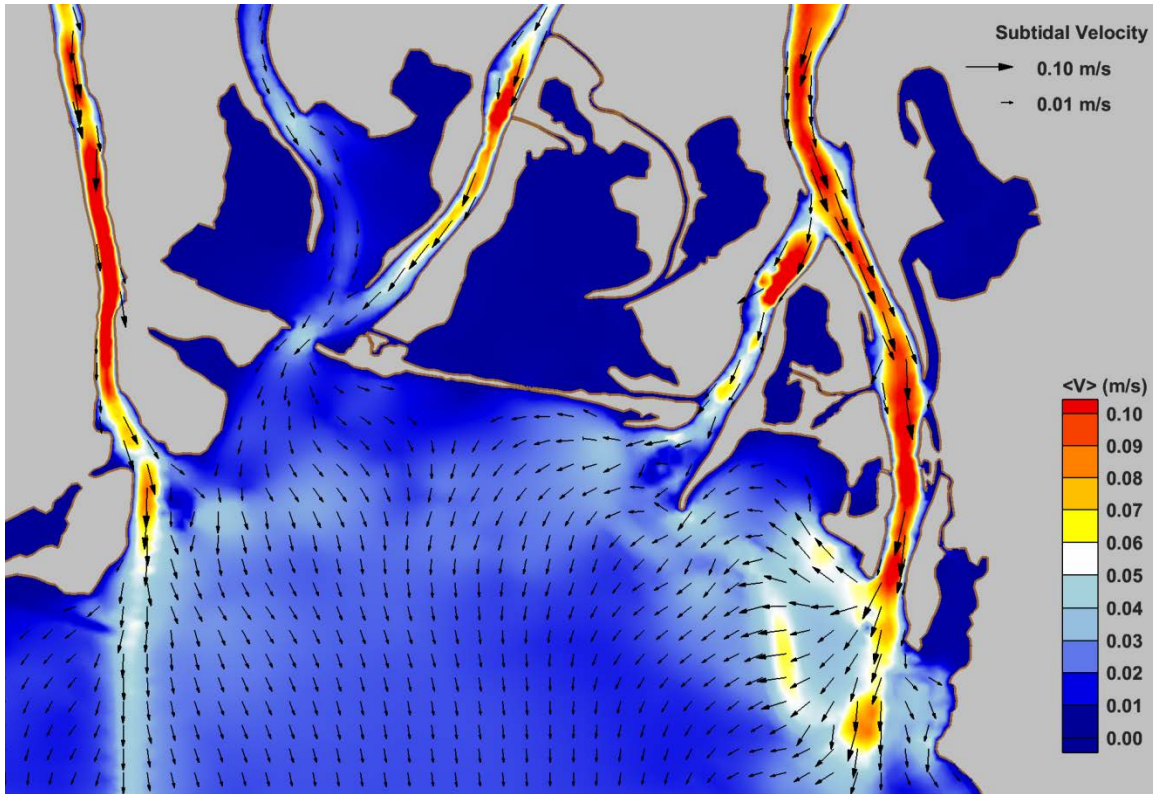


Figure 30. Subtidal Velocity Magnitude (Colors) and Direction (Vectors) for Case 002



Figure 31. Distribution and Direction of Tidal Exchange Volumes for Choccolatta Bay under Existing Conditions (Case 002). Values are Shown as Percentages of the Total Volume of Water Exchanged

Table 16. Maximum tidal Volume Exchanged (in Cubic meters) between Successive Low and High Water on a Maximum Flooding Tide for Case 002

Location		Tidal Volume Exchange (m ³)
Choccolatta Bay	I-10 Cut	2,204,867 (in)
	Little Creek	6,543 (out)
	Conway Creek	927,292 (out)
	Culverts	85,586 (in)
	Pass Picada	2,270,914 (in)
	Total (net)	3,627,533 (in)
Justins Bay	Sardine Pass	411,800 (in)

6.4.3 Sediment Transport Potential

The locations of the largest bedload and resuspension sediment transport rates corresponded to locations having the largest velocities throughout the study area. These areas included constricted tidal channels having high velocities, and also reaches within the Apalachee and Blakeley Rivers. Areas experiencing bedload transport also exhibited sediment resuspension. These potential bedload and resuspension sediment transport rates are shown in Figure 32 and Figure 33, respectively. The rates, expressed as the volume rate of bed material exchange per unit area, are potential transport rates averaged over the last 9 days of model simulation time. As

such, there are times when rates were higher and times when rates were lower than the values shown.

The predicted patterns of potential deposition throughout the study area are reflective of the characteristics and behavior of the system. For example, the depositional areas within Justins Bay somewhat mimic the bathymetry of the Bay. Furthermore, the noted deposition in North Shellbank River is representative of long-term shoaling (i.e., sediment deposition) that has occurred there. Potential sediment depositional areas within the study region were determined as described previously. These areas were flagged (1 = deposition, 0 = no deposition) and then averaged over the final nine days of the model simulation and shown on Figure 34.

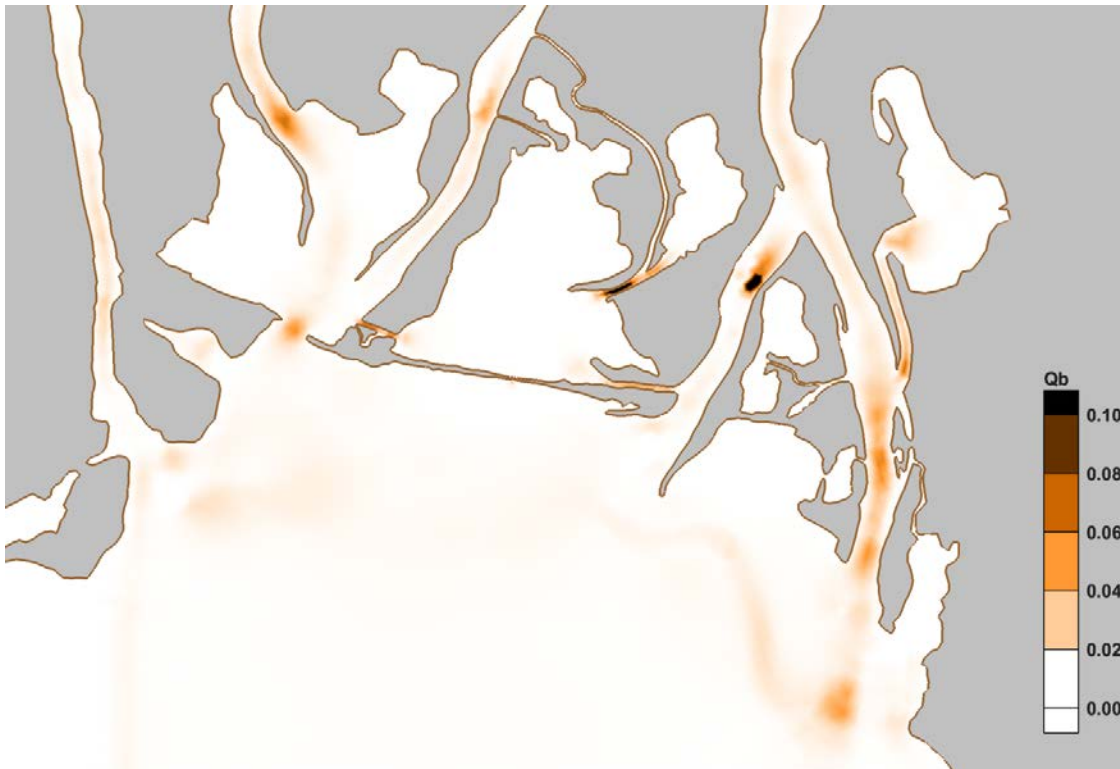


Figure 32. Potential Average Bedload (Qb) Sediment Transport Rates (m³/s/m²) for Case 002

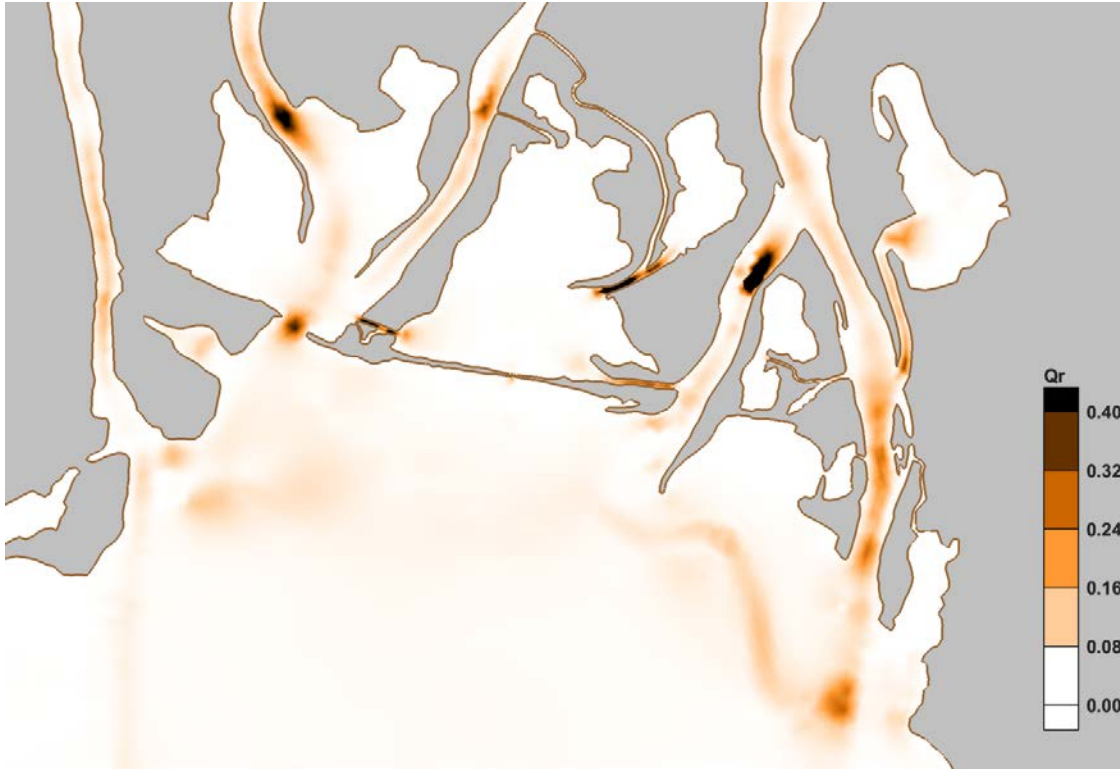


Figure 33. Potential Average Resuspension (Qr) Sediment Transport Rates (m³/s/m²) for Case 002

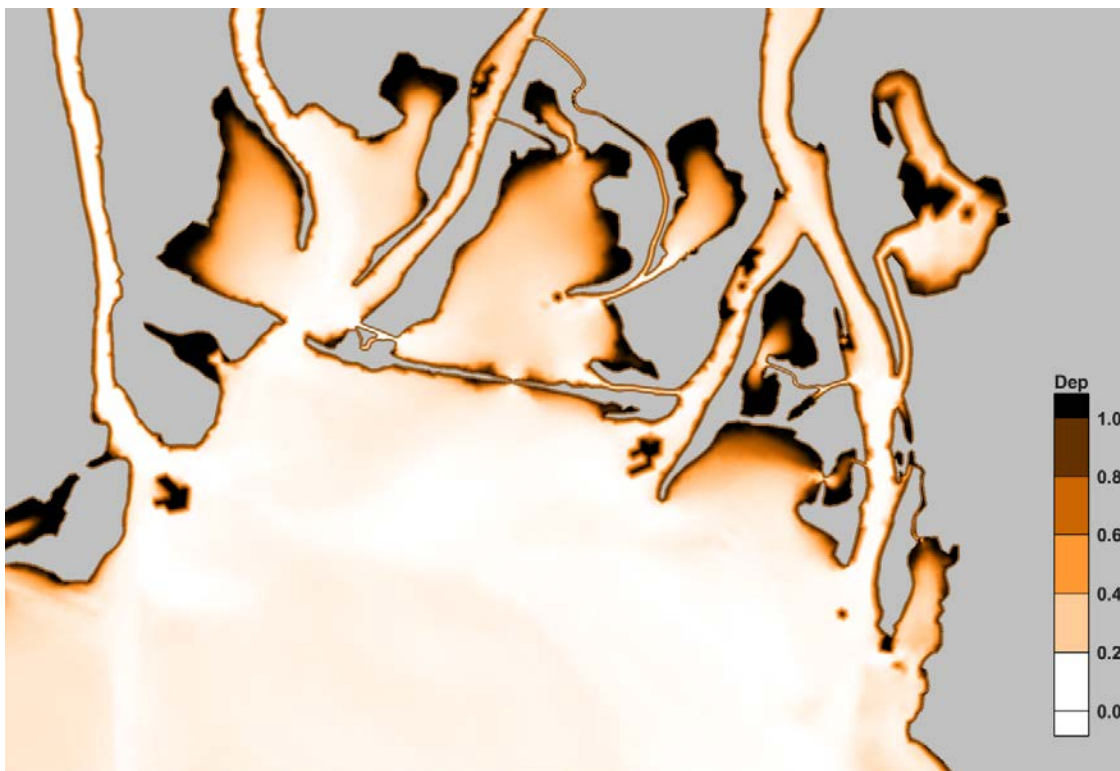


Figure 34. Sediment Deposition Potential for Case 002. Areas that are Strongly Depositional have a Value of 1.0. Areas that are Unlikely to Experience Deposition have a Value of 0.0

6.4.4 Flushing

The flushing potential of Choccolatta and Justins Bays were evaluated by passing the hydrodynamic model output to the Lagrangian Particle Tracking Model as described previously. The simulations were run for 10 days to capture the end of a neap tide and a full 7-day spring tide (strong tidal forcing). The first day worth of results were excluded from the analysis due to inaccuracies associated with model spinup. Particles were tracked over the last nine days of the model simulation to estimate residence times, exposure times, and percentage of particle removed from each water body. These characteristics were evaluated on a particle-by-particle basis as well as considering system-wide averages, which unfortunately are not completely representative of the nature of these systems.

Under existing conditions, the LPTM results indicated that just over 20% of particles would be flushed from Choccolatta Bay, while only 7% of particles would be flushed from Justins Bay. For Choccolatta Bay, 41% of the escaping particles left through I-10 Cut, 36% left through the culverts, and 19% left through Pass Picada, with the remaining (<5%) exiting through Little and Conway Creeks. Under existing conditions, 100% of escaping particles left Justins Bay through Sardine Pass. The residence times of particles within the systems, relative to their initial positions, are shown in Figure 35 under existing conditions. Note that the residence times are lower (<1 day) near system openings. The system-wide LPTM averages are provided in Table 17.

Since many of the particles do not leave either system, the reported system-wide averages for residence and exposure time are somewhat biased. Remember that the simulation results were limited to a period of nine days. Particles not leaving the system were assigned a value of 9 days, when in reality their values are unknown at present. The simulations need to be performed for a much longer duration in order to capture their true residence times.

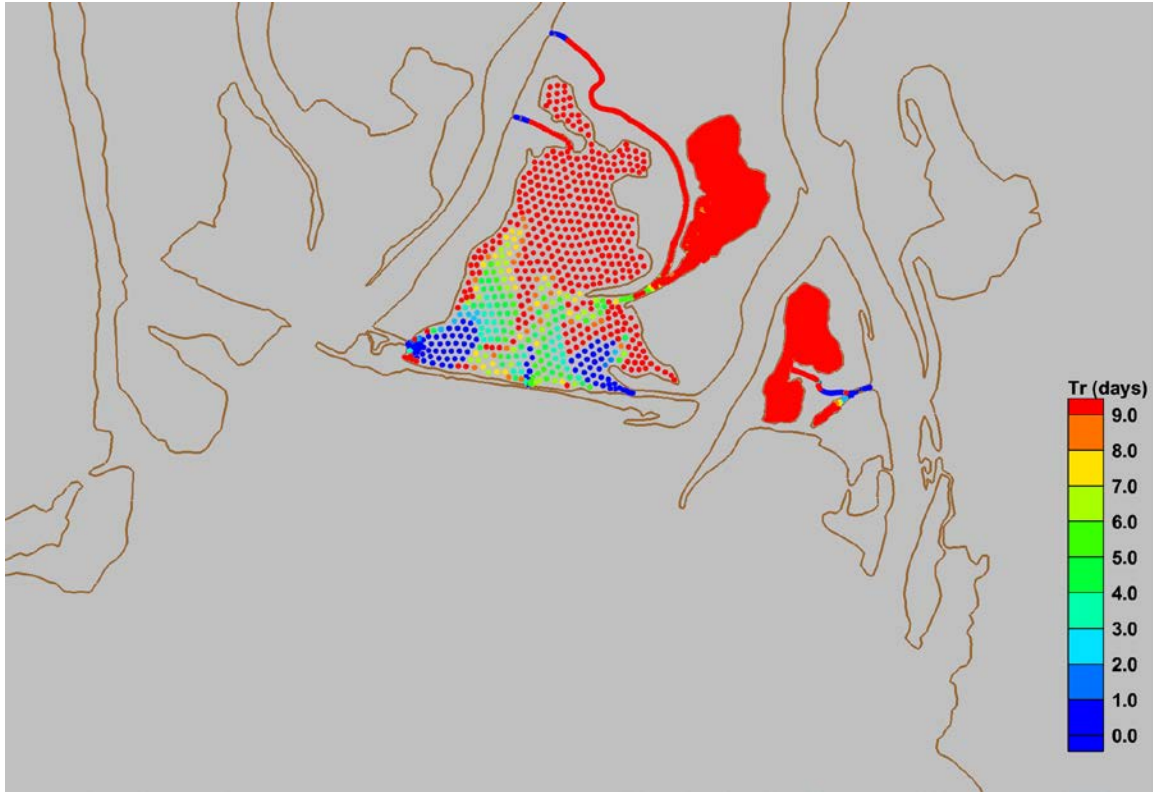


Figure 35. Residence Times (Tr) in Days of Passive Particles, Relative to Initial Position, for Case 002

Table 17. Flushing Characteristics for Choccolatta and Justins Bays in Case 002

Value	Choccolatta Bay	Justins Bay
Average Residence Time (days)	7.9	8.4
Average Exposure Time (days)	8.4	8.6
Percentage of Particles Removed	20.2	7.1

6.5 Choccolatta Bay Results - Case 102

This alternative restoration scenario considers a constructed opening through the Causeway at Choccolatta Bay only. The forcing conditions consist of representative tides and average summer river discharge under present day sea levels. Simulation results presented for Case 102 are shown as differences relative to existing conditions (Case 002).

6.5.1 Water Levels

The results indicate that the constructed opening resulted in maximum water levels that were approximately 3 cm higher than existing conditions. These results are shown in Figure 36. The figure shows the difference in maximum water levels between the two scenarios, calculated as the water levels for the modified scenario minus the water levels under existing conditions. Therefore, positive values represent increases in maximum water levels, while negative values indicate decreases in maximum water levels, relative to existing conditions.

When compared to a location just south of the constructed opening, the modified condition (Case 102) completely removed the existing one-hour phase lag in tide stage inside and outside of Choccolatta Bay (see Figure 37). Model results suggested that the constructed opening in Choccolatta Bay also affected the tidal range. A time-series of water levels in Choccolatta Bay for Case 002 and Case 102 is shown in Figure 38 with positive values showing increases relative to existing conditions and negative values showing decreases. The increase in high and low water is evident, as is the earlier arrival of low and high tides.

With the constructed opening in place, the model predicted an increase of 8% in Choccolatta Bay's tide range with negligible effects (<1%) noted elsewhere in the study area. Therefore, any potential restoration for Choccolatta Bay is not likely to have a measurable effect on tide ranges in other parts of the study area. The tide ranges at various locations in the study area are provided in Table 18.



Figure 36. Change in Maximum Water Levels (WSEmax') for Case 102, Shown in Meters. Positive Values Show Increases Relative to Existing Conditions and Negative Values Show Decreases

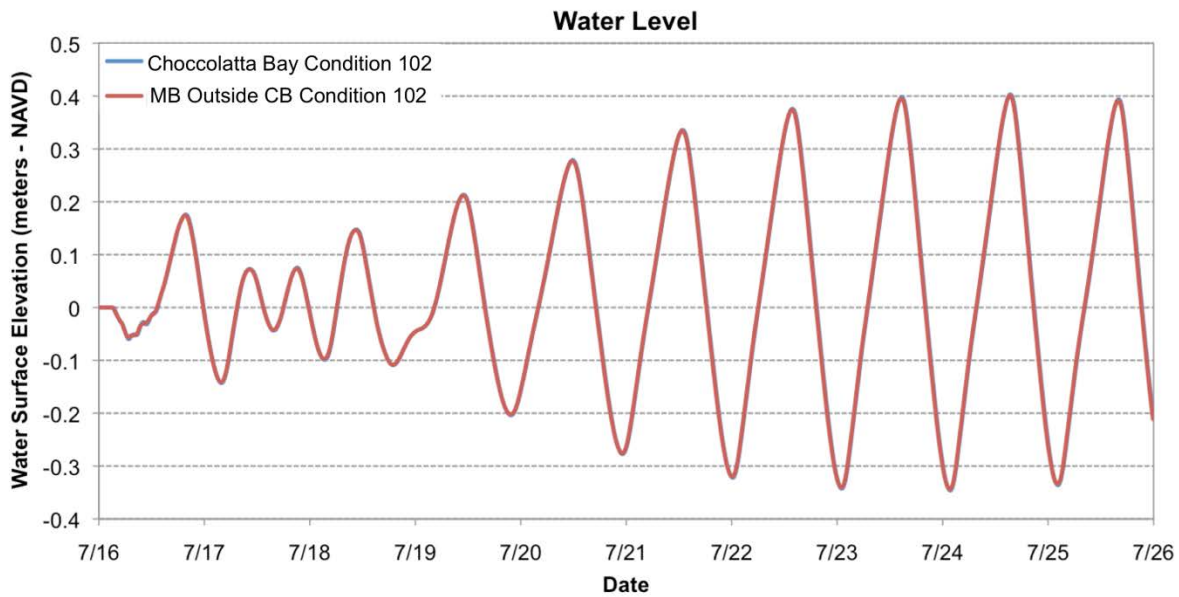


Figure 37. Comparison of Predicted Water Level Time Series Inside and Outside of Choccolatta Bay for Case 102

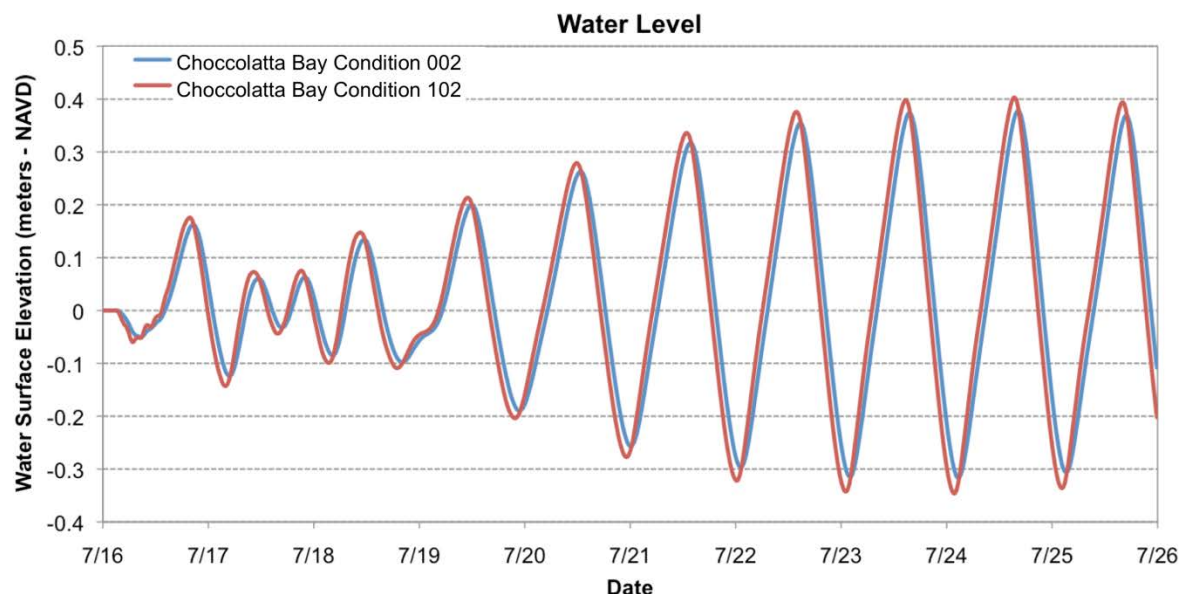


Figure 38. Comparison of Water Levels in Choccolatta Bay for Case 002 and Case 102

Table 18. Tide Range at Selected Locations for Case 102 and the Corresponding Change Relative to Case 002

Location	Tide Range (m)	% Change, 002
Choccolatta Bay	0.729	+8
North Mobile Bay	0.724	<+1
Justins Bay	0.442	<+1
Ducker Bay	0.720	<+1
Shellbank River North	0.723	<+1
Shellbank River South	0.721	<+1

6.5.2 Flows

The constructed opening at Choccolatta Bay, "Pass Choccolatta," relieved head differences between Choccolatta Bay and surrounding water bodies, thereby reducing velocities through existing relief channels like I-10 Cut and Pass Picada. These decreases were substantial in magnitude (30 cm/s). There were increases in maximum velocity of a similar magnitude in "Pass Choccolatta," immediately south of the opening in Mobile Bay, and also in the lower portion of Conway Creek. These results are shown in Figure 39 as changes, positive or negative, relative to existing conditions.

The model results suggest that Choccolatta Bay would have a measurable subtidal velocity that would export water from the system. The results, shown in Figure 40, suggest that there would be an increase in subtidal flow to the south through "Pass Choccolatta," an increase in subtidal inflow through Pass Picada, and a decrease in subtidal inflow through I-10 Cut.

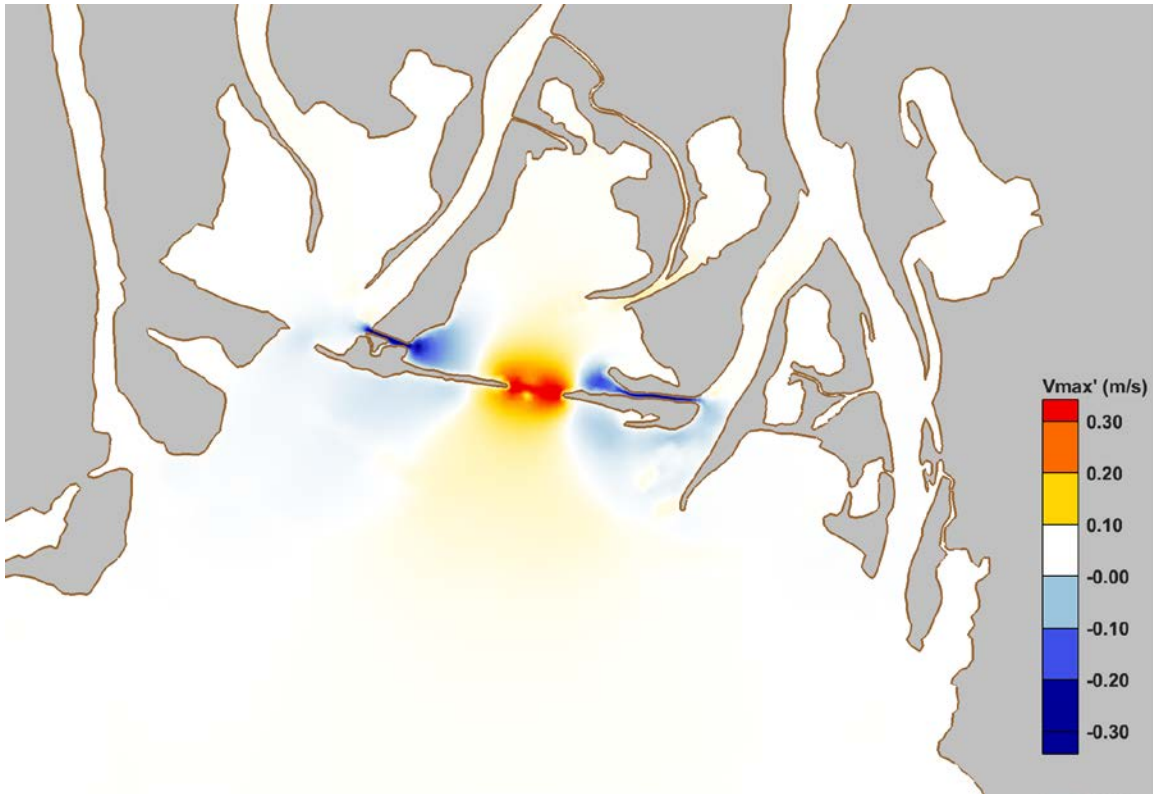


Figure 39. Change in Maximum Depth-averaged Velocity Between Case 102 and Case 002

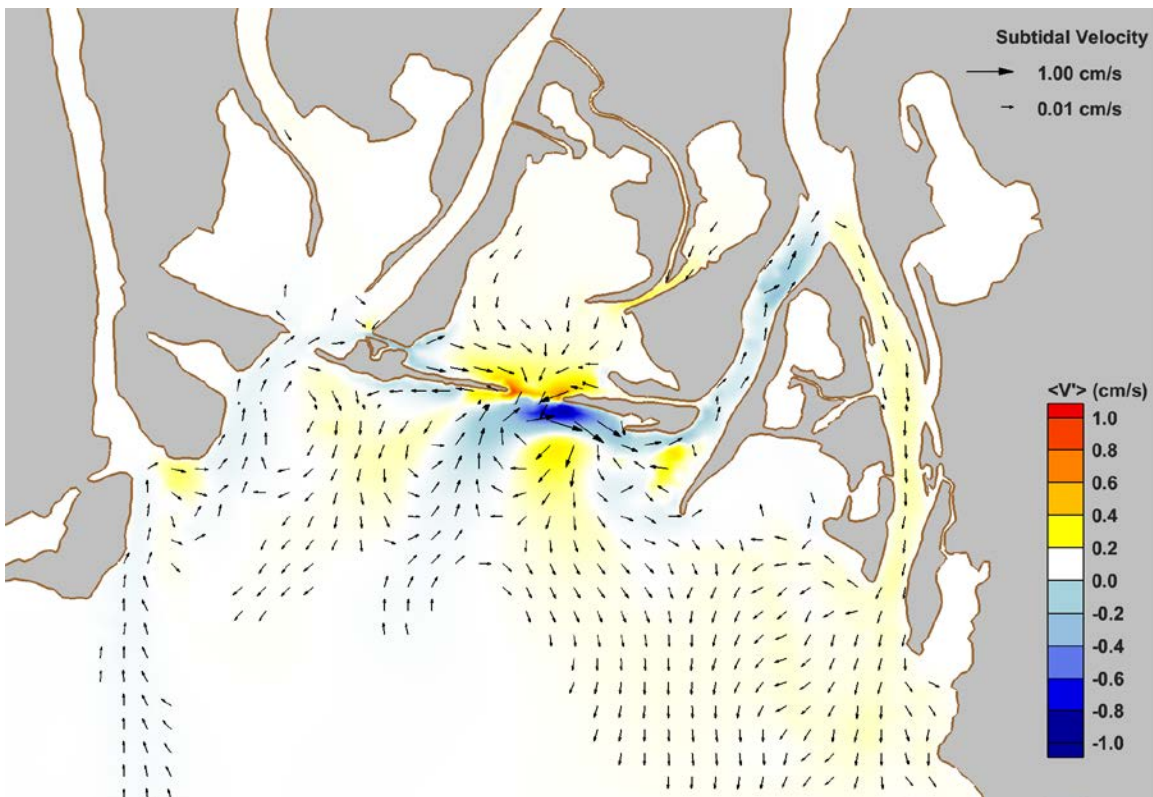


Figure 40. Change in Subtidal Velocity Between Case 102 and Case 002

Changes in the predicted velocities through each of Choccolatta Bay's connections produced substantial changes in volume discharge through those openings. For example, the effects of the new constructed opening on discharge through I-10 Cut and Pass Picada are shown in Figure 41 and Figure 42, respectively. Ignoring the first day of the time-series, which has oscillations attributed to model spinup, the discharge through each opening decreased by an order of magnitude when compared to existing conditions.

While the constructed opening had no effect on tidal exchange at Justins Bay, there was an 82.1% increase in the volume of water exchanged for Choccolatta Bay relative to existing conditions. The model predicted 90% reductions in tidal exchange through I-10 Cut and Pass Picada, and a more than 8000% increase in tidal exchange through "Pass Choccolatta," as compared to the culverts. The tidal exchange volumes associated with the maximum flood tide range for Case 102 are summarized in Table 19.

The substantial reductions in tidal exchange in I-10 Cut and Pass Picada could lead to changes in water quality over time. The extent to which water characteristics might change in these areas could be considered in future studies.

In terms of the percentage of total volume of water exchanged in the system, "Pass Choccolatta" was responsible for 84% of tidal exchange, with the I-10 Cut and Pass Picada exchanging only 1.4% and 2.6% of the total volume, respectively. This distribution is shown graphically in Figure 43.

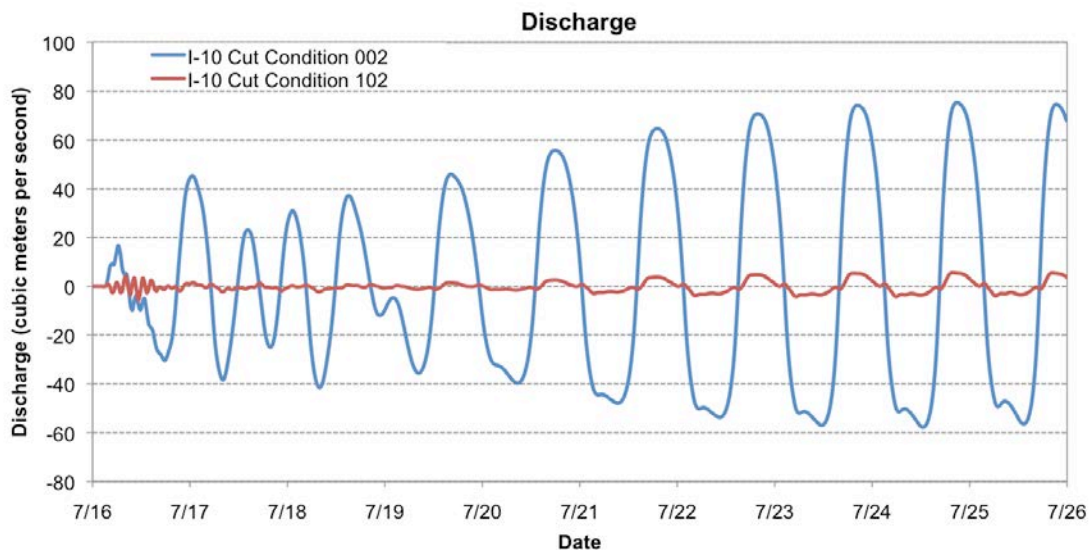


Figure 41. Time-Series of Discharge Through I-10 Cut for Case 102 and Case 002

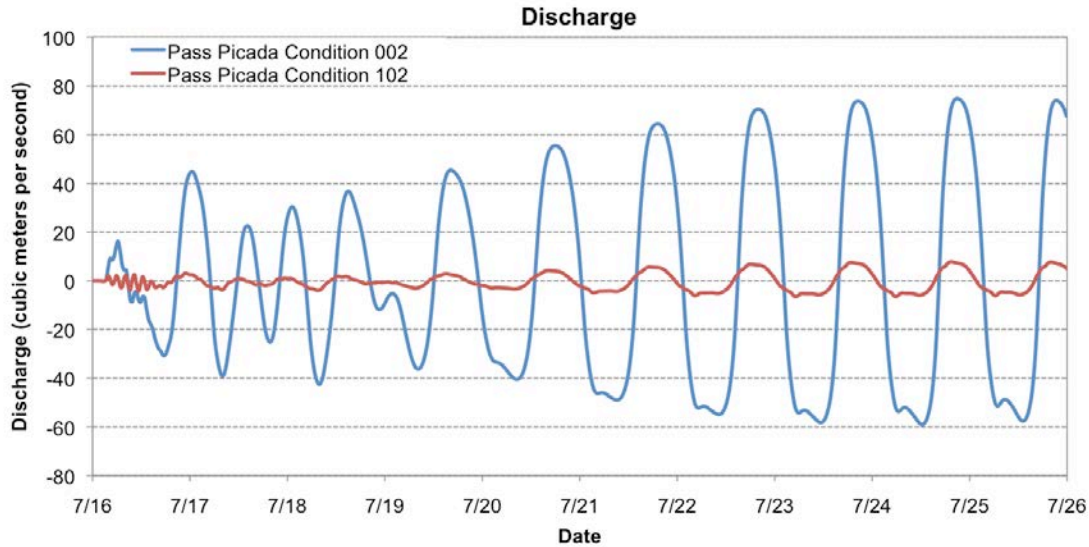


Figure 42. Time-Series of Discharge Through Pass Picada for Case 102 and Case 002

Table 19. Maximum Tidal Volume Exchanged (in cubic meters) Between Successive Low and High Water on a Flooding Tide for Case 102, and the Percent Change Relative to Existing Conditions (Case 002)

Location		Tidal Volume Exchange (m ³)	% Change, 002
Chocolatta Bay	I-10 Cut	121,073 (in)	-94.5
	Little Creek	11,770 (out)	+79.9
	Conway Creek	996,890 (out)	+7.5
	"Pass Chocolatta"	7,269,809 (in)	+8394.1
	Pass Picada	221,881 (in)	-90.2
	Total (net)	6,604,103 (in)	+82.1
Justins Bay	Sardine Pass	413,050 (in)	<+1



Figure 43. Distribution and Directions of Tidal Exchange Volumes, Expressed as Percentages of the Total Volume, for Choccolatta Bay in the Modified Scenario

6.5.3 Sediment Transport Potential

Predicted changes in velocity for the constructed opening result in decreased sediment transport through I-10 Cut and Pass Picada, with increased sediment transport likely in lower Conway Creek and "Pass Choccolatta." The magnitude of the changes is generally 25% to 50%, positive and negative, relative to sediment transport under existing conditions. As in previous comparisons, positive values indicate increases relative to existing conditions while negative values indicate decreases relative to existing conditions. These potential changes in sediment transport characteristics, including bedload transport, resuspension rates, and depositional patterns, are presented in Figure 44, Figure 45, and Figure 46, respectively.

The decreased velocities and tidal exchange through I-10 Cut and Pass Picada increased the potential for sediment deposition in those areas. Areas in and near "Pass Choccolatta," as well as in the upper portions of Choccolatta Bay, showed a tendency of becoming less depositional in this scenario. The potential changes in depositional areas and patterns are shown in Figure 46. Here, a value of +1.0 indicates an area that becomes depositional as a result of the modification; a value of 0.0 indicates no change in depositional patterns between the scenarios; and a value of -1.0 indicates that an area that was depositional under existing conditions is no longer.

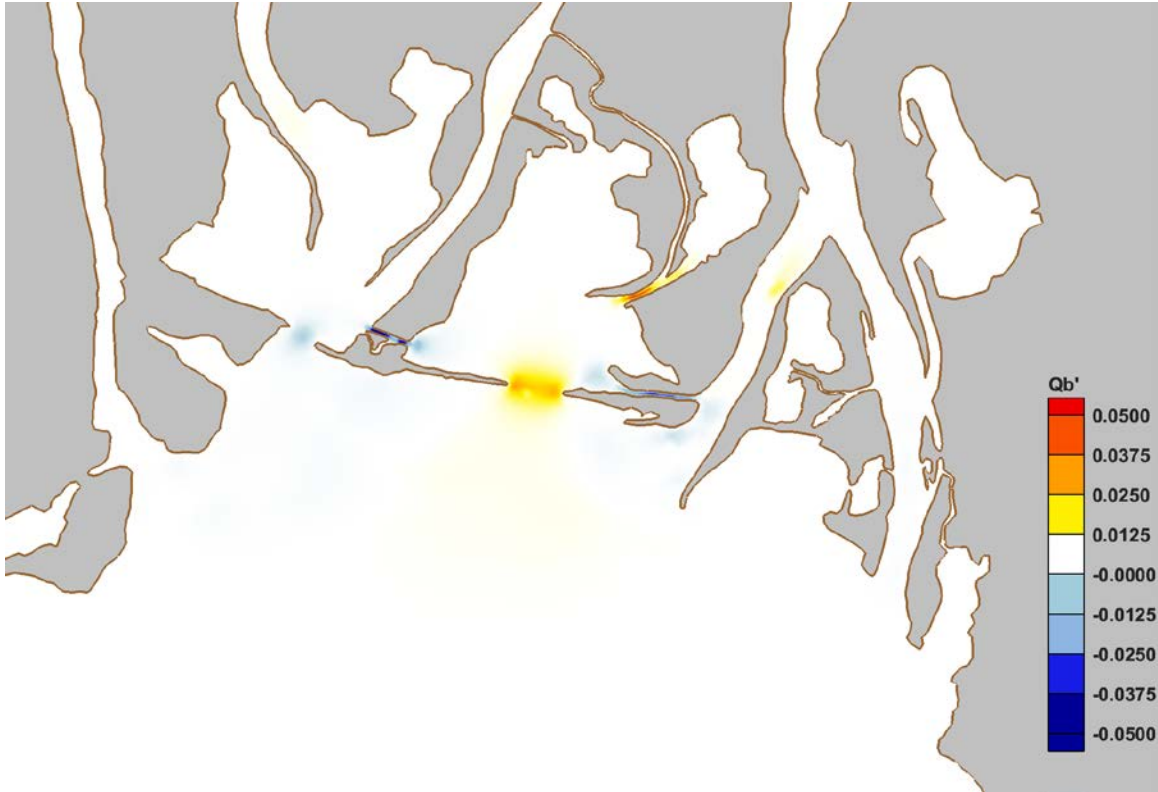


Figure 44. Changes in Potential Bedload Transport Rates ($m^3/s/m^2$) Between Case 102 and Case 002

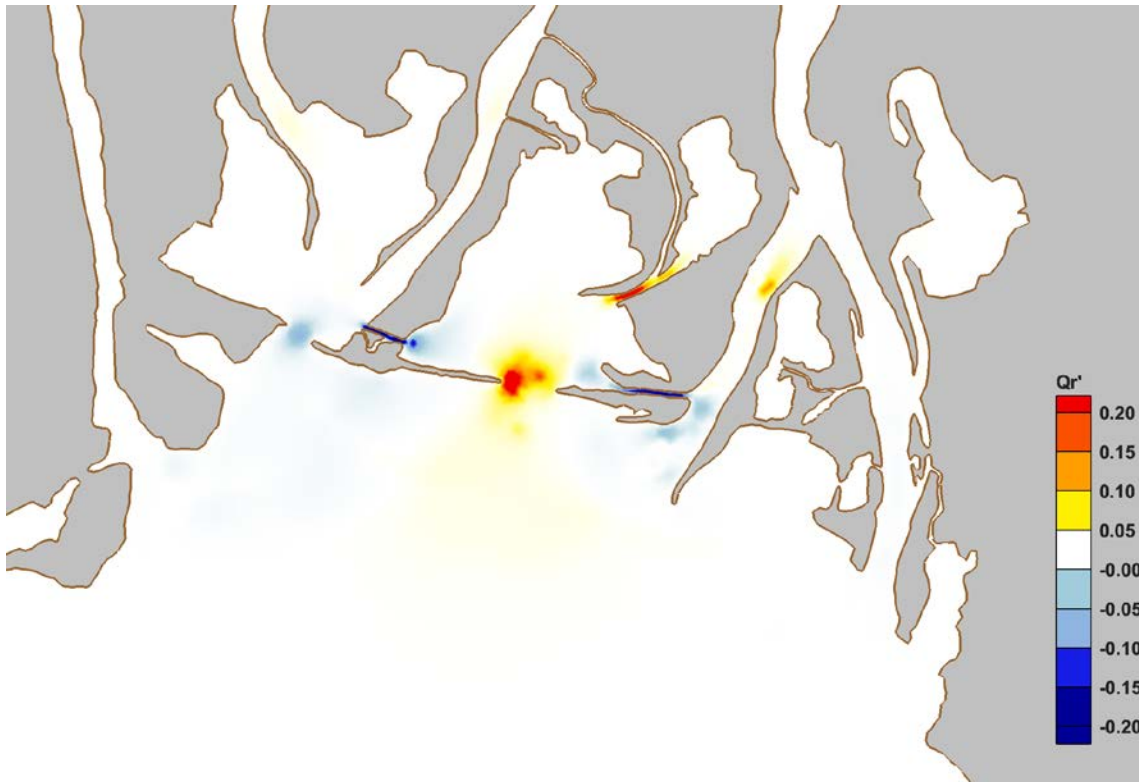


Figure 45. Changes in Potential Resuspension Rates ($m^3/s/m^2$) Between Case 102 and Case 002

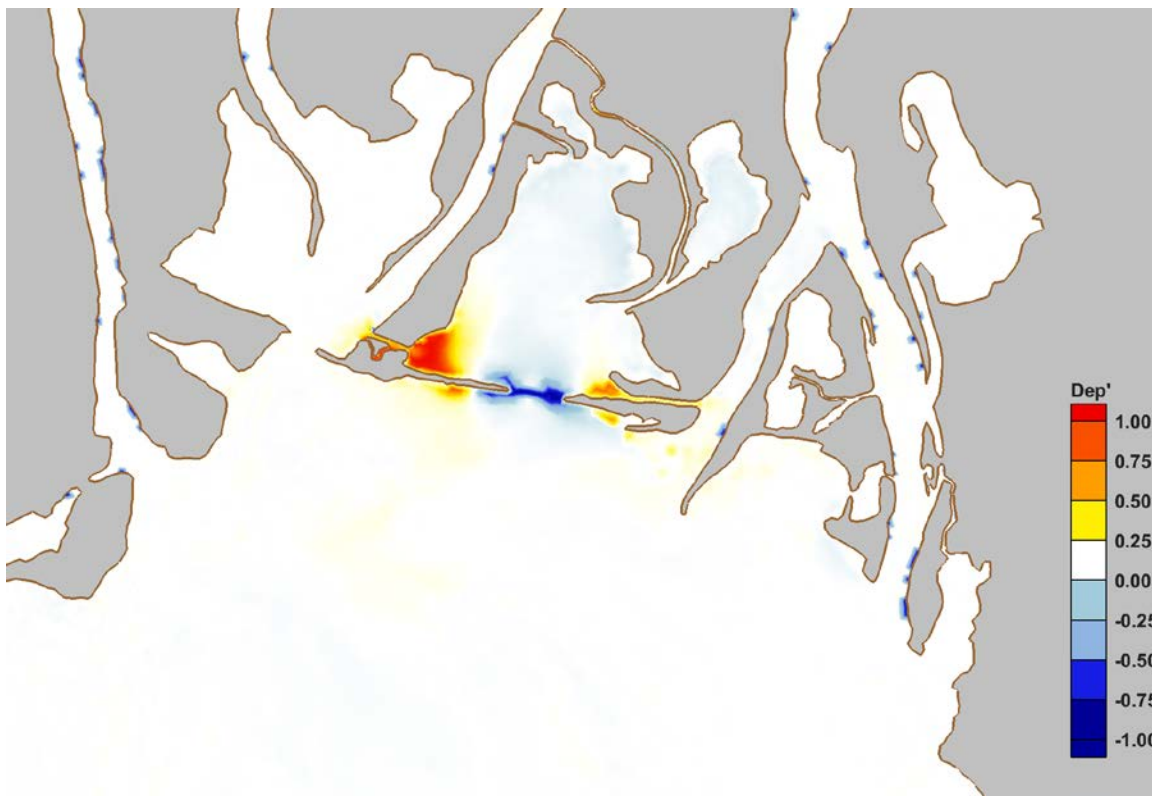


Figure 46. Changes in Potential Sediment Deposition Patterns (+1.0, More Deposition; 0.0 No Change; -1.0 No Longer Depositional)

6.5.4 Flushing

Increases in particle residence time were predicted near I-10 Cut and Pass Picada, whereas a decrease in residence time by more than 3 days extended far into Choccolatta Bay from the constructed opening. Therefore, some areas of the system saw improved flushing while other areas experienced decreased flushing. The potential effects of a constructed opening for Choccolatta Bay on its flushing characteristics are shown in Figure 47. The changes in residence time are presented as the difference between Case 102 and Case 002 ($Tr' = Tr_{102} - Tr_{002}$).

The simulation of "Pass Choccolatta" improved flushing of particles from the system by nearly 10% compared to existing conditions. Approximately 97% of the particles escaped through "Pass Choccolatta," with no particles exiting through I-10 Cut or Pass Picada. The system-wide averages for residence and exposure time, as well as the percent of particles removed from the system, are listed in Table 20. While the changes are modest, reductions in residence and exposure time are evident as is the increased number of particles removed from the system.

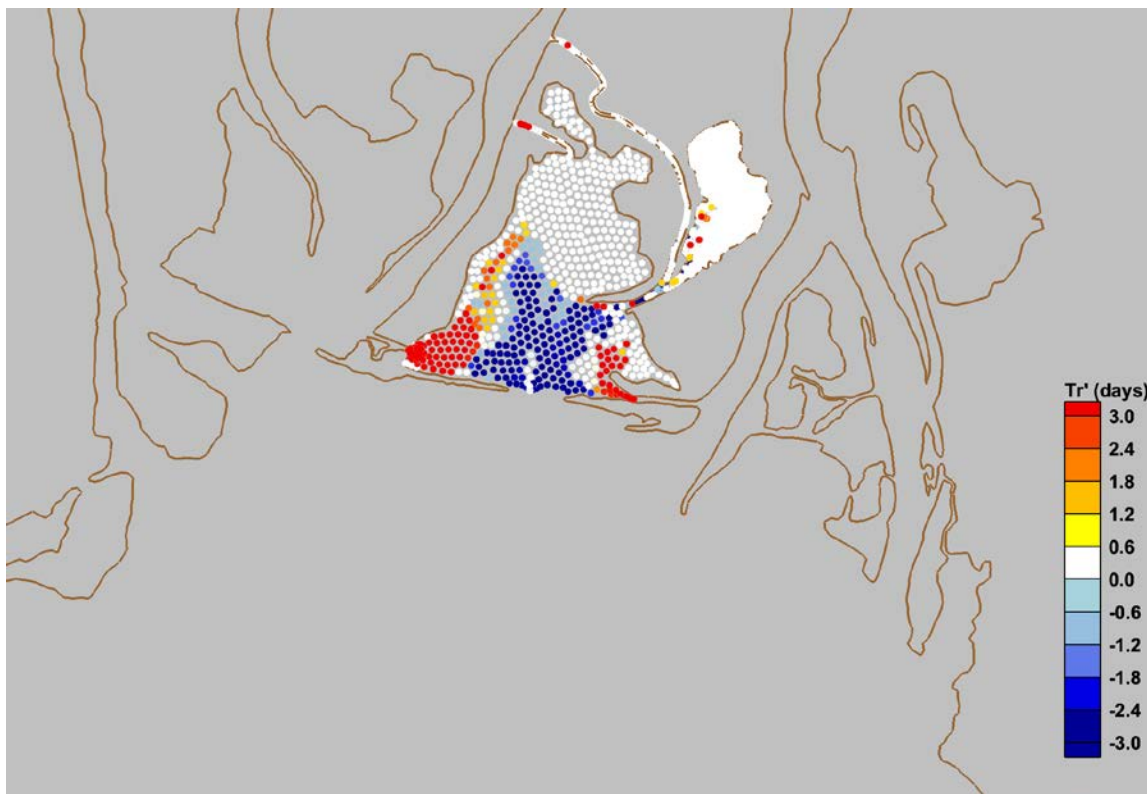


Figure 47. Change in Particle Residence Time (Tr') as a Function of Initial Position for Case 102

Table 20. Changes in Average Residence and Exposure Times and Percentage of Particles Removed for Case 102

Location	Avg. Residence Time (days)		Avg. Exposure Time (days)		% Particles Removed	
	Case 002	Case 102	Case 002	Case 102	Case 002	Case 102
Chocolatta Bay	7.9	7.8	8.4	8.3	20.2	21.6
Justins Bay	8.4	N/A	8.6	N/A	7.1	N/A

6.6 Justins Bay - Case 202

This alternative restoration scenario considers a hypothetical opening, "Pass Justin," through the Causeway at Justins Bay only. The forcing conditions consist of representative tides and average summer river discharge under present day sea levels. Simulation results for Case 202 are presented as differences relative to existing conditions (Case 002).

6.6.1 Water Levels

The constructed opening of "Pass Justin" resulted in a more than 10 cm increase in maximum water levels within Justins Bay, and an increase of approximately 5 cm in Sardine Pass. Model predictions revealed negligible changes in maximum water levels elsewhere in the study area. These changes are shown in Figure 48.

The model predicted a 63.7% increase in the tide range of Justins Bay while completely removing the exiting three-hour tidal phase lag with Mobile Bay (Figure 49). The opening did

not have a measurable effect on tide range elsewhere in the system. A comparison of water levels in time under existing and modified conditions for Justins Bay is shown in Figure 50, and a summary of tide ranges is listed in Table 21.

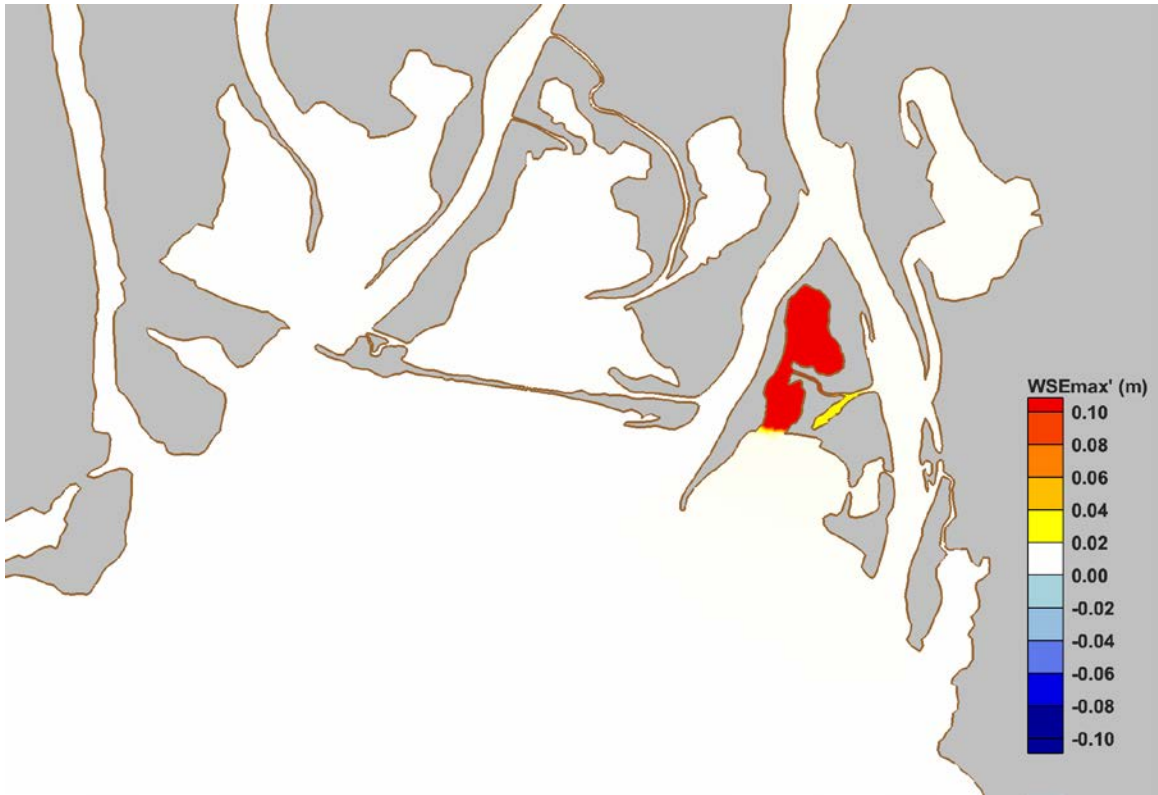


Figure 48. Changes in Maximum Predicted Water Levels (WSEmax') Between Case 202 and Case 002

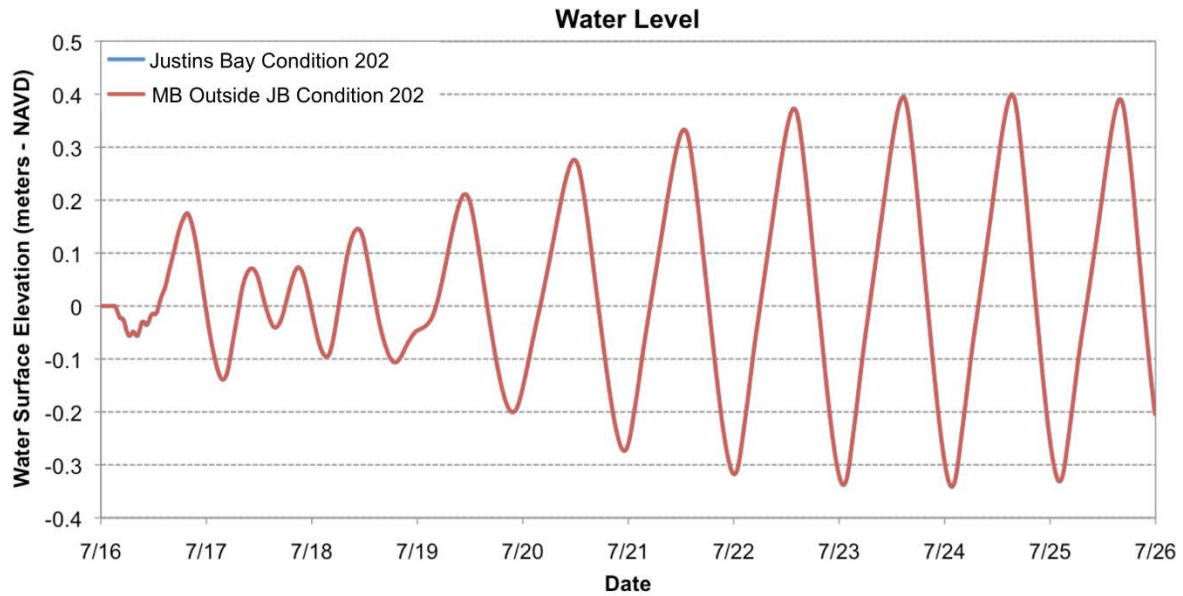


Figure 49. Comparison of Predicted Water Levels in Justins Bay and a Point in John's Bend for Case 202

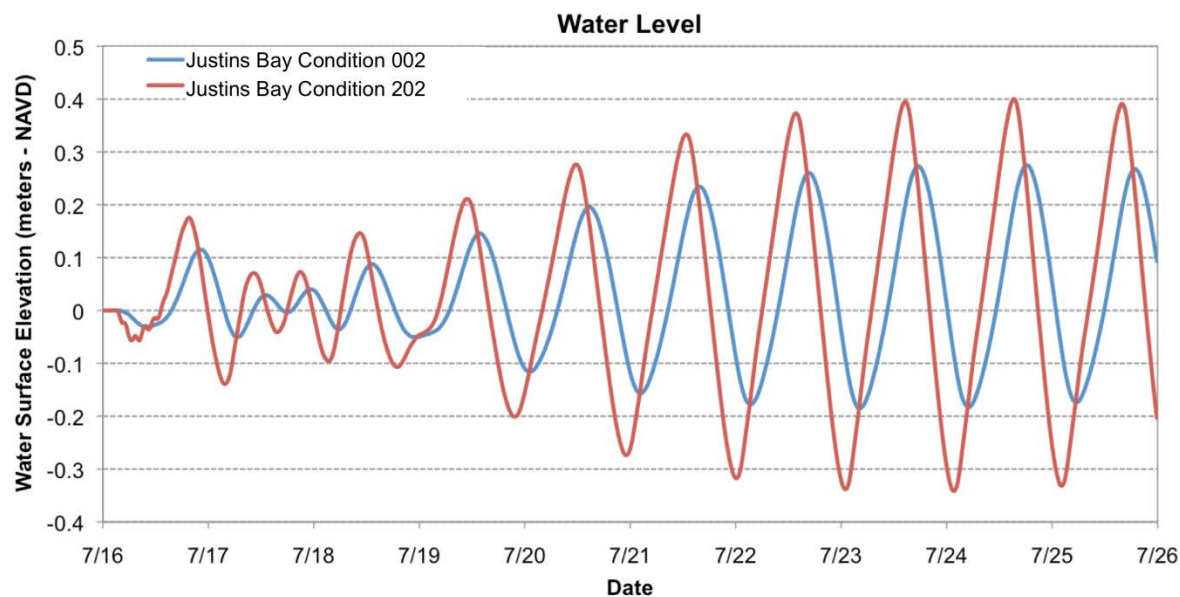


Figure 50. Time-series of Water Levels in Justins Bay for Case 202 and Case 002

Table 21. Maximum Tide Ranges for Case 202 and Changes Relative to Existing Conditions in the Study Area

Location	Tide Range (m)	% Change, 002
Chocolatta Bay	0.676	<+1
North Mobile Bay	0.720	NC
Justins Bay	0.722	+63.7
Ducker Bay	0.720	<+1
Shellbank River North	0.723	<+1
Shellbank River South	0.721	<+1

6.6.2 Flows

The predicted change in maximum depth-averaged water velocity relative to existing conditions is shown in Figure 51. The model predicted an increase in maximum velocity on the order of 10 to 15 cm/s throughout much of Justins Bay, with increases on the order of 5 to 10 cm/s in Ducker Bay and John's Bend. A substantial decrease in maximum velocity through Duck Skiff Pass and Sardine Pass was also predicted and is attributed to decreased hydraulic efficiency due to the constructed opening.

The model predicted an increase in subtidal flow to the west in Sardine and Duck Skiff Pass, and increased subtidal flow to the south in Justins Bay. Modest changes were also evident in the lower Apalachee and Blakeley Rivers. The magnitude of predicted subtidal velocity differences were on the order of ± 1 cm/s and extended beyond Justins Bay. Changes in subtidal velocity, relative to existing conditions, are shown in Figure 52 for the constructed opening at Justins Bay.

While a goal of the constructed opening for Justins Bay is to increase tidal communication with Mobile Bay, model results indicate that other portions of the existing system may be impacted. For example, consider the time-series of discharge through Sardine Pass under existing and

modified conditions shown in Figure 53. Under existing conditions Sardine Pass experienced a balanced discharge of $\pm 15 \text{ m}^3/\text{s}$, whereas under modified conditions the discharge magnitude decreased to $\sim 2 \text{ m}^3/\text{s}$ and was directed into the system on average.

When compared to the volume exchanges under existing conditions (Case 002), the total volume exchange between Justins Bay and adjacent water bodies increased by over 122% in spite of a more than 87% reduction in tidal volume exchange through Sardine Pass. As in the existing channels of Choccolatta Bay, the substantial reductions in tidal exchange and water velocities through Sardine Pass could affect water quality over time. This should be considered in future studies.

The effect of "Pass Justin" on volume exchange elsewhere in the study area was calculated as much less than 1%. The volume exchange through Pass Justin and Sardine Pass, as well as elsewhere in the system, is summarized in Table 22. As in previous comparisons, the volume exchange was computed as the cumulative discharge through an existing or potential opening between successive low and high water stages for the maximum flood tide.

In terms of the total volume of water exchanged, "Pass Justin" was responsible for 94% of the tidal exchange with Sardine Pass contributing only 6% of the exchange volume. A graphical representation of this tidal exchange distribution is shown in Figure 54.



Figure 51. Predicted Change in Maximum Depth-averaged Velocity (V_{max}') Between Case 202 and Case 002

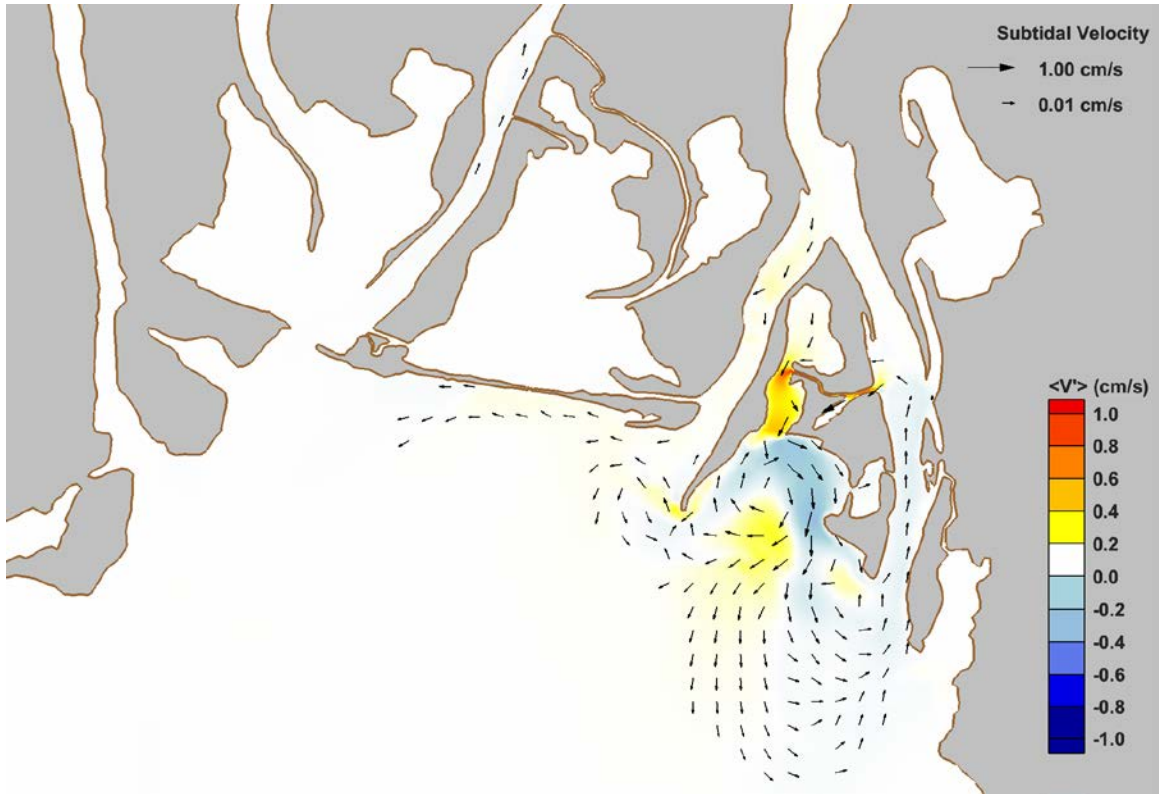


Figure 52. Predicted Change in Subtidal Velocity ($\langle V' \rangle$) Between Case 202 and Case 002

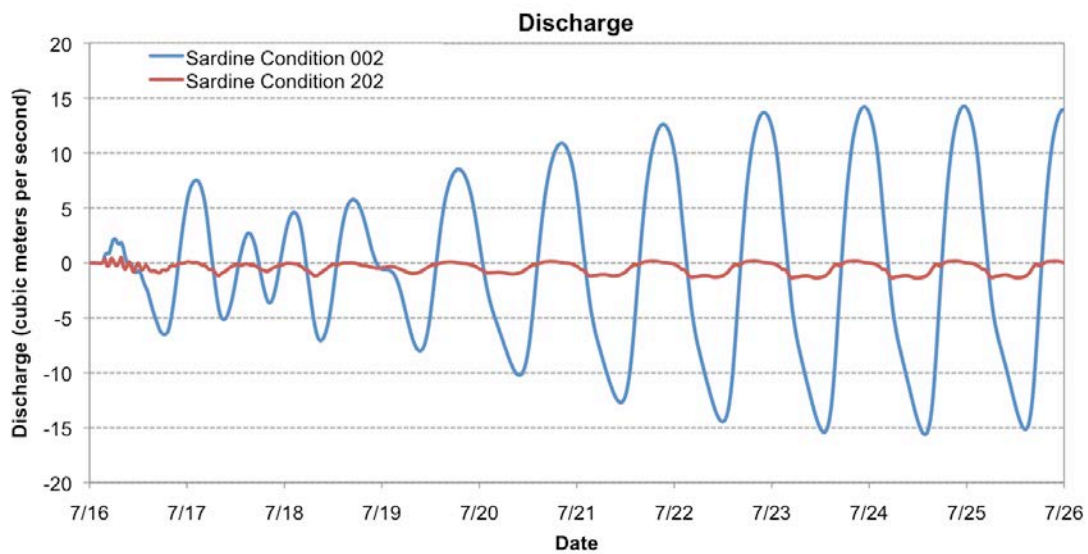


Figure 53. Time-series Discharge Through Sardine Pass for Case 202 and Case 002

Table 22. Maximum Tidal Volume Exchanged (in cubic meters) Between Successive Low and High Water on a Flooding Tide for Case 202, and the Percent Change Relative to Existing Conditions (Case 002)

Location		Tidal Volume Exchange (m ³)	% Change, 002
Choccolatta Bay	I-10 Cut	2,218,129 (in)	<+1
	Little Creek	6,696 (out)	+2.3
	Conway Creek	946,084 (out)	+2
	Culverts	86,418 (in)	+1
	Pass Picada	2,281,426 (in)	<+1
	Total (net)	3,633,194 (in)	<<+1
Justins Bay	Sardine Pass	52,063 (in)	-87.4
	"Pass Justin"	862,391 (in)	N/A
	Total (net)	914,454 (in)	+122.1



Figure 54. Distribution and Direction of Tidal Exchange Volumes in Justins Bay for Case 202, Expressed as Percentages of the Total Volume of Water Exchanged

6.6.3 Sediment Transport Potential

Changes in potential transport rates correspond to predicted changes of velocity increase and/or decrease throughout the system. For example, predicted increases in velocity throughout Justins Bay yielded higher transport rates in those areas, whereas decreased velocity in Duck Skiff and

Sardine Pass resulted in reductions in transport rates in those water bodies. The magnitude of bedload transport and resuspension rate changes, relative to existing conditions, was on the order of 5% and 25%, respectively. The predicted changes in potential bedload transport and resuspension rates, relative to rates under existing conditions, are shown in Figure 55 and Figure 56, respectively.

As a result of "Pass Justin," most of Justins Bay was predicted to become less depositional, whereas increased deposition was predicted to occur in Sardine Pass and some isolated portions of Ducker Bay. Predicted changes in sediment deposition patterns are shown in Figure 57.

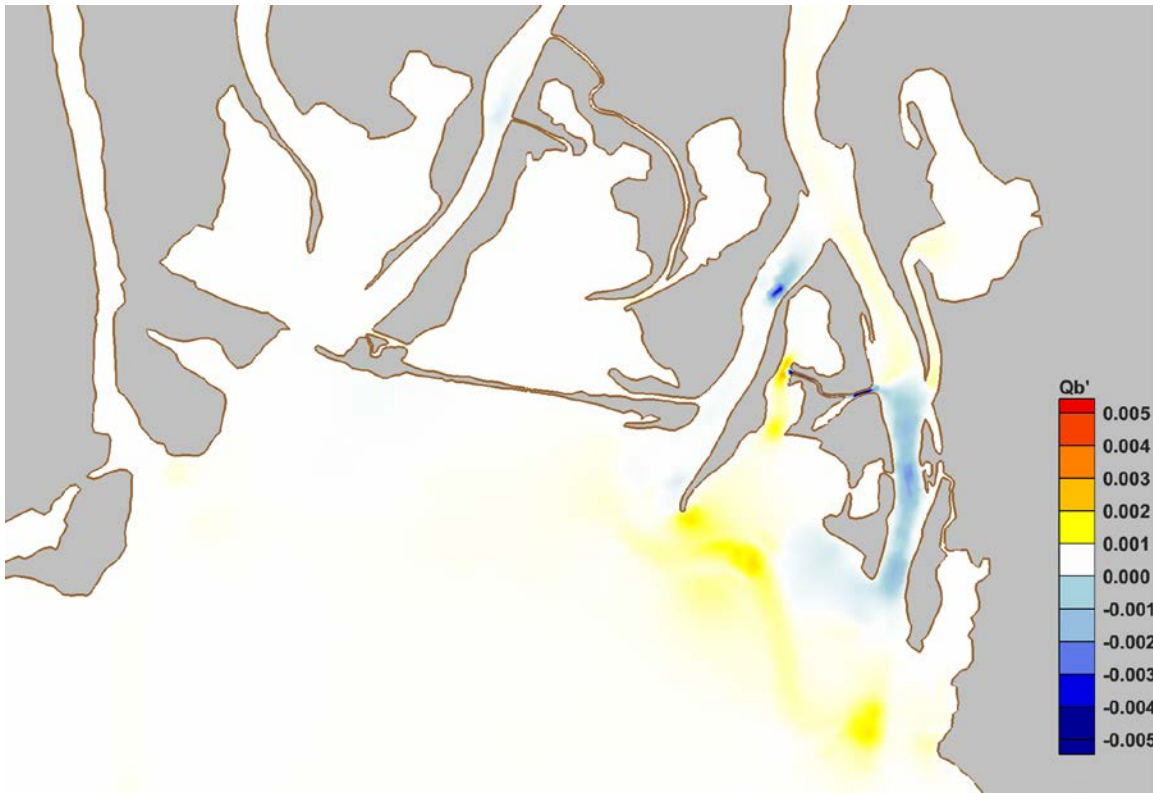


Figure 55. Predicted Change in Bedload Transport Rates ($m^3/s/m^2$) from Case 002 to Case 202.

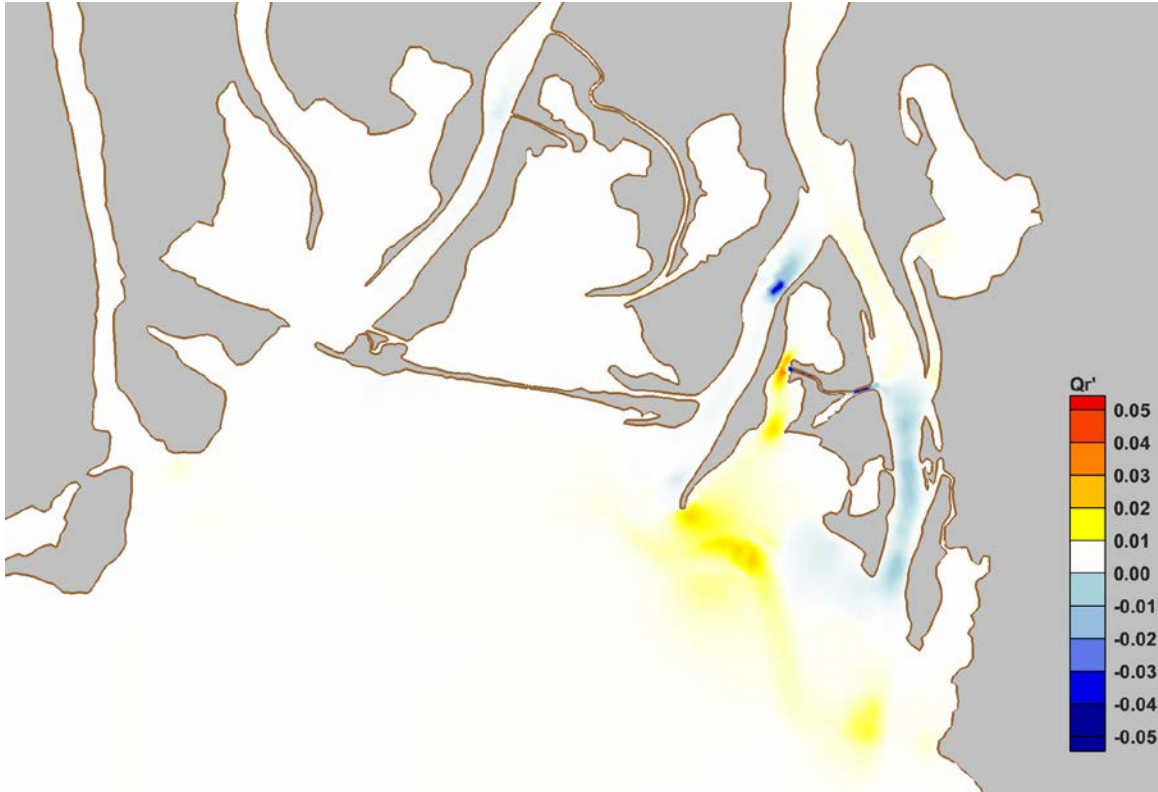


Figure 56. Predicted Change in Resuspension Rates ($m^3/s/m^2$) from Case 002 to Case 202

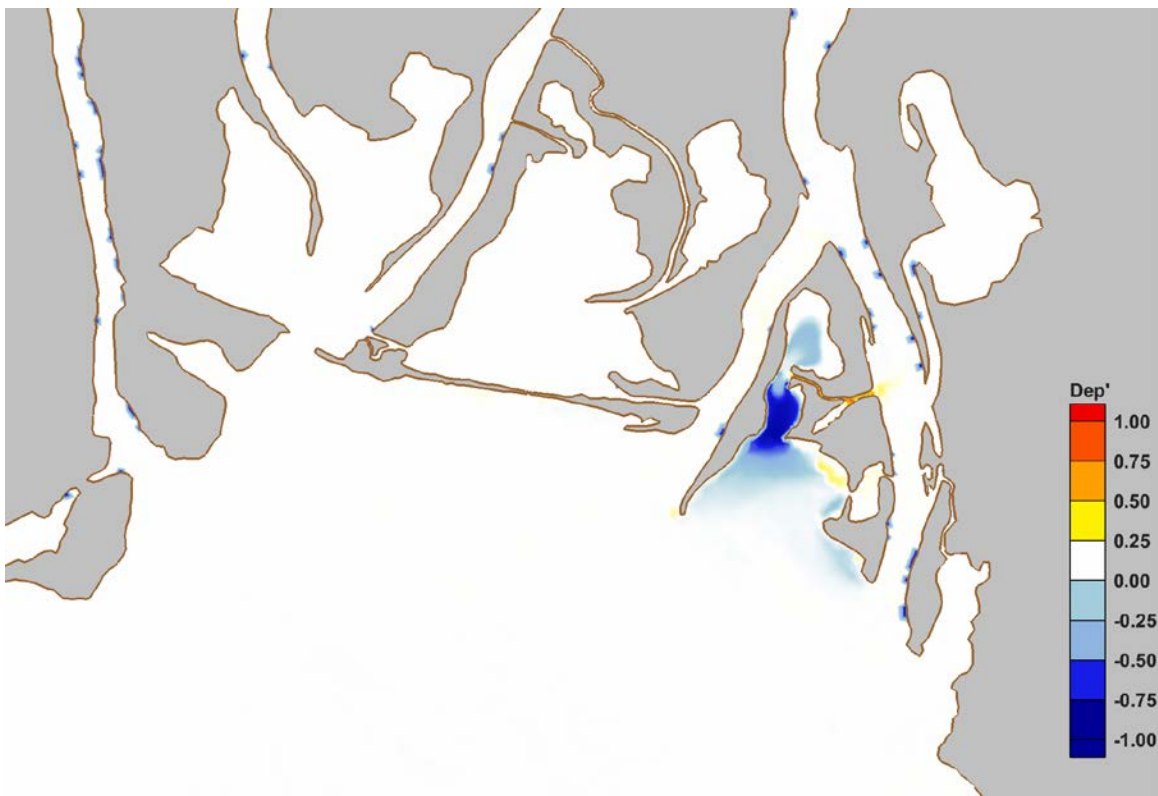


Figure 57. Potential Change in Sediment Depositional Areas from Case 002 to Case 202, Where 1.0 Indicates New Deposition, 0.0 Indicates No Change, and -1.0 Indicates the Area is No Longer Depositional

6.6.4 Flushing

The LPTM analysis predicted a substantial reduction in residence times throughout much of Justins Bay, but a substantial increase in residence times for particles in Sardine Pass. On average, residence and exposure times were predicted to decrease by 15% and the total number of particles removed from the system increased from 7.1% to 35.6%. That is a 500-fold increase in the number of particles flushed from the Justins Bay system. The predicted effects of "Pass Justin," on the flushing characteristics of Justins Bay and Sardine Pass are shown in Figure 58 and are summarized in Table 23.



Figure 58. Predicted Change in Residence Time (Tr') from Case 002 to Case 202 as a Function of Particle Initial Position

Table 23. Changes in Average Residence and Exposure Times, and Percentage of Particles Removed, for Case 202

Location	Avg. Residence Time (days)		Avg. Exposure Time (days)		% Particles Removed	
	Case 002	Case 202	Case 002	Case 202	Case 002	Case 202
Chocolatta Bay	7.9	N/A	8.4	N/A	20.2	N/A
Justins Bay	8.4	6.8	8.6	7.4	7.1	35.6

6.7 Shellbank River - Case 302

This alternative restoration scenario considers a hypothetical opening, "Shellbank Cut," through the Causeway at Shellbank River only. The forcing conditions consist of representative tides and

average summer river discharge under present day sea levels. Simulation results for Case 302 are presented as differences relative to existing conditions (Case 002).

6.7.1 Water Levels

The model predicted a very small, and very local, increase in maximum water levels (<1 cm) below "Shellbank Cut." The predicted changes are limited to areas south of the Causeway in Shellbank River and also the tidal creek connecting to D'Olive Bay. These results are shown in Figure 59. The constructed opening at Shellbank River had a negligible effect on tide ranges elsewhere in the study area, as shown in Table 24.



Figure 59. Predicted Change in Maximum Water Elevation (WSEmax') from Case 002 to Case 302

Table 24. Maximum Tide Ranges for Case 302 and Relative Changes from Case 002

Location	Tide Range (m)	% Change, 002
Chocolatta Bay	0.675	NC
North Mobile Bay	0.720	NC
Justins Bay	0.441	NC
Ducker Bay	0.718	NC
Shellbank River North	0.721	NC
Shellbank River South	0.720	<+1

6.7.2 Flows

Model predictions suggested an increase in maximum depth-averaged velocity, on the order of 4 to 8 cm/s, through Shellbank River as a result of the opening. Although difficult to see in the color scale, there are very minor changes to velocity in Sardine Pass and Duck Skiff Pass, which are discussed further below. The predicted changes in maximum depth-averaged velocity are shown in Figure 60.

The opening in Shellbank River may increase the subtidal flow to the south by 1 cm/s or more, with additional southward flow through the adjacent tidal creek and D'Olive Bay. These effects are demonstrated in Figure 61. The light blue colors and northward-pointing arrows in Blakeley River indicate a corresponding decrease in southward flow in that portion of the river. This reduction is due to Shellbank River acting as a supplemental flow path for Blakeley River flows.

The predicted discharge magnitude through Shellbank River was predicted to be $\sim 1 \text{ m}^3/\text{s}$ and was seaward directed on average. Due to river forcing, the model predicted very little northward flow in Shellbank River, but it did increase in magnitude as the tide range grew. A time-series comparison of discharge through Shellbank River under existing conditions (i.e., no flow) and with the potential opening is shown in Figure 62.

As in other simulations, the volume exchanges for Choccolatta Bay and Justins Bay were calculated as the cumulative discharge during successive low and high water events during the maximum flood tide. The results are provided in Table 25. The model predicts that an opening in Shellbank River would have a negligible ($\ll 1\%$ change from existing conditions) effect on volume exchange for Choccolatta Bay. However, the potential opening would have a measurable, but small, effect on the volume exchange for Justins Bay ($\sim 2\%$ decrease from existing conditions). Therefore, an opening at Shellbank River may have a measurable and unintended impact on a separate water body of concern within the study area. This was not the case in the previous simulations where potential openings at Choccolatta Bay and Justins Bay were predicted to act in complete isolation, not having measurable impacts at other restoration sites.



Figure 60. Predicted Change in Maximum Water Velocity (V_{max}') from Case 002 to Case 302

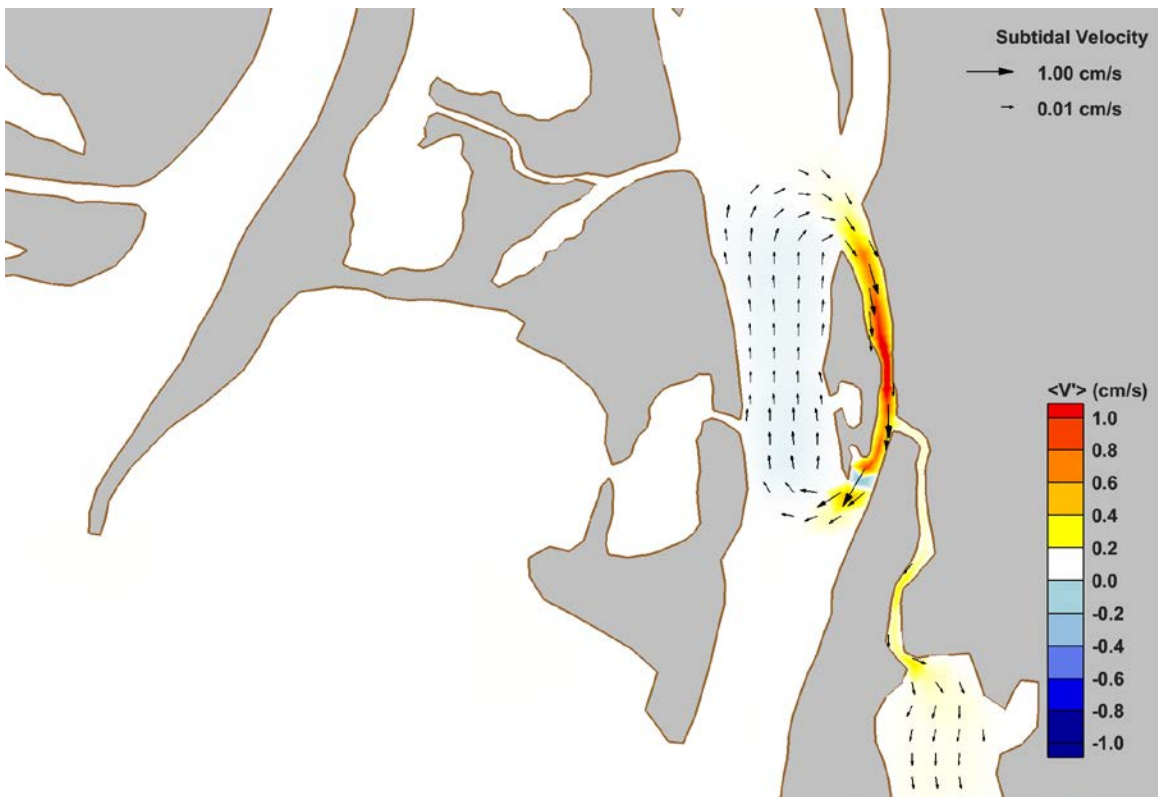


Figure 61. Predicted Change in Subtidal Velocity ($\langle V' \rangle$) from Case 002 to Case 302

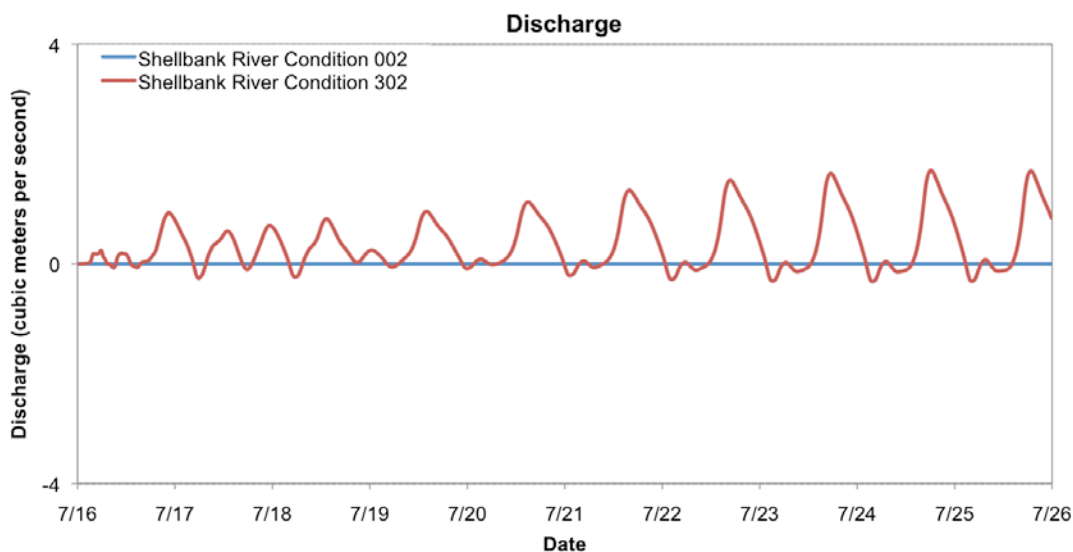


Figure 62. Time-series Comparison of Discharge through Shellbank River for Case 002 and Case 302

Table 25. Maximum Tidal Volume Exchanged (in m³) between Successive Low and High Water on a Flooding Tide for Case 302, and the Percent Change Relative to Existing Conditions (Case 002)

Location		Tidal Volume Exchange (m ³)	% Change, 002
Chocolatta Bay	I-10 Cut	2,217,002 (in)	<+1
	Little Creek	6,696 (out)	+2.3
	Conway Creek	946,355 (out)	+2.1
	Culverts	86,398 (in)	+1
	Pass Picada	2,280,440 (in)	<+1
	Total (net)	3,630,789 (in)	<<+1
Justins Bay	Sardine Pass	403,378 (in)	-2.1

6.7.3 Sediment Transport Potential

The opening of "Shellbank Cut" produced minor changes in sediment transport behavior. The potential change in bedload transport rates vary by less than 5%, with modest increases along Shellbank River and decreases along the Blakeley River immediately to the west. Predicted changes in resuspension rates varied from decreases of 1% along the Blakeley River to increases of <1% along Shellbank River and portions of lower Blakeley River. These potential changes in bedload sediment transport and resuspension rates are shown in Figure 63 and Figure 64, respectively, and are small relative to values under existing conditions. Note the compressed contour scale of these figures.

Predicted changes in sediment deposition potential are shown in Figure 65 for the potential opening along Shellbank River. There was a slight increase in deposition potential at the northern confluence of Blakeley and Shellbank Rivers. Elsewhere in Shellbank River, the effect of the potential opening would be to decrease sediment deposition in those areas and some areas extending south into D'Olive Bay.

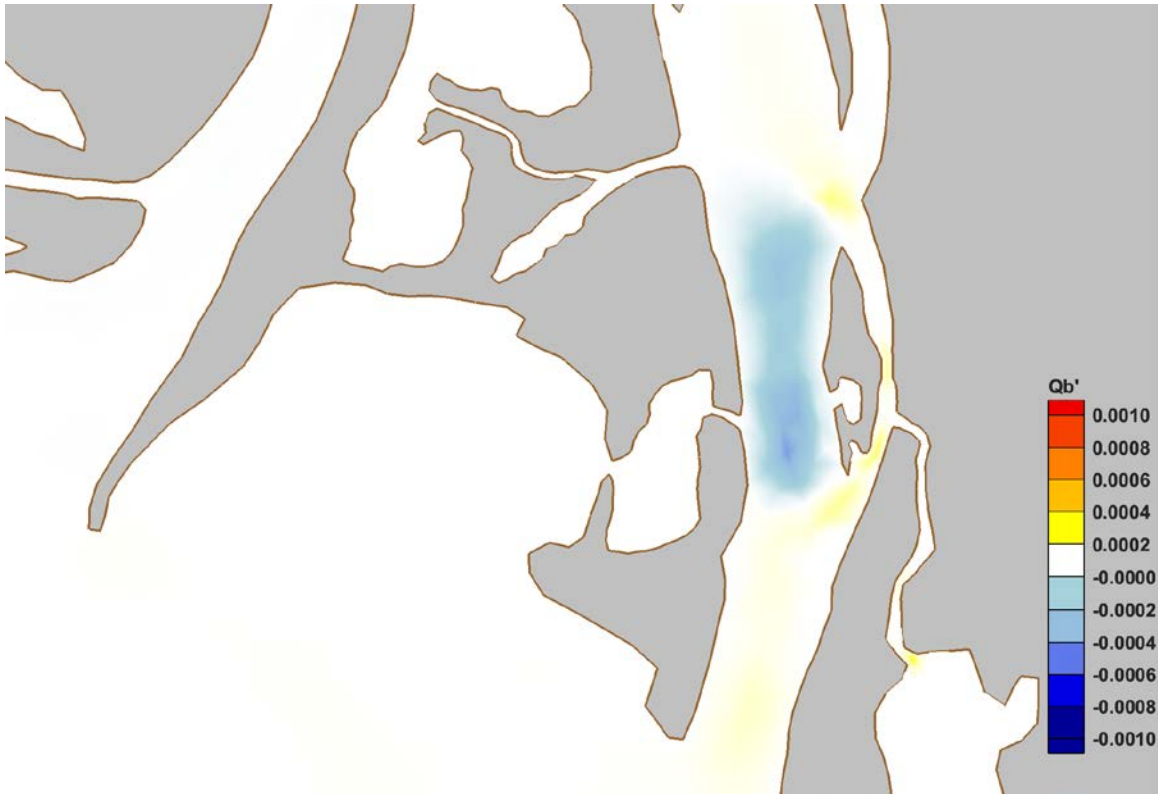


Figure 63. Predicted Change in Bedload Transport Rates ($m^3/s/m^2$) between Case 302 and Case 002

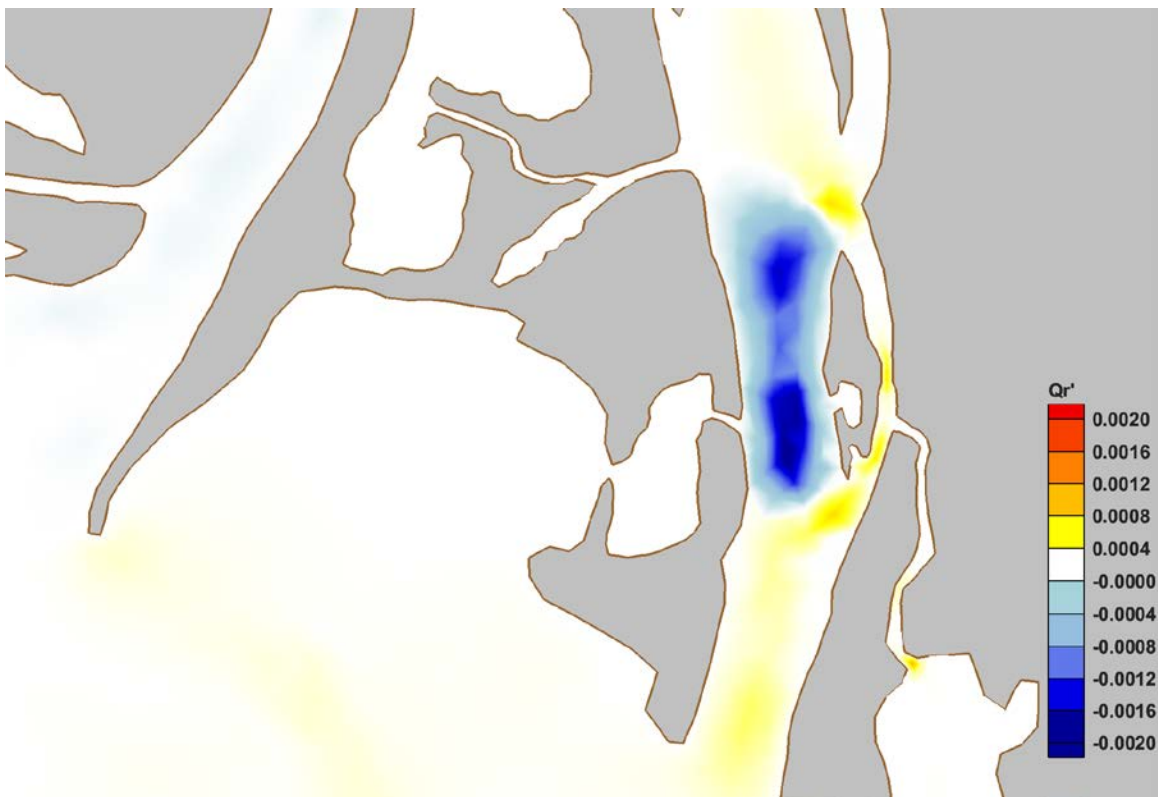


Figure 64. Predicted Change in Resuspension Rates ($m^3/s/m^2$) from Case 002 to Case 302

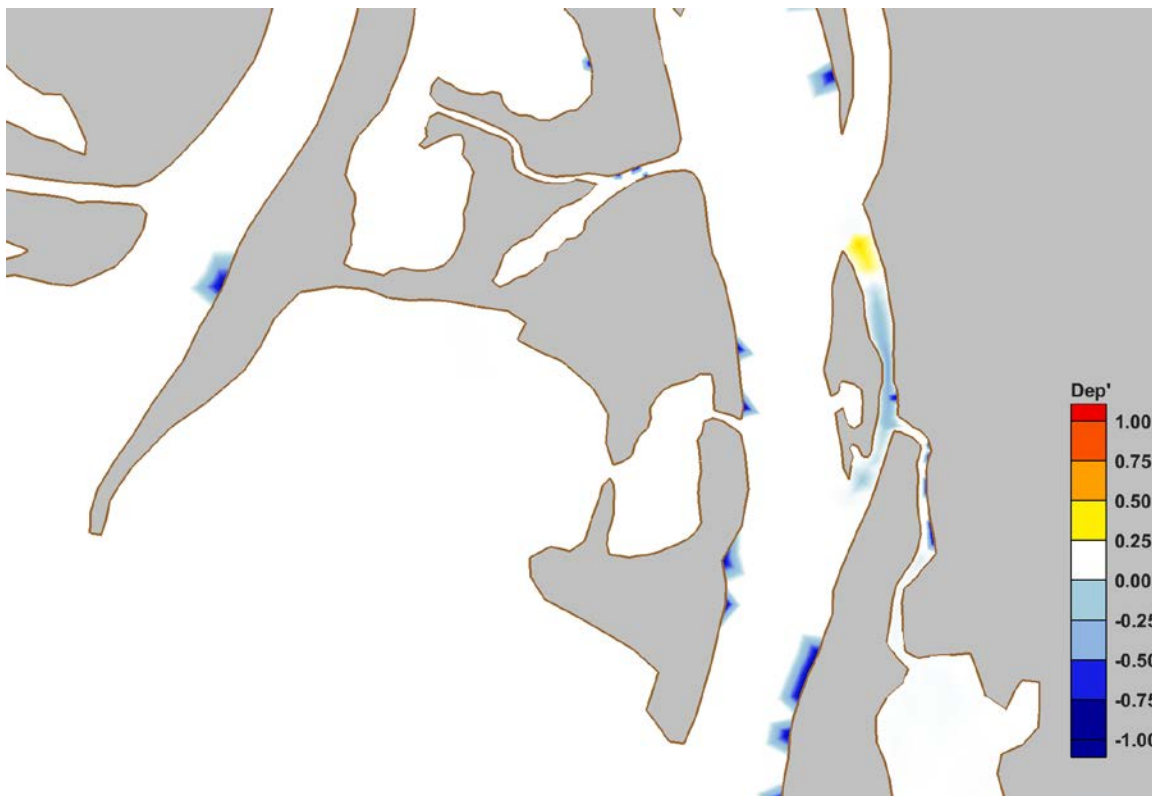


Figure 65. Potential Changes in Sediment Depositional Areas from Case 002 to Case 302. A Value of +1.0 Indicates an Area that Becomes Depositional, a Value of 0.0 Indicates No Change, and a Value of -1.0 Represents an Area that is No Longer Depositional

6.8 All Open - Case 402

This hypothetical restoration scenario considers all constructed openings through the Causeway acting simultaneously. The forcing conditions consist of representative tides and average summer river discharge under present day sea levels. Simulation results for Case 402 are presented as differences relative to existing conditions (Case 002).

6.8.1 Water Levels

The model predicted an increase in maximum water levels by 3 to 7 cm in Choccolatta Bay and Sardine Pass, while Justins Bay exhibited increases of more than 10 cm. Changes in maximum water levels, relative to existing conditions (Case 002), were negligible elsewhere in the study area. These predictions are shown in Figure 66. The figure shows almost identical behavior between this case (all open simultaneously) and each case considered individually (see Figure 36, Figure 48, Figure 59).

Similar to Case 102, the tide range in Choccolatta Bay increased by 8% from existing conditions, while Justins Bay experienced a nearly 64% increase in tide range. Changes to the tide range were negligible elsewhere in the study area. Tidal phase lags between Choccolatta Bay and Mobile Bay, and between Justins Bay and Mobile Bay, were completely relieved by their

constructed openings. Predicted maximum tide ranges at locations throughout the study area are listed in Table 26.

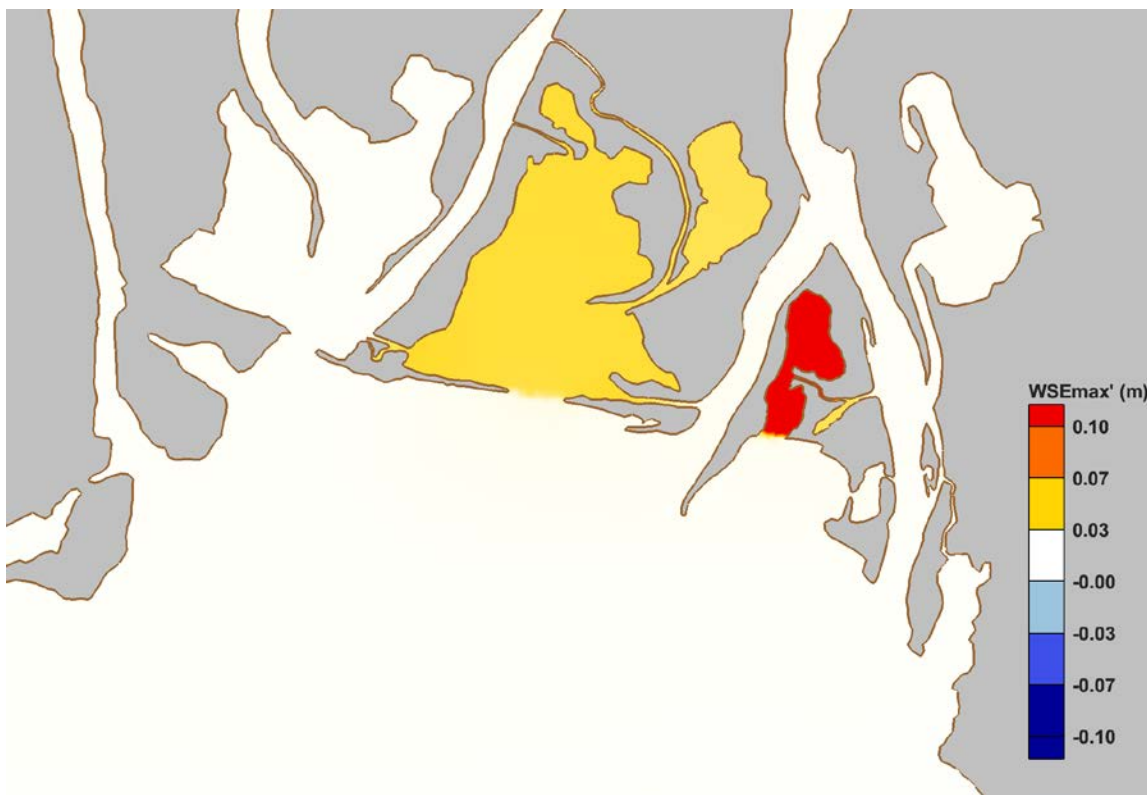


Figure 66. Predicted Change in Maximum Water Levels (WSEmax') from Case 002 to Case 402

Table 26. Maximum Tide Range at Selected Locations During Case 402 and Their Relative Changes from Case 002

Location	Tide Range (m)	% Change, 002
Chocolatta Bay	0.729	+8
North Mobile Bay	0.724	<+1
Justins Bay	0.722	+63.7
Ducker Bay	0.723	<+1
Shellbank River North	0.685	<+1
Shellbank River South	0.723	<+1

6.8.2 Flows

For Case 402, with all constructed openings acting simultaneously, the predicted changes in maximum depth-averaged water velocity were ± 30 cm/s throughout the study area, as shown in Figure 67. The most notable changes occurred within the constructed openings and their surrounding areas, and within existing tidal channels like the I-10 Cut, Pass Picada, and Sardine Pass, which all see substantial reductions in maximum water velocity due to their corresponding decrease in hydraulic efficiency. Note that a secondary effect of the openings was to increase maximum velocities by as much as 25%, relative to existing conditions, over broad areas of northern Mobile Bay.

The potential effects of the constructed openings on predicted subtidal velocities are shown in Figure 68, where magnitudes are generally ± 1 cm/s. An increase in seaward-directed flow was predicted in Choccolatta Bay, Justins Bay and Shellbank River, with some decreases in seaward directed subtidal flow in the Apalachee and lower Blakeley Rivers.

The tidal exchange for Choccolatta Bay increased by 78.6% relative to existing conditions, whereas Justins Bay experienced a 121.1% increase in tidal exchange with all constructed openings in place. It is interesting to note that these changes are actually slightly less than the calculated change for each opening acting alone (see Table 19, Table 22). While the differences are modest, no more than 5% in either case, it suggests that the constructed openings have some influence on each other when opened simultaneously. An evaluation of tidal exchange volumes for Choccolatta Bay and Justins Bay under this restoration scenario (Case 402) is provided in Table 27.

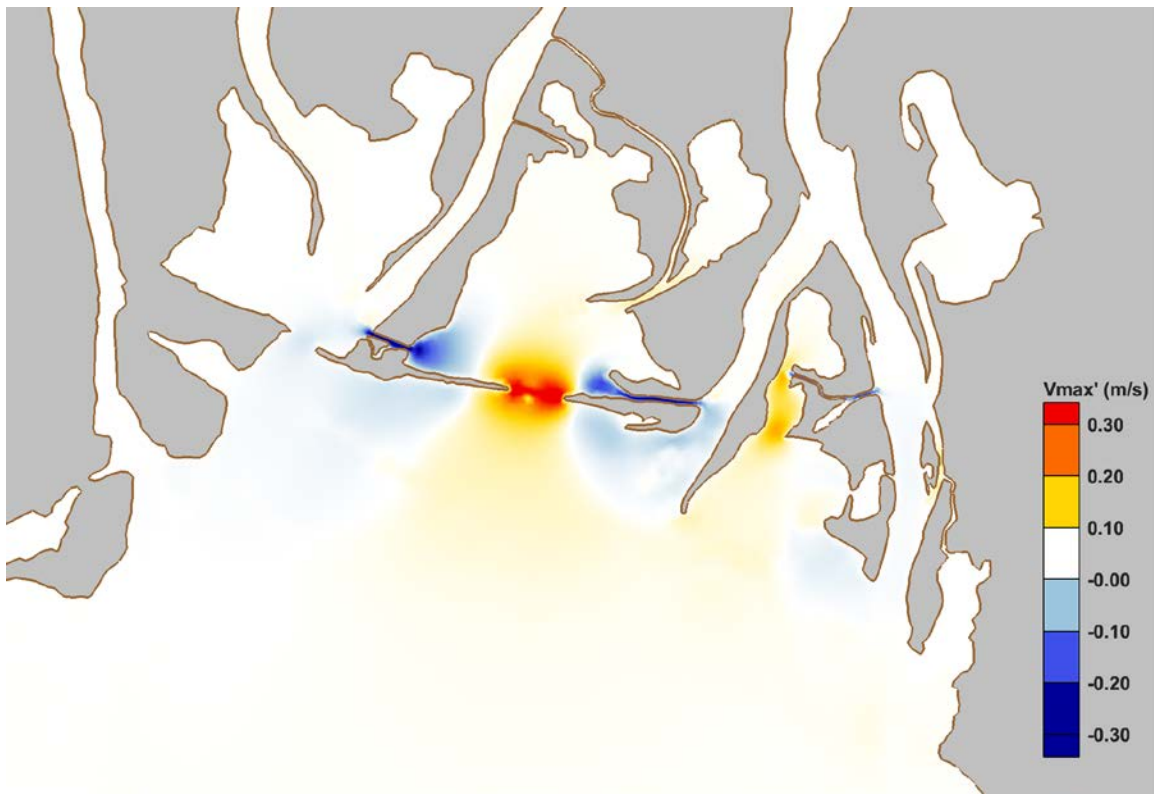


Figure 67. Predicted Change in Maximum Depth-averaged Velocity (Vmax') from Case 002 to Case 402

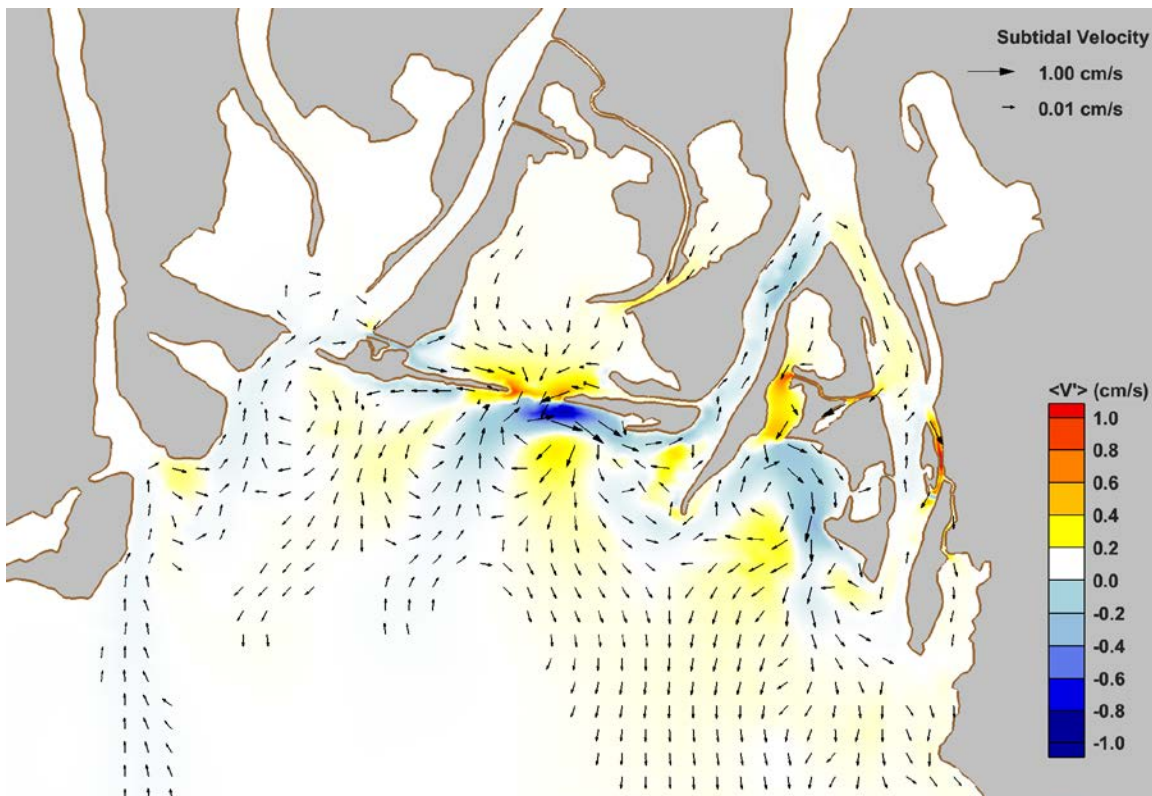


Figure 68. Predicted Change in Subtidal Velocity (<V'>) from Case 002 to Case 402

Table 27. Maximum Tidal Volume Exchanged (in m³) Between Successive Low and High Water on a Flooding Tide for Case 402, and the Percent Change Relative to Existing Conditions (Case 002)

Location		Tidal Volume Exchange (m ³)	% Change, 002
Chocolatta Bay	I-10 Cut	122,976 (in)	-94.4
	Little Creek	11,770 (out)	+79.9
	Conway Creek	1,126,255 (out)	+21.5
	"Pass Chocolatta"	7,271,341 (in)	+8395.9
	Pass Picada	222,593 (in)	-90.2
	Total (net)	6,478,886 (in)	+78.6
Justins Bay	Sardine Pass	45,967 (in)	-88.8
	"Pass Justin"	864,599 (in)	N/A
	Total (net)	910,566 (in)	+121.1

6.8.3 Sediment Transport Potential

As in the previous restoration scenarios, the model predicted increased bedload transport in and near the constructed openings on the order of 0.01 m³/s/m², or generally 25% to 50% greater than rates under existing conditions. Decreased bedload transport rates were predicted to occur in I-10 Cut, Pass Picada, Sardine Pass, and the lower portions of the Spanish/Tensaw, Apalachee, and Blakeley Rivers. Predicted changes in potential bedload sediment transport and resuspension rates, relative to existing conditions, for this restoration alternative are demonstrated in Figure 69 and Figure 70, respectively.

In terms of resuspension rates, increases and decreases on the order of 25% above/below existing conditions were predicted. Changes in resuspension rates relative to existing conditions were on the order of $\pm 0.1 \text{ m}^3/\text{s}/\text{m}^2$. The largest increases were found within the constructed openings and in lower Conway Creek. Substantial reductions were noted in I-10 Cut, Pass Picada, Sardine Pass, and the lower reaches of each river within the study area.

As in previous scenarios, reductions in sediment deposition (-1.0) were noted within the constructed openings and throughout broad areas of Choccolatta Bay, Big Bateau, Justins Bay, John's Bend, and Ducker Bay, and in much of Shellbank River. Notable increases in sediment deposition (+1.0) were predicted to occur in the southwest and southeast portions of Choccolatta Bay, I-10 Cut, Pass Picada, and Sardine Pass. Potential changes in sediment depositional areas and patterns, relative to existing conditions (Case 002), are shown in Figure 71 for this restoration scenario of all openings acting simultaneously.

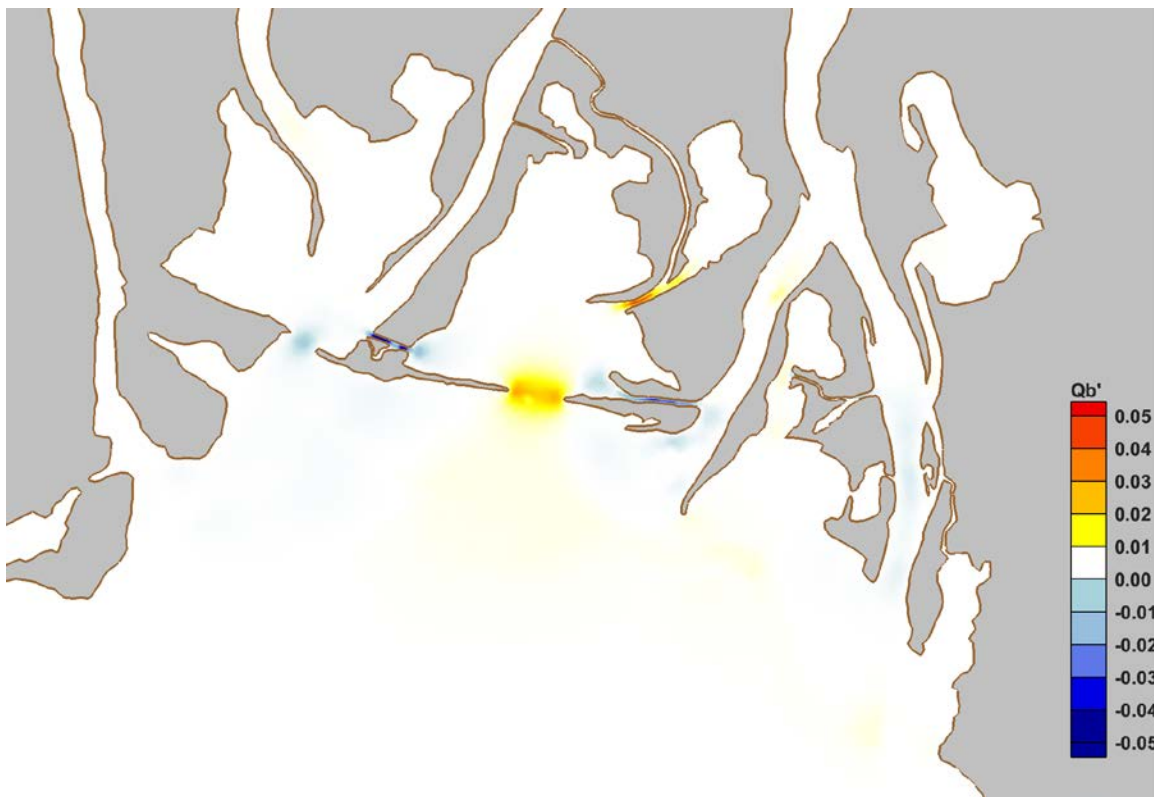


Figure 69. Predicted Change in Potential Bedload Transport Rates ($\text{m}^3/\text{s}/\text{m}^2$) from Case 002 to Case 402

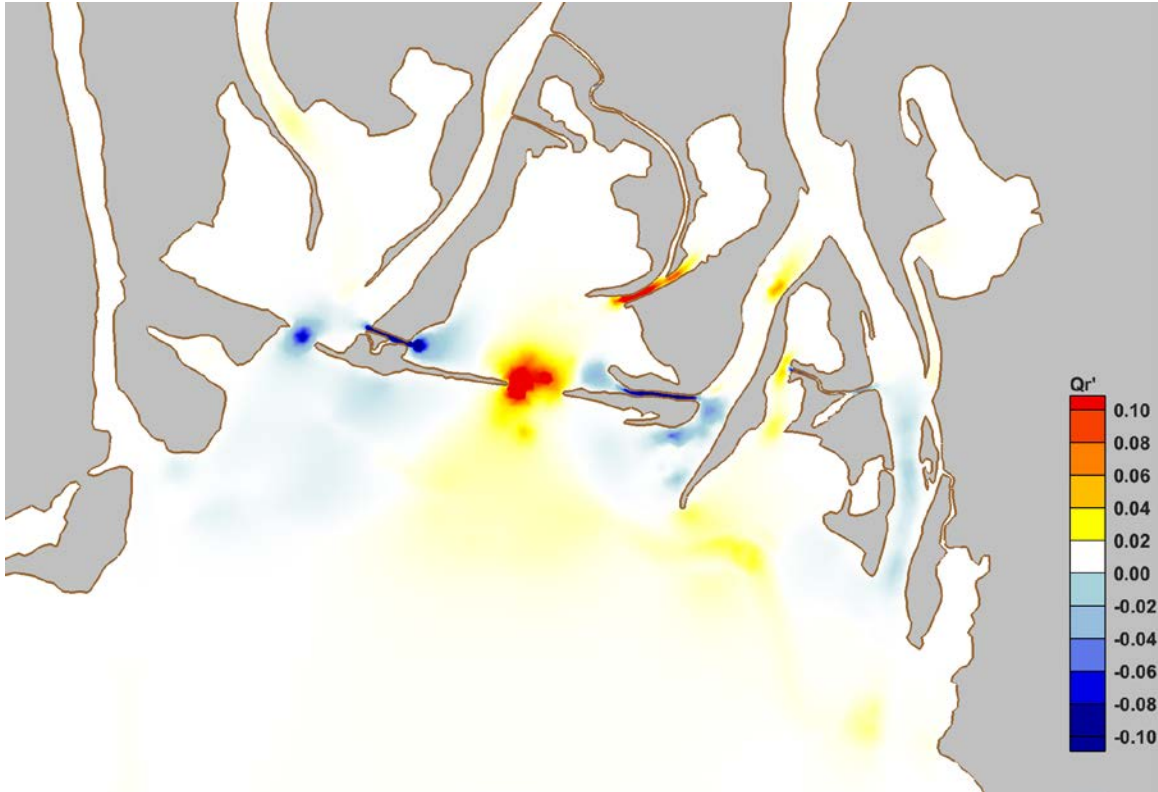


Figure 70. Predicted Changes in Resuspension Rates ($m^3/s/m^2$) from Case 002 to Case 402

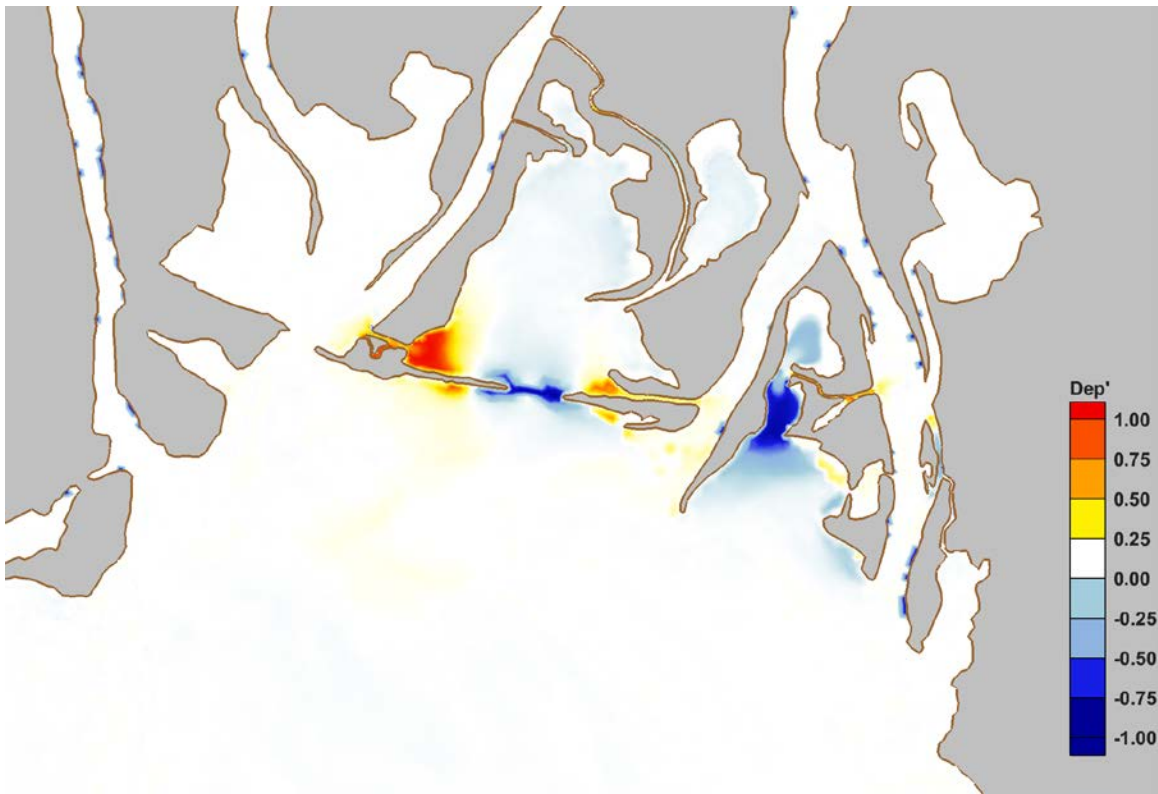


Figure 71. Potential Changes in Sediment Deposition Patterns Between Case 402 and Case 002 (+1: New Deposition; 0: No Change; -1: No Longer Depositional)

6.8.4 Flushing

The LPTM analysis results for this scenario (Case 403) look similar to those of Case 102 (see Figure 47) and Case 202 (see Figure 58). The model results show that the constructed openings lowered residence times considerably in areas close to them, but they increased in and near the existing tidal channels of each system. For example, residence times near the I-10 Cut, Pass Picada, and Sardine Pass increased by more than 5 days. Predicted changes in residence times for Choccolatta Bay and Justins Bay are shown in Figure 72. The figure shows the change in residence time, in days relative to existing conditions, for the restoration scenario having all openings acting simultaneously.

The flushing of Choccolatta Bay and Justins Bay improved by 10% and 500%, respectively, with the constructed openings in place. Justins Bay showed the most substantial reductions in residence and exposure times accompanied by a corresponding increase in the number of particles removed from the Bay as a result of the constructed opening. System-wide average residence and exposure times and percent of particles removed, for Case 002 and Case 402, are listed in Table 28.

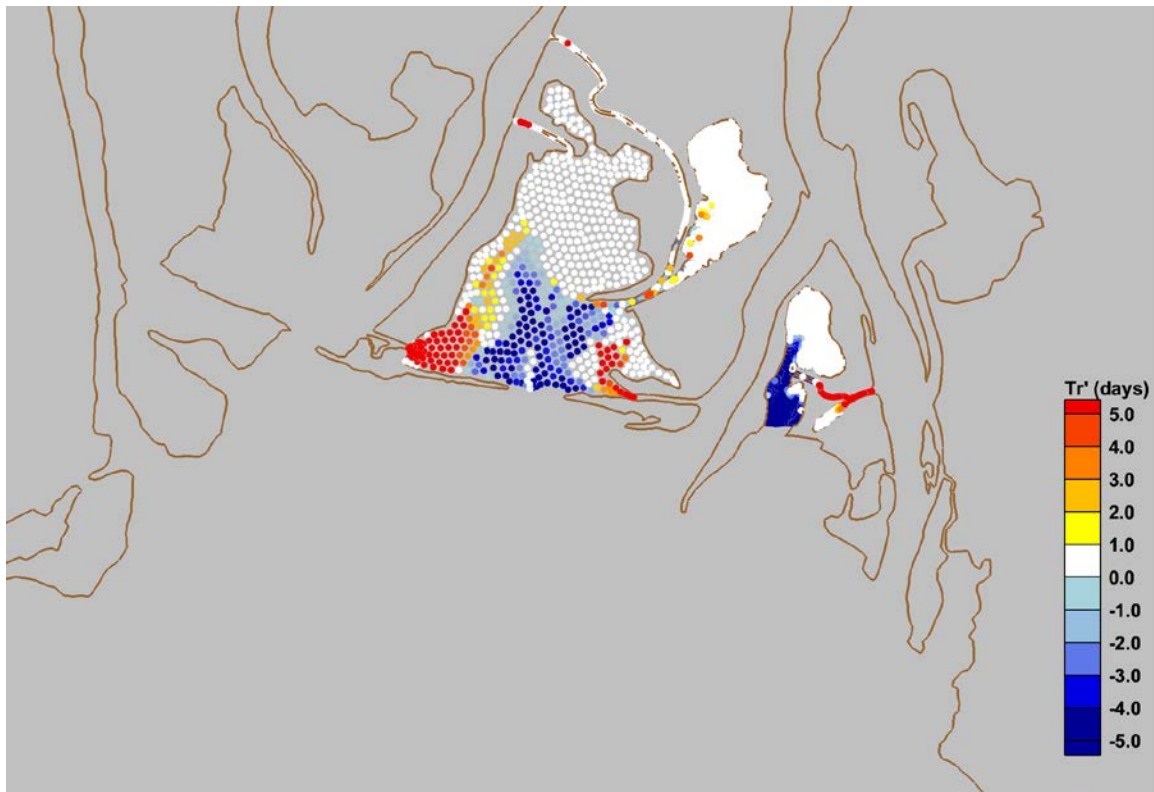


Figure 72. Potential Changes in Particle Residence Times from Case 002 to Case 402, Relative to Particle Initial Position

Table 28. System-wide Averages of Residence and Exposure Time and the Percent of Particles Removed for Case 402

Location	Avg. Residence Time (days)		Avg. Exposure Time (days)		% Particles Removed	
	Case 002	Case 402	Case 002	Case 402	Case 002	Case 402
Chocolatta Bay	7.9	7.8	8.4	8.3	20.2	22.3
Justins Bay	8.4	6.8	8.6	7.3	7.1	36.4

6.9 Chocolatta + Justins - Case 502

This hypothetical restoration scenario considers constructed openings through the Causeway at Chocolatta Bay and Justins Bay acting simultaneously. The forcing conditions consist of representative tides and average summer river discharge under present day sea levels. Simulation results for Case 502 are presented as differences relative to existing conditions (Case 002).

6.9.1 Water Levels

The predicted changes are nearly identical to those of Case 102 for Chocolatta Bay (Figure 36), Case 202 for Justins Bay (Figure 48), and Case 402 for both combined (Figure 66). These predicted changes are shown in Figure 73. Closer examination of the predicted maximum tide range at locations within the study area, provided in Table 29, suggests that the tide range in Justins Bay was slightly larger (~0.5%) than in Case 402 when Shellbank River was also open, but the magnitude of the difference was less than 0.5 cm.

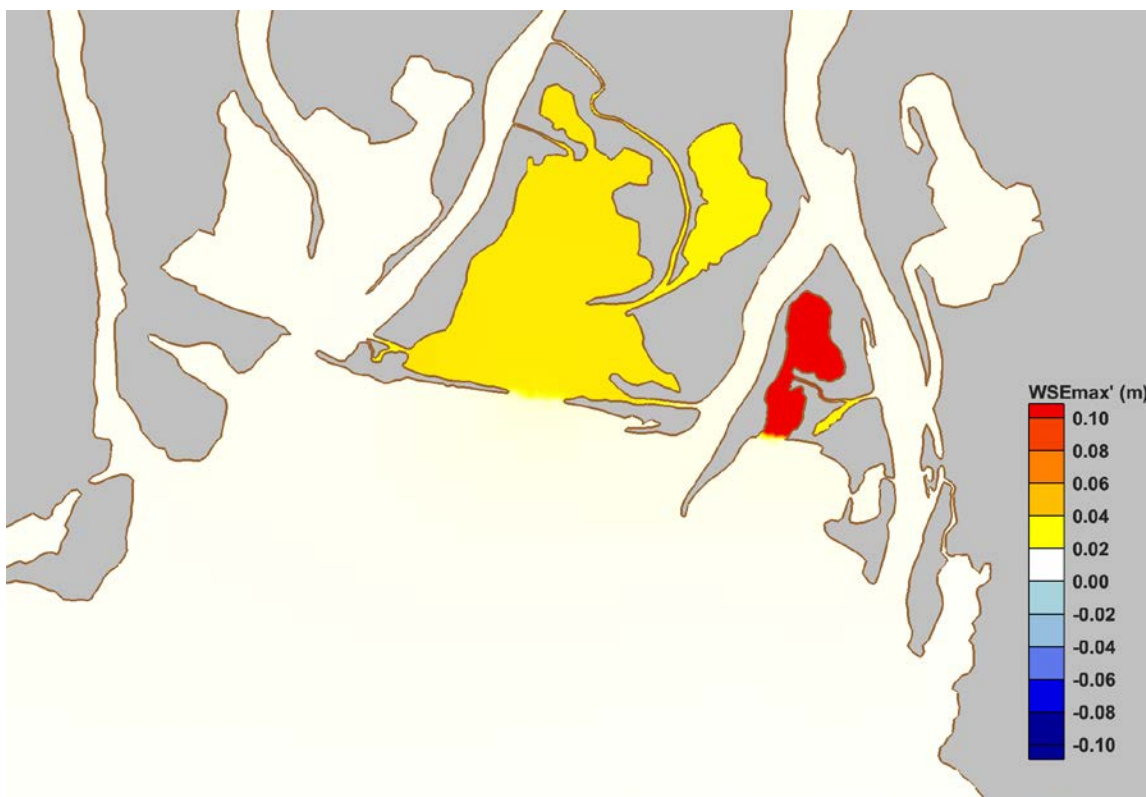


Figure 73. Predicted Change in Maximum Water Levels from Case 002 to Case 502

Table 29. Maximum Tide Ranges at Selected Locations for Case 502 and Their Relative Change from Case 002

Location	Tide Range (m)	% Change, 002
Chocolatta Bay	0.729	+8
North Mobile Bay	0.724	<+1
Justins Bay	0.724	+64.2
Ducker Bay	0.723	<+1
Shellbank River North	0.726	<+1
Shellbank River South	0.722	<+1

6.9.2 Flows

Model predictions of changes in maximum depth-averaged water velocity for the scenario of constructed openings at Chocolatta and Justins Bays are shown in Figure 74. The magnitude and pattern of changes are similar to cases presented previously: Case 102, Case 202, and Case 402. The predicted changes in subtidal velocity magnitude and direction, as demonstrated in Figure 75, were also similar to those of previous restoration alternative scenarios. Moreover, estimates of tidal volume exchange in Chocolatta Bay and Justins Bay were similar to previous cases where each opening was considered alone (Case 102 and Case 202) and also in a combined fashion (Case 402). These values are provided in Table 30. Under this potential scenario, the tidal volume exchange in Chocolatta Bay and Justins Bay were predicted to increase by over 80% and 120%, respectively, relative to existing conditions.

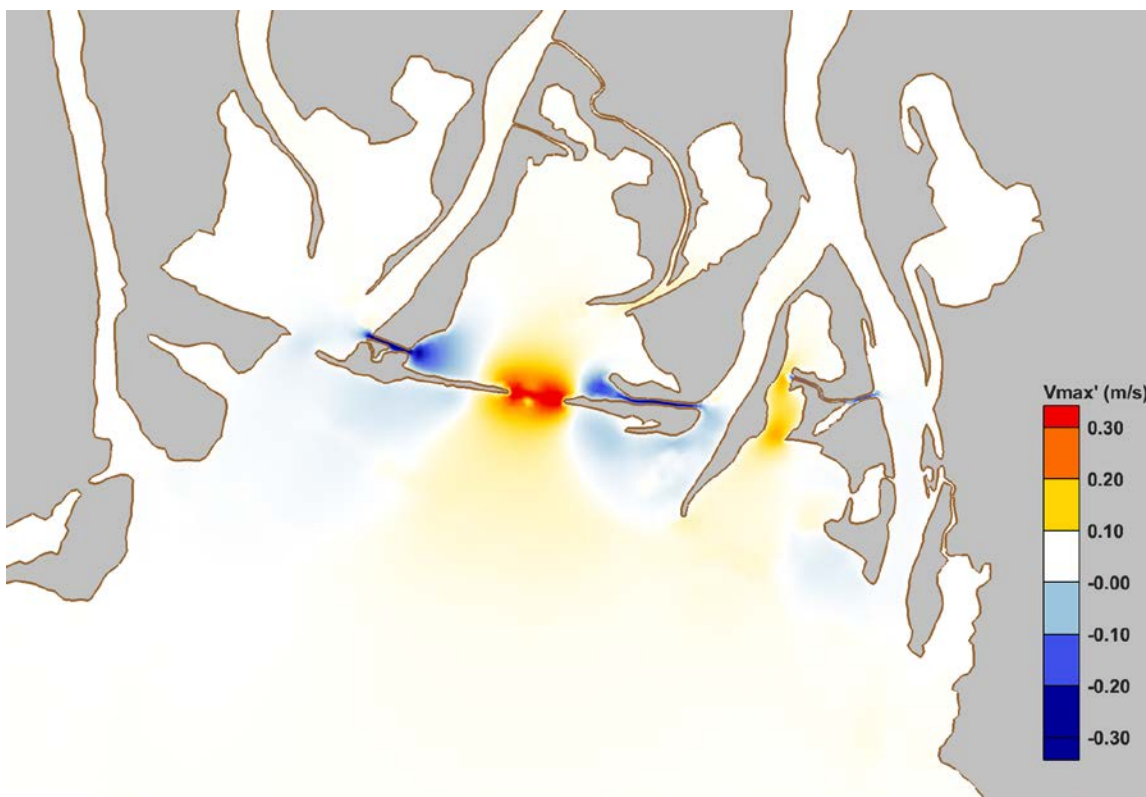


Figure 74. Predicted Change in Maximum Depth-averaged Velocity (V_{max}') from Case 002 to Case 502

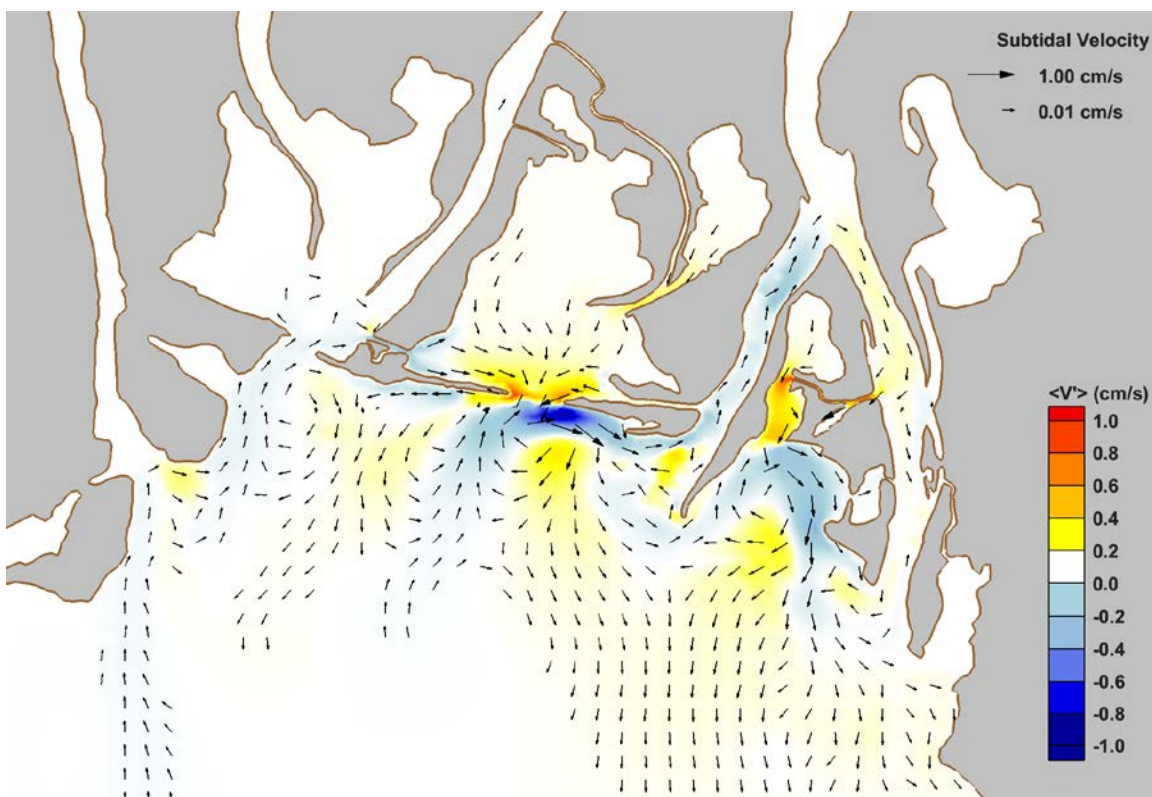


Figure 75. Predicted Change in Subtidal Velocity (<V'>) from Case 002 to Case 502

Table 30. Maximum Tidal Volume Exchanged (in Cubic Meters) Between Successive Low and High Water on a Flooding Tide for Case 502, and the Percent Change Relative to Existing Conditions (Case 002)

Location		Tidal Volume Exchange (m ³)	% Change, 002
Chocolatta Bay	I-10 Cut	122,969 (in)	-94.4
	Little Creek	11,770 (out)	+79.9
	Conway Creek	1,021,468 (out)	+10.2
	"Pass Chocolatta"	7,217,345 (in)	+8395.9
	Pass Picada	222,604 (in)	-90.2
	Total (net)	6,583,680 (in)	+81.5
Justins Bay	Sardine Pass	51,273 (in)	-87.6
	"Pass Justin"	863,897 (in)	N/A
	Total (net)	915,170 (in)	+122.2

6.9.3 Sediment Transport Potential

Model predictions of potential bedload transport and resuspension rates, as well as depositional tendencies, are shown in Figure 76, Figure 77, and Figure 78, respectively. The magnitudes, locations, and patterns of these changes were similar to those found in restoration alternatives Case 102 and Case 202, with very little influence in areas surrounding Shellbank and Blakeley Rivers.

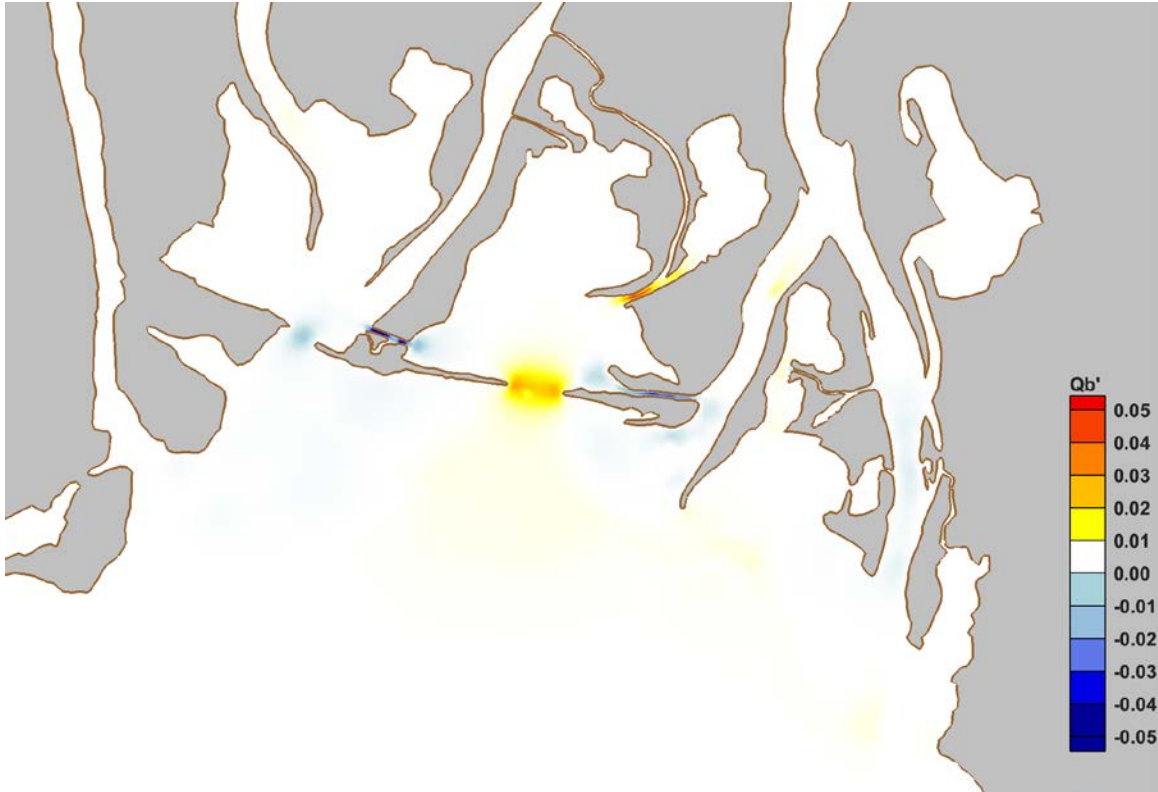


Figure 76. Predicted Change in Bedload Transport Rates ($m^3/s/m^2$) from Case 002 to Case 502

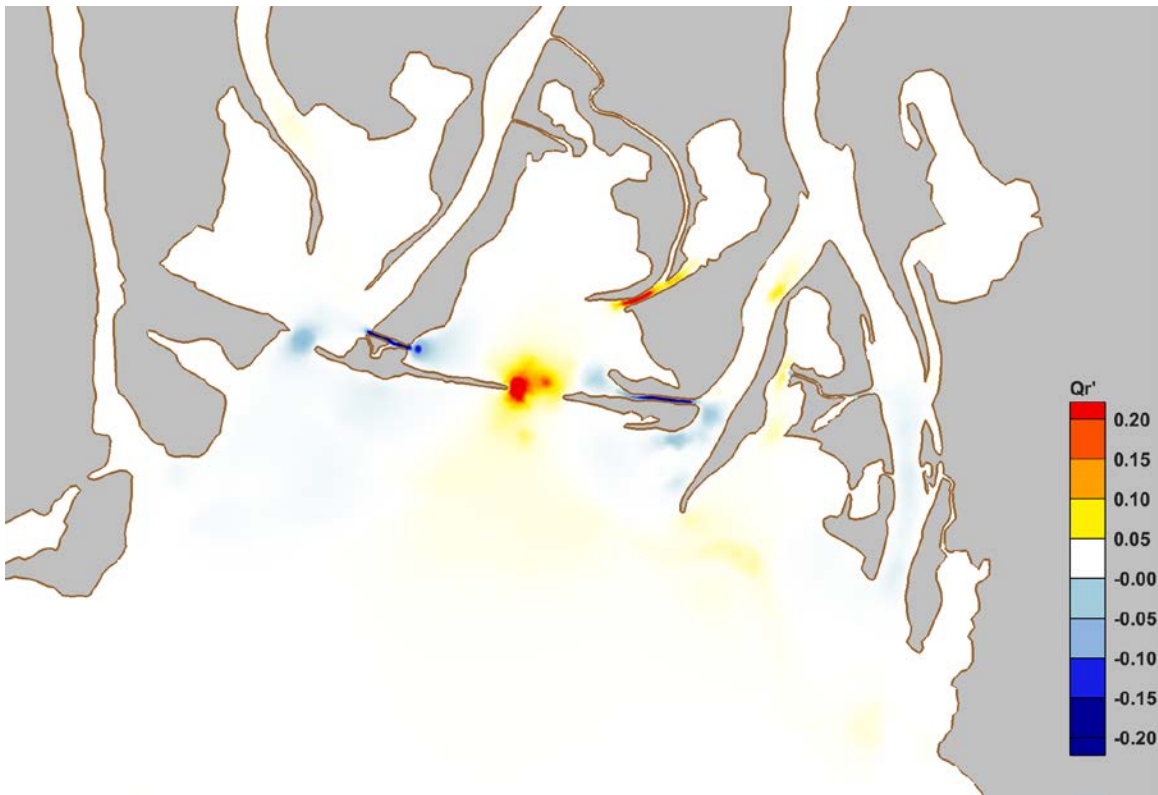


Figure 77. Predicted Change in Resuspension Rates ($m^3/s/m^2$) from Case 002 to Case 502

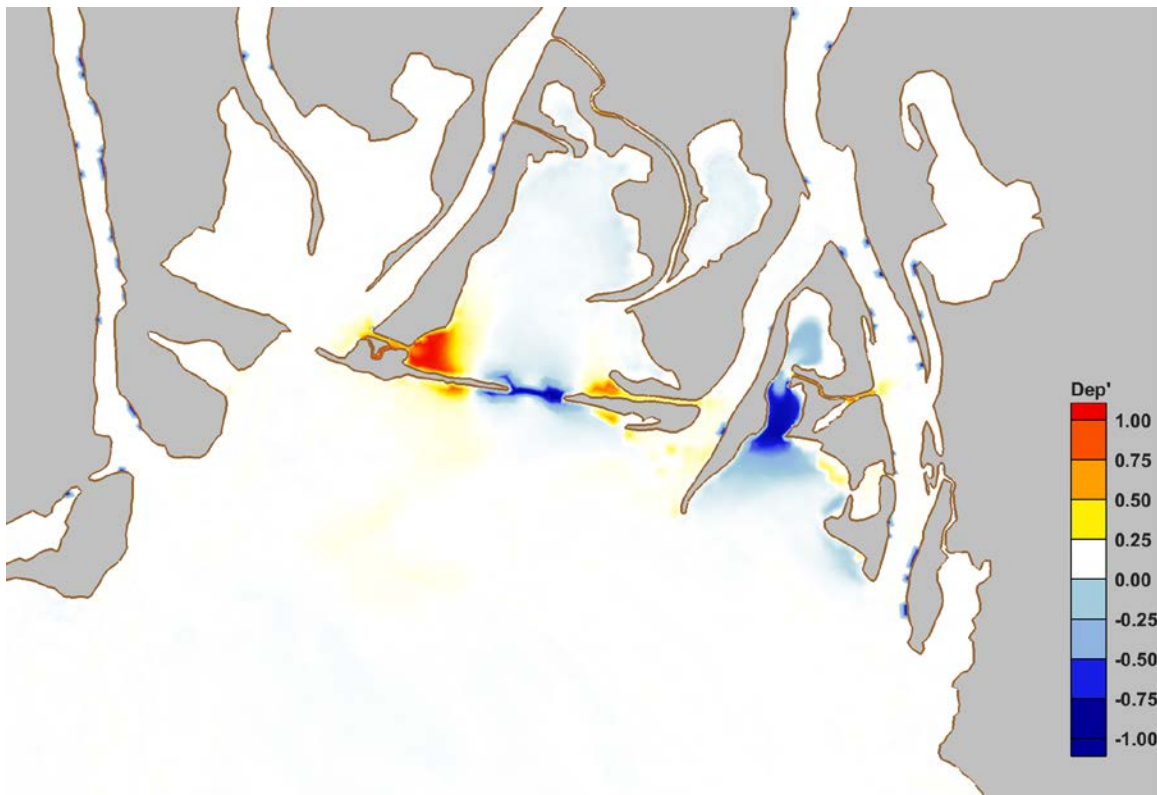


Figure 78. Potential Changes in Sediment Deposition from Case 002 to Case 502 (+1: New Deposition; 0: No Change; -1: No Longer Depositional)

6.9.4 Flushing

The flushing characteristics of this restoration scenario are not substantially different than those from the scenarios where each Bay was considered alone, and when all of the openings were acting simultaneously. Predicted changes in particle residence times, relative to initial position under existing conditions, are shown in Figure 79. Reductions in residence time up to 5 days were found near the constructed openings, where similar increases in residence times were predicted near I-10 Cut, Pass Picada, and Sardine Pass. The system-wide averages presented in Table 31 are similar to those presented for earlier Cases 102, 202, and 402. Of the particles that left these Bays, about 98% left Choccolatta Bay and 100% left Justins Bay through their constructed openings.

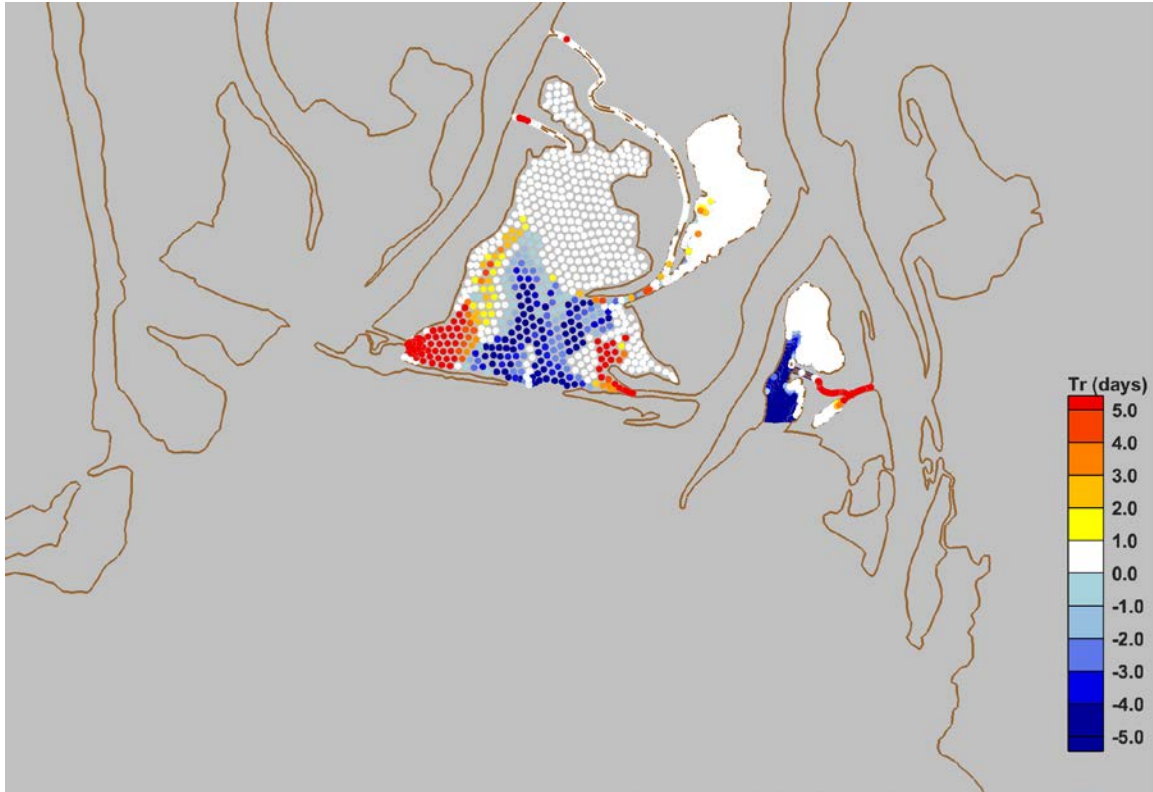


Figure 79. Predicted Change in Particle Residence Time, Relative to Initial Position, from Case 002 to Case 502

Table 31. System-wide Average Residence and Exposure Times and the Percent of Particles Removed from the System for Case 502

Location	Avg. Residence Time (days)		Avg. Exposure Time (days)		% Particles Removed	
	Case 002	Case 502	Case 002	Case 502	Case 002	Case 502
Chocolatta Bay	7.9	7.8	8.4	8.3	20.2	21.3
Justins Bay	8.4	6.8	8.6	7.4	7.1	35.2

6.10 High Flow Scenarios Simulation Results

The high flow modeling scenarios performed as part of this study describe the potential effects of hypothetical restoration alternatives on hydrodynamic characteristics under tidal and high flow conditions for present-day sea levels. The magnitude of river discharge considered in these simulations is greater than four times (4x) larger than the typical flows considered in Cases 002, 102, 202, 302, 402, and 502. The modeling of these scenarios under high conditions is presented in the Hydrodynamic Modeling Report (Appendix E), and existing conditions throughout the study area are described first, and then the potential effects of a single restoration alternative are described as changes (increases, decreases, etc.) relative to existing conditions under a high flow scenario.

6.11 Sea Level Rise Scenarios Simulation Results

This sea level rise modeling performed as part of this study describes the potential effects of hypothetical restoration alternatives on hydrodynamic characteristics under representative tidal and flow conditions for an estimated sea level in the year 2100. The sea level offset considered in these scenarios is +0.3 m (about +1 ft higher than present day). The magnitude of river discharge considered in these simulations is representative of the average summer (July) flows. The modeling of these scenarios under sea level rise conditions is presented in the Hydrodynamic Modeling Report (Appendix E), and existing conditions throughout the study area are described first, and then the potential effects of each restoration alternative are described as changes (increases, decreases, etc.) relative to existing conditions under typical conditions for present day sea levels. These comparisons are made to demonstrate the effects of both sea level rise and the restoration alternative on hydrodynamic conditions in the study area.

7.0 CONCLUSIONS

7.1 Sediments

Sampling was conducted in May 2014 to provide additional information on the physical properties and chemical concentrations in sediments near the Mobile Bay Causeway. The sediment study focused on the three locations identified by ADCNR as having the highest potential for success as conceptual hydrological restoration sites. The conceptual restoration locations are Choccolatta Bay, Justins Bay, and Shellbank River. This study supplements prior investigations by providing physical data to support modeling efforts and chemical data to assess the pre-existing potential ecotoxicological risks associated with the three sites. At each site, upper and lower sediment samples were obtained north and south of the Mobile Bay Causeway. The chemical results were compared with ecotoxicological benchmarks to identify chemicals of potential ecological concern (i.e., chemicals that exceeded at least one benchmark at a location). The major findings of the sediment study are provided below along with general findings by study area.

The following findings address chemical concentrations that occur above ecotoxicological benchmarks of concern in Mobile Bay and in waterbodies located north of the Causeway. These findings may not translate into concerns that constructing openings in the Causeway would measurably increase and/or spread potentially toxic compounds from one side of the Causeway to the other, as explained in the text that precedes the bulleted items. The intent of the sediment sampling, analysis, and reporting effort of this project was not to give a green light for project construction (or give a red light), but rather the intent was to collect data that could be used with other data (either from this study or others) to inform the best path forward to maintain and/or enhance the ecological system along the Causeway while considering other goals related to the Causeway and region.

Contaminants of concern were detected above ecotoxicological benchmarks in sediments from stations located both north and south of the Causeway in each of the three potential restoration locations. Additionally, contaminants occurred in both surficial (Top) sediment (0-15 inches in depth) and Bottom sediment (below 15 inches in depth). In general, more exceedances of ecotoxicological benchmarks occurred in the Shellbank River study area than in Choccolatta Bay or Justins Bay study areas.

7.1.1 Choccolatta Bay Findings

- Top and Bottom sediments at the eight stations located north of the Causeway contained slightly coarser sediments on average than the four stations located south of the Causeway.
- 4, 4'-DDT concentrations exceeded PEL value (PEL represents the concentration above which adverse effects are expected frequently [MacDonald et al., 1996]) at three stations, two were north of the Causeway and one was located south of the Causeway. Other DDT compounds also exceeded TEL (TEL represents the concentration below which adverse effects are expected to occur only rarely [MacDonald et al., 1996]) values both above and below the Causeway, and in Top and Bottom layers.
- PAH concentrations exceeded TEL values at three stations; two were located north of the Causeway and one was located south of the Causeway.

Three of eight locations north of the Causeway and four of four locations south of the Causeway were above ecotoxicological benchmarks. The range between the Total DDTs TEL value and PEL value is relatively large compared to other chlorinated pesticide constituents (Total DDTs TEL of 3.89 µg/kg and PEL of 51.7 µg/kg). All but two of the samples above the Total DDTs TEL value were much closer to the TEL value than the PEL value. The two samples where this was not the case had values of 28.8 µg/kg and 32.0 µg/kg; however, both of these samples were collected far from the Causeway (CB-N-03 collected near the outlet to Big Bateau Bay and CB-S-12 collected south of I-10). The spatial distributions of the results do not indicate a defined pattern or area of focus for Total DDTs along the Causeway at Choccolatta Bay. As predicted by the modeling task performed during this project, the change in the potential bedload transport rates and sediment resuspension rates for the Choccolatta Bay alternative would be limited primarily to the area along the Causeway alignment where the roadway would be removed to create an opening. There could be slight changes in bedload transport rates and sediment resuspension rates in the sediments in the areas just beyond the limits of removal; however, the modeling predicts these changes in the potential for bedload transport rates and sediment resuspension rates quickly dissipate north and south of the Causeway alignment (see Section 6.5.3). With elevated concentrations of Total DDTs both north and south of the Causeway at Choccolatta Bay and with the modeling predicting changes to the potential bedload transport rates and sediment resuspension rates primarily limited to near the Causeway alignment, the construction of an opening in the Causeway at Choccolatta Bay is not likely to significantly change the Total DDTs concentrations that exist both north and south of the Causeway.

The analytical results of 4,4'-DDT concentrations above the PEL ecotoxicological benchmark are also of concern. The majority of the samples collected for Choccolatta Bay were below the 4,4'-DDT RAG value, and that may indicate that elevated values of 4,4'-DDT are not present in the major areas along the Causeway at Choccolatta Bay. The two sites where the top profile concentrations were above the PEL value were both located far from the potential opening locations (the above-mentioned CB-N-03 and CB-S-12 locations). The one sample where 4,4'-DDT concentration was above the PEL in the bottom profile was located 500 feet north of the Causeway. This location is of less concern, because the elevated concentration was limited to the bottom profile, while concentration in the top profile was below the RAG value. Therefore, the results of one bottom profile sample near the Causeway above the 4,4'-DDT PEL value does not indicate that the construction of an opening in the Causeway at Choccolatta Bay would measurably change the 4,4'-DDT sediment concentrations that currently exist both north and south of the Causeway.

The three locations where measured values of PAHs were above the TEL value are of concern. One of these samples is located far from the Causeway (CB-N-03). The other two samples (only surface profiles analyzed for PAHs) had surface profile concentrations of 210 µg/kg and 130 µg/kg for the locations north and south of the Causeway, respectively. These values are closer to the TEL value of 88.8 µg/kg than the PEL value of 763 µg/kg. Nine of the 12 samples collected along the Causeway at Choccolatta Bay had results below the RAG value, which may indicate that elevated levels of PAHs are not widespread in the areas along either side of the Causeway at Choccolatta Bay. Because elevated values of PAHs were measured on both sides of the Causeway and those values were closer to the TEL value than the PEL value, the construction of an opening in the Causeway at Choccolatta Bay is not likely to increase the sediment PAHs north or south of the Causeway.

The above conclusions are based on data currently available. The Choccolatta Bay sampling study area covered an area of approximately 700 acres. The number of sediment core locations in this study was adequate to provide data for the restoration approach and type of evaluation performed; however, sampling was not intended to provide detailed horizontal and/or vertical delineation of all possible constituents of concern throughout the area. If a project were proposed in the future to provide an opening in the Causeway at Choccolatta Bay, the initial planning of that project should include refining/optimizing the design (discussed in Section 8.1). Part of the design refinement may include (1) modifying the opening in order to reduce the change in the potential for bedload transport and sediment resuspension along the project; (2) collecting and analyzing additional sediment cores in areas where there would be a potential for bedload transport and sediment resuspension; and (3) if required, removal and/or capping the areas with suitable materials where elevated concentrations of contaminants occur and the potential for bedload transport and sediment resuspension exists.

7.1.2 Justins Bay Findings

- Top and Bottom sediments at the four stations located south of the Causeway contained slightly coarser sediments on average than the seven stations located north of the Causeway.
- Nickel was the only metal exceedance detected in the Justins Bay study area (detected in Top sediment north of the Causeway).
- DDT compound concentrations exceeded RAGS (RAGS indicate chemical concentrations associated with a low probability of unacceptable risks to ecological receptors [USEPA, 2001] and were obtained by adopting the lowest, most conservative, value of the available benchmarks) values at seven stations but did not exceed PEL values; one station was located north of the Causeway while six were located south of the Causeway.
- PAH (benzo[a]pyrene) concentrations exceeded TEL values at five stations; three were located north of the Causeway, and two were located south of the Causeway.

The various measured values summarized above are of concern for the areas along the Causeway at Justins Bay. Modeling results were utilized to facilitate an evaluation of chemistry results in connection to the Justins Bay alternative presented in this report. The Justins Bay opening width shown in the Justins Bay alternate is fairly large in relationship to the surface area/volume of Justins Bay when compared to the Choccolatta Bay scenario. As such, the model predicted much less change in the potential for bedload transport rates and sediment resuspension rates (see Section 6.6.3) in comparison to changes predicted for the Choccolatta Bay alternative. The slight changes predicted would generally occur along the Causeway alignment, north of the Causeway extending just north of Duck Skiff Pass and south of the Causeway (see Section 6.6.3). The one location where nickel was above the TEL value was not located where the model predicted a change in bedload transport rates and sediment resuspension rates, and therefore was not considered to be a concern. With the exception of JB-S-09, JB-S-10, and JB-S-11, the DDT compound concentrations were either above the Total DDTs RAG value but below the TEL value (JB-S-06 and JB-S-08) or just above the Total DDTs TEL value (JB-N-02 and JB-S-07) or slightly above the 4,4'-DDE TEL value (JB-N-02 and JB-S-07). The one location with elevated values of 4,4'-DDE and Total DDTs within Justins Bay was collected about midway between the Causeway and Duck Skiff Pass. The locations just north and south of the Causeway had levels of DDT compounds below the RAG values. Three sampling locations within the lower Justins

Bay had values of PAHs (benzo[a]pyrene) above the TEL value but less than half the PEL value. In the immediate vicinity south of Justins Bay, PAH values were below RAG values, and two samples collected near I-10 were above the benzo (a) pyrene TEL value. Based primarily on the modeling results predicting only slight changes in the potential for bedload transport rates and sediment resuspension rates within Justins Bay, and based on the presence of elevated levels of DDT compounds and PAHs (benzo[a]pyrene) both north and south of the Causeway, the construction of an opening in the Causeway at Justins Bay would not measurably change the potential distribution of these constituents of concern.

Similar to the Choccolatta Bay conclusions, the Justins Bay conclusions are based on the data currently available. The Justins Bay sampling study area covered an area of approximately 300 acres. The number of sediment core locations in this study was adequate to provide data for the type of evaluation performed hereon; however, sampling was not intended to provide detailed horizontal and/or vertical delineation of all possible constituents of concern throughout the area. If a project were proposed in the future to provide an opening in the Causeway at Justins Bay, the initial planning of that project should include refining/optimizing the design (discussed in Section 8.1). Part of the design refinement may include modifying the opening. By including the modification, the potential for bedload transport and sediment resuspension along the project should be considered with other project goals (e.g., project costs). If the final design were predicted to result in a significant redistribution of constituents of concern, project planning should include collecting and analyzing additional sediment cores in areas where there may be potential for bedload transport and sediment resuspension.

7.1.3 Shellbank River Findings

- Top and Bottom sediments at the three stations located south of the Causeway contained slightly coarser sediments on average than the three stations located north of the Causeway.
- Concentrations of arsenic, cadmium, copper, lead, mercury, nickel, and zinc were measured above TEL benchmarks. Metal exceedances occurred at all but four of six stations.
- DDT compound concentrations above ecotoxicological benchmarks occurred across all Shellbank River sites, and were found in both Top and Bottom sediments located both north and south of the Causeway.
- PAH concentration of benzo(a)pyrene exceeded the TEL value one station (located north of the Causeway).

As summarized above and based on the frequency and high levels of measured values above ecotoxicological benchmarks (constituents of concern at concentrations near or exceeding PEL values north of the Causeway), the sediment results are of concern related to any project that would involve construction of an opening through the Causeway at Shellbank River. A project proposed at the Shellbank River should include additional sampling and analysis to further delineate both the horizontal and vertical extents of the elevated levels of constituents of concern.

7.2 Biology

Reestablishment of hydrology at the three potential locations along the Causeway is expected to result in a variety of ecological impacts, including both beneficial and detrimental effects on the natural communities of the upper bay and the lower delta. Effects would occur primarily through habitat alteration and reestablished tidal exchange at these sites. Potential impacts include changes in wetlands, SAV, endangered species' habitat, nekton and benthic communities, sedimentation and sediment quality, tidal flux, circulation, and water quality.

Wetlands occur at all three of the sites, north and south of the Causeway. Project implementation at each location would convert an area of fringing wetlands and upland right-of-way to open water. The opening at Justins Bay would affect the largest wetland area at 9.4 acres (Figure 80), followed by Choccolatta Bay (2.8 acres) (Figure 81), and Shellbank River (0.4 acre) (Figure 82). Wetlands in the affected areas are predominantly low marsh habitats, dominated by various sedges, grasses, and rushes. Both the Justins Bay and Shellbank River locations are bounded by wetlands along their entire lengths. The Choccolatta Bay alternative has wetlands in a relatively small area at its easternmost end, and wetland avoidance may be possible at this location.

The combined alternatives would also directly affect a total of 19 acres of subtidal habitat. These areas include 8.5 acres with SAV mapped in 2014, approximately 4 acres each at Choccolatta Bay and Justins Bay and a small area at Shellbank River. Greater depth due to excavation and channelization would result in reduced light availability and potentially could preclude SAV reestablishment in the affected areas. Project implementation could also affect SAV growth through changes in sediments, hydrodynamic flow, and hydrology in the deepened areas. The area affected would comprise a small portion of the SAV acreage that occurs during most years in the immediate vicinity of the three sites, and measurable impacts to local populations, including abundant motile epifauna and fishes, are unlikely. SAV is a major component in the diets of endangered Alabama red-bellied turtles and West Indian manatees, but project effects on these species are unlikely given the relatively small area of habitat alteration. Both are opportunistic foragers without preferences for particular SAV species.

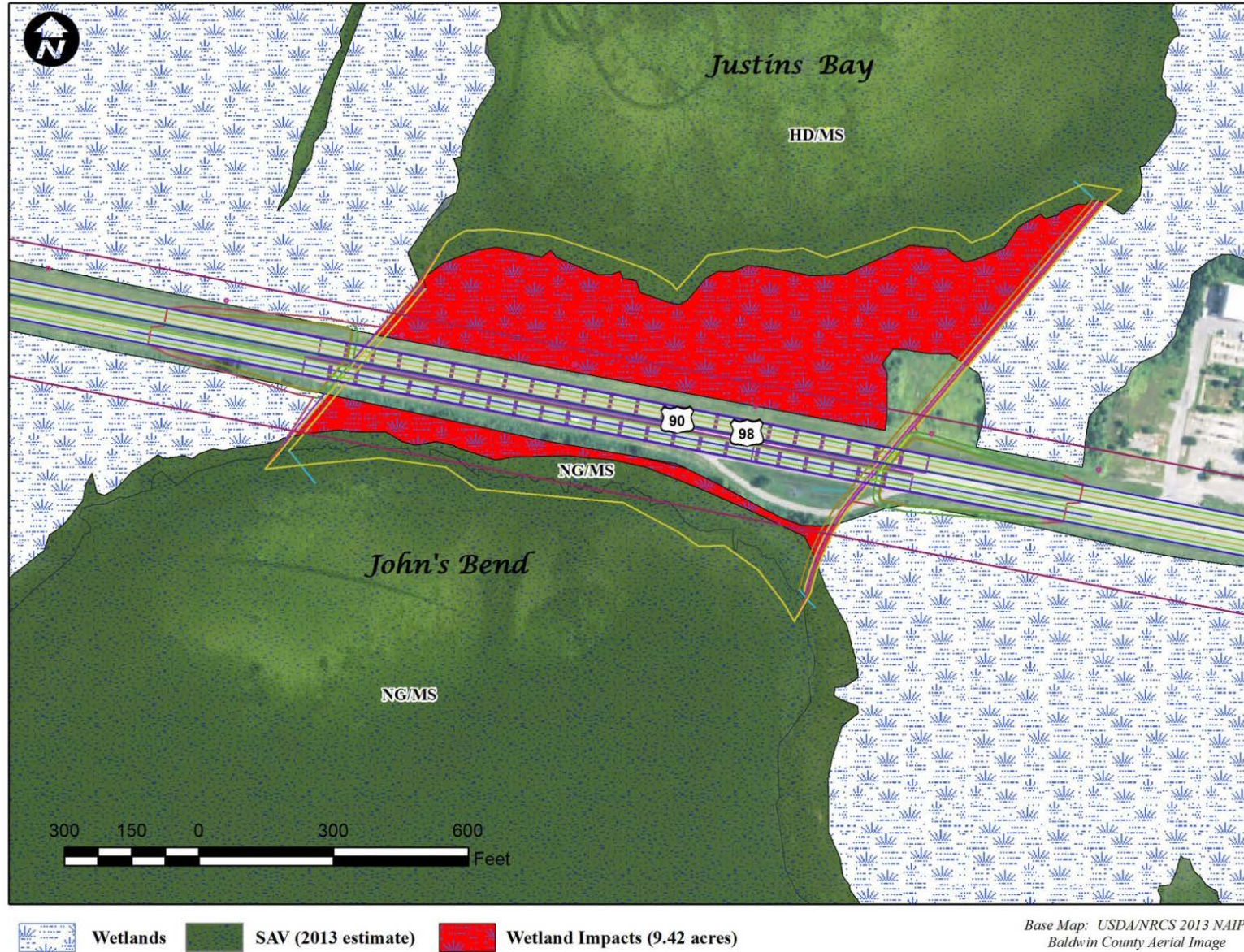


Figure 80. Estimated Wetland Impact for Justins Bay

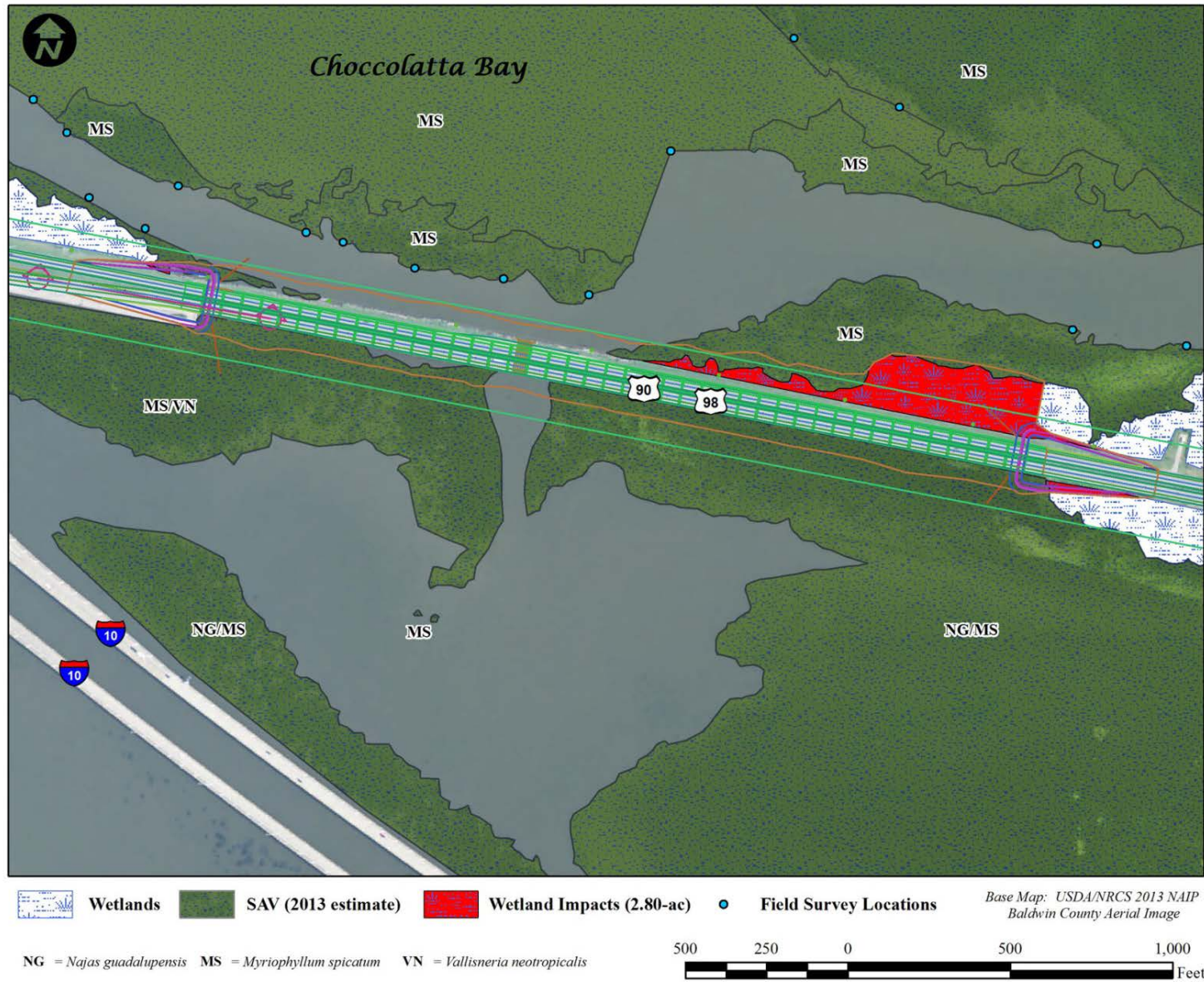


Figure 81. Estimated Wetland Impact for Choccolatta Bay

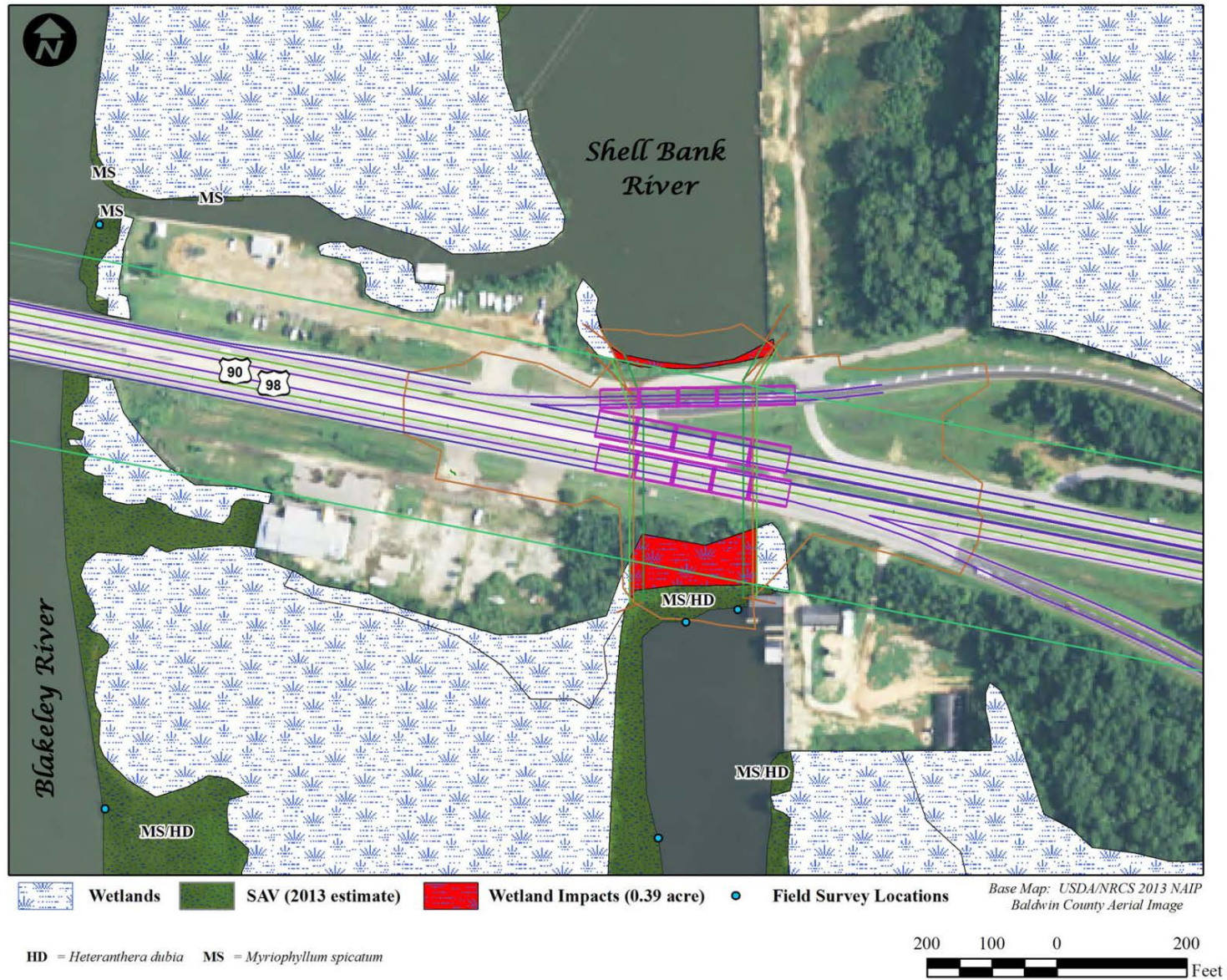


Figure 82. Estimated Wetland Impact for Shellbank River

Constructed openings would increase maximum predicted water levels more than 10 cm in Justins Bay (30% more than existing values), and to a lesser extent in Choccolatta Bay (2 cm to 4 cm, or 5% to 10% of existing values). An increase in tidal height has the potential to alter plant community structure on the margins of the fringing wetlands that surround these bays. Some shoreward receding of the marsh-water interface could occur, with the deeper, more inundated areas potentially converting to SAV habitat. Because model predictions suggested that affected water levels would be limited to the water bodies directly connected to the constructed openings, with negligible changes elsewhere in the study area, any ecological effects of increased tidal height on local plant communities are expected to be spatially limited.

A large number of endangered Alabama red-bellied turtles nest in the study area on sand banks along the Causeway, including areas immediately surrounding Justins Bay. Land removal in this area could potentially displace nesting or loafing turtles into smaller areas where they may be susceptible to an increase in mortality from vehicular traffic. Potential impacts to the endangered turtles may require additional investigation prior to project design and implementation.

Sediment transport and resuspension rates are predicted to increase in and adjacent to the constructed openings. For a period of time after construction, tidal currents may erode adjacent bay bottoms and shorelines until natural equilibrium is achieved under the ambient hydrodynamic regime at each opening. Eroded sediments and organic matter would potentially be dispersed into the larger bay systems, and could smother existing benthic resources. The magnitude of such impacts may be considered small within the larger deltaic and bay systems, where shoaling occurs naturally, both above and below the Causeway. Deposited sediments would be rapidly colonized by local populations of benthic invertebrates, and may also be colonized by submerged or emergent plants. Bathymetric changes resulting from erosion and deposition are expected to be limited to areas near the constructed openings. Reductions in tidal exchange and sediment transport rates predicted at Pass Picada, I-10 Cut, and Sardine Pass could result in sediment deposition over time, potentially resulting in gradual habitat changes at those locations.

Among the three study areas, Shellbank River sediments had the most exceedances of benchmark values for contaminants of concern. Numerous studies have investigated availability and bioaccumulation of heavy metals and other contaminants from sediments to biota. High contaminant levels in sediments alone do not indicate that substantial bioaccumulation or adverse environment effects will occur, and an apparently healthy benthic community can be supported in sediments that contain greater than ambient levels of contaminants. Nonetheless, project planning for an opening in the Causeway at Shellbank River would require more detailed consideration of sediment contamination issues.

In addition to reestablishing tidal exchange, an opening at Shellbank River would draw some of the flow off of the Blakeley River. Bidirectional flow at a Shellbank River opening has potential to complement ongoing restoration efforts to reduce the effects of sediment loading in D'Olive Bay, south of the Causeway.

Increased flushing and tidal communication would alter and potentially improve hydrology in the immediate vicinity of the Causeway, Choccolatta Bay, Justins Bay, and Shellbank River. Hypoxia and anoxia occur naturally in estuarine systems, particularly in enclosed embayments such as Choccolatta Bay and Justins Bay. With constructed openings that increase flushing and

reduce retention time, episodic hypoxia and anoxia in these bays may be less frequent during warm seasons compared to the current condition.

Tidal exchange would tend to equalize salinities in the areas of influence north and south of the Causeway during periods of low river flow. The hydrodynamic modeling indicates that tidal exchange would be reduced at higher river discharge due to a general reduction of tidal forcing. During high flow conditions, freshwater dominates the delta and is likely to mask tidal exchange effects at Causeway openings. Salinity changes due to the project may not result in measureable differences in the distributions of the predominant flora and fauna of the study area, since these groups tend to have wide salinity tolerances. The predominant wetland and SAV species in the study area occur both north and south of the Causeway, and their distributional patterns are unlikely to be altered by highly localized changes in salinity. Similarly the most abundant estuarine dependent fishery species in the study area occur throughout salinity zones of the upper bay and lower delta, often into fresh or nearly fresh water. An important freshwater species, largemouth bass, generally inhabits waters that range from fresh to oligohaline (0.5-5.0 parts per thousand), and these conditions are expected to continue to occur seasonally in the study area after project implementation. Both estuarine and freshwater fauna would adjust their position within the estuary in response to salinity variation across time and space.

There is potential for distributional shifts of red-bellied turtles away from the potential breach locations due to local increases in salinity north of the Causeway. Incidental observations from a long-term survey of road-killed Alabama red-bellied turtles along the Causeway seem to suggest that during periods of drought when salinity levels were higher individuals shifted north away from the Causeway to less saline waters (Nelson, 2014). The turtles presently occur on both sides of the Causeway, and population-level effects due to salinity changes at the constructed openings may be difficult to detect. The openings would provide Alabama red-bellied turtles with corridors to move between the upper bay and lower delta, potentially reducing mortality due to Causeway traffic.

Hydrologic connectivity established by constructed openings would provide corridors for a variety of aquatic fauna migrating between upper Mobile Bay and Choccolatta Bay, Justins Bay, and Shellbank River. Access to the SAV and fringing tidal marshes north of the Causeway would potentially increase larval and juvenile densities of important estuarine-dependent species at these locations, compared to the current condition. In general, the Causeway impedes faunal migration and has altered natural food web interactions in its immediate vicinity. The constructed openings would restore some level of natural function to the adjacent areas.

7.3 Hydrodynamic Modeling Conclusions

As part of the technical work plan formulation, the project team developed four main objectives that would be evaluated to support the stated project goal(s) of improving tidal exchange and water quality in the study area. A number of performance measures were linked to each objective with the purpose of providing specific, quantitative measures that could be used to assess each objective and potential outcomes of each restoration alternative. Conclusions drawn from the hydrodynamic model simulations are described below in terms of the project objectives and their performance measures.

7.3.1 Objective 1: Increase Tidal Communication

This objective specifically addresses the improvement in tidal communication between Mobile Bay and areas north of the Causeway that could occur as a result of constructed openings at Choccolatta Bay, Justins Bay, and/or Shellbank River. The objective was assessed by describing tidal volume fluxes; subtidal flows; tidal velocities; and sediment resuspension, transport and deposition potential throughout the study area. As a general statement, all restoration alternatives met the stated objective.

The constructed openings of each restoration alternative increased tidal volume exchange with Mobile Bay substantially. These increases were due to the improved tidal communication with Mobile Bay. A constructed opening to Choccolatta Bay was predicted to increase tidal exchange by over 80%. However, tidal exchanges through I-10 Cut and Pass Picada were predicted to decrease by 90%. Similarly, in Justins Bay a constructed opening was predicted to increase tidal exchange with Mobile Bay by over 120%. A subsequent decrease in tidal exchange, by almost 90%, was predicted for Sardine Pass as a result of the constructed opening. These patterns, and relative magnitudes, were consistent for both the low and high river discharge scenarios. Similar effects on tidal exchange were noted for simulations incorporating sea level rise, but the magnitude of the changes was different.

The constructed openings were predicted to increase subtidal flows by 1 cm/s under typical conditions, 2 cm/s for high river discharge, and 3 cm/s in the sea level rise scenario. It is difficult to express these increases as percentages, since there is almost zero (1E-04 cm/s) subtidal flow in the water bodies of interest under existing conditions. The subtidal flow was directed toward the constructed opening in each of the water bodies, and then directed toward the central portion of Mobile Bay and seaward.

Maximum tidal velocities within the study area increased by ~30 cm/s under representative tidal forcing and both low and high river discharge scenarios. Increases were predicted to be greatest in and adjacent to the newly constructed openings. However, maximum predicted tidal velocities decreased by similar magnitudes in the existing tidal channels (e.g., I-10 Cut, Pass Picada, and Sardine Pass).

Sediment transport rates were predicted to increase as a result of the constructed openings, but decreases were also noted in areas experiencing reduced velocities and exchange. Bedload sediment transport rates increased by 10% to 25%, on average, in and adjacent to constructed openings. Decreases of similar magnitudes were noted in I-10 Cut, Pass Picada, and Sardine Pass. Predicted resuspension rates exhibited similar patterns, with increases or decreases on the order of 25% to 50% relative to rates under existing conditions.

Both the bedload transport and resuspension rates were predicted to have the largest magnitudes under existing conditions and typical river discharge, slightly smaller magnitudes for the case of high river discharge, and still smaller values under the sea level rise scenario. Note that this generalization applies mainly to Choccolatta Bay, Justins Bay, and Shellbank River only. Substantially greater transport and resuspension rates were predicted in the main river channels under high river discharge.

With respect to potential changes in sediment deposition, Choccolatta Bay, Justins Bay, and Shellbank River became less depositional under typical and high flow scenarios. Their tidal channels, however, became strongly depositional due to the decreased flows and sediment transport potential in those areas. For the case of elevated sea levels, Choccolatta Bay was predicted to become more depositional while Justins Bay and Shellbank River were expected to be less depositional in nature.

7.3.2 Objective 2: Increase Tidal Prism

This objective specifically addresses tidal prism increases in water bodies north of the Causeway that could occur as a result of constructed openings at Choccolatta Bay, Justins Bay, and/or Shellbank River. The objective was assessed by describing changes in water levels, tide ranges, and tidal prisms in the study area. As a general statement, all restoration alternatives met the stated objective to varying degrees.

In terms of maximum predicted water levels throughout the study area, implementation of restoration alternatives resulted in increases of 2 cm to 4 cm in Choccolatta Bay (5% to 10% of existing values), more than 10 cm in Justins Bay (30% more than existing values), and almost a negligible amount in Shellbank River (0.5 cm to 1 cm). Model predictions suggested that affected water levels would be limited to the water bodies directly connected to the constructed opening with negligible changes elsewhere in the study area.

In each of the model simulations the effect of constructed openings was to greatly increase the tide range, and therefore the tidal prism, in water bodies north of the Causeway. Tide ranges in Choccolatta and Justins Bays were predicted to increase by 8% and 64%, respectively. Changes in tide ranges outside of the restoration areas were predicted to be less than 1%. Similar results were found during simulation of the hypothetical openings with elevated sea levels.

7.3.3 Objective 3: Decrease Tidal Phase Lag

This objective specifically addresses the degree to which tidal phase lags between Mobile Bay and areas north of the Causeway would be affected by selected restoration alternatives. The objective was assessed by describing the existing tidal phase lags in Choccolatta Bay, Justins Bay, and Sardine Pass, and their predicted changes. As a general statement, all restoration alternatives met the stated objective to decrease tidal phase lags.

The tidal phase lags were completely eliminated under every restoration and forcing scenario with one exception. In the high flow scenario the tidal phase lag between Sardine Pass and John's Bend was reduced by 50% (from 1 hour to 0.5 hour), but not completely eliminated. Tidal phase lags in Choccolatta Bay, Justins Bay, and Sardine Pass were on the order of 1 hour, 3 hours, and 0.5 hour, respectively, under representative tidal forcing and typical (low) river discharge. Under the high river discharge forcing, those tidal phase lags were predicted to be 1 hour, 3.5 hours, and 1 hour, respectively. In the sea level rise scenario they were noted as 1 hour, 1 hour, and 0.5 hour, respectively.

In the case of Choccolatta Bay, tidal phase lags were compared by noting the difference in high water times between a point in Choccolatta Bay and another located just south of the Causeway and the potential opening. For Justins Bay, the comparison was made between a point central to

Justins Bay and one immediately south of the Causeway in John's Bend. For Sardine Pass, the comparison was made between a point near Duck Skiff Pass and the point in John's Bend used to describe tidal phase lags in Justins Bay.

7.3.4 Objective 4: Increase Flushing

This objective specifically addresses the flushing of water bodies in the study area and potential improvements due to restoration activities. The objective was assessed by describing changes in particle residence times, percentage of particles flushed from the system, and estimates of turnover time based on tidal prism methods. As a general statement, all restoration alternatives met the stated objective(s) of increasing flushing and decreasing residence times.

As a general conclusion, particle residence times fell by 5 to 8 days near constructed openings, but some increases of similar magnitude were noted near and in the existing tidal channels like I-10 Cut, Pass Picada, and Sardine Pass. Under some forcing scenarios substantial decreases in residence time were noted well north in Choccolatta and Justins Bays; however, the upper portions of these bays remain poorly flushed with few to no particles escaping during the 9-day LPTM analysis.

Flushing of Choccolatta Bay and Justins Bay was improved substantially when constructed openings were simulated. These changes were generally 75% to 85% improvements in the amount of flushing for Choccolatta Bay, and as much as a 500% improvement in flushing for Justins Bay. Under every scenario the hypothetical opening was responsible for nearly all flushing with almost no particles leaving through existing tidal channels. This finding was supported by the substantial increases in particle residence time noted near existing tidal channels.

Since the LPTM analysis could only be considered over a nine-day simulation period, system-wide averages of residence time and exposure time are somewhat misleading: many (most) of the particles never leave the system in that short of a period. As demonstrated in Marr (2013), residence times were predicted to be well over 100 days for some values of river discharge. However, reductions in these system-wide averages were noted. In Choccolatta Bay the system-wide average residence and exposure times decreased by 0.5 day to 1.0 day. In Justins Bay, those values decreased by 1.5 days to 2.5 days (relative to existing conditions).

A simple tidal prism method can be used to describe changes in system turnover time as well. The tidal prism method (see Sheldon and Alber, 2006) estimates the number of tidal periods required to "renew" system water by considering the ratio of system volume to the tide range volume. Here, the tide range volume refers to the product of the tide range and the bay surface area. Since both the system volume and tide range volume include an estimate of the bay surface area, they may be cancelled and the result is a ratio of average system depth to tide range.

Application of this simple tidal prism method suggests that under existing conditions Choccolatta and Justins Bays would have turnover times of 1.5 days and 2.3 days, respectively. Based on the noted changes in tide range described earlier, turnover times in Choccolatta and Justins Bays would decrease by 7% and 39%, respectively. These estimated values are consistent with the noted improvements in flushing determined through the LPTM analysis.

8.0 POTENTIAL NEXT STEPS FORWARD

The purpose of the CIAP AL-12 project was to collect data relevant to the existing conditions along the Mobile Bay Causeway in support of evaluating the potential impacts and benefits associated with opening up portions of the Causeway for hydrological restoration. Through the process of preparing work plans, collecting and analyzing sediment cores, performing biological field studies, formulation of alternative designs, and hydrodynamic modeling, the project objectives, goals, and overall purpose have been satisfied. During the process of performing project-related tasks, primarily the evaluation of the results, it became apparent that additional data collection and assessments could be performed to further enhance the knowledge gained as a result of this project. These additional assessments are merely suggested items that, if performed, may provide a better understanding of the overall conditions within the study area and the potential hydrodynamic responses to projects that may be proposed along the Causeway. The areas that could be further evaluated in the future include, but are not limited to, modeling to optimize the opening size at Choccolatta Bay, modeling of wave action, expanded model boundary, and evaluations of water quality at key locations.

8.1 Modeling to Optimize Opening Size

For Choccolatta Bay, additional modeling could be performed with varying Causeway opening widths to evaluate the effects that changing the size will have on volume flows into and out of the bay. The modeling performed to date indicates that overall circulation would be greatly increased if an opening were constructed in the Causeway. However, the modeling also showed that under the assumed opening width that flow through Pass Picada and I-10 Cut would be significantly reduced. The goal of the optimization process would be to reduce the assumed width of the Causeway opening such that the tidal volume exchange is maximized with an appropriate distribution of flows through each tidal opening.

Similar to Choccolatta Bay modeling to optimize opening size, additional modeling could be performed for Justins Bays with a goal to reduce the width of the Causeway opening such that tidal volume exchange is significantly improved (compared to existing conditions), while minimizing the potential impacts to existing wetlands. Existing wetlands extend away from the Causeway in both north and south directions of varying distances (between approximately 100 to 450 feet). The design of an opening at this location could be optimized by evaluating the ecosystem value when considering both the open water and wetland areas associated with various opening widths.

Additionally optimization considerations for Justins Bay may include evaluating the tidal exchange with a reduced opening so that improvements, including an approach ramp do not encroach into an existing private property located near the eastern limits of the current design alternative. According the Spanish Fort Water Interconnection as-built plans (MCW Project No. M5712-2028, dated 20 November 2001), there is a privately owned parcel measuring approximate 1.01 acres located along the north side of the Causeway (centered at approximate station 483+25 of the referenced plans). The design may be reduced by approximately 500 feet to prevent the overlap of improvements with the private parcel. The above-mentioned optimization process to reduce wetland impacts at Justins Bay may result in a smaller opening that avoids the private parcel. In lieu of avoiding the private property, progression of a project at

this location may initiate communication with the property owners for the purposes of procuring the parcel.

8.2 Modeling of Wave Action

Building on the current modeling, two additional model scenarios could be prepared that would incorporate wave action in Choccolatta Bay and Justins Bay. This could be accomplished by simulating waves generated by south winds blowing from Mobile Bay into the bays. The increased wave action in these bays may result in different hydrology effects, compared to no wave action, in Choccolatta Bay and Justins Bay with the hypothetical Causeway openings. The model could evaluate each bay separately under the wave action condition.

8.3 Expand the Model Boundary to Include D'Olive Bay

The model resolution within D'Olive Bay and D'Olive Creek could be enhanced to reflect existing conditions with the goal of more accurately simulating tidal flows there. The bathymetry would be based on available data and may or may not include additional survey data collection. The results of the additional modeling could provide an estimate of how potential Causeway openings may affect flows and sedimentation/resuspension within D'Olive Bay.

8.4 Water Quality Evaluation

The potential water quality changes as a result of the hypothetical (optimized) opening could be evaluated. This evaluation may focus on areas where the modeling predicts a significant reduction in flow. The constituents that may be evaluated include temperature, salinity, dissolved oxygen and nutrients. Depending on the desired scope level and time frame for the completion of this type of study, the collection and analysis of water column samples may be performed. If applicable, the collection of samples should correspond to the period when water quality impacts are most likely, such as the summer months. In lieu of collecting samples, the evaluation may be limited to synthesis of data collected previously by various researchers and estimating, through modeling and/or calculations, the water quality in the focus areas for the hypothetical conditions relative to the water quality under the existing conditions (no openings).

8.5 Coordination with Utility Owners

Advancement of the planning of restoration projects along the Causeway should include coordination with utility owners to determine temporary (during construction) and permanent relocation options and associated costs. The major utilities within the Causeway right-of-way include water main, overhead power lines, and fiber optic communication lines. Relative to the fiber optic lines, the water main and overhead power lines may be fairly straight forward to relocate (water main) and fortify (power poles). In our research into the fiber optic lines, a consultant for AT&T indicated that the fiber optic line within the Mobile Bay Causeway is a back bone route that carries the highest level of service for any number of organizations between east and west, and there is no other path across Mobile Bay. Based on the service provided by the fiber optic conduit, coordination with the AT&T and its utility consultants should progress to determine construction options that will facilitate continuity of service as well as the detailed costs and schedules associated with such options.

8.6 Preliminary Engineering Design Plans

After completion of the opening size optimization effort (Section 8.1), preliminary engineering design plans may be prepared (e.g., 30% design sheets). The plans would show more details including bridge structural elements and calculations. Topography surveys and geotechnical evaluations may be performed and incorporated into the designs. The plans would then be used to generate more accurate limits of disturbance, cost estimates, and construction methods and corresponding schedules.

The preparation of preliminary engineering design plans must consider environmental permitting paths. Thus, this effort should include progressing the environmental permitting components to include determining the permits required, mitigation requirements (if applicable), and other environmental permitting considerations that may affect the engineering design and construction scheduling.

The preparation of preliminary engineering design plans may include an assessment of traffic control options during construction. As stated in the Alternatives Formulation Results section (5.4), openings in the Causeway may be constructed by either completely closing the roadways in the construction area or possibly by allowing traffic to pass through the construction area with one lane of travel in each direction. This would most likely require a temporary retaining wall, and the practicality of this design concept would need to be verified during this stage of design based on geotechnical engineering recommendations. There would be additional costs and construction durations associated with allowing traffic to continue, which may be offset by the improved traffic connection across the Mobile Bay. As such, this assessment should include a traffic impact study for both scenarios. This assessment may include an economic impact study to evaluate/predict how the businesses in the nearby areas may be affected by future potential projects.

The construction methods and phasing should be included as part of the preliminary engineering design effort. The methods to construct bridges and create opening through the Causeway will differ from those utilized to construct other bridges in the regions. For example, the nearby I-10 bridge is mostly located in deeper water accessible by barge. The waters adjacent to the Causeway are shallow (approximately 3.5 feet below mean lower low water elevation). Therefore, if construction methods include accessing the area by barge during construction, then the engineering plan would need to include details and associated permitting for dredging of an access channel. Barge access may not be required if most of the substructure work could be performed prior to excavation of earth materials (existing roadway embankment). The design effort should include evaluations of which method is more practical, and this effort should include consulting with construction contractors most likely to bid on area projects of this nature in the future.

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