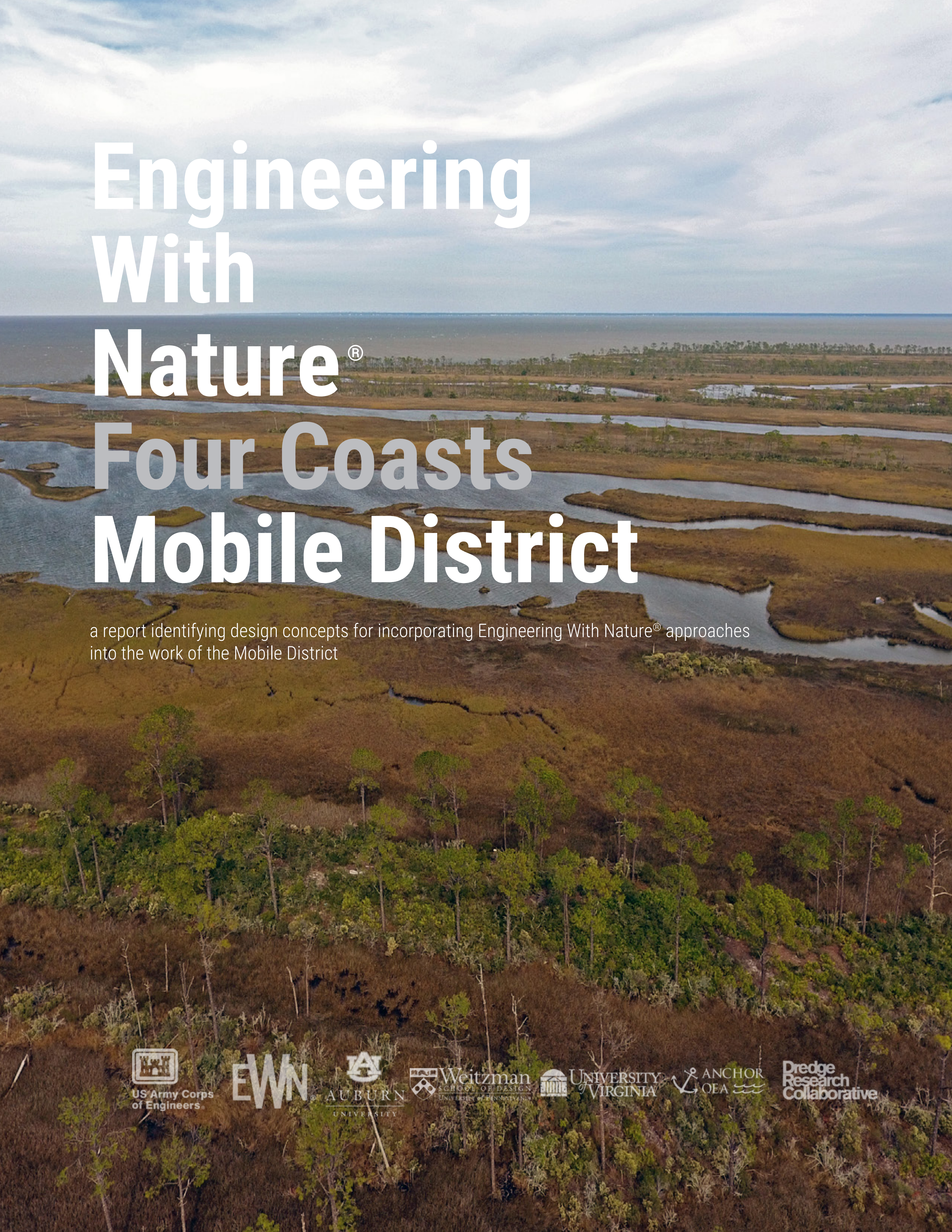
Engineering With Nature®

Four Coasts

Mobile District

a report identifying design concepts for incorporating Engineering With Nature® approaches into the work of the Mobile District



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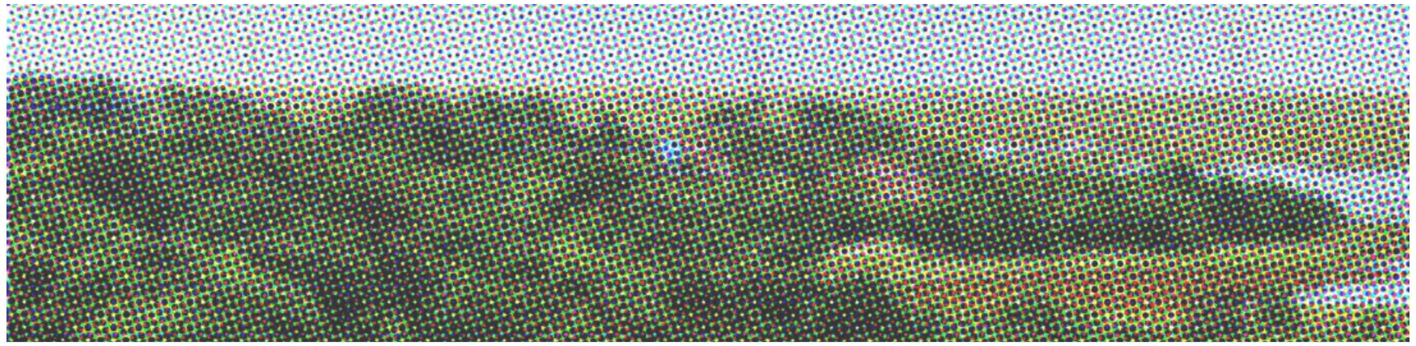

Engineering With Nature®

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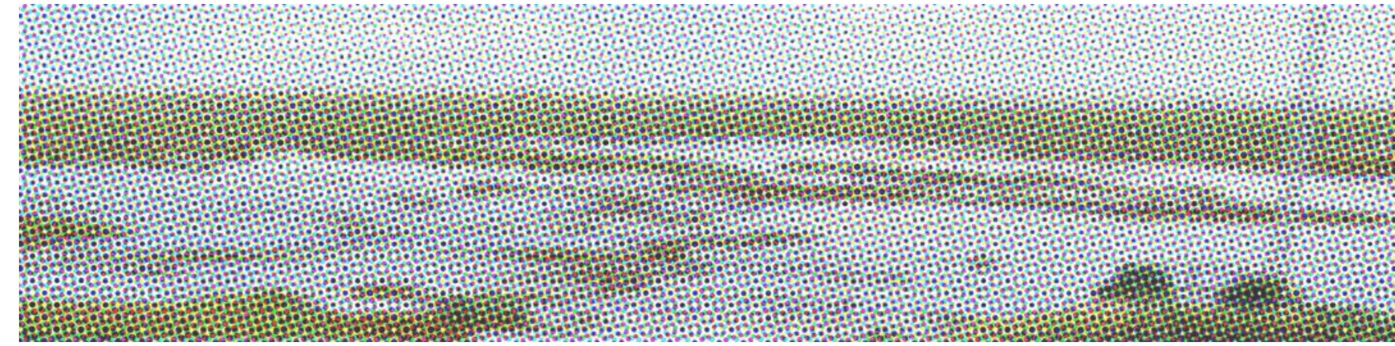

This report covers findings from research cooperative agreement W912HZ-20-2-0049 **Incorporating Engineering With Nature® (EWN®) and Landscape Architecture (LA) Designs into Existing Infrastructure Projects**, an agreement between the **U.S. Army Engineering Research Development Center** (ERDC) and **Auburn University** (AU).

This report has been prepared by the investigators at **Auburn University**, the **University of Virginia**, and the **University of Pennsylvania** in collaboration with **AnchorQEA** and consultants from the **Dredge Research Collaborative**; it also incorporates research and insights from ERDC's **Engineering With Nature®** project team.

Engineering with Nature® is the intentional alignment of natural and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaborative processes.

Sustainable development of water resources infrastructure is supported by solutions that beneficially integrate engineering and natural systems. With recent advances in the fields of engineering and ecology, there is an opportunity to combine these fields of practice into a single collaborative and cost-effective approach for infrastructure development and environmental management.

The Dredge Research Collaborative is an independent 501c3 nonprofit organization that investigates human sediment handling practices through publications, an event series, and various other projects. Its mission is to advance public knowledge about sediment management; to provide platforms for transdisciplinary conversation about sediment management; and to participate in envisioning and realizing preferred sedimentary futures.

http://engineeringwithnature.org
http://dredgeresearchcollaborative.org/

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Executive Summary

The Mobile District of the US Army Corps of Engineers operates and maintains over 2,200 miles of navigation channels, numerous deep and shallow water ports, and one of the largest recreation systems in the Southeast, which includes 27 lakes and 464 recreation areas that more 34 million people visit every year. The District's coastline begins in central Mississippi, runs east across Alabama, and covers the panhandle of Florida. The Mobile District stretches across 6 different watersheds, within which lie some of the most diverse ecosystems in the country.

Across this geography, the Mobile District is responsible for complex navigation, ecosystem restoration, coastal storm risk management, and flood risk management missions. These missions often intersect with the infrastructures that the District is responsible for, such as navigation channels, or the processes required to maintain those infrastructures, such as dredging, which produces millions of cubic yards of dredged material within the District's boundaries every year. The District is responsible not only for maintaining these infrastructures, but also for improving existing infrastructure and for providing new infrastructures where Congress and non-federal sponsors deem them necessary.

As the District has taken on these tasks over recent decades, it has become one of the nation's leading Districts in the exploration of Engineering With Nature® (EWN®) the practice of aligning water resources infrastructure with natural systems. Numerous projects within the District, such as the restorations of Deer and Ship Islands through the beneficial use of dredged sediment (Kuzmitski 2021) or the thin-layer placement of dredged material in Mobile Bay (Berkowitz et al 2019), exemplify innovation in Engineering With Nature®. In 2021, the Mobile District became an official Proving Ground District for Engineering With Nature®, recognizing and solidifying its leadership in the development of nature-based infrastructure (Kuzmitski 2021).

This document summarizes the Mobile District component of an effort sponsored by Engineering With Nature® to identify and advance key opportunities for further innovation in nature-based infrastructure within Proving Ground Districts across the United States. A multidisciplinary team, including landscape architects associated with the Dredge Research Collaborative and engineers from Anchor QEA, worked with the Mobile District between August 2022 and September 2023 to identify opportunities for and develop design concepts for five coastal sites within the Mobile District.

After initial research and meetings with the EWN® team at the Mobile District in fall 2022, five sites were selected that exemplify the particular challenges and opportunities across the three different coastal states within the District's boundaries, Mississippi, Alabama, and Florida. As delineated in the recent South Atlantic Coastal Study and District planning efforts like the Regional Sediment Management Strategy for Mobile Bay (Parson et al 2015), the District's coastline faces substantial challenges from sea level rise, tropical storms, and habitat loss, challenges which intersect with on-going economic development, infrastructural expansion, and population growth. Our initial research into such regional characteristics, including the specific issues and opportunities faced within the District, and the subsequent site selection are summarized in the first section of this report, an overview of the District and our site selection entitled Mobile District.

The bulk of the report is primarily organized by project location, grouped into three distinct regions: the Mississippi Sound, Mobile Bay, and the Florida Gulf Coast and Estuaries. These project studies begin in Holistic River Reconnection, which details our study of the Escatawpa River, a river that historically built a large marsh complex in a portion of the Mississippi Sound known as Grand Bay. Today, the river is disconnected from the marsh complex due to an interplay of natural and human causes, and the marsh complex is consequently facing an accelerated decline. Our study illustrates strategies to simultaneously address habitat loss in Grand Bay and local community flood risk in adjacent municipalities like Moss Point.

The next section, Beneficial Use for Ecological Restoration, focuses on three case studies in Mobile Bay, the largest bay within the District's boundaries, where roughly 7 million cubic yards of dredged material are removed from the bay's navigation channels during a typical year's maintenance operations. The case studies focus on how this very large sedimentary surplus could be directed to beneficial use locations where that sediment can support ecosystem restoration and storm risk reduction efforts, including a dispersive placement area strategy for the western bay, a sediment choreography study for Blakeley Island, and a series of nature-based features that could be implemented along the Fort Morgan Peninsula and Bon Secour Bay. This last series of features has been explored in particular detail, including through hydrodynamic modeling, the results of which are summarized in that section and delineated in detail in Appendix 1.

Finally, in Choreographing Natural Infrastructure, we look closely at storm risk, habitat vulnerability, and sea level rise in Perdido Bay, an estuary east of Mobile Bay that lies on the border between Alabama and Florida. There, we detail three sets of nature-based strategies: seagrass bed augmentation, marsh creation, and oyster habitats, each of which has the capacity to simultaneously support the ecological health of Perdido Bay, promote the growth of blue-green industries that interact with a healthy bay, and reduce storm risk on the bay's shorelines.

As a whole, this report is indicative of the rich opportunities for expanding nature-based infrastructure and implementing EWN® approaches within the Mobile District. Further work should build on this report to refine, test, and design in greater detail. Potential next steps include:

- Expanding and strengthening existing efforts at holistic assessment of EWN® approaches within the District's boundaries, with that holism understood as a matter of both geographic approach (considering, for instance, flows of sediment between a bay like Mobile Bay and an estuary like the Mississippi Sound) and institutional connections (planning across the full range of federal, state, and local entities with responsibility for the region's coasts)
- Building strong regional coalitions to support innovation and implementation, including but not limited to funding new nature-based infrastructure
- Further design and engineering study, including hydrodynamic modeling, to better understand the potentials and constraints of the design concepts documented in this report
- Public engagement and outreach, in order to both build public understanding of and support for nature-based approaches and to understand how nature-based infrastructure can best meet the needs of the specific communities it will impact

Introduction

Engineering With Nature® (EWN®) is a program based out of the USACE Engineer Research and Development Center (ERDC). This report has been produced as part of a larger collaborative research project, referred to as the Four Coasts project. In this project, the engineering firm Anchor QEA and a team of landscape architects affiliated with the Dredge Research Collaborative (DRC) were tasked by the USACE ERDC as part of the EWN® program to work with Proving Ground Districts along the Atlantic of Ocean, Pacific Ocean, Gulf of Mexico, and Great Lakes, collectively known as the four coastal regions, to identify key nature-based infrastructure opportunities. These collaborative partners selected three to five representative projects on each coast, with the projects ranging from the integration of natural and nature-based features (NNBF) within existing District work to the advancement of new EWN® design concepts that the project team has developed. This reports documents in detail five such projects located within the bounds of the USACE Mobile District (SAM).

EWN® is the "intentional alignment of natural and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaborative processes" (Engineering With Nature®). In the EWN® approach, sustainable development of water resources infrastructure is supported by solutions that beneficially integrate engineering and natural systems. With recent advances in the fields of engineering and ecology, there is an opportunity to combine these fields of practice into a single collaborative and cost-effective approach for infrastructure development and environmental management. EWN® outcomes are "triple-win," which means that they systematically integrate social, environmental, and economic considerations into decision-making and actions at every phase of a project to achieve "innovative and resilient solutions" that are more socially acceptable, viable, and equitable, and ultimately, more sustainable.

Four Coasts builds on and expands four years of earlier work in the EWN®-LA initiative, which has engaged new and existing water resources infrastructure projects in Districts ranging from Alaska to Florida, with the aim of supporting the deployment of EWN® approaches through the application of the methods and knowledge of landscape architecture. As a field, landscape architecture is presently concerned with many of the same issues of infrastructural performance and potential that EWN® is currently pursuing, including the re-imagination of traditional infrastructure to meet more diverse criteria encompassing engineering functions, ecological value, cultural significance, and aesthetic benefits (Spirn 1984; Mossop 2006; Orff 2016; Belanger 2017). The landscape architecture work of this initiative has been led by members of the DRC, including Sean Burkholder, Brian Davis, Rob Holmes, Justine Holzman, Brett Milligan, and Gena Wirth, together with ORISE Fellow Tess Ruswick, supported by colleagues and students at our respective universities, which, over the lifespan of the initiative so far, have been Auburn University, the University of Pennsylvania, the University of Toronto, and the University of Virginia.

For the current Four Coasts project, the DRC landscape architects have worked collaboratively with engineers at Anchor QEA to ensure concepts are based in sound engineering principles. This collaboration allows for the development of unique infrastructure concepts through an iterative process of concept development, technical assessment, and refinement. Broadly, the engineers on the research team bring a precise and analytical approach based on values that can be quantified, which the landscape architects offer a synthetic approach that considers cultural values alongside environmental characteristics. This collaborative integration of engineering and landscape architecture promotes a holistic alignment in the development and visualization of EWN® design concepts.

MOBILE DISTRICT

MOBILE DISTRICT

DISTRICT OVERVIEW AND PROJECT SELECTION

In this section, we review general conditions within the Mobile District's boundaries that are relevant to Engineering With Nature®, beginning with broad characteristics such as physiography, ecoregions, and the distribution of infrastructure within the District. We then look more closely at the dynamics of sediment management in the District, and conclude by identifying the three coastal regions, the Mississippi Sound, Mobile Bay, and the Florida Gulf Coast and Estuaries, where the design concepts delineated in this report are located.

1 DISTRICT OVERVIEW
PHYSIOGRAPHY

Today, SAM, a part of the South Atlantic Division of the USACE, touches six states and six different watersheds, each of which is a major river basin that drains to the Gulf Coast. For the purposes of this report we have categorized our projects into three different areas on the Gulf Coast: the Mississippi Sound, Mobile Bay and the Florida Gulf Coast and Estuaries.

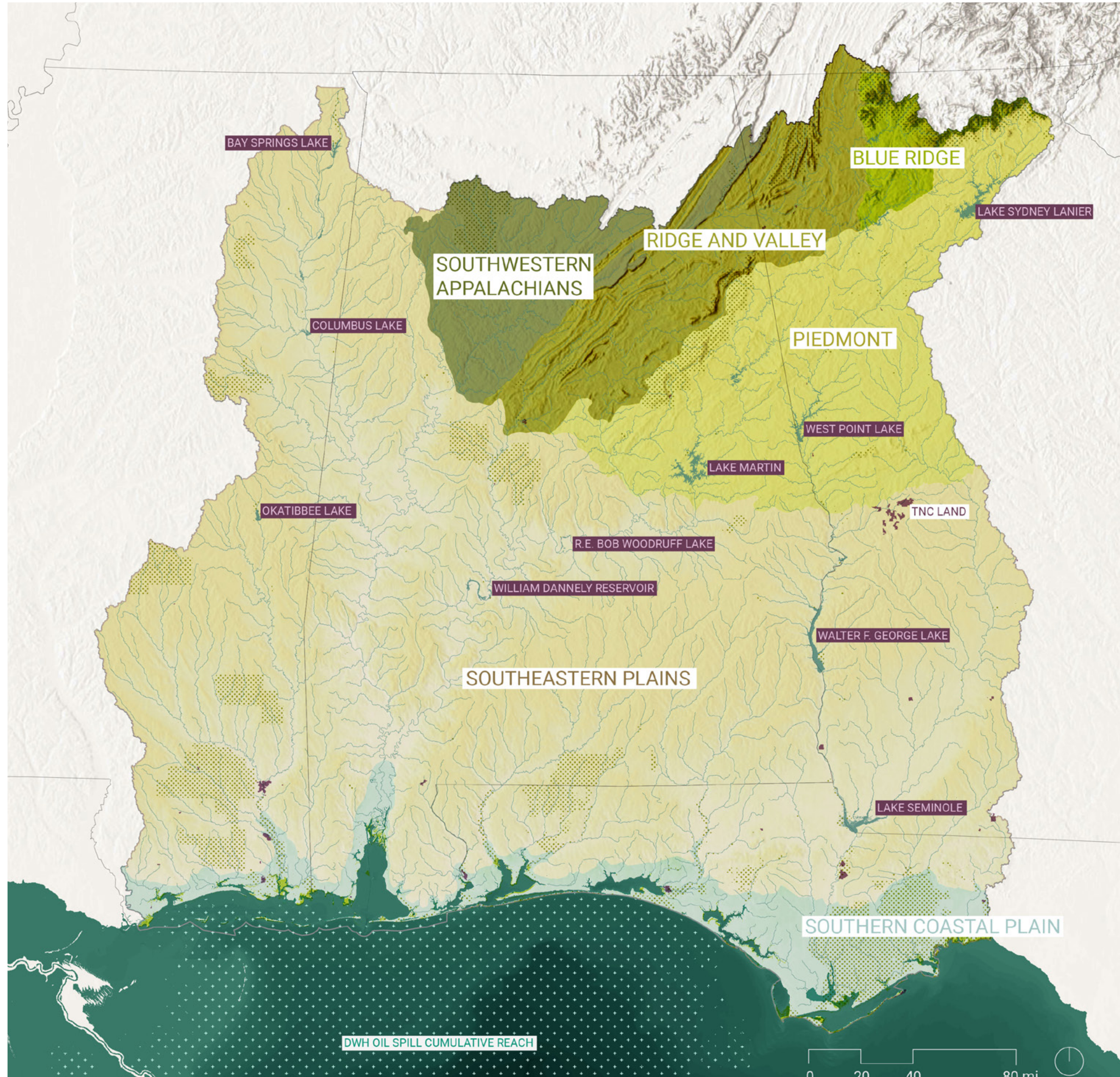
The Mississippi Sound, located on the southern coasts of Mississippi and Alabama is characterized by the barrier islands that run from the west (beginning with Cat Island) to east (ending at the Dauphin Island Bridge), and separate the sound from some of the larger dynamics of the Gulf of Mexico. Our project is located in Grand Bay which is a shrinking estuary system just across the Alabama border in Mississippi formed by the former course of the Escatawpa River. This area is one of the least developed areas on the Gulf Coast and holds important cultural relics and wet pine savanna habitat.

Mobile Bay is the fourth largest estuary in the United States with both the Mobile and Tensaw River emptying into the bay on the north end. Along with the city of Mobile and the Port of Mobile several smaller communities surround the 24 mile wide bay. Fort Morgan Peninsula juts into the bay on the southeastern edge and forms the southern end of the bay.

The Florida Gulf Coast and Estuaries stretch east from Mobile Bay to the Saint Marks River in Florida and include three major river basins, the Choctawatchee-Escambia, the Apalachicola, and the Ochlockonee. This region is characterized by long barrier islands and peninsulas which often separate large back bays from the Gulf proper, opening occasionally for inlets that lead into major bays like Perdido, Escambia, Choctawatchee, Saint Andrews, and Apalachicola.

2 DISTRICT OVERVIEW
ECOLOGY

The Mobile District spans five distinct eco-regions: the Southern Coast Plain, the Southeastern Plains, the Piedmont, the Ridge and Valley, and the Southwestern Appalachians. The Mobile District is one of the most biodiverse places in the country due to warm latitudes and moisture from the Gulf of Mexico. This ecological range from sea to mountain contains a multitude of saltwater and estuarine plants and animals along with diverse freshwater species such as mussels, fish, and salamanders. Across these ecoregions, the District and its partners maintain more than 540 recreation areas that feature campgrounds, beaches, marinas, boat ramps, parks, and trails.

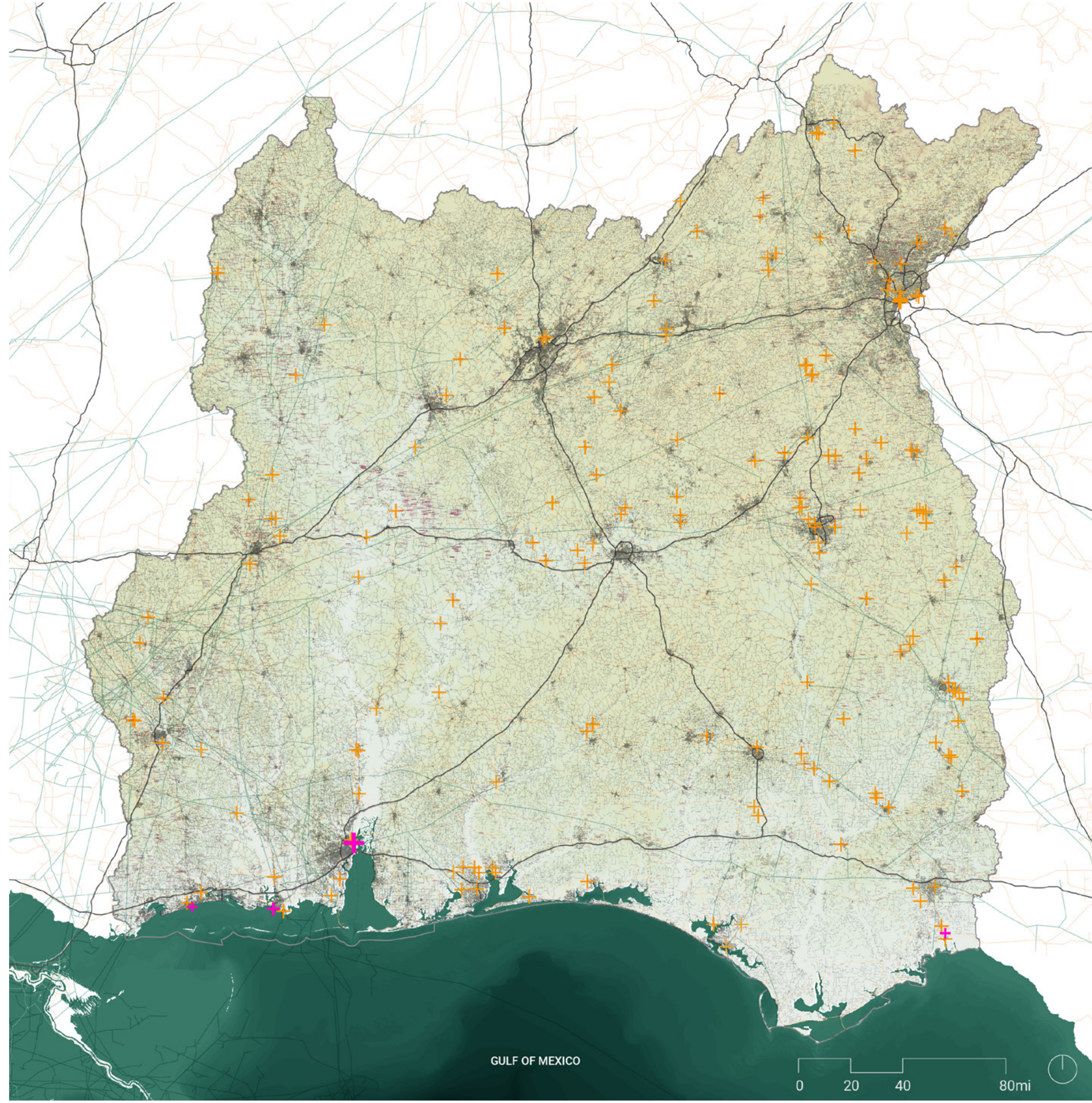


3 DISTRICT OVERVIEW
INFRASTRUCTURE

The Gulf of Mexico is the nation's largest source of offshore oil and gas production. A submerged web of platforms and pipelines meet production and distribution infrastructure that crisscross the District. The region also supplies more than a third of domestic seafood products nationally; this seafood is harvested in the coast's waters, processed on its shorelines, and shipped for distribution locally, regionally, and nationally. Along with these large scale economies, municipal, tourist, and military infrastructure dot hundreds of miles of coastline within the Mobile District. Much of this vital infrastructure, especially that of the near coast, is vulnerable to storm hazards and is often threatened by sea-level rise. Protection and mitigation efforts like the use of EWN® strategies and the deployment of NNBFs are important steps towards resilience and climate change adaptation in the Gulf.

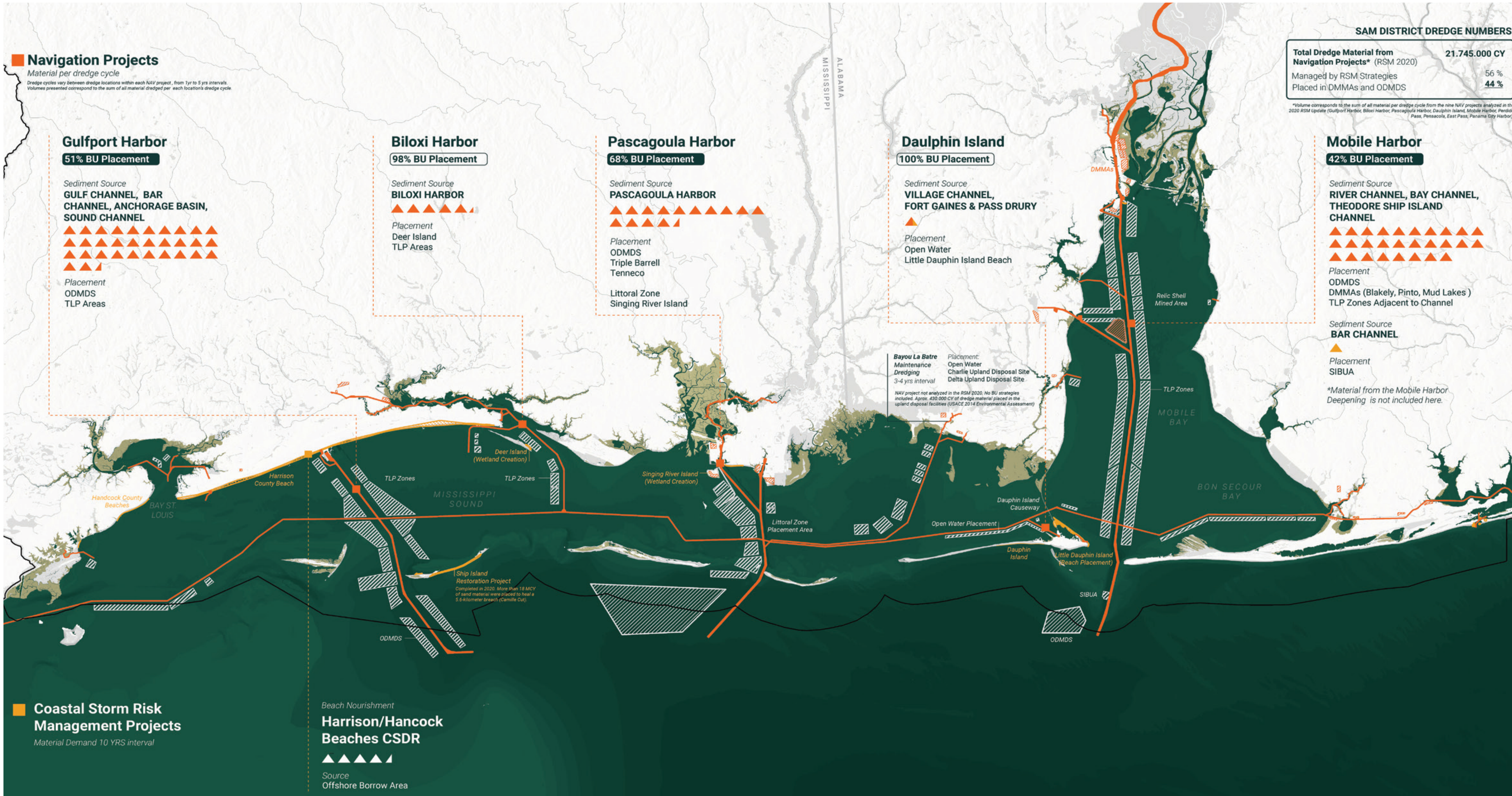
INFRASTRUCTURE

- *Dams and levees*
- *Power plants*
- *Ports*
- *Oil and natural gas pipelines*
- *Electric transmission lines*
- *Freeways and roadways*



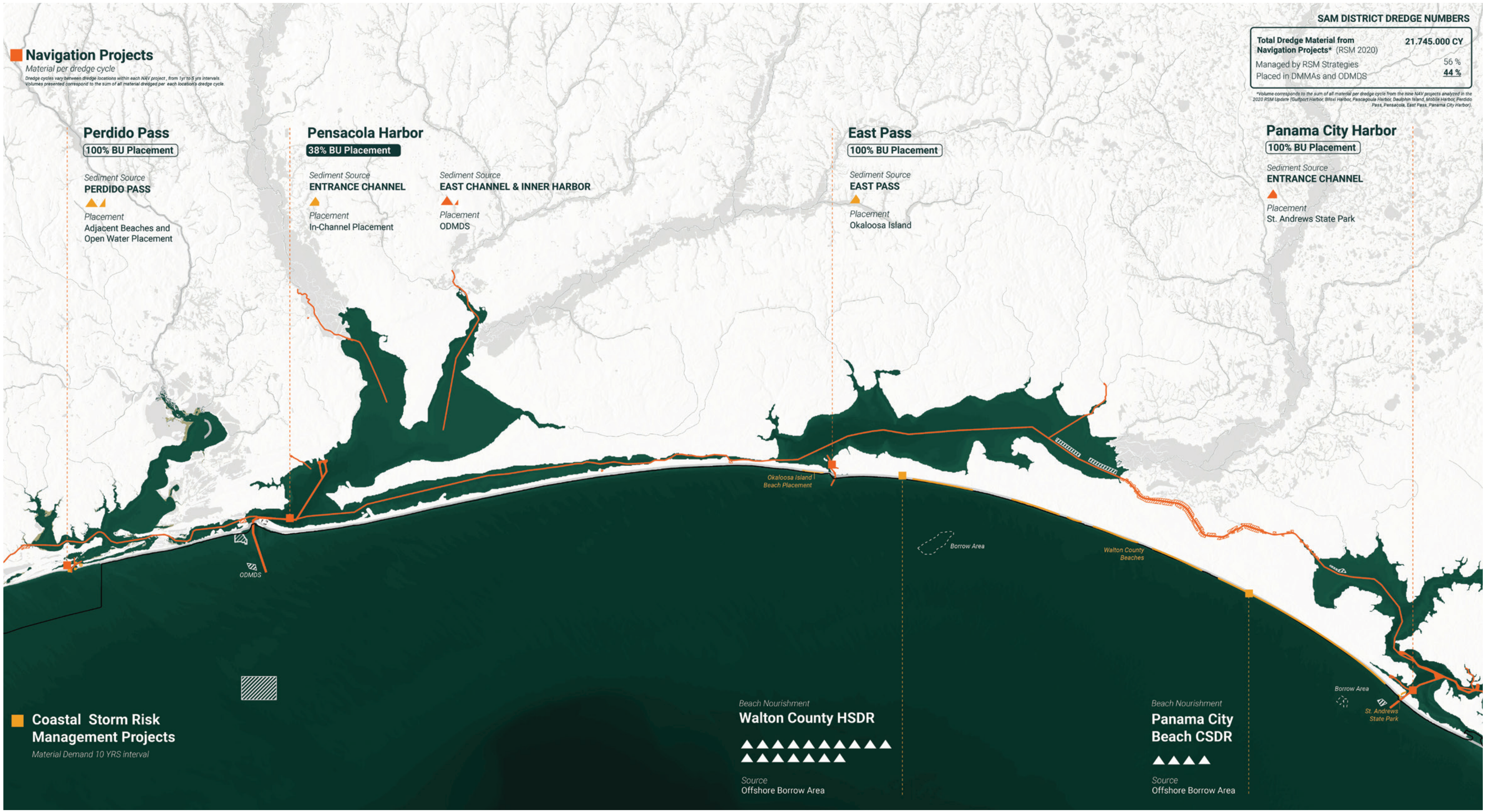
4 DISTRICT OVERVIEW
SEDIMENT DYNAMICS

The bulk of the navigational dredging by the Mobile District happens in the western half of its Gulf coastline, with Gulfport, Pascagoula, and Mobile in particular having very large annual dredging volumes. Each of these ports also has substantial opportunities to increase the volume of dredged material beneficially used, particularly given Gen. Spellmon's 70/30 goal, which aims at beneficially using 70% of all sediment dredged across all Districts by 2030 (EWN® Podcast, 2023). The beneficial use projects explored in the Mobile Bay section of this report are representative of the kind of EWN® concepts that could be researched and implemented across the region.



4 DISTRICT OVERVIEW
SEDIMENT DYNAMICS

Dredging volumes are much lower in the Florida Gulf Coast and Estuaries. Here, the challenge is less how to beneficially use material, and more where to source adequate sediment for the deployment of nature-based features. The Perdido Bay study in this report is representative of these challenges and discusses this issue of sediment supply and demand.



5 DISTRICT OVERVIEW
FOCUS PROJECTS

Five project locations were selected across the three coastal regions of the District for their diversity in terms of types and scales of nature-based infrastructures, timelines, phases, and objectives. Each seeks to highlight forward-thinking and innovative design concepts, some already in development by SAM, others building off of the planning and operations of the District.

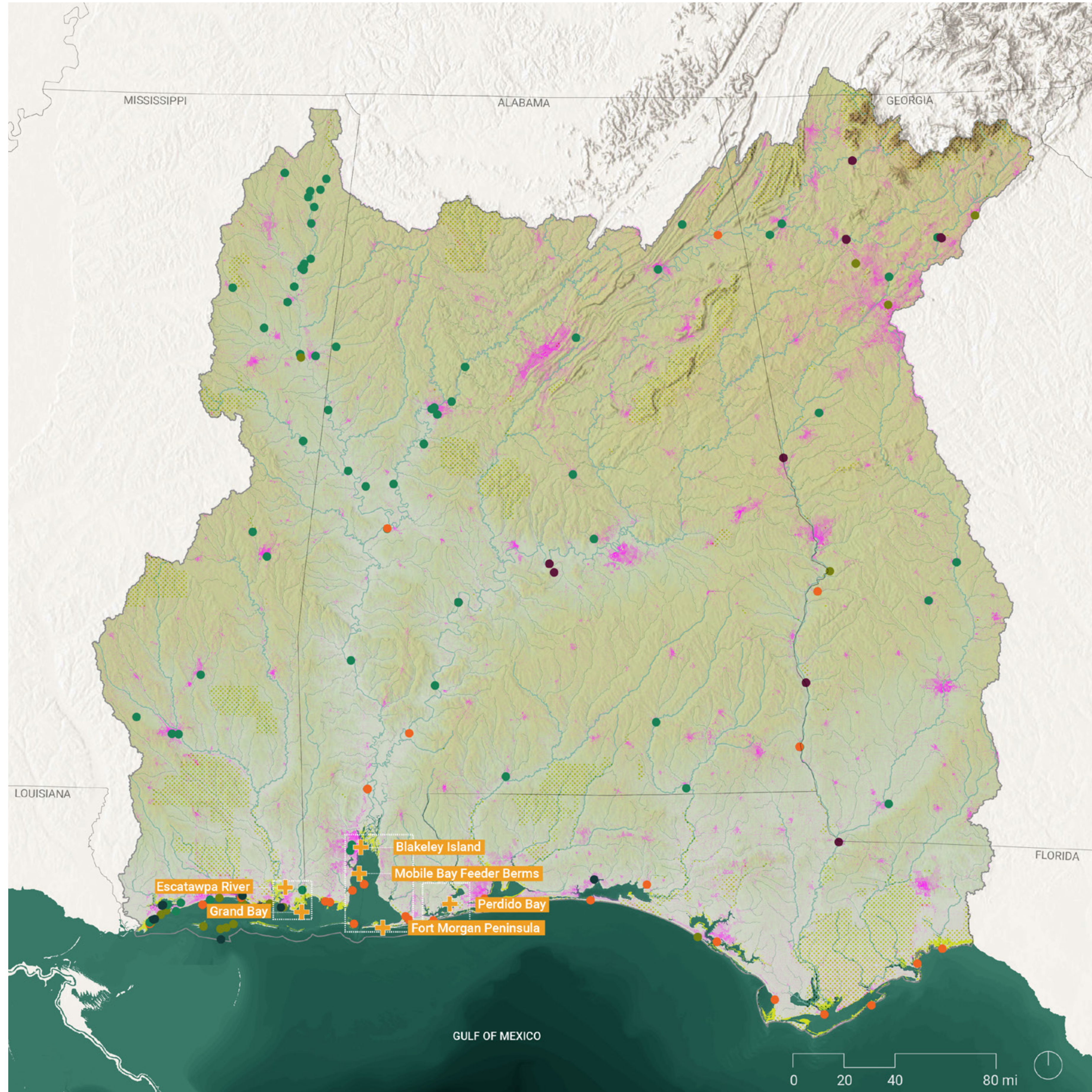
These selected projects included a broad study of Grand Bay and the Escatawpa River system which attempt to provide a panoramic of possible designs to address the decreased sediment flow to the estuary system and as well as localized flooding, a study of Mobile Bay including beneficial use of sediment at Blakeley Island and nature-based infrastructure design in Bon Secour Bay, and, finally, sediment-focused strategies for resilience in Perdido Bay.

ARMY CORPS ACTIVITY
- Ecosystem Restoration
- Flood Risk Management
- Hydropower
- Navigable Waterways
- Hurricane, Storm Damage Reduction

ECOLOGICAL & SOCIAL ASSETS
- Parks and Protected Areas
- Wetlands

At Risk Communities
- 0-20% poverty
- 20-40%
- 40-60%
- 60-80%

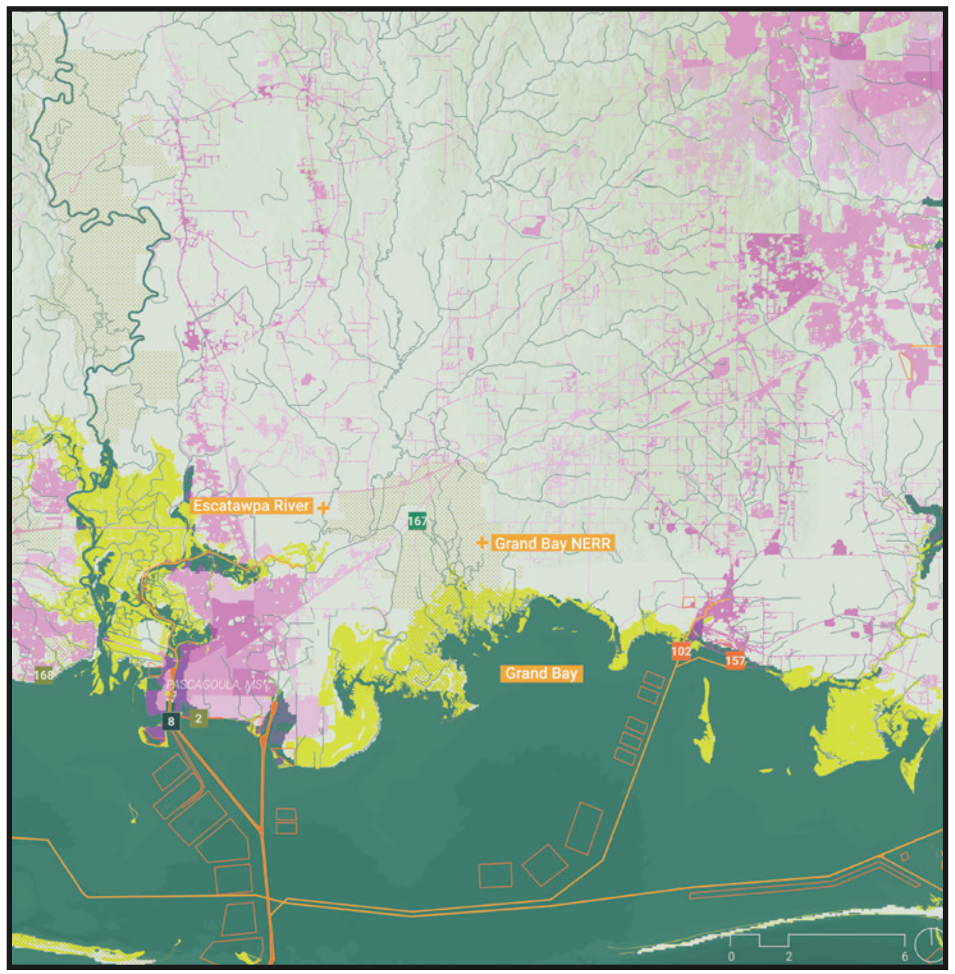
LA+EWN PROJECTS IN THIS REPORT



5 DISTRICT OVERVIEW
REGIONS

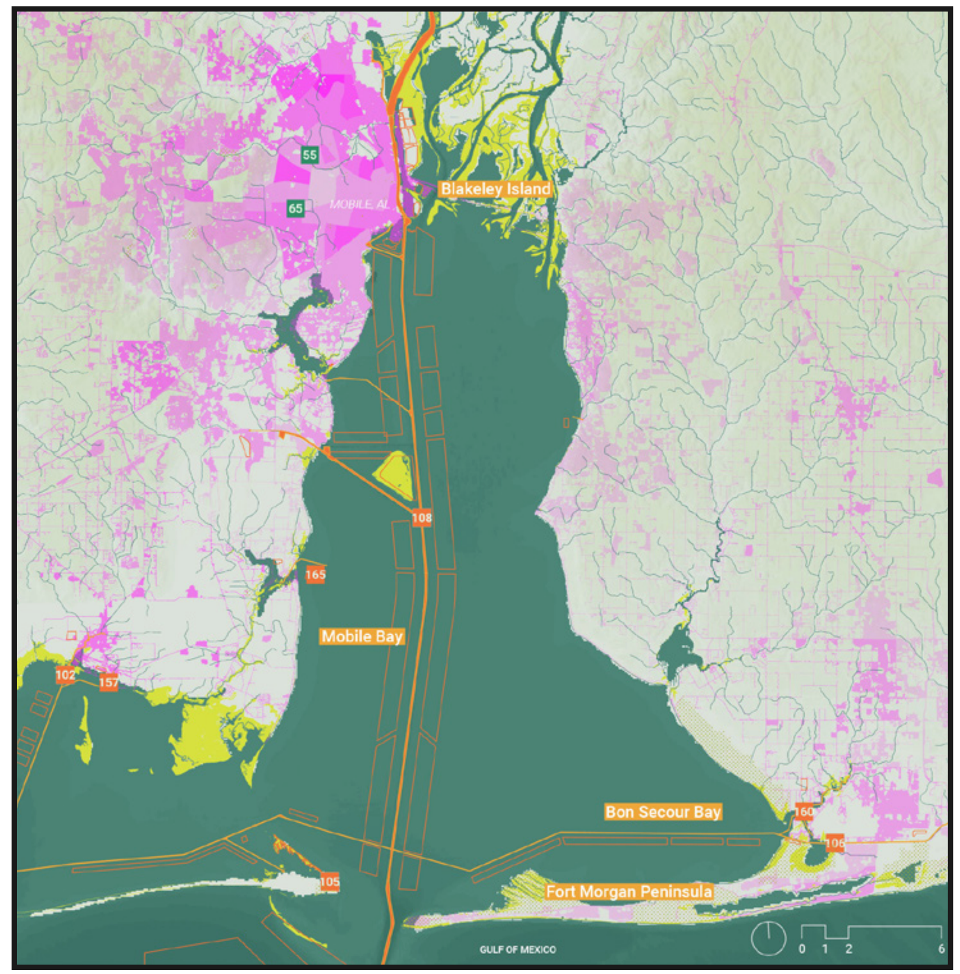
Our projects were selected within these three different regions of the northern Gulf Coast. Though relatively close in proximity, these projects grapple with varying concerns related to their unique natural, infrastructural, and social systems. The sections of the report that follow dive into each of these projects in detail.

THE ESCATAWPA RIVER AND GRAND BAY
HOLISTIC RIVER CONNECTION



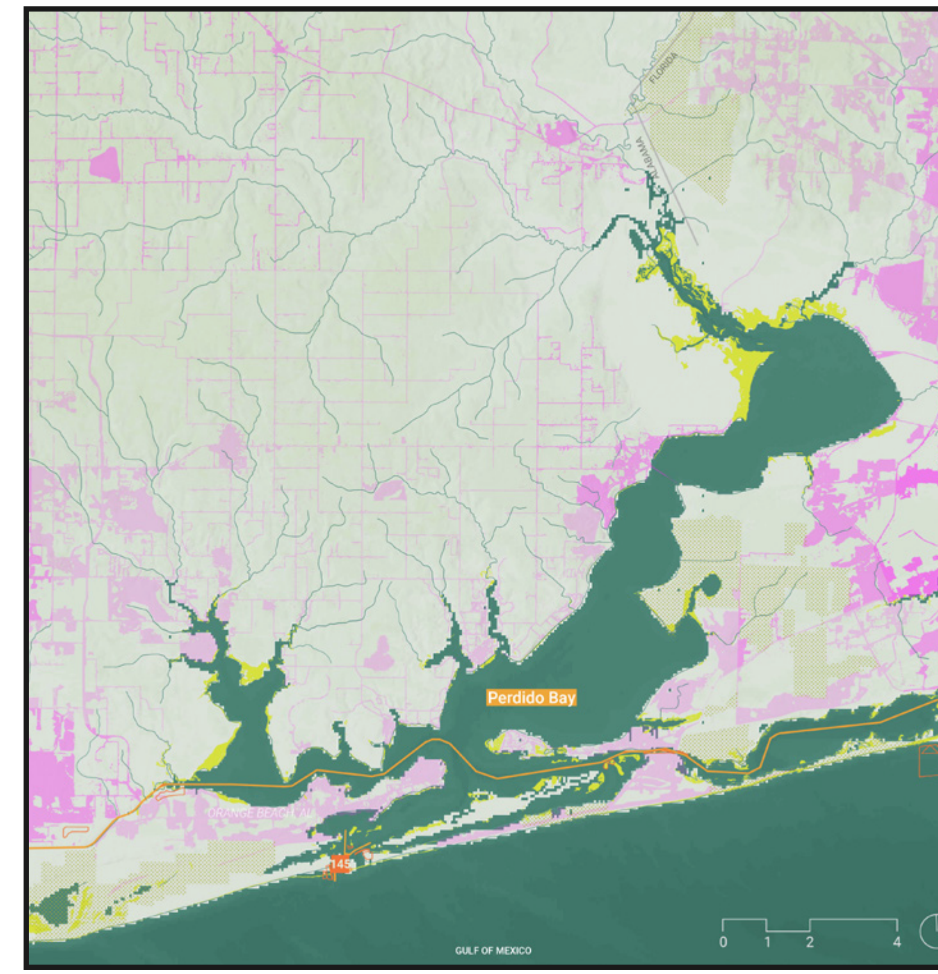
1. **ESCATAWPA RIVER** | MOSS POINT, MS
2. **GRAND BAY** | GRAND BAY, MS

MOBILE BAY
BENEFICIAL USE FOR ECOLOGICAL RESTORATION



3. **DISPERSIVE PLACEMENT AREAS** | MOBILE BAY, AL
4. **BLAKELEY ISLAND** | MOBILE BAY, AL
5. **FORT MORGAN PENINSULA** | MOBILE BAY, AL
6. **BON SECOUR BAY** | MOBILE BAY, AL

PERDIDO BAY
CHOREOGRAPHING NATURAL INFRASTRUCTURE



7. **PERDIDO BAY** | ALABAMA/FLORIDA

THE ESCATAWPA RIVER AND GRAND BAY

HOLISTIC RIVER RECONNECTION

ESCATAWPA RIVER AND GRAND BAY

The Escatawpa River is a large tributary of the Pascagoula River, which it flows into on the north side of the community of Moss Point, Mississippi, just before the Pascagoula flows into the Mississippi Sound and the Gulf of Mexico. Much earlier in the geologic Holocene Era, the Escatawpa flowed directly south toward the sound, without intersecting the Pascagoula. As it flowed south, it built a large delta complex in this part of the Mississippi Sound, which is known as Grand Bay. Today, this delta complex is the largest area of tidal marsh with an intact transition into upland wet pine savanna found in either Mississippi or Alabama.

The areas between the Escatawpa River and Grand Bay have been heavily modified by human activity, including digging canals to channel water flows and building embankments to elevate transportation infrastructure, including roads and a railway, above the low floodplain. These modifications have exacerbated both flooding problems experienced by local communities and habitat degradation in the region, which has led to the identification of two projects by the Corps in the South Atlantic Coastal Study, an Escatawpa River Diversion and a Franklin Creek Ecosystem Restoration (USACE 2021b). The Mississippi Coastal Improvements Program also identified a Bayou Cumbest Ecosystem Restoration project (USACE 2016).

Much of the land between the Escatawpa and Grand Bay is designated as the Grand Bay National Estuarine Research Reserve, which has made the NERR and the agency that operates it, the Mississippi Department of Marine Resources, key partners for the Mobile District in advancing these projects. The Grand Bay NERR, along with other adjoining land designated for conservation, is a haven for a highly diverse population of plants and animals. Its landscapes also includes numerous shell middens, both ancient and recent, which were constructed by indigenous people prior to European colonization. Today the NERR fulfills its mission of outreach and service to regional communities, particularly its nearest neighbor Moss Point, through environmental stewardship, monitoring and reporting, social science, and building community relationships (Grand Bay NERR 2023).

In this section, we describe EWN® strategies for responding to the linked issues of flooding and habitat degradation between the Escatawpa and Grand Bay. The design concepts that follow aim to show how projects identified by both the Mobile District and its partners have the potential, if they are coordinated as part of a holistic vision, to positively transform the lives of citizens of local communities and to support the long-term ecological health of the region. Doing so will require extensive collaboration and coordination between agencies, partners, funding sources, and communities, but doing this well is both necessary for the future of the region and a tremendous opportunity.

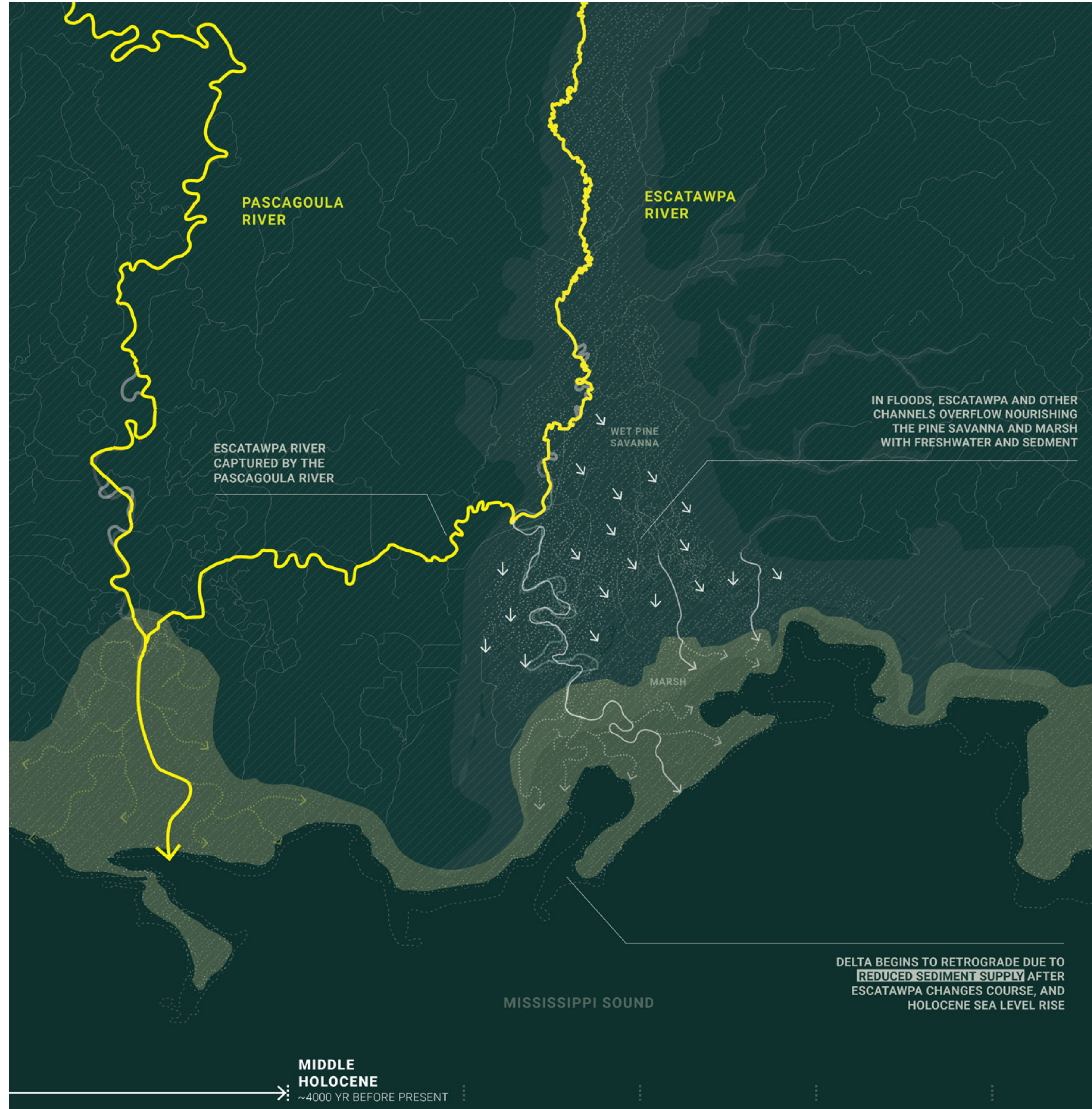
1 **ESCATAWPA RIVER AND GRAND BAY** HISTORIC TRANSFORMATIONS: EARLY HOLOCENE

In the early Holocene period, the Escatawpa River drained south into the Mississippi Sound. As it approached the sound, its course grew shallower and meandered widely across a broad floodplain, carrying and depositing sediment that formed the Grand Bay Delta, much as the Pascagoula formed its own delta just to the west. Relict Pleistocene stream channels lay between the two rivers, but their main courses did not connect. The waters of the Gulf of Mexico were substantially lower at this point than they are today, and the shoreline correspondingly extended much further south than it does today.

1 ESCATAWPA RIVER AND GRAND BAY HISTORIC TRANSFORMATIONS: MIDDLE HOLOCENE

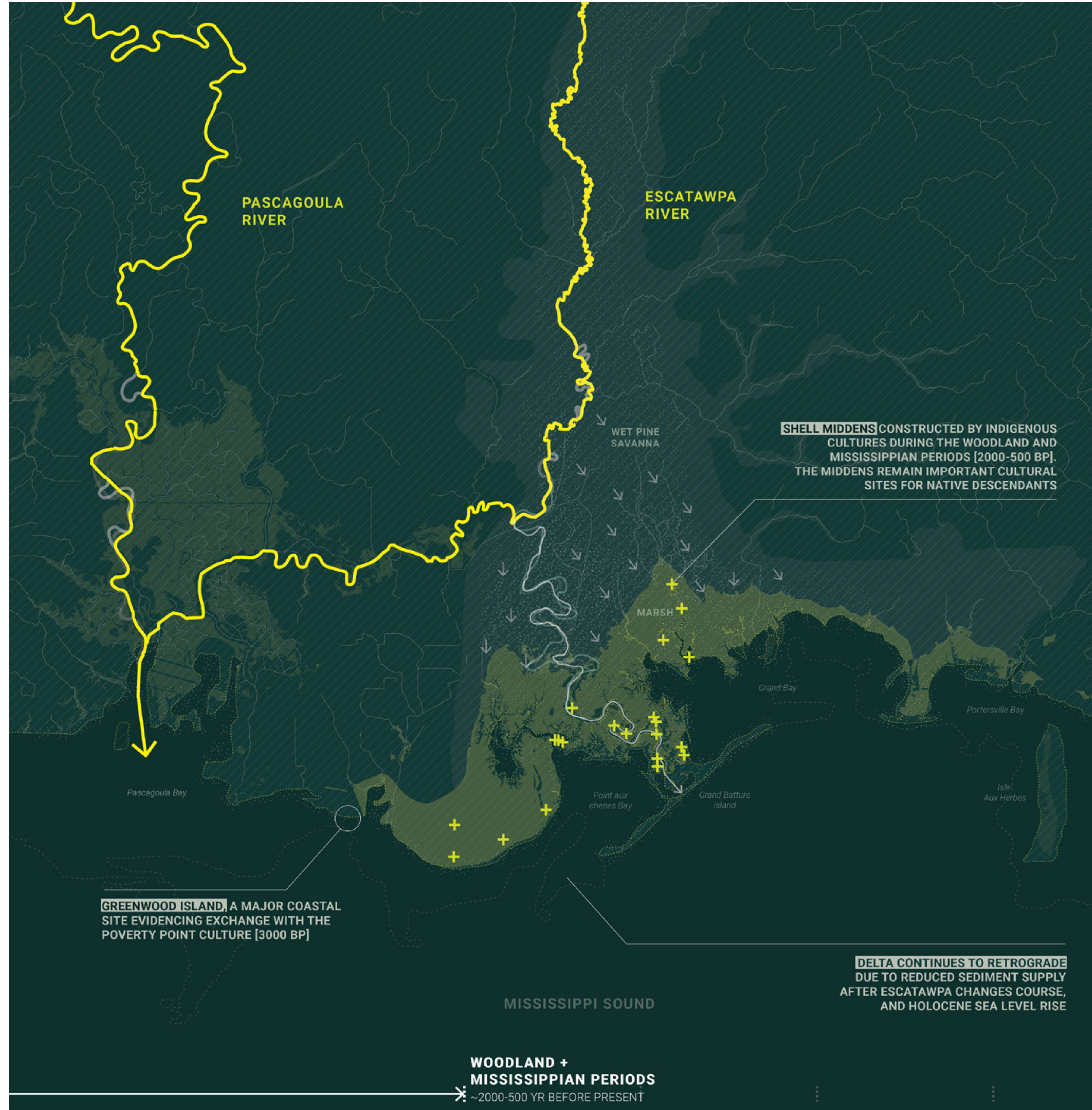
Thousands of years passed and, as the Escatawpa built up its delta, the river eventually found that a course to its west, along the relict Pleistocene stream channels that had become a small tributary of the Pascagoula, offered a steeper gradient to the sound. The Escatawpa was thus captured by the Pascagoula, and its course diverted west, so that it abandoned its southernmost channels and no longer flowed directly to Grand Bay. The delta stopped growing, tides began to reach further up the former channels of the Escatawpa like today's Bayou Cumbest, and the delta retrograded as the Mississippi shoreline transgressed with natural Holocene sea level rise (Peterson et al 2007).

Still, when the Escatawpa swelled with floodwaters and overtopped its banks, much of the sediment and water that spilled out was carried south along the Escatawpa's former channels and through its floodplains, nourishing the still-grand delta and the landscapes in-between, like the extensive wet pine savannas.



1 **ESCATAWPA RIVER AND GRAND BAY**
HISTORIC TRANSFORMATIONS: WOODLAND + MISSISSIPPIAN PERIODS

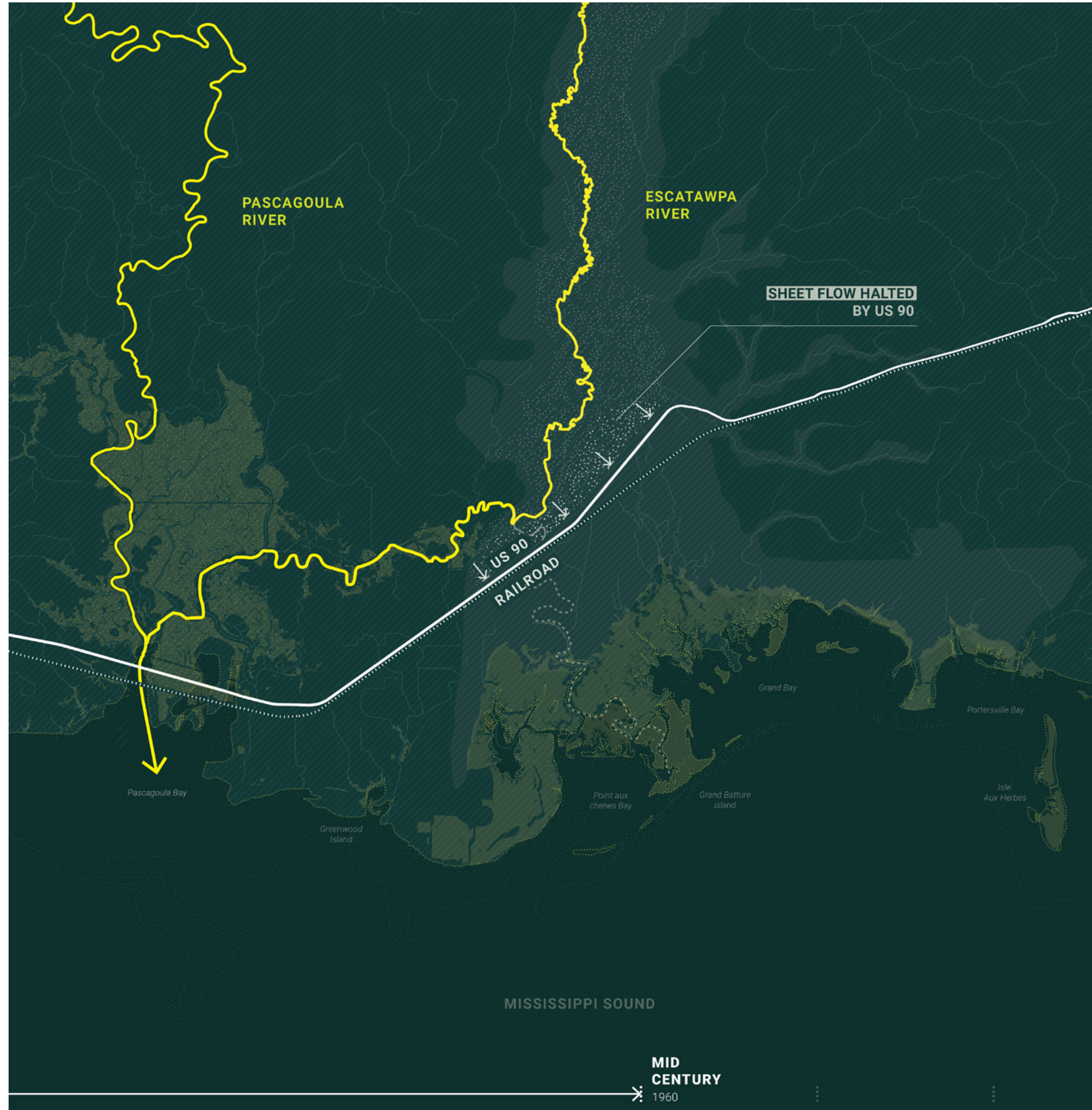
The shorelines of Grand Bay were occupied by a succession of indigenous cultures for millenia prior to the present. The diets and practices of the original inhabitants of this place are evident in the numerous shell midden sites and archaeological evidence of settlement and food sources within the retrograding delta (Jackson 2015). The middens remain important cultural sites for the present-day descendants of these natives.



1 **ESCATAWPA RIVER AND GRAND BAY** HISTORIC TRANSFORMATIONS: MID CENTURY

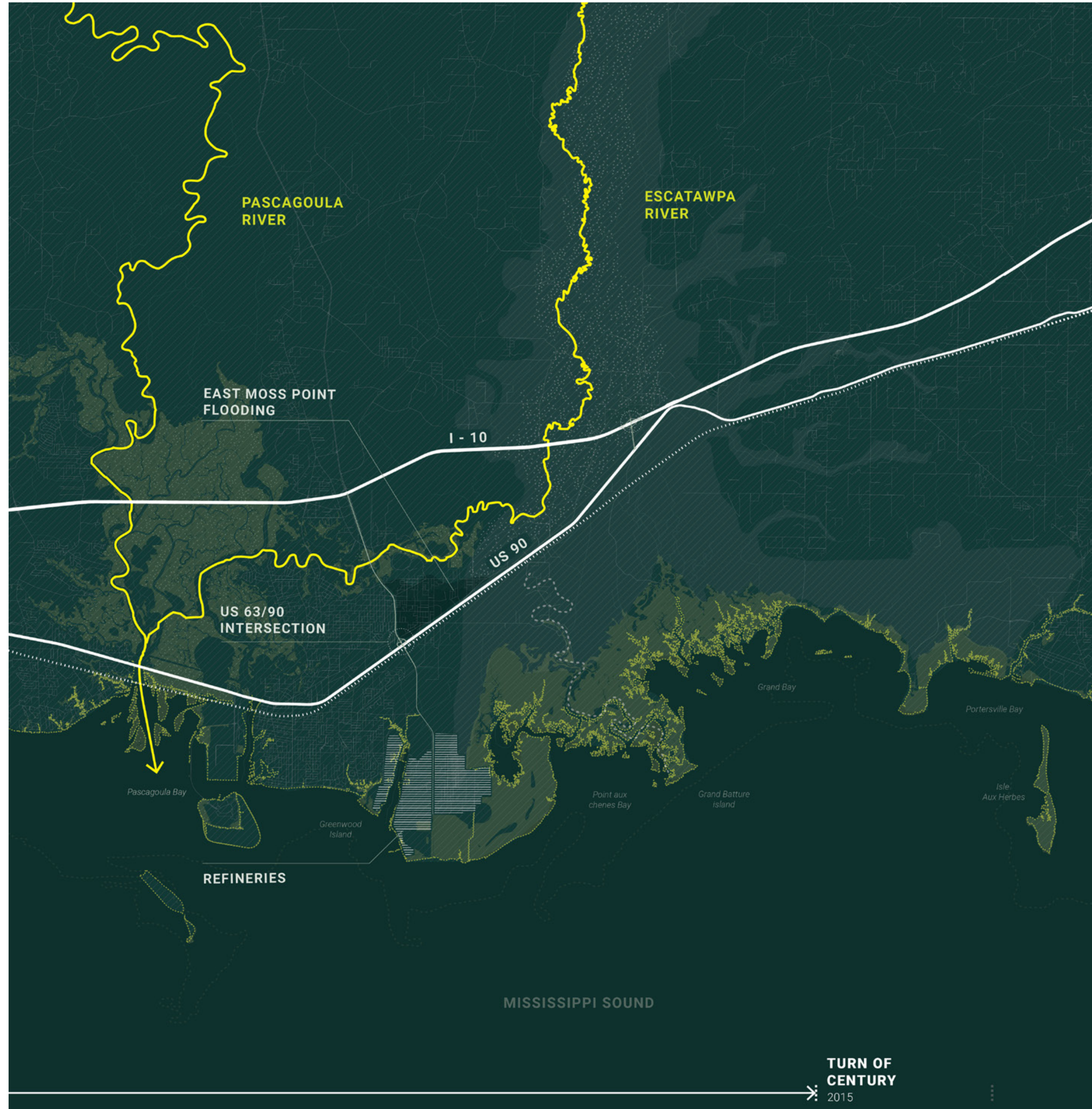
By the middle of the 20th century, two long embankments were constructed for a railway line and a major coastal highway, US-90. These embankments disconnected the retrograding delta and the wet pine savannas from overland sheetflow with its nourishing water and sediment.

Meanwhile, the disappearance of most of Grand Batture, the barrier island that had laid at the southern tip of the preserve, clearly demonstrates the erosive forces that now held sway at the shoreline.



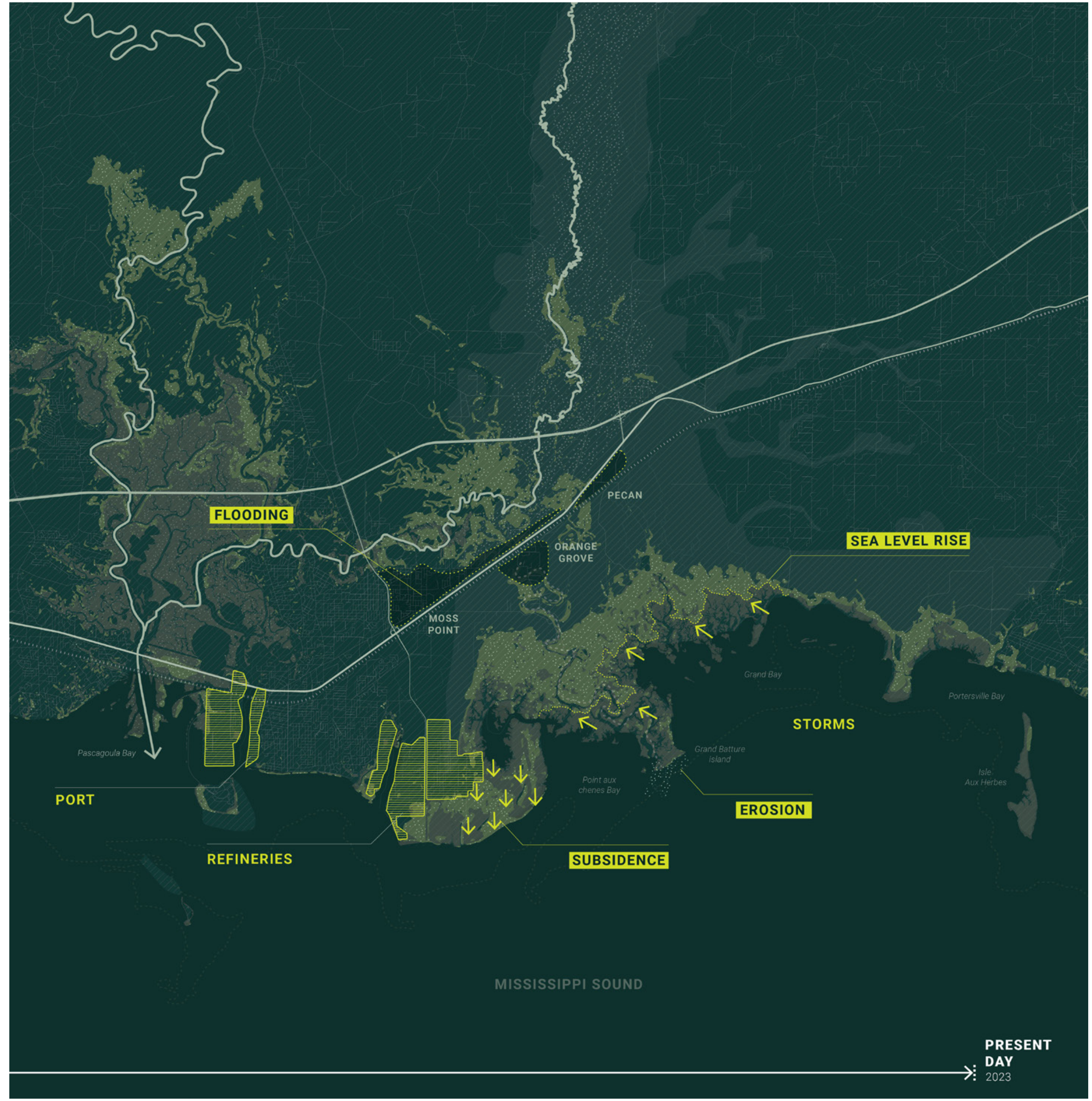
1 ESCATAWPA RIVER AND GRAND BAY
HISTORIC TRANSFORMATIONS: TURN OF CENTURY

As the cities of Moss Point and Pascagoula grew, infrastructure continued to expand. Interstate 10 was constructed north of US-90, and a large interchange was built recently to connect US-90 with US-63. South of Moss Point and to the west of the NERR, the city of Pascagoula is home to Mississippi's largest employer, the Ingalls Shipbuilding Company, and Chevron's biggest oil refinery facility.



1 **ESCATAWPA RIVER AND GRAND BAY** HISTORIC TRANSFORMATIONS: PRESENT DAY

Today, the region faces multiple vulnerabilities that are exacerbated by the design of these infrastructures. Like the rest of the Gulf of Mexico, hurricanes and other tropical storms are a consistent threat, and, with climate change, intensifying summer storms bring increasingly heavy rainfall. Sea level rise, erosion, and subsidence are all contributing to habitat loss that both threatens ecological communities and reduces the natural buffers available to protect human communities and the important industrial infrastructure of the region. Overland sheetflow from the Escatawpa, which once would have reached Grand Bay, no longer mitigates these forces. Flooding, particularly in the rural communities of Pecan and Orange grove and the neighborhoods of Moss Point that lie east of US-63 and north of US-90, is substantially intensified by infrastructures that interrupt drainage and trap floodwaters. This is a major issue of environmental justice given both persistent poverty in these working-class communities and the racial demographics of Moss Point, which is heavily African-American.



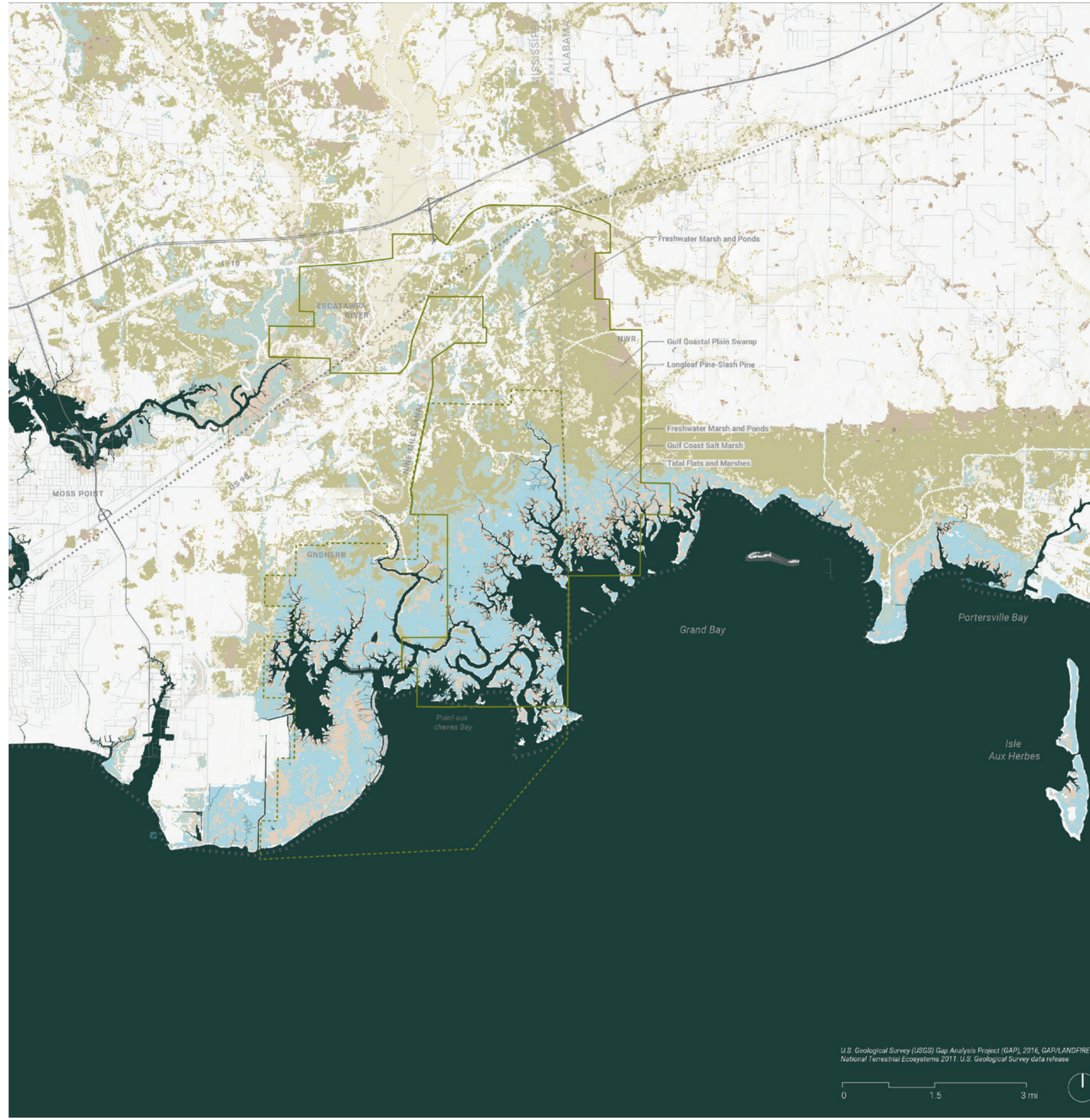
2 ESCATAWPA RIVER AND GRAND BAY
EXISTING ECOSYSTEMS

The course of the Escatawpa is heavily forested, with Bald Cypress-Tupelo swamp the dominant plant community along much of its lower reaches. Moving south toward the Gulf in its former floodplain, the cypress and tupelo give way to extensive flatwoods dominated by longleaf pine. These wet pine savannas are historically heavily-dependent on disturbance regimes, particularly flooding and fire, which encourage the growth of keystone species including the longleaf pine and its typical understory, such as wiregrass and a rich diversity of flowering perennials, while suppressing other woody species that could overturn the delicate ecological balance of the flatwoods. Continuing south, the intertidal marsh is dominated by black needlerush. Each of these ecological communities is adapted to the cycles of disturbance that shaped the coast of the Mississippi Sound for thousands of years prior to European settlement.

Open Water
GNDNERR Grand Bay National Estuarine Research Reserve
GNDNWR Grand Bay National Wildlife Refuge

KEY PLANT COMMUNITIES

LF 46: Atlantic Coastal Plain Swamp
LF 47: Gulf Coastal Plain Swamp
LF 50: Tidal Flats and Marshes
LF 58: Introduced Woody Wetlands and Riparian Vegetation
LF 59: Introduced Herbaceous Wetlands and Riparian Vegetation
SAF 100: Pond Cypress
SAF 83: Longleaf Pine-Slash Pine
SAF 89: Live Oak
SAF 92: Sweetgum-Willow Oak
SRM 806: Gulf Coast Salt Marsh
SRM 819: Freshwater Marsh and Ponds

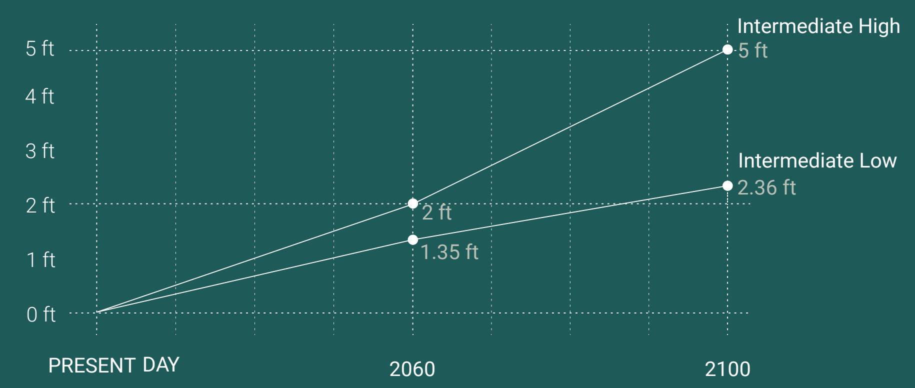


3 ESCATAWPA RIVER AND GRAND BAY
SLR AND HABITAT MIGRATION

Intertidal
- 0.08 to 1.45 ft

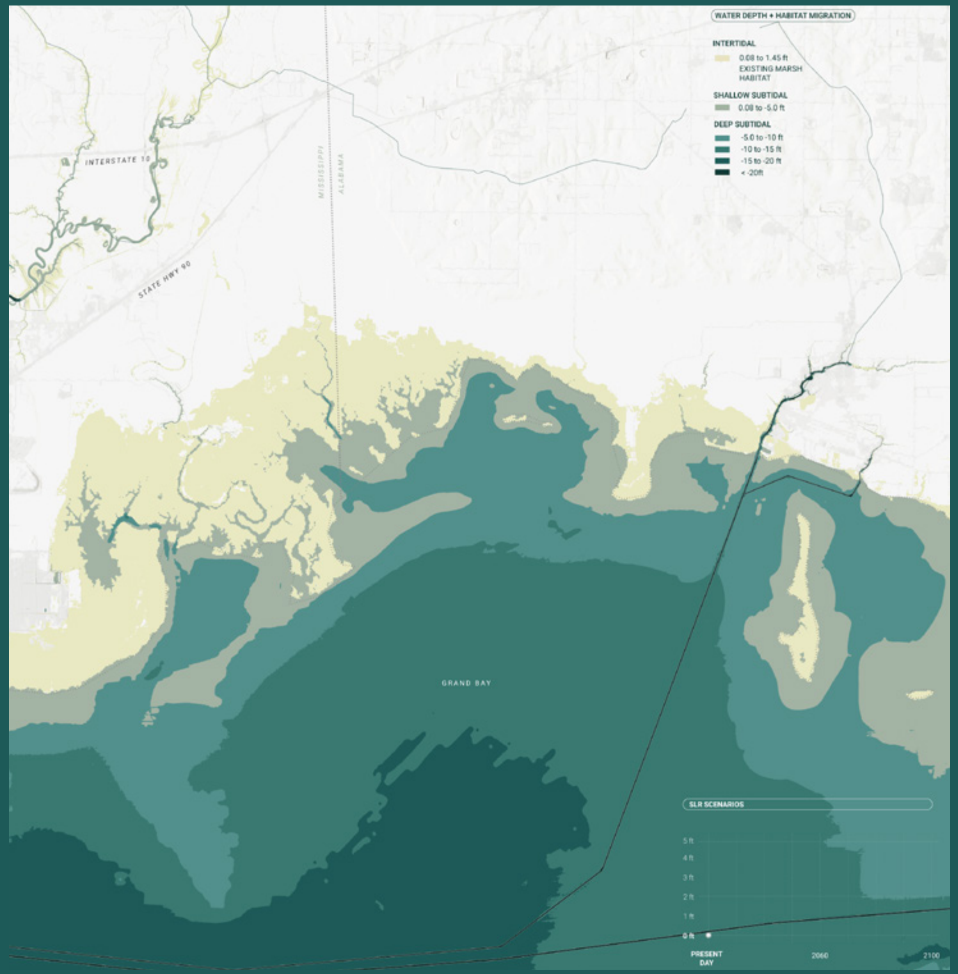
Shallow Subtidal
- 0.08 to -5.0 ft

Deep Subtidal
- -5.0 to -10 ft
- -10 to -15 ft
- -15 to -20 ft
- < -20ft



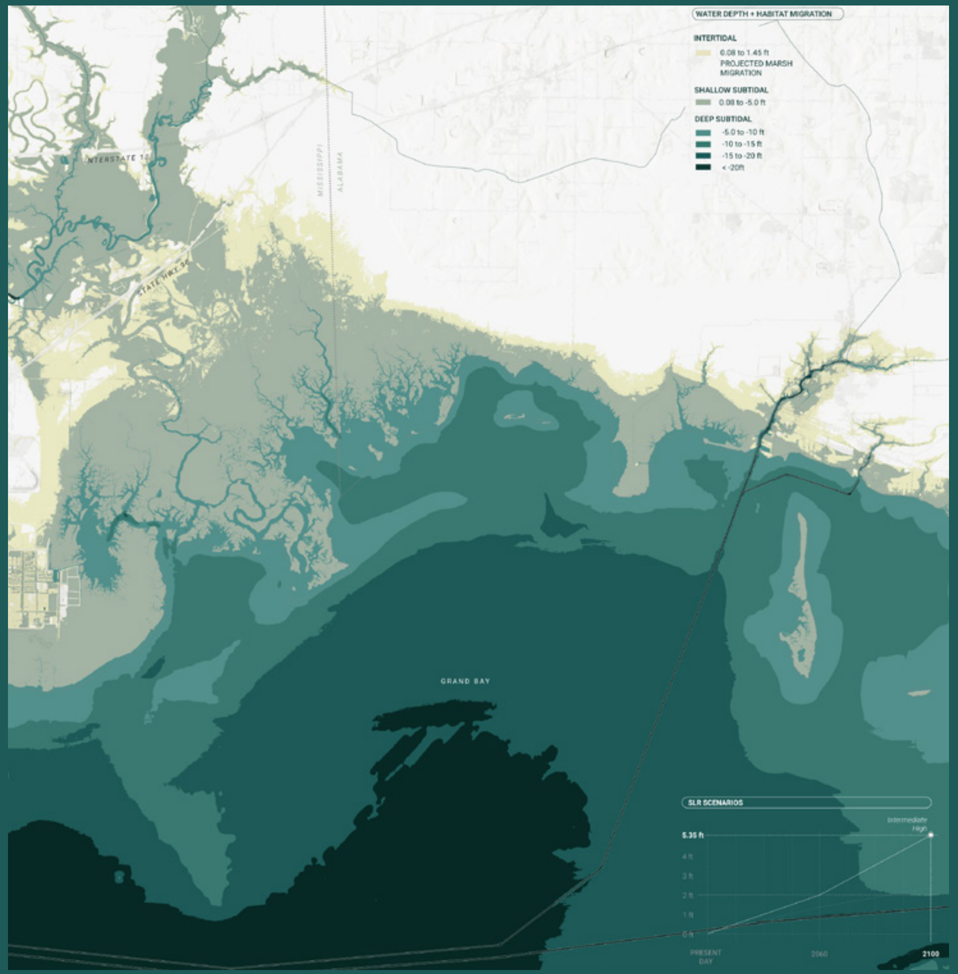
The rich ecological communities of the Escatawpa and Grand Bay face substantial projected transformation under anticipated sea level rise scenarios for the remaining decades of the 21st century. The maps here show projected habitat transformation for both aquatic and upland habitats under 2' and 5' of sea level rise. Roughly 2' of rise is projected for 2100 under NOAA's intermediate low scenario or for 2060 under their intermediate high scenario, while 5' is projected for 2100 in that intermediate high scenario. While these projections represent transformations without adaptive interventions of the kinds proposed later in this section, they are clearly illustrative of the speed and magnitude of environmental change that the region is facing.

PRESENT DAY



+2 FT SLR

+5 FT SLR



4 ESCATAWPA RIVER AND GRAND BAY AUTHORIZED PROJECTS

The South Atlantic Coastal Study and the Mississippi Coastal Improvements Plan both designate projects for this region. SACS recommends both an Escatawpa River Diversion project and a Franklin Creek Ecosystem Restoration project for the near term (within 5 years). The Escatawpa River Diversion is intended to address issues created by the absence of floodwater, nutrient, and sediment supply from the Escatawpa within Grand Bay's savannas and marshes. It anticipates that redirecting some of these flows toward Grand Bay could "help restore the predominant wet pine savannah habitat" and also potentially address shoreline erosion, including the loss of the Grand Batture. The smaller Franklin Creek Ecosystem Restoration project aims to restore hydrological connection between Franklin Creek, a tributary of the Escatawpa, and adjacent pine savanna, connection which was broken when part of the creek was cut off by the construction of a ditch on the north side of US-90. MS-CIP also incorporates a recommendation for an aligned ecosystem restoration project at Bayou Cumbest, one of the former distributaries of the Escatawpa River, which is now a degraded tidal channel. The aim of the work documented in this section has been to advance EWN® concepts aligned with each of these designated projects, and to help sketch a framework for holistically integrating these projects alongside other efforts by agencies, stakeholders, and local partners in the region.

AUTHORIZED PROJECTS

- **A** **Escatawpa River Diversion**
- **B** **Franklin Creek Ecosystem Restoration**
- **C** **Bayou Cumbest Restoration**

- ACE Navigation channels
- ACE Placement Areas
- Urban Areas
- Public Land
- Tidal Marsh

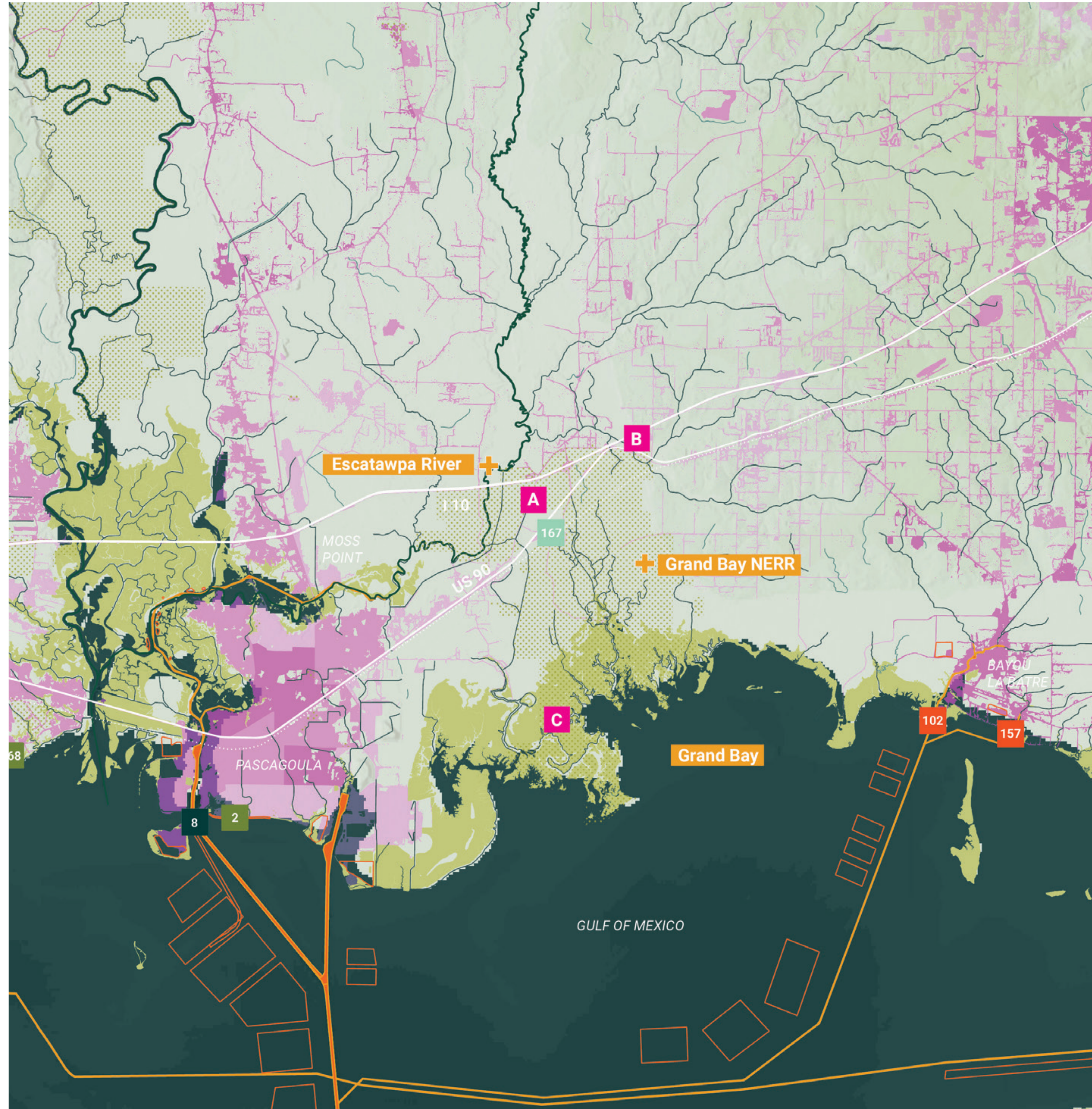
OTHER ACE PROJECTS

Ecosystem Restoration
- 2 Pascagoula Beach

Hurricane, Storm Damage Reduction
- 8 Pascagoula Harbor

Navigable Waterways
- 102 Bayou La Batre - Katrina
- 157 Gulfport - Katrina

Flood Risk Management
- 167 Franklin Creek Floodway

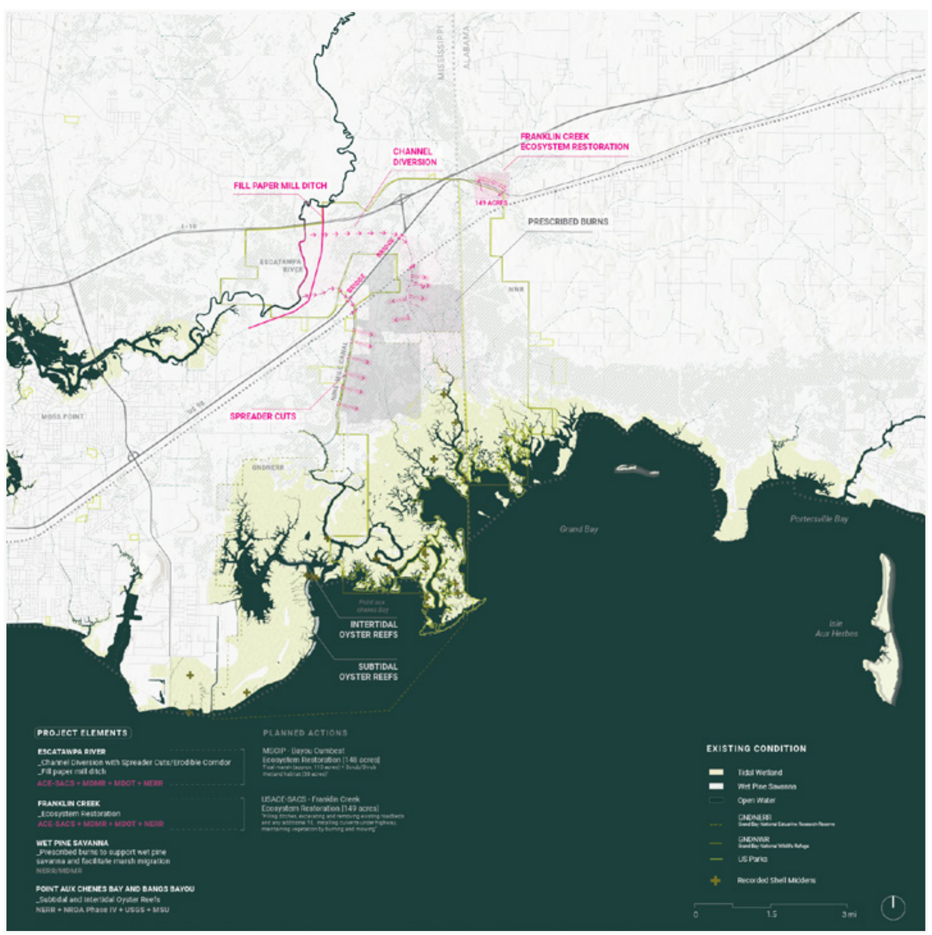


5 ESCATAWPA RIVER AND GRAND BAY ALTERNATIVES

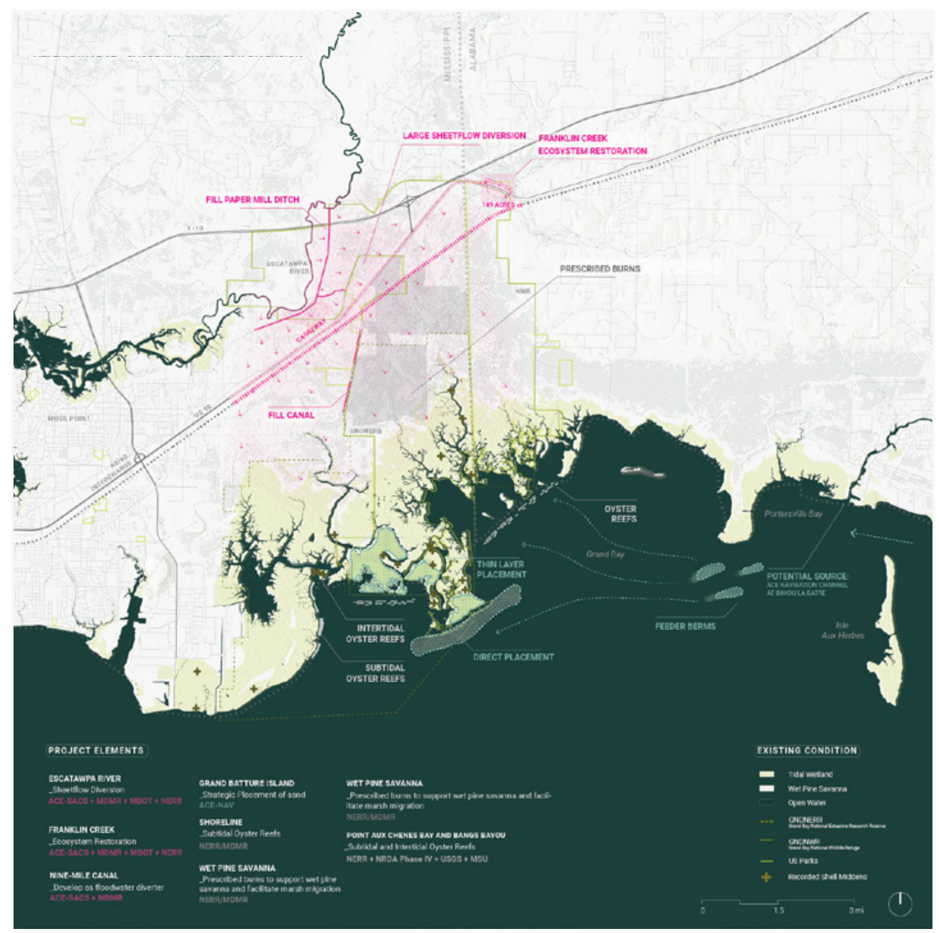
We explored three sets of design concepts, each of which is intended to accomplish these aims. On the maps below, design concepts associated with the three USACE authorized projects are shown in pink. Concepts associated with on-going USACE navigation projects are shown in blue, while related projects that are either on-going or proposed by potential partner organizations, including the Grand Bay NERR, are shown in orange (proposed) or grays (on-going). The intention of showing these projects together is not to imply that they would be part of one single planning, design, and construction project, but rather to suggest the transformative potential of holistic collaboration and coordination across agencies, partners, and projects.

None of these alternatives have undergone hydrological modeling, ecological modeling, detailed engineering design, or detailed site design. Existing land use and land ownership have been criteria for developing these concepts, with efforts made wherever possible to site proposed features on public lands, but there has not been a detailed real estate analysis. Advancing them toward implementation would require substantial work both on these technical fronts and in engaging appropriate stakeholders, including the local communities and non-federal sponsors.

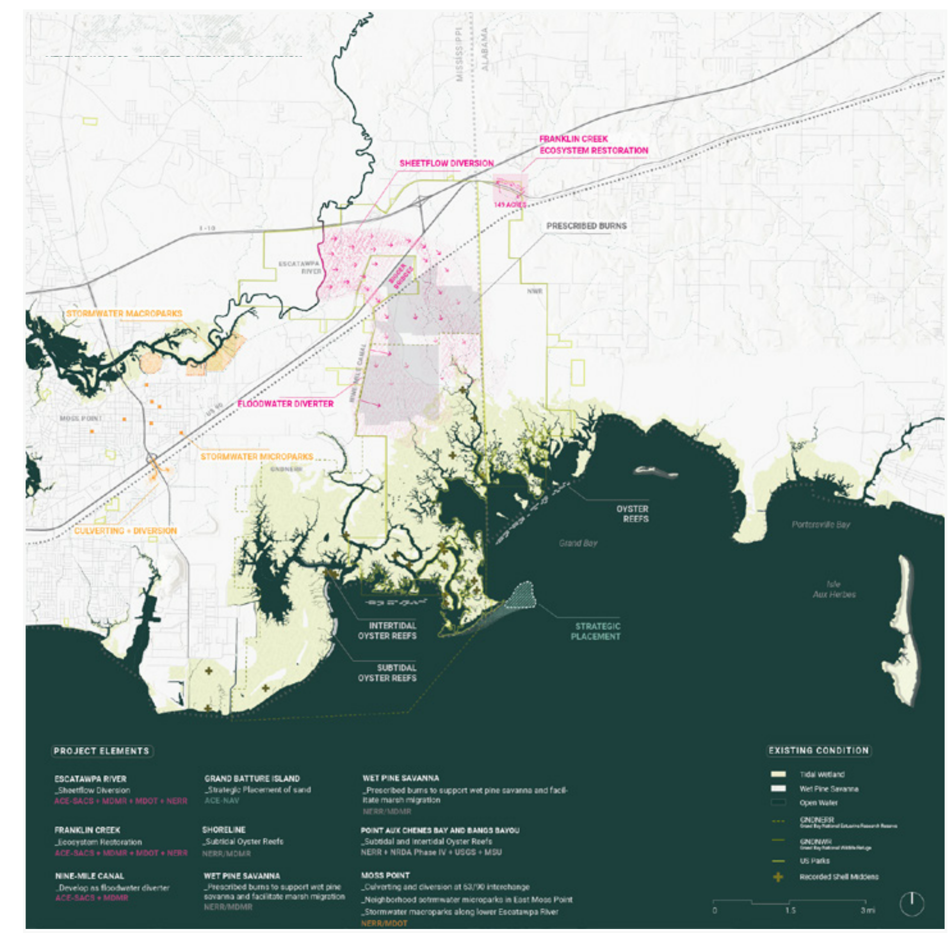
ALTERNATIVE 01
CHANNEL DIVERSION



ALTERNATIVE 02
CAUSEWAY SHEETFLOW DIVERSION



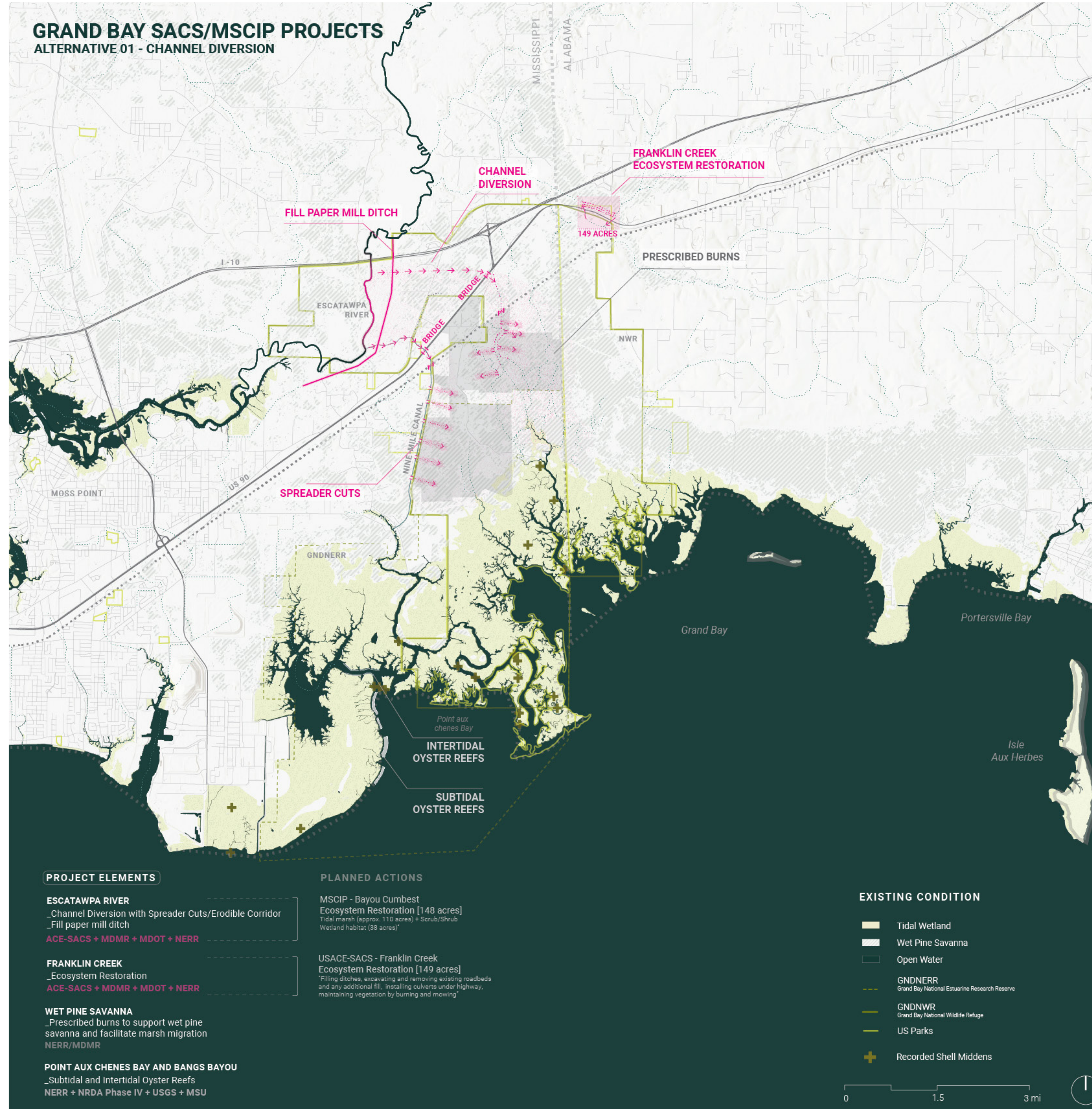
ALTERNATIVE 03
BRIDGED SHEETFLOW DIVERSION



5 ESCATAWPA RIVER AND GRAND BAY ALTERNATIVE 01

In the first alternative, freshwater, sediment, and nutrients from the Escatawpa could be diverted across US-90 in a pair of watercourses, parts of whose alignments would follow existing canals. The remnant paper mill ditch that parallels the Escatawpa would be filled, potentially using material from these excavations, to reduce interception of flow toward Grand Bay. Once these flows cross US-90 and the CSX railway (under short bridges), they would need to be diverted to the east and west into the wet pine savannas and tidal marshes via "spreader cuts," with the intent of restoring some of the hydrological qualities of overland sheetflow. Like all three alternatives, this alternative also includes reconnection of Franklin Creek with its historic southern course to support wet pine savanna restoration in the vicinity. However, though neither detailed design nor modeling for the Escatawpa River flow alterations have been completed, conceptual analysis indicates that this alternative would be sub-optimal in terms of its capacity to restore historic hydrological regimes across the broader savanna and marshes.

The only non-USACE actions indicated in this alternative are prescribed burns in the wet pine savannas, an action which is being implemented by the NERR, and intertidal and subtidal oyster reef pilot projects, which have already been installed by the NERR and its partners. This alternative offers very limited mitigation of shoreline erosion concerns, and while it would likely provide some relief of flood risk to communities along US-90, it is not likely to provide as much relief as the other two alternatives. It is also the most conventionally engineered of the alternatives, and does the least to implement EWN® principles.



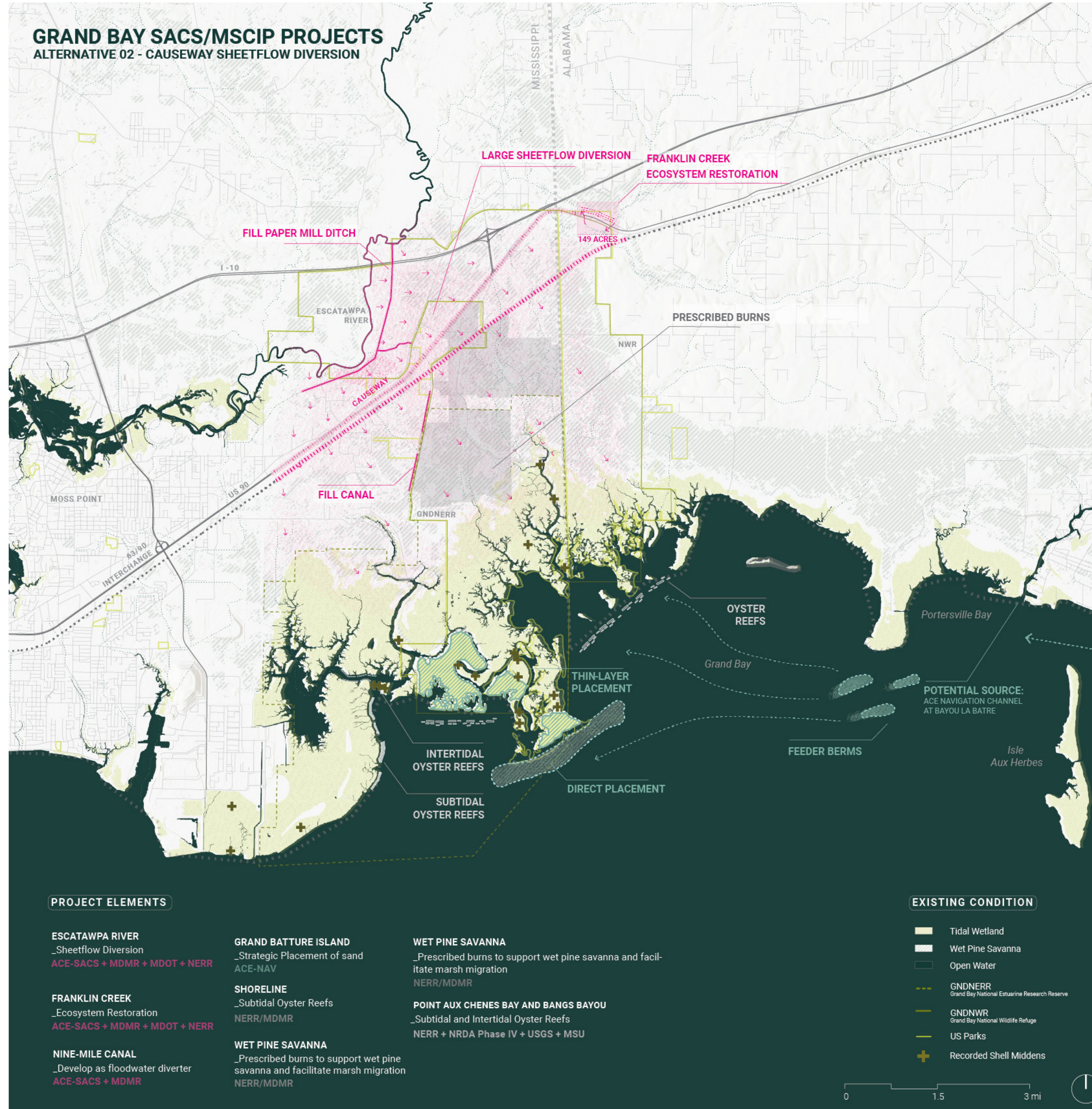
5 ESCATAWPA RIVER AND GRAND BAY ALTERNATIVE 02

The second alternative shows the elevation of both US-90 and the CSX railway on a pair of long causeways, accompanied by the filling of both the paper mill ditch and Nine-Mile Canal, which stretches south from US-90 to Bayou Cumbest. The long causeways would maximally facilitate the restoration of the historic late Holocene flow regime, including overland sheetflow from the Escatawpa south to Grand Bay during flood events. This would substantially support efforts to re-establish historic disturbance regimes in the wet pine savannas as well as nourishing tidal marshes.

Offshore, this alternative shows the restoration of Grand Batture through direct placement of dredged material, likely sourced from the navigation project at Bayou La Batre. Once Grand Batture is rebuilt, dredged material could continue to be strategically placed in subtidal feeder berms south of Point aux Pins, and these berms could nourish both Grand Batture and the marshes of Grand Bay Savanna, the nature preserve east of the NERR, which is managed by Alabama's State Lands Division. Thin-layer placement of fines in the lower tidal marshes, which are most exposed to the effects of erosion and sea level rise, could enhance the natural capacity of those marshes to accrete and gain elevation. (There is a substantial concentration of shell mounds in those areas, and care would need to be taken to avoid impacting those cultural and archaeological resources.) Subtidal oyster reefs could be extended east from the pilot projects the NERR has already installed to build shellfish habitat and protect shorelines in Point Aux Chenes Bay and Grand Bay.

Inland, culverts might be constructed at the US-63/US-90 interchange in Moss Point, supporting the expansion of the Escatawpa's floodplain in alleviating flood risk in neighborhoods like East Moss Point and Kreole.

The relative merits of this alternative and the third, which is indicated here as the preferred alternative, should likely be analyzed through modeling and further design, in consultation with local communities, non-federal partners, and other stakeholders, in order to assess their relative performance and desirability against the costs of such extensive natural infrastructure measures. Conceptually, the final alternative appears to better balance benefits and costs, and it is also possible that there would be more conflicts with existing land uses, but this has not yet been analyzed quantitatively analysis due to the limitations of this study.

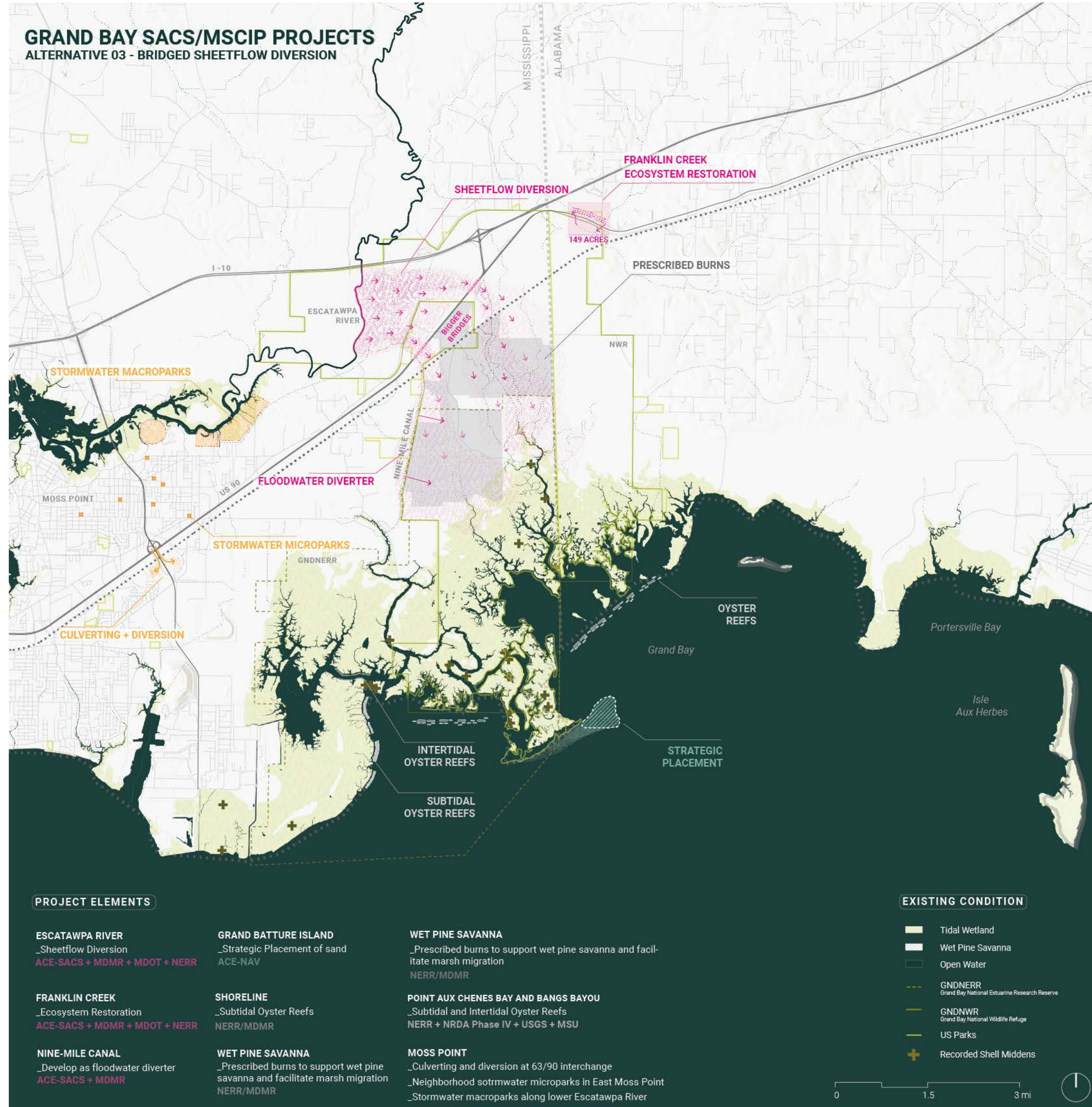


5 ESCATAWPA RIVER AND GRAND BAY PREFERRED ALTERNATIVE

In this alternative, two sets of bridges, each bridge roughly a mile long, would be used to elevate US-90, the CSX railway, and Old Stage Road over two low drainage routes, each of which has the potential to reconnect the Escatawpa with much of its former floodplain to the south, providing water, nutrients, and sediment to the wet pine savannas and tidal marshes. Orienting sheet flow along these two corridors also has the potential to facilitate protection for existing private properties along US-90, many of which have important commercial and cultural purposes. The alternative also shows a pair of floodwater diversion structures on Nine-Mile Canal, the purpose of which would be to spread flow traveling south along the canal east into the adjacent savannas, restoring a flow regime in that area that would also be more like the historic overland flow.

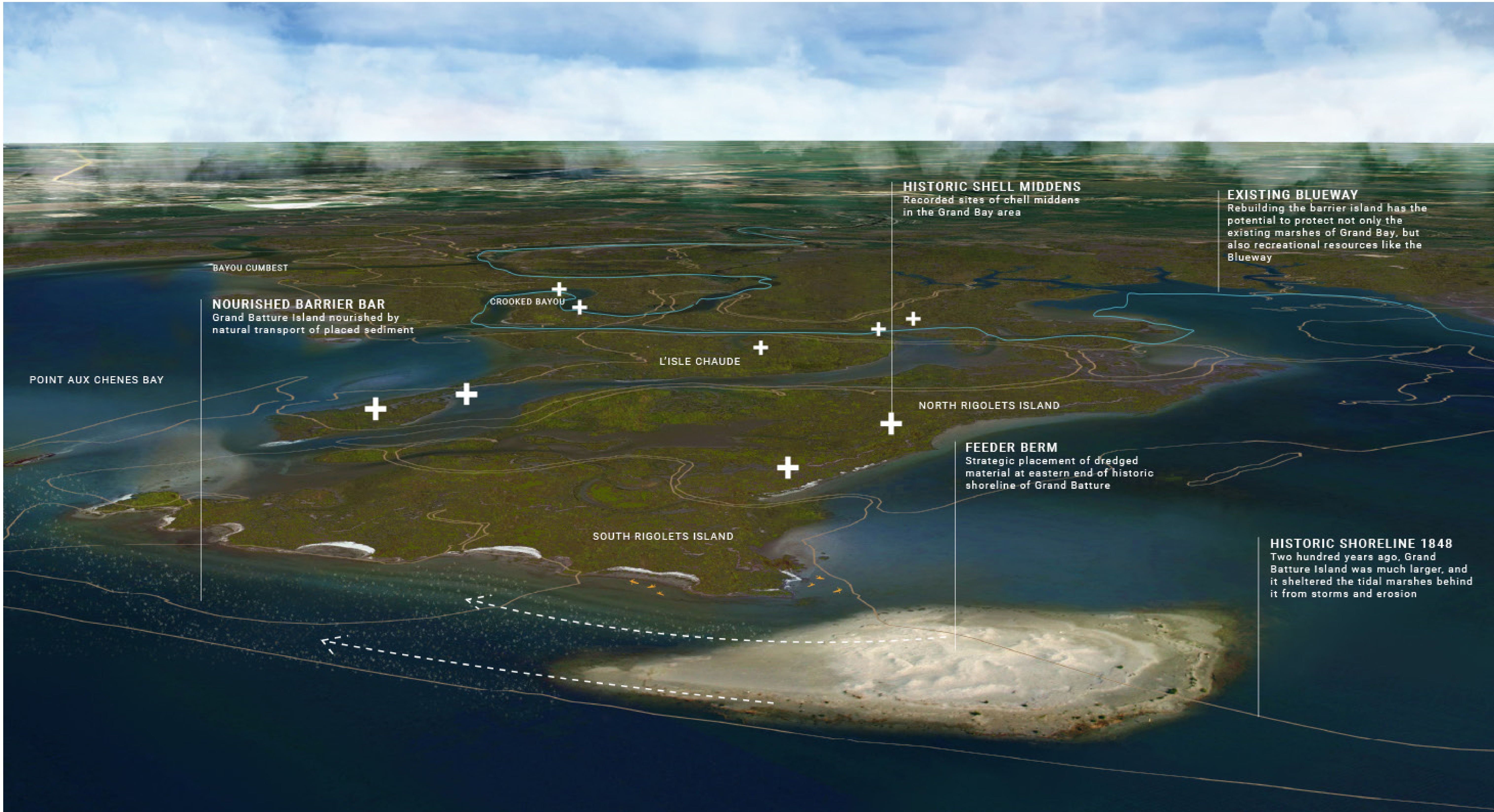
Offshore, it shows a large strategic placement of dredged material at the east end of the former Grand Batture. This strategic placement should be designed so that longshore transport will convey it westward along the historic alignment of Grand Batture, nourishing the shoals and ideally rebuilding much of the island to an emergent elevation, where it can provide protection from storms and erosion for the tidal marshes. Like the second alternative, this alternative also shows the expansion of the constructed oyster reefs within Point aux Chenes Bay and Grand Bay.

Finally, a substantial program of green infrastructure improvements for Moss Point is shown, including stormwater microparks distributed throughout the neighborhoods of Kreole and East Moss Point, larger floodplain management parks along the Escatawpa and former industrial canals, and culverting at the US-63/US-90 interchange. While outside of the anticipated scope of USACE authorized projects, these efforts, likely to be led by the NERR, would amplify the flood risk mitigation impacts of the USACE projects and correspondingly should be taken into consideration in the planning of local USACE projects through collaborative discussion and information sharing.



5 ESCATAWPA RIVER AND GRAND BAY
REBUILDING GRAND BATTURE

The strategic placement of sandy dredged material could be designed to gradually rebuild Grand Batture along its former footprint, similar to other projects developed by USACE on the Florida Gulf Coast in recent years (Gailiani et al 2019). A restored Grand Batture could not only rebuild habitat, but also protect Rigolets Island, the historic shell middens within the marsh complex, and the existing blueway.

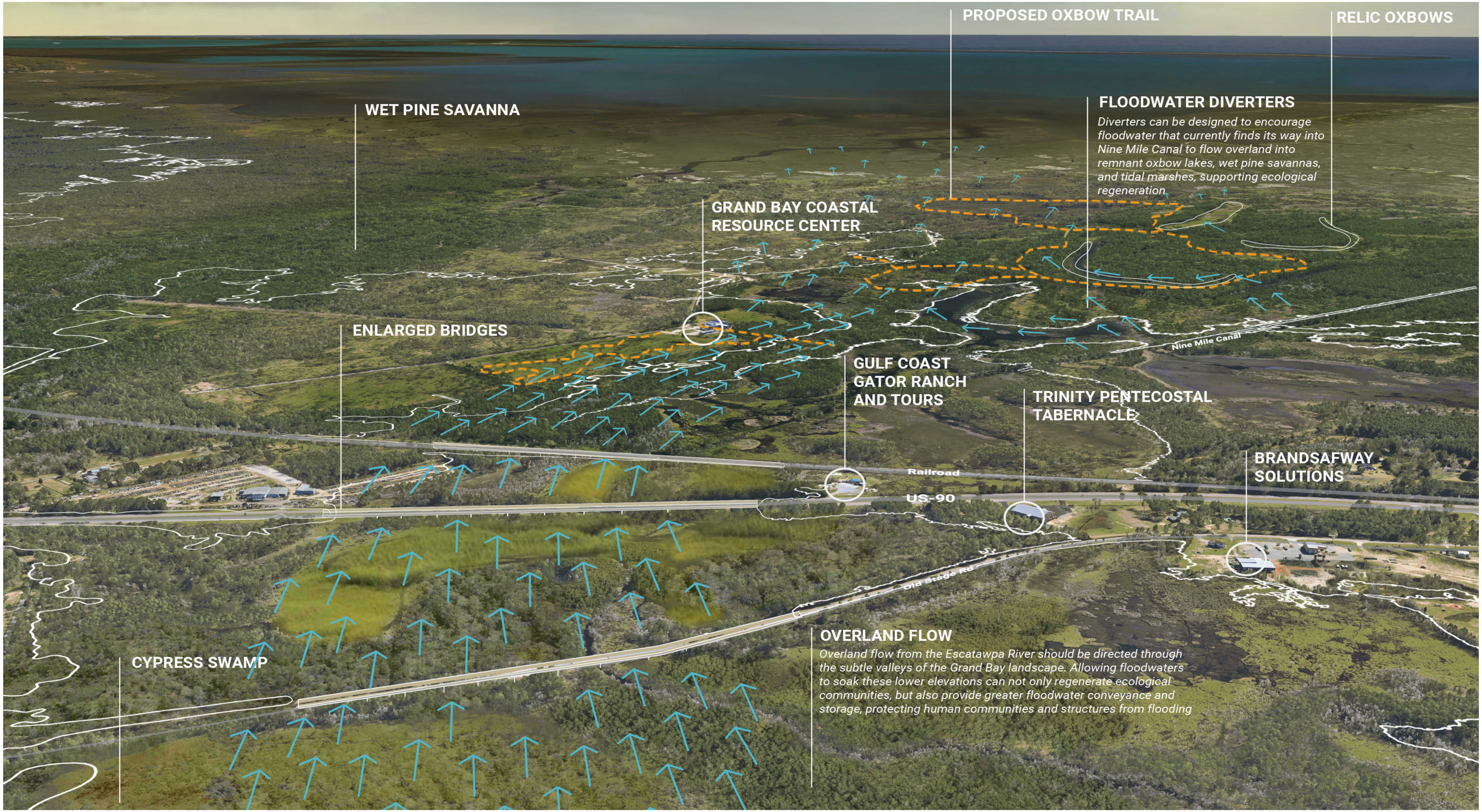


5 ESCATAWPA RIVER AND GRAND BAY
VIEW AT FRANKLIN CREEK ROAD

Below, an illustrative aerial view looking southwest along US-90 from Franklin Creek Road, showing new bridge infrastructures, reconnected flood flows from the Escatawpa River, and a mixture of forested ecosystems dependent on flood flows including wet pine savanna and cypress-tupelo swamps.

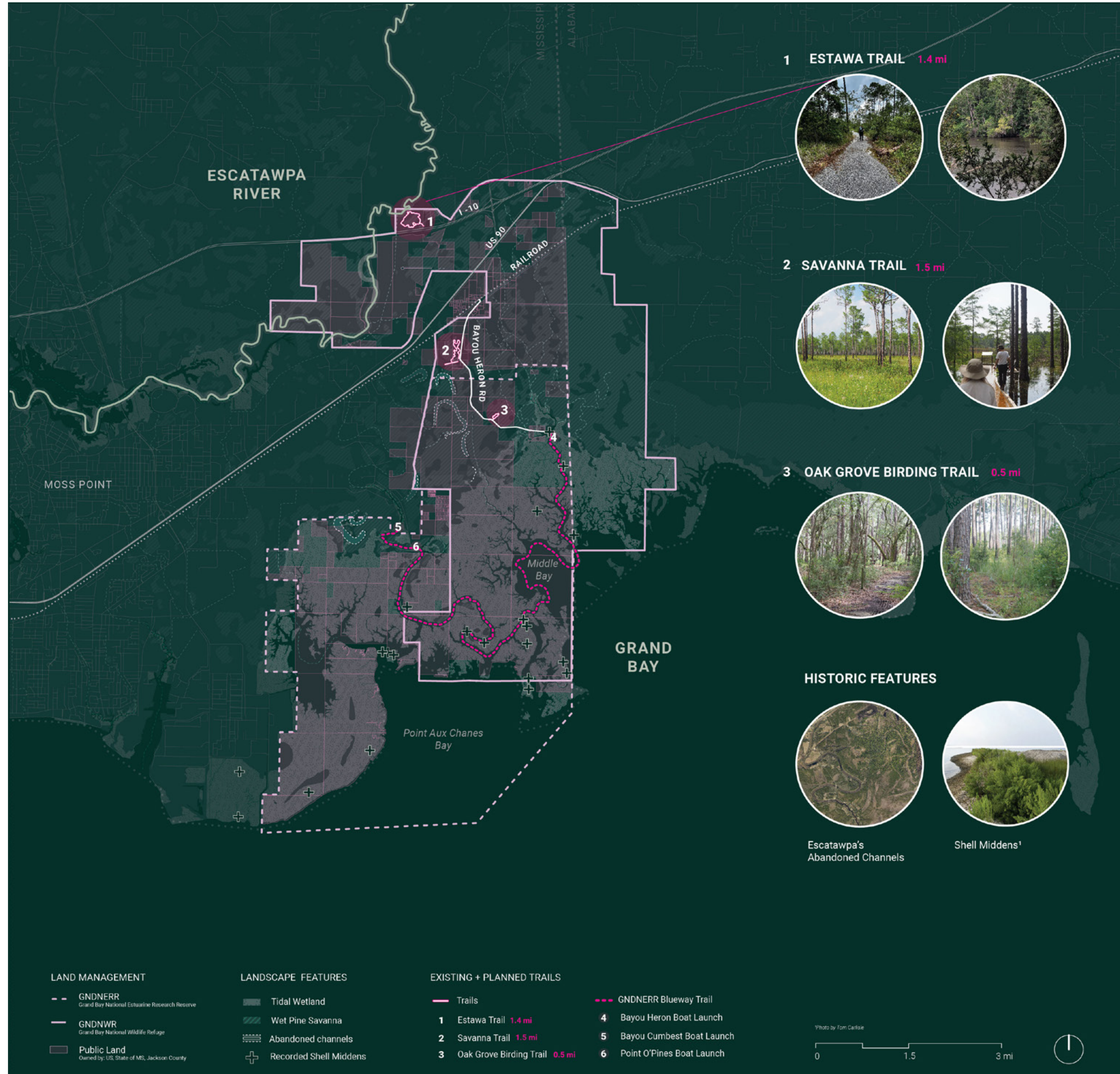
5 ESCATAWPA RIVER AND GRAND BAY
A REGENERATED FLOODPLAIN

To successfully implement reconnection between the Escatawpa River and Grand Bay while alleviating flood risk north of US-90, a regenerated floodplain corridor will need to be carefully designed and engineered to ensure that freshwater, sediment, and nutrients from sheet flows of flood water are appropriately conveyed to the pine savannas and marshes of Grand Bay, while avoiding unintentionally increasing flood risk in new areas. Below, such an appropriate corridor is illustrated, as seen from north of US-90, looking south toward Grand Bay near Nine Mile Creek.



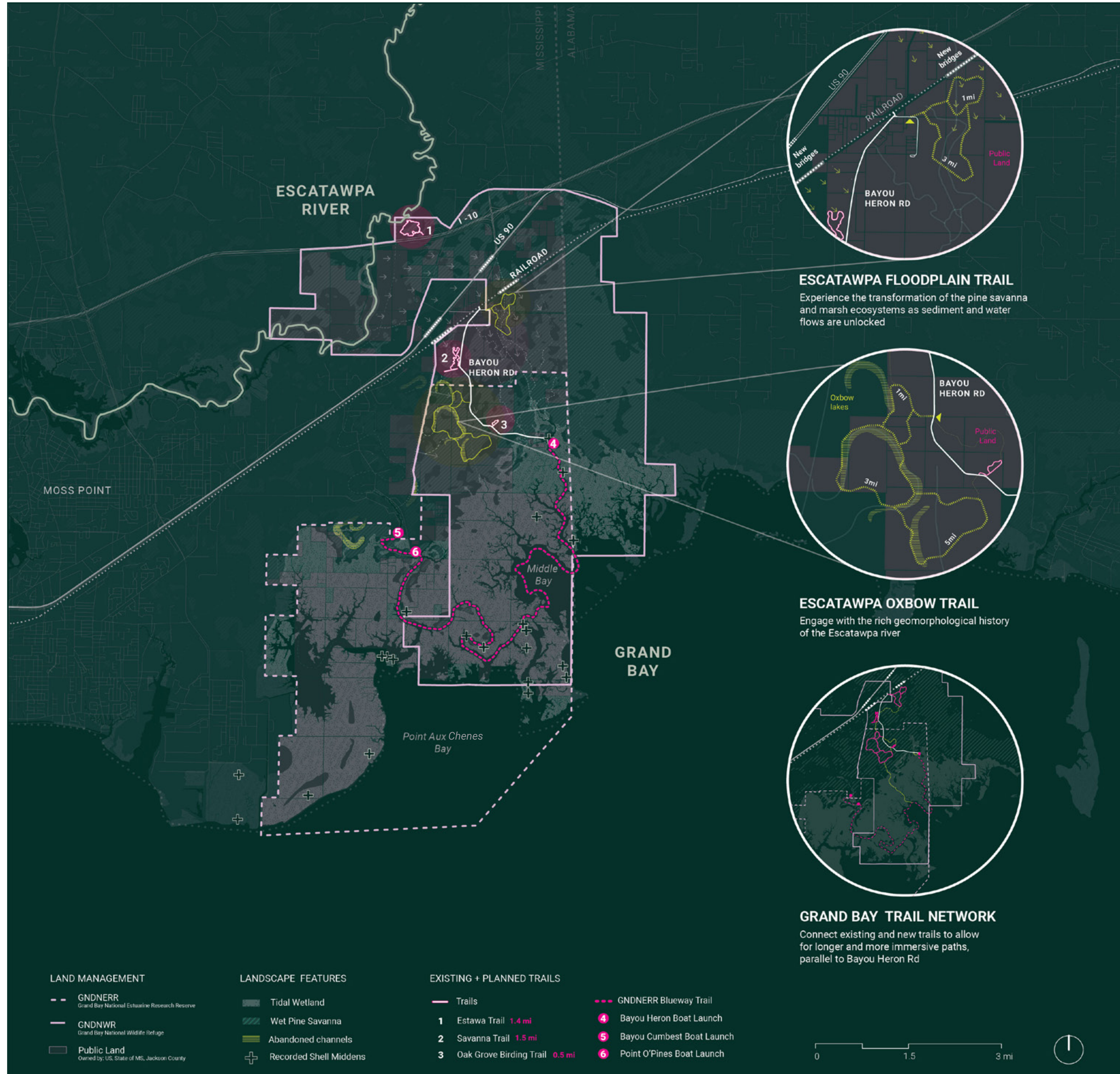
6 ESCATAWPA RIVER AND GRAND BAY
EXISTING TRAIL SYSTEM

The USACE projects for the Escatawpa River, Franklin Creek, and Bayou Cumbest have the potential to directly align with the NERR's on-going ecosystem restoration efforts. The NERR also works to facilitate public access to and public understanding of the ecosystems that are being regenerated. Currently, there are five public trails on the lands of the NERR and the overlapping Grand Bay National Wildlife Refuge, four of which are short terrestrial trails offering access to some of the refuges' typical habitats, and one which is the Grand Bay NERR Blueway, a kayak and canoe trail that loops around and through the bay's tidal marshes.



6 ESCATAWPA RIVER AND GRAND BAY PROPOSED ADDITIONAL TRAILS

As USACE, NERR, and partner efforts facilitate further ecological regeneration, the existing trail system could be expanded to include additional longer trails, which could offer public access to the regenerating ecosystems and relic geomorphological features, helping visitors and community members connect contemporary natural infrastructure efforts to the long history of natural dynamics that has made the Escatawpa and Grand Bay such rich environments. Eventually, such new trails and the existing trails might also be connected into a larger trail network, offering even more diverse and varied experiences. Such trail expansions would support the Engineering With Nature® (EWN®) goal of linking social benefits to ecological and engineering benefits.



6 ESCATAWPA RIVER AND GRAND BAY FLOODPLAIN TRAIL

For instance, a new floodplain trail could allow local community members and visitors to experience the regeneration of the wet pine savannas as floods bring freshwater, nutrients, and sediment back south of US-90. Longer trails and loops would allow for more immersive experiences of the rich flora and fauna of the savannas, supporting appreciation of the ecosystems and stewardship over time.

MOBILE BAY

BENEFICIAL USE FOR ECOLOGICAL RESTORATION
MOBILE BAY CASE STUDIES

Mobile Bay is a singular feature in the state of Alabama, as over two-thirds of the state's waterways — the vast Mobile-Tensaw River Basin — drain to the bay. Its shallow estuarine waters hold not only an intense diversity of plants and animals but also the intensity of human interaction with ecosystems that surround it. The aim of this study was to look at the Mobile Bay system holistically and to then address specific issues of sediment management, shoreline erosion, and habitat loss within the bay system.

We have focused our attention on three general locations within the bay. The western shore of Mobile Bay is low and marshy, but substantially challenged by shoreline erosion and habitat loss in its tidal marshes. The first approach described here, the design of feeder berms, would use strategic placement of dredged material, primarily from the long Bay Channel, to nourish those shorelines and marshes in an economically and logistically efficient fashion. The second general location is Blakeley Island, where USACE dredged material management areas are currently at or near capacity. Finding beneficial uses for material currently stored on the island has both the potential to support ecological objectives in the northern bay and to open capacity in the island, smoothing dredging operations in and around the port. The third location is in the southeast corner of Mobile Bay, where the Fort Morgan Peninsula and the shores of Bon Secour Bay host a rich tapestry of flora and fauna as well as unique geomorphological features like the peninsula's beach ridges. These littoral habitats are challenged by erosion in the present and the anticipated impacts of sea level rise in the near future, and the construction of natural infrastructure features beneficially using dredged material has the potential to ameliorate these challenges while supporting biodiversity, habitat quality, and recreational uses. The following pages first discuss the general context of Mobile Bay, and then dive into each of these potential EWN® projects, with particularly focused attention on the Fort Morgan Peninsula and Bon Secour Bay.

1 MOBILE BAY
SURFICIAL GEOLOGY

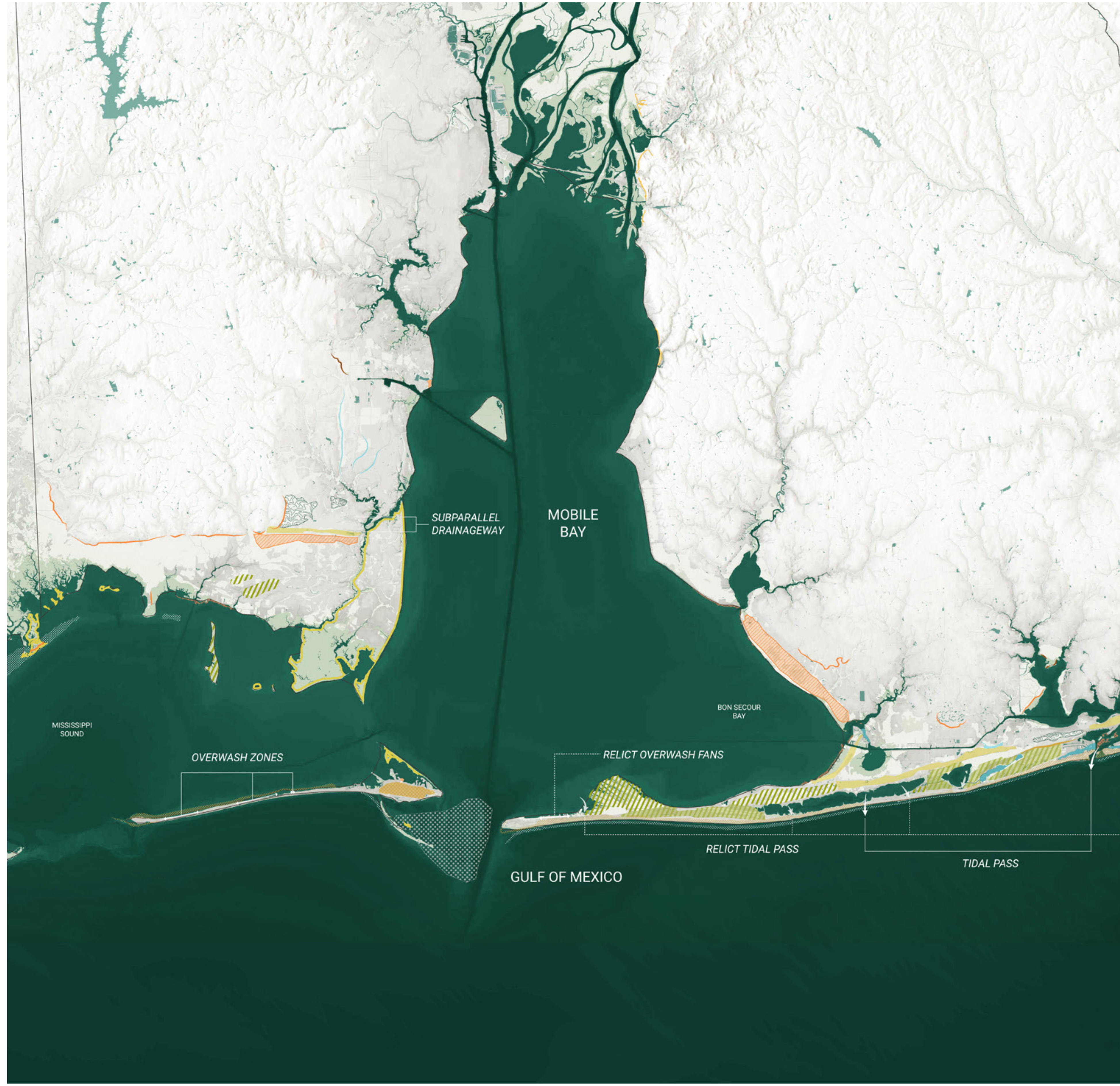
The landforms that bound Mobile Bay to the north, south, east, and west are markedly different in geologic history and present-day geomorphology. The northern bound is the Mobile-Tensaw River Delta, a long, narrow river delta which lies along a Pleistocene river valley and meets the bay roughly along the line of Battleship Parkway (US 90/98, known locally as "the causeway"). The delta is largely forested swamp, though it transitions to marshes, flats, and seagrass beds as it enters the bay. The bay also lies within this same drowned river valley. On its western side, the bay rises gently into shallow-sloped, marshy margins; large expanses of tidal marsh lie between and along winding rivers like the Dog and Fowl. On the eastern side, though, land rises much more rapidly away from the bay in clear bluffs, with the more shallow and thus marshier edges of southeastern Bon Secour Bay a notable exception. To the south, the bay is bounded by larger barrier formations of geologically recent origin, a sandy island, Dauphin, and a peninsula, Fort Morgan, composed largely of relict beach ridges.

GEOMORPHOLICAL FEATURES

WETLANDS
- Freshwater Forested/Shrub Wetland
- Freshwater Emergent Wetland
- Estuarine + Marine Wetland

WATER BODIES
- Freshwater Lakes + Ponds
- Estuarine + Marine Deepwater

GEOMOPHOLOGY
- Tidal Flat
- Sand Spit
- Dune Field
- Ebb-tide Delta
- Submerged Offshore Bar
- Relict Pleistocene Estuary
- Pleistocene Offshore Barrier Bar
- Islands
- Beach Ridges
- Relict Beach Ridges
- Relict Stream Channel
- Bluff
- Terrace Escarpment
- Escarpment
- Relict Escarpment



2 MOBILE BAY
SEDIMENT DYNAMICS

Mobile Bay receives the great bulk of its sediment supply via the Mobile-Tensaw River Delta, which conveys almost 3 million cubic yards of sediment to the bay on an annual basis (Byrnes et al 2013). Smaller rivers that empty directly into the bay, such as the Dog, Deer, and Fowl on the western shore, carry substantially smaller loads. Of the material that enters the bay, only about 500,000 cubic yards heads out into the Gulf of Mexico through Mobile Pass. The remainder either settles in the bay or is dredged out.

Shoreline erosion is a substantial concern within the bay. Most stretches of the bay's shoreline are currently experiencing significant erosion, with rates varying from less than a foot a year in the northeastern portions of the bay, near Fairhope and Spanish Fort, to over four feet a year along Little Dauphin Island. The precise nature of the processes driving shoreline erosion in the bay is an important topic for further scientific study, but anthropogenic activity, including development, shoreline hardening, interruption of sediment transport processes, habitat degradation, and reductions in sediment supply to the bay, is believed to be a substantial contributor (Byrnes et al 2013; Stout et al 1998).

ACCRETION/EROSION DYNAMICS

BAY
Bathymetric change 1984-2011

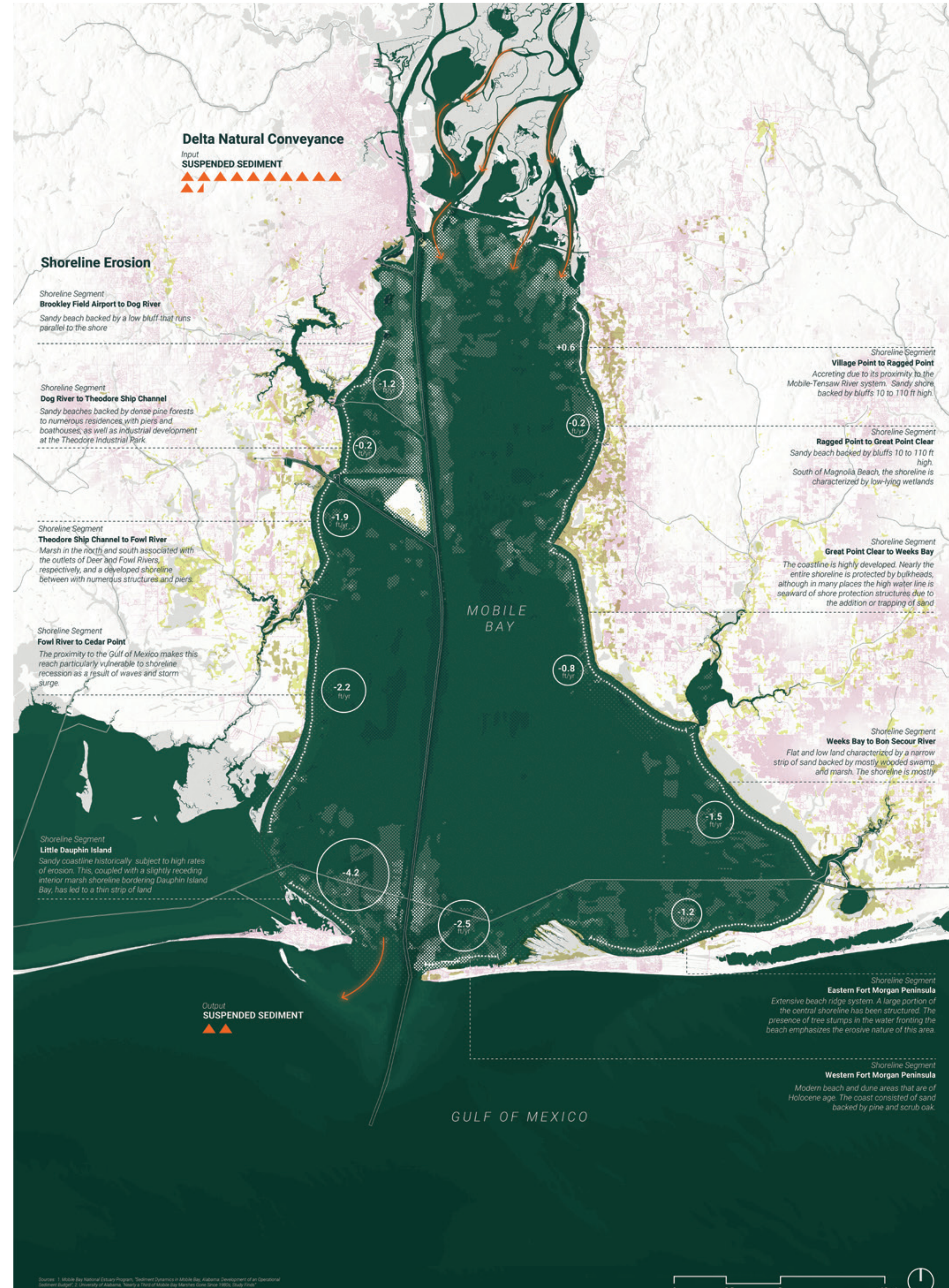
- < 10 ft
- 3ft to 10 ft
- 0 to 3ft
- 0 to -3 ft
- < -10 ft

SHORELINE
Average annual change 1850-2010

- Accreted
- Eroded
- -0.2 ft/yr
- -4.2 ft/yr

WETLANDS
Wetland loss since 1984

- Emergent wetland loss
- Woody wetland loss
- Developed and Agriculture land



2 MOBILE BAY
SEDIMENT DYNAMICS

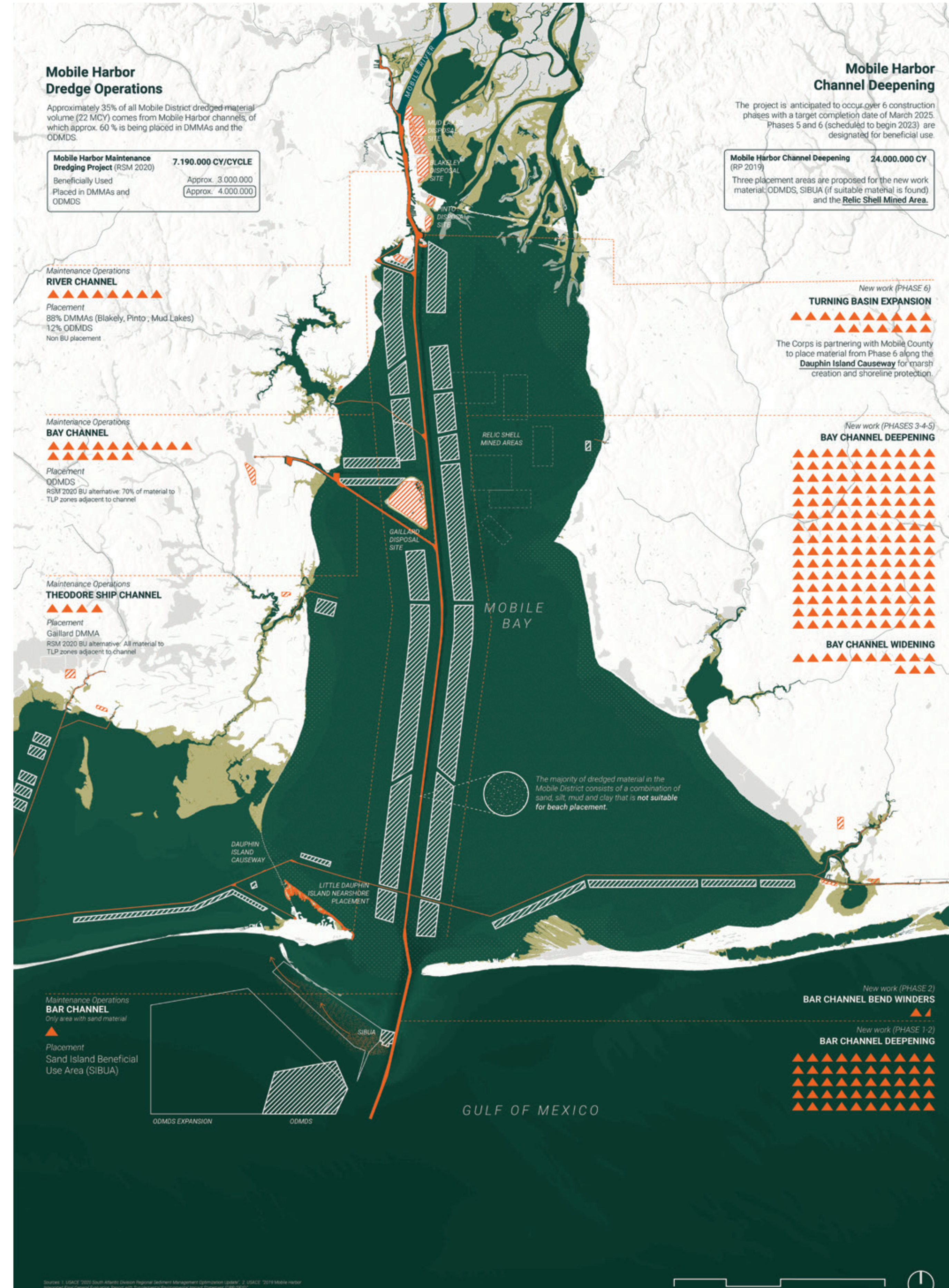
Mobile Bay is extremely shallow and large, while its ports of Mobile proper and Theodore handle large volumes of ship traffic, particularly in bulk cargos. Consequently, SAM is responsible for a very large network of dredging operations within the bay.

As of 2020, roughly 7 million cubic yards of material are dredged in an annual maintenance cycle (USACE 2020). Of this, roughly 3 million cubic yards is beneficially used through the thin-layer placement of dredged material into designated zones along the length of the Bay Channel, while the remaining 4 million cubic yards is placed in upland management facilities (Blakeley, Pinto, Mud Lakes, and Gaillard) or offshore (at the ODMDS). The great majority of this material is a combination of sand, silt, mud, and clay that is not suitable for beach placement. Another quarter of a million cubic yards, which is largely beach-quality sand, is removed from the Bar Channel and placed at the Sand Island Beneficial Use Area, approximating the natural longshore transport of sand from Fort Morgan Peninsula to Dauphin Island and points west in the Mississippi Sound.

The Mobile District is also in the process of dredging the Mobile Harbor Channel Deepening project, which is targeted for completion in March 2025. This project is expected to generate around 24 million cubic yards of material, much of which is being beneficially used in-bay at locations including Dauphin Island Causeway and the Relic Shell Mined Areas (USACE 2019).

SEDIMENT MANAGEMENT

- 250000CY of dredged material
- ACE Navigation Channel
- Upland Placement Area
- Open Water Placement
- Beach Nourishment



BENEFICIAL USE FOR ECOLOGICAL RESTORATION

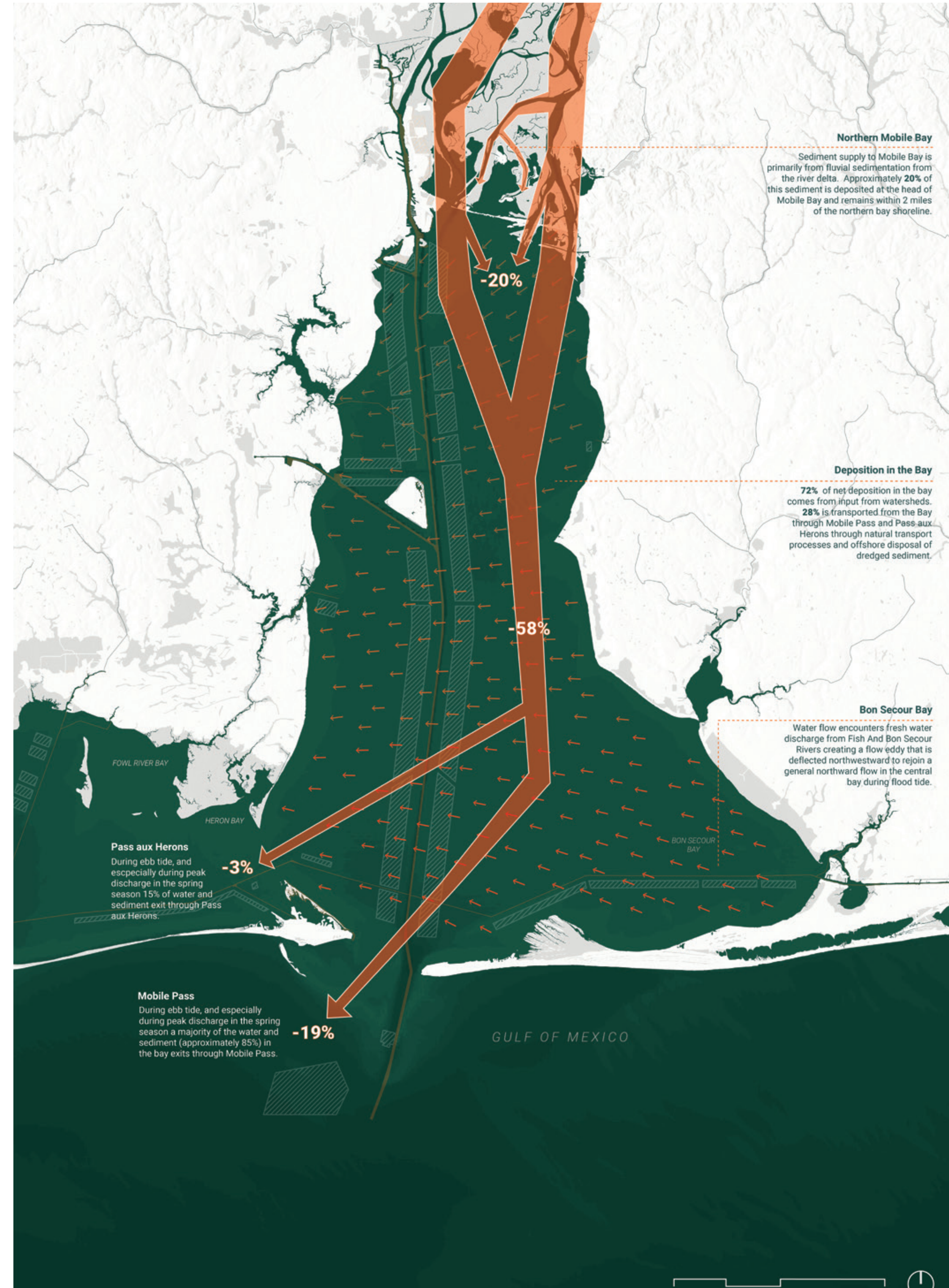
MOBILE BAY DISPERSIVE PLACEMENT AREAS

The large volume of material being dredged within Mobile Bay presents both opportunities to increase the percentage of material that is beneficially used, in accordance with Gen. Spellmon's directive to beneficially reuse 70% of all dredged material by 2030, and, through the application of EWN® strategies, to increase the benefits derived from material that is so used.

One such strategy is the strategic placement of dredged material in dispersive placement areas. Dispersive placement areas can be substantially more efficient economically and logistically than direct placement, because they harness natural processes to move dredged material from the placement area to the intended beneficial use, such as a marsh nourishment, rather than requiring mechanical transport. They can also enhance the ecological benefits of placement, as material that is moved through natural processes often moves more gradually over time, facilitating ecosystem adaptation. Dispersive placement areas thus have the potential to align the dictates of navigation dredging projects in Mobile Bay with the aims of on-going ecological restoration work.

1 MOBILE BAY
SEDIMENT TRANSPORT PATTERNS

Within Mobile Bay, the general patterns of sediment transport are from north to south, as sediment enters the bay from the delta, and from east to west, in accordance with the prevailing winds, currents, and tidal forces (personal communications, Wendell Mears, Anchor QEA). The Bay Channel bisects the bay from north to south, and likely collects some sediment that would otherwise continue west to nourish shorelines and marshes on the western edge of the bay. Discharge through Pass aux Herons, to the Mississippi Sound, is also much diminished relative to baseline conditions.



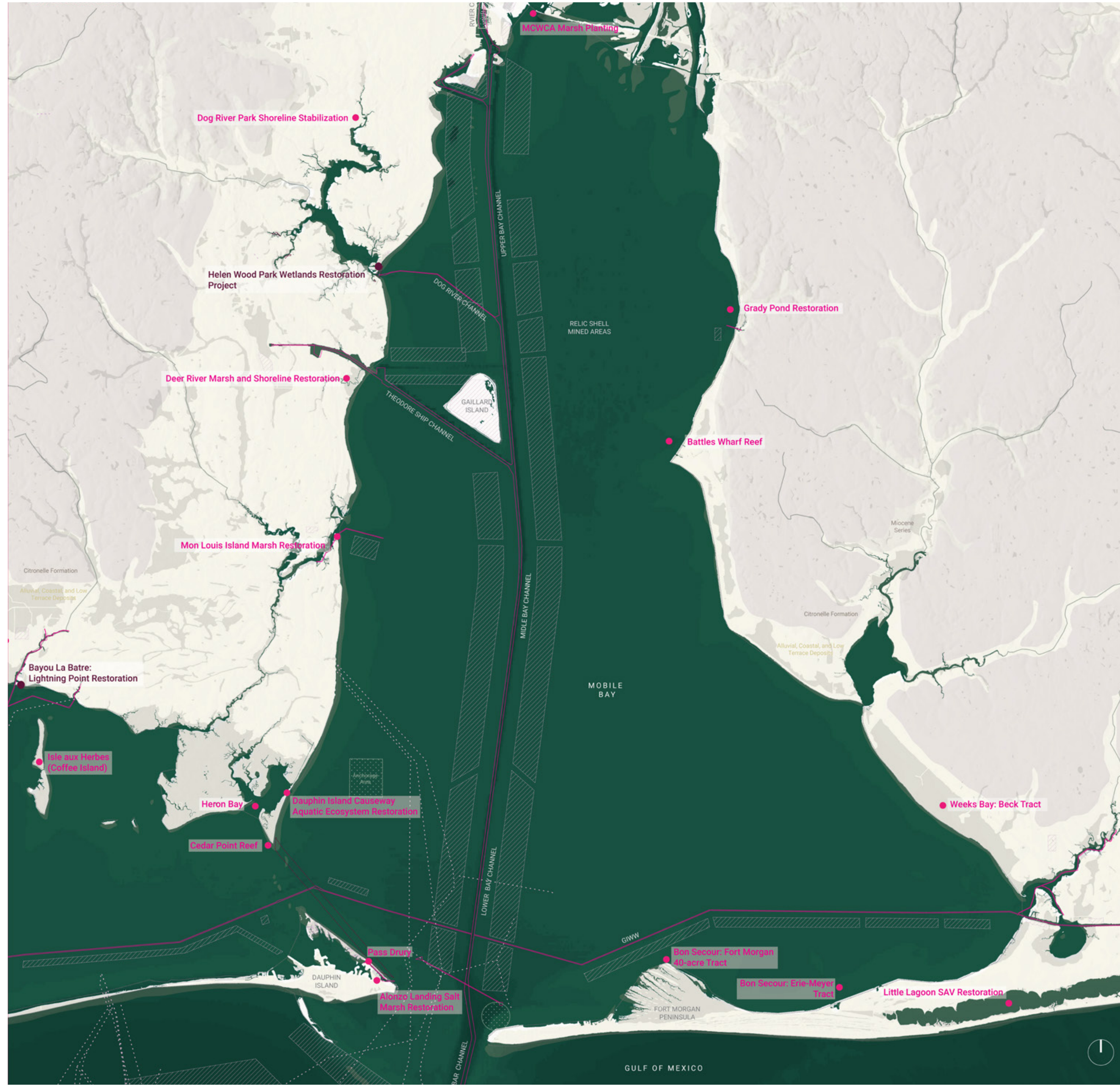
2 MOBILE BAY ECOSYSTEM RESTORATION PROJECTS

Ecosystem restoration is a substantial priority for many organizations and people in the Mobile Bay region. Much of this effort has focused on three key aquatic habitats: tidal marsh, oyster reefs, and seagrass beds. Each of these habitats has seen substantial decline since the 19th century, and a range of organizations, including the Mobile District, the Mobile Bay National Estuary Program, and The Nature Conservancy of Alabama, are working on ecosystem restoration projects that aim to rebuild scale and function for these habitat types (MBNEP 2019). Tidal marsh restoration projects, in particular, require sediment supply both to construct new marsh platforms and to maintain restored marsh against the forces of erosion and sea level rise. Some of this sediment can be supplied through direct placement, but strategic placement offers an important opportunity to support such ecosystem restoration through the economically-efficient delivery of sediment. Doing so can also support recreation, shoreline protection, and coastal storm risk management, as restored habitats are capable of providing all of these benefits.

Restoration Projects
- Project Title
- Completed Project

Navigation
- ACE Navigation Channel
- ACE Placement Areas
- Anchorage Area
- Cable Area
- Submarine Pipelines

Wetlands
- Tidal Wetland
- Shallow Subtidal
- Deep Water (5ft intervals)

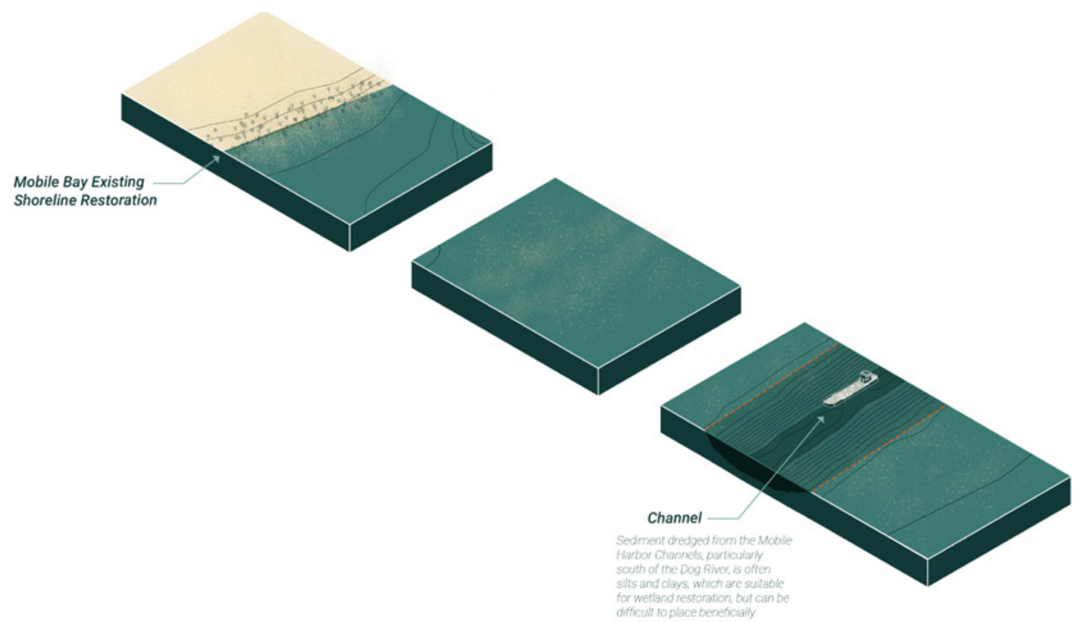


3 MOBILE BAY
DISPERSIVE PLACEMENT AREA CONCEPT

Dispersive placement areas could be constructed on the west side of the Bay Channel to support ecosystem restoration and these associated benefits. Along much of the length of the channel, areas could be located in zones that are already designated for placement; in the more southern reaches, it would likely be preferable to locate new placement areas further west than the existing placement areas, to facilitate delivery of sediment to key restoration projects and existing marshes. Placements within these areas could vary in height from roughly one to four feet, depending on location, and could be constructed roughly 200 feet in width by swinging a placement pipe 100 feet in either direction. The placed sediment should be entirely submerged.

The diagram below describes the general intended transport of sediment that can be achieved through this strategic placement method. More study, including hydrodynamic and sediment transport modeling, is needed to define precise locations that would be appropriate for placement in these dispersive areas, as it is important to ensure that strategically-placed sediment constructively feeds marshes without negatively impacting privately-owned shorelines. Coordination between dispersive placement area design and construction of living shorelines, which can benefit from increased sediment supply, would also be desirable.

EXISTING CONDITION



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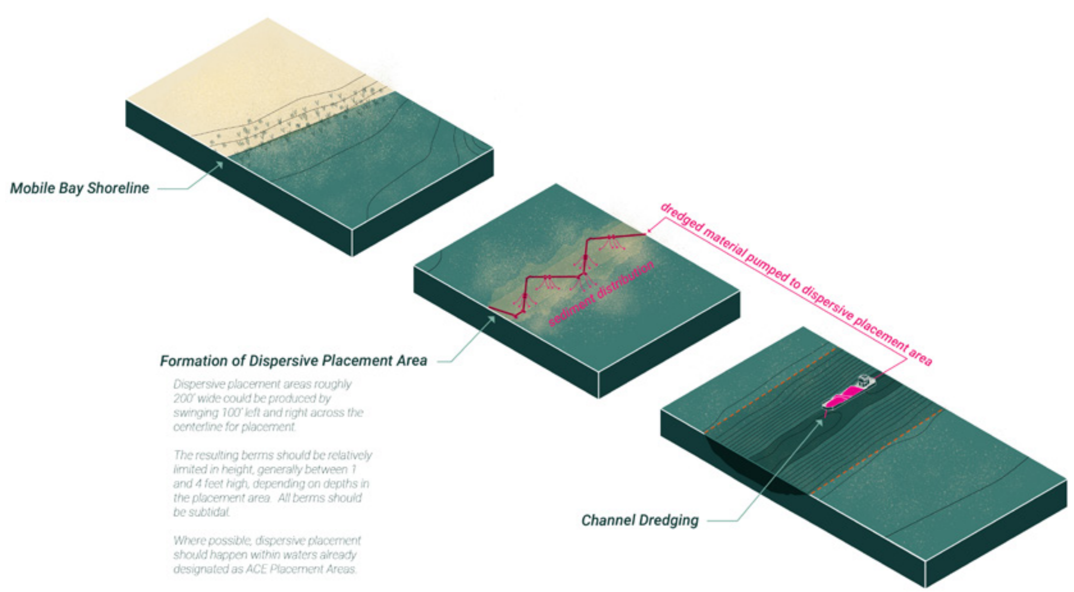

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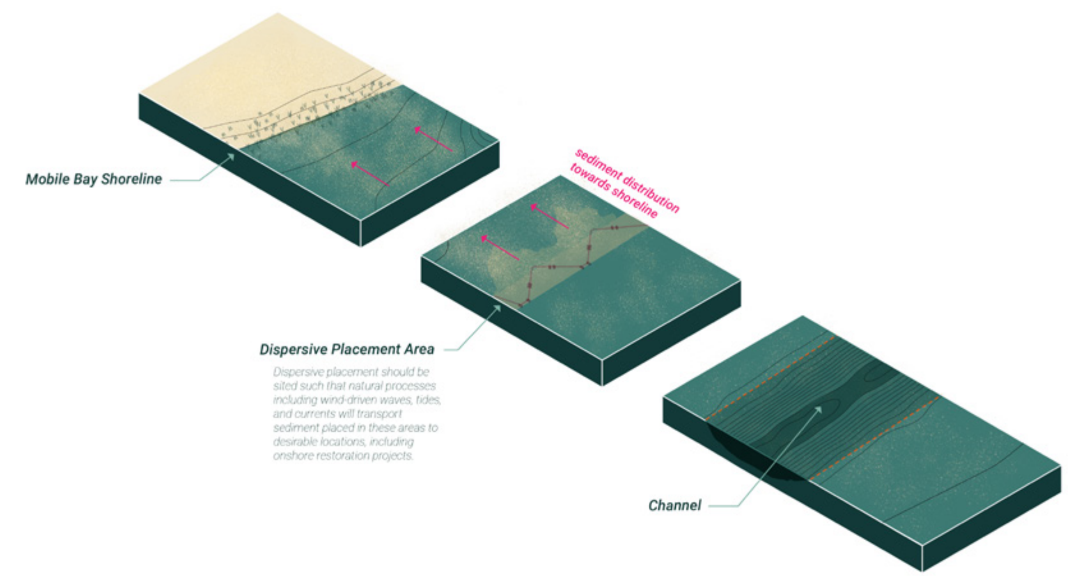

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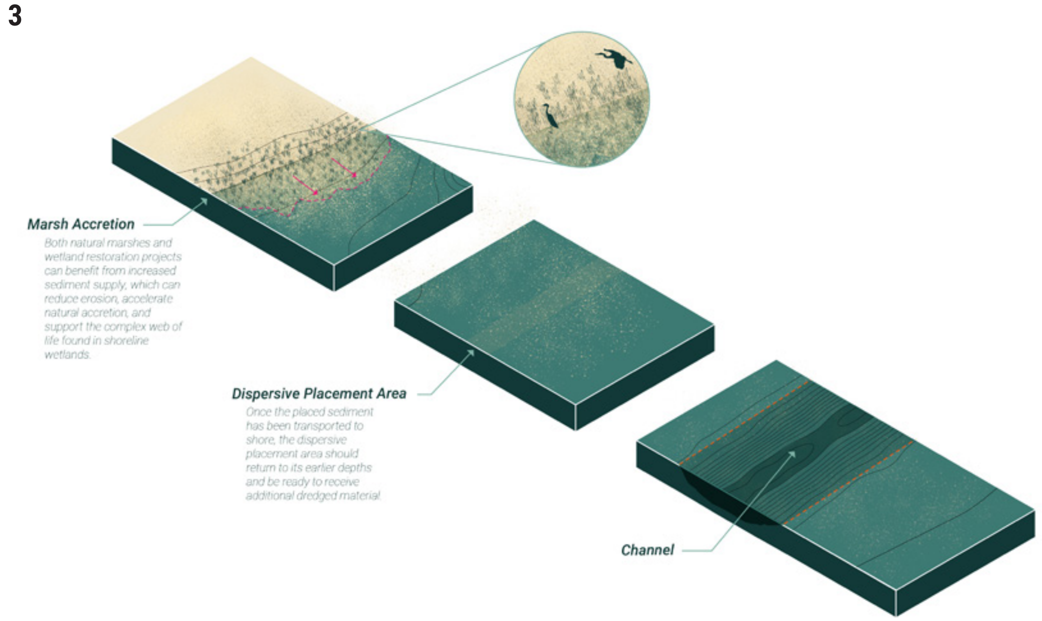
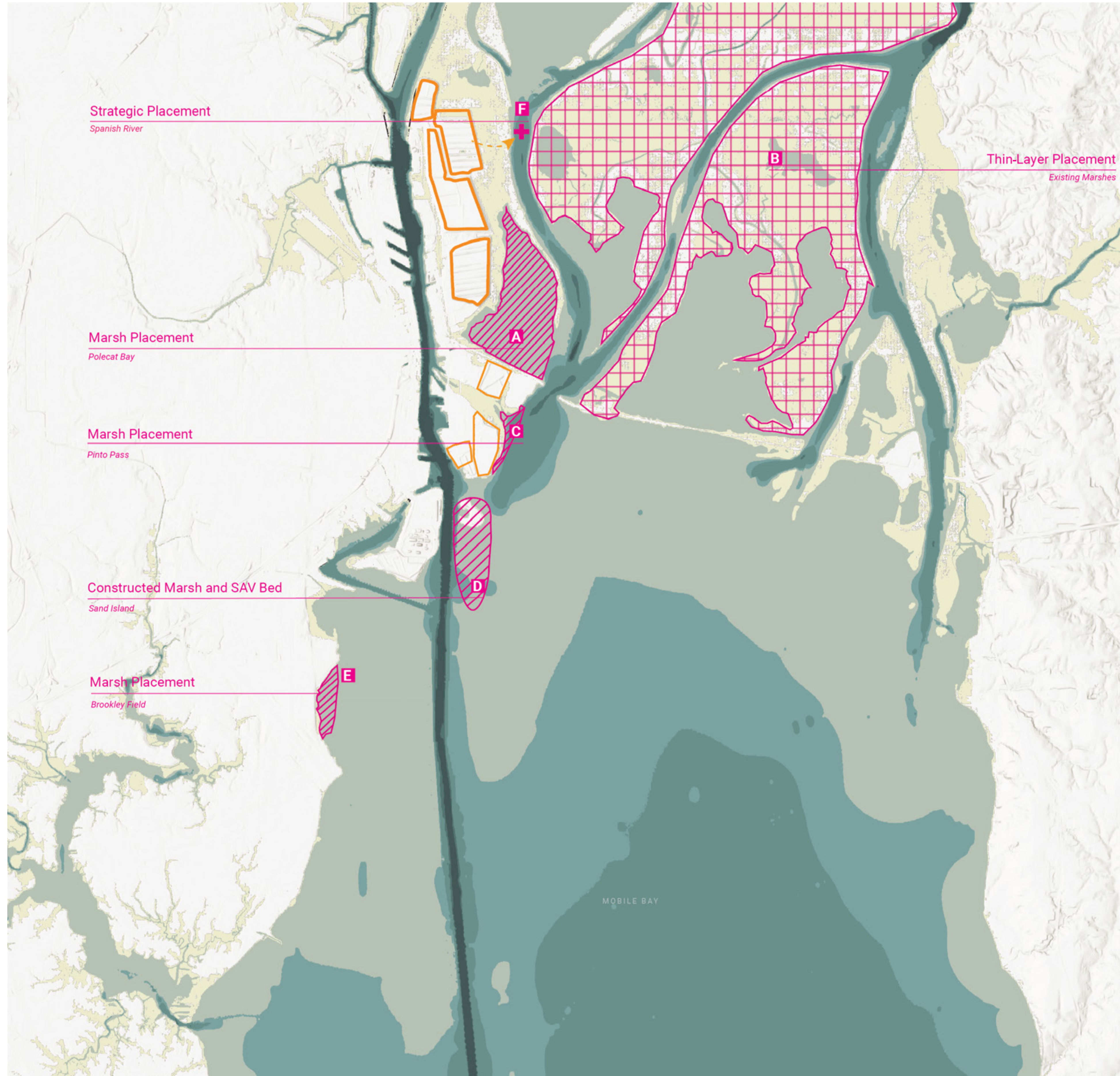


BENEFICIAL USE FOR ECOLOGICAL RESTORATION
BLAKELEY ISLAND

Blakeley Island sits on the east side of the Port of Mobile, between the main stem of the Mobile River and the secondary Spanish River. The island has seen a number of industrial uses in its recent history, and is currently host to major dredged material management areas, both areas managed by the federal Mobile District and areas managed by the state Alabama Port Authority. Large volumes of material are dredged from the channels and docks west of the island every year, and SAM's Blakeley Island dredged material management areas are generally at or near capacity, which presents substantial logistical challenges for the required navigation dredging operations.

1 BLAKELEY ISLAND
PROSPECTIVE BENEFICIAL USE SITES

Finding beneficial uses for some of the material currently emplaced at Blakeley Island has the potential to both support sediment management aims and facilitate the construction of large-scale ecological features in northern Mobile Bay. The map at right identifies some such opportunities. Polecat Bay, on the southeast of Blakeley Island, could be brought up to marsh elevation and planted as tidal marsh. The existing marshes of the southern delta, which lie to the east of Blakeley Island, are potential candidates for thin-layer placement of fines, which could support natural accretion. A smaller area of Pinto Pass, just south of the Pinto Island placement area, also harbors the opportunity for expansion of an existing marsh. Little Sand Island could be extended south, potentially on a long, shallow slope that could go from an expanded upland maritime forest through tidal marsh to subtidal seagrass beds. Near Brookley Field, existing marsh could be expanded east, potentially aligning with an on-going city public recreation project at Brookley Field. Finally, a pipeline could potentially be constructed from the Blakeley Island DMMA to the Spanish River, where material could be strategically placed during periods of high flow, when river currents could carry it south to build marsh and seagrass beds at the river mouth.



DREDGE MATERIAL PLACEMENT
- Existing DMMA/ASPA Areas
- Potential Thin Layer Placem
- Potential Marsh Placement ,

NAVIGATION
- Navigation Channel

WETLANDS
- Tidal Wetland
- Shallow Subtidal
- Deep Water (5ft intervals)

BENEFICIAL USE FOR ECOLOGICAL RESTORATION
FORT MORGAN PENINSULA

The Fort Morgan Peninsula, and the shores of adjacent Bon Secour Bay, are located in the southeast corner of Mobile Bay. They are relatively sparsely populated, although there are both many single-family residences along the north shore of the peninsula and a number of larger developments, including a few condo towers on the central peninsula. Around half of the bay shoreline in this area, including the great majority of its undeveloped shoreline, is managed by the US Fish and Wildlife Service as the Bon Secour National Wildlife Refuge.

Where undeveloped, the shoreline is generally characterized by either broad tidal marshes with sand beach margins or, in the Wildlife Refuge's Little Point Clear Unit, the intricate ridge-and-valley topography of relic beach ridges. Developed shorelines are often armored in some fashion, generally on a property-by-property basis. Like most other shorelines around Mobile Bay, these shorelines face substantial erosion concerns, which will likely be exacerbated as sea level rise accelerates in coming decades.

Sea level rise also presents significant challenges to habitat management, as the area is marked by very low elevations that could transition to subtidal habitat with even relatively low sea level rise. A great deal of biodiversity and ecological productivity is at risk, including endangered species like the Alabama Beach Mouse. Moreover, the loss of these habitats would increase the exposure of the peninsula's human population to storms and flooding.

Mobile Bay's broader sediment management needs could potentially be aligned with these local concerns in a program of beneficial use for ecological restoration. The following section of this report explores this potential, focusing in particular on "erodible berms" which could facilitate marsh construction and the construction of new beach ridge-like features. While further design, modeling, and discussion with stakeholders and potential project partners like the FWS and Baldwin County would be needed to advance these concepts to implementation, the research team has used an iterative design process including computational hydrodynamic modeling to explore the feasibility of and appropriate designs for these features.

1 FORT MORGAN CONTEXT
GEOMORPHOLOGY

The Fort Morgan Peninsula and the shores of Bon Secour Bay are unique among the shorelines of eastern Mobile Bay in that they have extensive tidal wetlands. This can be attributed to their geomorphological characteristics, including the presence of beach ridge formations, the relatively recent formation of the shallow shores in the Pleistocene and Holocene geologic eras, and the wide terrace escarpment along northeastern Bon Secour Bay. This geomorphology provides the foundation for the present-day ecological communities that could benefit from nature-based infrastructure approaches.

WETLANDS
- Freshwater Forested/Shrub Wetland
- Freshwater Emergent Wetland
- Estuarine + Marine Wetland

GEOMOPHOLOGY
- Tidal Flat
- Sand Spit
- Dune Field
- Ebb-tide Delta
- Submerged Offshore Bar
- Relict Pleistocene Estuary
- Pleistocene Offshore Barrier Bar
- Islands
- Beach Ridges
- Relict Beach Ridges
- Relict Stream Channel
- Bluff
- Terrace Escarpment
- Escarpment
- Relict Escarpment

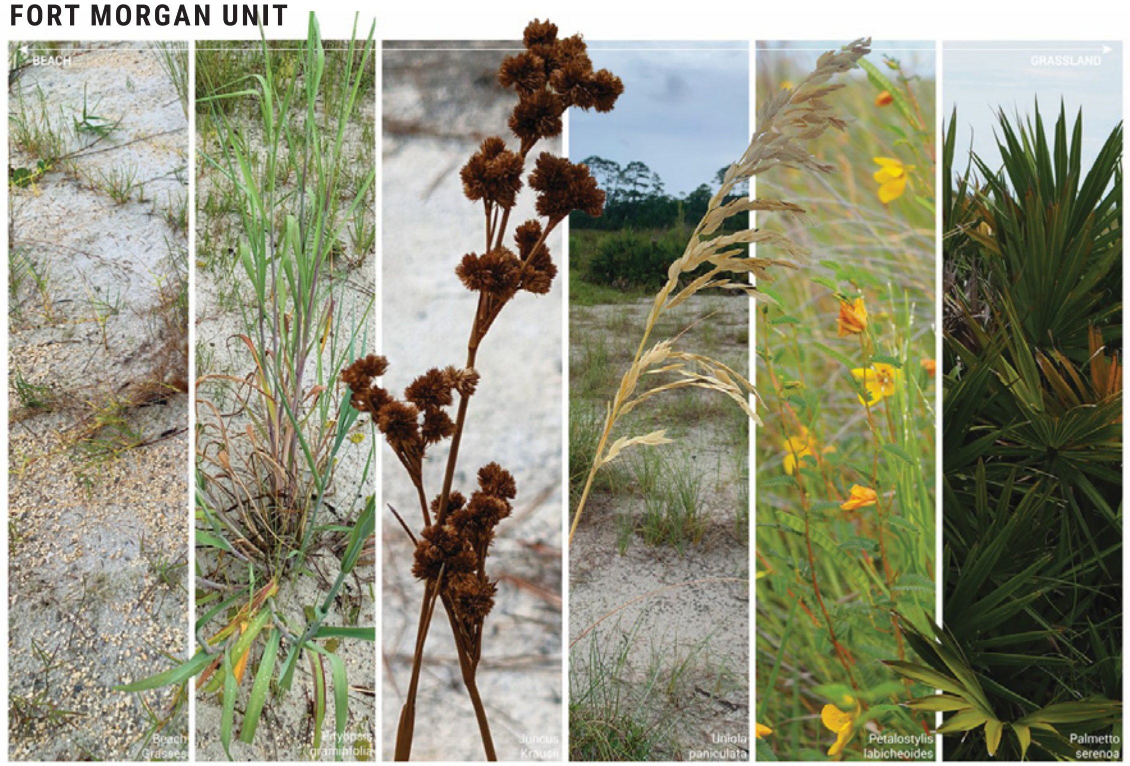
2 FORT MORGAN CONTEXT
ECOLOGICAL COMMUNITIES

The Fort Morgan Peninsula, owing to its relatively light development, contains much significant habitat. This coastal barrier landform, which does not exist anywhere else in Alabama, is crucial for storm protection and animal survival. While development is lighter than in other Alabama coastal regions like adjacent Gulf Shores, the zones between the protected units of the Bon Secour National Wildlife Refuge are threatened by habitat fragmentation. Within the Refuge, extents of undeveloped dunes and beach ridges provide secure breeding and food sources are critical to animals like the Alabama Beach mouse, migratory birds, sea turtles, and many other Gulf species.

Across the peninsula, a mosaic of varied plant communities vary in relationship to relatively small elevation changes. Live oaks dominate inland dunes, slash pine forests cover low lying dunes, and dunes closer to the Gulf host a sparse forest of dwarf evergreen oaks and sand pines along with grasses such as sea oats. The peninsula contains palustrine, estuarine, and marine wetland habitat systems, though palustrine wetlands are predominant. The peninsula's wetland systems include both fresh and saltwater marshes. Freshwater swamps with cypress and black gum are found throughout the Refuge, though most are small or intermittent. One of the most unique habitats in the region and on the peninsula is the interdunal swales and beach ridge habitat. The habitat is characterized by permanent or semi-permanent swales that are found between dune ridges. These areas are flooded primarily by freshwater but receive frequent saltwater intrusion. Maritime forests anchor the fragile dune system in the southern portion of the Refuge and provide a foundation to this otherwise highly dynamic environment. Pine savannas, riparian buffers, and scrub forests consist predominantly of pine flatwoods, with the main species being slash or sand pine. These forests canopies are mixed with occasional hardwoods such as southern magnolia and live oak. This type of mixed woodland habitat is sparse throughout the peninsula, but it is a critical habitat for the gopher tortoise.

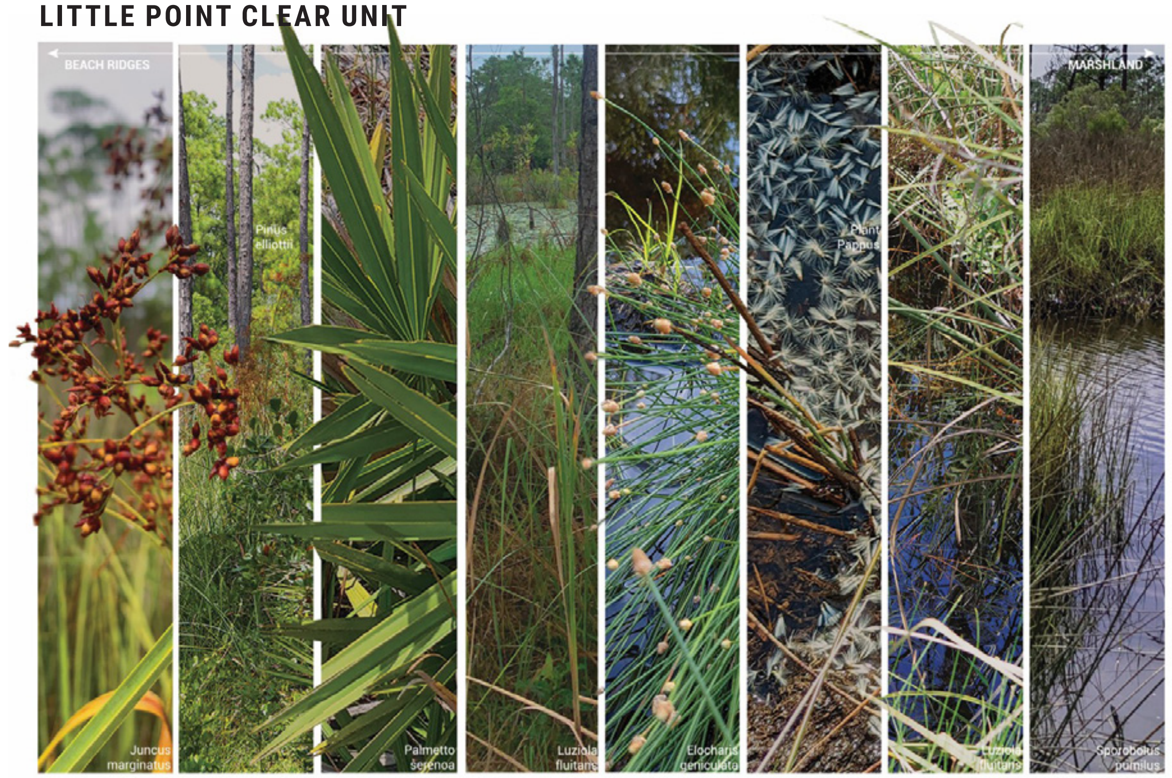
2 FORT MORGAN CONTEXT
ECOLOGICAL COMMUNITIES

FORT MORGAN UNIT



PERDUE UNIT

LITTLE POINT CLEAR UNIT



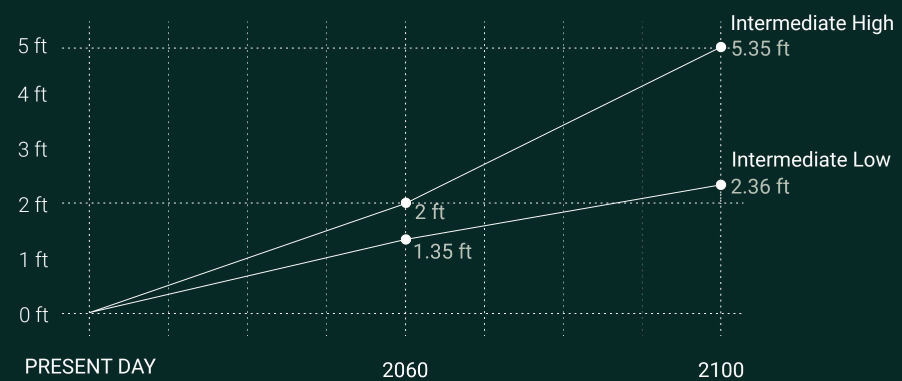
SAND BAYOU UNIT

3 FORT MORGAN CONTEXT
SLR AND HABITAT MIGRATION

Intertidal
- 0 to 1.2 ft

Shallow Subtidal
- 0 to -5.0 ft

Deep Subtidal
- -5.0 to -10 ft
- -10 to -15 ft
- -15 to -20 ft
- < -20ft

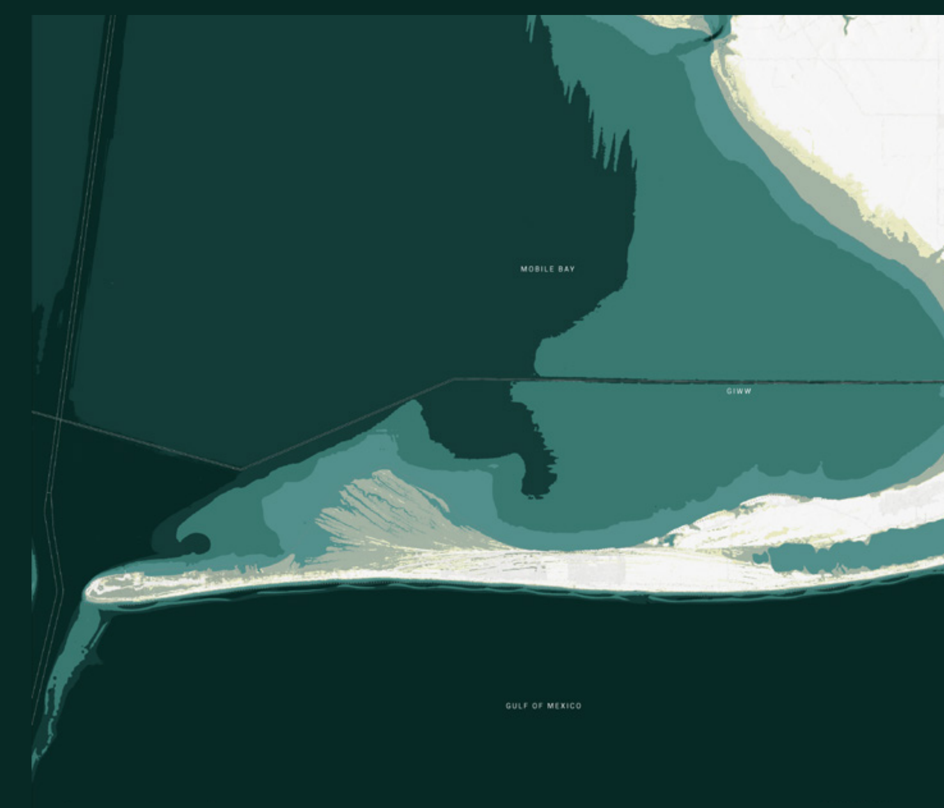


Due to its low elevations, the Fort Morgan Peninsula faces the potential for substantial habitat transformation in many projected sea level rise scenarios. The maps here show projected habitat transformation for both aquatic and upland habitats under 2' and 5' of sea level rise. Roughly 2' of rise is projected for 2100 under NOAA's intermediate low scenario or for 2060 under their intermediate high scenario, while 5' is projected for 2100 in that intermediate high scenario. While these projections represent transformations without adaptive interventions of the kinds proposed later in this section, they are clearly illustrative of the speed and magnitude of environmental change that this corner of Mobile Bay faces.

PRESENT DAY

+2FT SLR

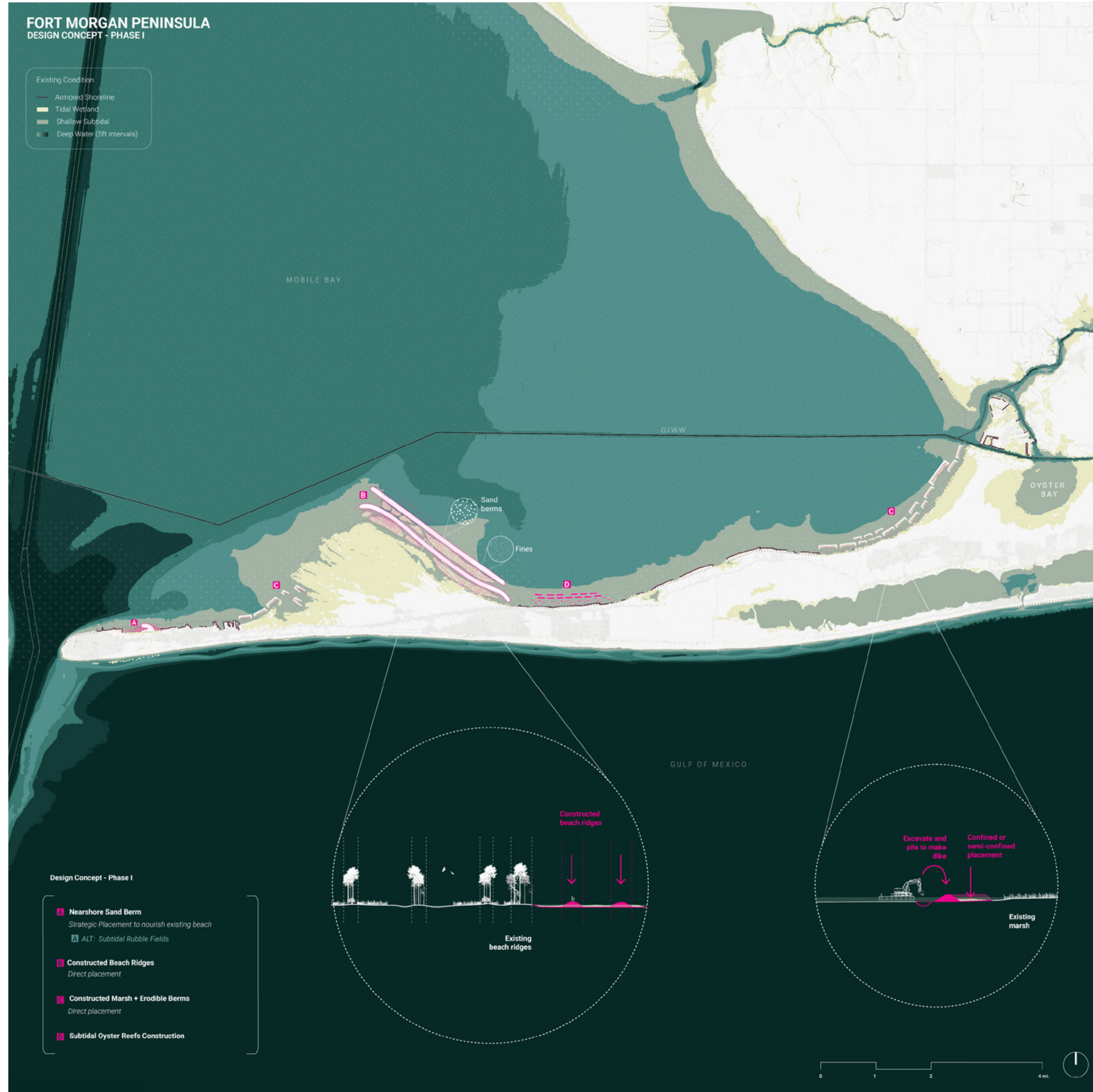
+5.35 FT SLR



4 FORT MORGAN PENINSULA
DESIGN CONCEPTS

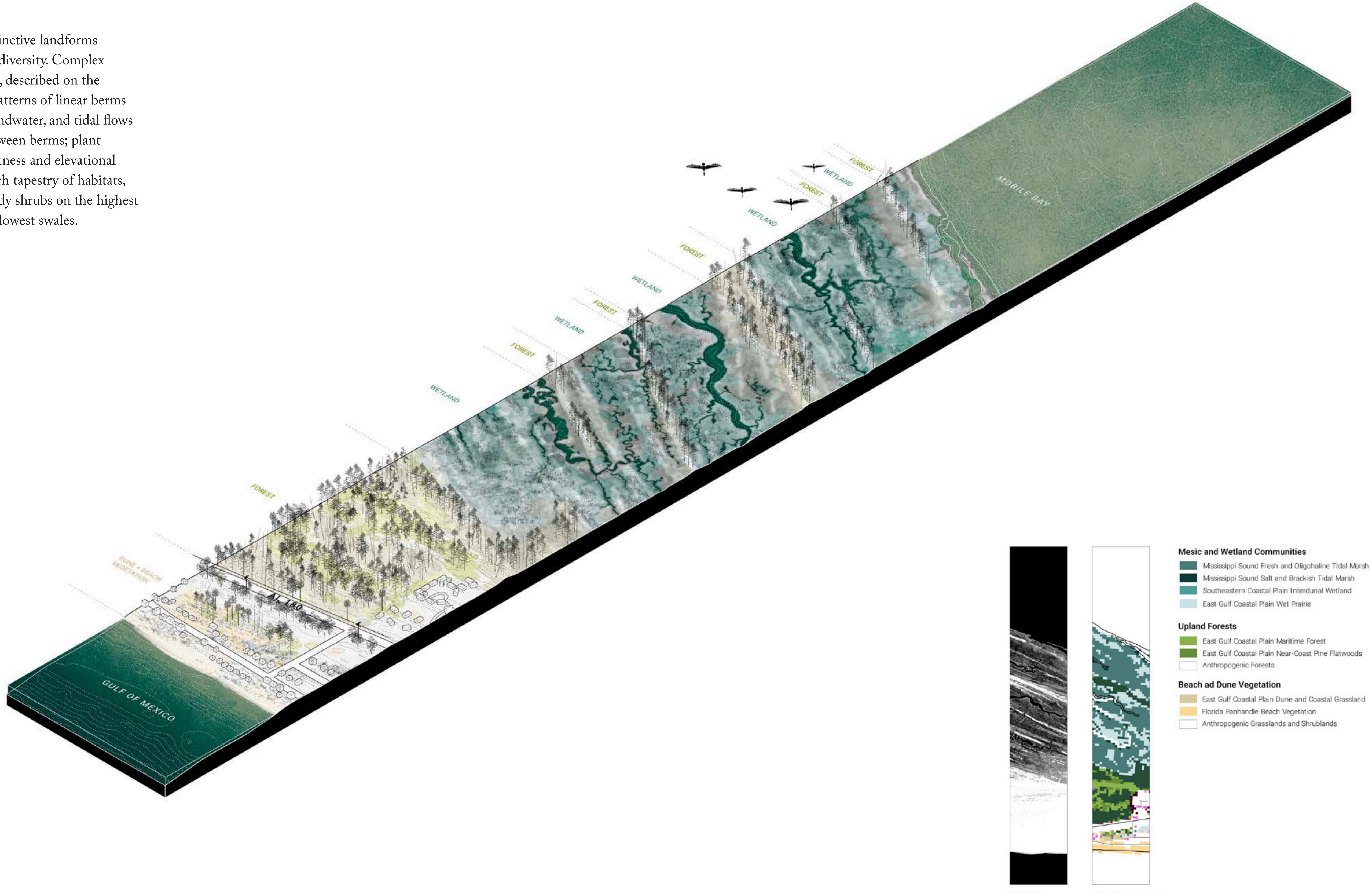
We propose four categories of nature-based features that could be constructed along the north side of the Fort Morgan Peninsula to address the issues of shoreline erosion and habitat loss. The plan at right shows these features aligned with existing shoreline conditions. From the west, the first of these is a Nearshore Sand Berm, which could be placed on the eastern end of a short stretch of sand beach to nourish and build up that beach. A second feature, Constructed Beach Ridges, would involve designing, constructing, and managing new landforms analogous to the complex ridge-and-swale topography of the existing relic beach ridges. A third type of feature, Erodible Berms, would be used to create protected calm-water zones in which dredged fines could be placed, bringing those zones up to marsh elevation and permitting the establishment of new tidal marsh. The berms would be designed to partially erode as the new marsh establishes, facilitating the development of tidal channels connecting the new marshes to existing marshes and leaving behind gentle sand margins similar to the margins of the area's existing tidal marshes. Finally, Subtidal Oyster Reefs could be placed in zones where emergent features would interfere with existing uses, such as the vicinity of the Pines Public Boat Launch. Oysters historically grew in Bon Secour, as the 1968 survey located several reefs in the area, and there is currently an oyster farm at Navy Cove, on the western end of the peninsula (Bannon and Herman 2020). The following pages explore two of these concepts, the Constructed Beach Ridges and the Erodible Berms, in more detail.

More study is needed to fully validate these design concepts, including assessment of their relationship to cultural and archaeological resources (such as the cemetery near Navy Cove), further hydrodynamic modeling (particularly for the beach ridge concept), study of costs and construction logistics, assessment of ecological benefits and impacts, and engagement with both relevant stakeholders (including but not limited to the US Fish and Wildlife Service and Baldwin County) and the local community.



5 CONSTRUCTED BEACH RIDGES
BEACH RIDGE ECOLOGY

Beach ridges are highly distinctive landforms that support a wealth of biodiversity. Complex geomorphological processes, described on the following spread, produce patterns of linear berms and swales. Rainwater, groundwater, and tidal flows variably soak the swales between berms; plant communities respond to wetness and elevational gradients by generating a rich tapestry of habitats, ranging from trees and woody shrubs on the highest berms to tidal marsh in the lowest swales.

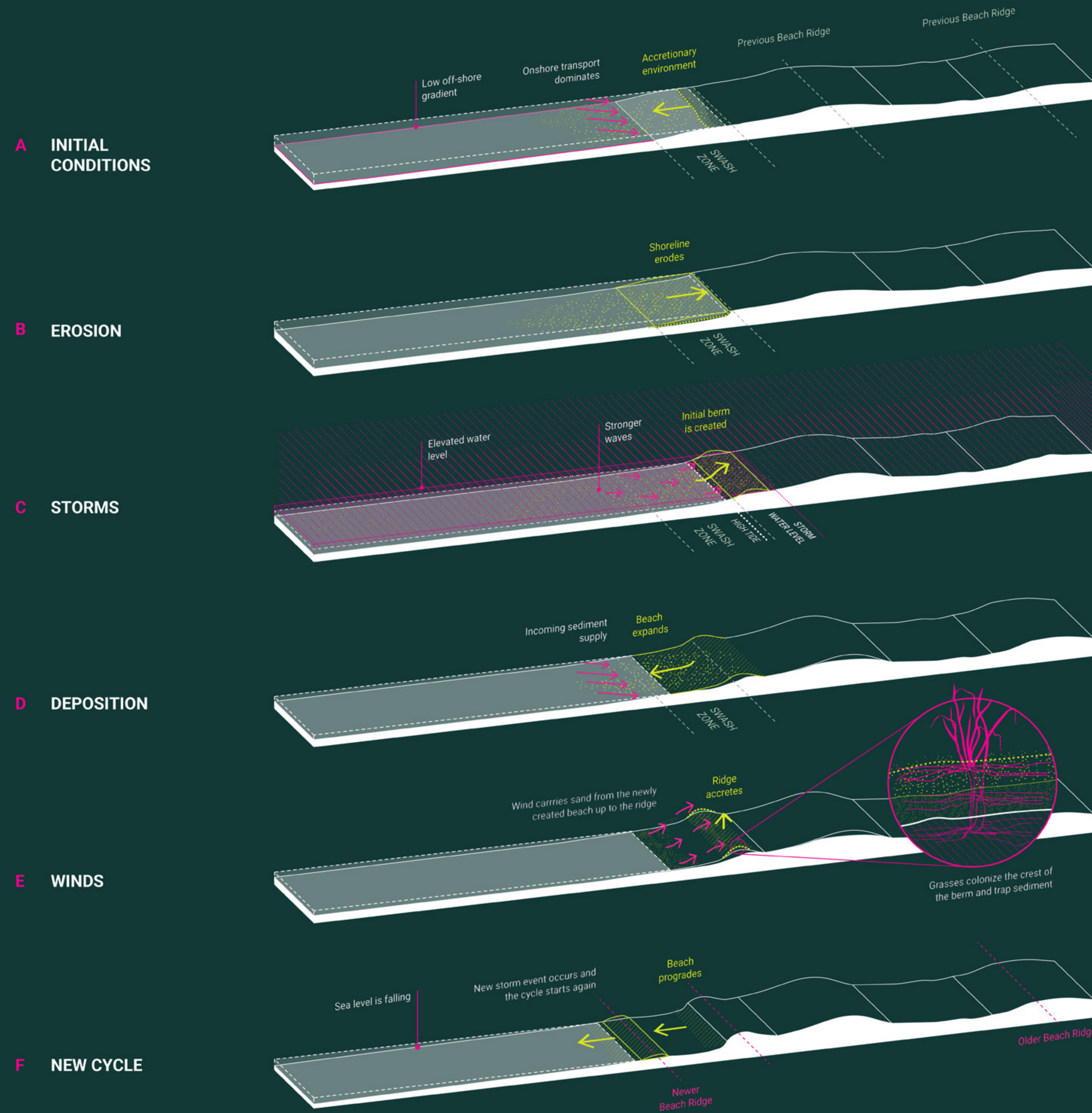


5 CONSTRUCTED BEACH RIDGES
BEACH RIDGE FORMATION

This sequence of drawings depicts the natural dynamics that contribute to the formation of beach ridges, delineating each process individually. Firstly, beach ridges are likely to form in accretionary environments, such as those where there is an abundance of sediment and a gentle offshore slope (A) (Taylor and Stone 1996).

Under these environmental conditions, beach ridge development is then influenced by waves, winds, and vegetation. While theories on beach ridge development vary and the processes at work also vary from region to region, storm waves and water fluctuations have been identified as primary forces producing beach ridges, and some studies have acknowledged the impact of vegetation and aeolian deposition on beach ridge accretion and stabilization (Taylor and Stone 1996). In a case such as the beach ridges of the Fort Morgan Peninsula, the interaction of these forces might be described as follows.

Erosion of the shoreline caused by wave energy contributes to the creation of a future swale (B). During a storm event, stronger waves and elevated water levels drive sediment beyond the swash zone, producing a berm and initiating a future ridge (C). Further deposition takes place in front of this berm, supporting beach progradation (D). Winds reinforce ridge formation by carrying sediment from the newly created beach to the crest of the berm, where it is trapped and stabilized with the assistance of colonizing grasses (E). With subsequent storm events, the cycle restarts; erosive and depositional forces continue to interact throughout the evolution and progradation of the beach ridges (F), forming a complex of multiple ridges, such as those found within the Bon Secour National Wildlife Refuge.

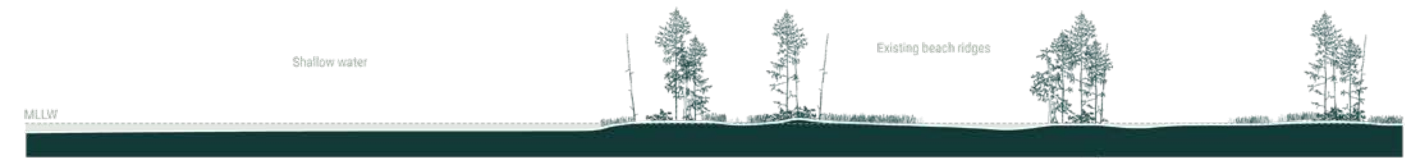


5 CONSTRUCTED BEACH RIDGES
LEARNING FROM NATURAL FORM

The conditions that favored beach ridge formation in the past are not readily duplicated in the present, as sea level is rising far faster than it did in the past and shorelines are eroding rather than accreting. Moreover, beach ridge formation took place on timescales much greater than the few decades that are projected to lie between the present and several feet of sea level rise. Thus, building new beach ridge-like habitat requires using machinery to rapidly constructing analogues to the natural landforms.

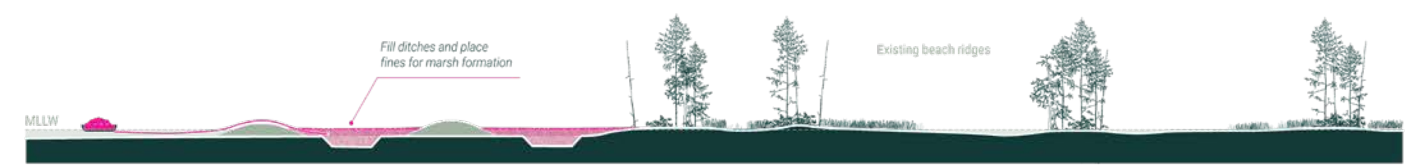
The diagrams at right show how one such analogue could be constructed. As the shallow bay bottom near the Little Point Clear Unit beach ridges is largely sand, it should be suitable for constructing sand berms by sidecasting locally-excavated sediment. Once these protective berms are in place, dredged fines can be barged from the Bay Channel and pumped to the newly-created swales, filling them to marsh elevation. Upland species can be planted along the sand berms, while marsh species can be planted in the new marsh platforms. With time, these constructed forms should take on much of the character and ecological richness of the natural beach ridges.

00
EXISTING CONDITION

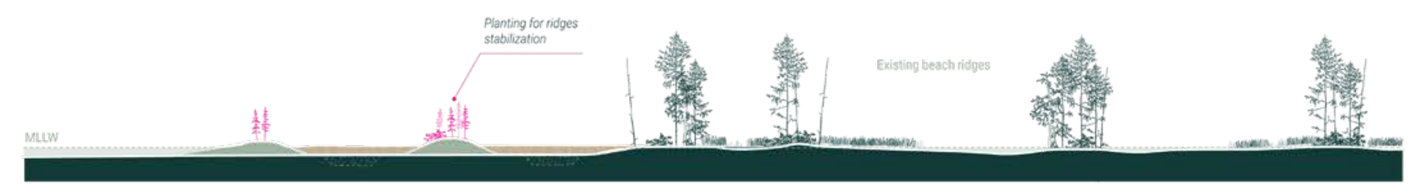


01
SAND BERMS CONSTRUCTION

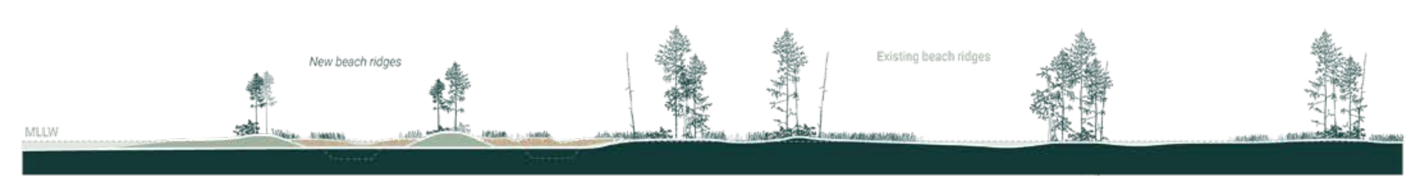
02
FINES PLACEMENT



03
PLANTING



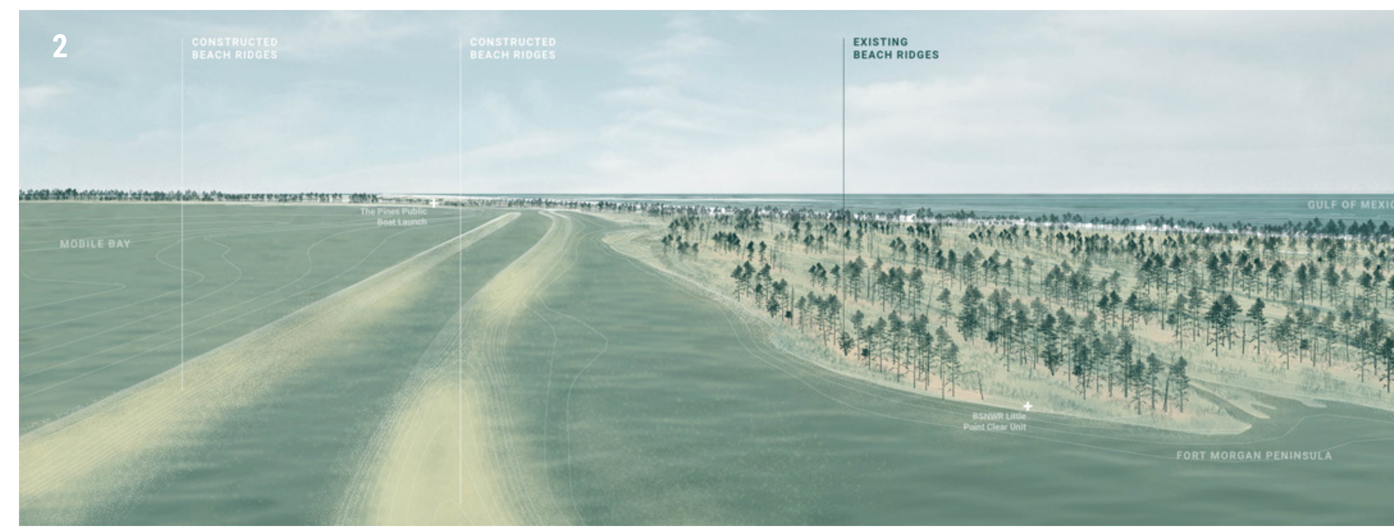
04
CONSTRUCTED BEACH RIDGES

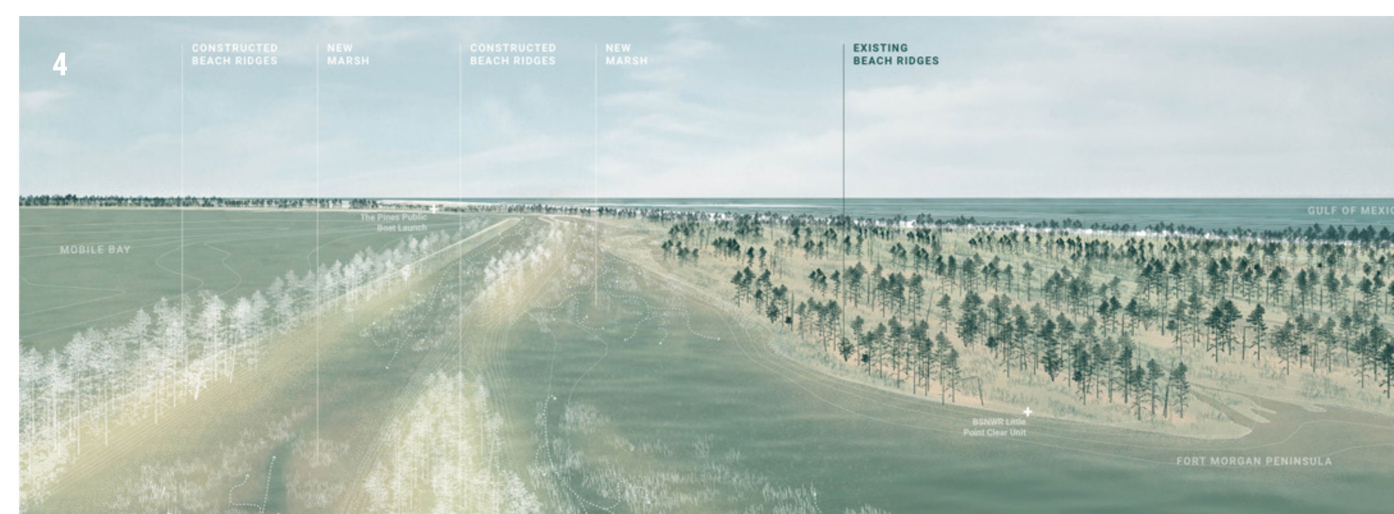


5 CONSTRUCTED BEACH RIDGES
DEVELOPMENT OVER TIME

These diagrams show the same process of construction as the previous pages, but from an aerial perspective above the northern end of the constructed ridges, facing southeast toward the Pines Boat Launch.

Successfully constructing such features will require not just careful design, modeling, and engineering, but also monitoring and adaptive management well into future decades. If a project is successful here, it would become a model for natural infrastructure design in many other locations, including other regions of the Gulf Coast, where natural beach ridge formations dominate but are also imperiled by sea level rise.





5 CONSTRUCTED BEACH RIDGES
AERIAL VIEW

Designing natural infrastructure that can be built efficiently using available construction methods and materials while also achieving aesthetic results that maintain the virtues of subtlety that characterize bay landscapes is a substantial challenge, but meeting this challenge is important because it can lead to making places that people will want to experience and conserve.

6 ERODIBLE BERMS
CONCEPT OVERVIEW

The second design concept that we have developed in detail for the Fort Morgan Peninsula and Bon Secour Bay is an erodible berm intended to facilitate marsh construction. Through an iterative design and modeling process, we have studied a range of potential arrangements and orientations for this feature along the southeast rim of Bon Secour Bay, just offshore from the Sand Bayou Unit of the Bon Secour National Wildlife Refuge. This site was selected because it is the largest stretch of contiguous tidal marsh shoreline in the study area and, owing to its public ownership and conservation-focused land use, there are no access infrastructures such as docks or boat launches that constructed marsh could interfere with the operations of.

While further design, modeling, and engineering, as well as collaboration with potential project partners and stakeholders including the USFWS and Baldwin County, would be necessary before implementation, we do believe that the design and modeling to date demonstrates the viability and applicability of this design concept.

6 ERODIBLE BERMS
BUILDING A NATURAL EDGE

The intention of this design concept is to facilitate marsh creation using dredged material without relying on features such as rock containment dikes that would be out of place both aesthetically and ecologically on the peninsula and in Bon Secour Bay.

The diagrams at right show how this concept would be constructed and behave. First, local sandy material from the shallow nearshore bay bottom would be dredged and placed to construct sand berms. Dredged fines would be pumped into the protected zone between these berms and the existing shoreline, filling the excavations and bringing the area behind the berms up to marsh elevation. Marsh species would be planted on the new marsh platform, and, as the marsh establishes, the sand berms would be notched at strategic locations to facilitate the formation of breaches during storm events that can develop over time into tidal channels, connecting bay, constructed marsh, and existing marsh beyond. Further into the future, the sand berms would continue to naturally degrade as they are reshaped by wind and waves, producing a thin and subtle sandy beach margin in front of the constructed marsh.

SEDIMENT TYPES

- 1 Sand
- 2 Sandy Clay
- 3 Clayey Sand
- 4 Clay
- 5 Silty Clay
- 6 Silty Sand
- 7 Silt
- Oyster reefs

00
EXISTING CONDITION

01
LOCAL DITCH AND DIKE CONSTRUCTION

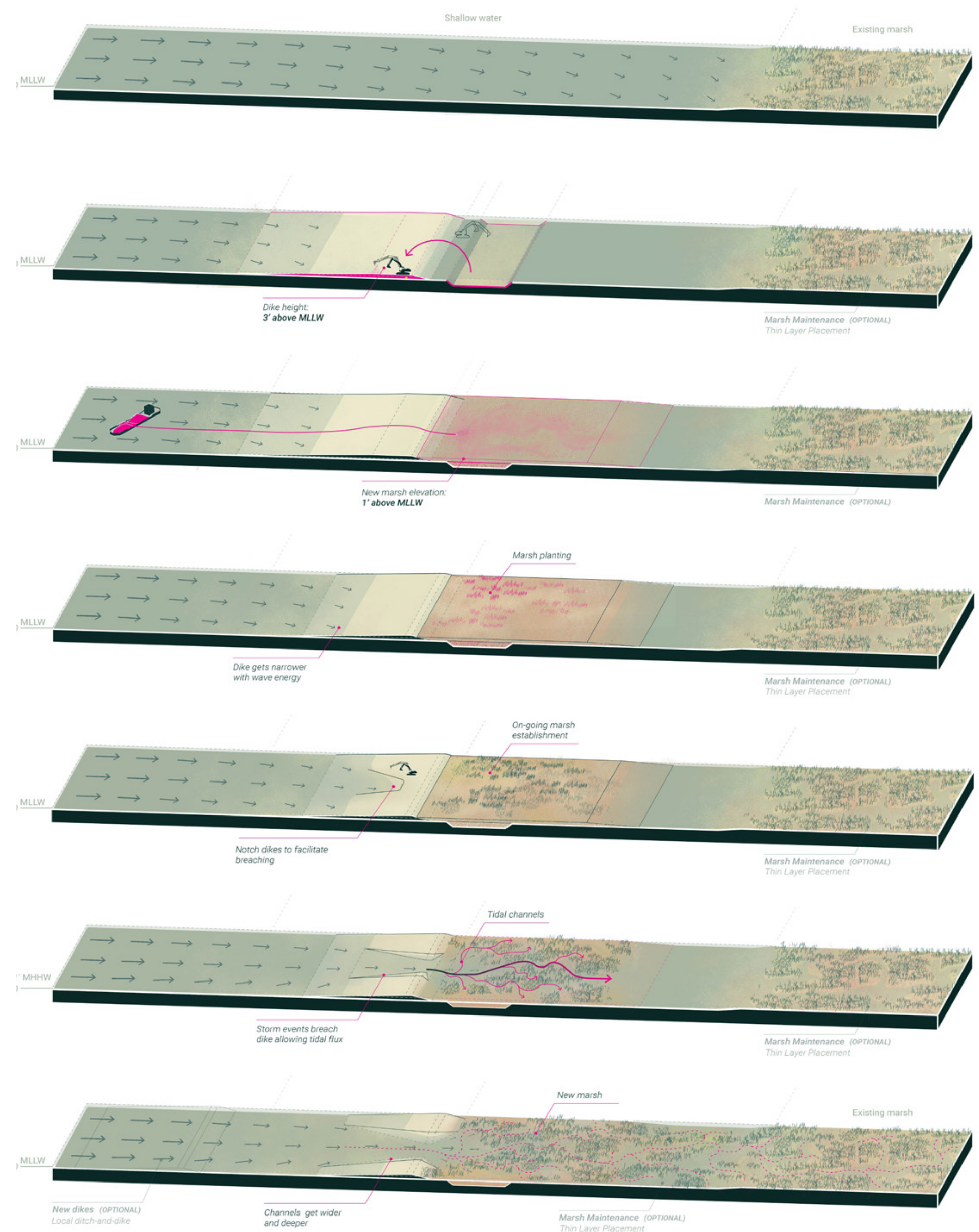
02
FINES PLACEMENT

03
MARSH PLANTING

04
DIKE NOTCHING

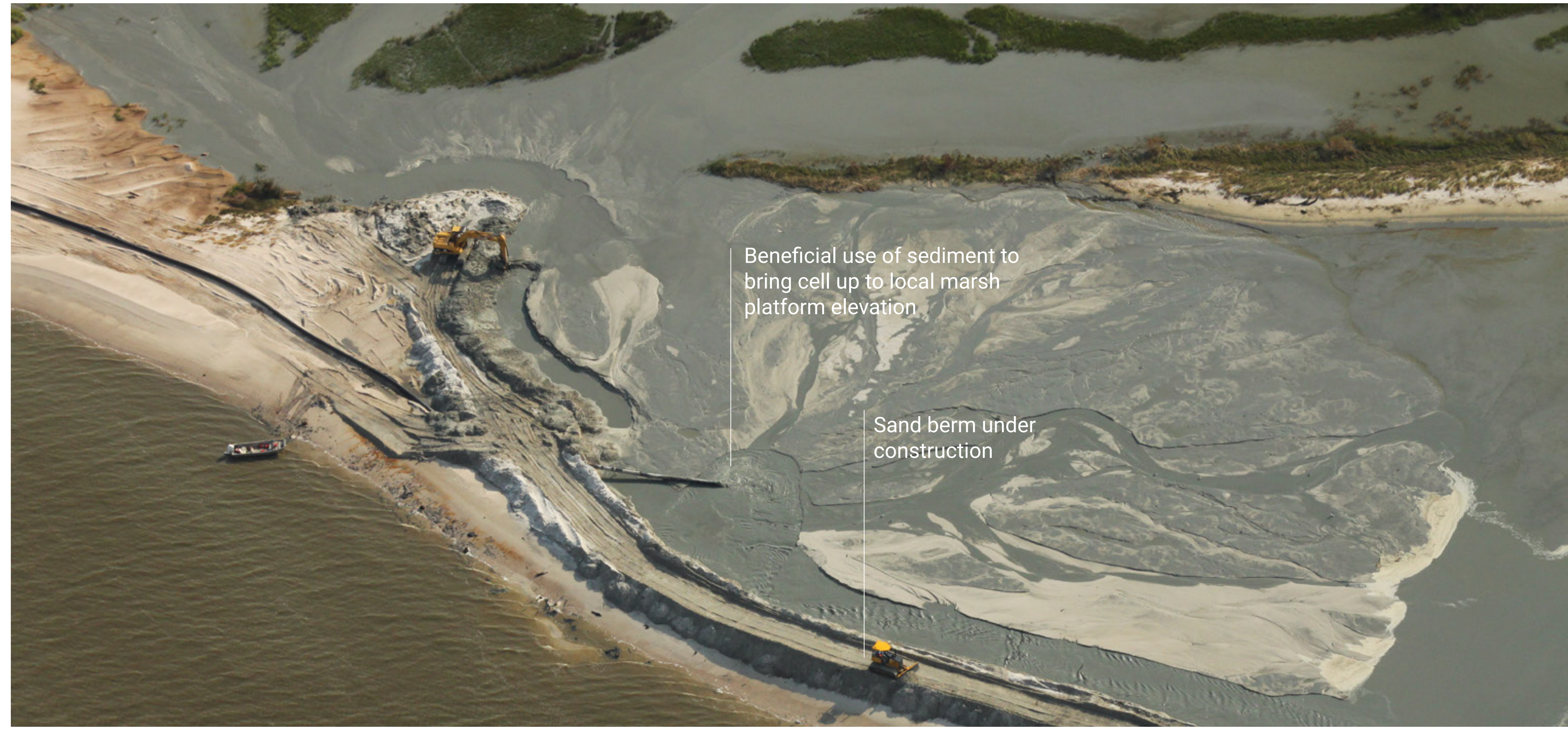
05
DIKE BREACHES AND MARSH GAINS TIDAL CHANNELS

06
DIKE KEEPS NATURALLY DEGRADING



6 ERODIBLE BERMS
PRECEDENTS

This process of berm construction and fines placement would be similar to the construction methods employed in a Mobile District project at Eastpoint, Florida. Engineered by Anchor QEA, this project is constructing a beneficial use site using local excavation of borrow areas within the interior of the beneficial use cell to obtain sand suitable for berm creation. This sand is being shaped into containment berms that are initially constructed with 60 to 80 foot widths, and then will be gradually re-shaped by wave action into roughly 10 foot wide crests. The cell behind these berms will be filled with dredged sediment to marsh elevation, and the re-shaped berm will remain as a thin sand beach along the Gulf edge of the cell (USACE 2021a).

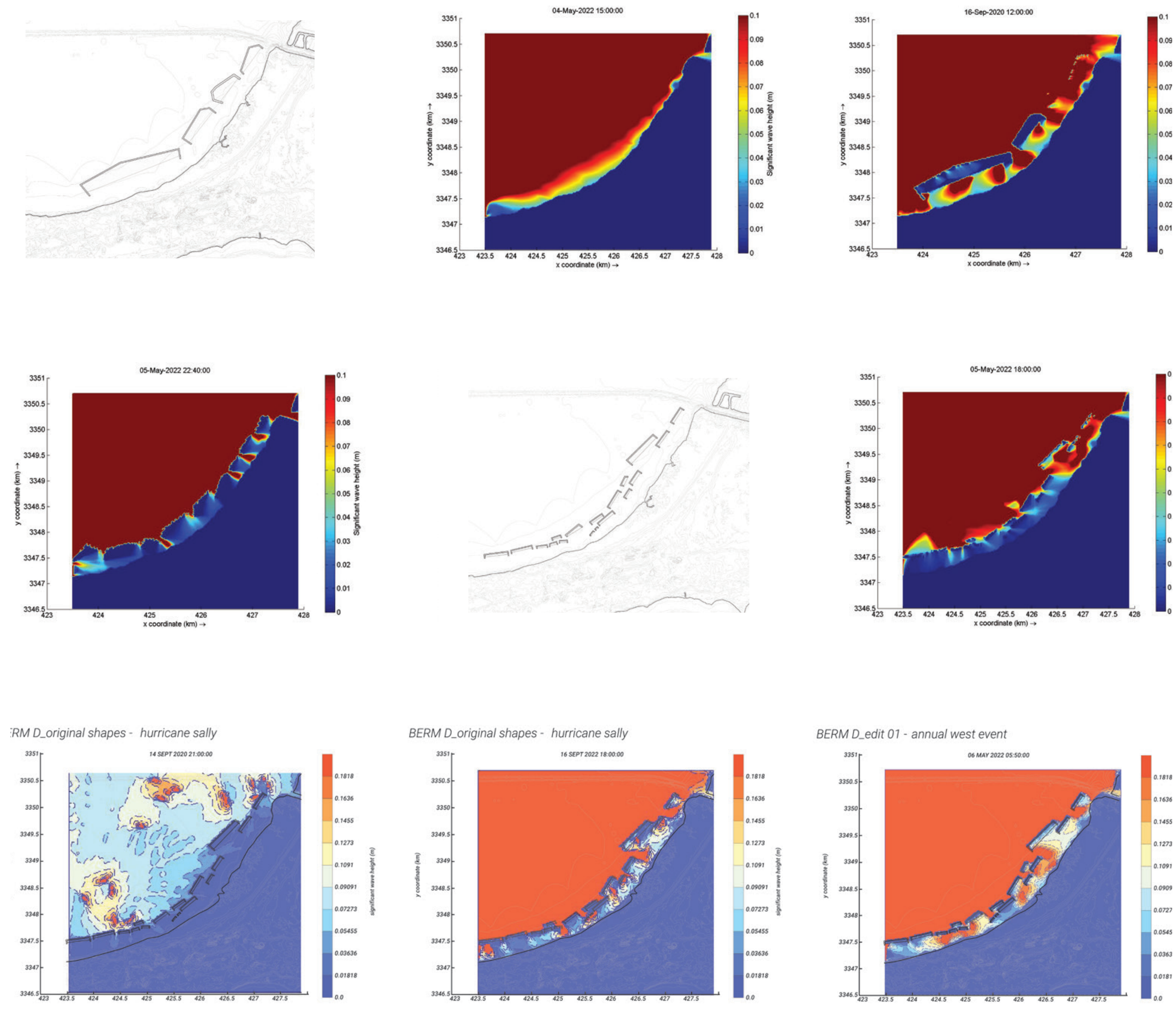


6 ERODIBLE BERMS
ITERATIVE REFINEMENT

Once the appropriate construction method described on the previous pages was selected, our design process focused on the iterative development of berm configurations and evaluation of those configurations through computational hydrodynamic modeling. This modeling was done both in a rough, quick fashion by the DRC research team at Auburn and with a higher degree of precision by Anchor QEA. This process allowed us to generate a large number of alternatives, select the most promising forms, and evaluating those most promising forms carefully. Drawings at right are illustrative of some of this process work. The second and most detailed round of modeling is described in more detail on the following pages and in Appendix 1.

AUBURN MODELING TEAM

Delft3D_Tests and Iterations



6 ERODIBLE BERMS
MODELING

After narrowing our initial testing to the configuration that performed the best in initial Anchor QEA modeling runs, we began to refine that design. The research team at Auburn used a process of relatively quick tests using simplified hydrodynamic modeling in Delft3D, utilizing forcing inputs provided by Anchor QEA from their Mobile Bay model, for the purpose of being able to make design refinements and to then pass those ideas on to Anchor QEA for more precise testing. These refined designs sought to address the issues of greater wave height and velocity occurring between the erodible berms, identified in Anchor QEA's initial modeling of the first design iterations. The images at the right depict results from Anchor QEA's second round of modeling: the existing conditions during annual events from multiple directions in Bon Secour Bay and those same conditions with two refined iterations of our berms placed in the bay.

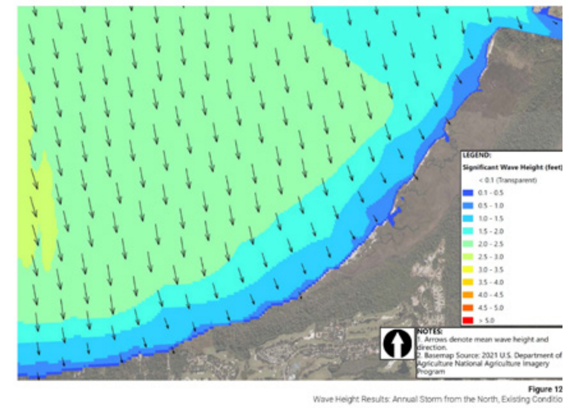
After analyzing the two results, the team selected Alternative 1 as the current preferred alternative, with two particular concerns being key in differentiating the alternatives:

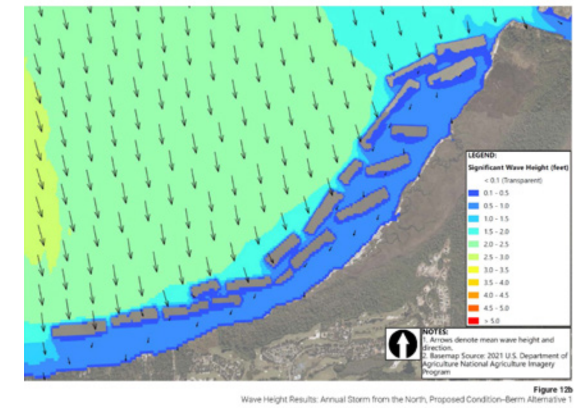
- Under annual storms from both the north and west, Alternative 1 brought wave height reductions closer to the existing shoreline than Alternative 2, likely better supporting marsh establishment behind the erodible berms and eventual integration of new constructed marshes with the existing shoreline.
- Bed shear stress behind the proposed berms and along the existing shoreline was notably higher with Alternative 2 under the annual storm from the north. Mobilization or resuspension of sediment in these areas would be undesirable.

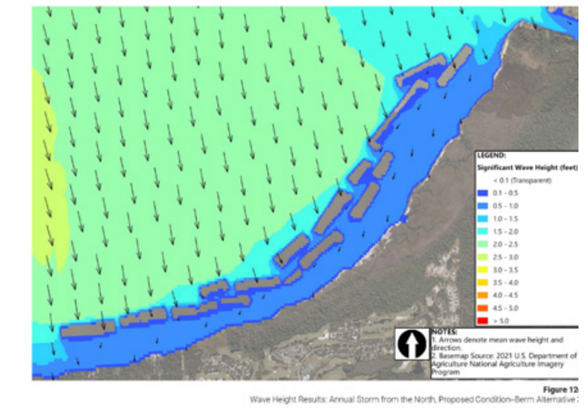
On the following pages, we discuss further refinement that will be necessary in order to develop an optimal berm configuration.

EXISTING CONDITION | **ALTERNATIVE 1** | **ALTERNATIVE 2**

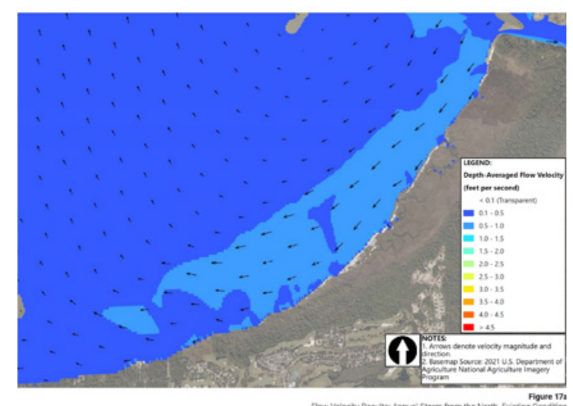
WAVE HEIGHT

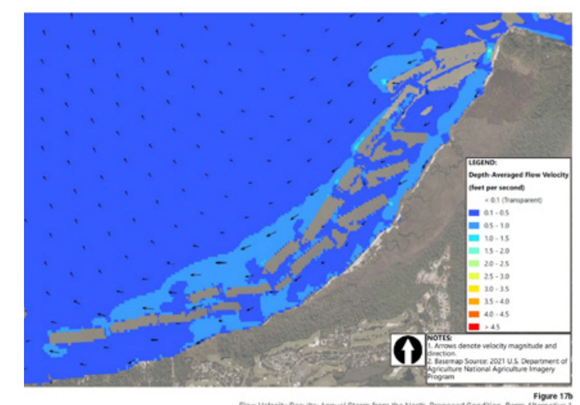


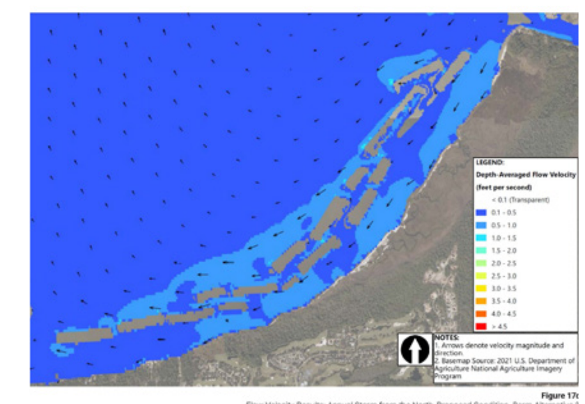




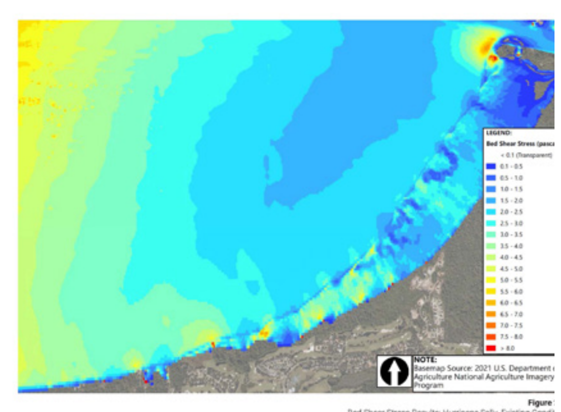
FLOW VELOCITY

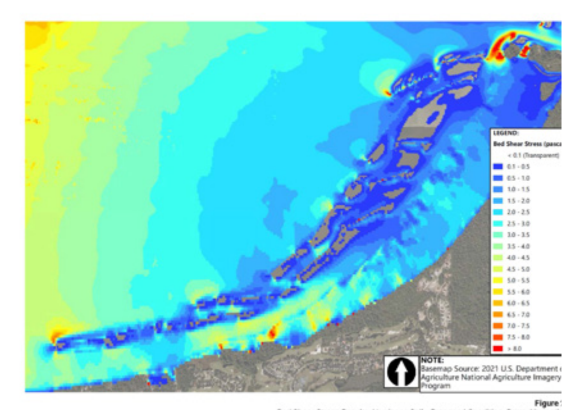


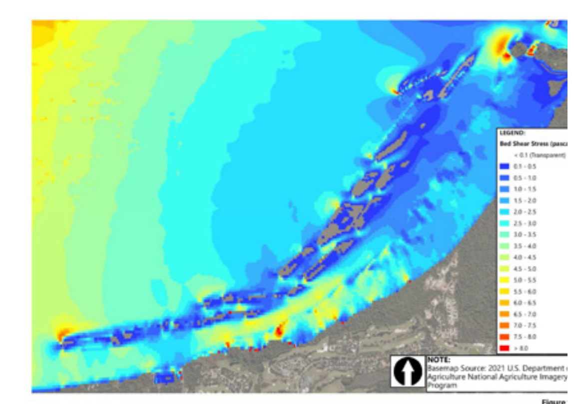




BED SHEAR STRESS







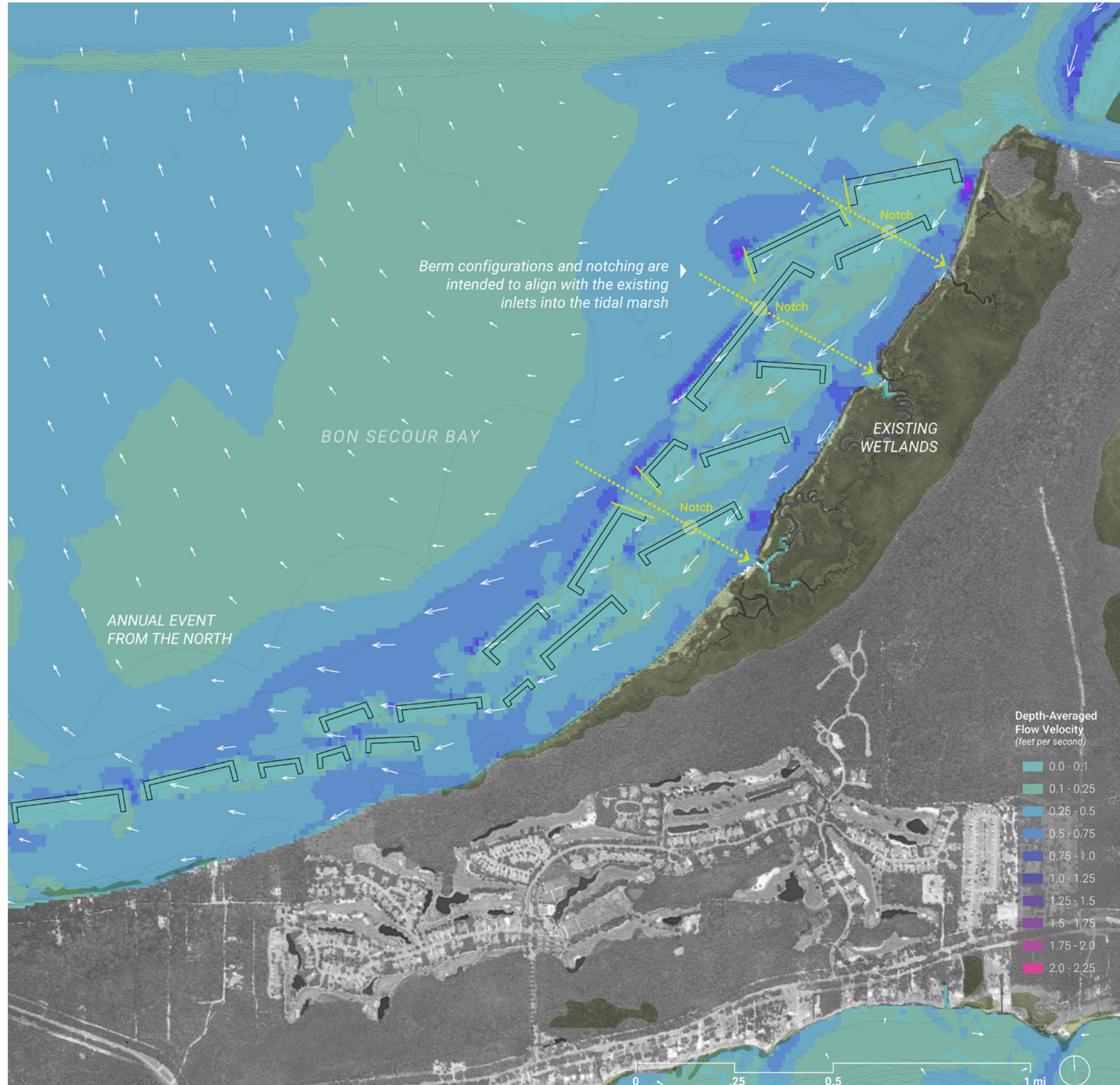
6 ERODIBLE BERMS
CURRENT ALTERNATIVE

The current preferred configuration, Alternative 1, is shown at right, overlaid with model results showing depth-averaged flow velocities under the annual storm from the north scenario.

The aims of the configuration include:

- Construct berms using excavation from local borrow areas and allow wind-driven waves to naturally reshape the berms into desirable landforms
- Beneficially use fines dredged from Mobile Bay navigation channels to establish marsh platform elevations behind the berms
- Produce a low energy environment behind the berms conducive to the establishment of native marsh vegetation
- Encourage the formation of tidal channels through newly constructed marsh through berm alignment and notching of berms in key locations corresponding to existing tidal channels
- Substantially reduce erosion of the existing marshes behind the new landforms, facilitating the capacity of the existing marshes to accrete and match pace with sea level rise
- Generate new high-quality tidal marsh, sand beach, and, to a lesser extent, upland habitat
- Design nature-based infrastructure that is in keeping with the key aesthetic qualities of existing natural landforms, such as the subtlety of the thin sand beach that lines the edge of much of Bon Secour Bay's tidal marshes
- Produce opportunities for water-based recreation such as kayaking and fishing
- Avoid creating negative impacts in the form of unintentionally increased flow velocities or bed shear stress in adjacent areas

Further refinement will be necessary to optimize berm design. For instance, Alternative 1 currently produces some higher flow velocities under annual storm scenarios where its berms draw particularly close to the existing shoreline. The configuration should be refined to balance these velocities with wave height reduction and bed shear stress minimization in areas where marsh establishment and sediment deposition are desirable. Study to date, though, suggests that the concept is viable and has the potential to be an innovative approach to sediment management and habitat restoration on the Gulf Coast.

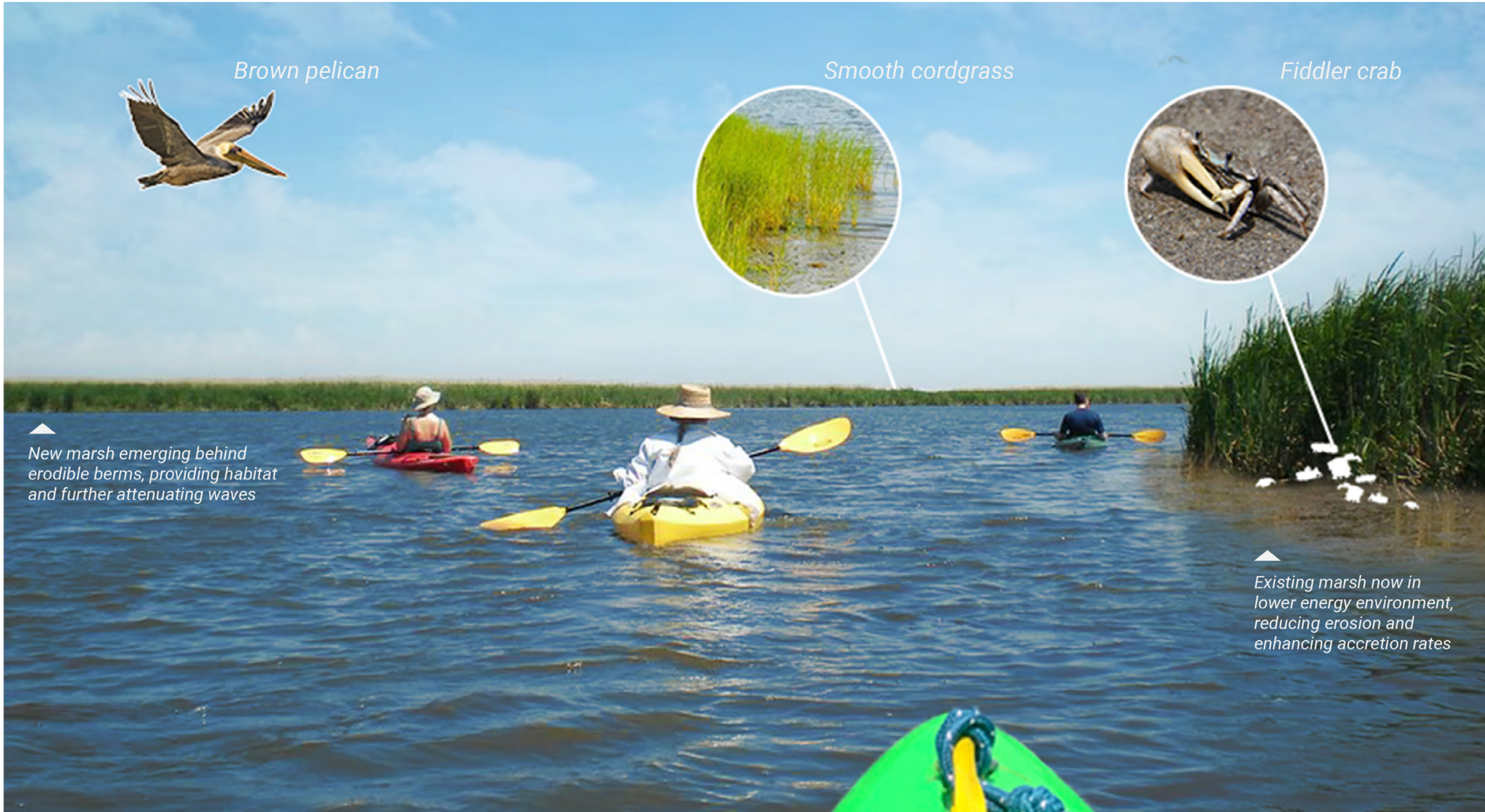


6 ERODIBLE BERMS
AERIAL VIEW

Over time, the intention of the erodible berm design is to allow the new nature-based infrastructure to be altered by natural processes in desirable ways, producing a landscape that increasingly is both functionally and aesthetically linked to the naturally-occurring marsh behind it. This bird's-eye rendering shows the erodible berms and constructed marshes as they might appear a couple of decades after initial construction, as wind, waves, sediment, and tides have reworked them and substantially effected new forms such as tidal channels and thin sand beaches.

6 ERODIBLE BERMS IN THE MARSHES

The calm, shallow waters behind the erodible berms and constructed marshes could become a venue for waterborne recreation like kayaking. Kayakers would have the opportunity to observe some of the many species that thrive in Gulf tidal marshes, like pelicans, crabs, and cordgrass.



PERDIDO BAY

CHOREOGRAPHING NATURAL INFRASTRUCTURE

STUDYING PERDIDO BAY RESILIENCE

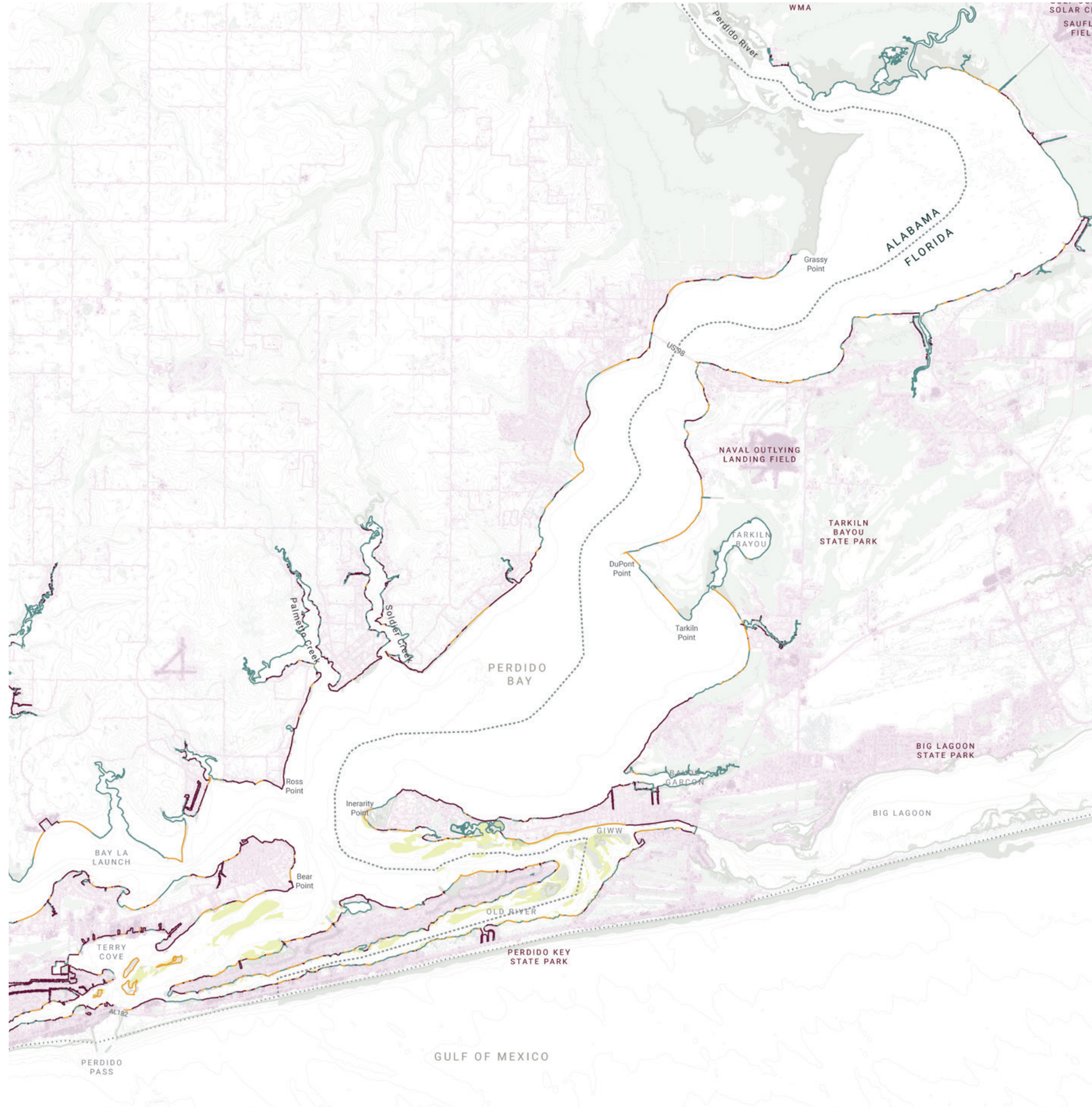
Perdido Bay is located on the southern border of Alabama and Florida. The bay is relatively small compared to some other Gulf Coast bays, covering some 50 square miles. However its watershed covers over 1200 square miles, mostly within Alabama. The bay is generally divided into three geographic areas: the upper bay is the fresh water inlet from the Perdido River, the middle bay generally understood to begin where Highway 98 crosses the bay, and the lower bay covers the remaining area of the bay, south of Innerarity Point.

The EWN® design concepts described in this section are situated largely in the lower bay. Recreation and tourism are the dominant economy in Perdido Bay as the city of Orange Beach, Gulf State Park, and islands within the bay attract over 6.5 million visitors every year concentrated primarily in Lower Perdido Bay. Lower Perdido Bay is connected to the Gulf of Mexico through Perdido Pass, an inlet that was built by and maintained by the USACE, and both the Gulf beach and the interior of the bay are heavily used by residents and visitors. The lower bay is characterized by the traffic of these boats and beachgoers, residences bolstered with hardened shorelines, large seagrass beds, and a series of small undeveloped islands, which include Rabbit Island to the far east and four more heavily trafficked islands closer to Perdido Pass, Walker, Robinson, Bird and Gilchrist Islands. These islands, along with the remaining undeveloped shoreline in the bay, are key ecological features providing important terrestrial and aquatic habitat for many species. Ecological restoration is thus one important concern addressed by the design concepts in this section.

Because of the intensity and density of development on its shores, the communities around Perdido Bay also face substantial coastal storm and flood risks. As documented later in this section, these risks were recently identified by mapping and analysis efforts during the South Atlantic Coastal Study, and SACS recommended that a feasibility study be conducted on coastal storm risk for Orange Beach and Gulf Shores, including the back bay area of Perdido Bay (USACE 2022). The relative smallness of Perdido Bay made it possible to look at the whole of the lower bay closely during our effort, so it was selected for this effort with the understanding that the approach and concepts documented here can be understood as prototypical of the approach and kinds of EWN® concepts that could be explored in conjunction with other feasibility studies along the Florida Gulf Coast.

1 PERDIDO BAY
SHORELINE CHARACTERISTICS

Much of Perdido Bay's shoreline, particularly in the lower bay, has been armored or hardened in some fashion, whether with bulkheads, revetments, or rip-rap. Those armored shorelines are shown in dark magenta in the map at right. Despite the extent of this armoring, there are also long stretches of natural shoreline, both wide sand beaches (shown in orange) and marsh or other vegetation (shown in a light green). The latter vegetated category is most common in the middle and upper bays, as well in the adjacent Bay La Launch and Wolf Bay.



SHORELINE
- Armored Shoreline (Bulkheads, Revetment, Rip Rap)
- Wide Beach Shoreline (>10ft at high tide line)
- Vegetated Shoreline (no apparent built infrastructure)

WETLANDS
- Estuarine and Marine Wetlands
- Freshwater Wetlands
- 2020 Seagrass cover

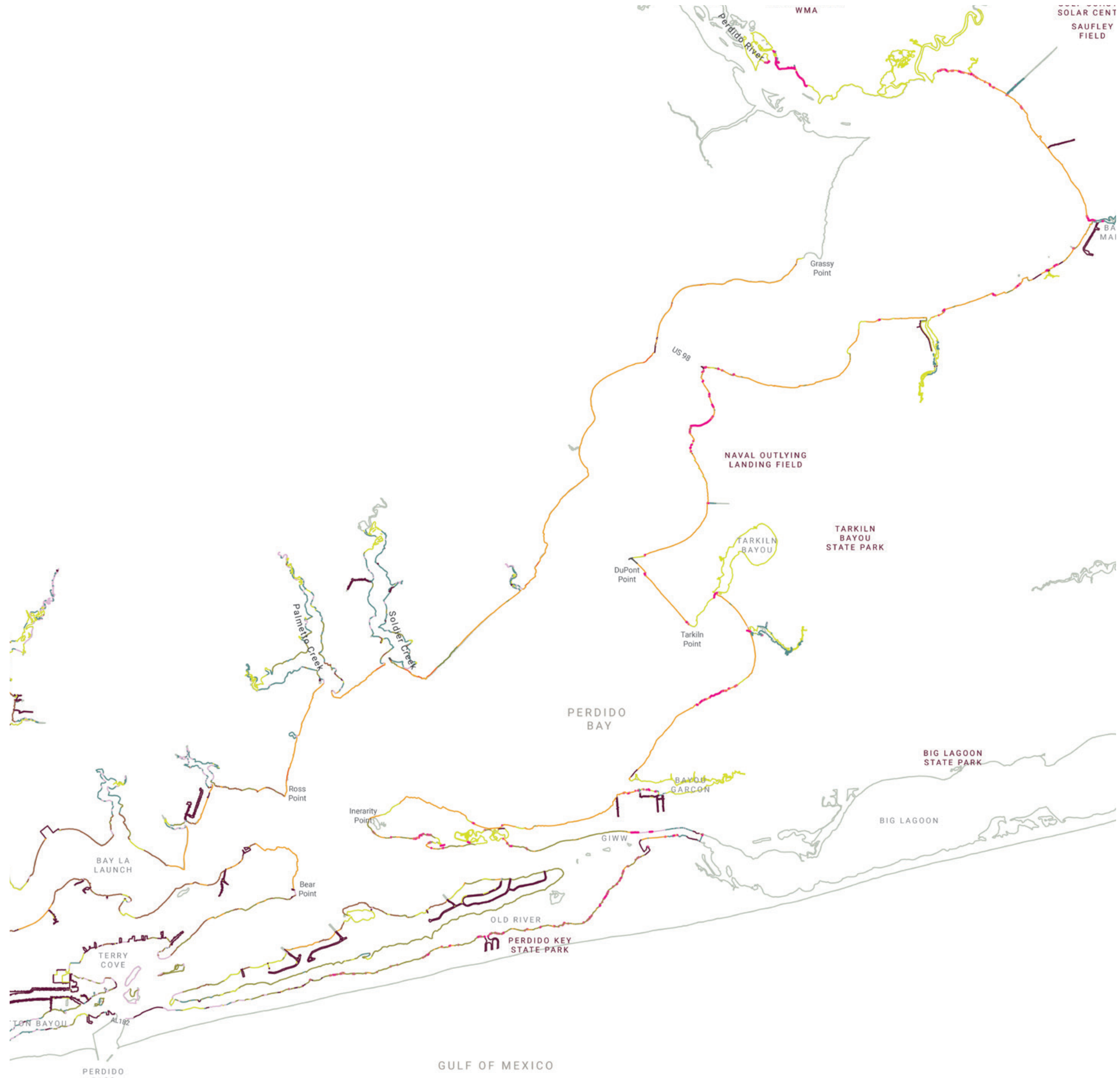
LAND USE
- Developed
- Agriculture

1 PERDIDO BAY
NOAA SHORELINE SUITABILITY STUDY

The prevalence of armored shorelines in the lower bay promotes habitat loss (as natural shorelines are replaced by armored), reduces storm risk resilience in the long term (as armored shorelines are not capable of accreting to gain elevation or adapting in the ways that natural shorelines or nature-based infrastructure can), and likely contributes to shoreline erosion in adjacent areas. Shoreline suitability studies have been conducted within Perdido Bay to identify locations where nature-based approaches such as constructing marshes with sills could be implemented (Tidwell et al 2020; Boyd et al 2022). In highly modified areas, such as most of the lower bay, it recommends seeking expert advice about what measures might be appropriate. The design concepts in this section aim to identify measures that could be appropriate for the lower bay, including many of these areas of difficulty.

RECOMMENDED ACTION

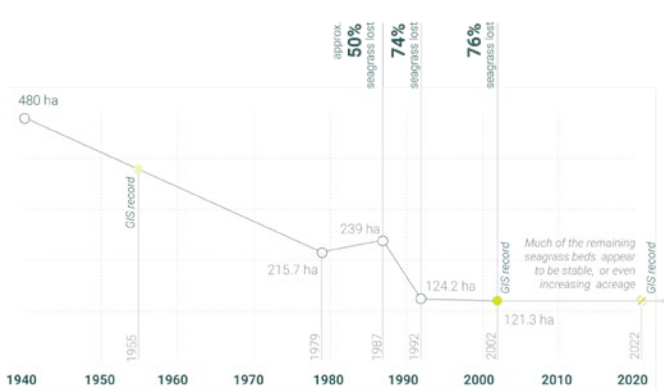
- Existing Marsh Sill
- Revetment
- Groin Field with Beach Nourishment
- Maintain Beach or Offshore Breakwater with Beach Nourishment
- Plant Marsh with Sill
- Non-Structural Living Shoreline
- No Action Needed
- Special Geomorphic Feature. Seek expert advice.
- Ecological Confilicts. Seek regulatory advice.
- Highly Modified Area. Seek expert advice.



2 PERDIDO BAY
SEAGRASS HABITAT

Perdido Bay is broad and very shallow, and much of the bay has long been excellent seagrass habitat, which in turn has made it rich nursery habitat for many of the Gulf's species, including juvenile fish, crabs, and shrimp.

During the 20th century, though, there was a stark decline in the extent of seagrass beds within the bay. Between 1940, when 480 hectares of beds were surveyed in the bay, and 2002, when only 121.3 hectares remained, three-quarters of the bay's total acreage was lost. The largest contributor to this decline was reduction in water quality, which steadily fell over the course of the 20th century, owing to a broad range of land uses and activities in the bay's watershed, including effluent inflow from wastewater systems and nearby paper mills, runoff from agricultural and silvicultural land, and residential and resort development (Kirschenfeld et al 2006; PPBEP 2022).



POINT SOURCE POLLUTANTS

- ✚ Storm Water Industrial
- ● Other point source pollutant types

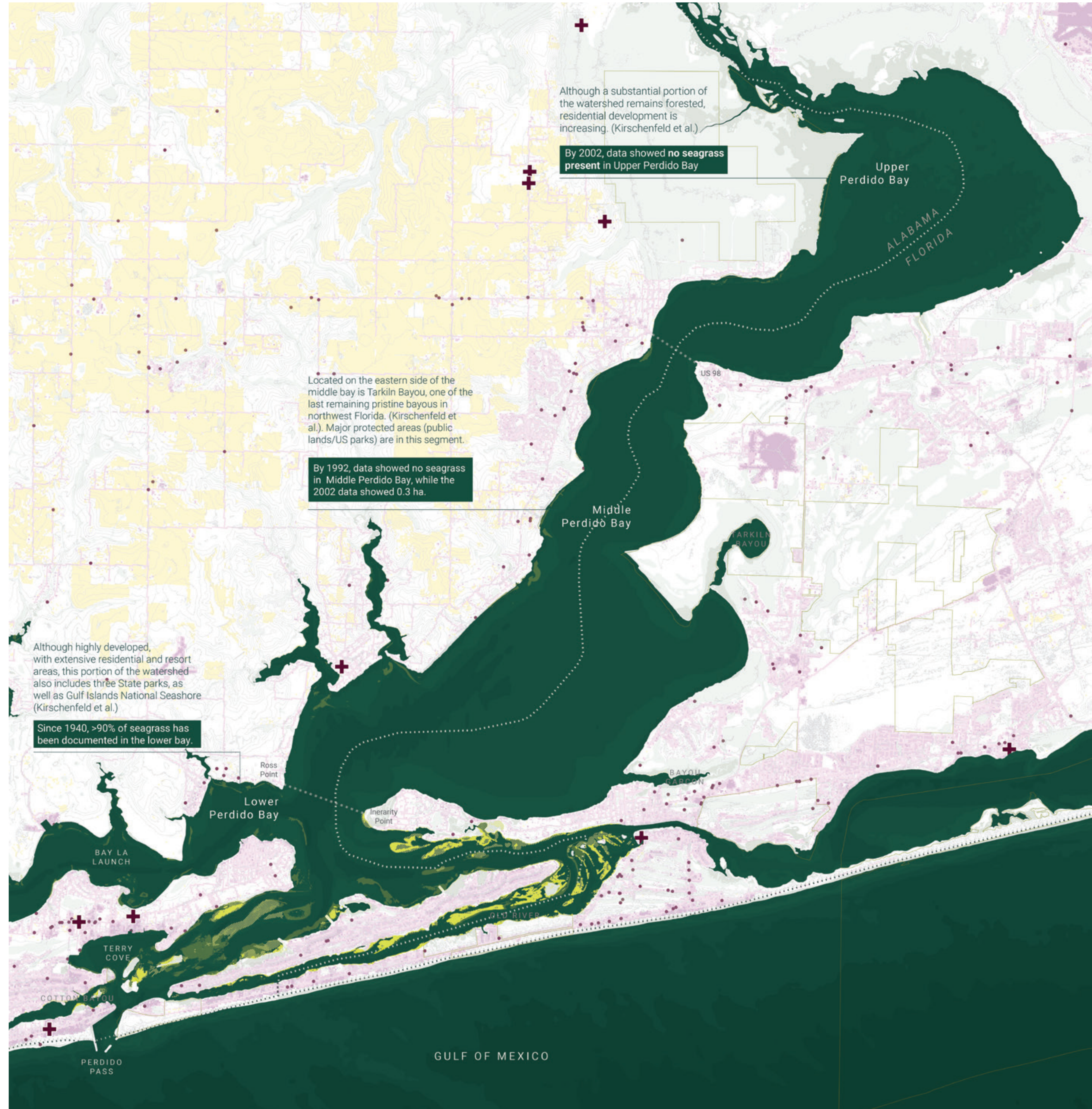
ICIS-NPDES Non-Major (1454)
Storm Water Construction (1074)
ICIS-NPDES Unpermitted (72)
POTW (11)
Biosolids (9)
ICIS-NPDES Major (9)
NPDES Pretreatment Program (9)
Concentrated Animal Feeding Operation (1)
NPDES Permitted (1)

NONPOINT SOURCE POLLUTANTS

- Development land runoff
- Agriculture land runoff

SEAGRASS RECORDS

- 1955 Seagrass coverage (AL)
- 2002 Seagrass coverage
- 2020 Seagrass coverage



2 PERDIDO BAY
SEAGRASS HABITAT

By the 1990s, declining water quality was a substantial issue for the communities surrounding Perdido Bay, and significant efforts were made to reduce both point source and nonpoint source pollution, the sources of which are documented in the map at right. In 2013, for instance, a treatment wetland was constructed for the International Paper mill, which had long been the single biggest point source, as it had previously discharged its effluent directly into Elevenmile Creek, which runs into Upper Perdido Bay near the mouth of the Perdido River.

POLLUTION SOURCES

Point Source Pollutants

National Pollutant Discharge Elimination System (NPDES)

Interest Type

- ✚ Storm Water Industrial
- • Other point source pollutant types in the watershed

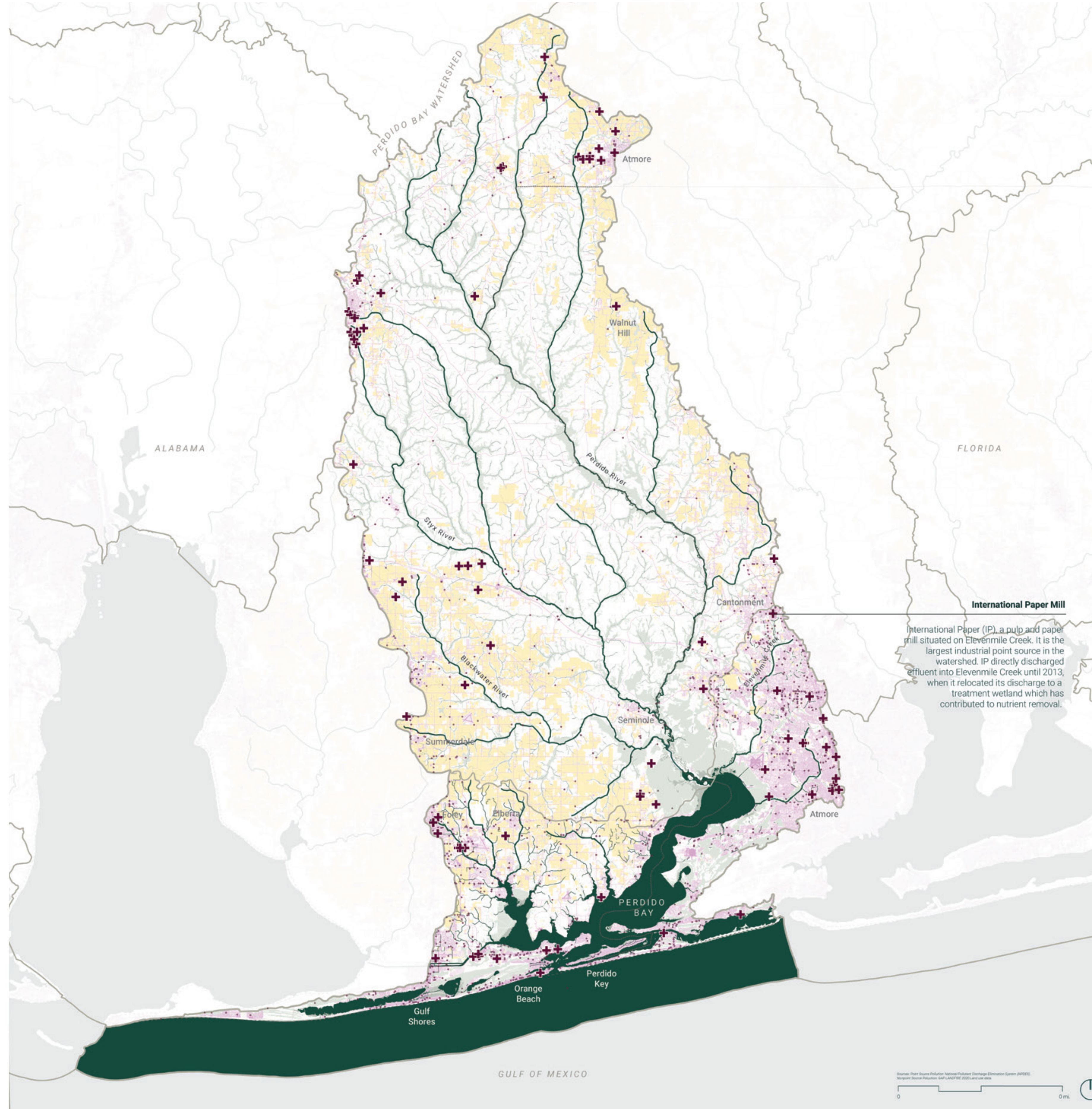
ICIS-NPDES Non-Major (1454)
Storm Water Construction (1074)
ICIS-NPDES Unpermitted (72)
POTW (11)
Biosolids (9)
ICIS-NPDES Major (9)
NPDES Pretreatment Program (9)
Concentrated Animal Feeding Operation (1)
NPDES Permitted (1)

Nonpoint Source Pollutants

- Agriculture land runoff
- Developed land runoff

WATER BODIES

- Deep Water
- Estuarine and Marine Wetlands
- Freshwater Wetlands
- US Rivers
- Watersheds (HUC8)



2 PERDIDO BAY
SEAGRASS HABITAT

Water quality improvements and other restoration efforts, such as those led by the researchers at the Dauphin Island Sea Lab (Washington 2020), have bolstered Lower Perdido Bay's seagrass beds, which have generally stabilized or even, in places, begun to spread in the first decades of the 21st century. This positive trajectory suggests that water quality has improved to the point that further seagrass restoration efforts also have a high probability of success, and that seagrass beds can be considered as viable components of a nature-based infrastructure strategy for Perdido Bay.

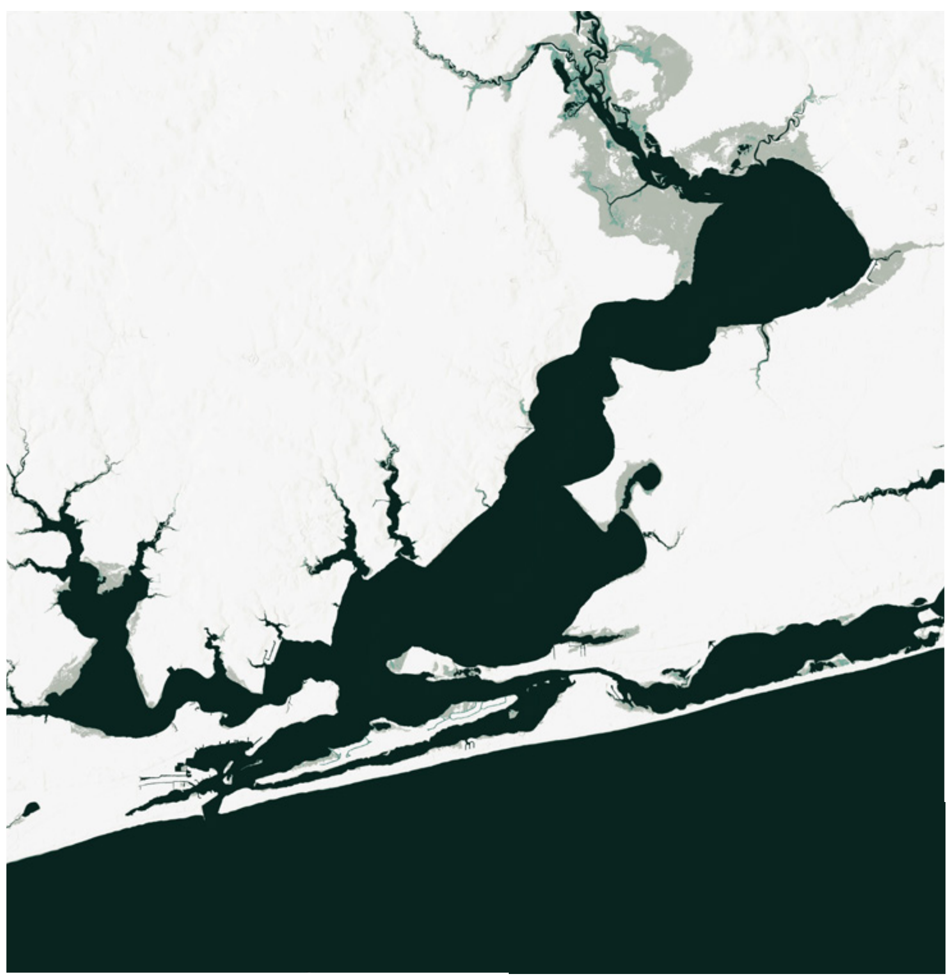
2 PERDIDO BAY
OYSTER HABITAT

Another major subtidal habitat in the back bays of the northern Gulf Coast, like Perdido Bay, is oyster reefs. Perdido Bay is not currently designated as an Approved Shellfish Harvesting Area by the FDA's National Shellfish Sanitation Program, but both the Florida Marine Research Institute and the Alabama Marine Resources Division have done suitability analyses for Perdido Bay, focusing on salinity conditions, which, according to both analyses, are generally appropriate for oysters in much of Lower Perdido Bay as well as parts of Bay La Launch and Arnica Bay. (Oysters also have optimum ranges in terms of temperature and oxygen levels, neither of which are shown in the map below.) While further study and field testing will be required to establish the viability of various stretches of Perdido Bay for oyster reefs and, ideally, suitability of Perdido Bay oysters for human consumption, there is solid evidence, including these analyses and the evidence of frequent oyster growth on various structures in the bay, to indicate that oyster reefs are also likely a viable component of a nature-based infrastructure strategy for Perdido Bay.

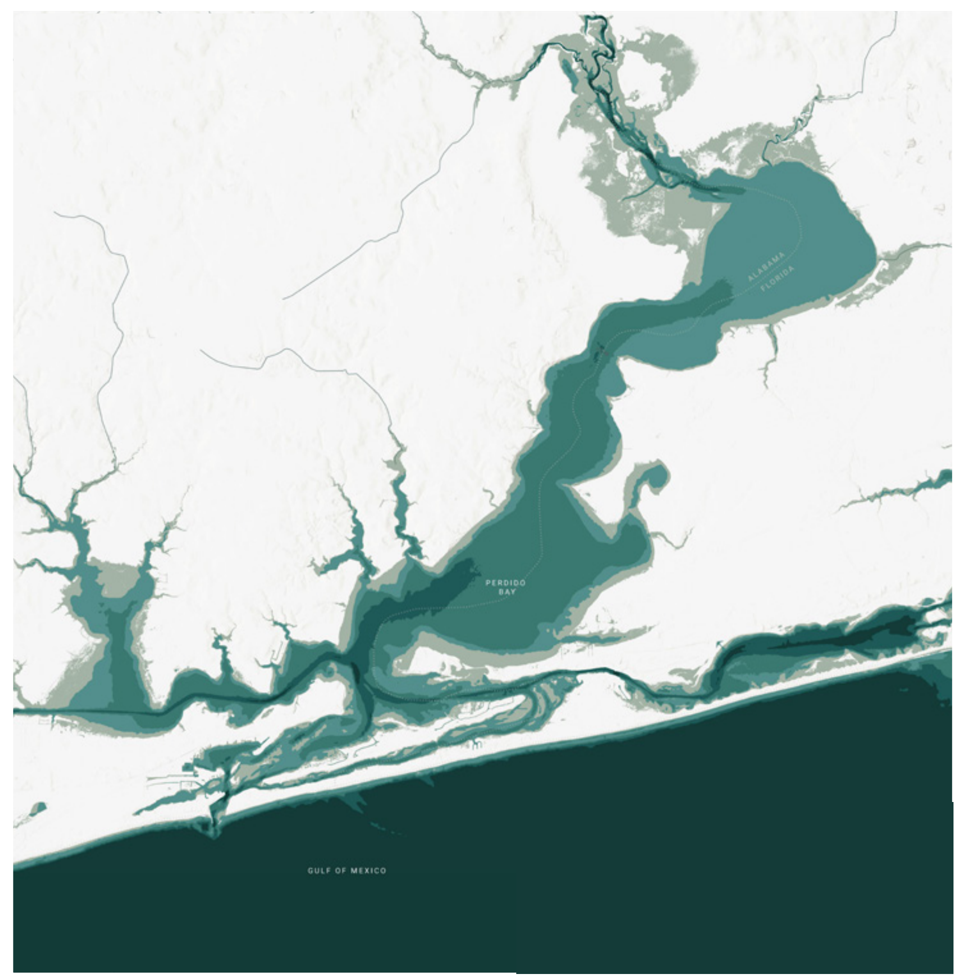
3 PERDIDO BAY
SLR AND HABITAT MIGRATION

Developing appropriate nature-based infrastructure strategies for Perdido Bay requires not only considering the present distribution of subtidal, tidal, and upland habitats, but also understanding how those habitats are likely to shift over coming decades in response to changing environmental conditions like sea level rise. To begin to do this, we combined the three data layers shown below: sea level rise projections by NOAA, direct adjustments of depths in bathymetric data in ArcMap to align with those sea level rise projections, and habitat migration data from NOAA. Layered together, these three data sets produce maps that track habitat migration both above and below the waterline, as shown on the next following pages.

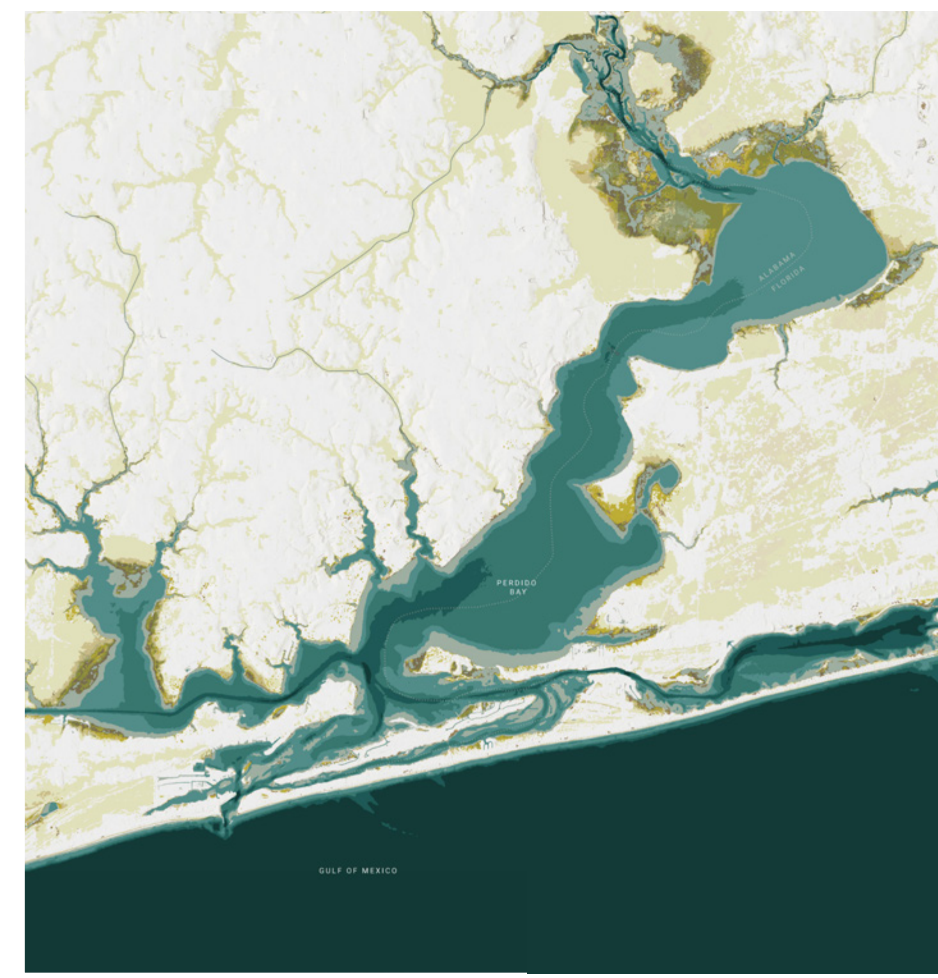
SEA LEVEL RISE
2FT SCENARIO



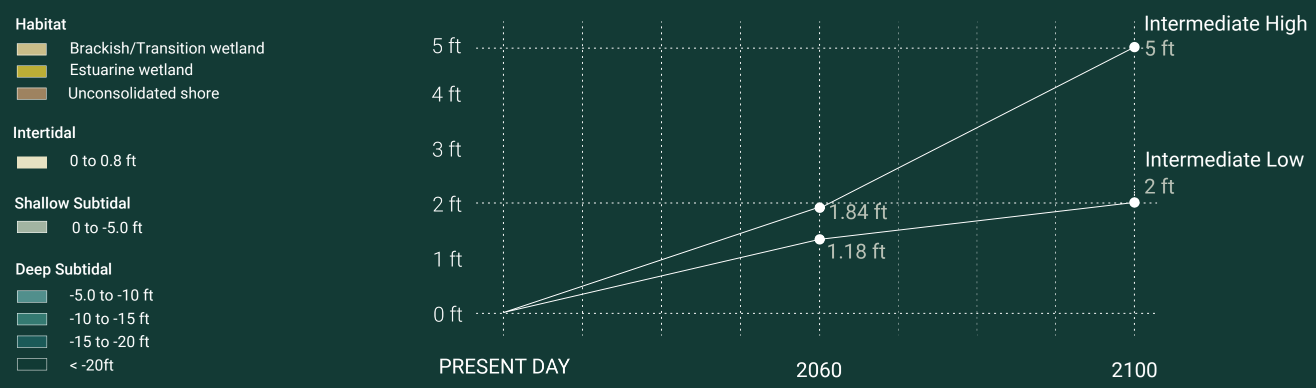
BATHYMETRY
2 FT SCENARIO



HABITAT MIGRATION
2 FT SCENARIO



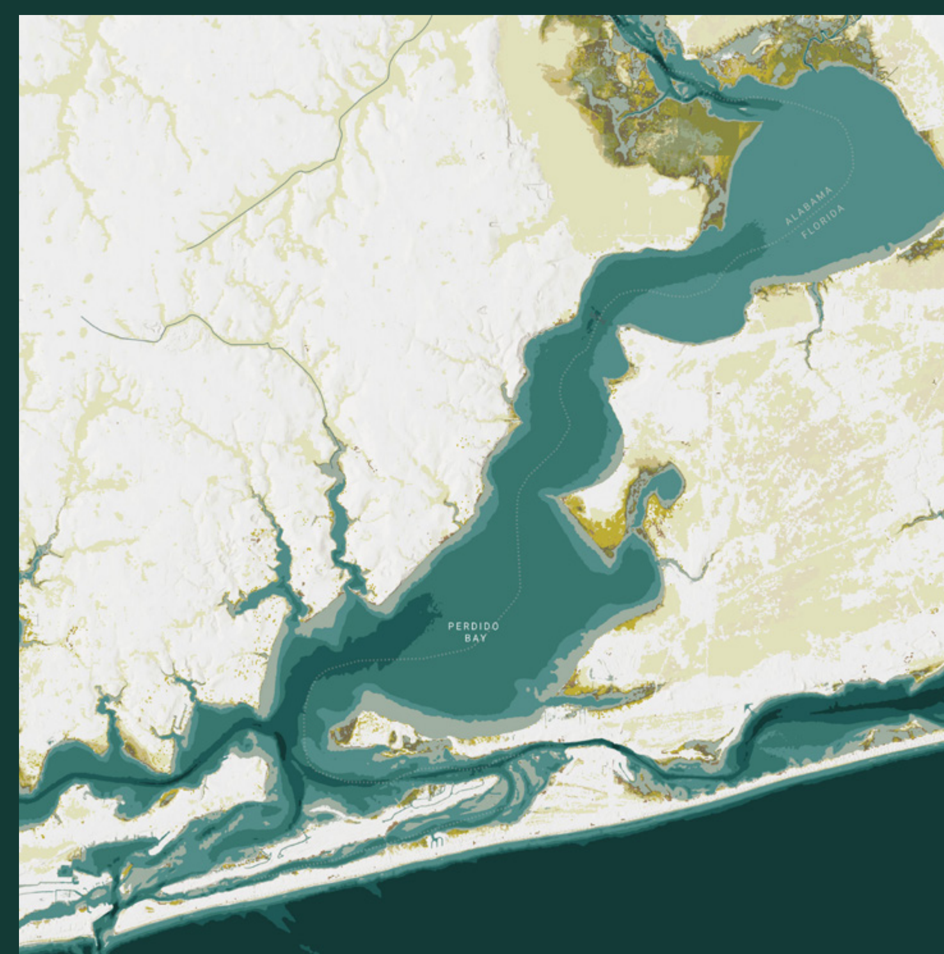
3 PERDIDO BAY
SLR AND HABITAT MIGRATION



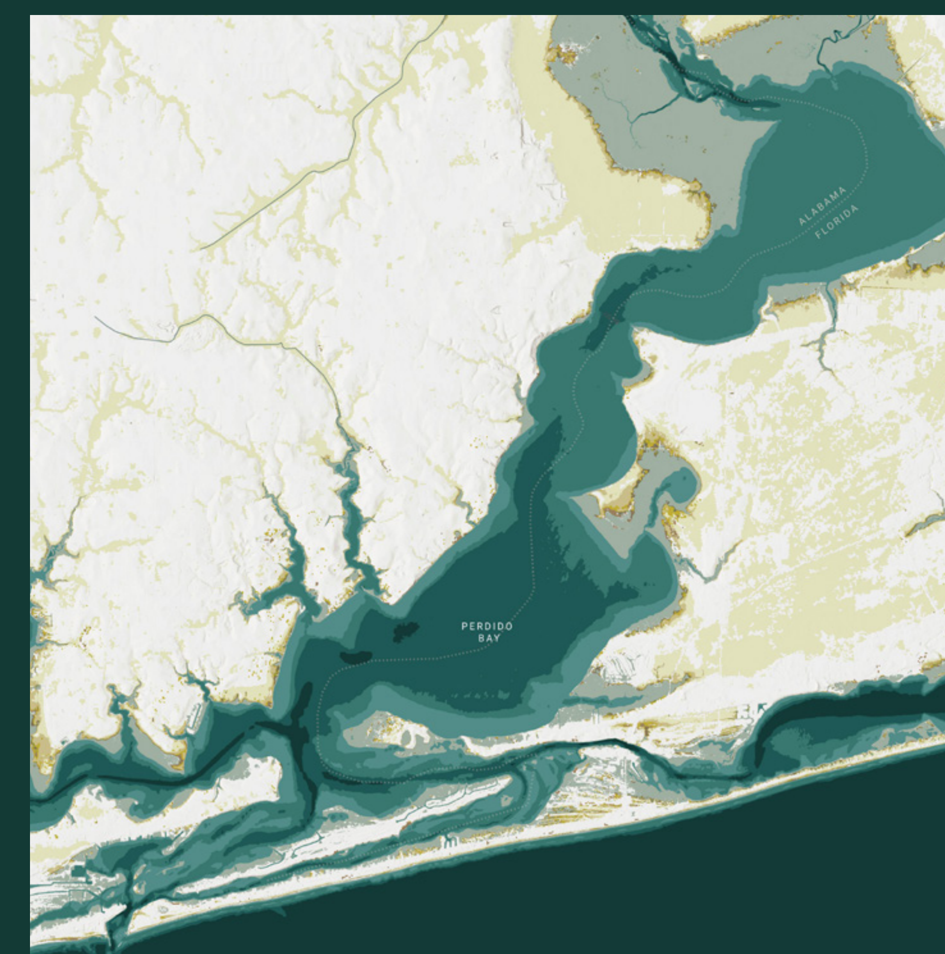
The maps here show projected habitat transformation for both aquatic and upland habitats under 2' and 5' of sea level rise. Roughly 2' of rise is projected for 2100 under NOAA's intermediate low scenario or for 2060 under their intermediate high scenario, while 5' is projected for 2100 in that intermediate high scenario. While these projections represent transformations without adaptive interventions of the kinds proposed later in this section, they are clearly illustrative of the speed and magnitude of environmental change that the region is facing. For instance, the bay bottom along the Alabama-Florida state line east of Rabbit Island is currently largely at a shallow subtidal depth which is appropriate for (and hosts) large seagrass beds. With 5' of sea level rise, that area will almost entirely become too deep for seagrasses, unless accretion in the area is able to counterbalance sea level rise.

PRESENT DAY

+2 FT SLR



+5 FT SLR

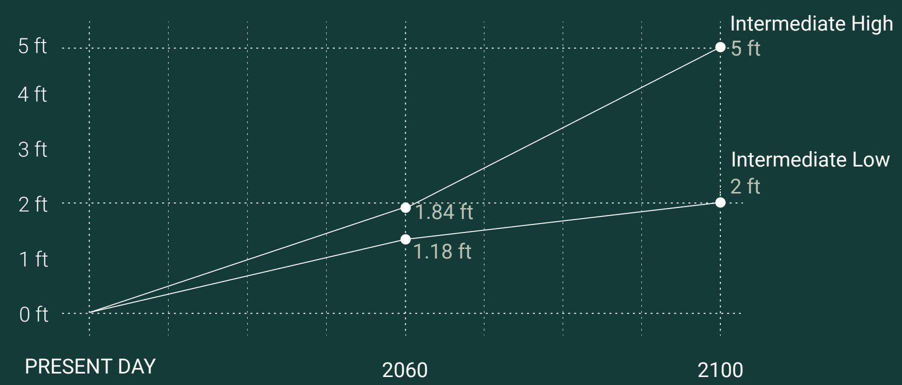


3 PERDIDO BAY
SLR AND SEAGRASS

Intertidal
- 0 to 0.8 ft

Shallow Subtidal
- 0 to -5.0 ft

Deep Subtidal
- -5.0 to -10 ft
- -10 to -15 ft
- -15 to -20 ft
- < -20ft

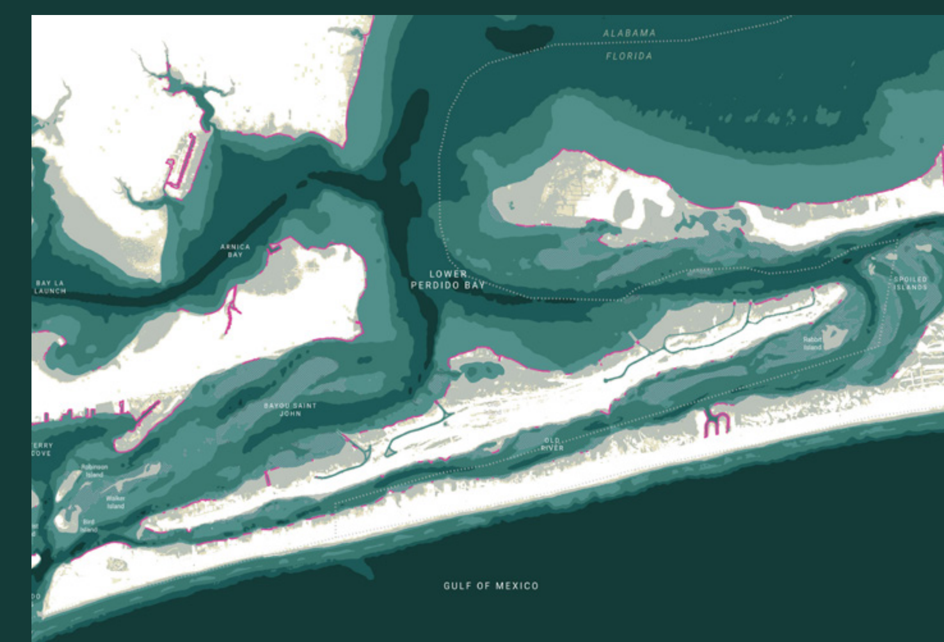


The maps below zoom into lower Perdido Bay and focus on tidal and subtidal habitat migration. The present-day extent of seagrass beds is overlaid on the habitat mapping to highlight areas where seagrass can be expected to be lost under these SLR scenarios, barring some form of intervention. Armored shorelines are also highlighted, noting that those shorelines may inhibit desirable habitat migration such as the adaptation of tidal marshes to SLR.

PRESENT DAY

+2 FT SLR

+5 FT SLR



2020 Seagrass extent

Armored Shoreline

Shoreline defenes may inhibit the shoreward migration of seagrass beds

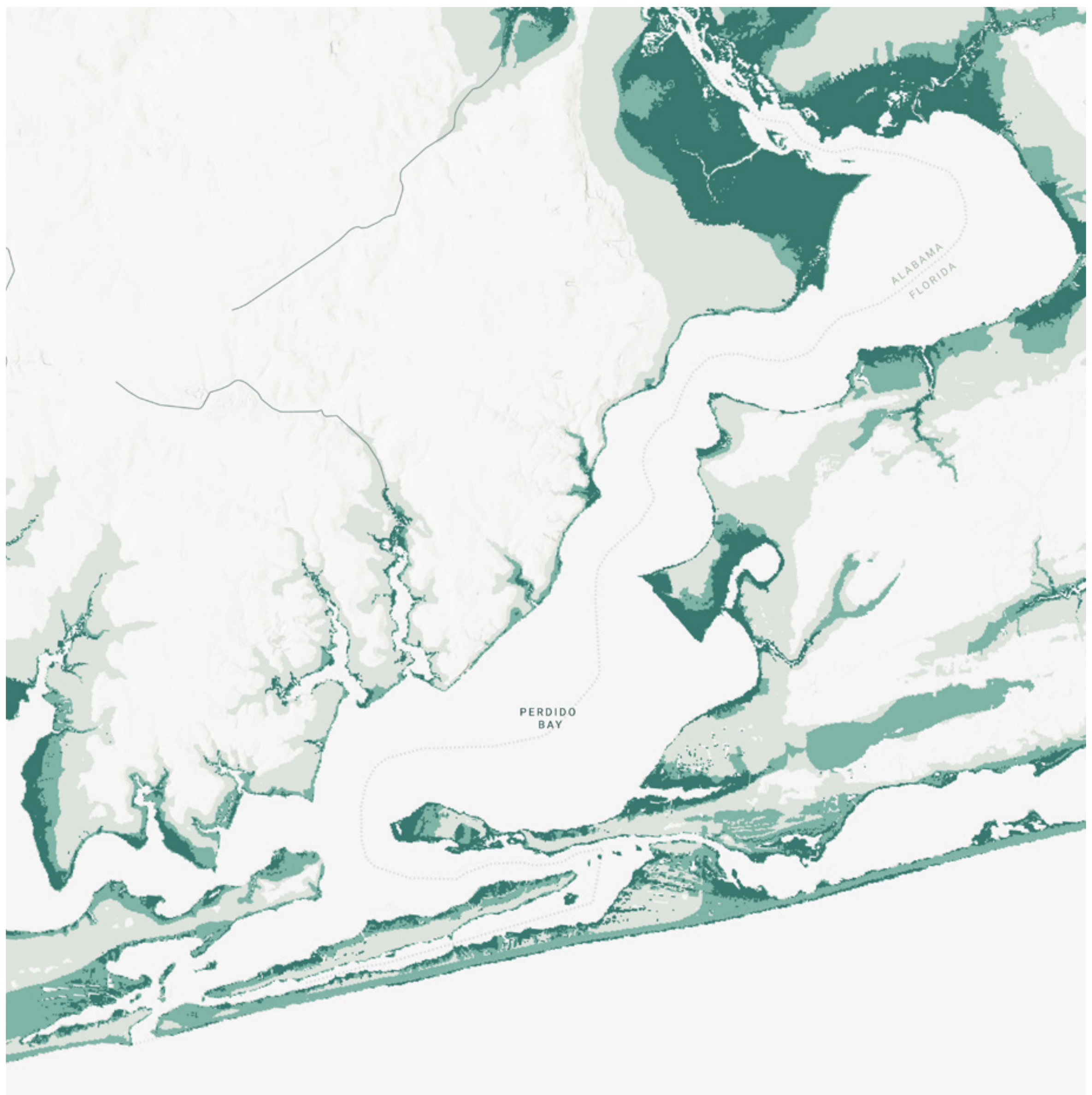
4 PERDIDO BAY
COASTAL STORM RISK AND SLR

Perdido Bay also faces substantial storm risk, which will likely be intensified by sea level rise. In the South Atlantic Coastal Study, three inundations were used as proxies for storm risk: a 10-year flood event (10% annual exceedance probability flood), a 100-year flood event (1% annual exceedance probability flood), and storm surge from a Category 5 hurricane. As shown on the maps below, even in the present day, almost all of the land around Lower Perdido Bay would be inundated under such a hurricane, and much of the area, including much of its developed land, is vulnerable to the lesser flood events. These risks expand and intensify under the 3-foot SLR scenario used in SACS.

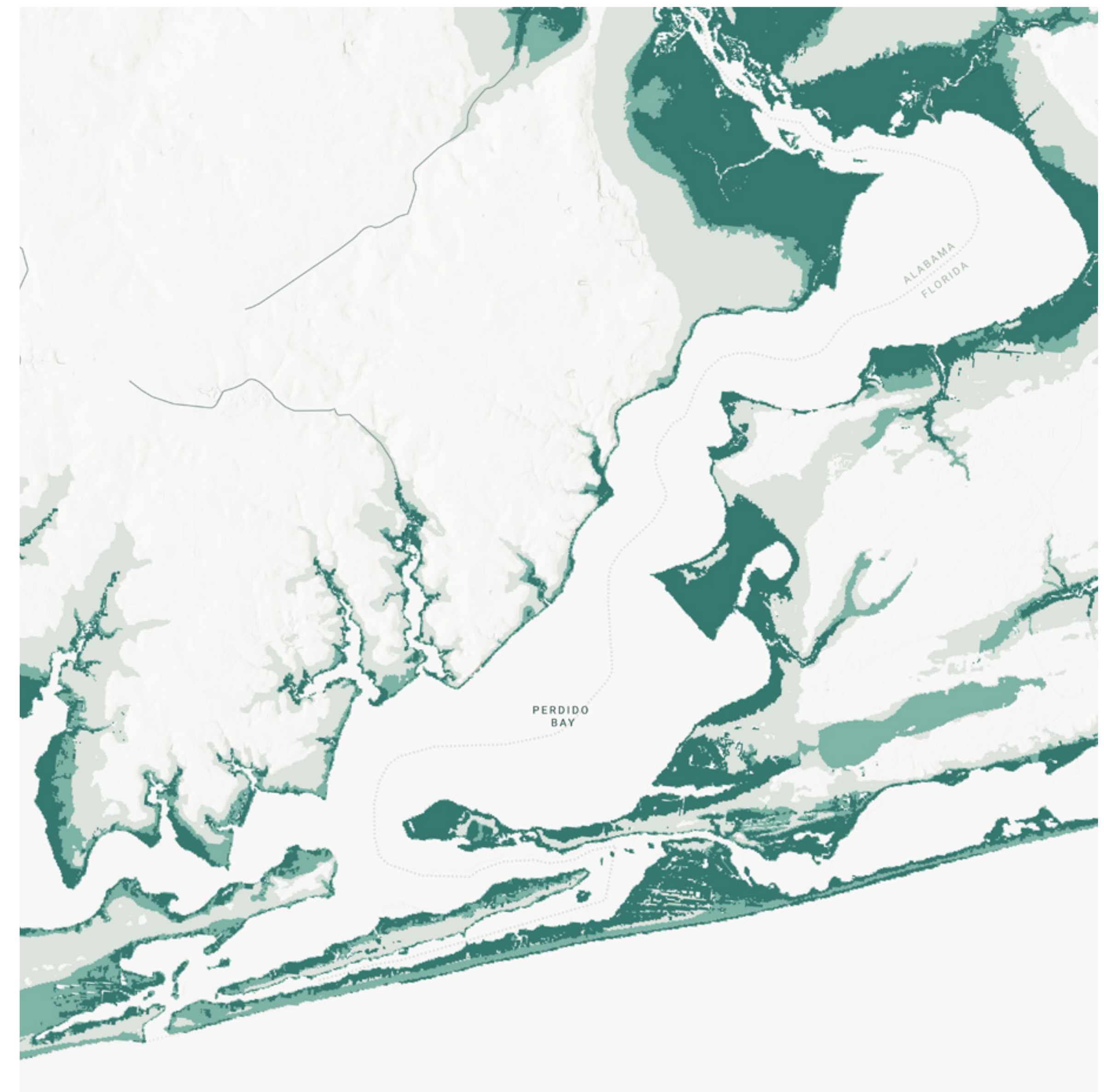
COMBINED HAZARD

- Category 5 MOM Storm Surge Inundation
- 1 % Annual Exceedance Probability Flood
- 10 % Annual Exceedance Probability Flood

PRESENT DAY



+3FT SLR SCENARIO



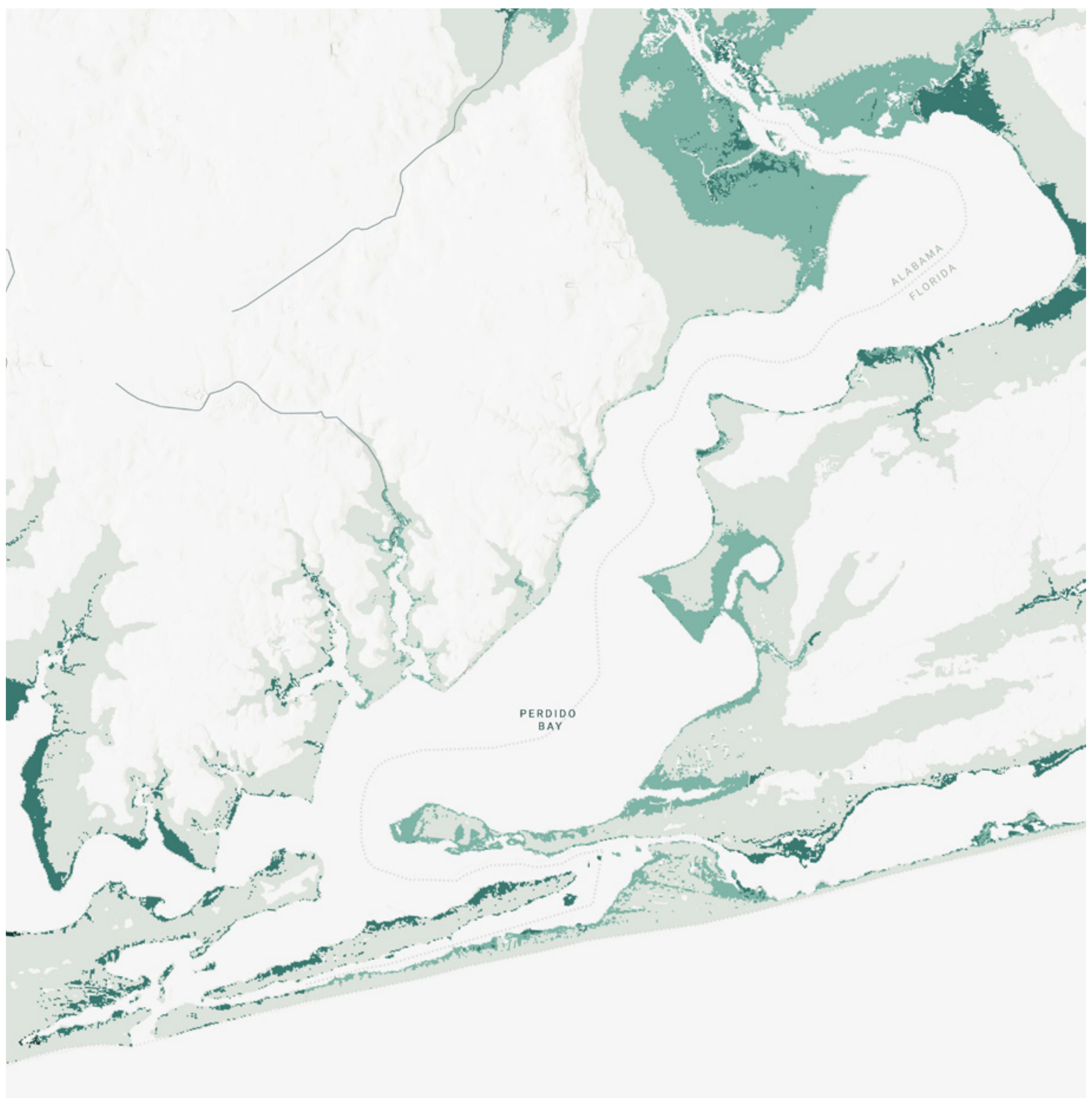
4 PERDIDO BAY
COASTAL STORM RISK AND SLR

The South Atlantic Coastal Study cross-referenced the hazard mapping on the previous pages with three indices of exposure: infrastructure and population, environmental and cultural resources, and social vulnerability. The product of this cross-referencing was a Composite Risk Index, which is mapped below. Sea level rise, again shown as a 3-foot scenario, substantially exacerbates these risks: much of the developed shoreline of Orange Beach, Perdido Key, and western Pensacola is exposed to significant risk.

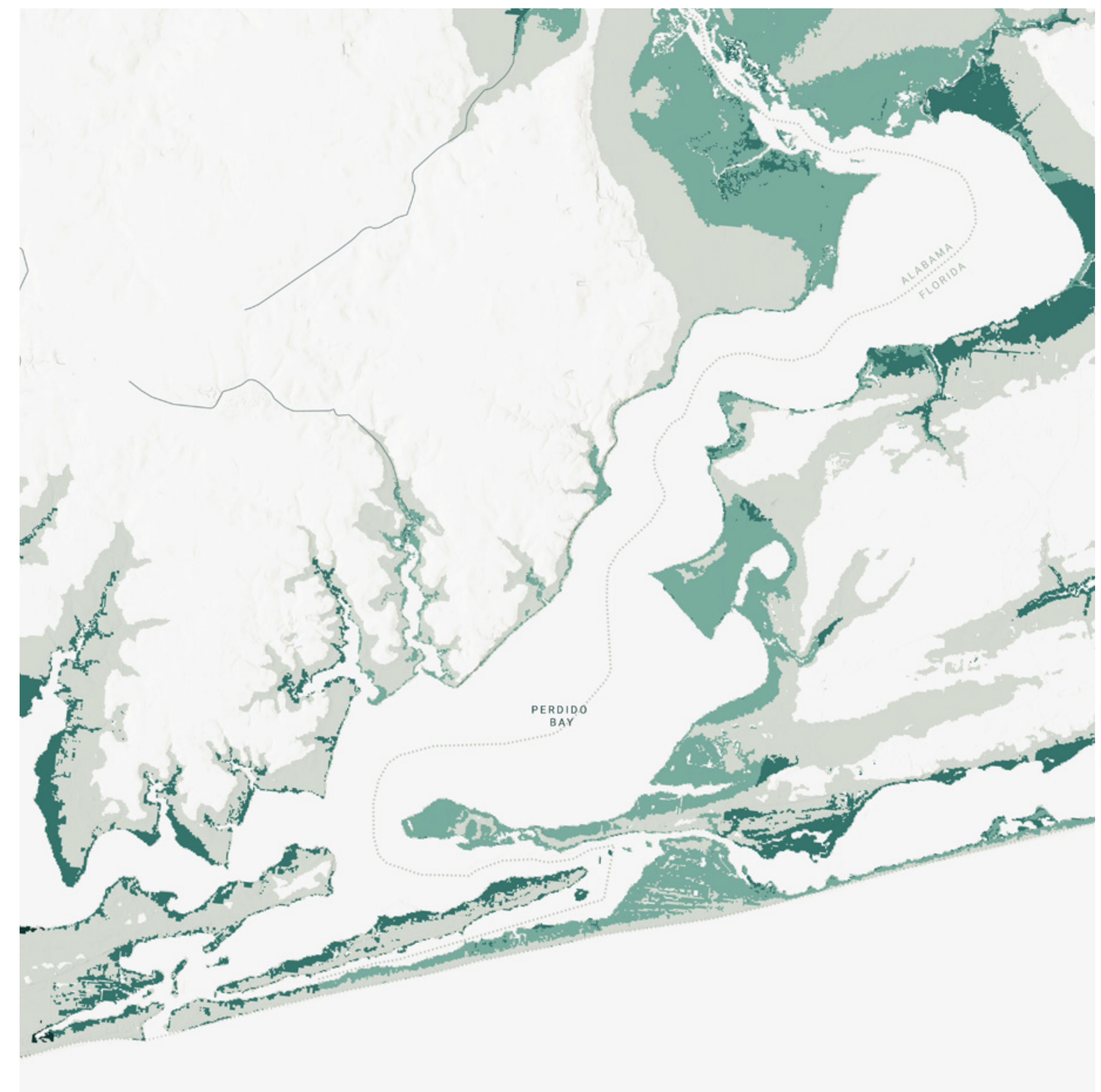
COMPOSITE RISK INDEX

- Potential Low Risk
- Potential Medium Risk
- Potential Medium/High Risk
- Potential High Risk

PRESENT DAY



+3FT SLR SCENARIO



4 PERDIDO BAY
COASTAL STORM RISK AND SLR

The South Atlantic Coastal Study also included an economic risk assessment, which quantified anticipated annual damages given predicted hazards. As shown on the maps below, this economic risk assessment finds risk concentrated in Lower Perdido Bay, which is one of the key reasons that we have focused the development of EWN® strategies in the lower bay.

ECONOMIC RISK

Depreciated Replacement Losses Expected Annual Damages ($ millions)

- 0 - 1
- 1 - 2
- 2 - 3

PRESENT DAY

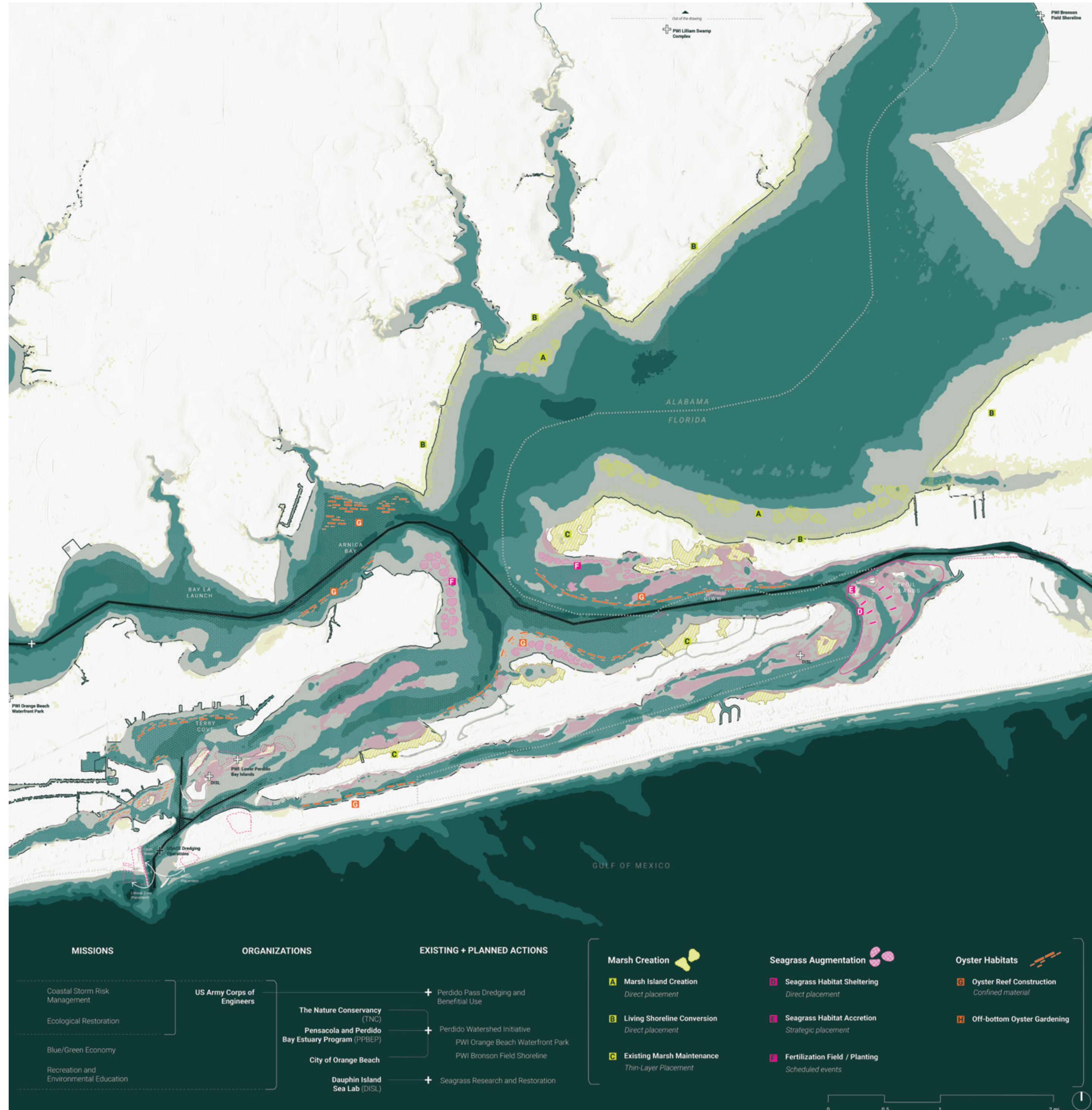
+3FT SLR SCENARIO

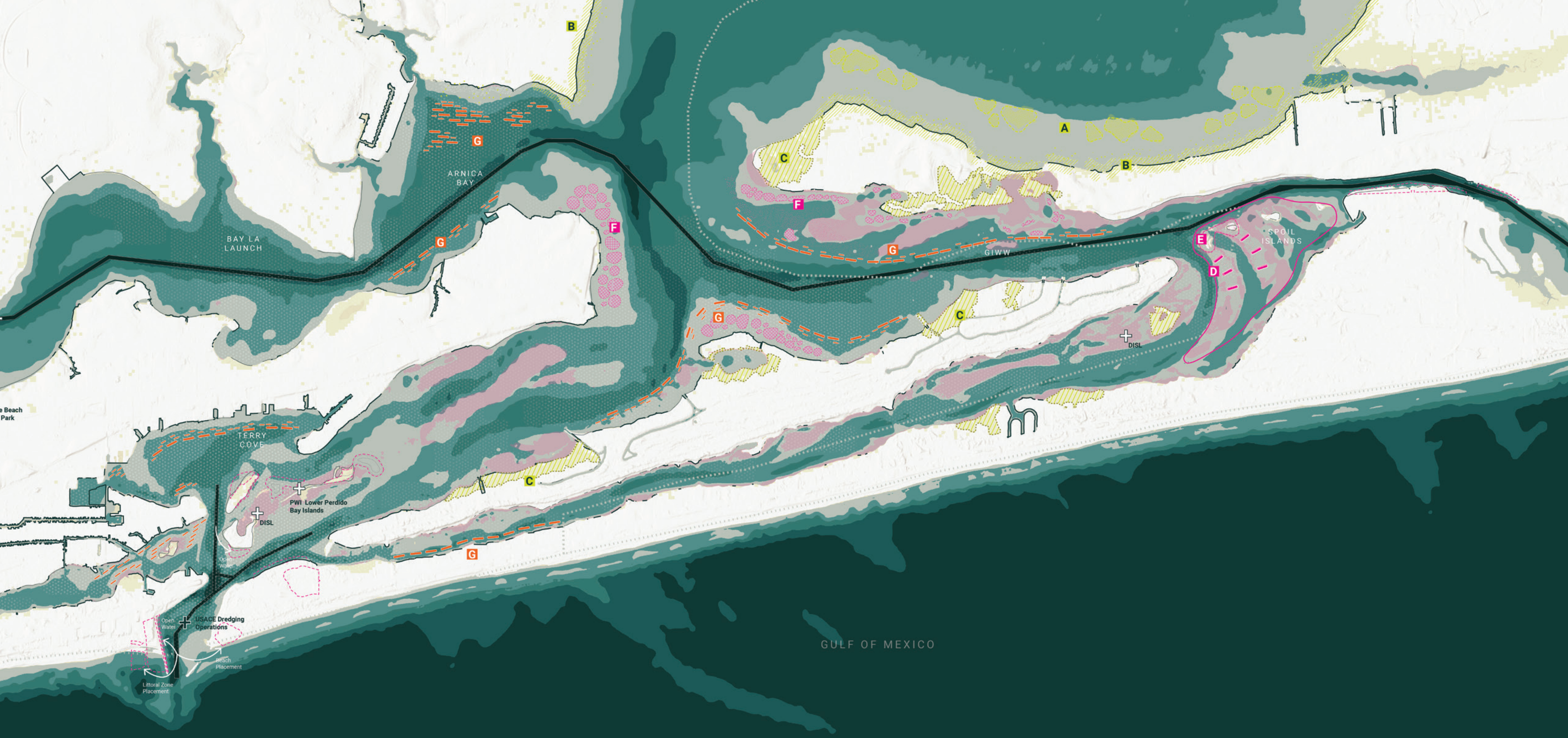
5 PERDIDO BAY
NATURAL INFRASTRUCTURE DESIGN CONCEPTS

Our proposed EWN® strategies are organized into three categories: marsh creation, seagrass augmentation, and oyster habitats. Each category contains a set of potential NNBF that would have the capacity to reduce coastal storm risk, support ecological restoration, and provide recreational, aesthetic, and public health benefits. Often, features from the three categories can be aligned to synergistic effect: for instance, along the south side of Innerarity Point, oyster reefs could buffer plantings of seagrass beds from wave energy, and seagrass beds could in turn provide protection from shoreline erosion for existing marshes that could be augmented by thin-layer placement.

Any effort to build a holistic, nature-based resilience strategy for Perdido Bay (or any other Gulf Coast back bay) will require collaboration and coordination across a broad range of agencies, stakeholders, and communities. Correspondingly, this plan also identifies some of the key organizations currently working in Perdido Bay, including The Nature Conservancy, the Pensacola and Perdido Bay Estuary Program, the City of Orange Beach, and the Dauphin Island Sea Lab, all of whom have on-going and planned actions that new resilience efforts can and should align with.

The following pages use a series of diagrams to describe the factors that went into identifying prospective locations for the potential NNBF.





MISSIONS

- Coastal Storm Risk Management
- Ecological Restoration
- Blue/Green Economy
- Recreation and Environmental Education

ORGANIZATIONS

- **US Army Corps of Engineers** → Perdido Pass Dredging and Beneficial Use
- **The Nature Conservancy** (TNC), **Pensacola and Perdido Bay Estuary Program** (PPBEP), **City of Orange Beach** → Perdido Watershed Initiative
  - PWI Orange Beach Waterfront Park
  - PWI Bronson Field Shoreline
- **Dauphin Island Sea Lab** (DISL) → Seagrass Research and Restoration

EXISTING + PLANNED ACTIONS

Marsh Creation

- **A** **Marsh Island Creation** *Direct placement*
- **B** **Living Shoreline Conversion** *Direct placement*
- **C** **Existing Marsh Maintenance** *Thin-Layer Placement*

Seagrass Augmentation

- **D** **Seagrass Habitat Sheltering** *Direct placement*
- **E** **Seagrass Habitat Accretion** *Strategic placement*
- **F** **Fertilization Field / Planting** *Scheduled events*

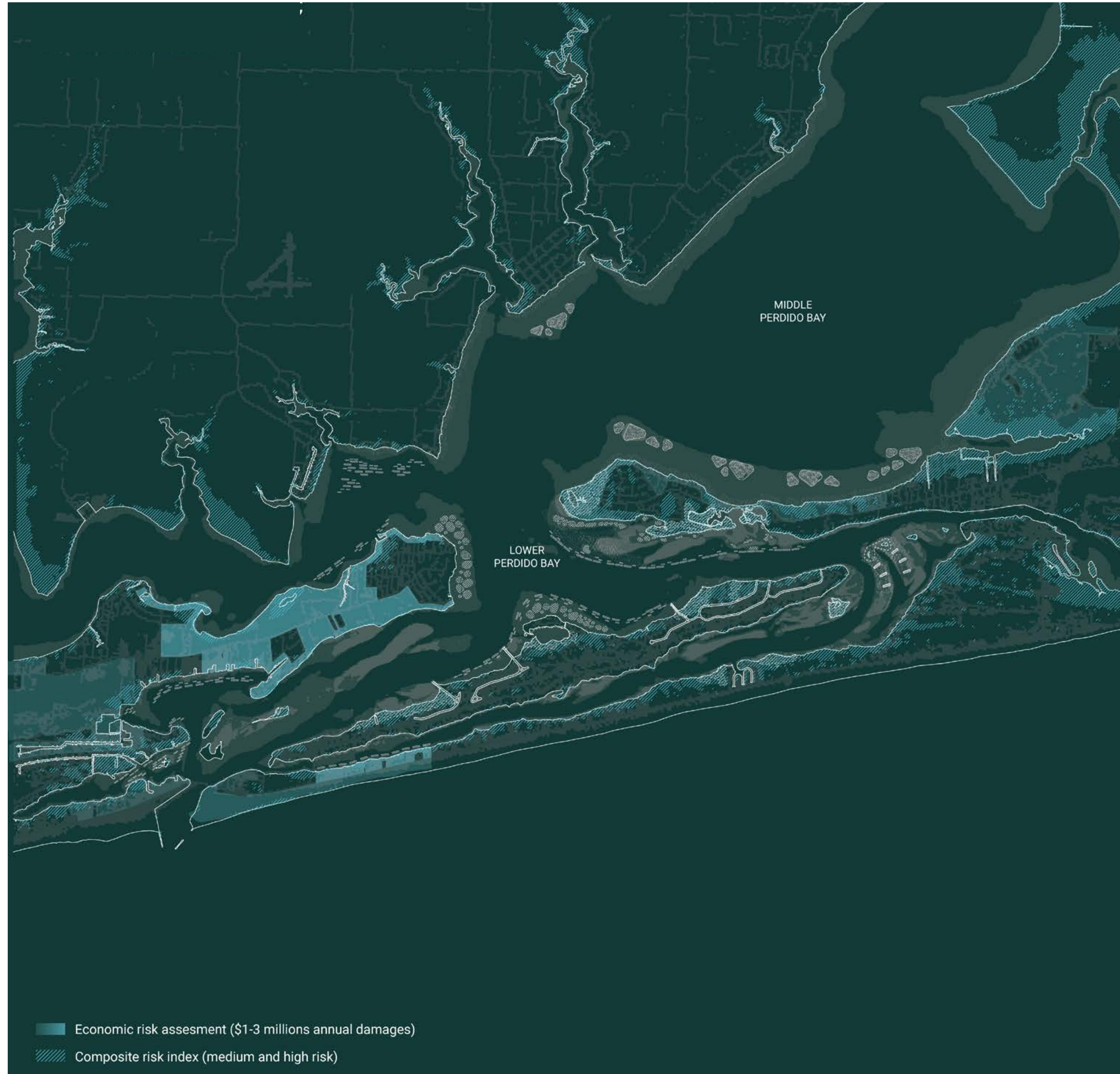
Oyster Habitats

- **G** **Oyster Reef Construction** *Confined material*
- **H** **Off-bottom Oyster Gardening**

0 0.5 1 2 mi.

5 PERDIDO BAY
SOCIAL AND ECONOMIC VULNERABILITY

Both the economic risk assessment and the composite risk index from SACS were used in identifying locations with social and economic vulnerability as priorities for protection with nature-based strategies from all three categories of features.

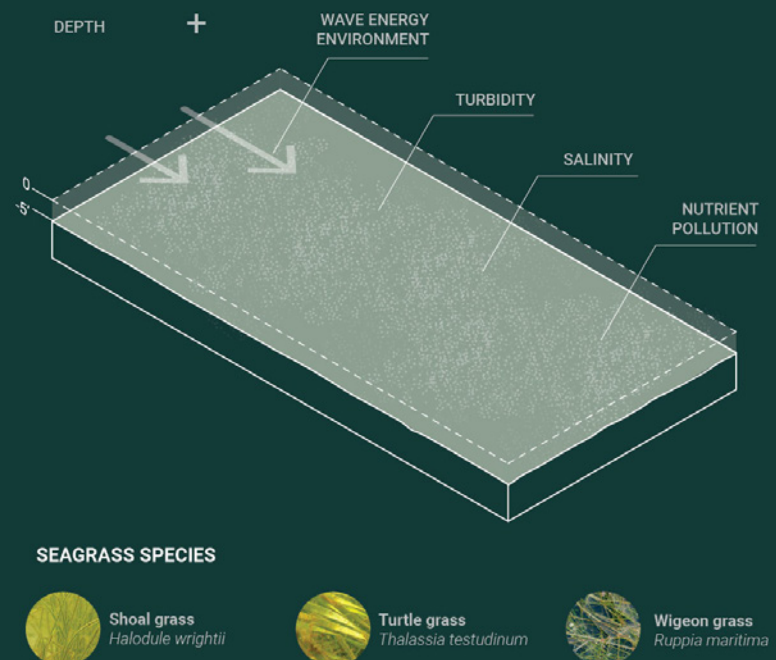


5 PERDIDO BAY
SEAGRASS AUGMENTATION

Three primary EWN® strategies for seagrass augmentation are proposed. (The three strategies are diagrammed on the pages immediately following these.) Habitat sheltering via the construction of subtidal berms is recommended in locations where suitable depths for seagrasses already exist, but seagrass beds can be hypothesized to not exist at least in part due to high-energy wave environments. Where natural forces, including tides and currents, are oriented appropriately, the strategic placement of dredged material has the potential to accelerate the accretion of sediment within existing seagrass beds, aiming to help them to keep pace with sea level rise. Finally, in shallows where there are currently no seagrass beds, planting and fertilizing can be used to encourage the formation of new beds.

5 PERDIDO BAY
SEAGRASS AUGMENTATION

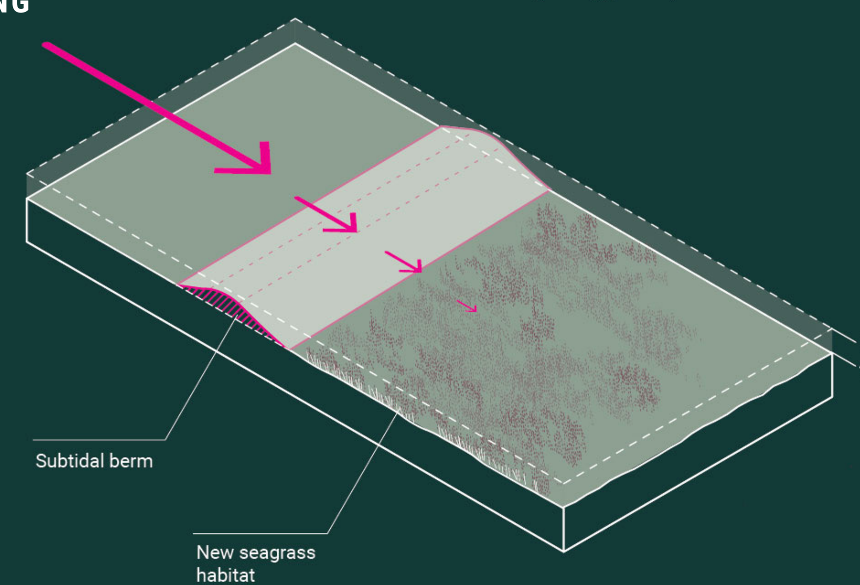
SEAGRASS SUITABILITY



HABITAT SHELTERING

Direct placement

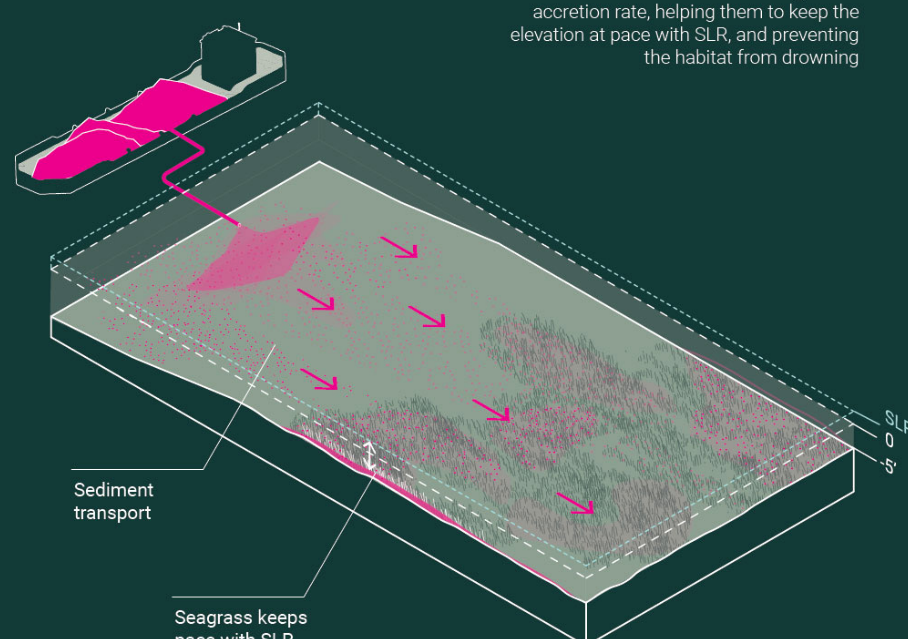
Subtidal landforms create sheltered zones for seagrasses to naturally establish in areas that are at a suitable depth but where seagrasses are not currently growing, possibly due to wave action



HABITAT ACCRETION

Strategic placement

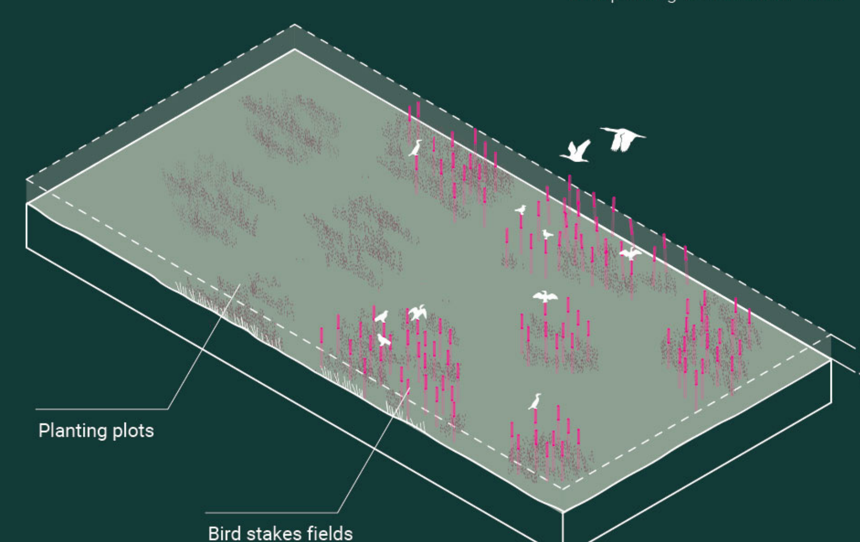
Placed material accelerates seagrasses accretion rate, helping them to keep the elevation at pace with SLR, and preventing the habitat from drowning



PLANTING + FERTILIZATION

Bird stakes and planting

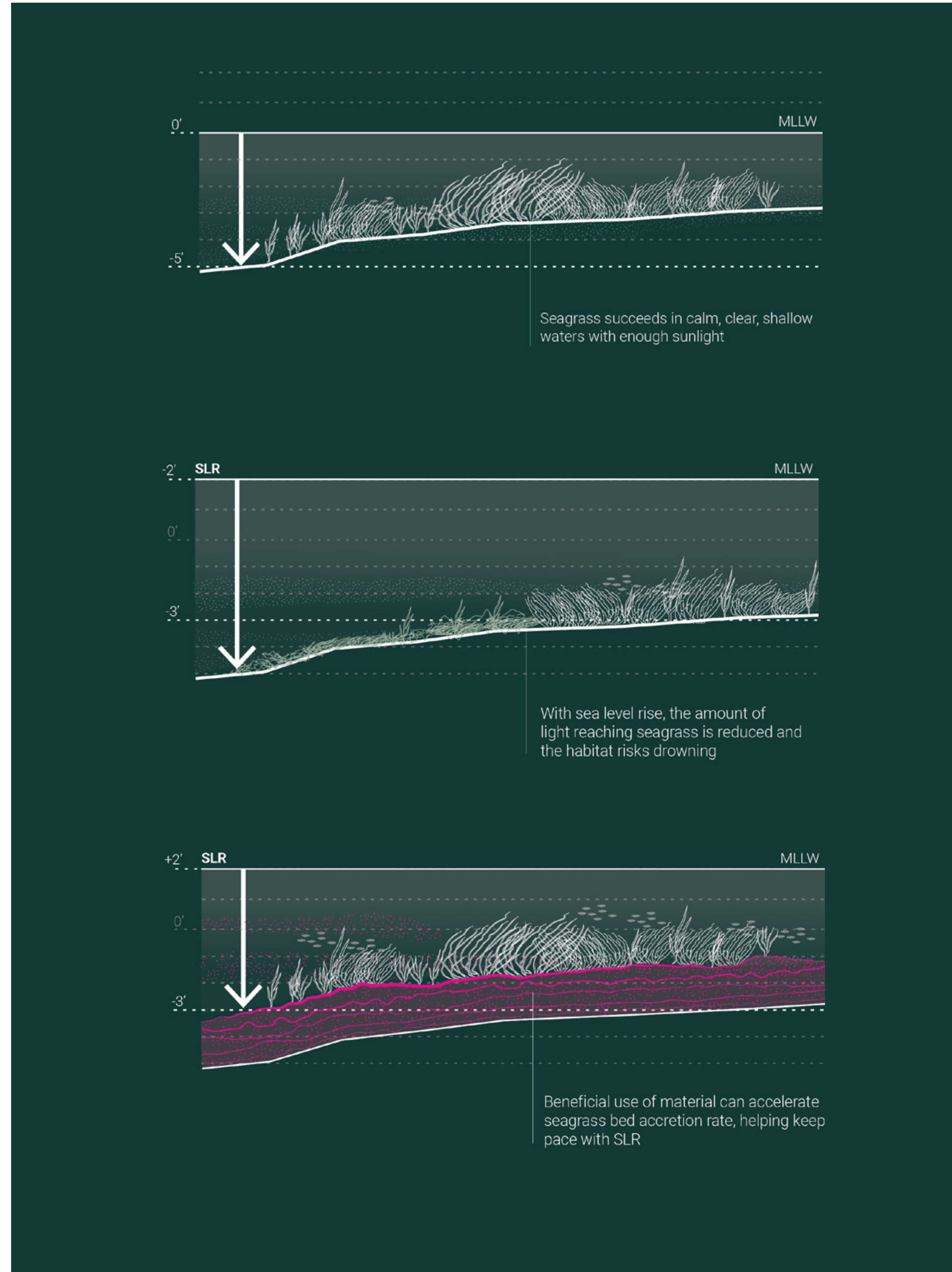
Bird stakes attract seabirds who defecate into the water adding nutrients that stimulate seagrasses' growth. This can be done in unvegetated shoals or to accompany transplanting to create new beds.



5 PERDIDO BAY
SEAGRASS AUGMENTATION

Collectively, the seagrass augmentation strategies are intended to both expand the acreage of Perdido Bay's seagrass beds and to help the bay's beds adapt to sea level rise. As shown in the diagrams at right, even moderate sea level rise has the potential to substantially impact seagrass beds if they transition to depths where insufficient light reaches them for photosynthesis. The beneficial use of dredged material has the potential to facilitate SLR adaptation by increasing accretion rates within beds and helping them to keep pace with SLR (Russ et al 2023; Dumbauld et al 2022).

This is important for several reasons. Seagrass beds have great value as habitats, both because by supporting juvenile aquatic species, they support the fisheries species that coastal economies rely on, and because they are foundational to the biodiversity of Gulf Coast back bays (Heck et al 2008; DISL 2022). Seagrass beds also have the capacity to perform as coastal storm risk reduction features through wave attenuation, accretion of sediment, erosion reduction, and, potentially, contributing to beneficial changes in shoreline morphology (Twomey et al 2022).



5 PERDIDO BAY
SEAGRASS AUGMENTATION

Along the western reaches of the Gulf Intracoastal Waterway in Perdido Bay, all three seagrass augmentation strategies can be utilized: subtidal berms to shelter shallow areas adjacent to existing beds, strategic placement to feed appropriate sediment to support bed accretion, and planting and fertilization to directly emplace new beds.

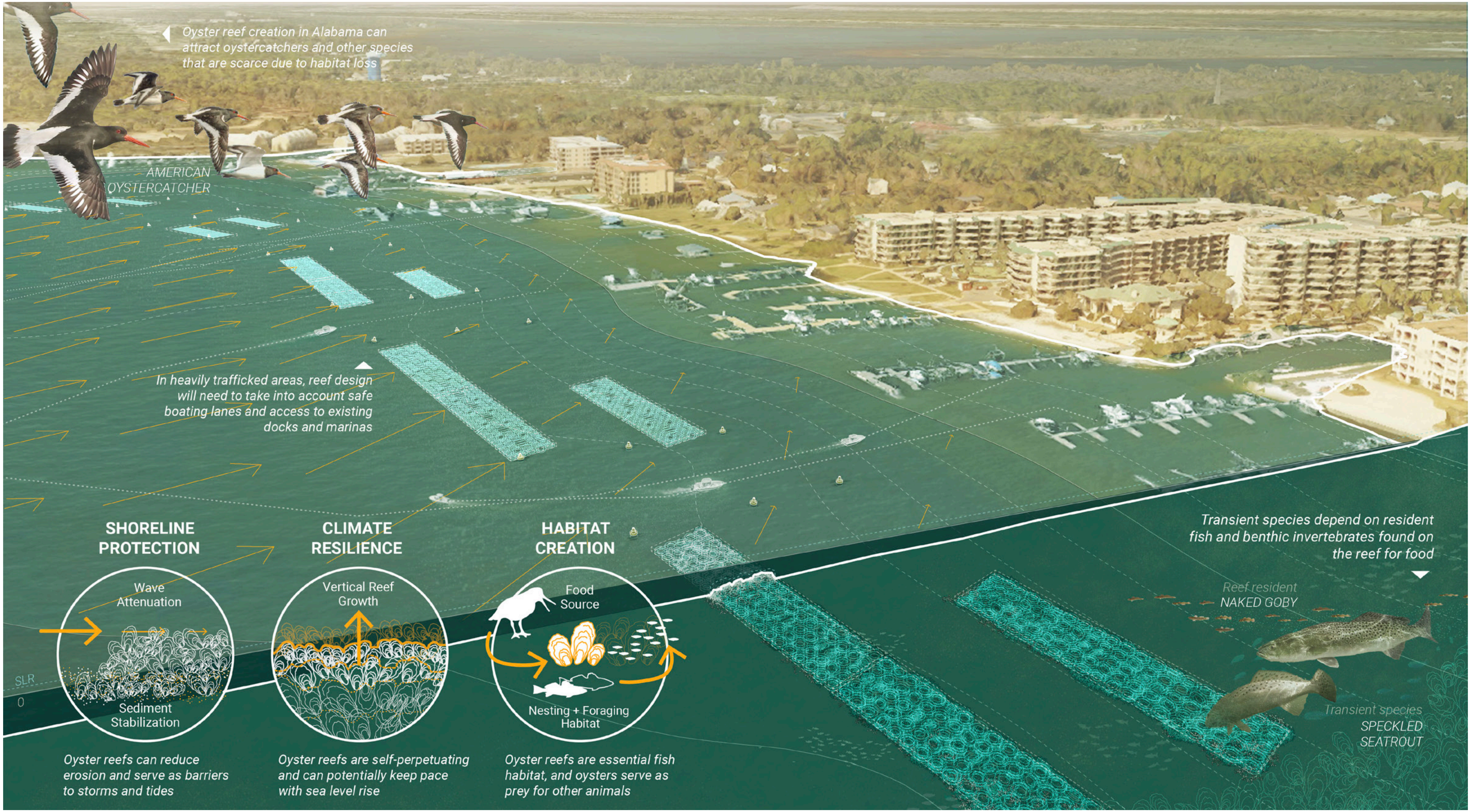

COASTAL PROTECTION
Wave attenuation
Sediment stabilization
Seagrass prevents erosion and protects from storm surge
SPAWNING + NURSERY HABITAT
Juvenile fish feed and seek shelter in seagrass
FOOD WEB SUPPORT
Aquatic fauna and fisheries production rely on seagrass
Cormorants, terns, ospreys, gulls, and pelicans help fertilize the seagrass
Redfish
Trout
Mullet
Blue crab
Shrimp
Scallops
Seagrass in Perdido Bay provides habitat for many commercially and recreationally important species

5 PERDIDO BAY
OYSTER HABITATS

The proposed oyster habitat features are organized first in relation to appropriate salinity levels, as identified in the suitability analyses described earlier in this section. Oyster reefs would be particularly appropriate within this zone in both areas where waterways are too narrow to support more horizontally-extensive features (such as the heavily-trafficked channel between Perdido Key and Ono Island) and areas where reefs at the outer edges of shoals could reduce erosion and encourage deposition behind the reefs, supporting both seagrass and marsh habitats.

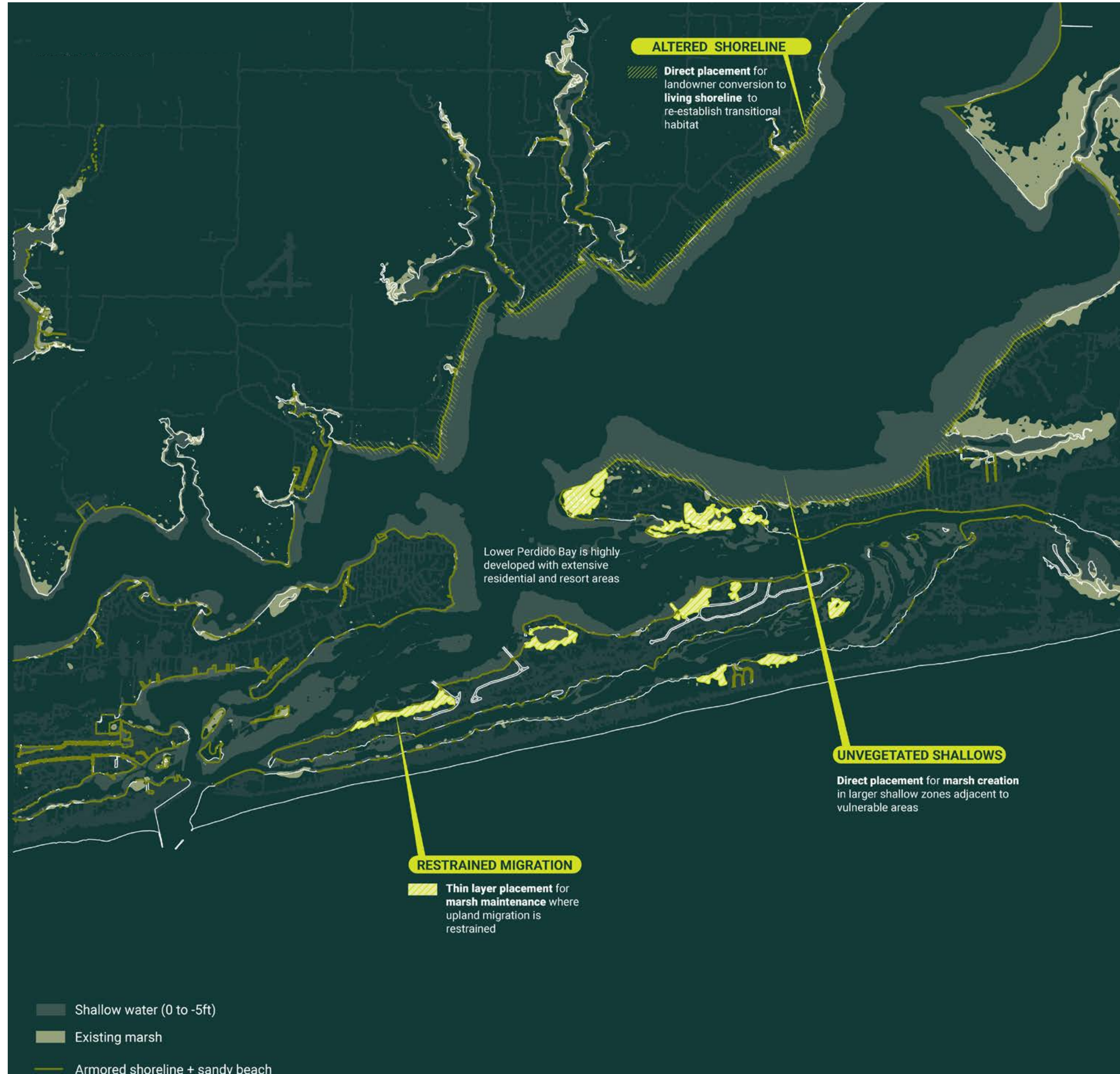
5 PERDIDO BAY
OYSTER HABITATS

Like seagrass beds, oyster reefs and other oyster habitats provide multiple benefits. The form and arrangement of oyster reefs should vary in response to site conditions. This image shows oyster reefs in one of the more heavily developed portions of the bay.



5 PERDIDO BAY
MARSH CREATION

Three marsh creation strategies are recommended. First, in some unvegetated shallows, direct placement of dredged material can be used to construct relatively large marsh islands. Second, where upland migration opportunities are limited to due development, armored shorelines, or other infrastructure, thin-layer placement of dredged fines can be used to accelerate marsh accretion in-situ and facilitate adaptation to sea level rise. Third, direct placement in smaller quantities can be used to facilitate private landowner conversion of altered shorelines to living shorelines to re-establish transitional habitat and, in the long term, support marsh habitat quality and upland migration.



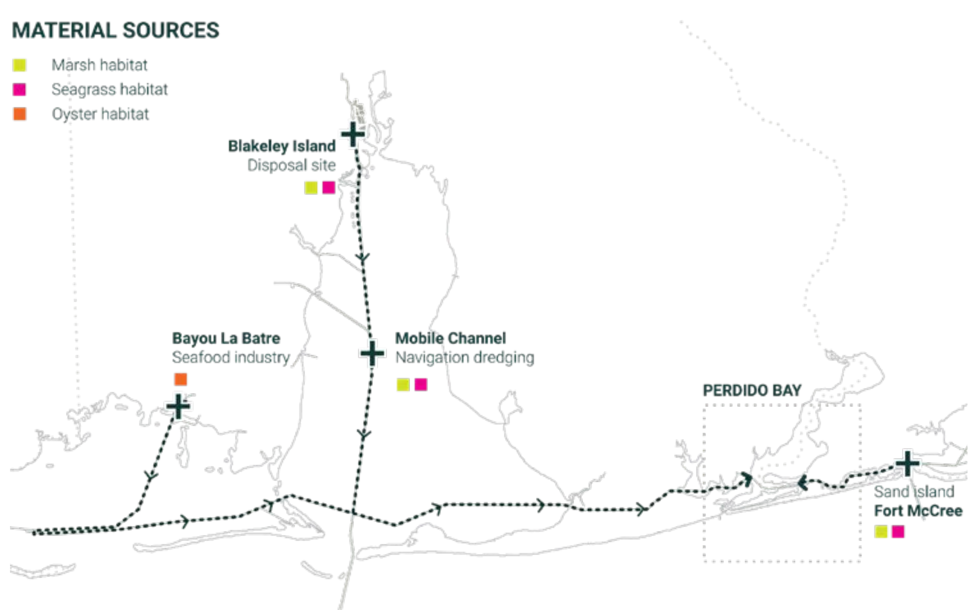
5 PERDIDO BAY MARSH CREATION

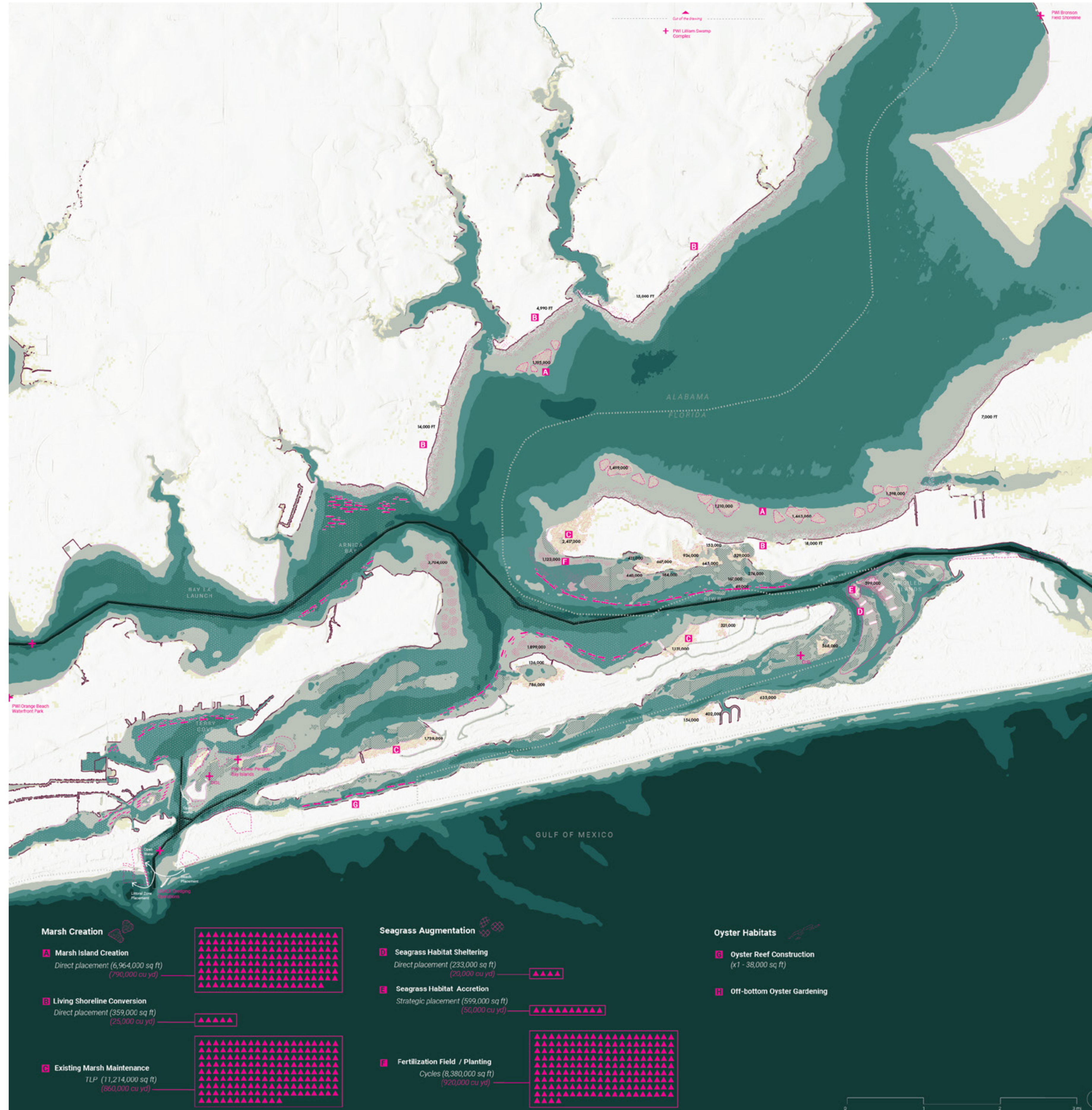
In addition to providing storm risk reduction through wave attenuation and serving as habitat for many of the bay's key animal species, marshes offer rich recreational opportunities. A blueway trail, for instance, might weave between existing landscapes and the new marsh islands created as part of a beneficial use strategy.

6 PERDIDO BAY SEDIMENT CHOREOGRAPHY

Constructing the features shown in this section would require substantial volumes of dredged material. The plan at right estimates rough volumes of material required for each type of feature, based on simple calculations of area and elevation. As such, it does not account for processes like subsidence or natural accretion, which would significantly affect the exact quantities of material required to construct the proposed features.

Below, sources for this material could include the Blakeley Island dredged material management area, the navigation channels in Mobile Bay, and Sand Island near Fort McCree in Florida. All of these sources would require barging material to Perdido Bay and thus would require supplemental funding to offset the costs of transport. (This plan assumes that the material dredged out of Perdido Pass would continue to be used beneficially locally, and thus not be available for the construction of new in-bay features.) Aligning the multiple benefits of NNBF with appropriate funding sources would be crucial to being able to implement any of these measures.



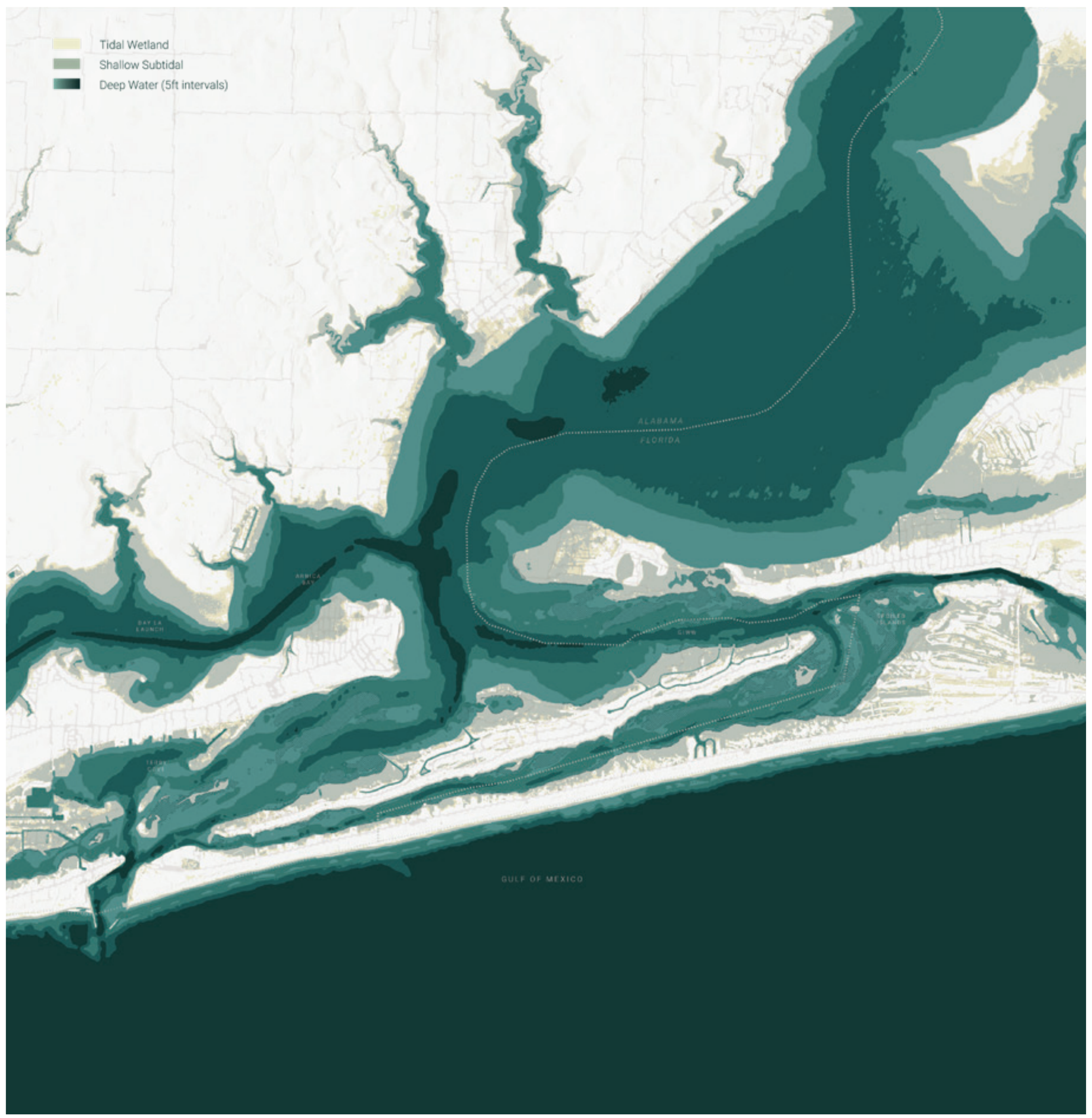


7 PERDIDO BAY
NATURAL INFRASTRUCTURE OVER TIME

Nature-based infrastructure is best understood as dynamic and adaptive, like the natural features that it is modeled after. The maps below compare potential habitat transitions under NOAA's 5' SLR scenario with and without the adaptation measures proposed in this report, showing that these measures have the potential to significantly preserve valuable habitat as sea level rises and to provide protective benefits to the communities of Perdido Bay well into the future. Implementing them successfully, though, will require continual monitoring and adaptive management to respond to unanticipated contingencies and the actual performance of constructed features.

The plan for choreographing natural infrastructure in Perdido Bay documented in this report is thus only a start to effectively planning, designing, and implementing Engineering With Nature® (EWN®) strategies in the bay. Hydrodynamic modeling, further design iteration, effective community engagement, and partnerships with stakeholder organizations will all need to be developed in order to facilitate a successful planning effort that can maximize benefits to the people and landscapes of Perdido Bay.

5' SLR WITHOUT ADAPTATION MEASURES



5' SLR WITH PROPOSED ADAPTATION MEASURES

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APPENDIX 1

BON SECOUR BAY ERODIBLE BERMS HYDRODYNAMIC MODELING ANALYSIS

Prepared for:

US Army Corps of Engineers

ERDC

EWN

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1 INTRODUCTION

The Fort Morgan Peninsula (the Peninsula) is located between the mouth of Mobile Bay (the Bay) and the Florida panhandle in Baldwin County, Alabama (Figure 1). The Peninsula is an important natural resource for the state of Alabama for the following reasons:

- It acts as a natural land barrier, that separates the waters of the Gulf of Mexico from Mobile Bay and blocks wave energy and storm surge from entering the Bay.
- It is home to the Bon Secour National Wildlife Refuge, which provides habitat for migratory birds and threatened and endangered species (USFWS 2023).
- It is a popular tourist destination and revenue source for the state (Liu et al. 2007).

The northeastern shoreline of the Peninsula is vulnerable to erosion from Mobile Bay waves, particularly those from the north and west. This vulnerability is shown by Byrnes et al. (2013), who determined that the northeastern shoreline of the Peninsula receded an average of 1.2 feet per year between 1849 and 2011.

To protect the northeastern shoreline of the Peninsula (the Site) through the use of natural and nature-based features (NNBF), the Dredge Research Collaborative (DRC) and Anchor QEA, LLC, developed multiple alternative design concepts for a series of earthen berms in the nearshore region of the Site, which could be constructed with material dredged from the nearby Mobile Bay navigation channel. The primary goal of the project is to protect the shoreline from wave energy responsible for its erosion on an annual basis.

Anchor QEA has performed wave and hydrodynamic modeling of the alternative design concepts developed by the DRC to evaluate the wave attenuation performance of each configuration to inform the selection of the most effective configuration for shoreline protection. Model simulations were conducted for the existing (pre-project) and proposed (post-project) conditions to evaluate changes in waves and hydrodynamics due to implementation of each design alternative. Two annual storms and one hurricane were modeled for the project.

1.1 Report Organization

This report describes the modeling evaluation performed to assess potential changes in wave and hydrodynamic patterns in the vicinity of the proposed project area under varying conditions. The report is divided into the following sections:

- **Coastal Setting:** Description of general wind, wave, and hydrodynamic conditions in Mobile Bay
- **Wave and Hydrodynamic Model Development:** Details on the model grid development, modeled scenarios, and the associated logic for their selection and use
- **Model Results:** Details on the analysis of the results of the wave and hydrodynamic modeling and the effects of the simulated berm configurations on wave and hydrodynamic patterns
- **Summary:** Summary of the model results and conclusions reached regarding the effectiveness of the proposed berms to meet the project objectives

2 COASTAL SETTING

Mobile Bay is situated between the Mississippi Sound and the panhandle of Florida on the Alabama Gulf Coast. Mobile Bay covers an area of approximately 413 square miles and has an average water depth of approximately 10 feet (Dauphin Island Sea Lab 2008). In general, the waves at the Site are locally generated as a result of seasonal wind patterns and tropical and extratropical storms.

2.1 Water Levels

Mobile Bay is considered a microtidal estuary because the mean diurnal tide range reported near its mouth is approximately 1.2 feet, as shown at National Oceanic and Atmospheric Administration (NOAA) tidal station 8735180, Dauphin Island, Alabama (NOAA 2023a). The location of this tide station in relation to the project area is shown in Figure 1. Tidal elevations based on the NOAA Dauphin Island station relative to the North American Vertical Datum of 1988 (NAVD88) throughout the 19 year tidal epoch from 1983 through 2001 are as follows:

- Mean higher high water (MHHW) is 0.70 foot NAVD88.
- Mean high water is 0.68 foot NAVD88.
- Mean tide level is 0.09 foot NAVD88.
- Mean low water is -0.50 foot NAVD88.
- Mean lower low water is -0.52 foot NAVD88.

Figure 2 shows a cumulative frequency distribution of 6 minute water level measurements from the NOAA Dauphin Island station from November 2003 through March 2023. The 95th percentile water level (i.e., the water level greater than 95% of the measurements) from this data record is 1.5 feet NAVD88. For reference, the 10 year water level at this location estimated by the U.S. Army Corps of Engineers (USACE) South Atlantic Coastal Study (SACS) is 4.0 feet NAVD88 (USACE 2023a).

2.2 Wind

Wind data in the vicinity of the Site were gathered from the National Data Buoy Center (NDBC) Middle Bay Lighthouse station (NDBC MBLA1; NOAA 2023b). The location of this station is shown in Figure 1. The available data from this station consist of 30 minute measurements from 2006 to 2022. A wind rose of the NDBC MBLA1 data is shown in Figure 3. The prevailing winds are from the north, but winds from the long westerly fetch, although less frequent, can also generate waves that impact the Site.

3 WAVE AND HYDRODYNAMIC MODEL DEVELOPMENT

To evaluate reductions in wave energy under various berm options, 2D coupled hydrodynamic flow and wave models were used to simulate nearshore waves, water levels, and currents under a variety of meteorological conditions. This section includes details of the model grid development, selected simulations, and the associated logic for their selection and use.

3.1 Model Selection

The numerical model selected for use in this evaluation was Delft3D. Delft3D was developed and supported by Deltares and validated for use in riverine, estuarine, and open coast hydrodynamic systems. Wave growth and transformation modeling was performed with the 2D Delft3D-WAVE (WAVE) model. The WAVE model is based on the Simulating Waves Nearshore (SWAN) model. The SWAN model was developed by the University of Delft and includes all relevant wave processes, such as refraction, shoaling, diffraction approximated by directional spreading of the phase-averaged waves, and wave breaking. The hydrodynamic modeling was performed with the 2D version of the Delft3D FLOW (FLOW) model. The FLOW model provided computed hydrodynamic information resulting from water level fluctuations and wind to the WAVE model (via online coupling) and evaluated changes in current velocity and bed shear stress patterns due to the proposed berms.

3.2 Modeling Approach

To inform the development and performance of the proposed project alternatives, two levels of modeling were performed at the following two scales:

1. Regional modeling of Mobile Bay was performed to compute Bay-wide waves and hydrodynamics and to provide boundary conditions for site-specific modeling at various potential project locations throughout the Bay.
2. Using the results of the Mobile Bay model at its boundaries, site-specific modeling of the northeast area of the Peninsula was performed to evaluate changes in nearshore waves and hydrodynamics due to the proposed berm features.

The model grids for these two areas are described in the following subsection.

3.2 Model Grids

Figures 4 and 5 show the WAVE and FLOW model grids for the Mobile Bay and Fort Morgan model domains. Each model grid had a different coverage area with spatially variable resolution. The Mobile Bay model grids were constructed to represent the regional Bay geometry, shoreline features, and navigation channels affecting the waves and hydrodynamics incident to the Site. The Fort Morgan model grids were constructed to a resolution that would adequately capture the key Site features and berm alternatives to be evaluated (Figures 6 and 7). Table 3-1 shows the range of grid cell resolution for each model grid.

Table 3-1

Model Grid Cell Resolutions

Grid	Offshore Boundary (feet)	At the Project Site (feet)
Mobile Bay WAVE and FLOW	490 by 580	310 by 570
Fort Morgan WAVE and FLOW	40 by 70	40 by 70

3.4 Model Elevation Data

Model bathymetry of the Mobile Bay and Fort Morgan grids was based on the following:

- July 2022 to January 2023 hydrographic surveys of Mobile Bay and the Gulf Intracoastal Waterway (GIWW) navigation channels in the vicinity of the Site (USACE 2023b)
- NOAA Continuously Updated Digital Elevation Model of the Bay bottom and upland areas (NOAA 2023c)

3.5 Model Simulations

The evaluation for the proposed earthen berm alternatives focuses on reducing wave energy produced by annual maximum wave conditions and associated water levels. Therefore, model simulations were developed to represent higher wave conditions that could occur annually at the Site during extratropical conditions.

A hurricane near the Site with an estimated return period of 10 years was also selected for simulation to evaluate the effects of an extreme storm on the proposed design features.

Current velocities, circulation patterns, and bed shear stresses in the vicinity of the proposed berm features were also evaluated for the simulated storms.

3.5.1 Annual Storm Scenarios

Annual storm scenarios were developed for the WAVE model to evaluate the height and direction of waves that impact the Site and contribute to annual shoreline erosion. The wind and wave directions estimated to have the most influence on the Site were determined from the wind rose at NDBC station MBLA1 (Figure 3) and the geometry of Mobile Bay relative to the Site. Based on these considerations, the most influential directions were determined to be north (the most frequent wind direction as shown in Figure 3) and west. The 1-year return period wind speeds from these two directions were computed from the data record at NDBC station MBLA1 from 2006 to 2022 for use in the annual storm scenarios. These wind speeds are shown in Table 3-2.

Table 3-2
Wind Speeds for Annual Storm Scenarios

Wind Direction	1-Year Wind Speed (mph)
North	36
West	29

Note: mph: miles per hour

To evaluate the potential wave conditions associated with shoreline erosion at the Site for the 1 year wind conditions shown in Table 3-2, a tidal boundary condition was selected for use in the annual storm simulations. The selected tidal boundary condition was developed from 6 minute water level data measured at the NOAA Dauphin Island station from May 4 to 6, 2022. As shown in Figure 8, this water level record ranges from approximately -0.2 foot NAVD88 to +1.5 feet NAVD88, and its average value is close to MHHW at the Dauphin Island station (+0.7 foot NAVD88). The peak value of +1.5 feet NAVD88 represents an elevated water level for this area, equal to approximately the 95th percentile value of the historical 6-minute record at the Dauphin Island station (i.e., approximately 95% of water level measurements were below this value). Combined with the effects of the wind and wave setup in the coupled model simulations, this water level record is considered appropriate to evaluate the upper range of annual wave conditions acting on the shoreline for the wind conditions shown in Table 3-2.

For each of the annual simulations, the Mobile Bay FLOW model was driven with a constant steady state wind field corresponding to the magnitudes and directions in Table 3-2, combined with the time-varying water surface elevations shown in Figure 8 imposed along the southern grid boundary. Upon completion of each simulation on the Mobile Bay grids, the simulation was performed on the Fort Morgan model grids by mapping the Mobile Bay FLOW and WAVE results to the respective boundaries of the Fort Morgan FLOW and WAVE model grids. The uniform wind fields for the Mobile Bay simulations were used for the Fort Morgan simulations.

3.5.2 Hurricane Scenario

Hurricane Sally (September 2020) was selected as an event with a return period of approximately 10 years, based on the maximum storm surge elevation measured at the NOAA Dauphin Island station, with waves coming from the west after the storm made landfall and proceeded northeast of Mobile Bay. The maximum storm surge measured at the Dauphin Island station during Hurricane Sally was 3.8 feet NAVD88 (Figure 9).

For the Hurricane Sally simulation, the Mobile Bay FLOW model was driven with space-varying wind and pressure forcing applied through the construction of a Delft3D spiderweb file, using time varying storm parameters published in the NOAA National Hurricane Center Atlantic Hurricane Database 1851–2022 (Landsea and Franklin 2013). The resulting wind and pressure fields near the time of landfall are shown in Figure 10. In conjunction with the space-varying wind and pressure fields, the time-varying water surface

elevations shown in Figure 9 were imposed along the southern grid boundary. Upon completion of the simulation on the Mobile Bay grids, the simulation was performed on the Fort Morgan model grids by mapping the Mobile Bay FLOW and WAVE results to the respective boundaries of the Fort Morgan FLOW and WAVE model grids. The space-varying wind and pressure fields for the Mobile Bay simulation were used for the Fort Morgan simulation.

3.6 Proposed Berm Configurations

The developed conceptual designs include two proposed berm configurations. These geometries were evaluated with the WAVE and FLOW models (Figure 11). Each configuration consisted of variable-length and variably spaced berm features placed in the northeastern nearshore region of the Peninsula. Each berm feature consisted of a three-sided crest that partially enclosed an area of lower elevation earthen material. The crested portions of each berm feature generally faced Mobile Bay, and the non-crested portion generally faced the Fort Morgan shoreline. The crest elevations varied generally between 7 and 8 feet NAVD88, and the top elevations of the semi-enclosed earthen material varied generally between 2 and 3 feet NAVD88.

Berm Alternative 1 contained 19 berm features, and Berm Alternative 2 contained 17. Berm Alternative 1 contained a higher density of berm features closer to the northeastern shoreline of the Peninsula, near where the GIWW enters Oyster Bay.

4 MODEL RESULTS

This section describes the results of the wave and hydrodynamic modeling.

4.1 Existing Condition

Figures 12a, 13a, and 14a show the predicted near-field wave heights at the Site under existing conditions, at the time of peak wave height, for each of the modeled storm scenarios. Similarly, existing-condition current velocities at the Site are shown in Figures 17a, 18a, and 19a, and existing condition bed shear stresses at the Site are shown in Figures 21a, 22a, and 23a.

Table 4-1 summarizes the ranges of maximum water levels, significant wave heights, current velocities, and bed shear stresses near the shoreline of the Site predicted by the WAVE and FLOW models under existing conditions. The nearshore alignment along which these results were extracted is shown in Figure 11 and is located approximately 150 feet offshore of the existing shoreline. Table 4-1 also provides the estimated return period for each event at the Site. For the two annual storm scenarios, the estimated return period is 1 year, based on the return periods of the wind conditions used to drive the model (Table 3-2). For Hurricane Sally, the estimated return period is based on the maximum still water elevation at the Site predicted by the model, in comparison with the best estimate annual exceedance frequency still water elevation curve at USACE SACS Save Station 28646, which is located near the center of the Site (USACE 2023a).

Table 4-1

Model Results Summary: Existing Condition

Model Storm Scenario	Approximate Return Period at the Project Site	Water Level (feet NAVD88)	Significant Wave Height (feet)	Current Velocity (feet per second)	Bed Shear Stress (pascals)
Annual Storm from the North	1 year	1.1–1.4	0.7–1.2	0.2–0.9	0.8–3.9
Annual Storm from the West	1 year	2.1–2.2	1.0–1.5	0.3–1.3	2.9–4.5
Hurricane Sally	100 years	6.7–7.3	2.3–3.6	2.4–5.0	1.6–6.7

Table 4-1 summarizes the ranges of maximum water levels, significant wave heights, current velocities, and bed shear stresses near the shoreline of the Site predicted by the WAVE and FLOW models under existing conditions. The nearshore alignment along which these results were extracted is shown in Figure 11 and is located approximately 150 feet offshore of the existing shoreline. Table 4-1 also provides the estimated return period for each event at the Site. For the two annual storm scenarios, the estimated return period is 1 year, based on the return periods of the wind conditions used to drive the model (Table 3-2). For Hurricane Sally, the estimated return period is based on the maximum still water elevation at the Site predicted by the model, in comparison with the best estimate annual exceedance frequency still water elevation curve at USACE SACS Save Station 28646, which is located near the center of the Site (USACE 2023a).

For the Hurricane Sally simulation, it is worth noting that although the storm produced an approximately 10-year storm surge elevation at the mouth of Mobile Bay, approximately 18 miles west of the Site (NOAA station 8735180, Dauphin Island, Alabama; Figure 9), locally generated surge in the Bay produced an approximately 100-year storm surge elevation at the Site, as shown in Table 4 1. The extreme storm surge at the Site resulted in nearshore significant wave heights of 2.3 to 3.6 feet, current velocities of 2.4 to 5.0 feet per second, and bed shear stresses of 1.6 to 6.7 pascals.

4.2 Proposed Condition

Figures 12b, 12c, 13b, 13c, 14b, and 14c show the predicted near-field wave heights at the Site under proposed conditions for each berm alternative, at the time of peak wave height, for each modeled storm scenario. Figures 15a to 15f show wave height differences at the Site, comparing the existing and proposed conditions for each model simulation. The model results show that, compared to existing conditions, the predicted significant wave heights in the nearshore area between the proposed berm alternatives and the existing shoreline were reduced up to approximately 2 feet for the annual storm scenarios and up to approximately 4.5 feet for Hurricane Sally. The greatest wave attenuation occurred immediately on the leeward side of the berms. Figures 16a to 16c show comparisons of cumulative frequency distributions of wave heights near the existing shoreline for existing conditions and the two berm alternatives. As shown in these figures, the median wave heights for the annual storm scenarios were reduced by 25% to 50% near the existing shoreline for the proposed berm alternatives.

Figures 17b, 17c, 18b, 18c, 19b, and 19c show the predicted near-field flow velocities at the Site under proposed conditions for each berm alternative, at the time of peak flow velocity, for each of the modeled storm scenarios. Figures 20a to 20f show flow velocity differences at the Site, comparing the existing and proposed conditions for each model simulation. The model results show that, compared to existing conditions, changes in flow velocities for the proposed berm alternatives ranged from reductions of approximately 1 foot per second to increases of approximately 1.5 feet per second for the annual storm scenarios. For Hurricane Sally, changes in flow velocities for the proposed berm alternatives—compared to existing conditions—ranged from reductions of approximately 4 feet per second to increases of approximately 5.5 feet per second. The results showed fewer alterations of the existing-condition current fields for Berm Alternative 2 than for Berm Alternative 1.

Figures 21b, 21c, 22b, 22c, 23b, and 23c show the predicted near-field bed shear stresses at the Site under proposed conditions for each berm alternative, at the time of peak bed shear stress, for each of the modeled storm scenarios. Figures 24a to 24f show bed shear stress differences at the Site, comparing the existing and proposed conditions for each model simulation. Overall, the model results indicate the berm alternatives would reduce bed shear stresses in the nearshore area between the berms and the existing shoreline for the annual storm scenarios and would reduce the associated erosive forces acting at the Site. The model results also show that the berm alternatives would yield not only a smaller reduction in nearshore erosive forces from an extreme hurricane like Hurricane Sally than from annual storms but also areas of increased bed shear stress due to two factors: 1) the constriction of longshore currents landward of the proposed berm features and 2) the deflection of longshore currents bayward of the proposed berm features (Figures 24e and 24f).

5 SUMMARY

A wave and hydrodynamic modeling evaluation of using NNBF to protect the shoreline at the northeastern end of the Fort Morgan Peninsula in Mobile Bay, Alabama, was performed. A regional model of Mobile Bay was used to compute far-field waves and hydrodynamics incident to the Site, and a high-resolution Site model was used to compute nearshore waves and hydrodynamics. The modeling evaluation simulated two annual storm scenarios and one extreme hurricane for existing conditions (without the proposed NNBF) and proposed conditions for two NNBF alternatives (consisting of two configurations of earthen berm features).

Of the two annual storm scenarios, the model results showed that the annual storm scenario with winds and waves from the west resulted in the highest water levels and tallest waves at the Site. The model results also showed that, under existing conditions, predicted nearshore flow velocities at the Site were less than 1.5 feet per second for the annual storm scenarios. For the hurricane scenario, the model results showed that locally generated surge in Mobile Bay could produce extreme water levels, waves, and currents at the Site.

The model results indicated that, for the annual storm scenarios, each berm alternative would reduce wave energy and bed shear stresses in the nearshore area between the berms and the existing shoreline, thus reducing the associated erosive forces acting on the Site. Of the two berm alternatives evaluated, the results showed Berm Alternative 2 changed the existing-condition current fields less than Berm Alternative 1 did.

The model results also showed that the berm alternatives would reduce nearshore erosive forces less for an extreme hurricane than for annual storms and would result in areas of increased bed shear stress due to two factors: 1) the constriction of longshore currents landward of the proposed berm features and 2) the deflection of longshore currents bayward of the proposed berm features.

6 REFERENCES

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7 FIGURES

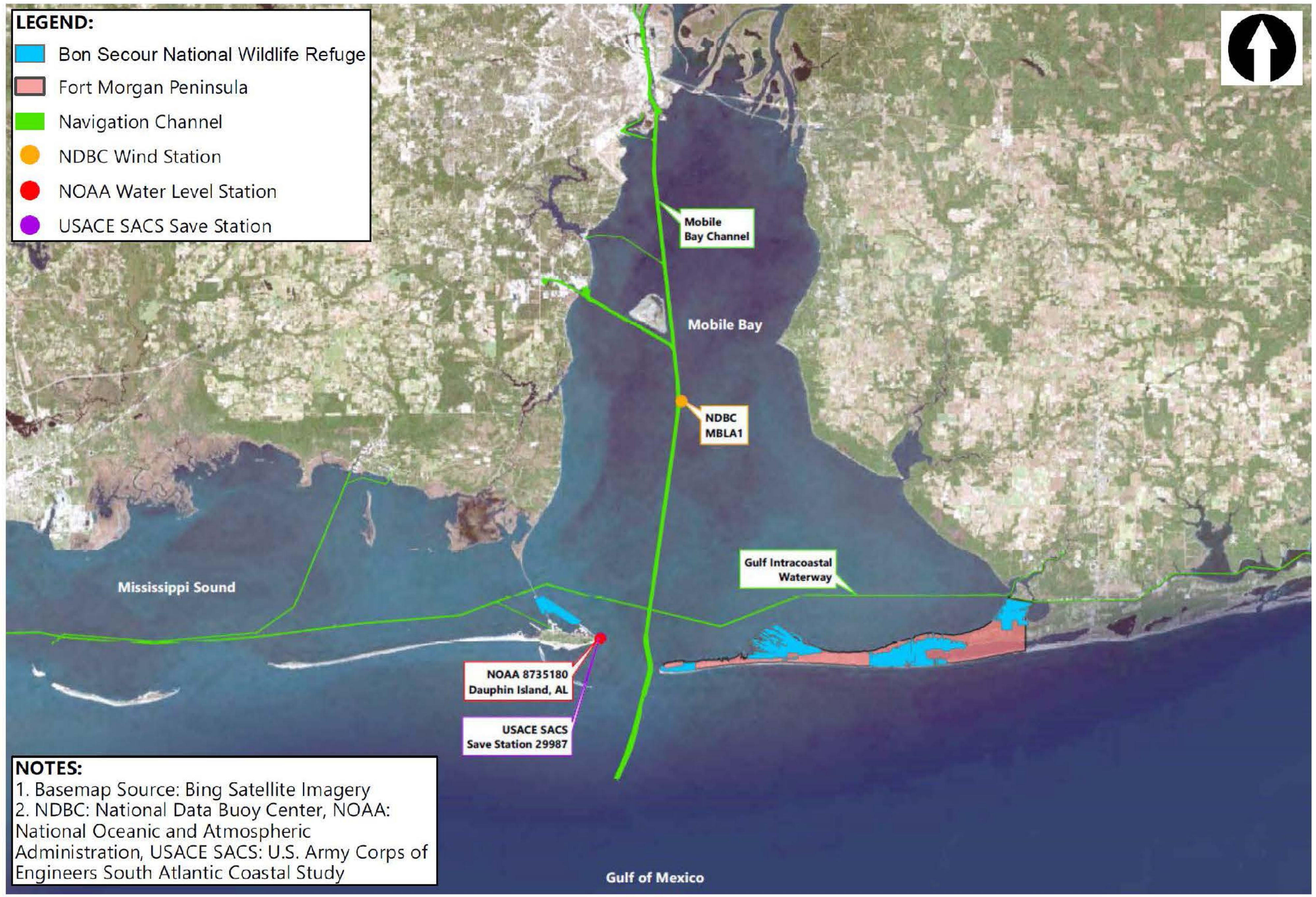
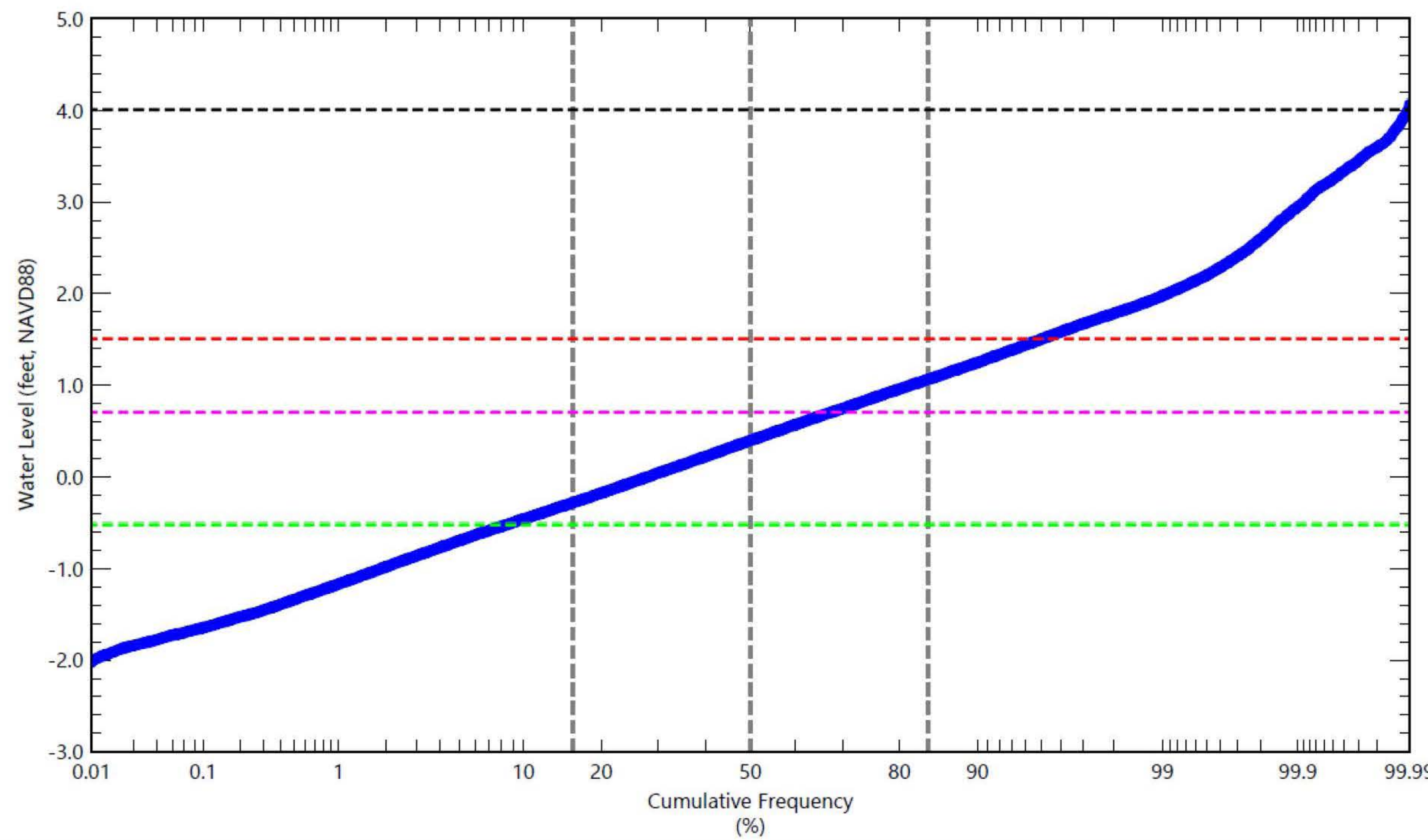


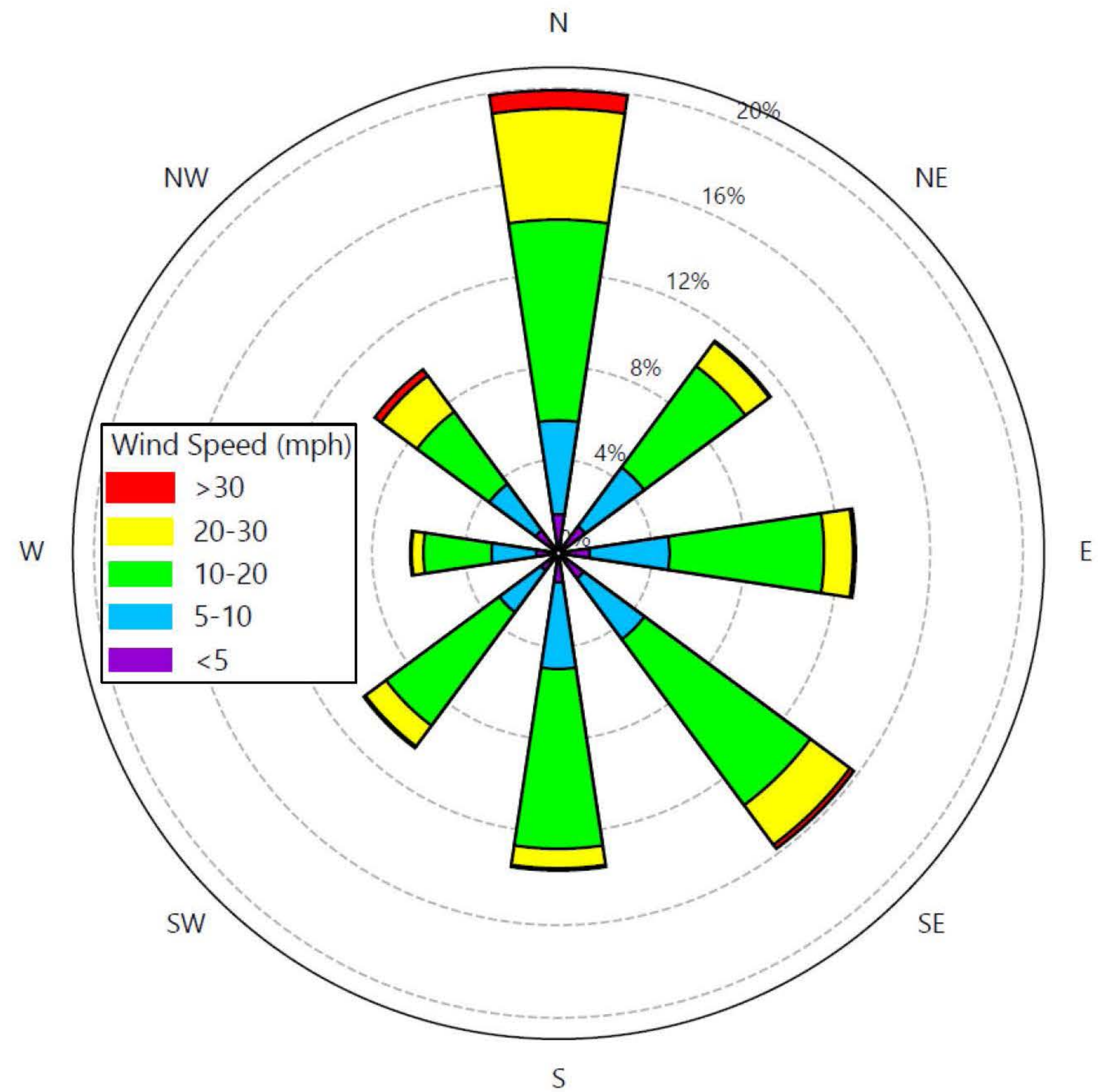
Figure 1
Coastal Setting and Data Stations



Notes: NAVD88: North American Vertical Datum of 1988, NOAA: National Oceanic and Atmospheric Administration, USACE SACS: U.S. Army Corps of Engineers South Atlantic Coastal Study

- NOAA 8735180, Dauphin Island, AL (November 2003–March 2023)
- 10-Year Water Level at USACE SACS Station 29987 (4.0 feet NAVD88)
- 95th Percentile Water Level at NOAA 8735180 (1.5 feet NAVD88)
- Mean Higher High Water at NOAA 8735180 (0.7 feet NAVD88)
- Mean Lower Low Water at NOAA 8735180 (-0.5 feet NAVD88)

Figure 2
Cumulative Frequency Distribution of Measured 6-Minute Water Levels Near Project Site



Notes:
1. Hourly Wind Data Obtained from NDBC Station MBLA1 for Years 2006 through 2022
2. Calm and Variable Winds: 0.4%
3. Maximum Recorded Wind Speed: 83.9 mph
4. Wind data are presented as the "blowing from" direction.

Figure 3
Wind Rose for NDBC Station MBLA1

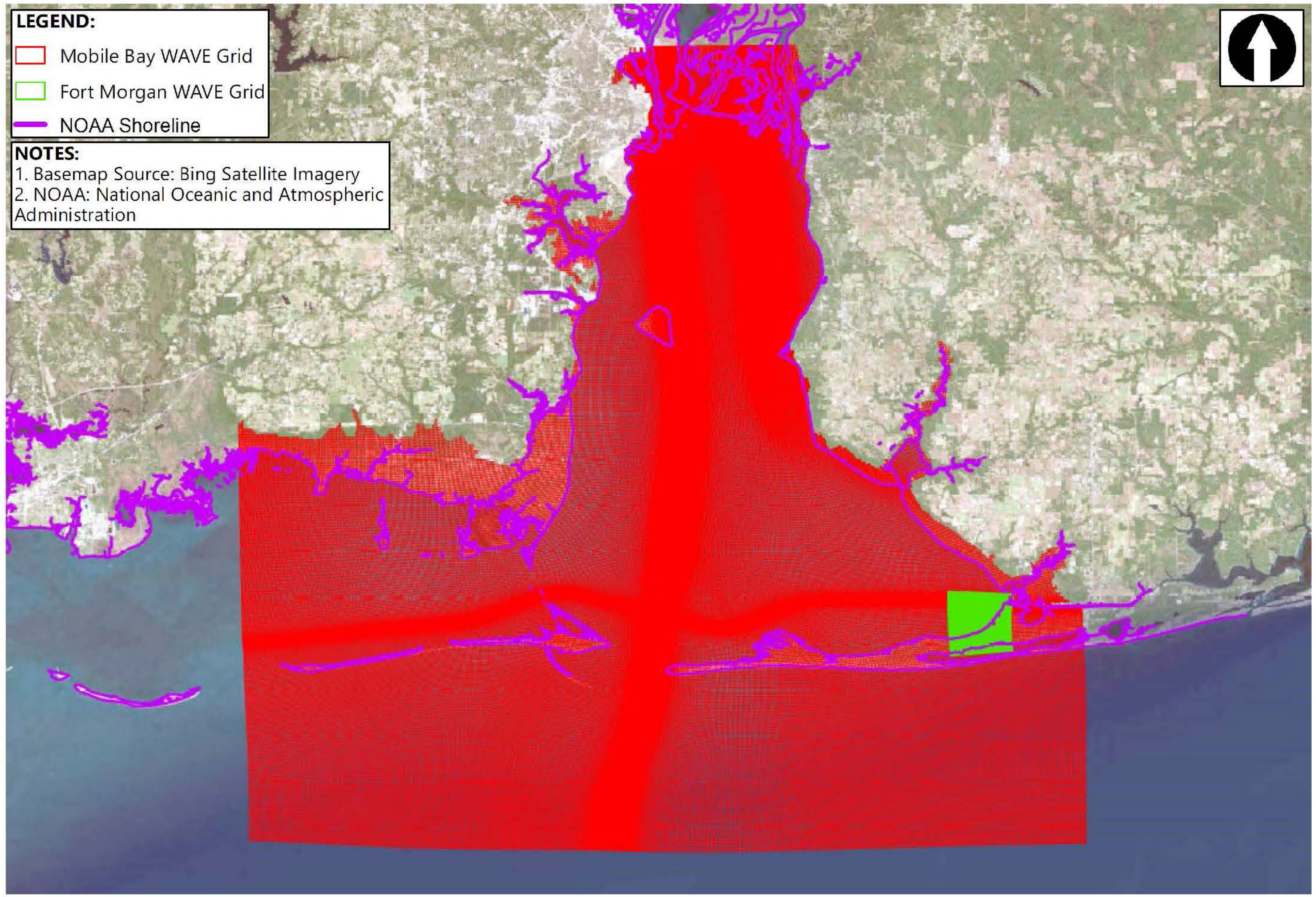


Figure 4
WAVE Model Grids

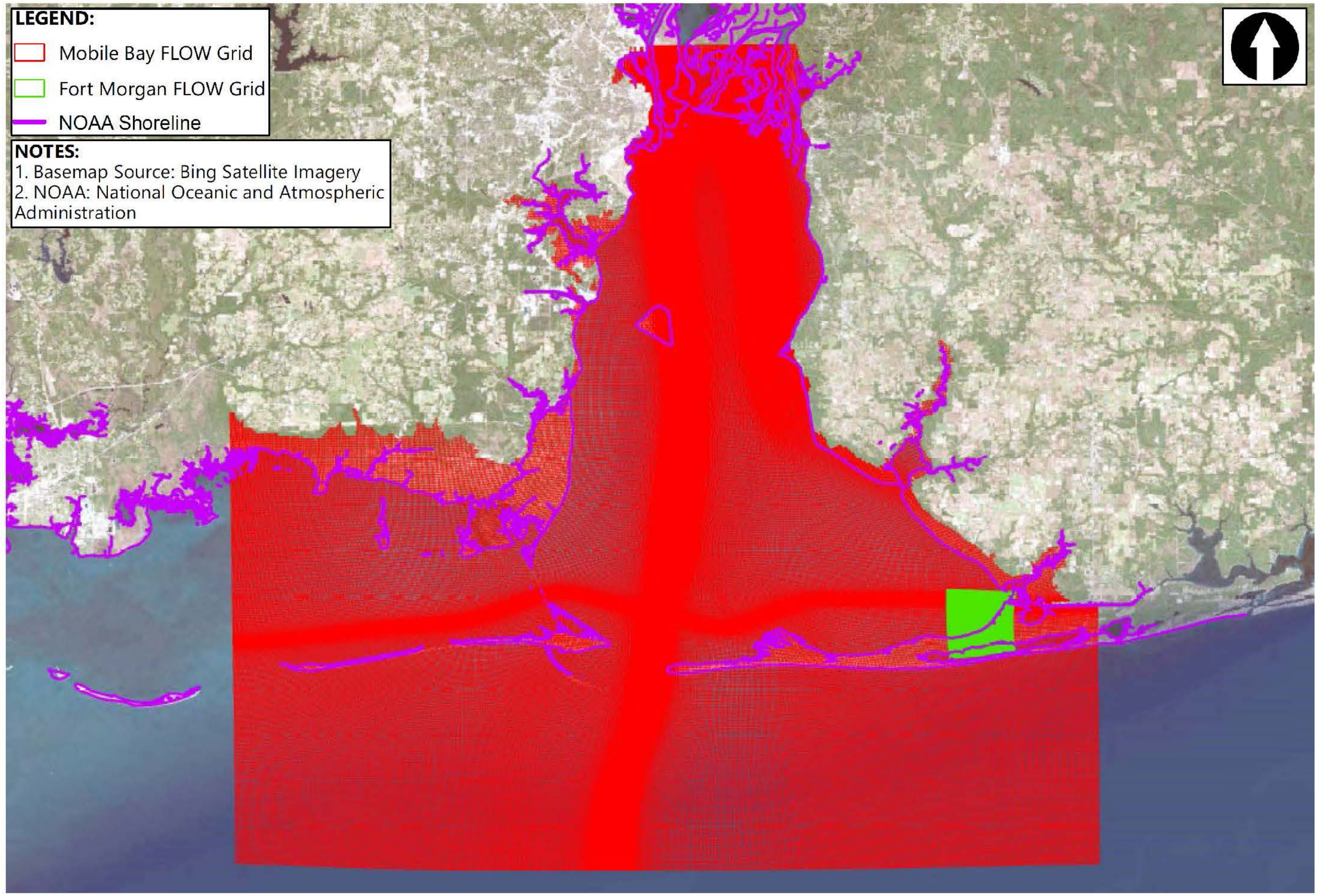


Figure 5
FLOW Model Grids

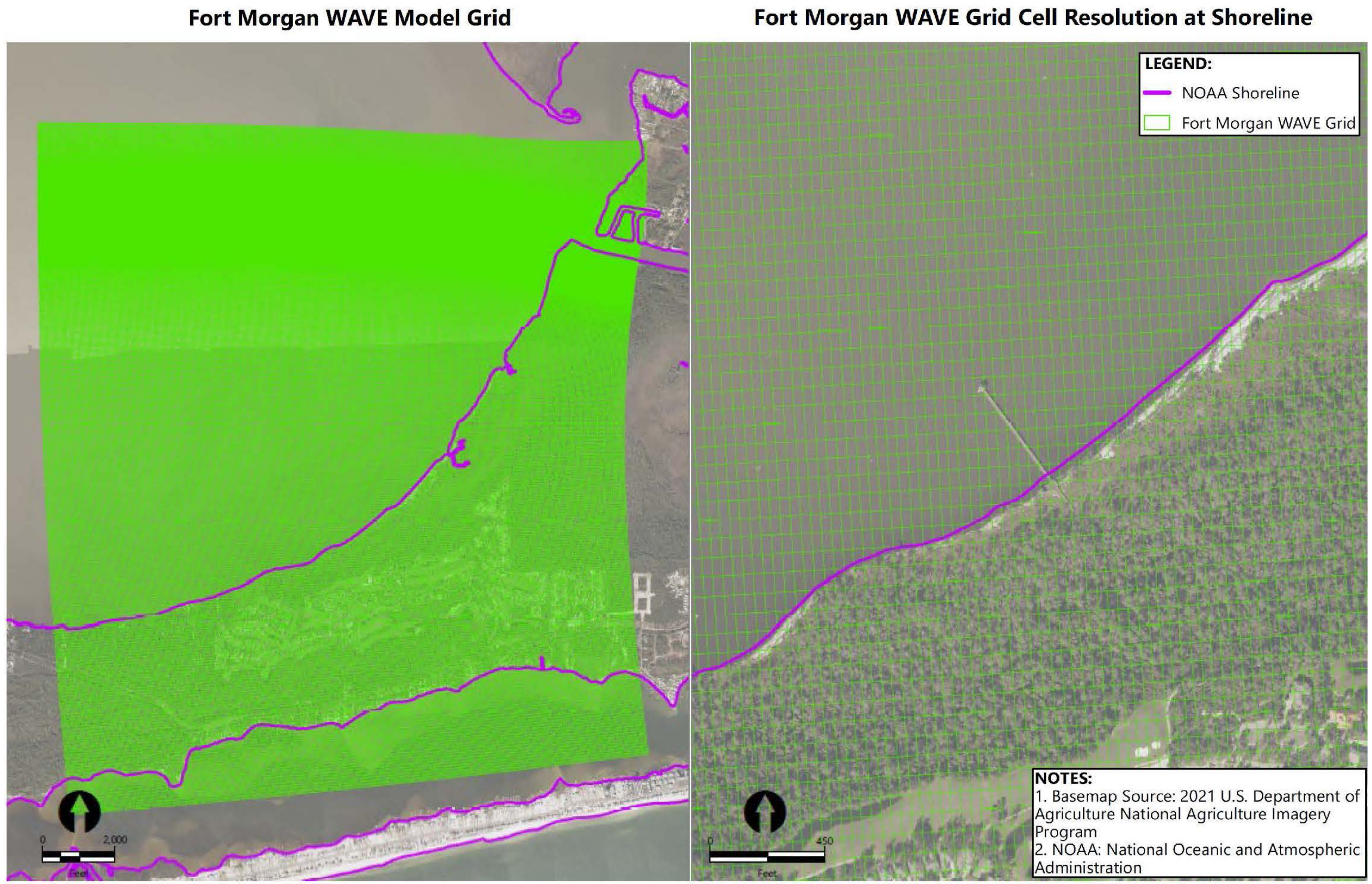


Figure 6
Fort Morgan WAVE Model Grid Resolution

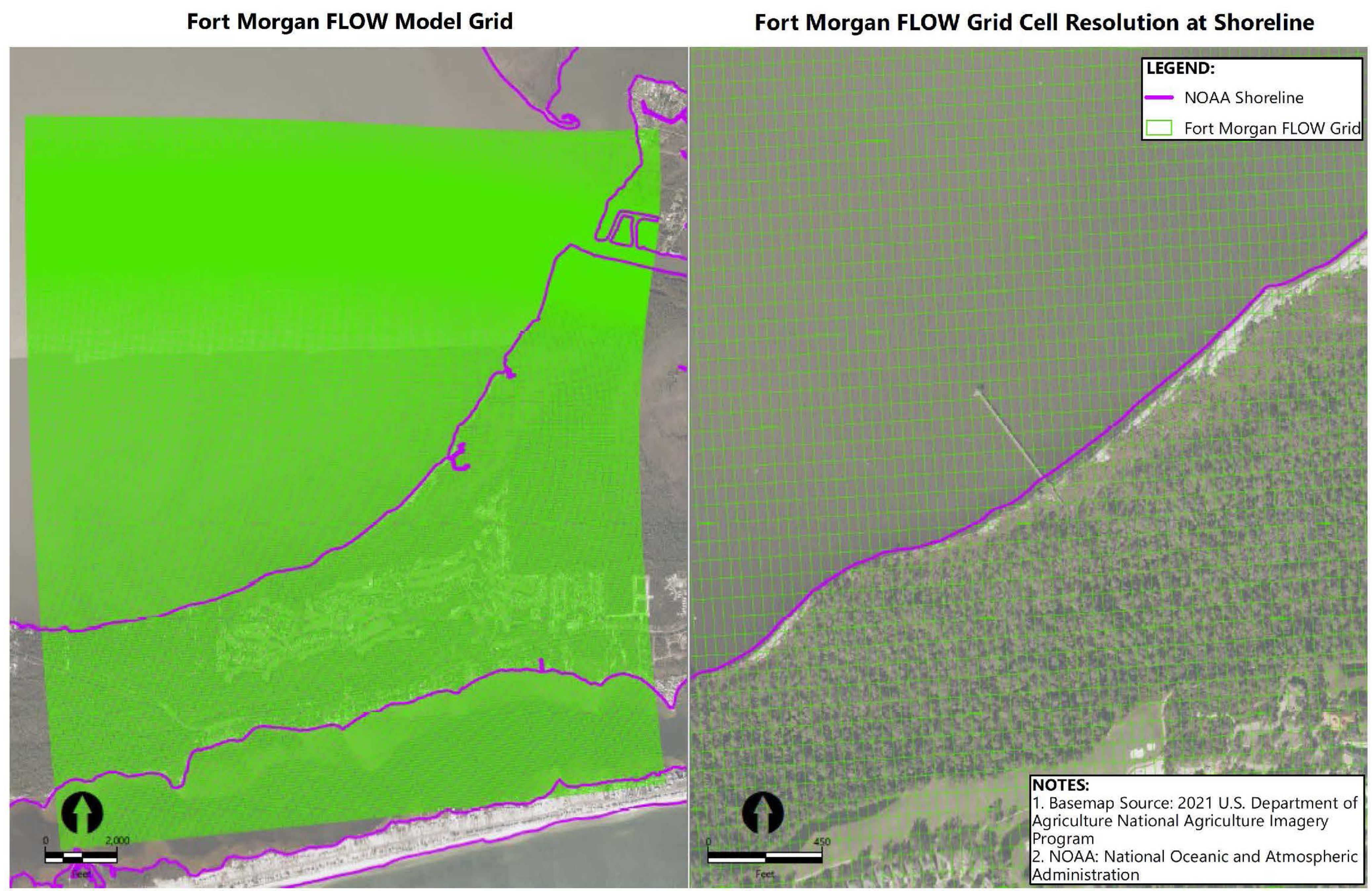


Figure 7
Fort Morgan FLOW Model Grid Resolution

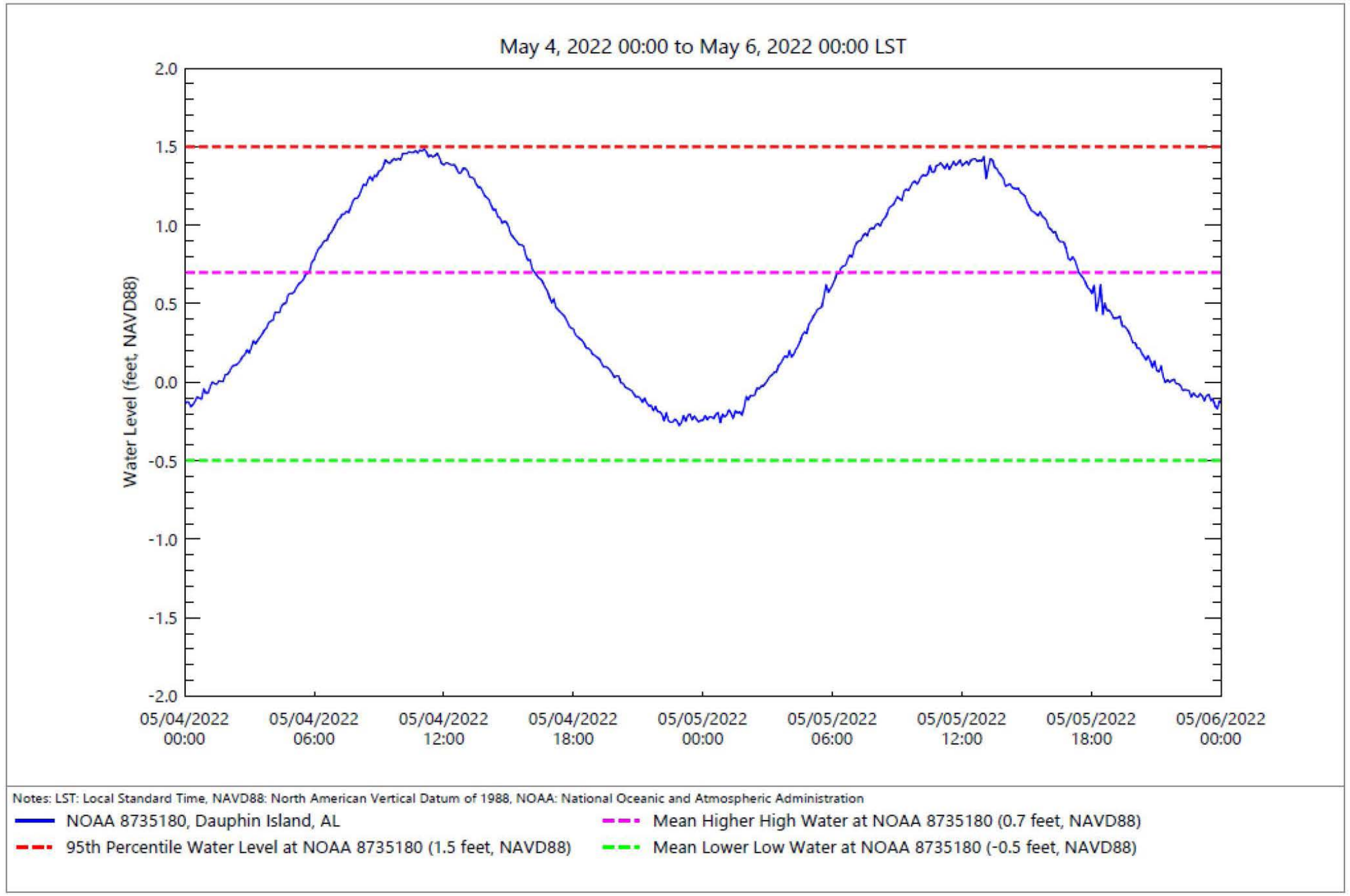


Figure 8
Measured 6-Minute Water Levels at Dauphin Island, Alabama, During Elevated Tide (May 2022)

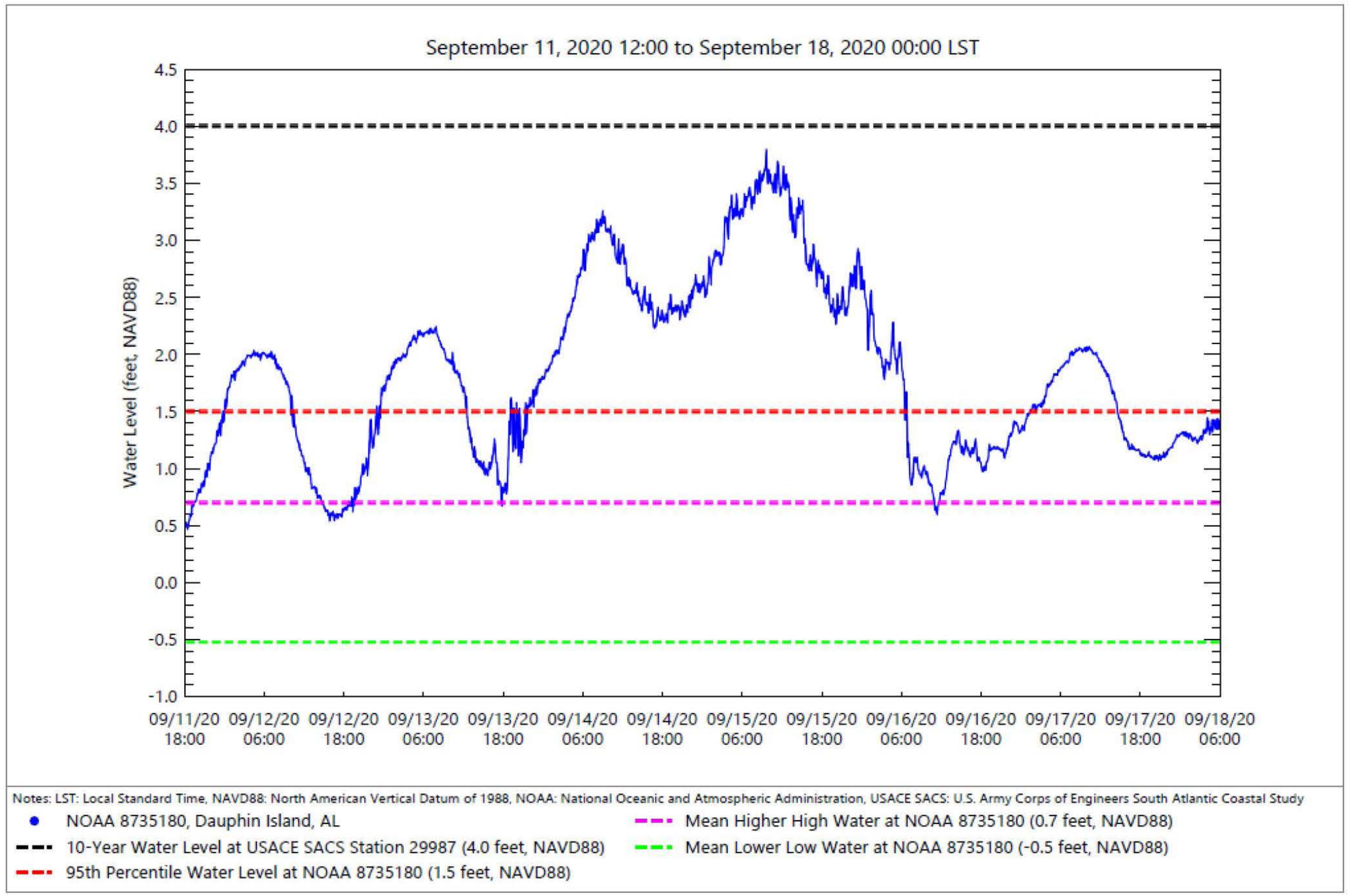


Figure 9
Measured 6-Minute Water Levels at Dauphin Island, Alabama, During Hurricane Sally (September 2020)

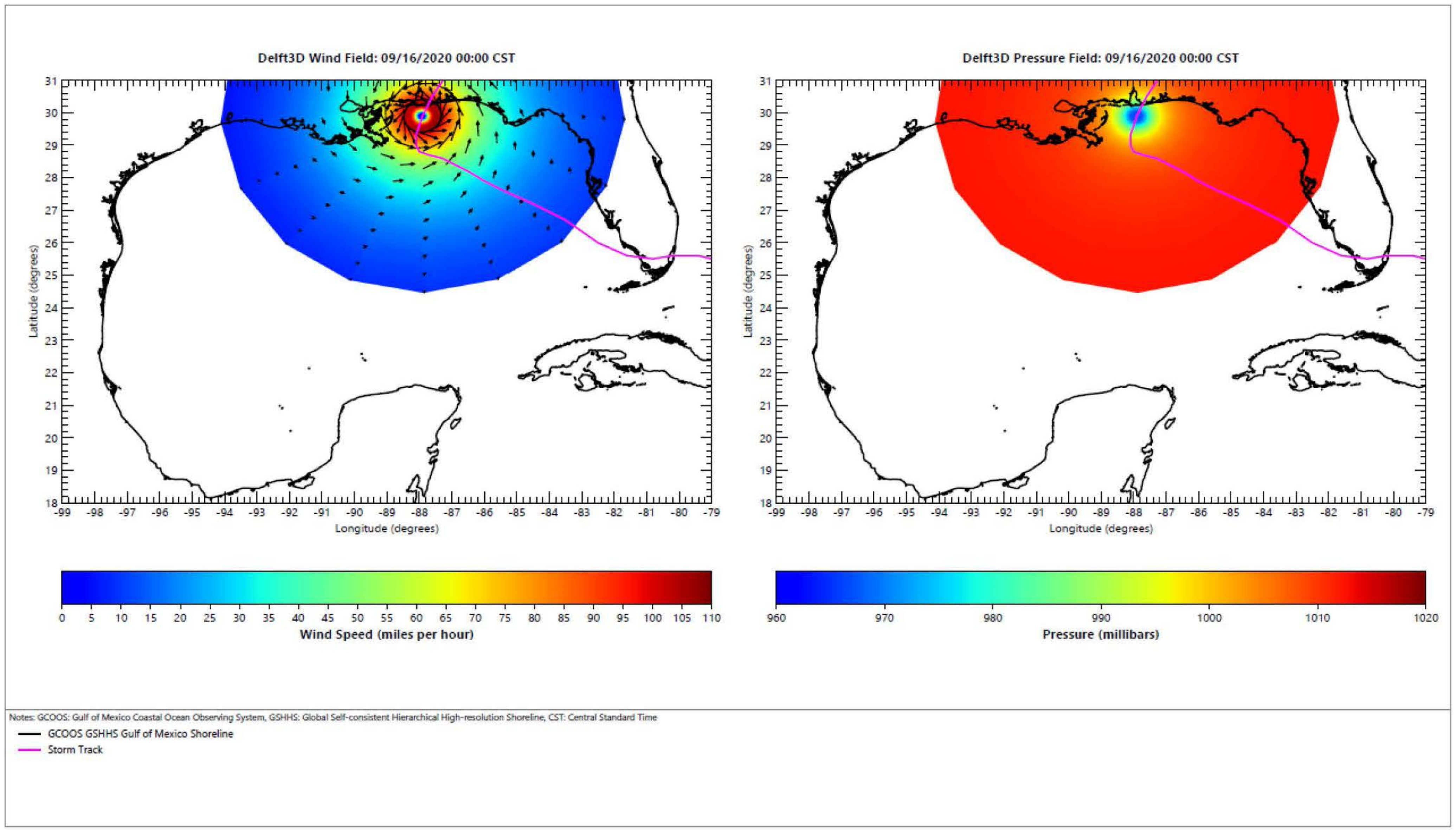


Figure 10
Delft3D Wind and Pressure Fields for Hurricane Sally: 09/16/2020 0000 CST

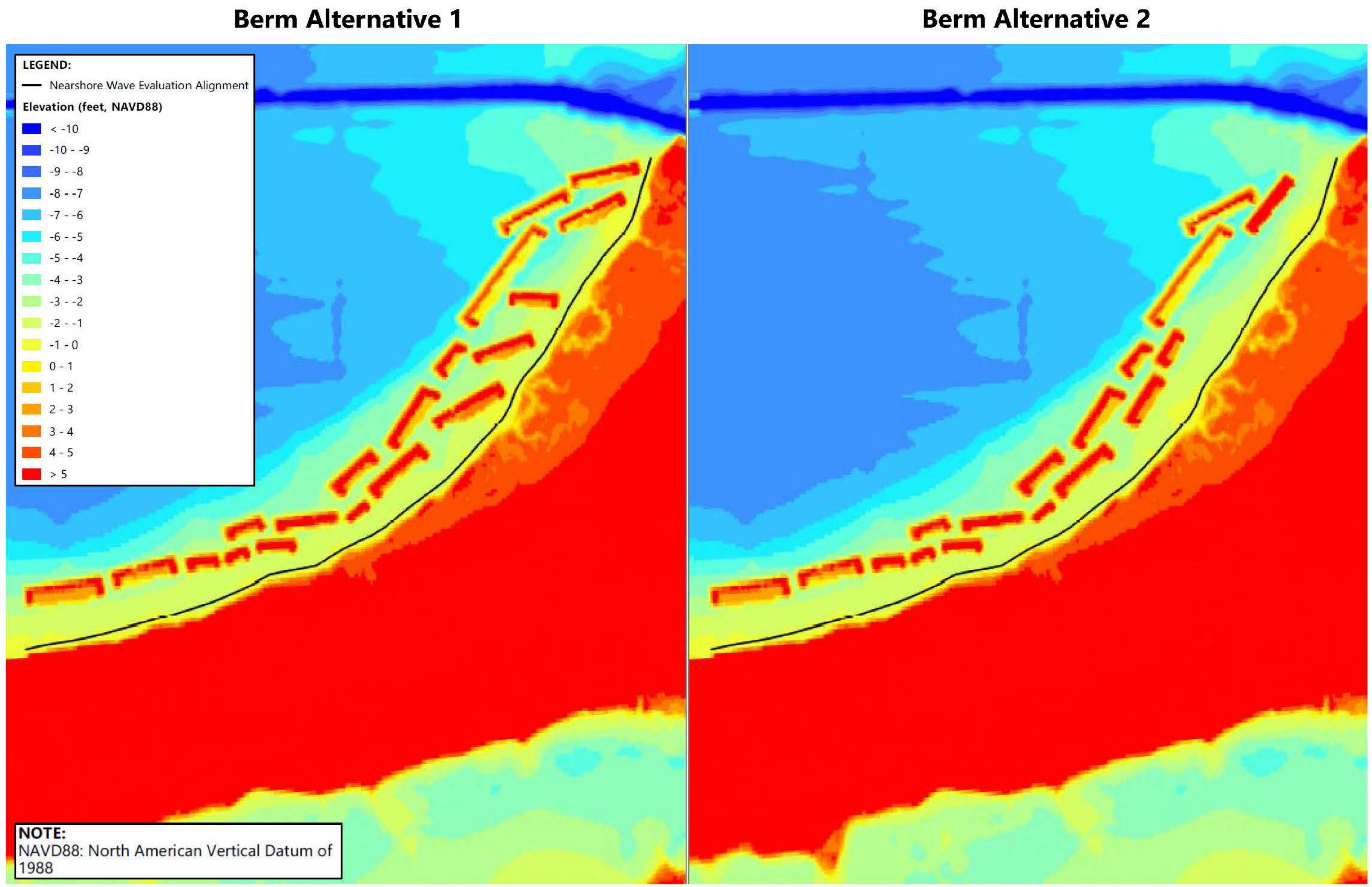


Figure 11
Proposed Beneficial Use Alternatives

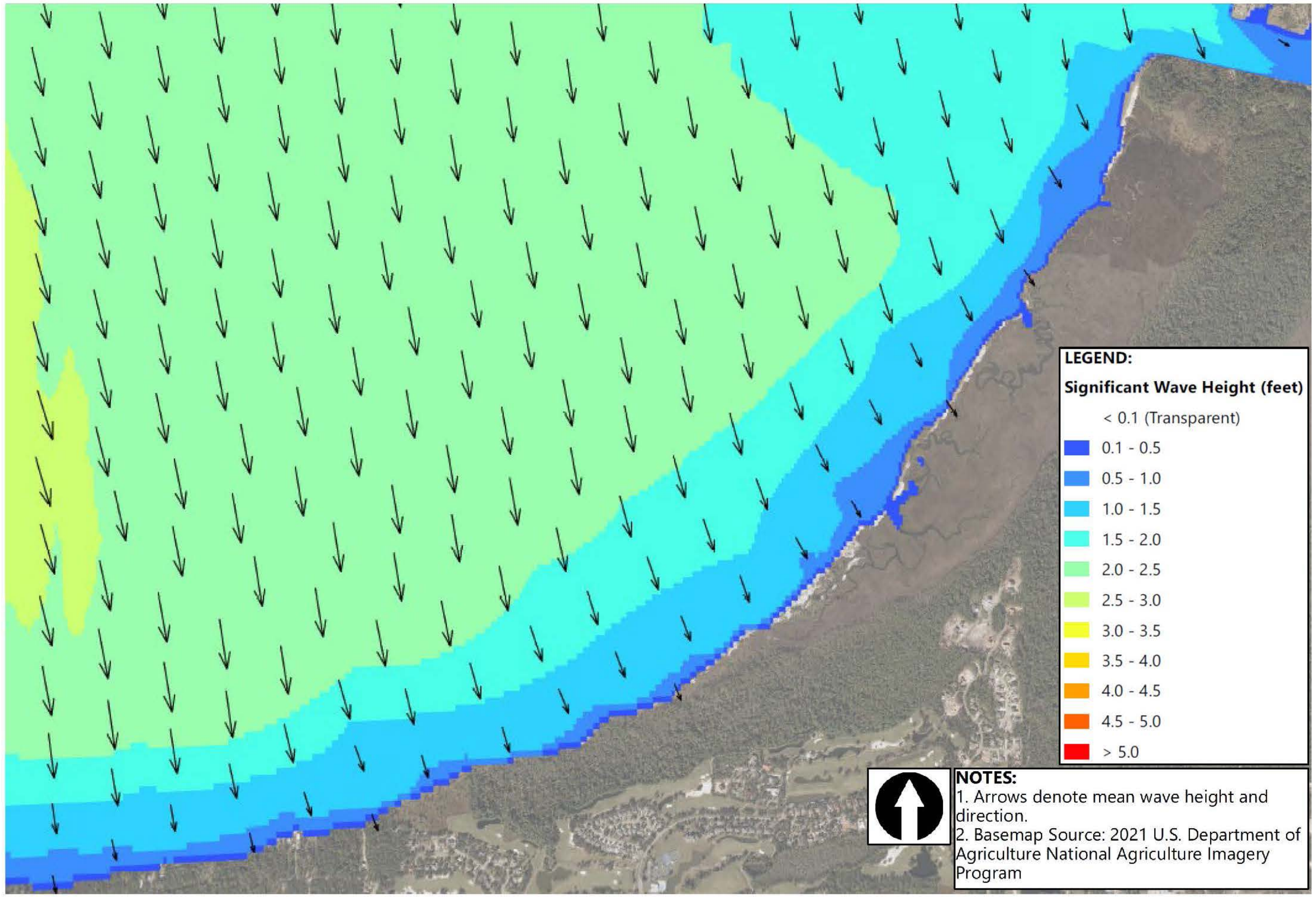


Figure 12a
Wave Height Results: Annual Storm from the North, Existing Condition

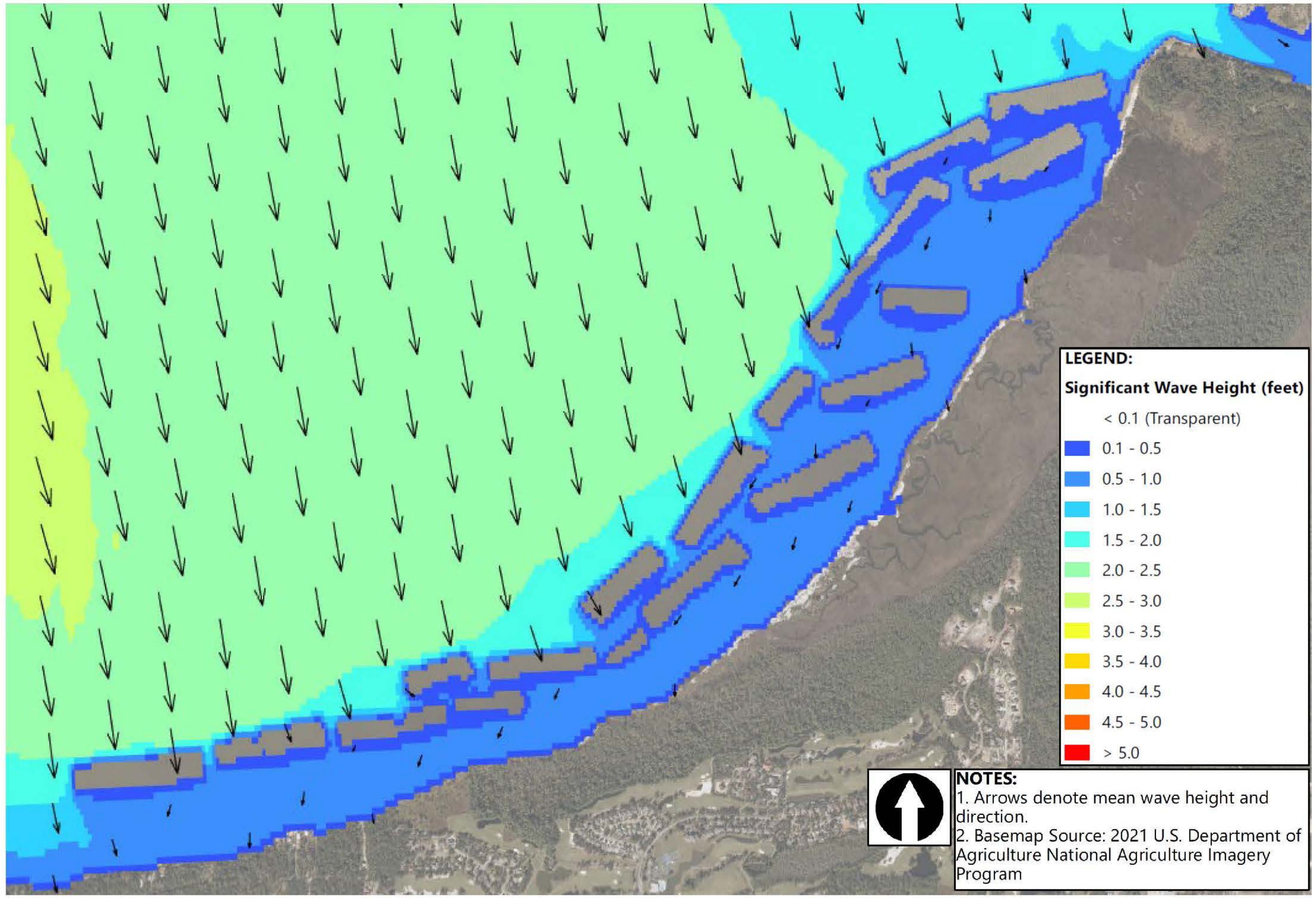


Figure 12b
Wave Height Results: Annual Storm from the North, Proposed Condition–Berm Alternative 1

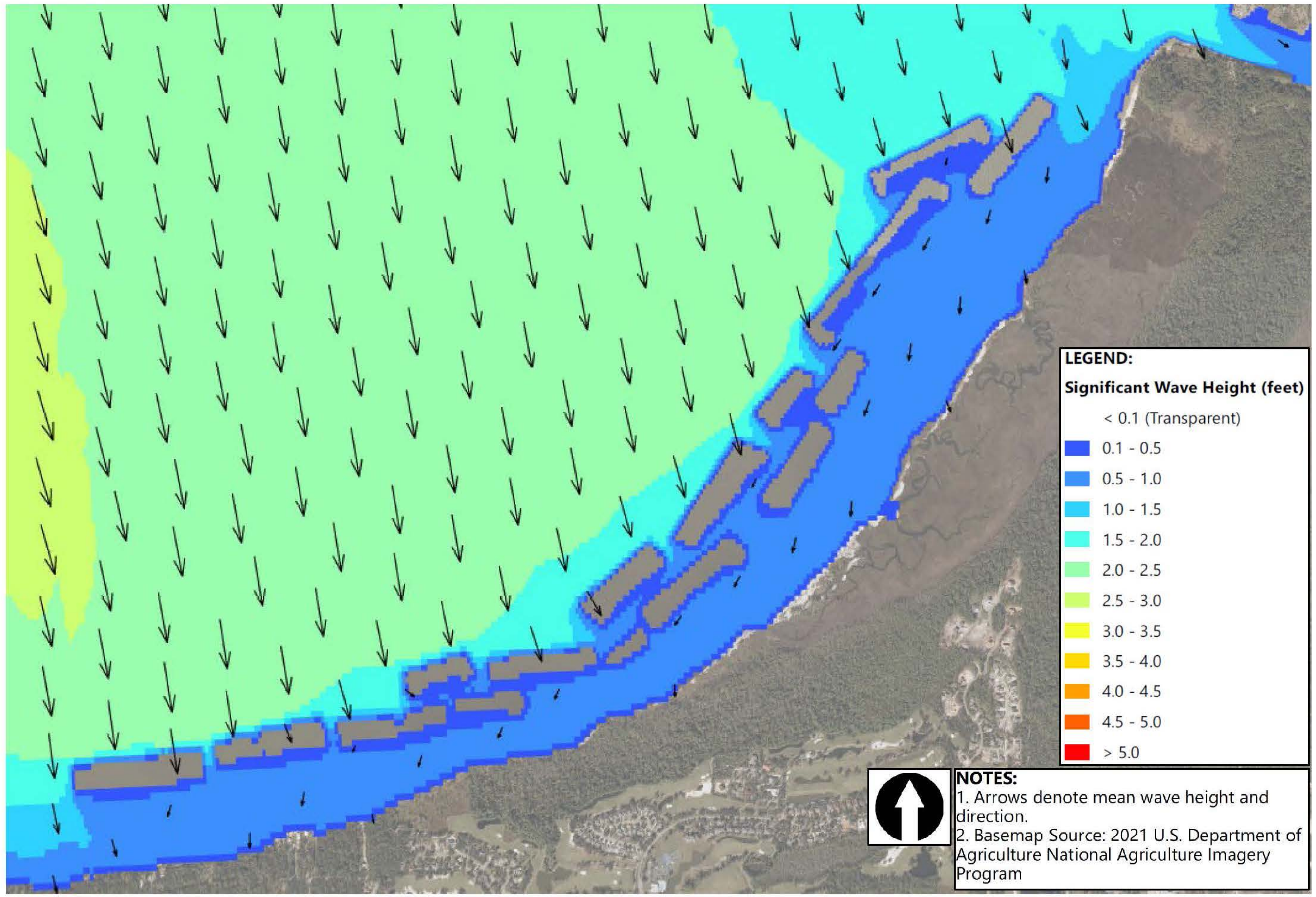


Figure 12c
Wave Height Results: Annual Storm from the North, Proposed Condition–Berm Alternative 2

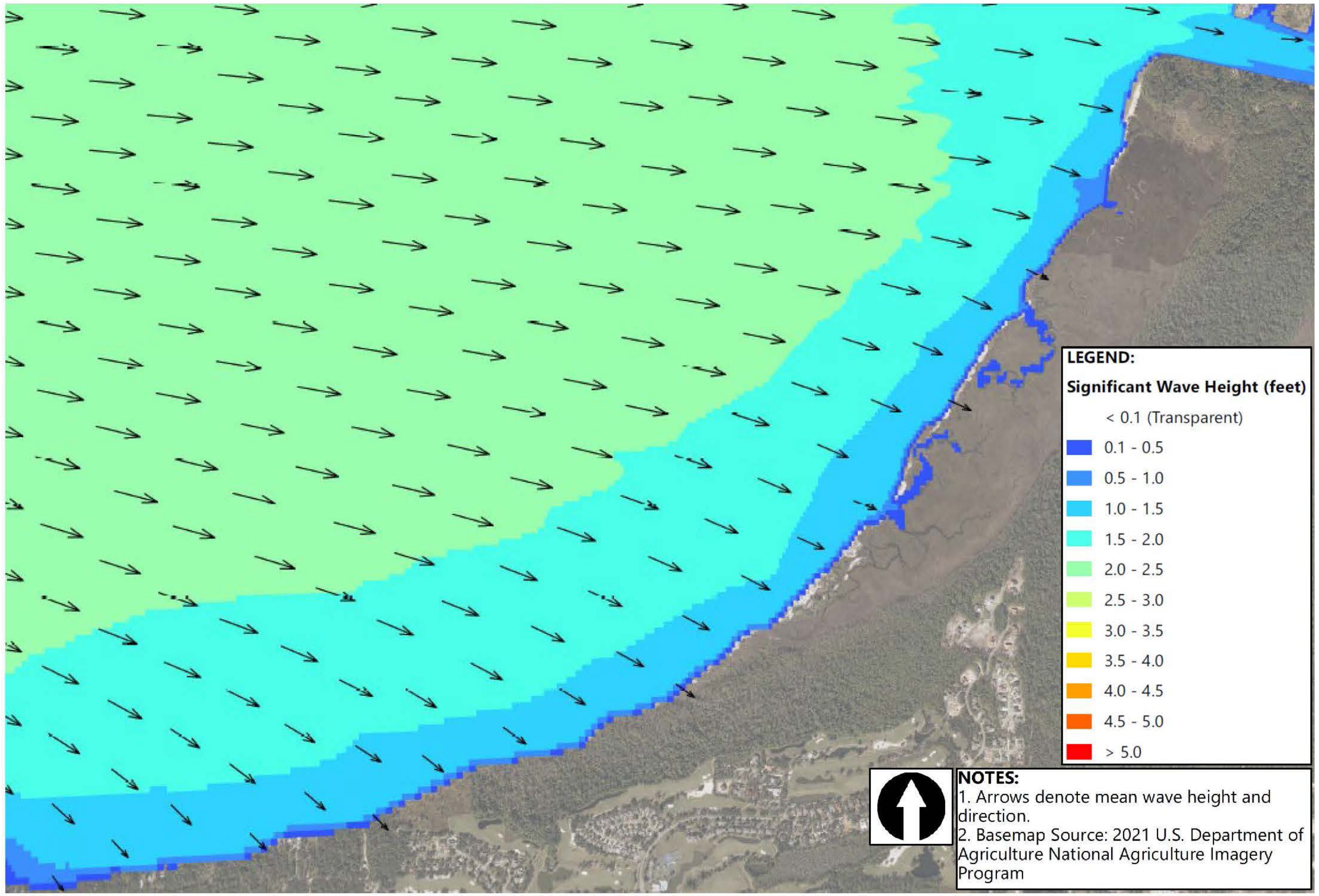


Figure 13a
Wave Height Results: Annual Storm from the West, Existing Condition

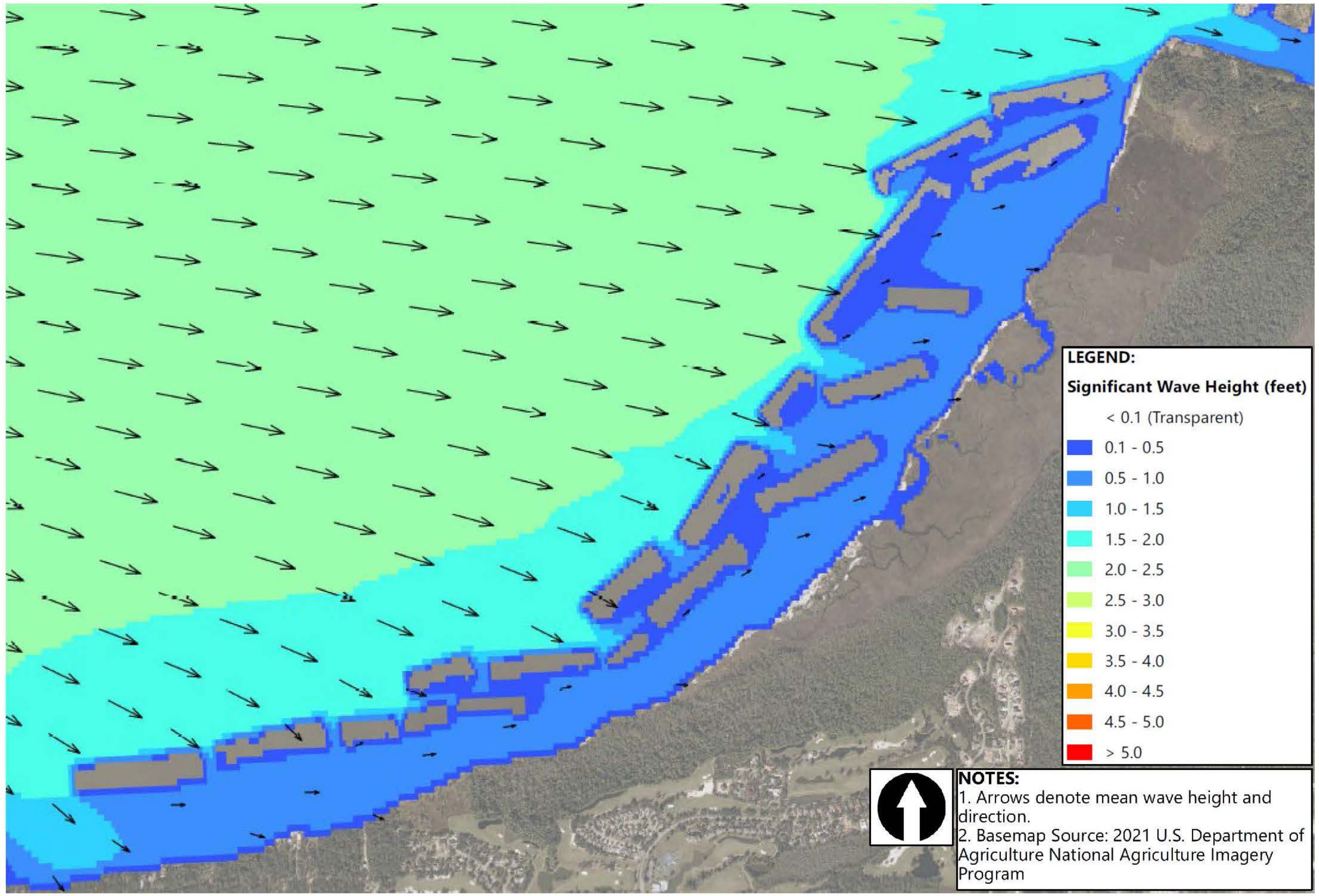


Figure 13b
Wave Height Results: Annual Storm from the West, Proposed Condition–Berm Alternative 1

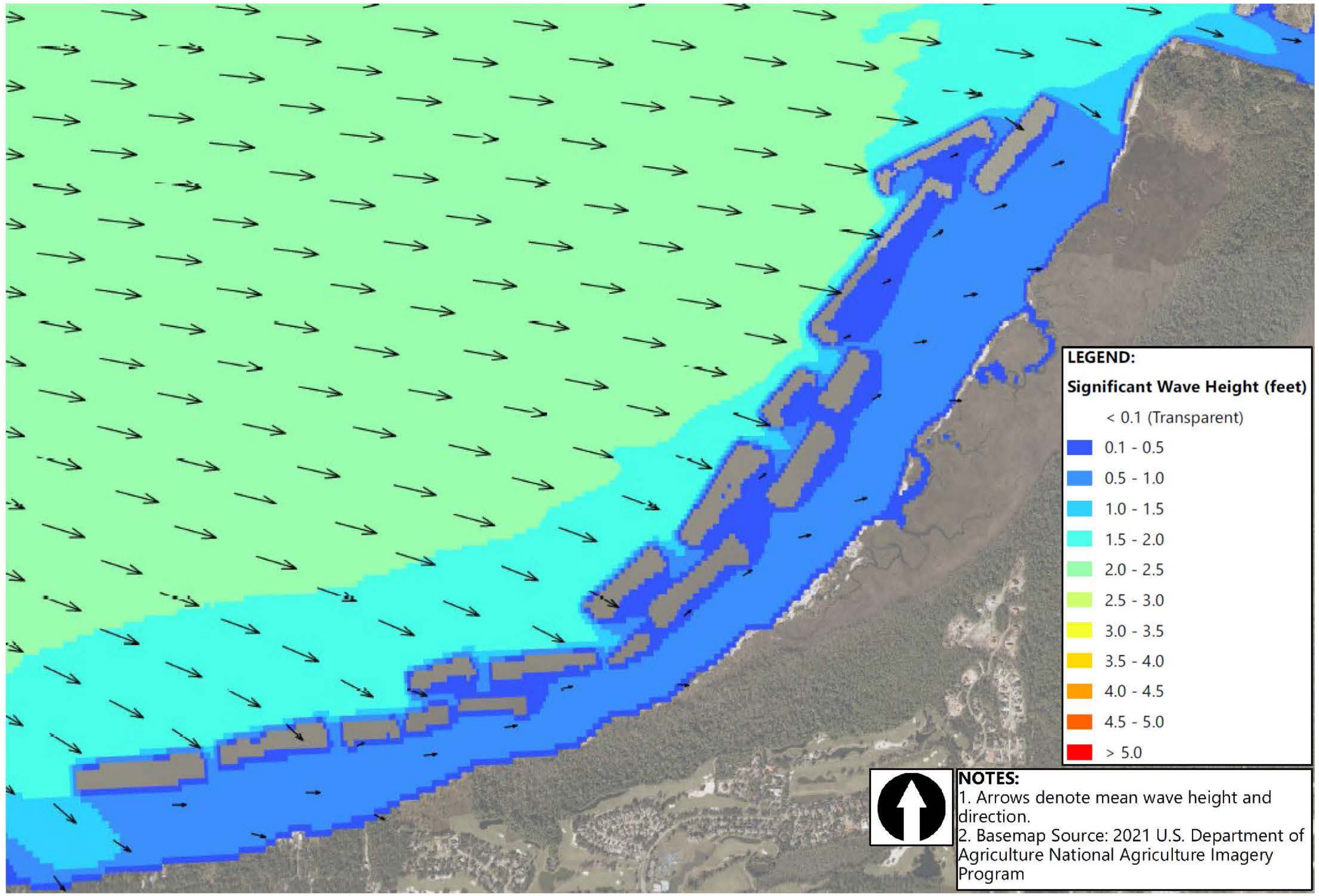


Figure 13c
Wave Height Results: Annual Storm from the West, Proposed Condition–Berm Alternative 2

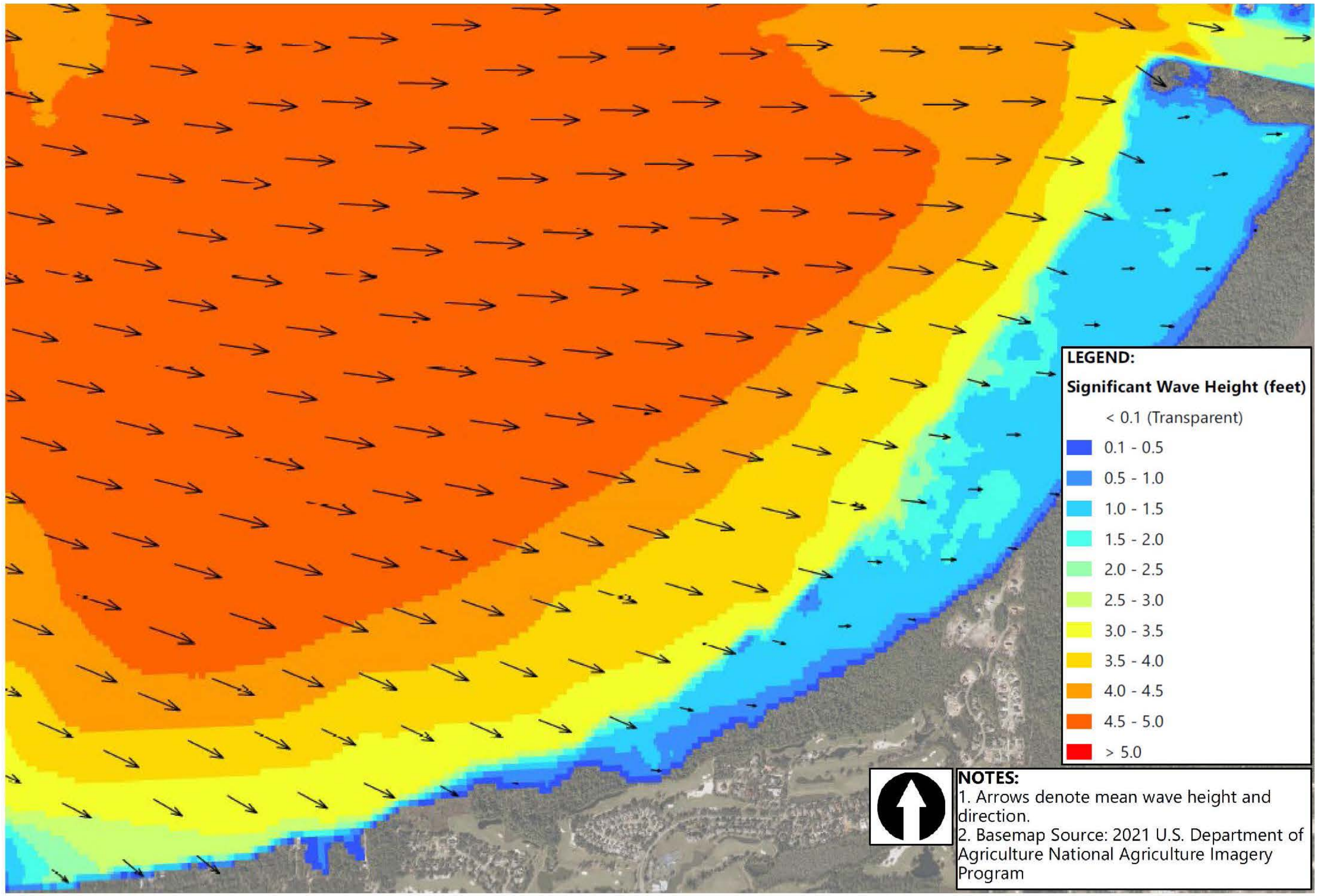


Figure 14a
Wave Height Results: Hurricane Sally, Existing Condition

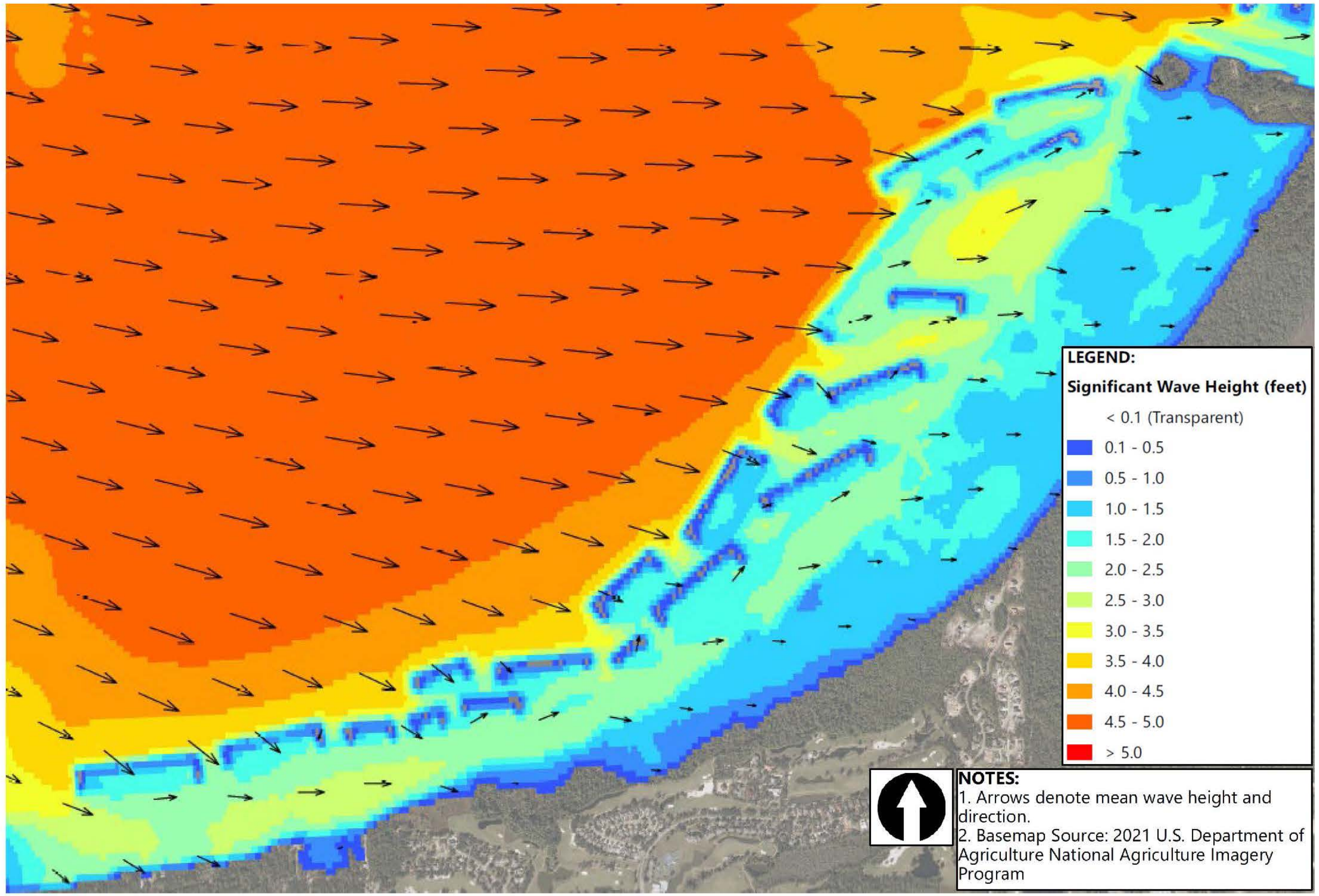


Figure 14b
Wave Height Results: Hurricane Sally, Proposed Condition–Berm Alternative 1

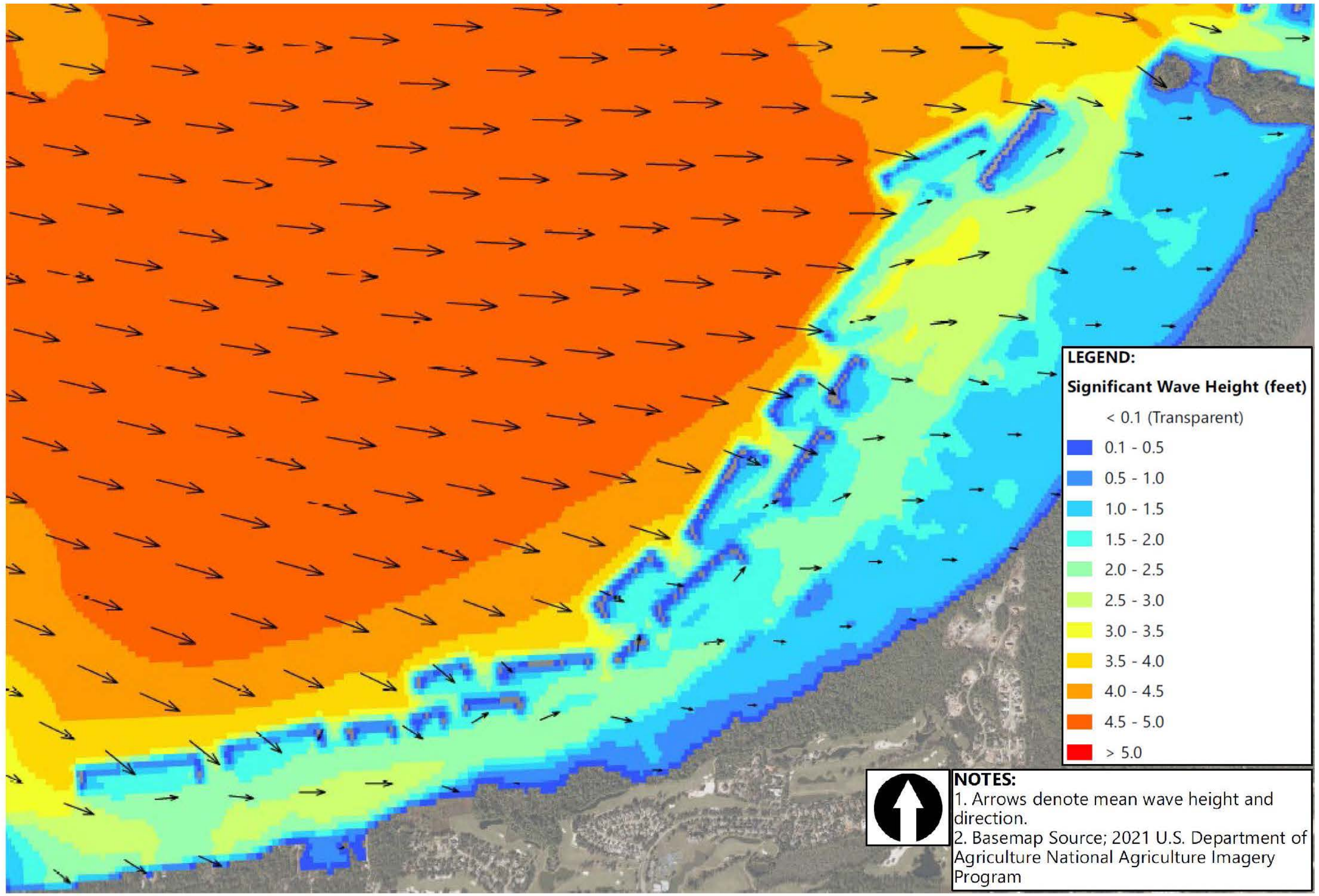


Figure 14c
Wave Height Results: Hurricane Sally, Proposed Condition–Berm Alternative 2

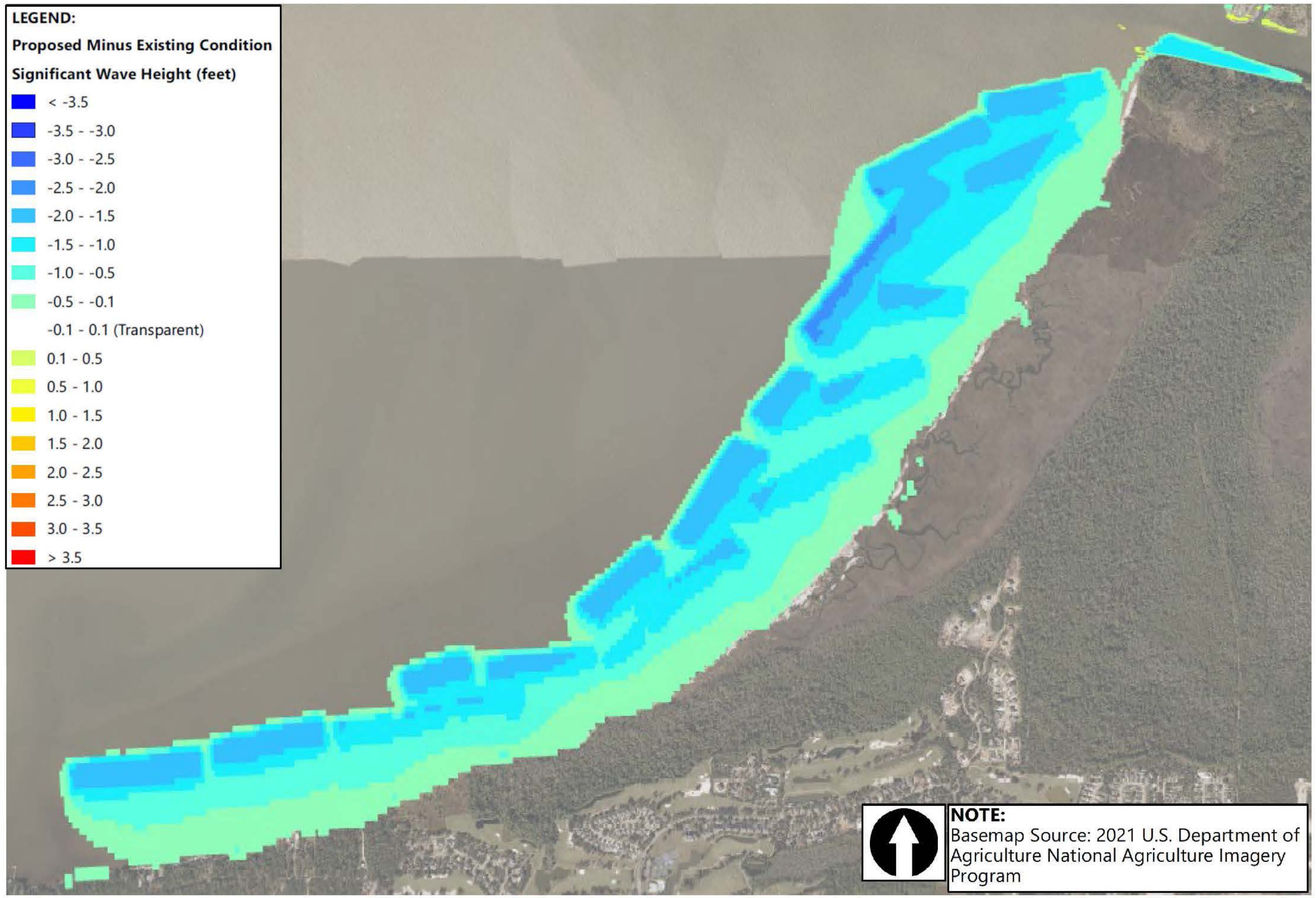


Figure 15a
Wave Height Difference Results: Annual Storm from the North, Proposed Versus Existing Condition–Berm Alternative 1

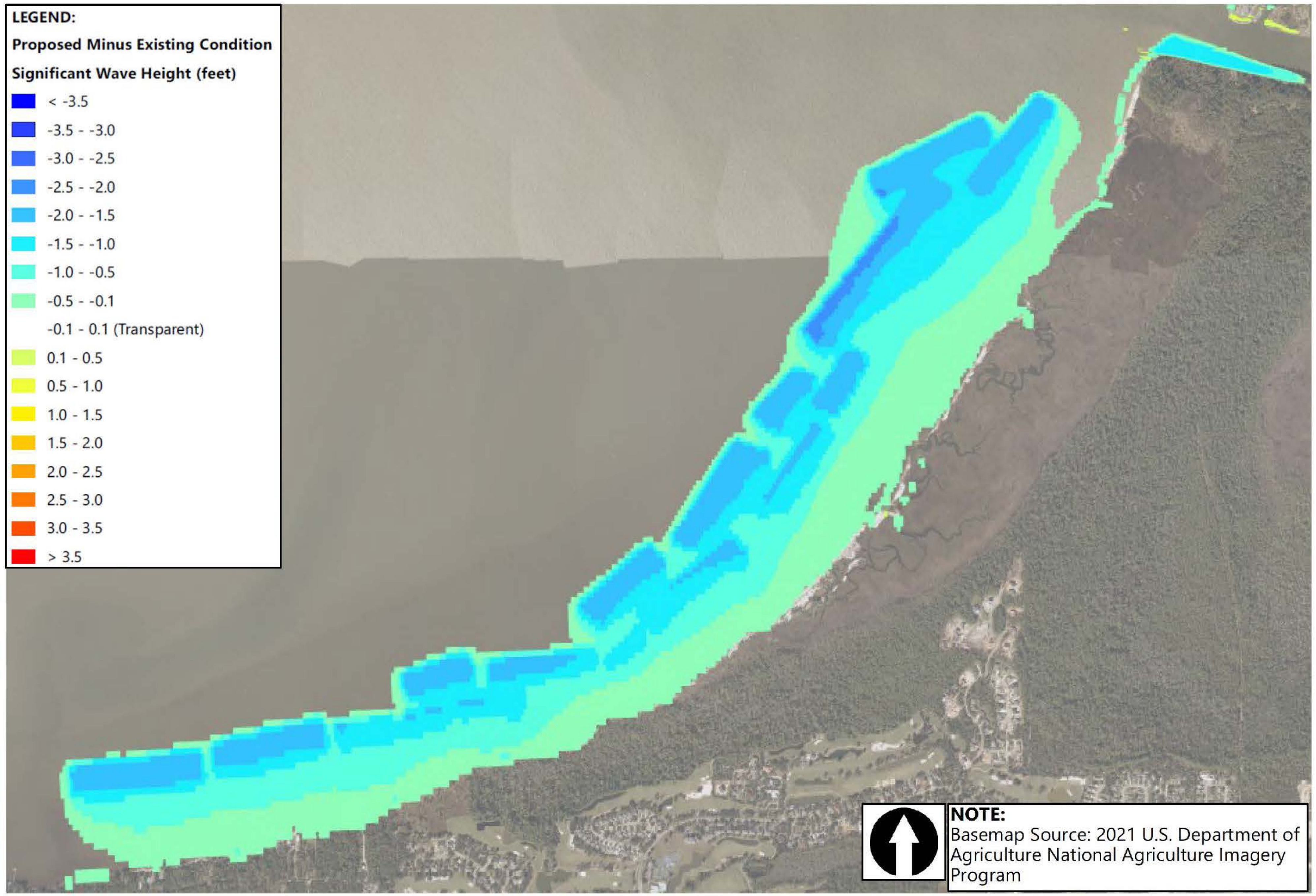


Figure 15b
Wave Height Difference Results: Annual Storm from the North, Proposed Versus Existing Condition–Berm Alternative 2

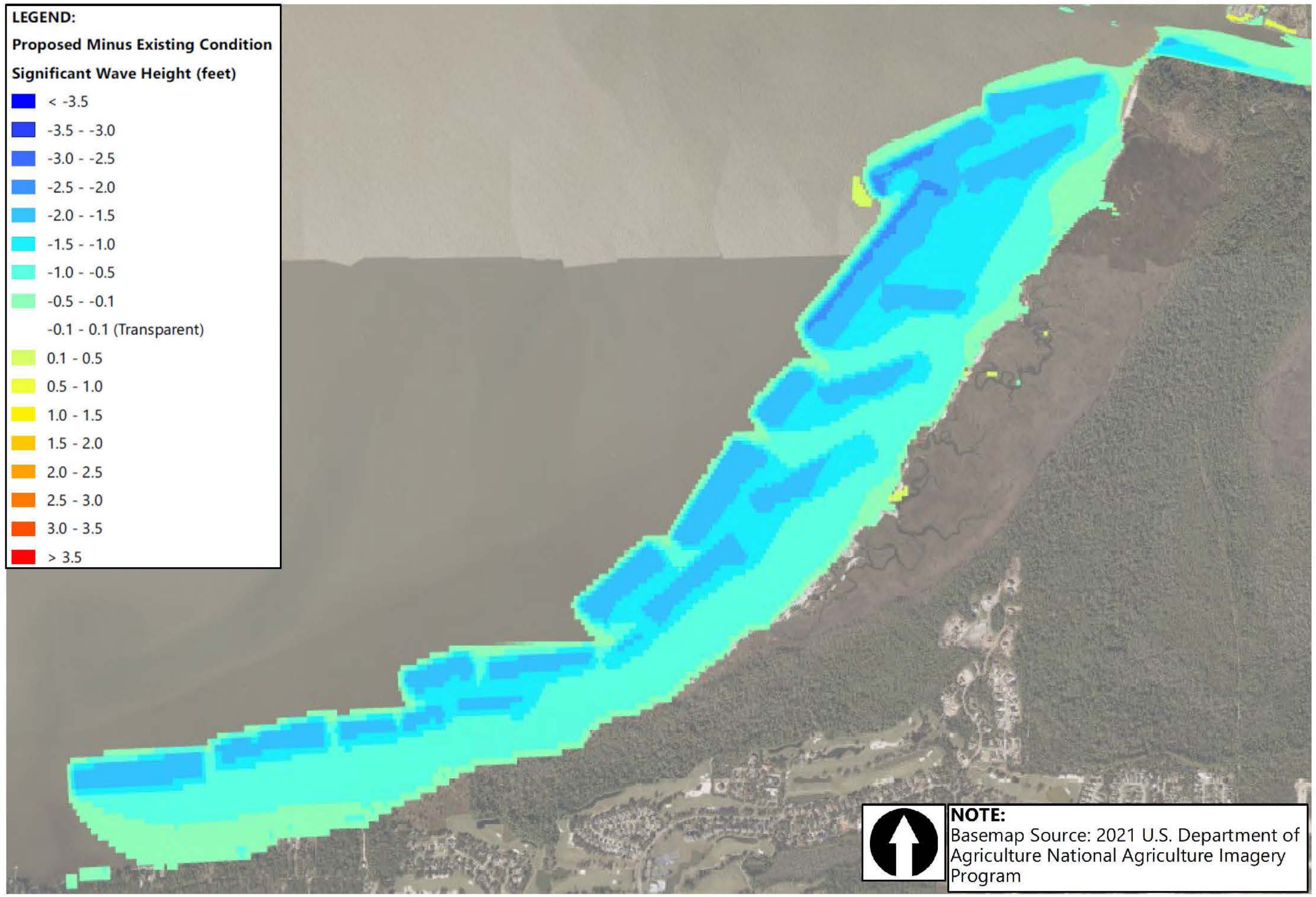


Figure 15c
Wave Height Difference Results: Annual Storm from the West, Proposed Versus Existing Condition–Berm Alternative 1

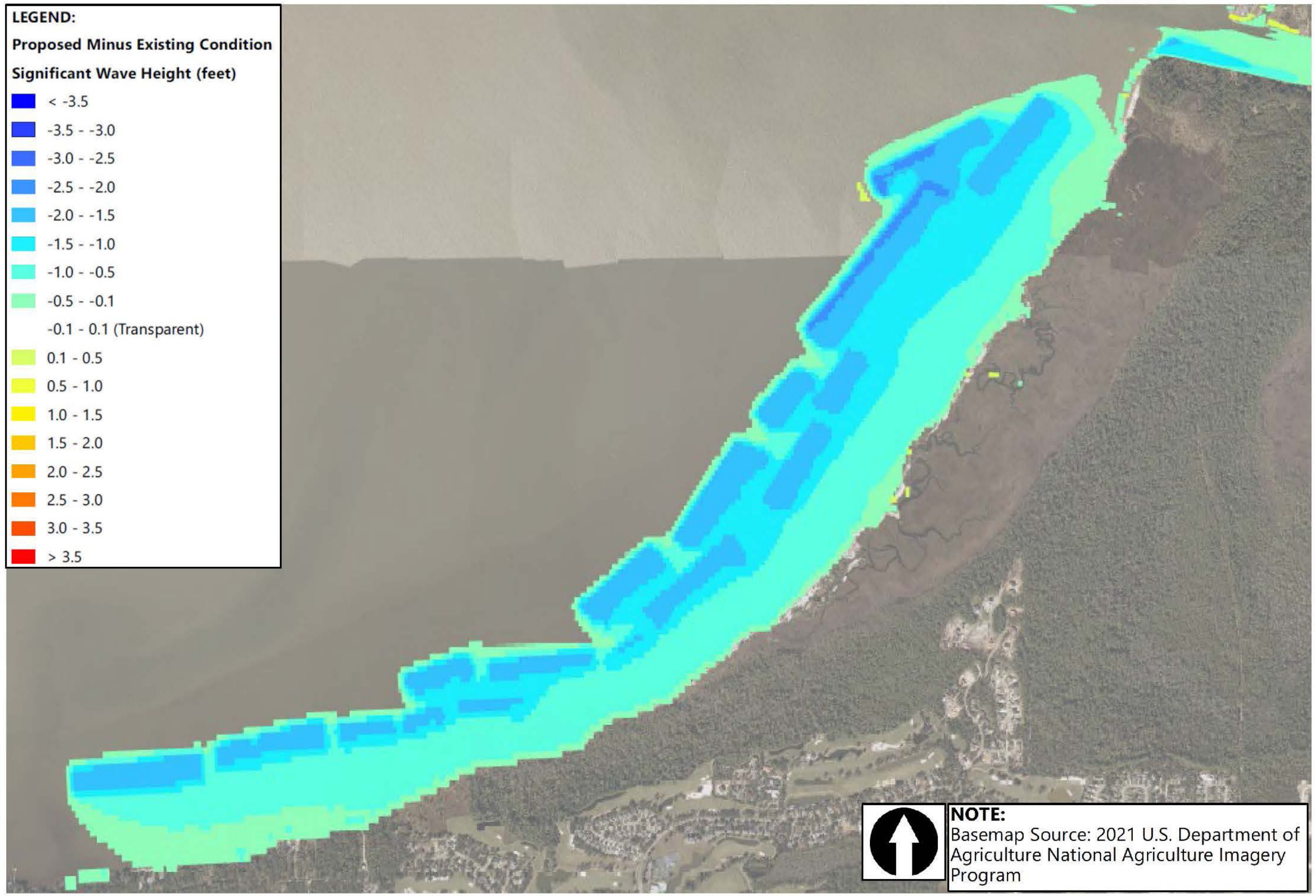


Figure 15d
Wave Height Difference Results: Annual Storm from the West, Proposed Versus Existing Condition–Berm Alternative 2

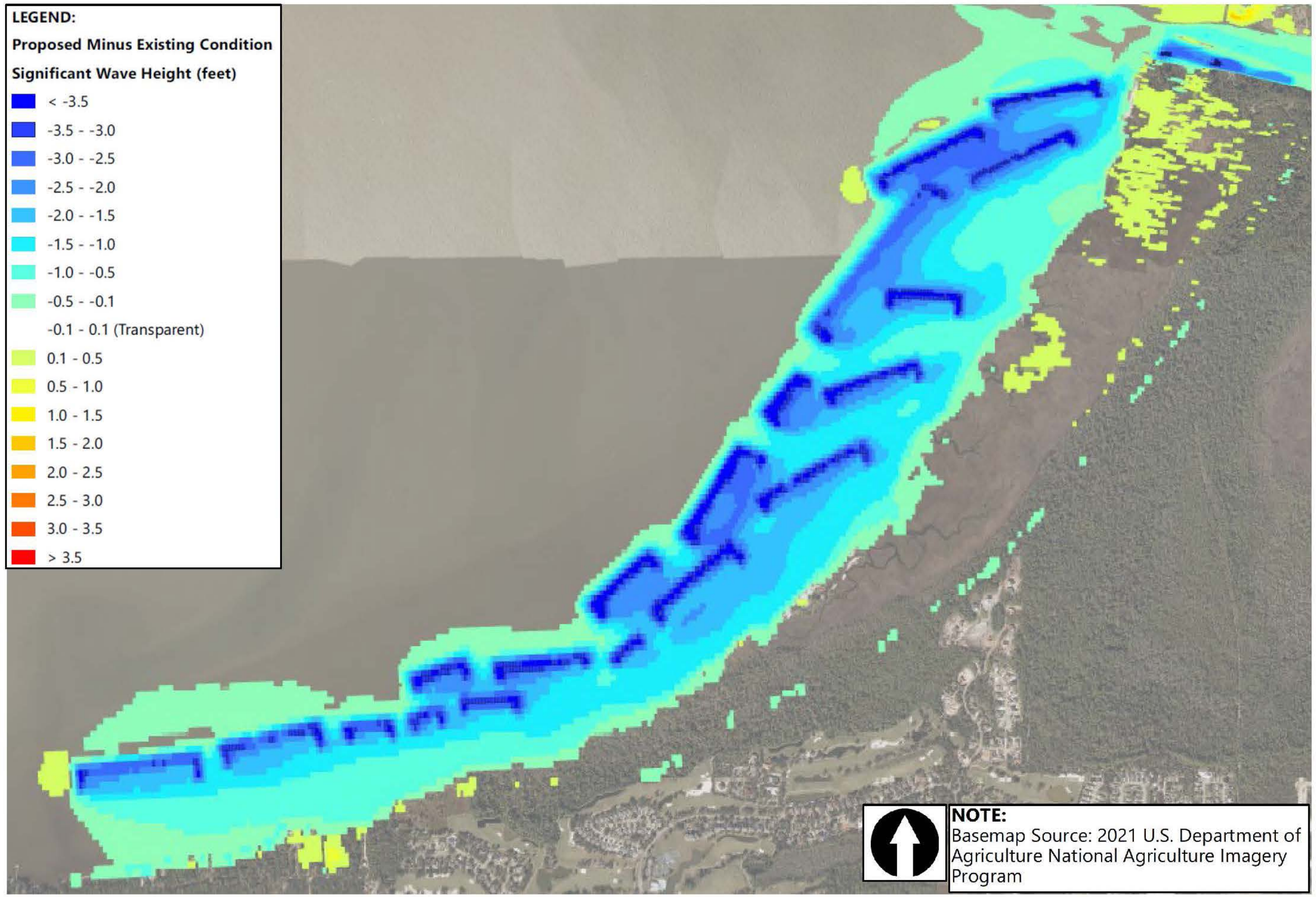


Figure 15e
Wave Height Difference Results: Hurricane Sally, Proposed Versus Existing Condition–Berm Alternative 1

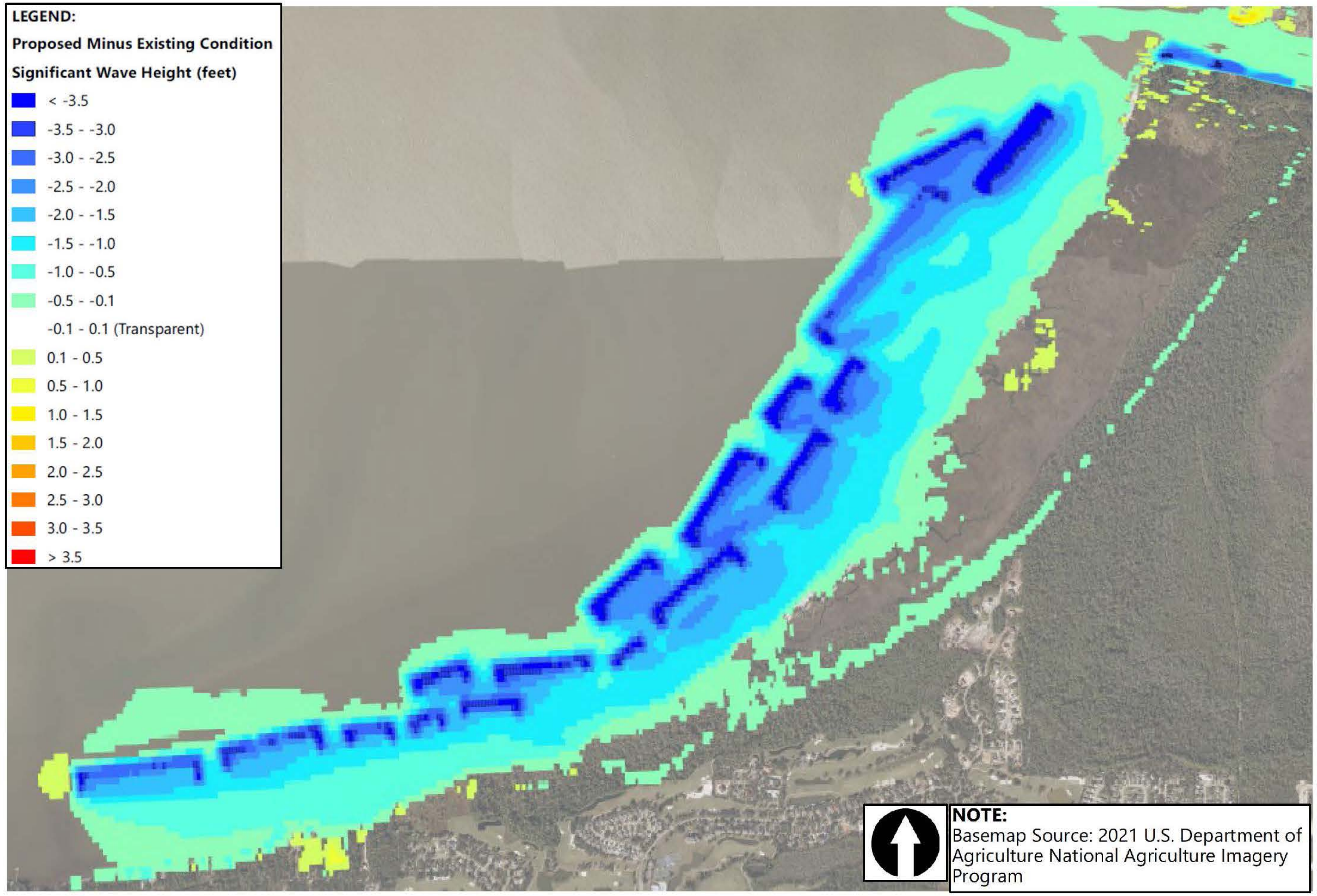
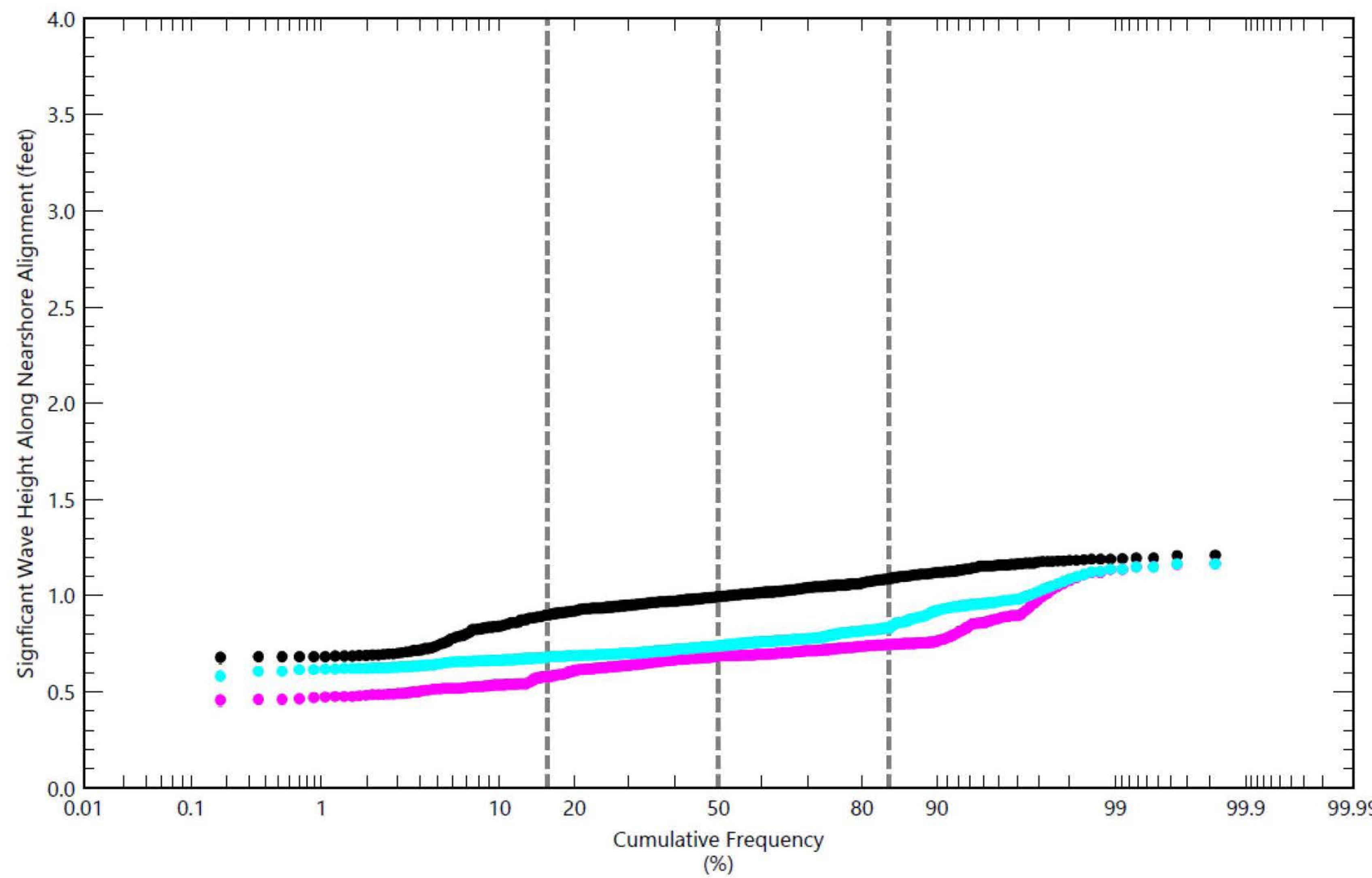


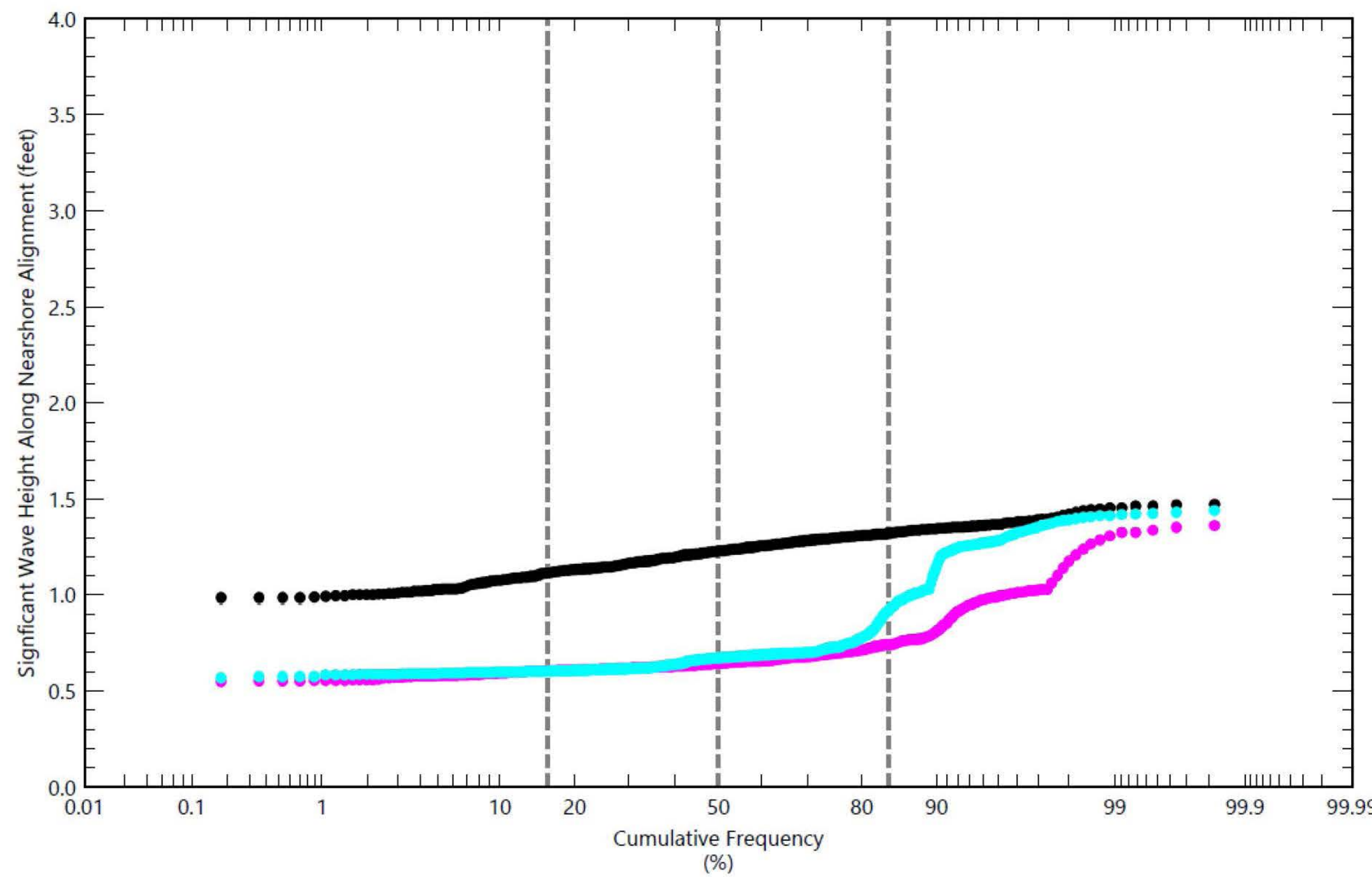
Figure 15f
Wave Height Difference Results: Hurricane Sally, Proposed Versus Existing Condition–Berm Alternative 1



Note: Nearshore breakwater alignment is located approximately 150 feet offshore of the existing shoreline.

- Existing Condition (Median: 1.0 feet)
- Proposed Condition: Berm Alternative 01 (Median: 0.7 foot)
- Proposed Condition: Berm Alternative 02 (Median: 0.7 foot)

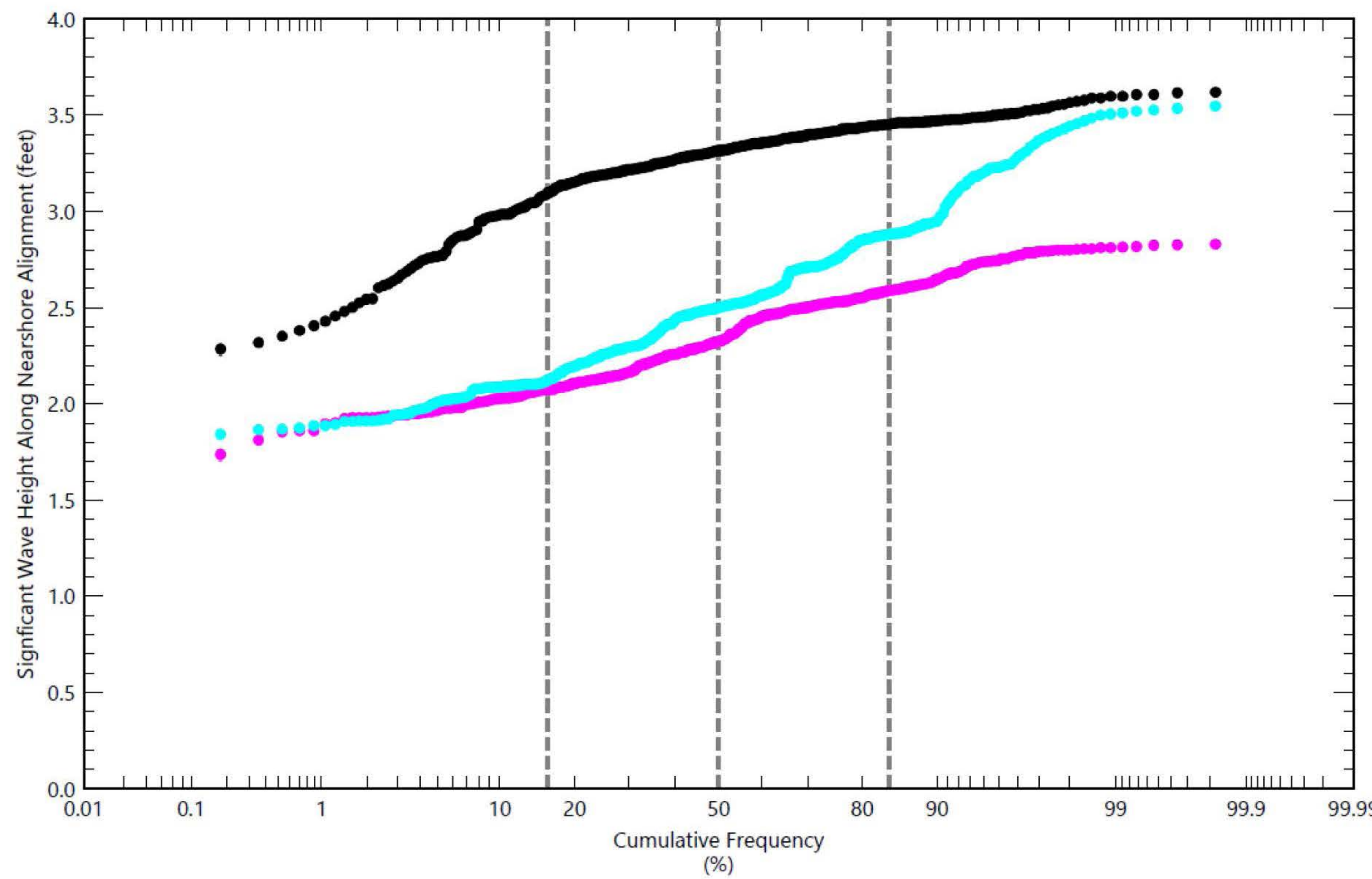
Figure 16a
Nearshore Wave Height Reduction Behind Proposed Berm Features: Annual Storm from the North



Note: Nearshore breakwater alignment is located approximately 150 feet offshore of the existing shoreline.

- Existing Condition (Median: 1.2 feet)
- Proposed Condition: Berm Alternative 01 (Median: 0.6 foot)
- Proposed Condition: Berm Alternative 02 (Median: 0.7 foot)

Figure 16b
Nearshore Wave Height Reduction Behind Proposed Berm Features: Annual Storm from the North



Note: Nearshore breakwater alignment is located approximately 150 feet offshore of the existing shoreline.

- Existing Condition (Median: 3.3 feet)
- Proposed Condition: Berm Alternative 01 (Median: 2.3 feet)
- Proposed Condition: Berm Alternative 02 (Median: 2.5 feet)

Figure 16c
Nearshore Wave Height Reduction Behind Proposed Berm Features: Annual Storm from the North

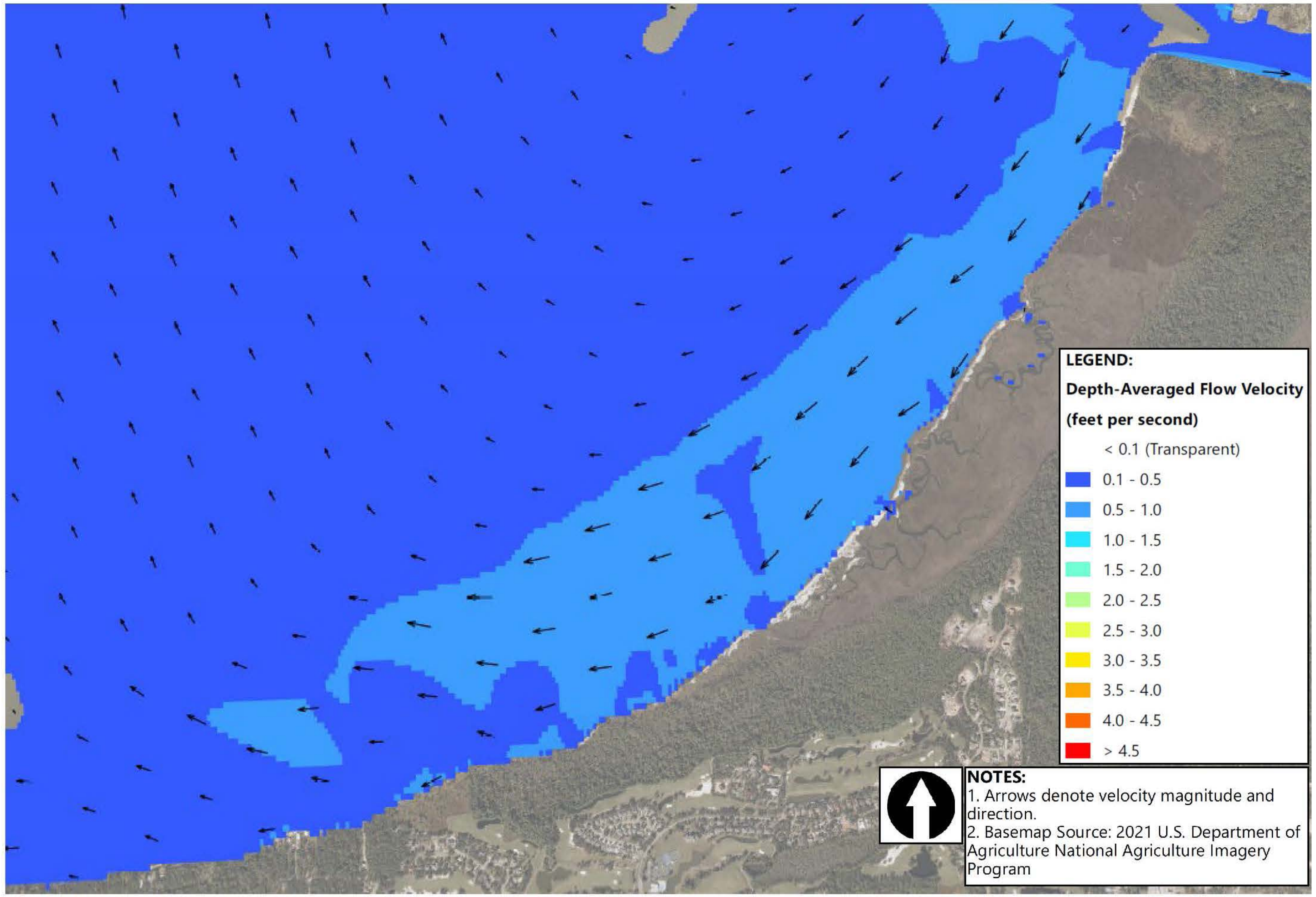


Figure 17a
Flow Velocity Results: Annual Storm from the North, Existing Condition

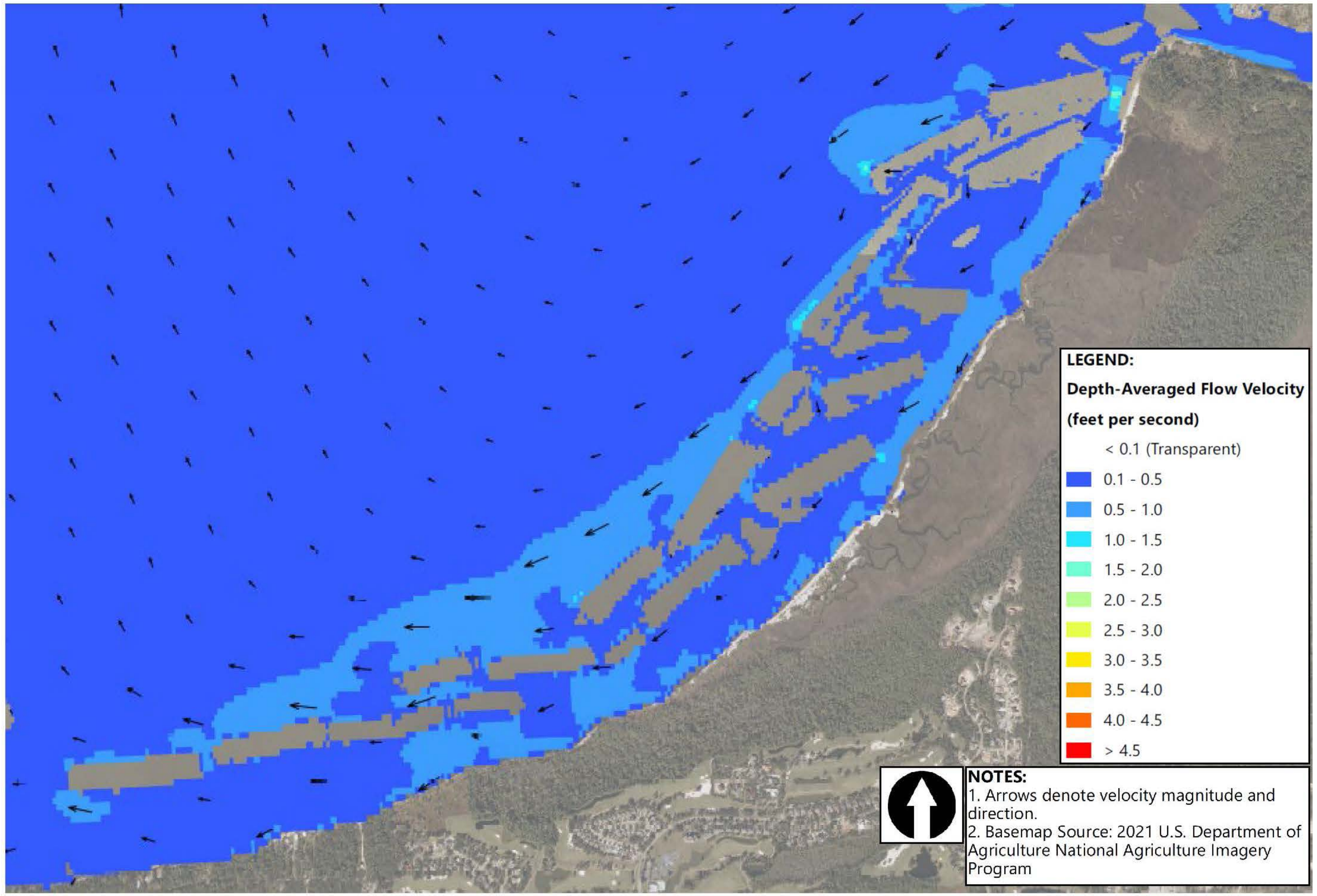


Figure 17b
Flow Velocity Results: Annual Storm from the North, Proposed Condition–Berm Alternative 1

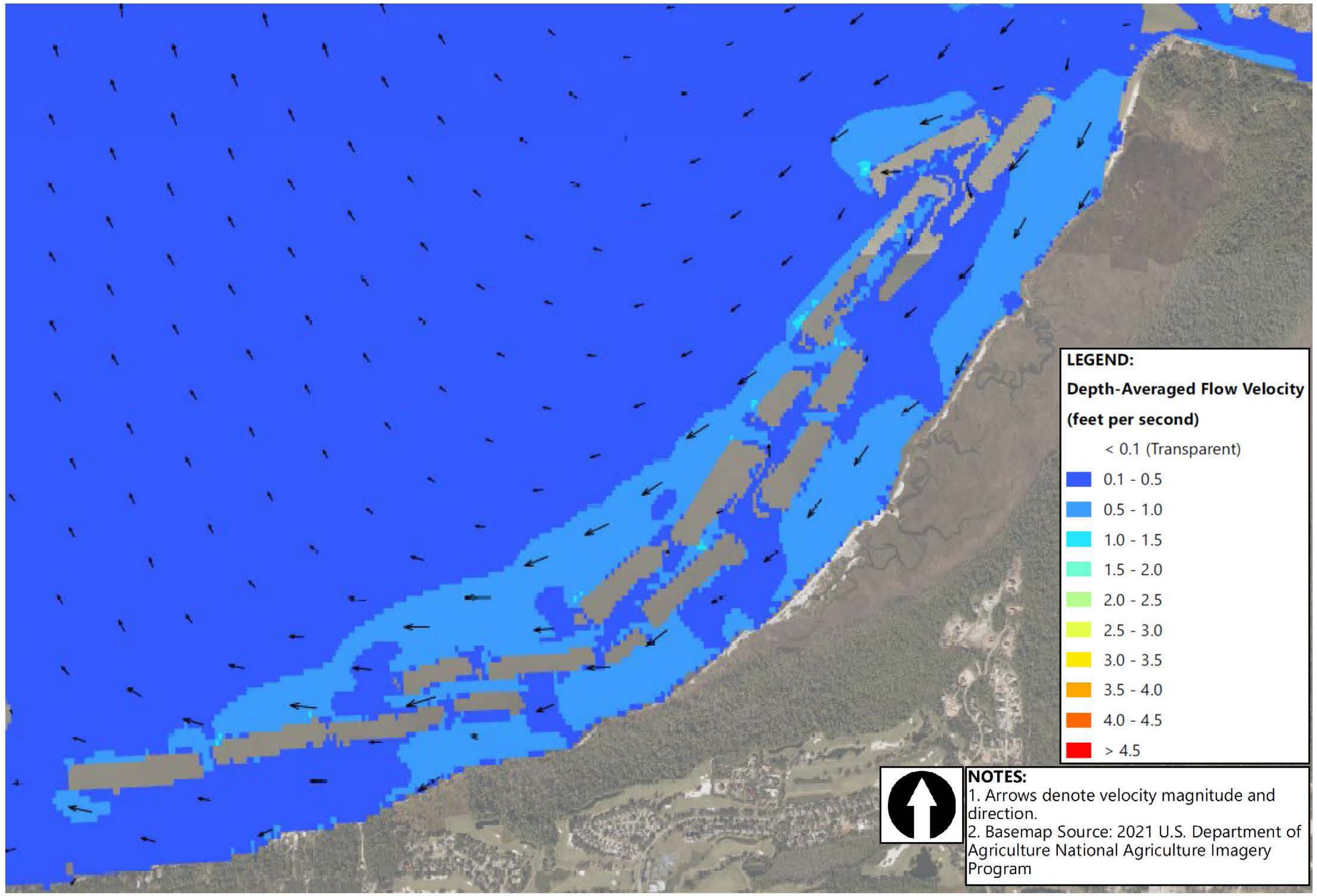


Figure 17c
Flow Velocity Results: Annual Storm from the North, Proposed Condition–Berm Alternative 2

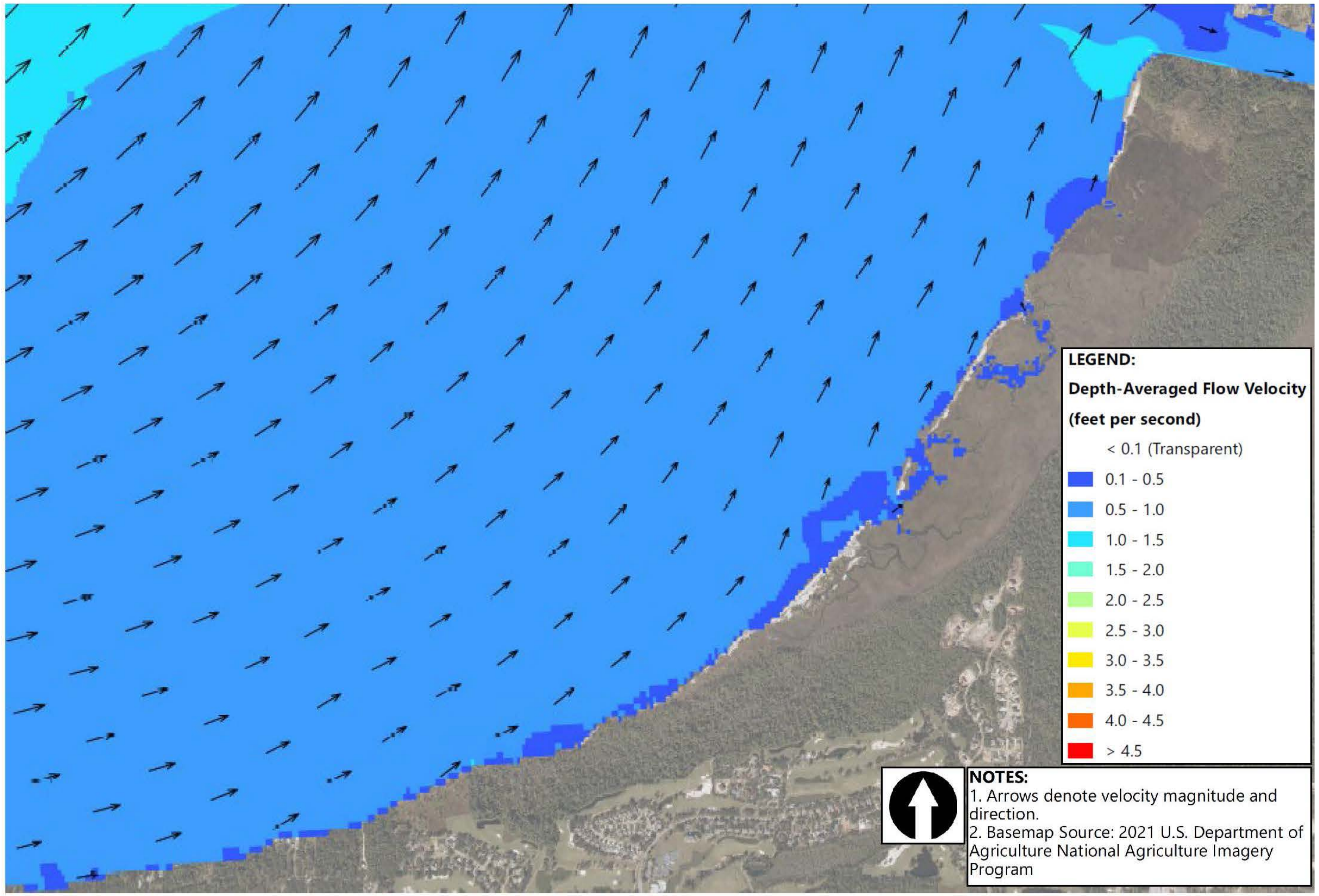


Figure 18a
Flow Velocity Results: Annual Storm from the West, Existing Condition

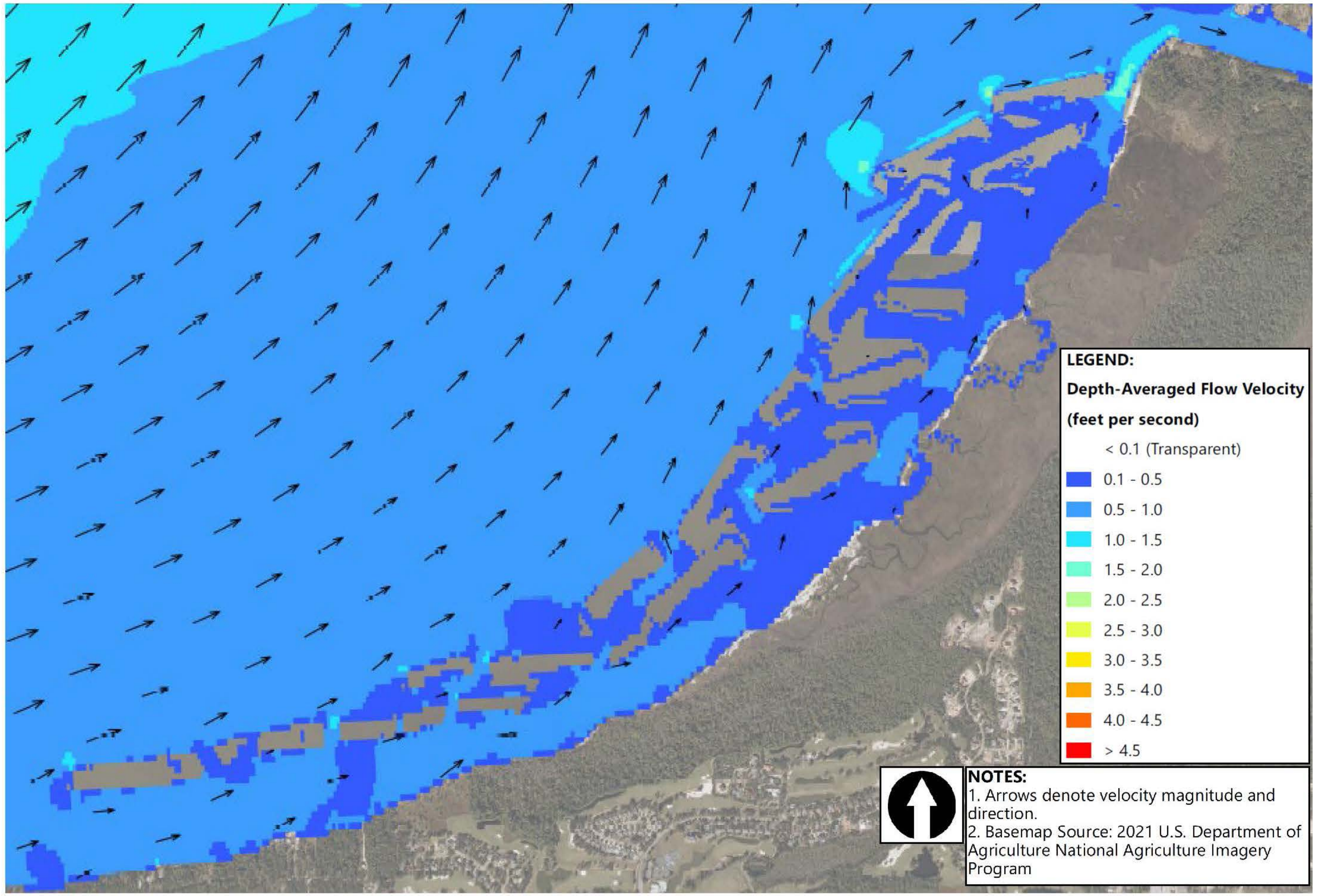


Figure 18b
Flow Velocity Results: Annual Storm from the West, Proposed Condition–Berm Alternative 1

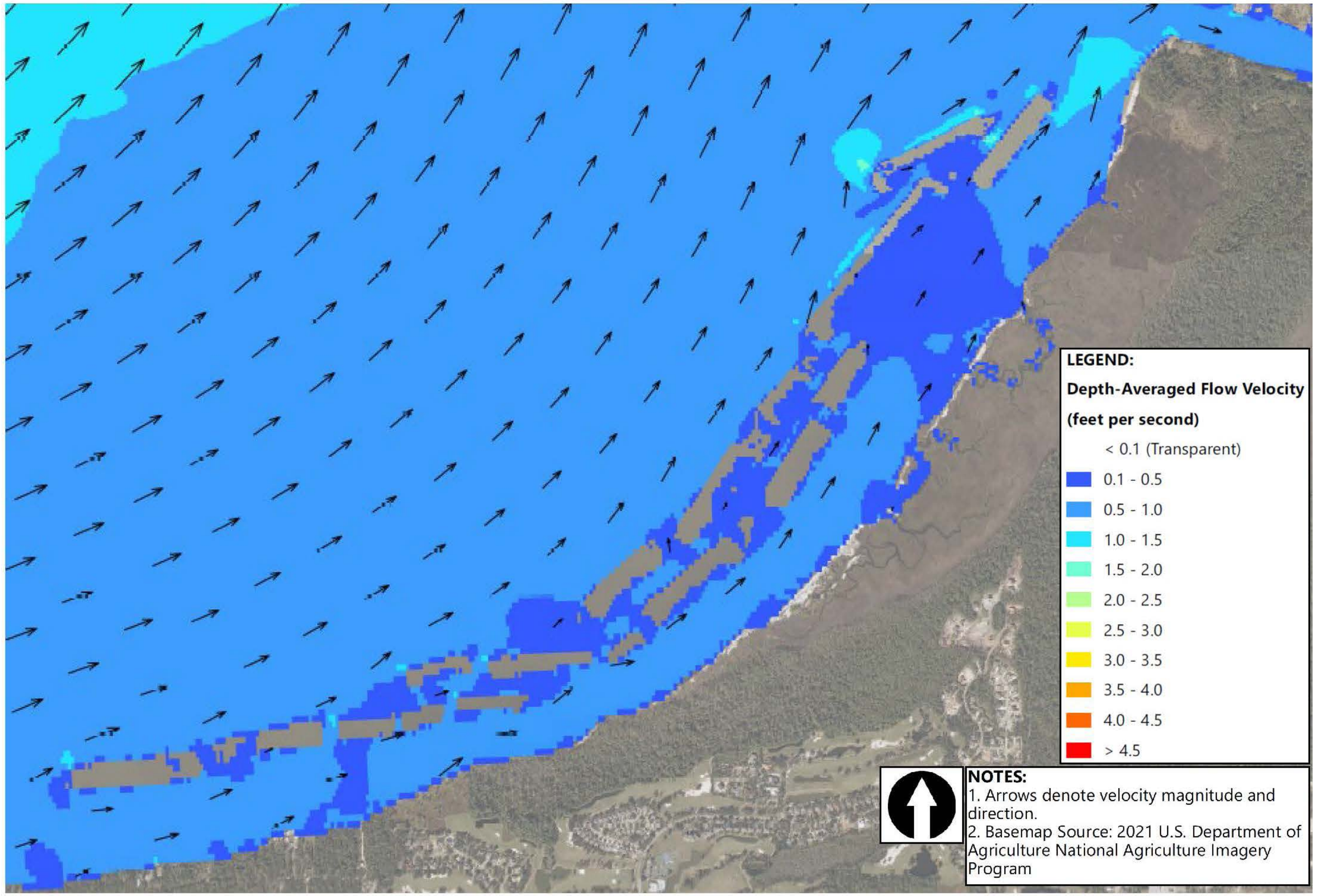


Figure 18c
Flow Velocity Results: Annual Storm from the West, Proposed Condition–Berm Alternative 2

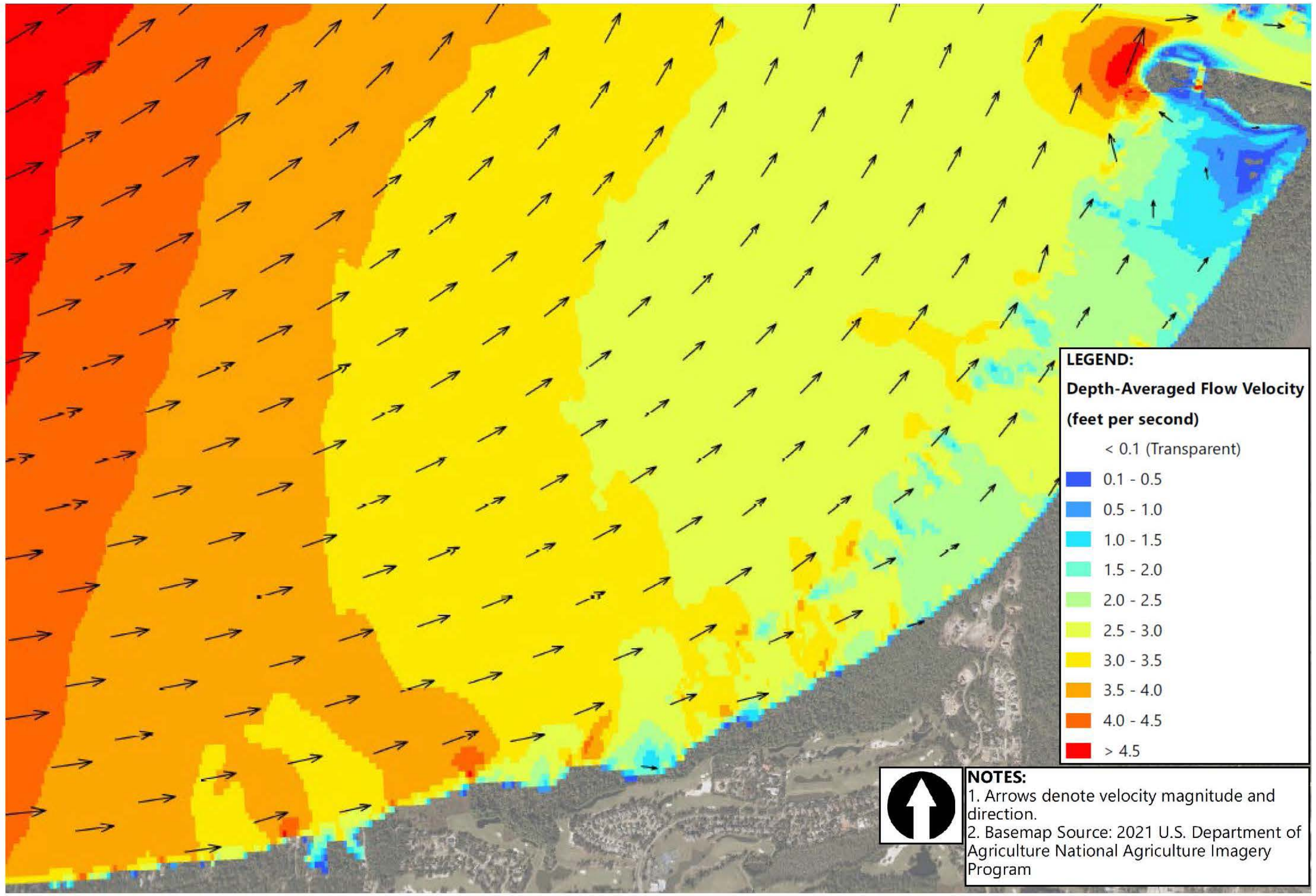


Figure 19a
Flow Velocity Results: Hurricane Sally, Existing Condition

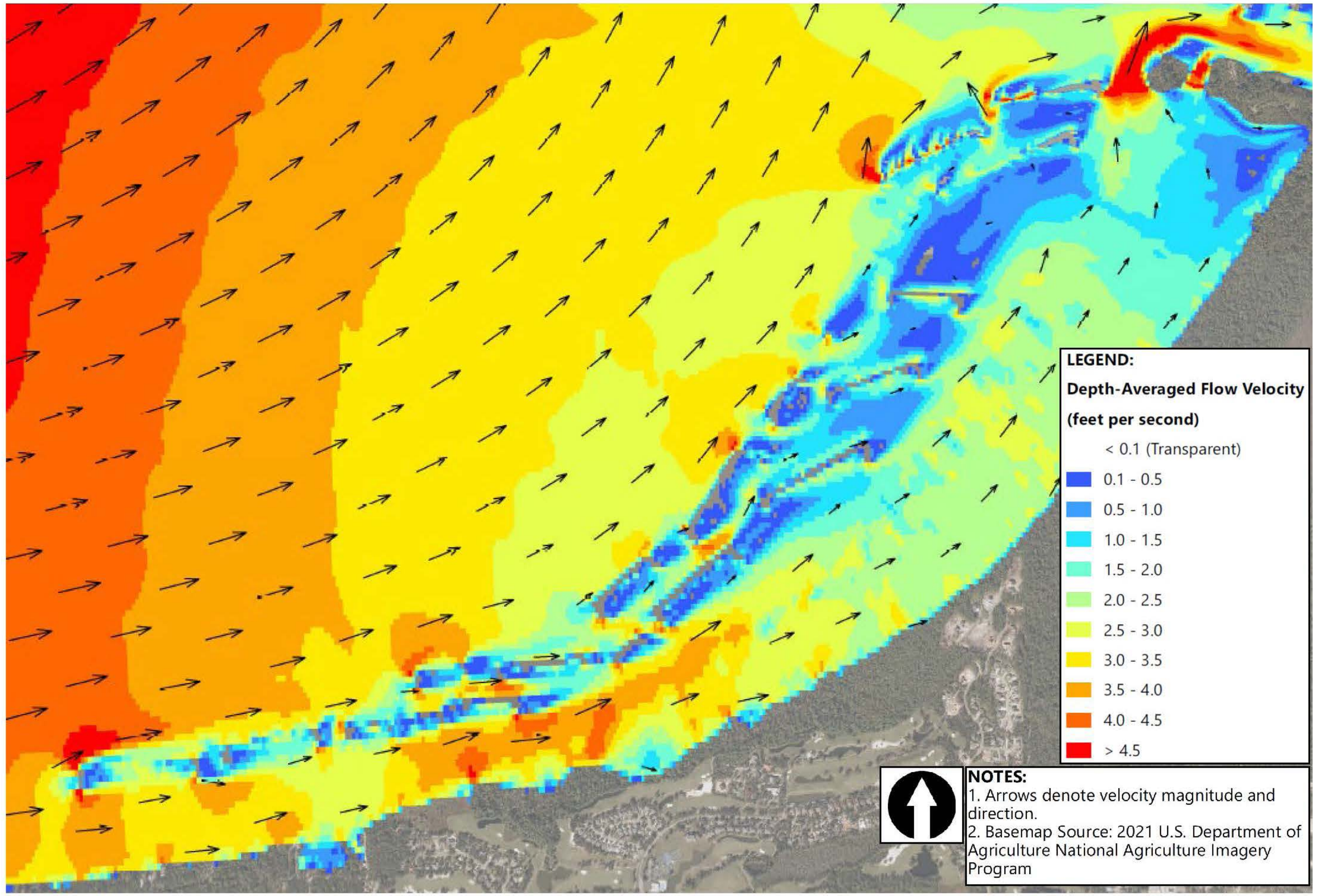


Figure 19b
Flow Velocity Results: Hurricane Sally, Proposed Condition–Berm Alternative 1

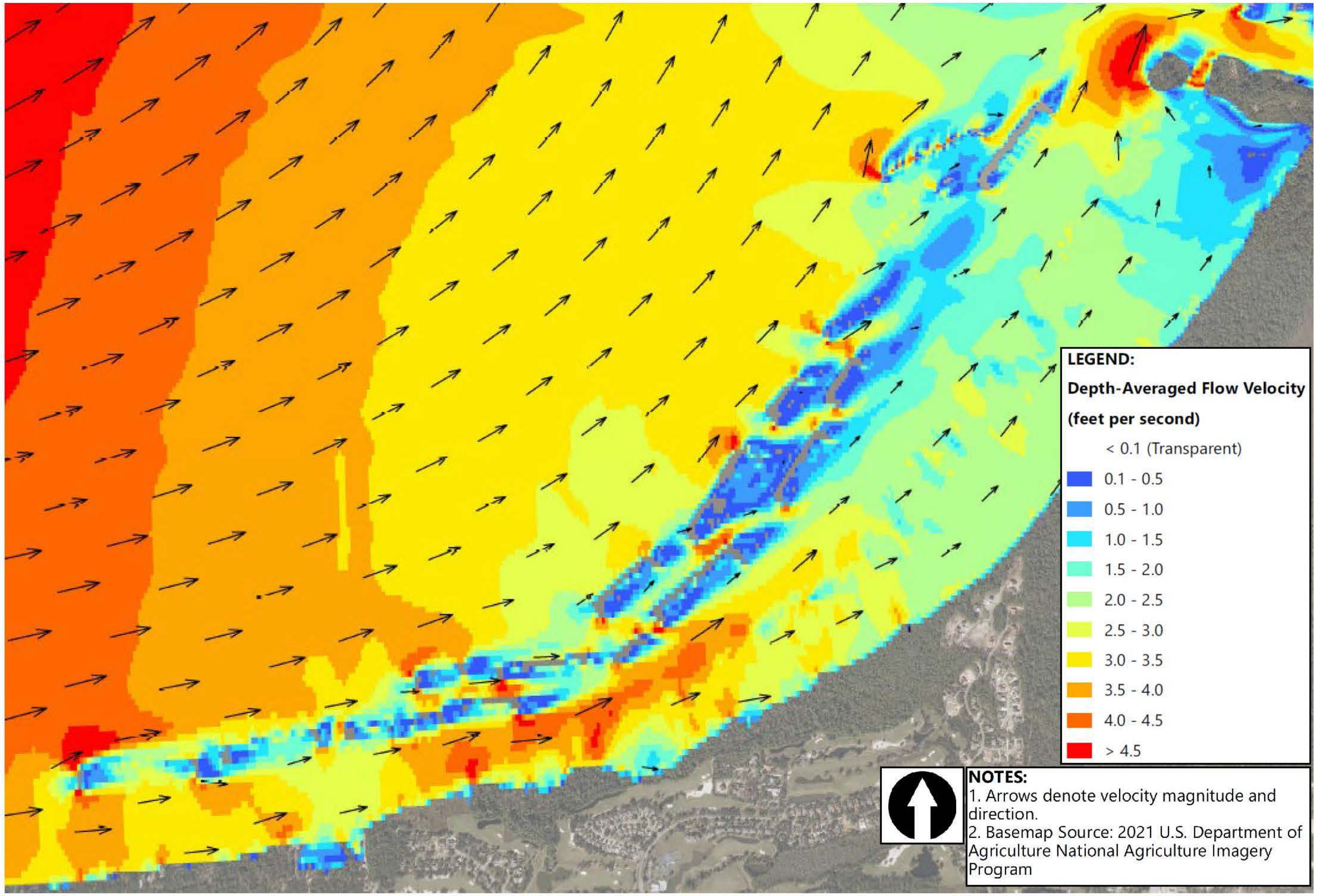


Figure 19c
Flow Velocity Results: Hurricane Sally, Proposed Condition–Berm Alternative 2

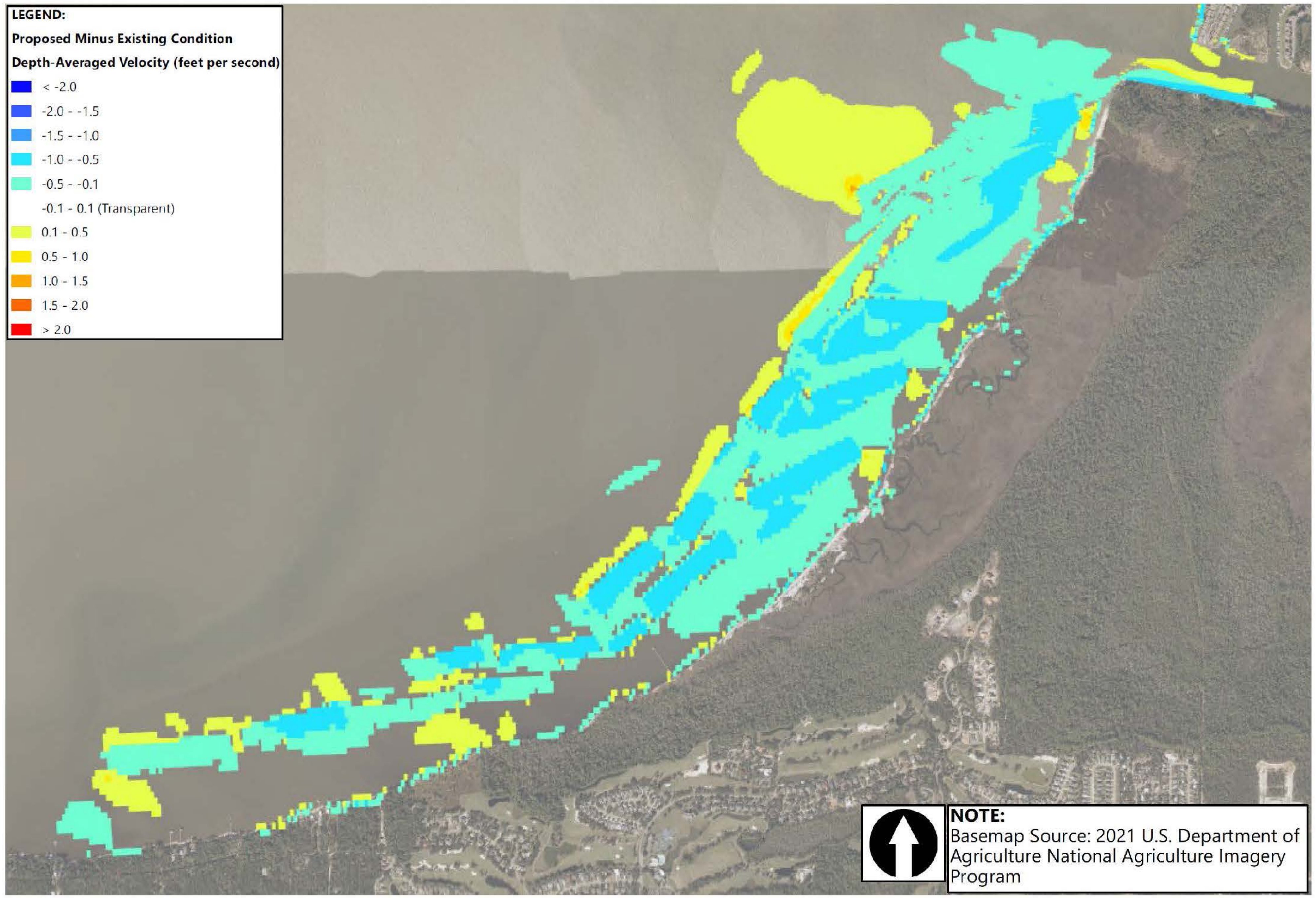


Figure 20a
Flow Velocity Difference Results: Annual Storm from the North, Proposed Versus Existing Condition–Berm Alternative 1

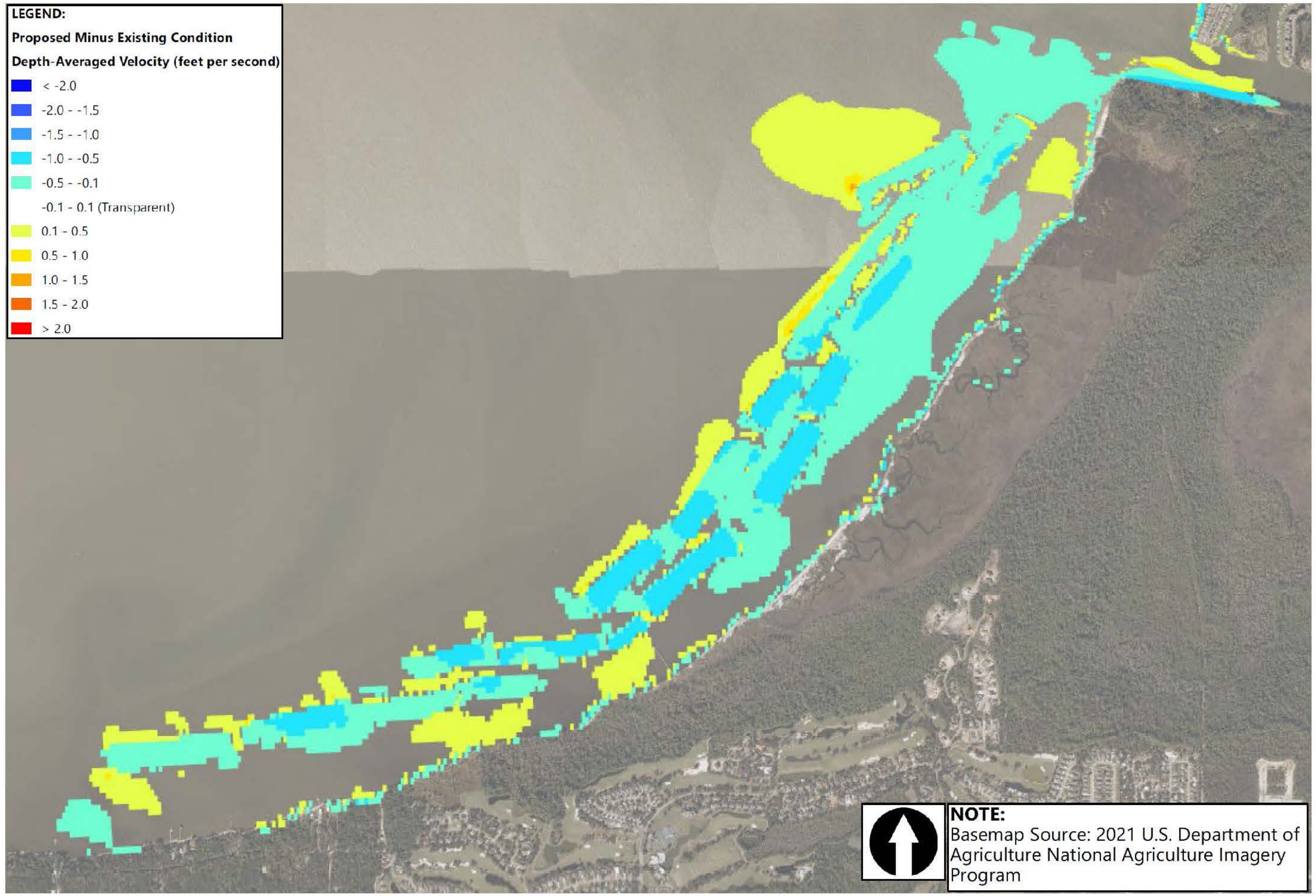


Figure 20b
Flow Velocity Difference Results: Annual Storm from the North, Proposed Versus Existing Condition–Berm Alternative 1

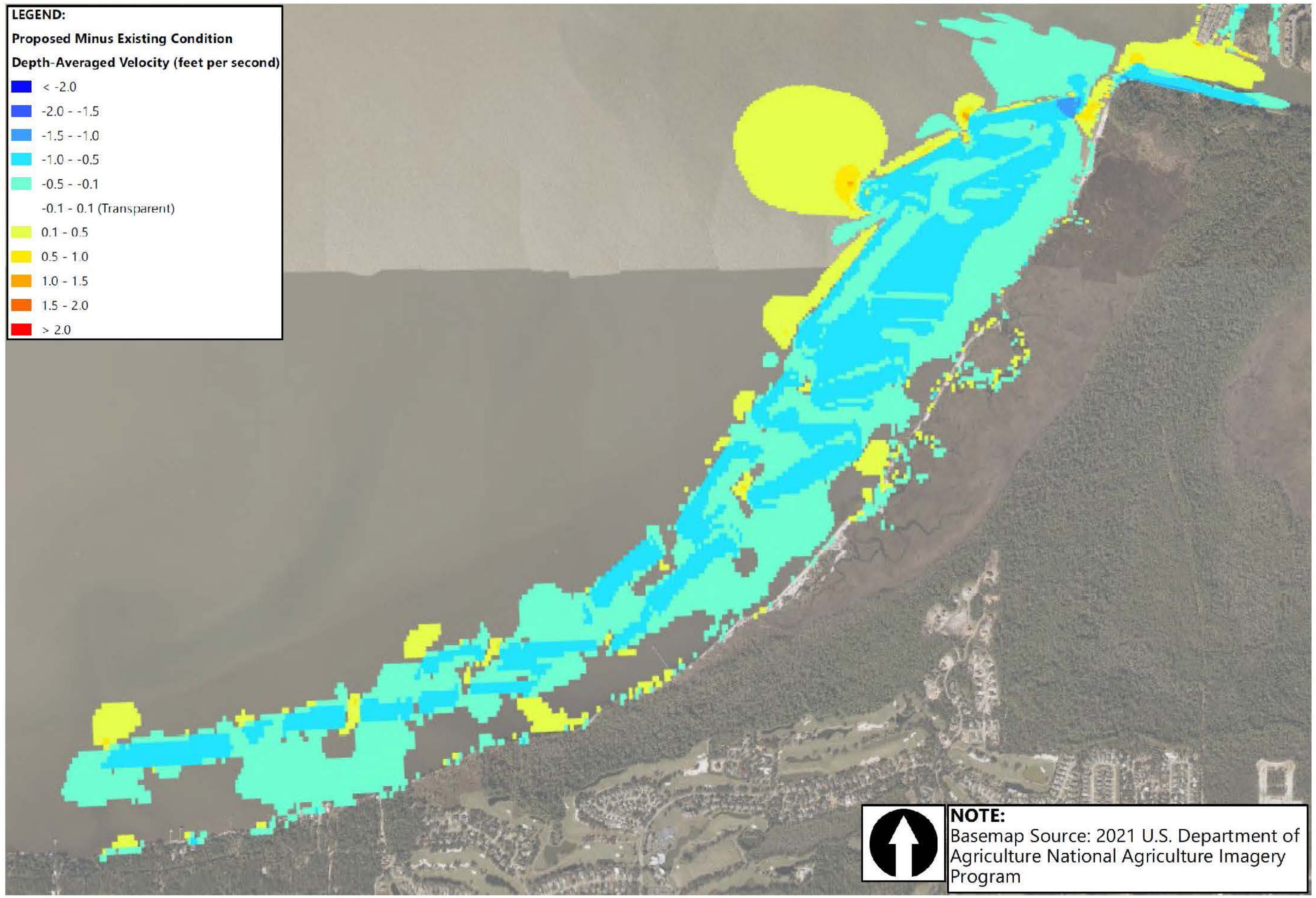


Figure 20c
Flow Velocity Difference Results: Annual Storm from the North, Proposed Versus Existing Condition–Berm Alternative 1

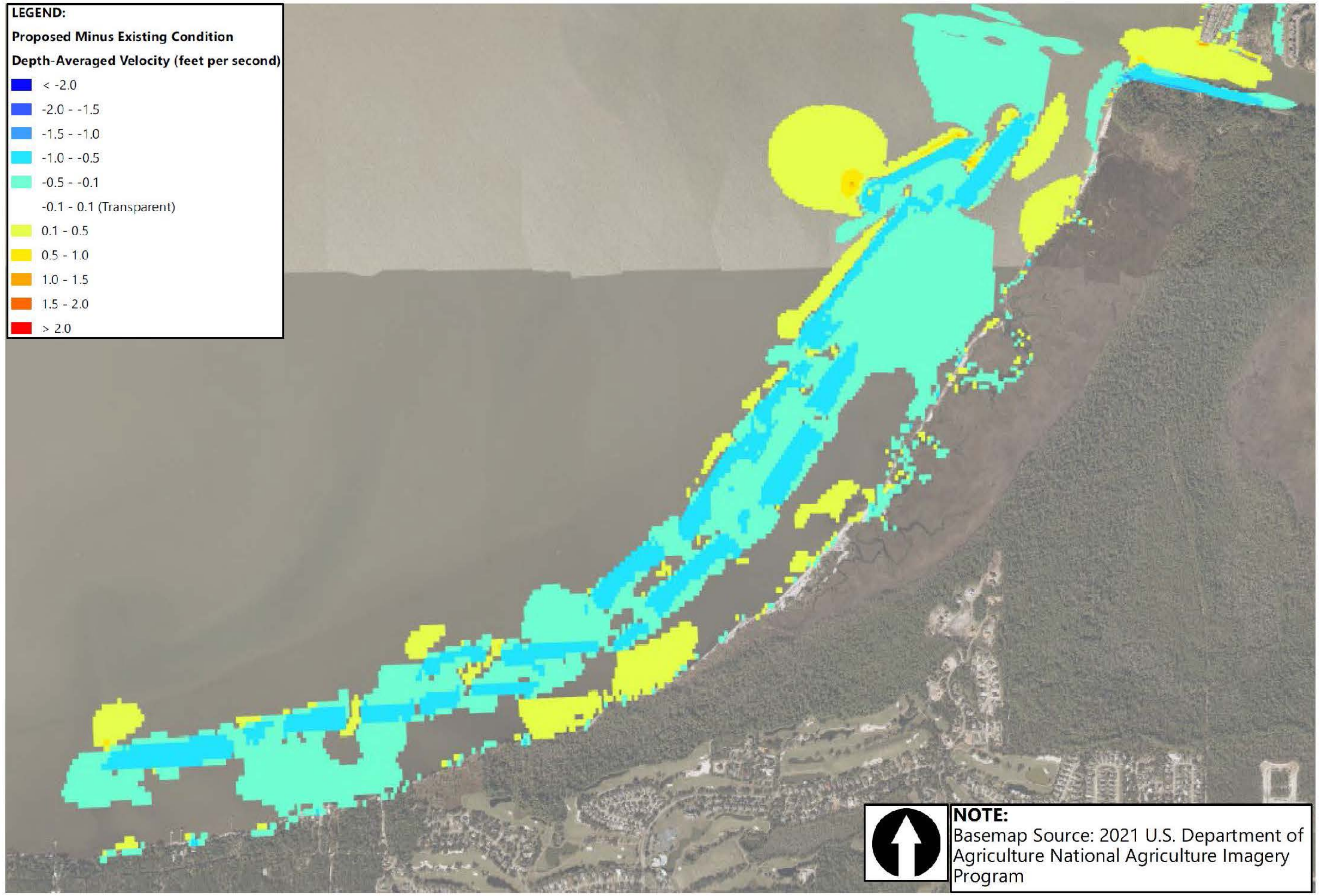


Figure 20d
Flow Velocity Difference Results: Annual Storm from the North, Proposed Versus Existing Condition–Berm Alternative 1

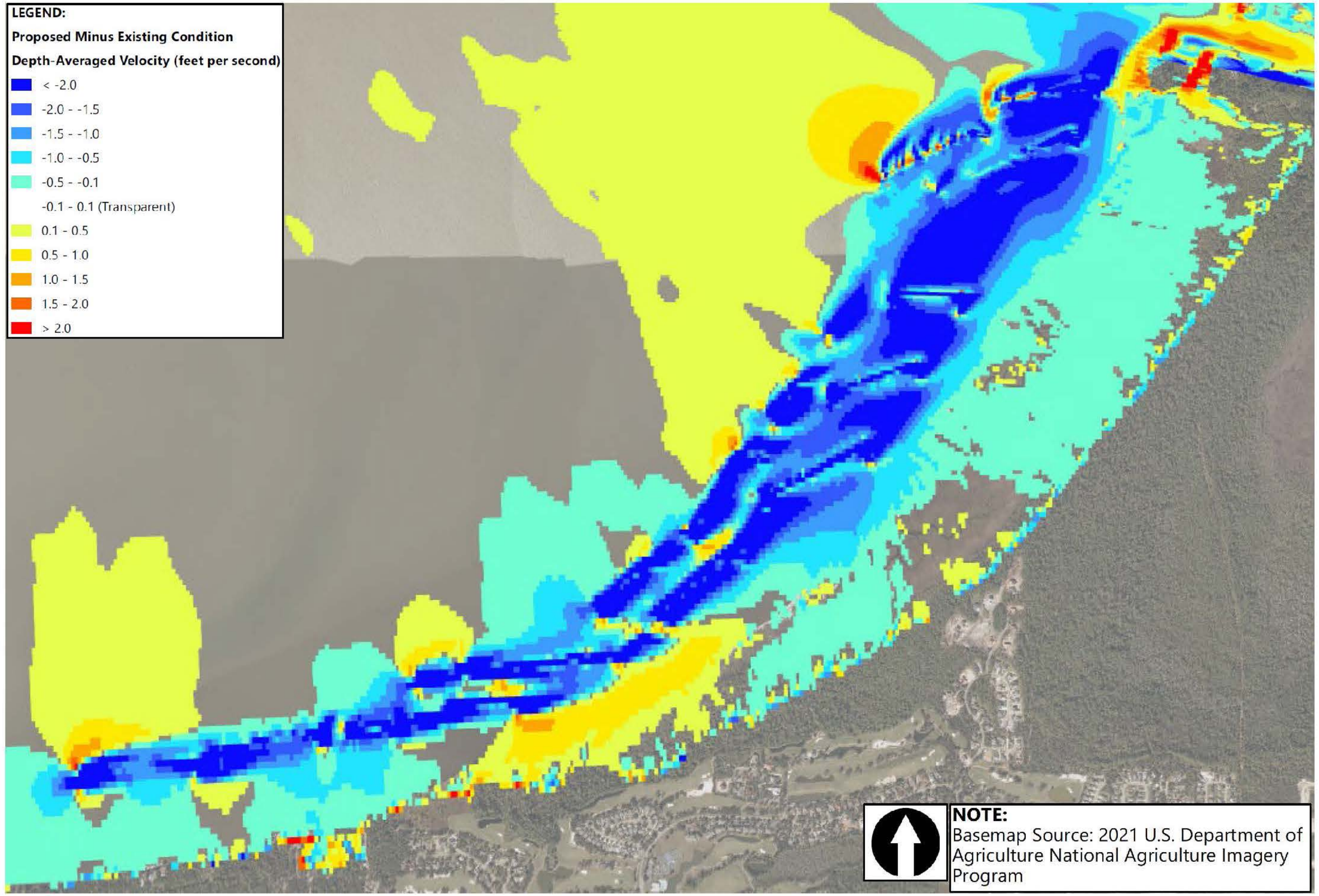


Figure 20e
Flow Velocity Difference Results: Annual Storm from the North, Proposed Versus Existing Condition–Berm Alternative 1

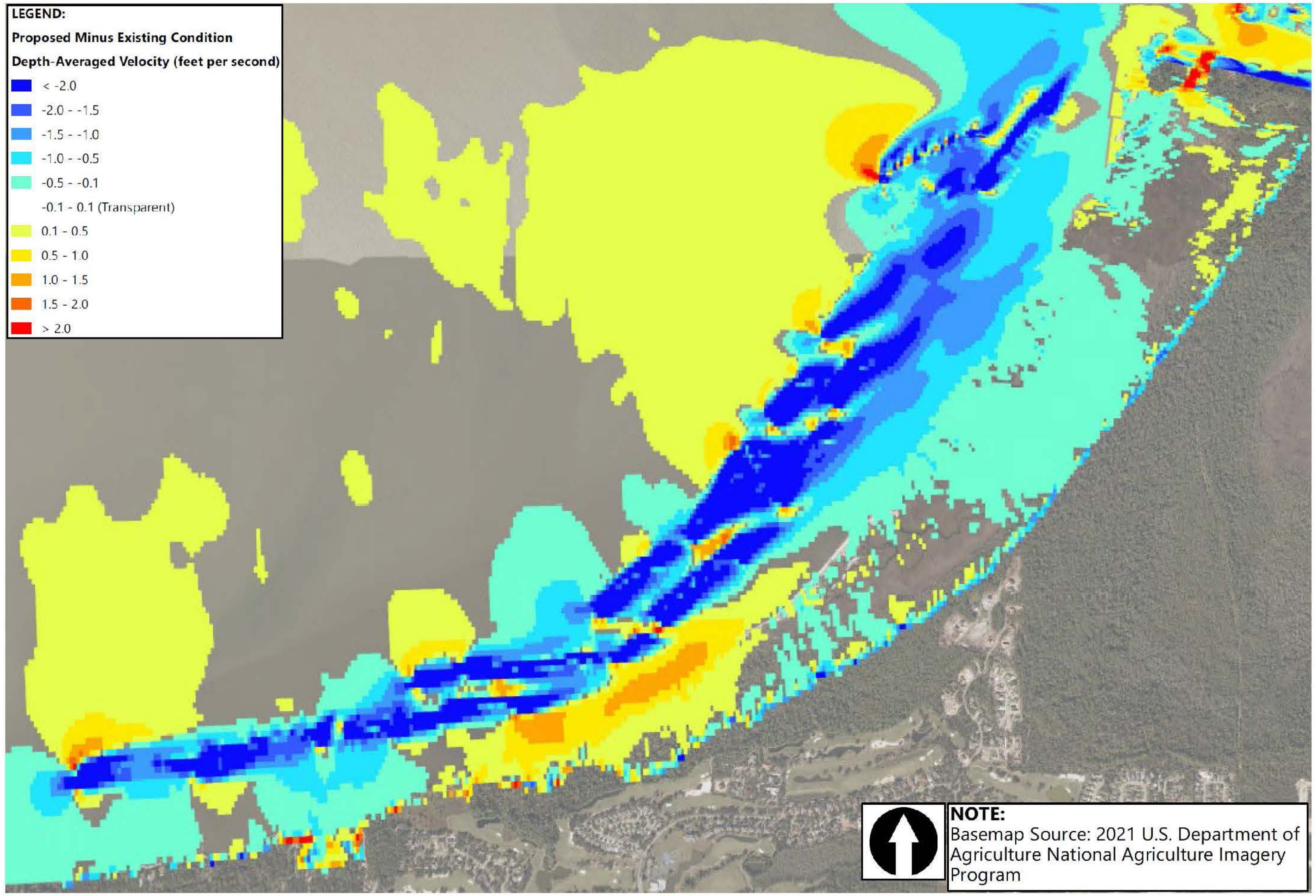


Figure 20f

Flow Velocity Difference Results: Annual Storm from the North, Proposed Versus Existing Condition–Berm Alternative 1

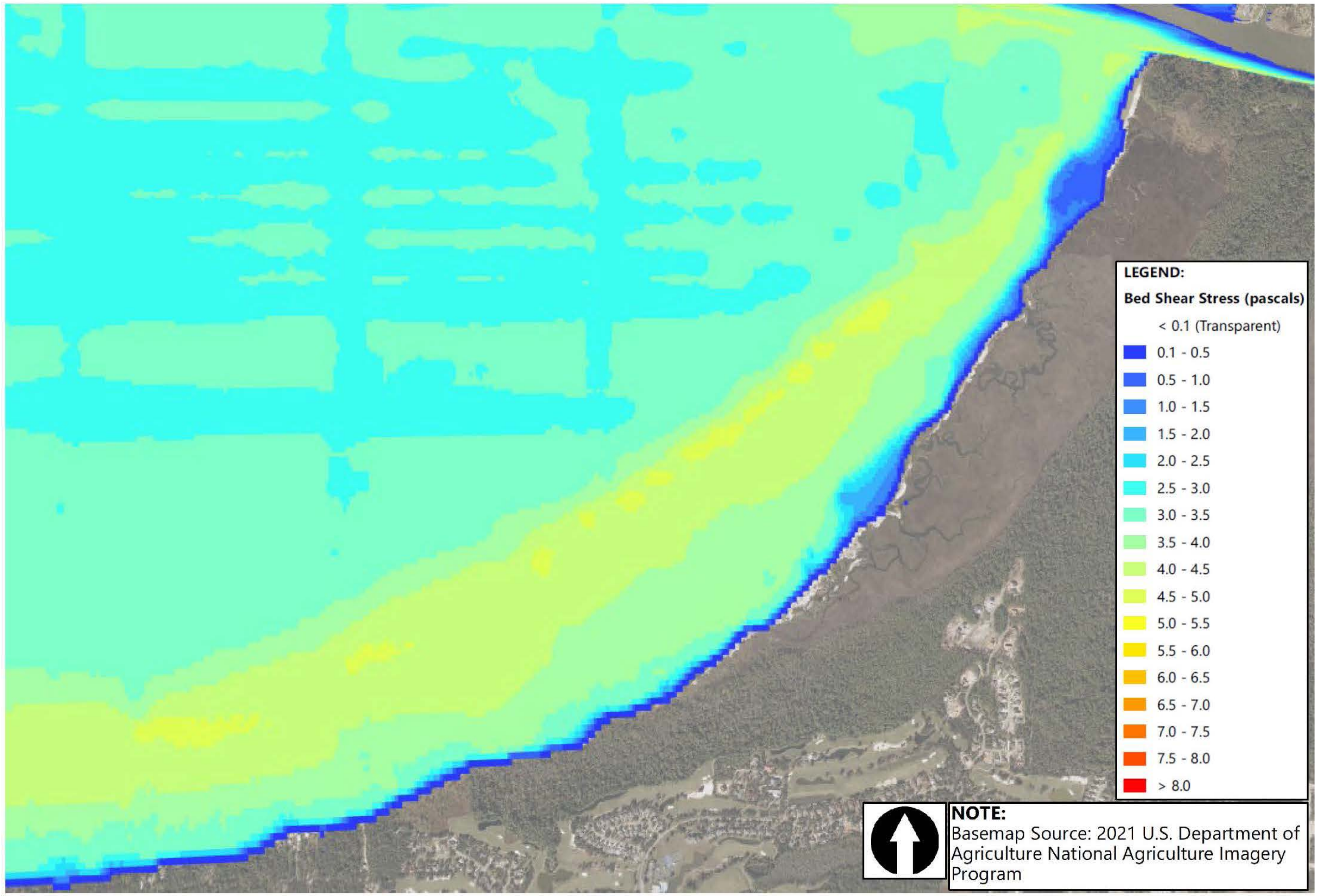


Figure 21a
Bed Shear Stress Results: Annual Storm from the North, Existing Condition

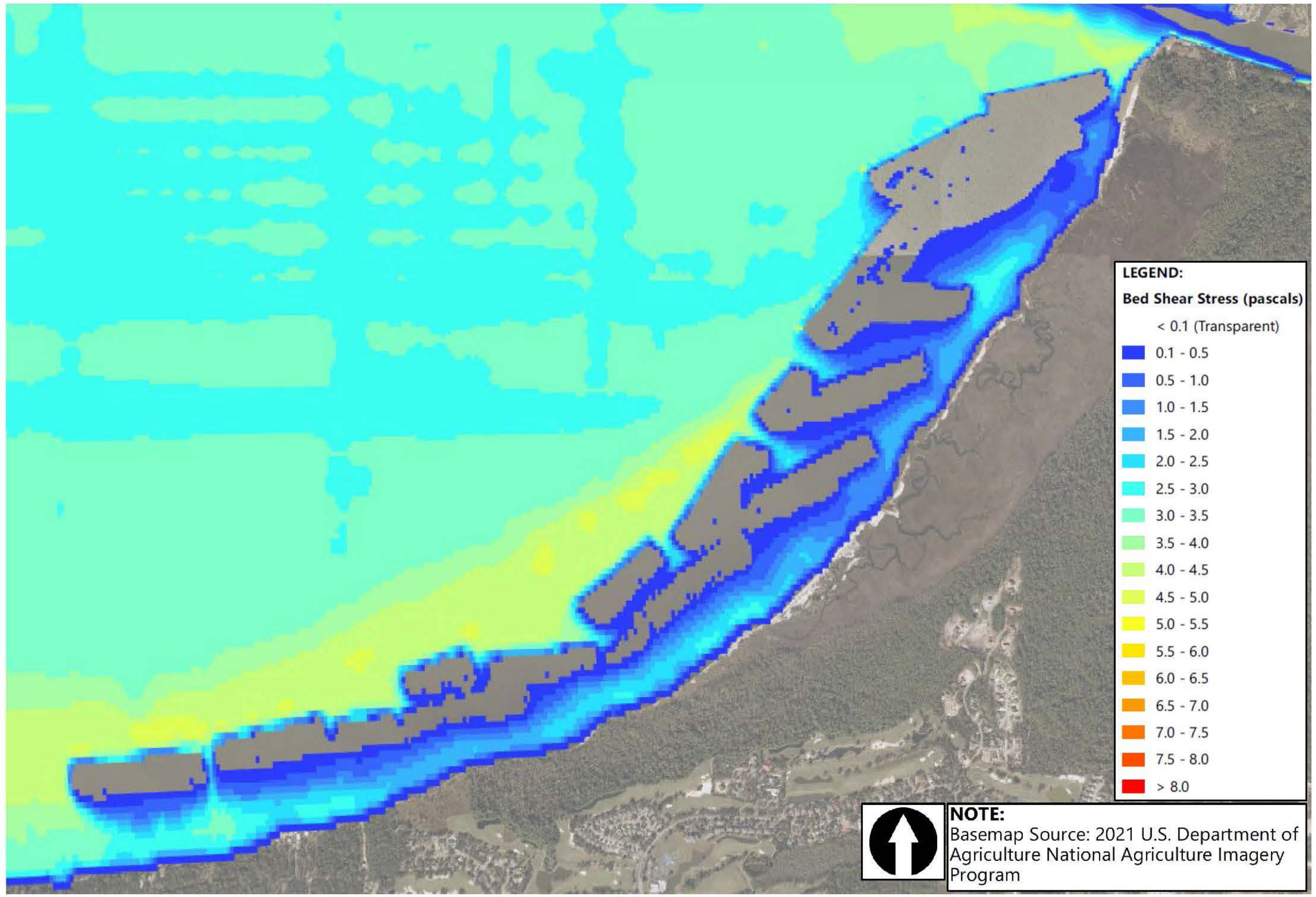


Figure 21b
Bed Shear Stress Results: Annual Storm from the North, Proposed Condition–Berm Alternative 1

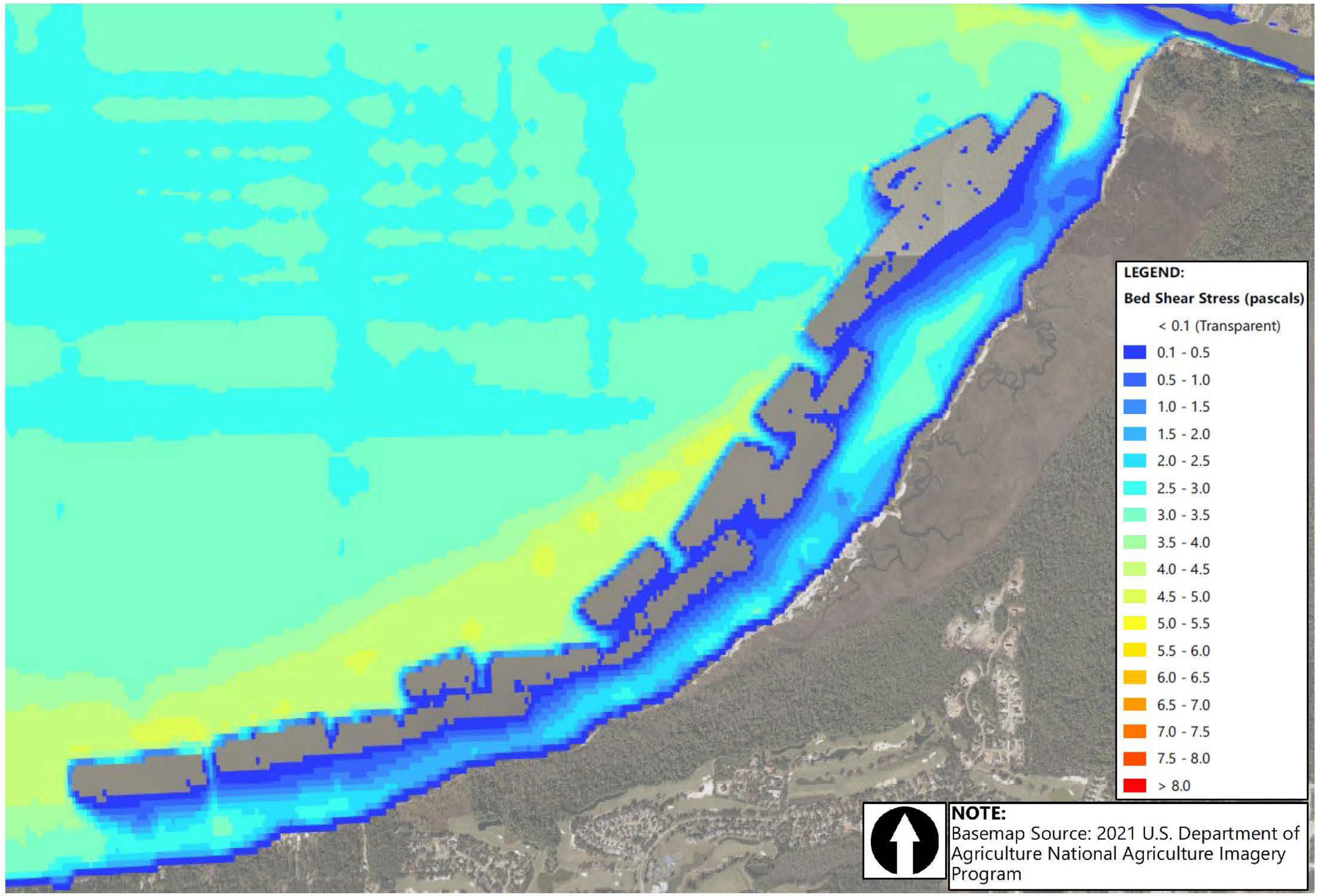


Figure 21c
Bed Shear Stress Results: Annual Storm from the North, Proposed Condition–Berm Alternative 2

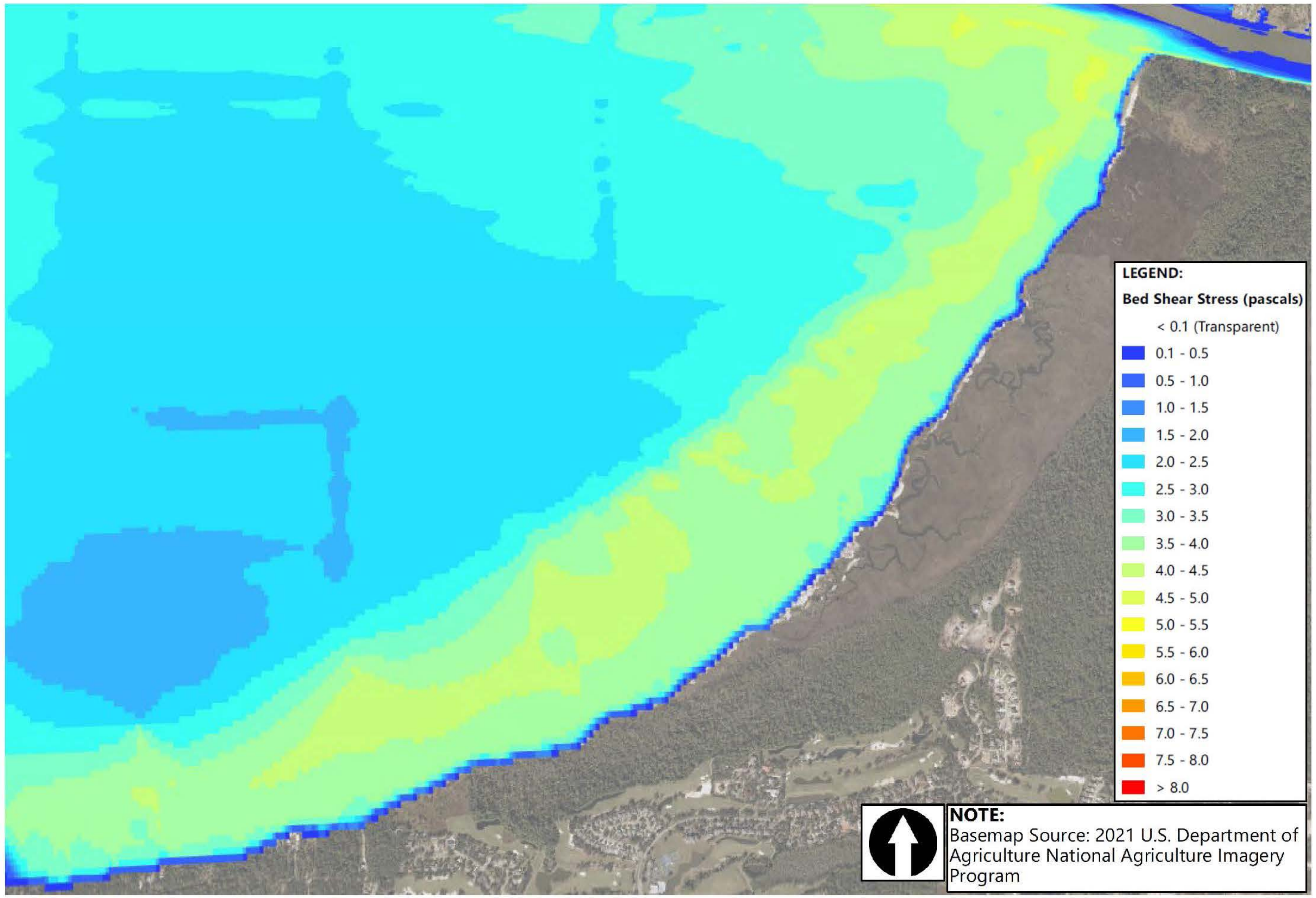


Figure 22a
Bed Shear Stress Results: Annual Storm from the West, Existing Condition

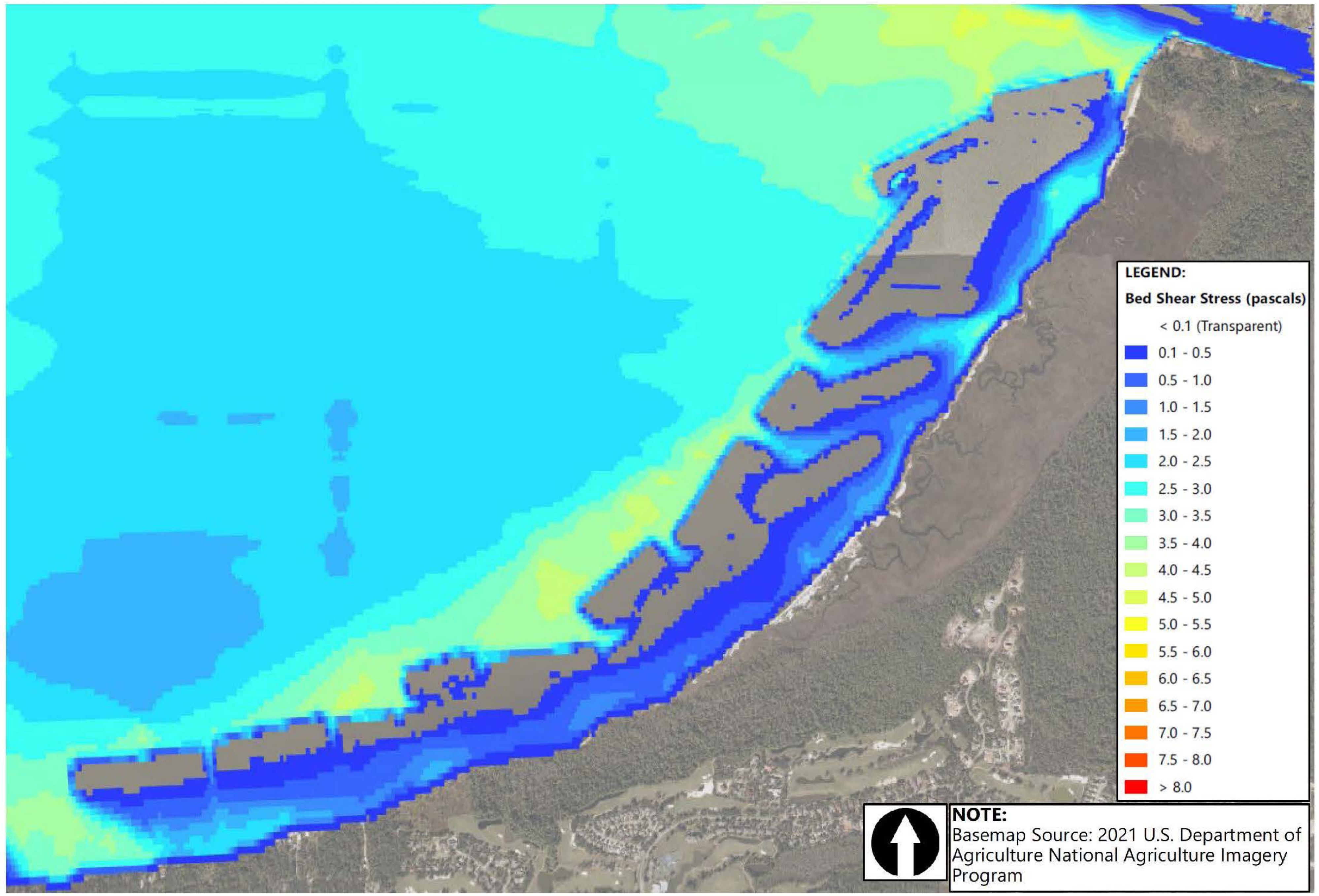


Figure 22b
Bed Shear Stress Results: Annual Storm from the West, Proposed Condition–Berm Alternative 1

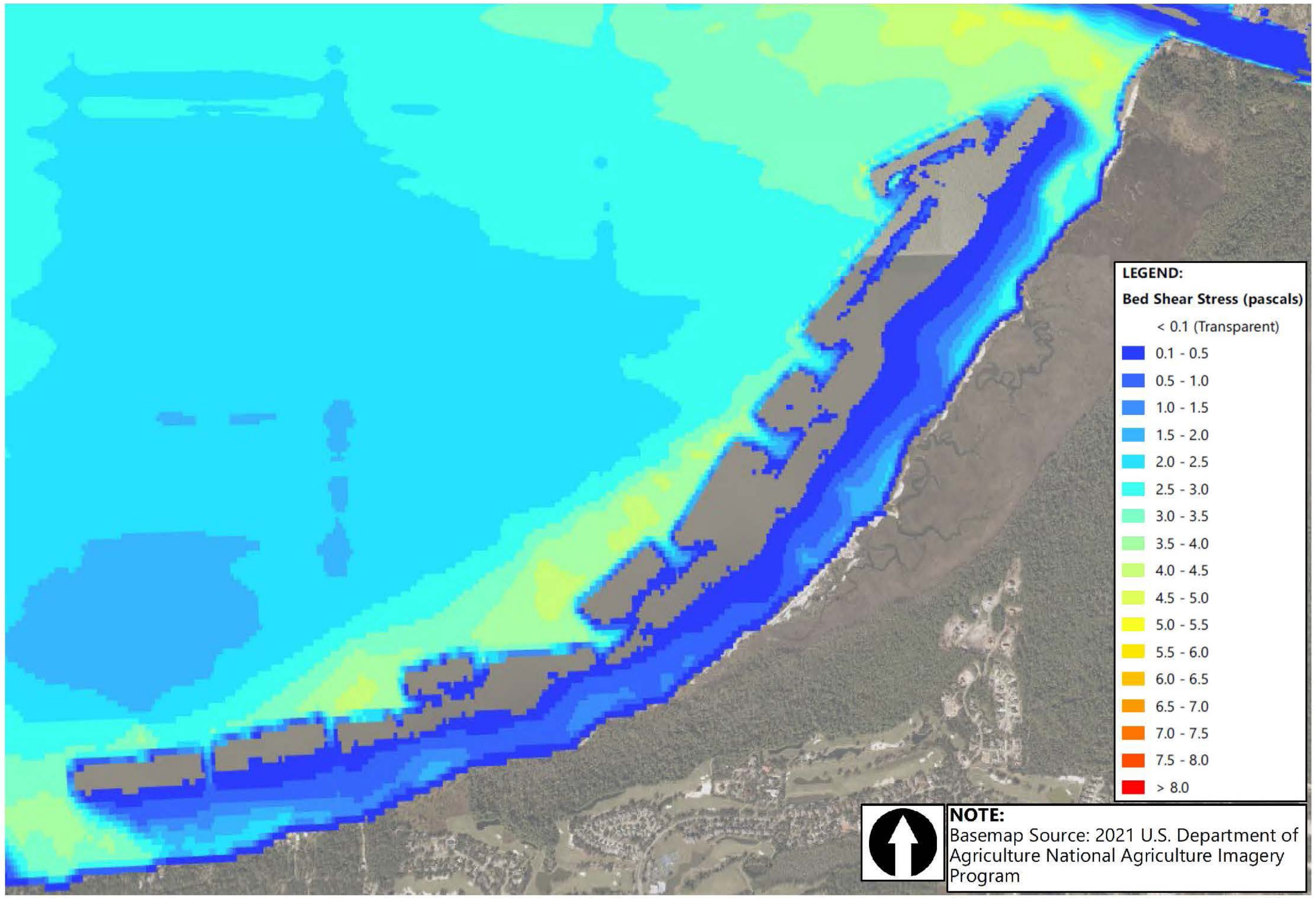


Figure 22c
Bed Shear Stress Results: Annual Storm from the West, Proposed Condition–Berm Alternative 2

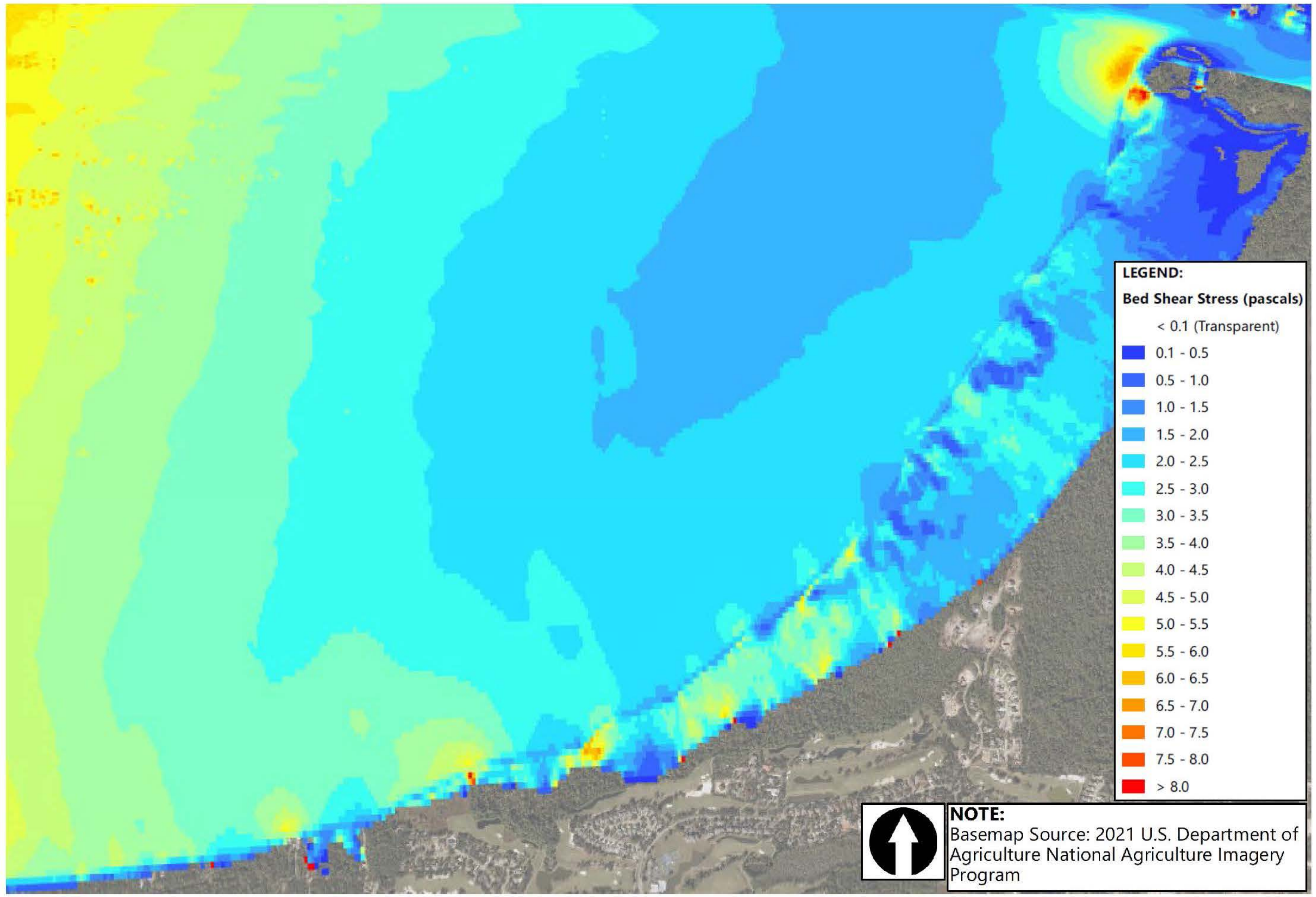


Figure 23a
Bed Shear Stress Results: Hurricane Sally, Existing Condition

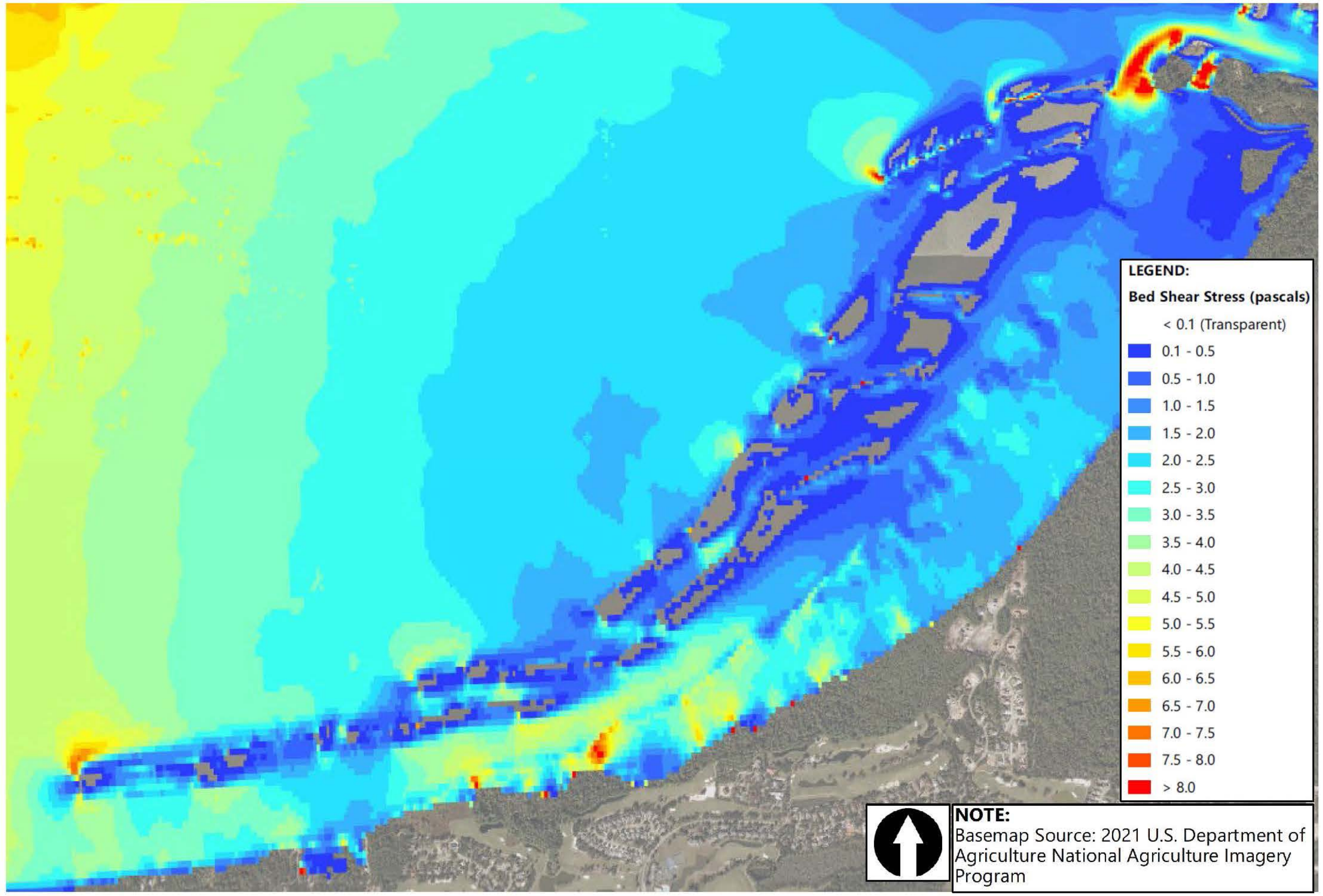


Figure 23b
Bed Shear Stress Results: Hurricane Sally, Proposed Condition–Berm Alternative 1

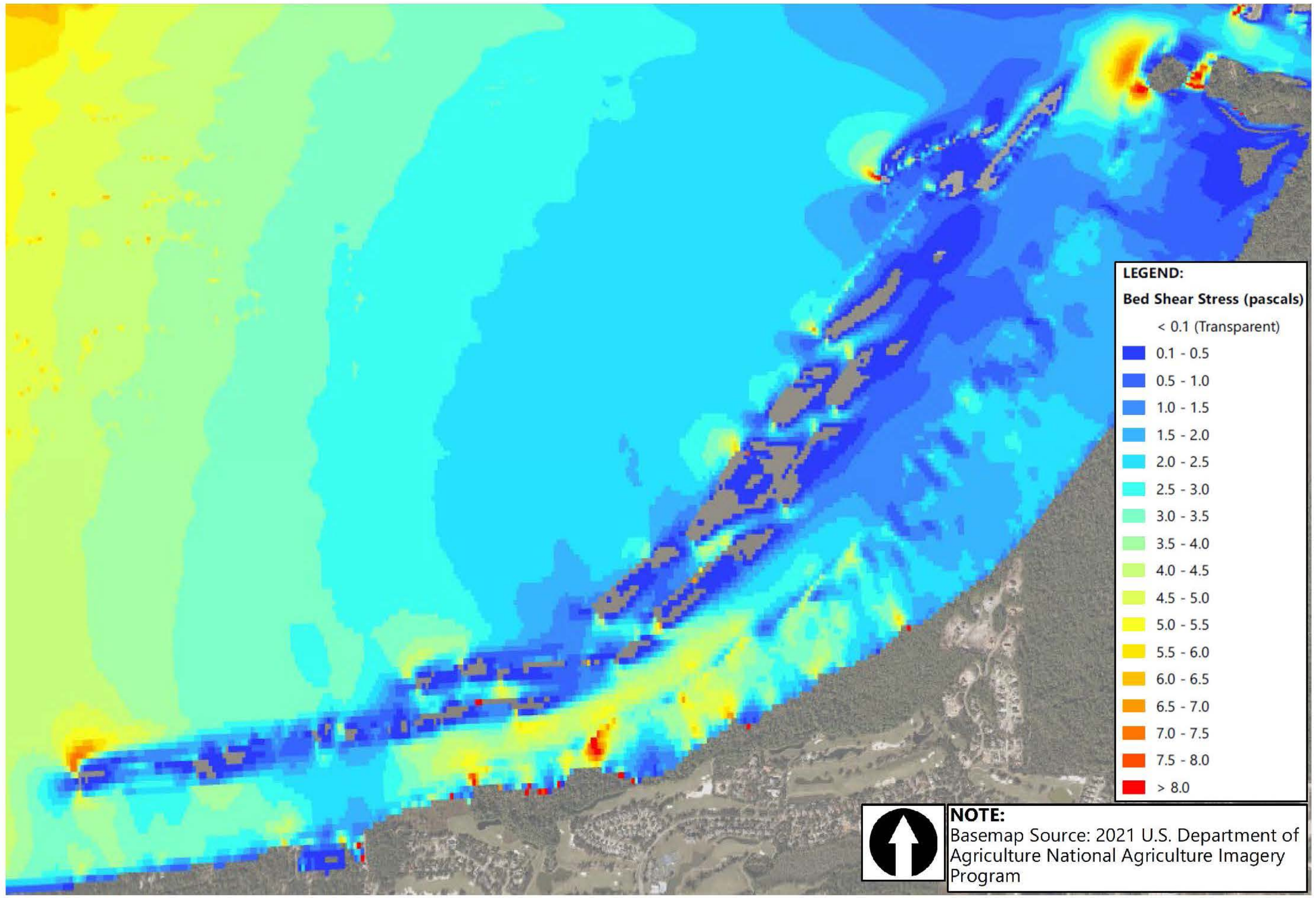


Figure 23c
Bed Shear Stress Results: Hurricane Sally, Proposed Condition–Berm Alternative 2

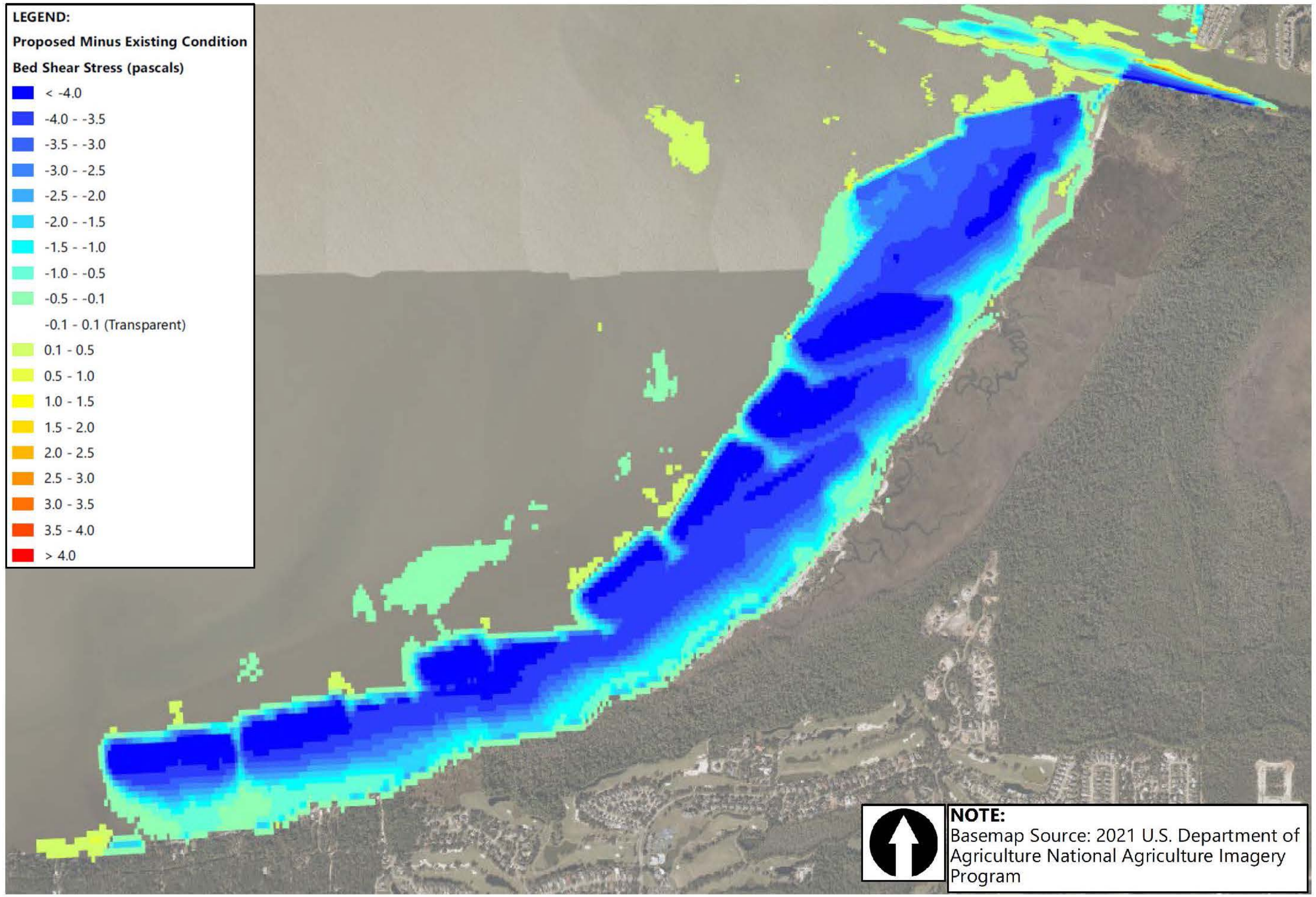


Figure 24a

Bed Shear Stress Difference Results: Annual Storm from the North, Proposed Versus Existing Condition–Berm Alternative 1

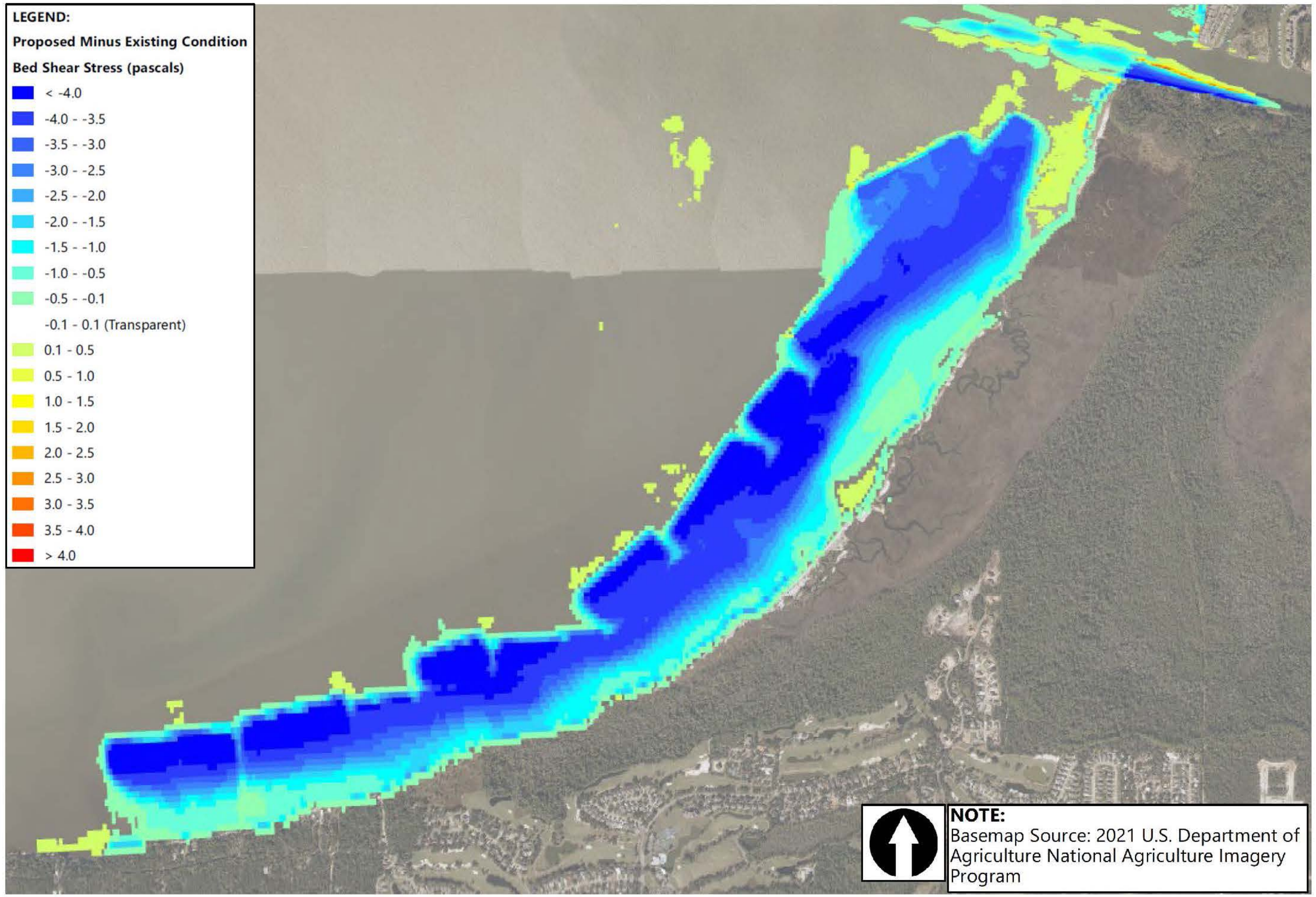


Figure 24b
Bed Shear Stress Difference Results: Annual Storm from the North, Proposed Versus Existing Condition–Berm Alternative 2

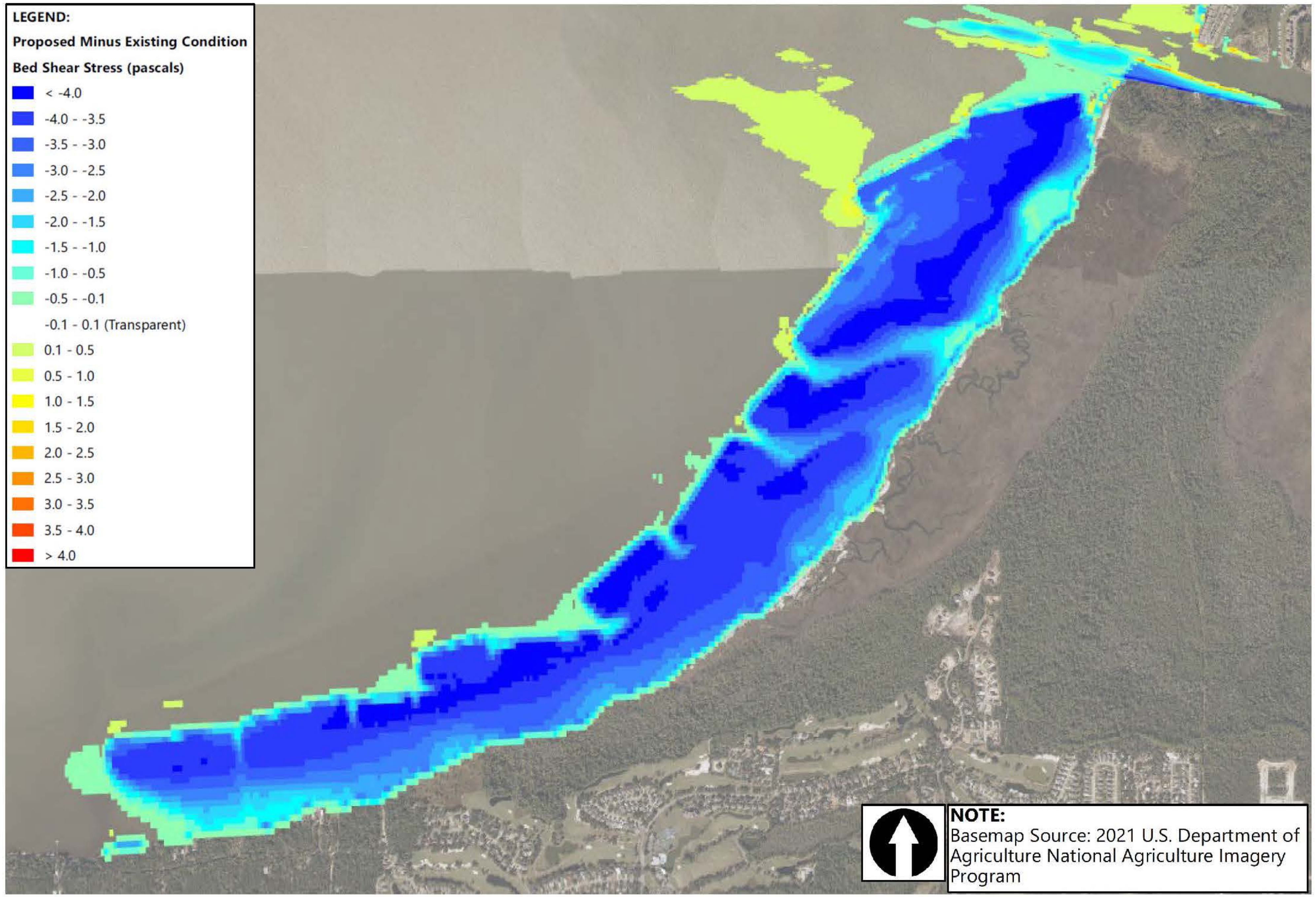


Figure 24c
Bed Shear Stress Difference Results: Annual Storm from the West, Proposed Versus Existing Condition–Berm Alternative 1

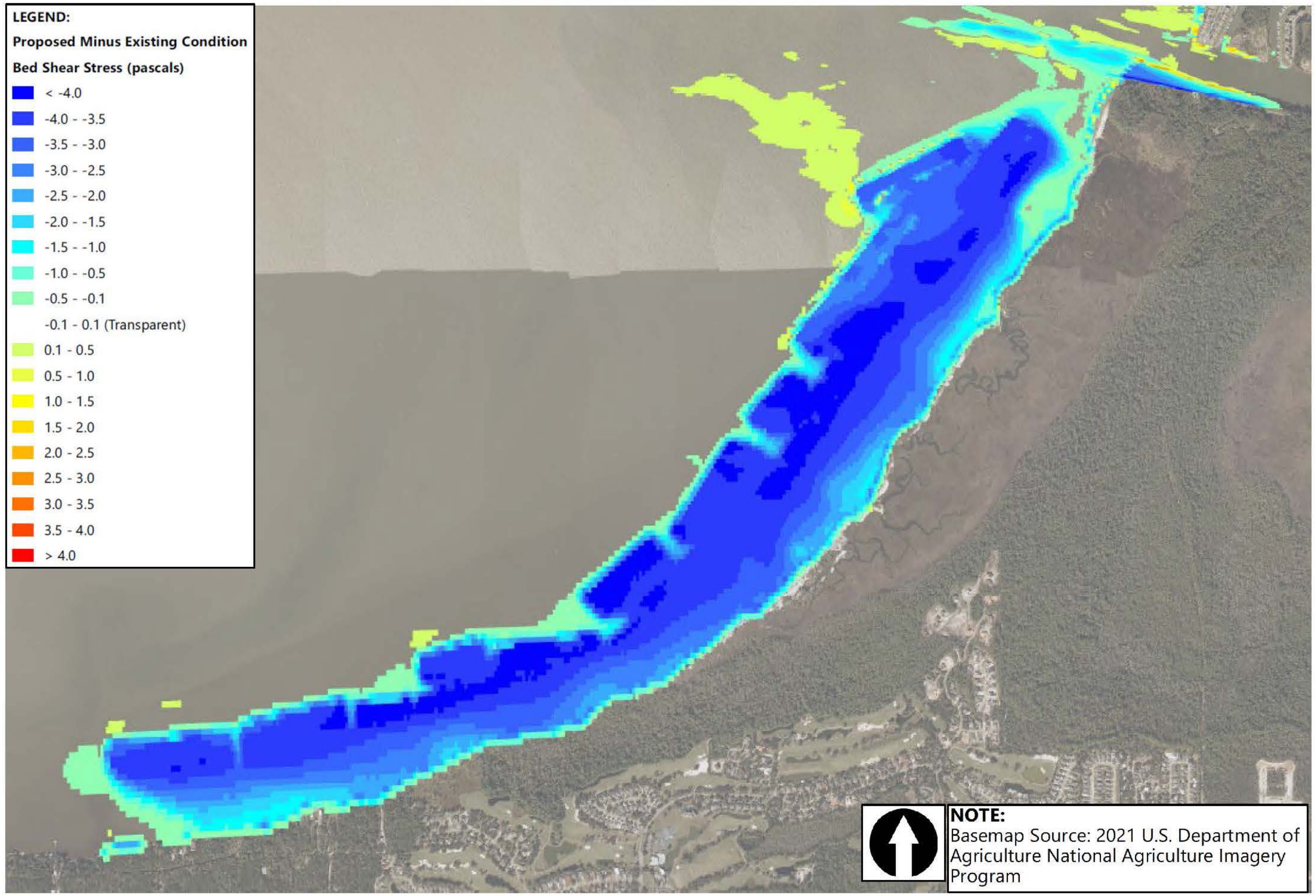


Figure 24d
Bed Shear Stress Difference Results: Annual Storm from the West, Proposed Versus Existing Condition–Berm Alternative 2

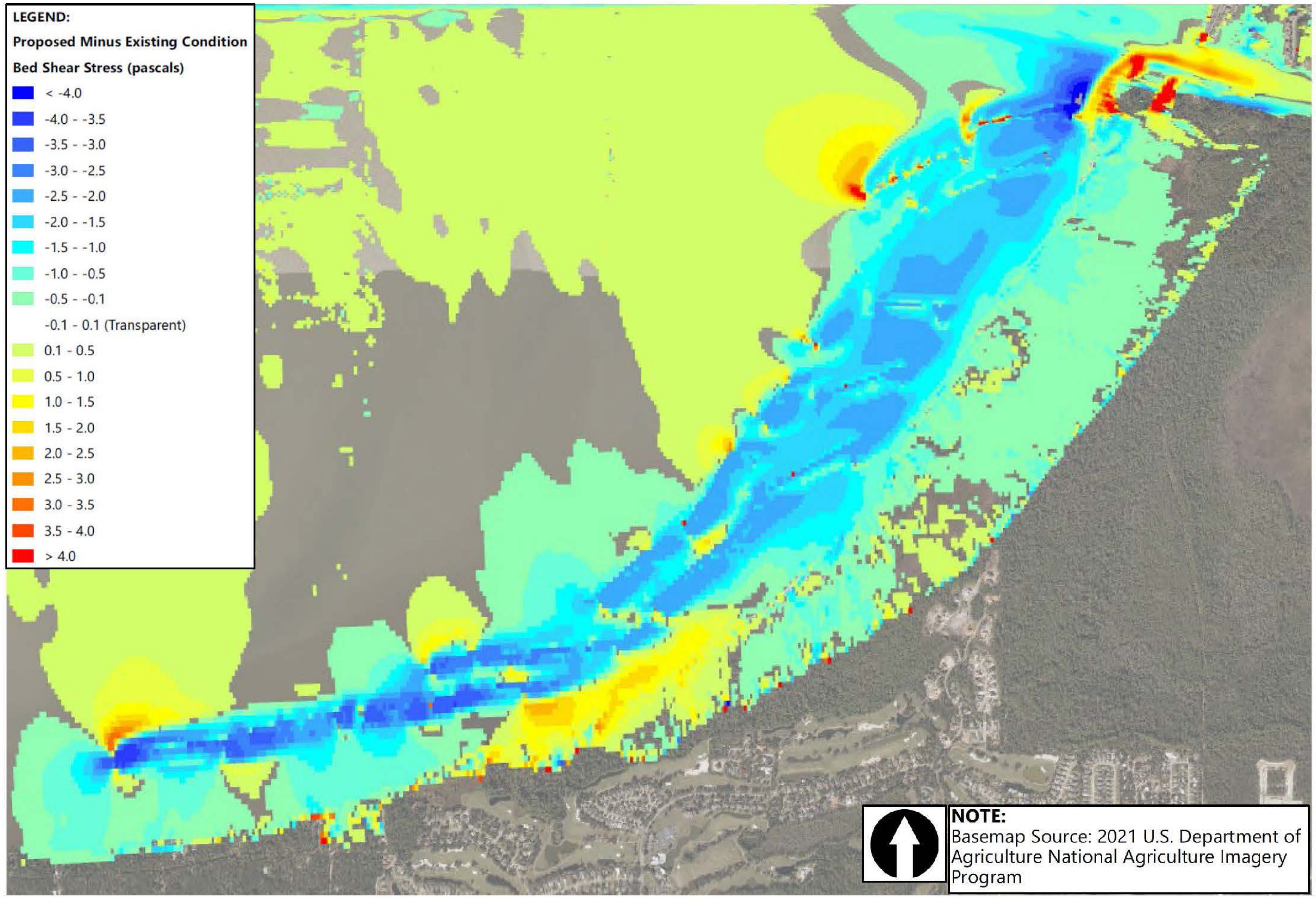


Figure 24e
Bed Shear Stress Difference Results: Hurricane Sally, Proposed Versus Existing Condition–Berm Alternative 1

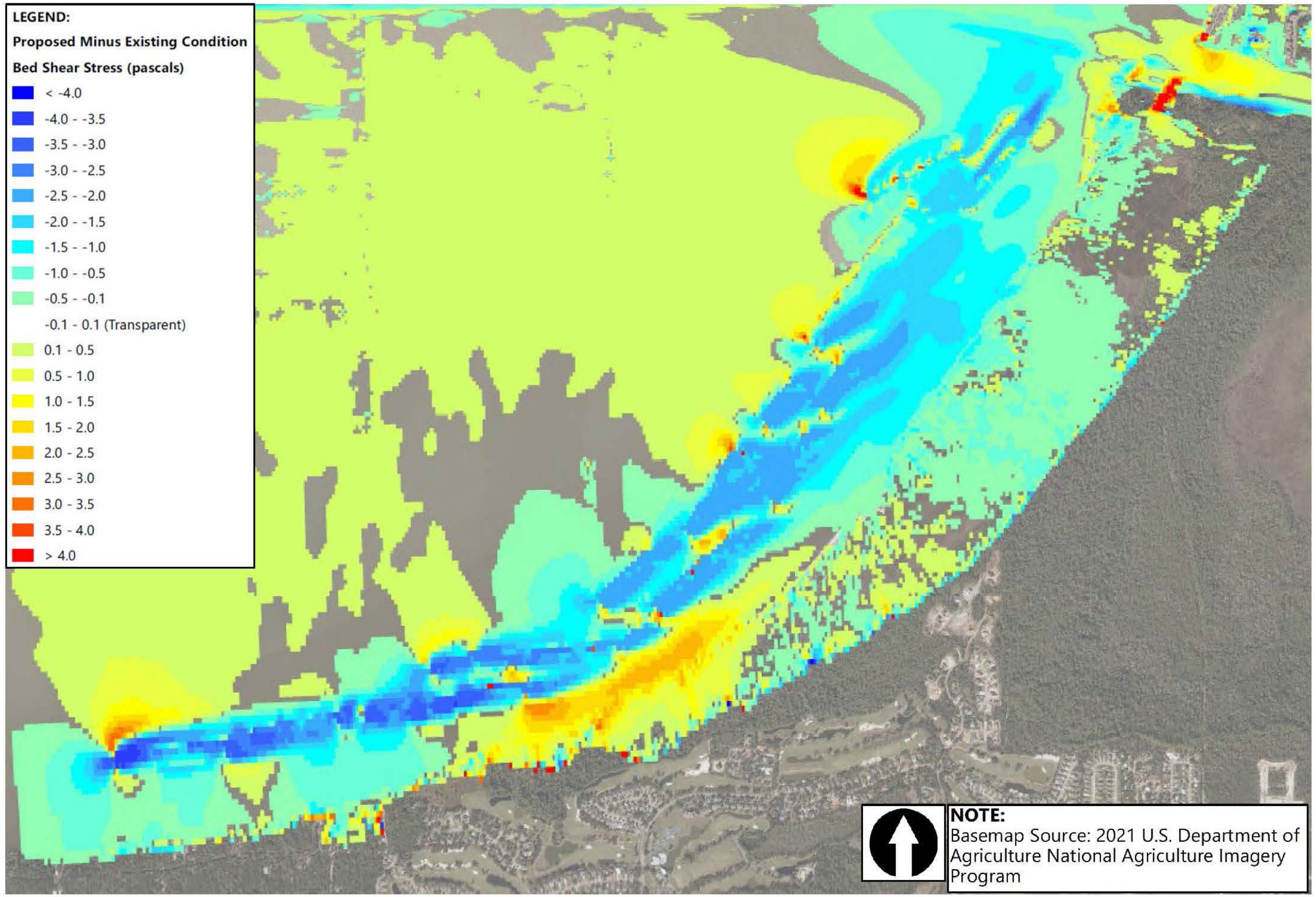


Figure 24f

Bed Shear Stress Difference Results: Hurricane Sally, Proposed Versus Existing Condition–Berm Alternative 2

This report covers findings from research cooperative agreement W912HZ-20-2-0049 **Incorporating Engineering With Nature® (EWN®) and Landscape Architecture (LA) Designs into Existing Infrastructure Projects**, an agreement between the **U.S. Army Engineering Research Development Center** (ERDC) and **Auburn University** (AU).

This report has been prepared by the investigators at **Auburn University**, the **University of Virginia**, and the **University of Pennsylvania** in collaboration with **AnchorQEA** and consultants from the **Dredge Research Collaborative**; it also incorporates research and insights from ERDC's **Engineering With Nature®** project team.

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