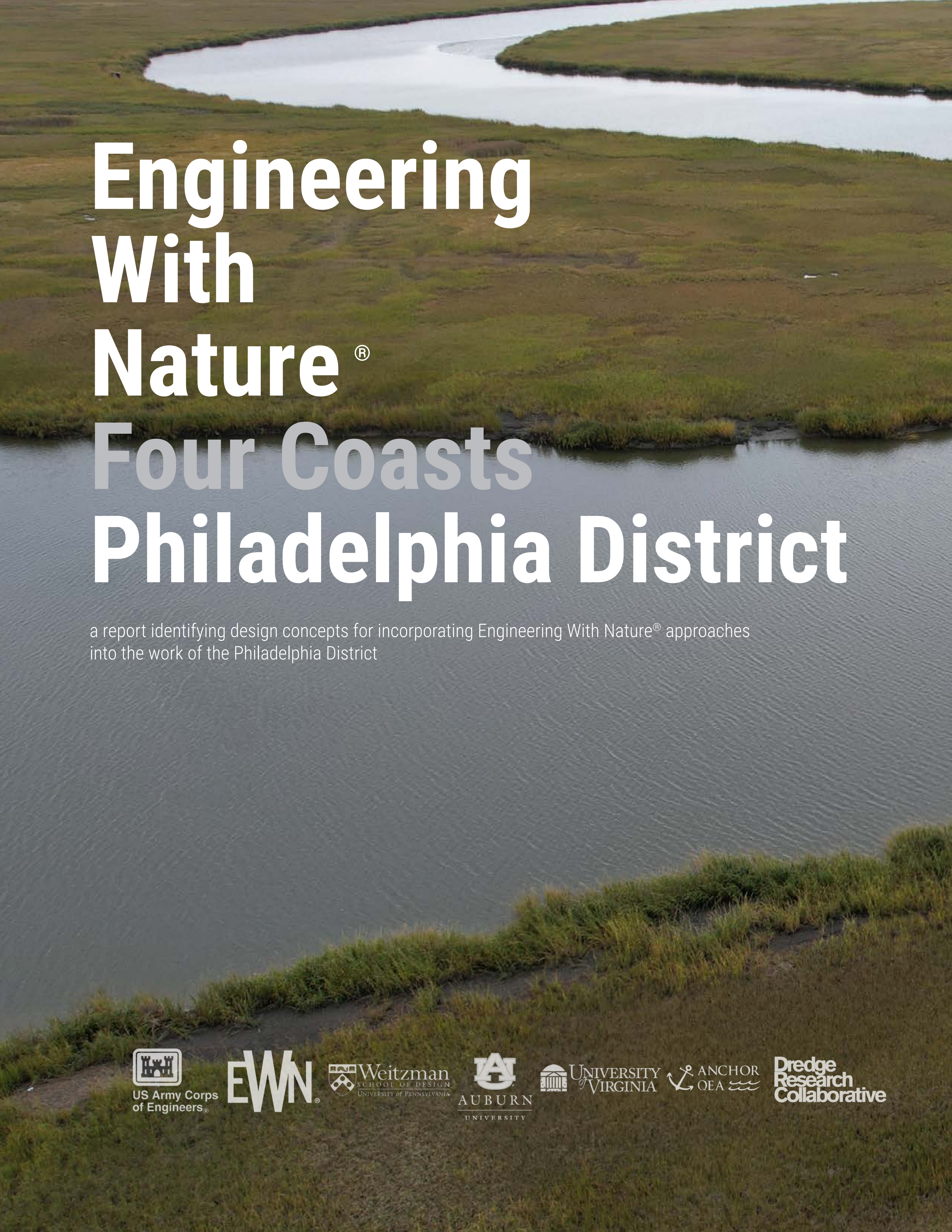


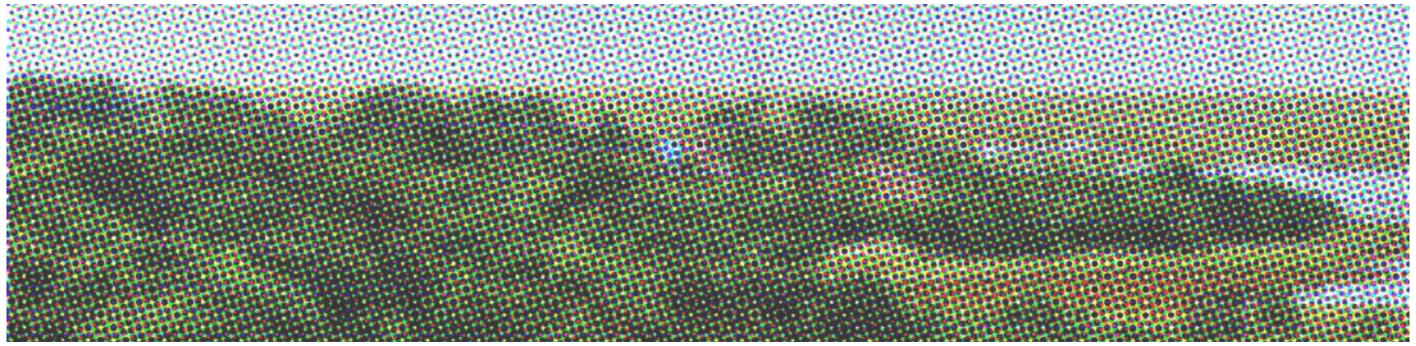
Engineering With Nature®

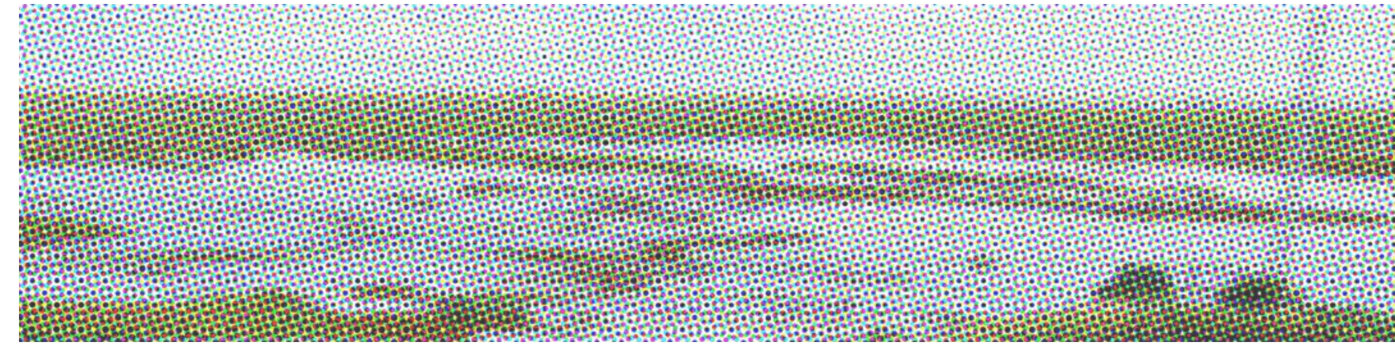
Four Coasts

Philadelphia District

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

US Army Corps of Engineers®
EWN®
Weitzman School of Design, University of Pennsylvania
Auburn University
University of Virginia
Anchor QEA
Dredge Research Collaborative





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This report covers findings from research cooperative agreement W912HZ-18-2-0008 **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) for FY2022-2023

This report has been prepared by the investigators at **University of Pennsylvania**, **Auburn University** and the **University of Virginia** in collaboration with **Anchor QEA**, 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

Spanning 550 miles of waterways, 150 miles of coastline, and 1.1 million acres of wetlands, the U.S. Army Corps of Engineers (USACE) Philadelphia District (NAP) supports more than ten million people in portions of New York, Pennsylvania, New Jersey, and Delaware. Like many Army Corps districts, the NAP's mission is eclectic and includes managing several reservoirs in eastern Pennsylvania, restoring ecologies, cleaning up contaminated sites, and surveying and maintaining several hundred miles of federal navigation channels. With its navigation mission, NAP routinely manages the dredging of major rivers, coastal inlets, and the New Jersey Intracoastal Waterway. Sediment dredged from these channels is increasingly being used to provide ecological benefits and NAP has become a national leader in the beneficial use of dredged material. These endeavors unfold within the context of rising sea levels that pose threats to coastal communities and introduce alterations to ecological habitats and their functioning.

Given NAP's established mission in navigation, flood risk mitigation, and ecosystem restoration, coupled with its role as a USACE Engineer Research and Development Center (ERDC) Engineering with Nature® (EWN) Proving Ground district, the district is strategically positioned to continue to lead the way in addressing the complexities of these issues through innovative natural and nature-based solutions. It is imperative to note that what follows in this report are conceptual explorations—innovative ideas and designs within the realm of Engineering with Nature (EWN). These are not finalized and vetted proposals but rather visionary projects that aim to highlight and potentially develop groundbreaking EWN concepts. Each project is crafted with the intention of incorporating economic, ecological, and social resilience. The comprehensive, regional, and long-term approach advocated in this report emphasizes the exploratory nature of these concepts in adapting to and mitigating the impacts of climate change in the region and may include approaches that require support, collaboration, and possibly funding from entities beyond NAP.

The work summarized in this EWN-LA Four Coasts NAP report took place between January 2022 and September 2023. The report is primarily organized by hydrological subregions: Delaware River, Delaware Bay, and New Jersey and Delaware Coast. After initial research and meetings with representatives at NAP, five sites that exemplified the opportunities for conceptual application of nature-based solutions (NBS) within the three subregions were selected. This initial research into the regional characteristics, including the specific issues and opportunities, and the subsequent site selection are summarized in Part 1. Part 2 delves into the Delaware River with a project to mitigate urban flooding in the Eastwick neighborhood of Philadelphia. Part 3 examines the beneficial use of sediment in two projects: the use of dredged sediment to restore mosquito-ditched marshlands along Murderkill River and the reuse of confined disposal facility (CDF) material to create habitat in Cape May. Finally, Part 4 looks to the Delaware and New Jersey beaches and the back bay environment of New Jersey to describe a dune resiliency research project and a storm surge mitigation project on Holgate Peninsula, respectively.

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 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) to existing work to the advancement of new EWN opportunities that the project team has developed. This report documents in detail five such projects located within the bounds of the USACE Philadelphia District (NAP).

EWN is the philosophy behind 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.

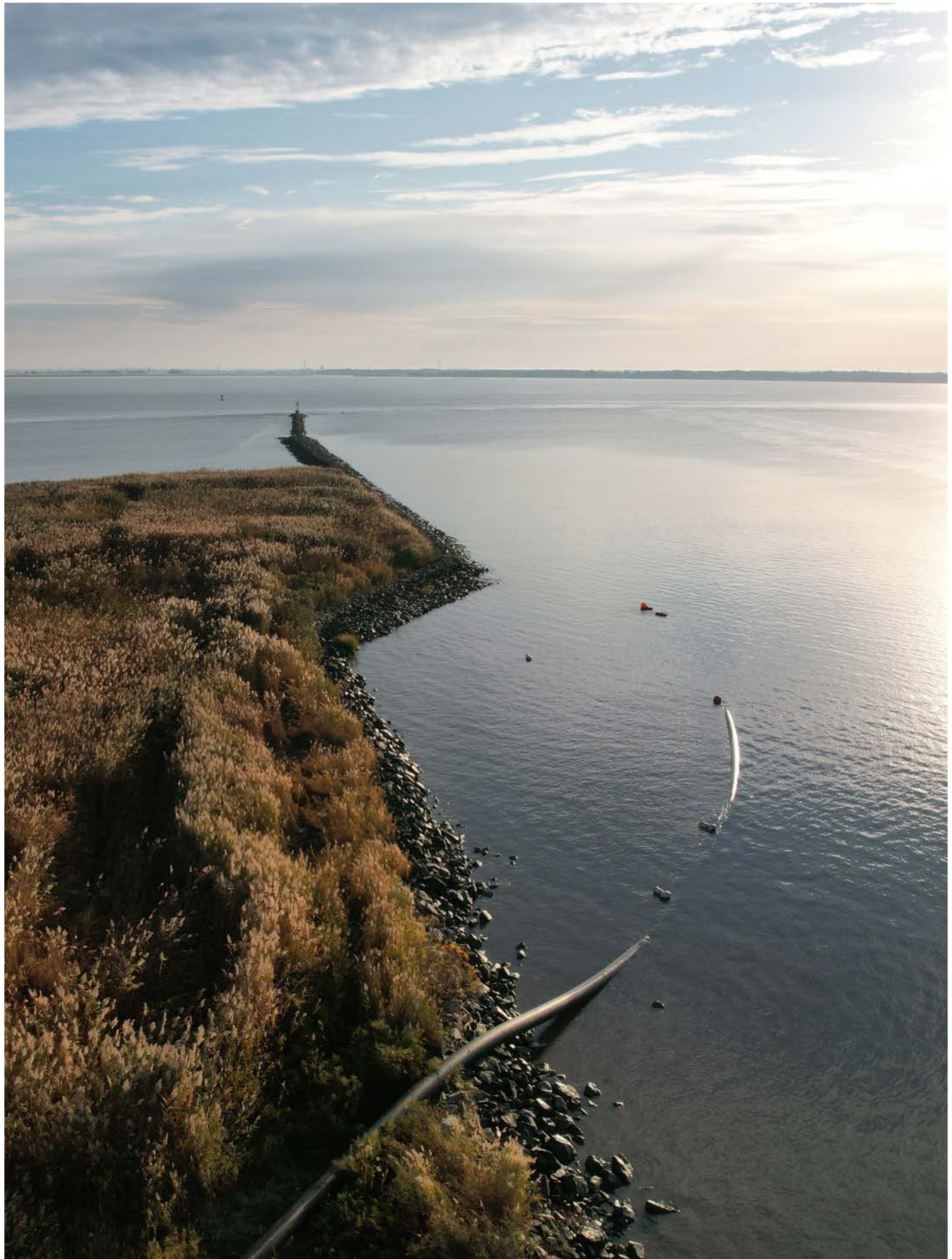
EWN outcomes are "triple-win," which means that they systematically integrate social, environmental, and economic considerations into decision-making and actions at every phase of a project to achieve "innovative and resilient solutions" that are more socially acceptable, viable, equitable, and ultimately, 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 on 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, while 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.

PART 1

PHILADELPHIA DISTRICT



PHILADELPHIA DISTRICT
OVERVIEW

Established in 1866, the US Army Corps of Engineers (USACE) Philadelphia District boasts a diverse history deeply intertwined with navigation, coastal storm risk management, flood risk mitigation, and ecological restoration. Initially centered on harbor improvements, the District played a pivotal role in deepening the Delaware River federal channel during World War II, extending its oversight to 500 miles of navigable waterways. In response to rising sea levels and intensified storms, the District has markedly increased its engagement in flood mitigation projects through robust Coastal Storm Risk Management (CRSM) and Flood Risk Management (FRM) programs. Particularly instrumental in coastal storm risk management, the district employed beach nourishment and dune restoration strategies to safeguard coastal communities, as evidenced by extensive restoration efforts following Superstorm Sandy in 2012.

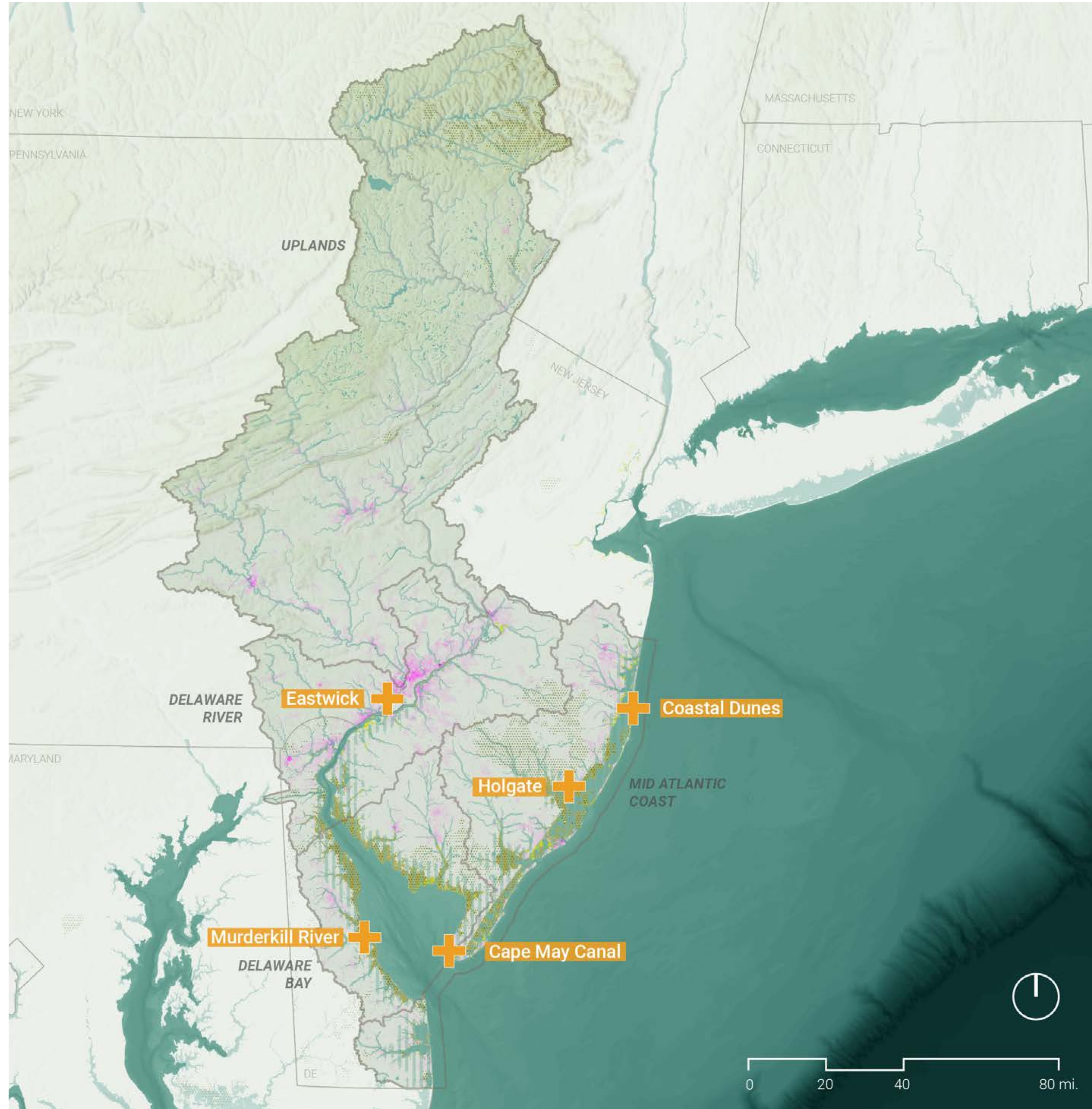
The Philadelphia District also manages the 117-mile New Jersey Intracoastal Waterway and various coastal inlets in New Jersey and Delaware. Regular dredging ensures safe navigation, and when the dredged material is clean, the USACE actively pursues beneficial uses, including marsh restoration and island creation for wildlife habitat and coastal resilience. Although historically present, these practices gained increased attention since Hurricane Sandy in 2012. The District actively engages in the beneficial use of dredged material through initiatives such as championing Regional Sediment Management projects for over two decades, establishing itself as an Engineering with Nature Proving Ground, and collaborating on the Seven Mile Island Innovation Laboratory in Cape May County with the New Jersey Division of Fish & Wildlife and The Wetlands Institute. These initiatives underscore the District's commitment to pushing boundaries, showcasing engineering expertise, and aligning ecological innovation with broader environmental goals and priorities.

1 DISTRICT OVERVIEW
FOCUS PROJECTS

It is essential to highlight that the content within this report delves into conceptual explorations—innovative ideas and designs falling under the framework of Engineering with Nature (EWN). These are not finalized applications; instead, they represent visionary projects intended to underscore and potentially advance EWN concepts. Importantly, these projects may operate independently of current ongoing feasibility studies or intentionally overlook particular implementation challenges in an attempt to describe the EWN potential of the concepts. While they are related to district missions, their focus is on highlighting potential areas to expand the social and ecological implications of the NAP work.

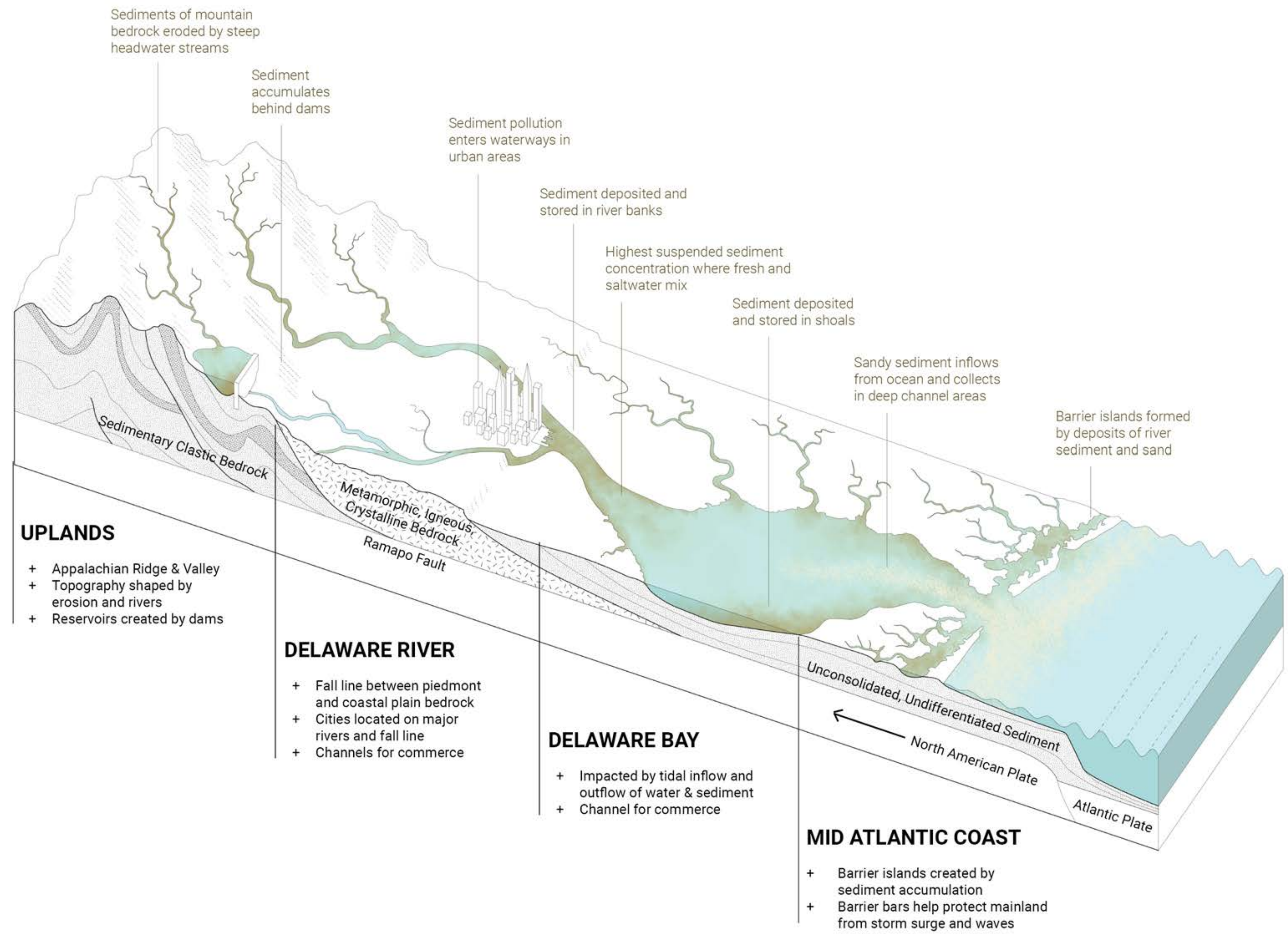
The selection of the five projects for this study is specifically tailored to address both current and future opportunities and challenges within the district. This selection aims to showcase a diverse range of scales, timelines, objectives, and regions, providing a comprehensive exploration of innovative possibilities within the realm of Engineering with Nature.

+ An urban levee project in Eastwick, PA
+ A beneficial use marsh restoration project in Murderkill, DE
+ A habitat-producing CDF project in Cape May, NJ
+ A storm-surge mitigation project in Holgate, NJ
+ A dune resiliency research project along the DE and NJ Coast



1 DISTRICT OVERVIEW
GEOMORPHOLOGY

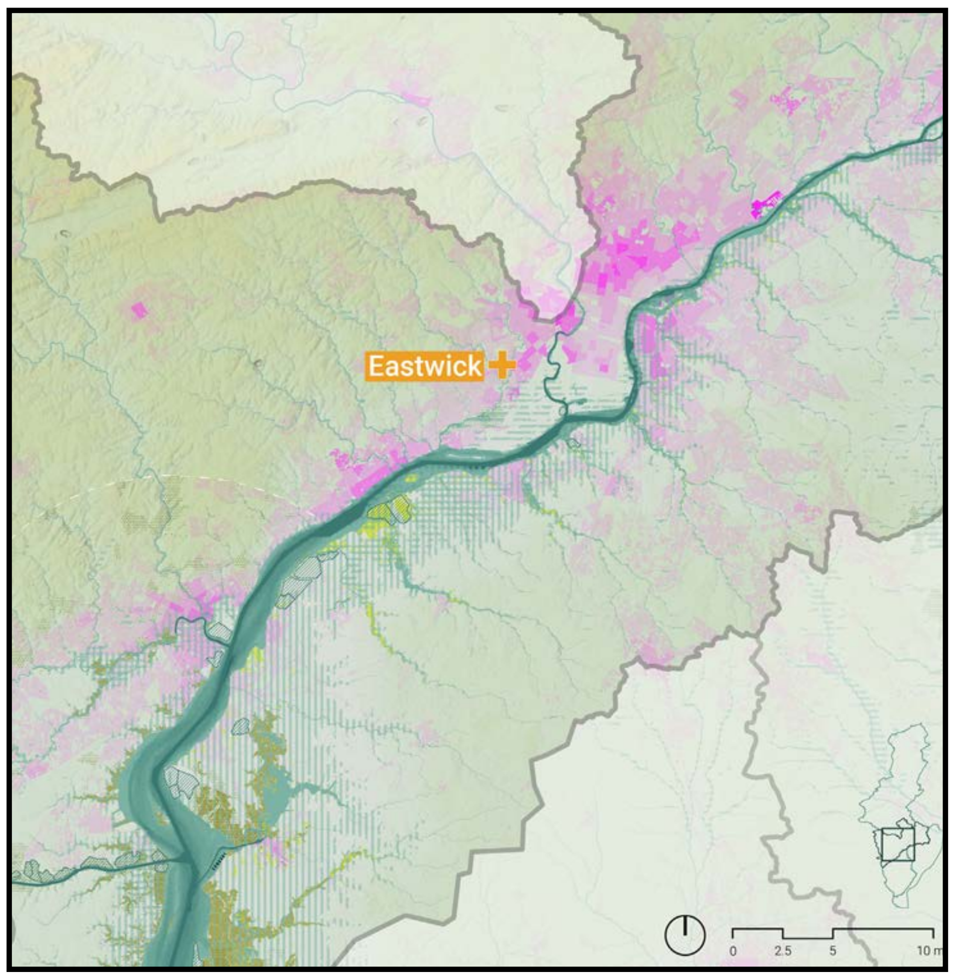
NAP encompasses the Delaware River Watershed and most of the New Jersey and Delaware Coast. This district has four distinct regions: the uplands, river, bay, and coast. These regions are characterized by their unique sediment management and shoreline infrastructure needs.



1 DISTRICT OVERVIEW
REGIONS

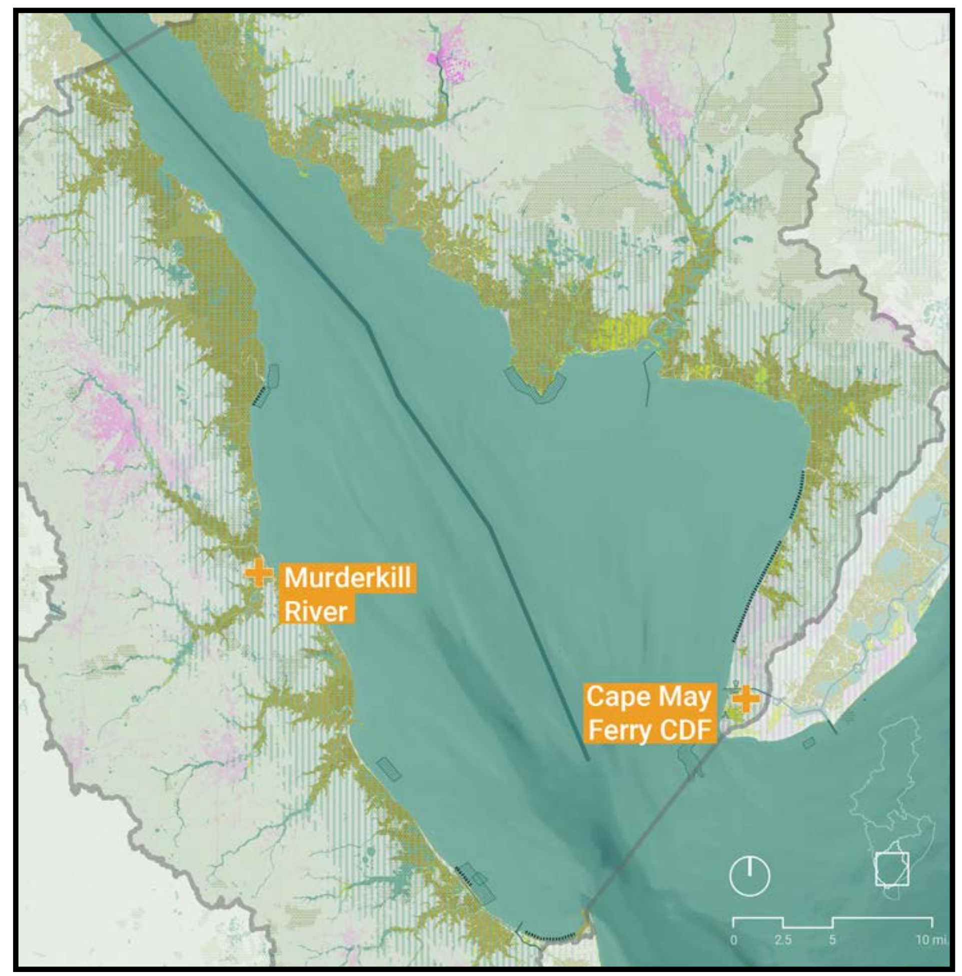
The following sections explore the characteristics of the regions (Delaware River, Delaware Bay, and Delaware and New Jersey Coast). Projects that seek to respond to the specific challenges and opportunities that represent those regions were selected.

DELAWARE RIVER



EASTWICK, PA | URBAN LEVEE

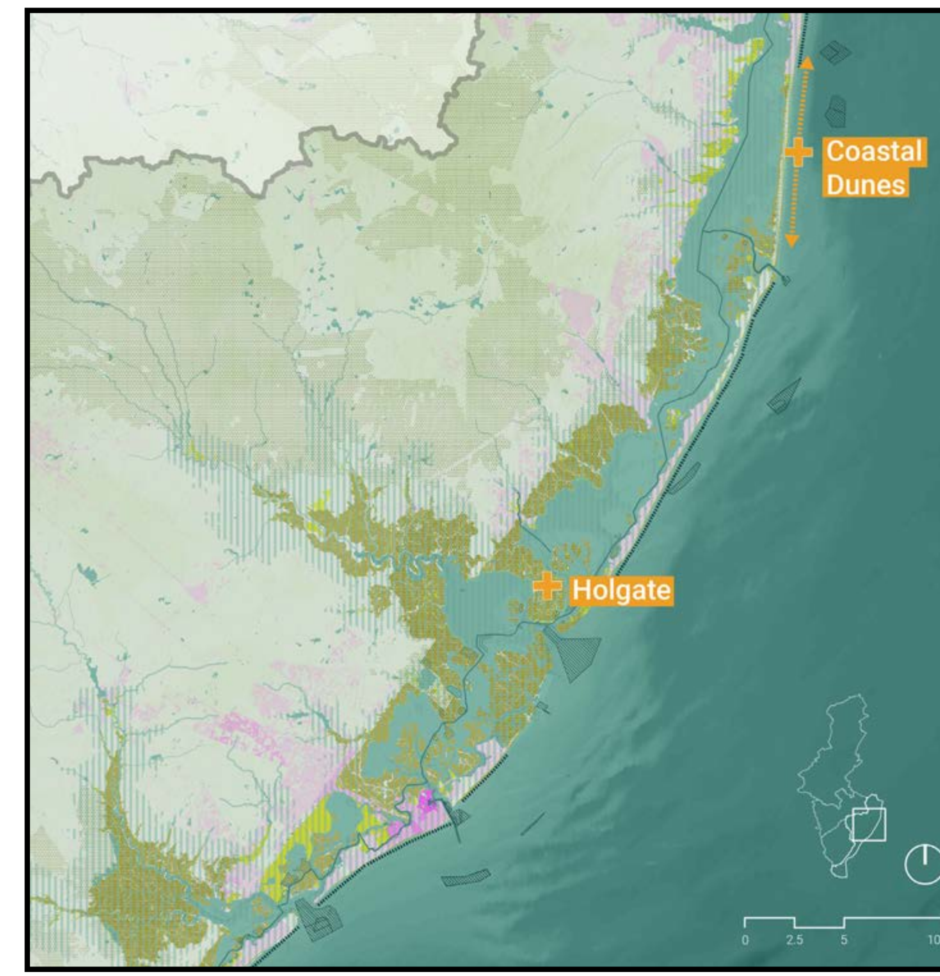
DELAWARE BAY



MURDERKILL RIVER, DE | BENEFICIAL USE MARSH RESTORATION

CAPE MAY FERRY CDF, NJ | HABITAT-PRODUCING CDF

DELAWARE + NEW JERSEY COAST
PARTIALLY SHOWN, TOMS RIVER TO GREAT EGG HARBOR



HOLGATE, NJ | STORM SURGE MITIGATION

COASTAL DUNES | DUNE RESILIENCY RESEARCH

PART 2

DELAWARE RIVER

DELAWARE RIVER
OVERVIEW

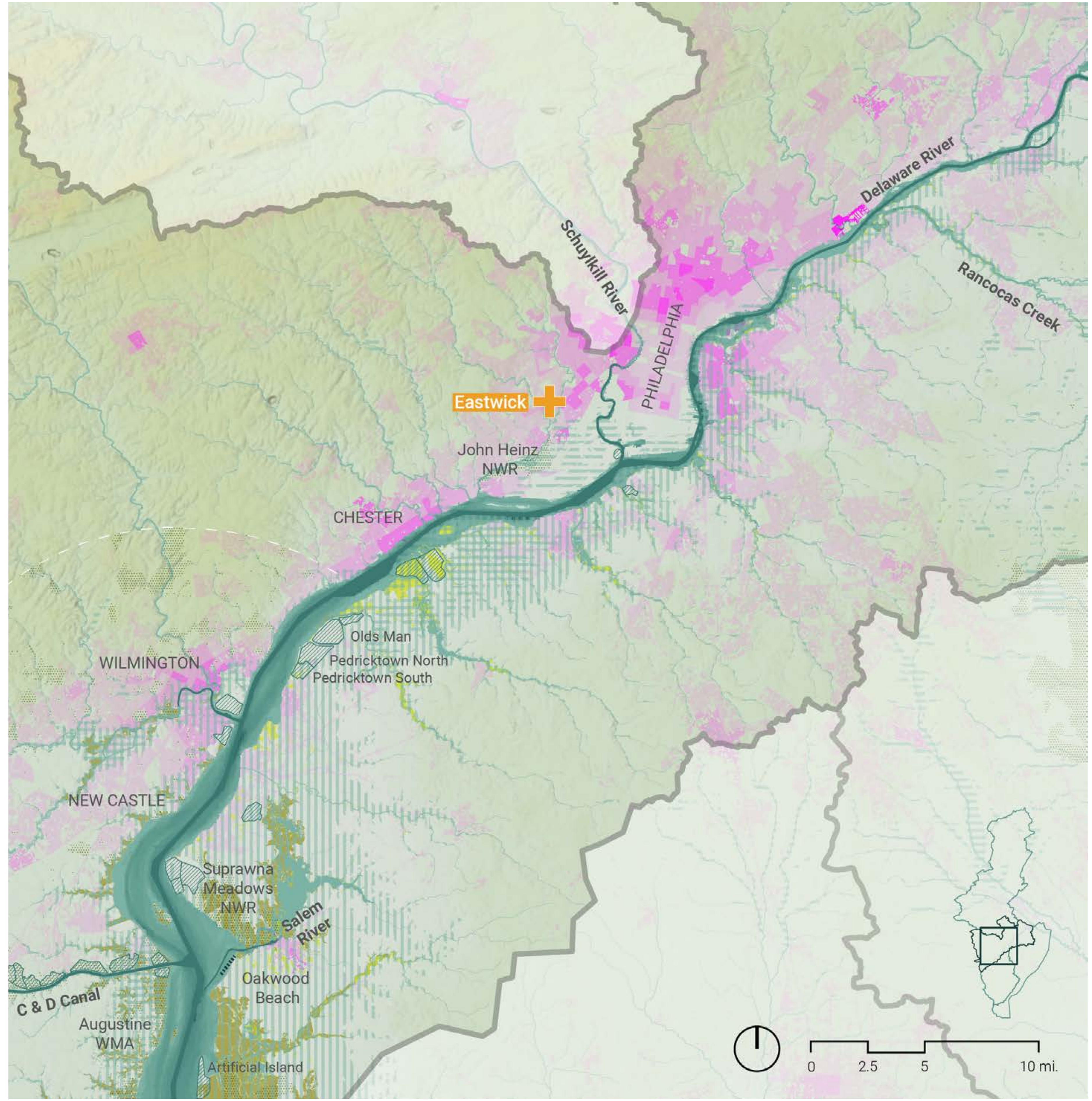
The section of the Delaware River and its watershed between Trenton and the mouth of the Delaware Bay, refereed to as the Delaware River region within this report, is the most densely populated region within the NAP, encompassing vital port cities like Trenton, Camden, Philadelphia, and Wilmington. NAP plays a pivotal role in fulfilling USACE missions, including coastal storm risk management (CRSM), flood risk management (FRM), and the operation and maintenance of federal navigation channels, with a primary focus on the Delaware River, Schuylkill River, and Chesapeake and Delaware (C+D) Canal. This involves surveying, periodic dredging and material placement to ensure navigability and connectivity between ports. While the district traditionally deposits silty fine dredged material in confined disposal facilities (CDFs) along the river, NAP is actively engaged in comprehensive studies exploring the beneficial reuse of such material, as evidenced by the Delaware River Dredged Material Utilization efforts.

Furthermore, in response to the escalating challenges posed by rising sea levels and intensified storms, NAP has significantly expanded its involvement in coastal protection and flood mitigation projects. The district, in alignment with the overarching USACE mission, has robust CRSM and FRM programs implemented throughout the region. This strategic approach becomes increasingly crucial as cities, particularly those in low-lying and justice-impacted neighborhoods, face heightened vulnerability to flooding.

Though certain areas have been impacted by industry, this section of the Delaware River Watershed still features rich ecosystems ranging from riparian forests and floodplain wetlands to freshwater estuaries, freshwater wetlands, and adjacent stream environments. These environments support a variety of wildlife, including important fish species and migratory birds. Freshwater wetlands provide habitat for freshwater eelgrass, smallmouth bass, channel catfish, hybrid muskellunge, bullhead, white perch, and walleye pike. Anadromous fish travel up the Delaware River and use its tributaries for spawning grounds. The adjacent riparian forests and grasslands provide food and shelter for various resident and migratory birds and are essential to the Atlantic Flyway, one of North America's four major waterfowl routes. The Delaware and Schuylkill Rivers are valued recreational resources, especially in the urban areas of Philadelphia and Trenton, where continuous riverside trails invite visitors to bike, walk, picnic, and hang out by the rivers. Boating and fishing are also popular pastimes along the rivers and their tributaries.

1 DELAWARE RIVER
ACE PROJECT FOCUS

The following map seeks to examine the relationship between areas of social and ecological vulnerability within the region to identify projects that can potentially mitigate those vulnerabilities. Highlighted is the community of Eastwick, where complementary measures were proposed to the planned urban levee project there as one of the focus projects of this study.



ECOLOGICAL + SOCIAL VULNERABILITY
- FEMA 100 YR Floodplain
- CAT 1-4 SLOSH Model
- Vulnerable Wetlands* *According to TNC Resiliency Study*

Social Vulnerability Index
- 0-20% Poverty
- 20- 40%
- 40-60%
- 60-80%

ECOLOGICAL + SOCIAL ASSETS
- Wetlands
- Parks and Protected Areas *National, State, and Local Parks*

EWN-LA FOCUS AREAS
- Eastwick Urban Levee

USACE PROJECTS + OPERATIONS
- USACE Channel Areas
- USACE Placement Areas
- Federal Shoreline Projects

Center for Disease Control Agency for Toxic Substances and Disease Registry. 2018. Social Vulnerability Index-Overall.

URBAN LEVEE
EASTWICK, PENNSYLVANIA

Built atop 6,000 acres of historic wetlands, Eastwick is one of the lowest-lying communities in Philadelphia. Historically, this area has been prone to flooding due to its low elevation and proximity to Darby and Cobbs Creek and the Delaware River. Present-day, the neighborhood, composed of densely organized residential homes adjacent to a historic landfill, has been experiencing increases in the frequency, duration, and intensity of riverine and stormwater flooding during storm events. In addition to environmental threats, Eastwick residents have a complicated history of environmental injustices, disenfranchised and excluded in decisions surrounding land and community domain (EFNC 2012). As part of the Philadelphia City Planning Commission urban renewal project in the 1950s, nearly half of the Eastwick residents were displaced, and a radical reduction of the natural flood mitigating tidal marshland was recorded. Nevertheless, in 2015, residents won a pledge from the city to be included in future planning efforts. Coalition groups addressing environmental concerns and advocating for Eastwick's sustainable future have formed Eastwick Friends and Neighbors Coalition, Inc. (EFNC), and the next steps in flood risk management (FRM) are underway. To address these environmental injustices further, the City of Philadelphia Office of Sustainability (OOS) is spearheading coordination amongst community organizations and local, state, and federal agency partners such as the USACE and the EPA.

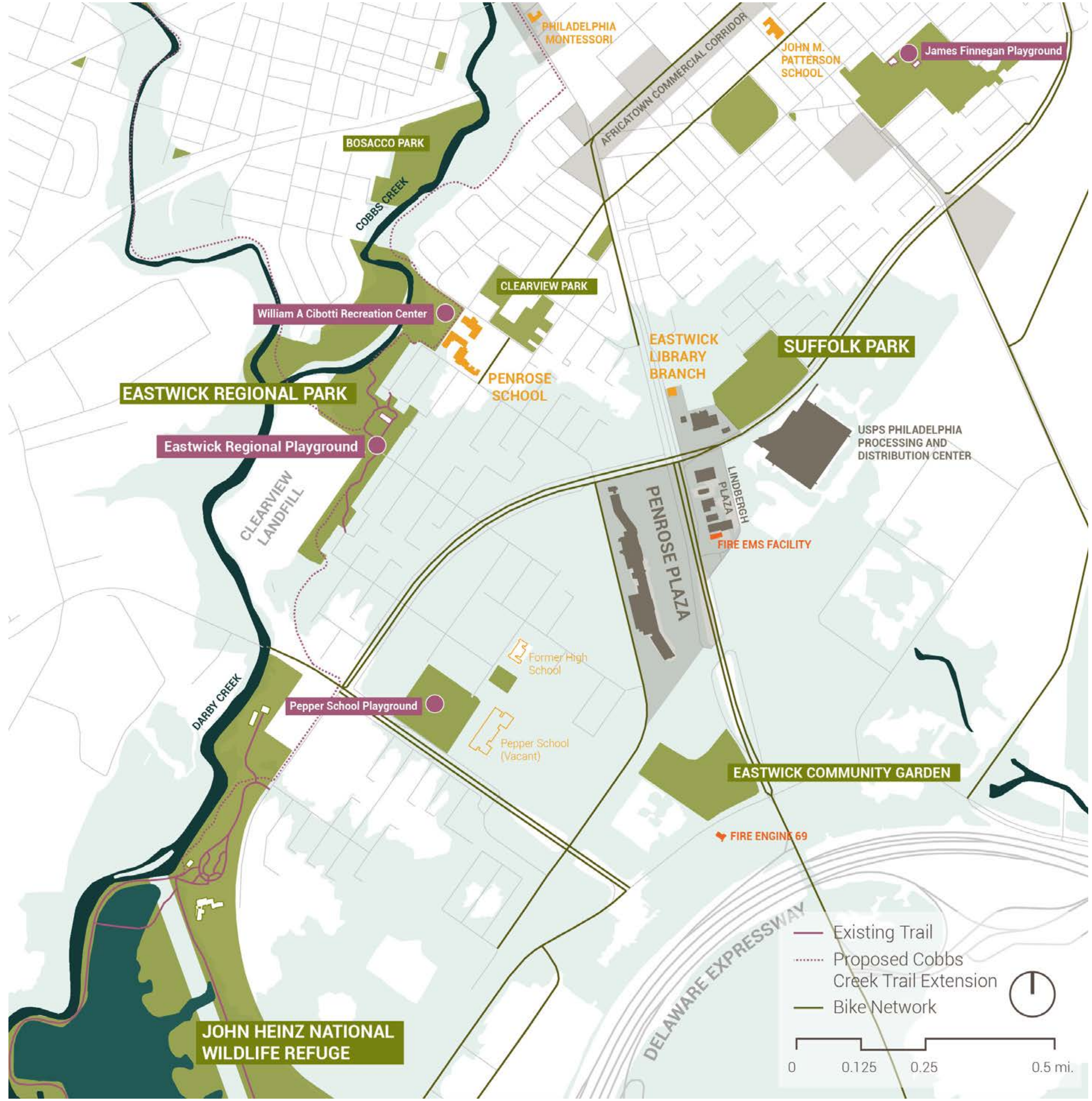
FRM projects implementing nature-based components experienced higher levels of preparedness, greater resistance, quicker recovery, and the ability to adapt to flooding events. After evaluating multiple FRM measures, the USACE proposed levee construction due to its cost-effectiveness, reduced home risk, and minimal impact on community cohesion. A holistic approach to traditional levee design can be invaluable to a community experiencing recurring and intensifying flooding events such as Eastwick while increasing the ecological and social value of the project. Additionally, it is crucial to incorporate public engagement throughout the process to address potential concerns and incorporate desired elements.

1 EASTWICK CONTEXT
FLOOD RISK

Underserved communities are often situated in floodplain areas that are susceptible to flooding (Gourevitch et al., 2022; Chakraborty et al., 2014; Collins et al., 2019). Along the Delaware River, an area of southern Philadelphia comprising the Philadelphia International Airport, the John Heinz National Wildlife Refuge, and Eastwick are all in the 100-year floodplain. In the Eastwick area, there are four primary sources of flooding—riverine flooding, coastal flooding, tidal flooding, and stormwater flooding (Arcadis, 2022). Combined flooding from any or all these sources threatens residents and infrastructure in the area. Riverine flooding is the most acute form of flood risk threatening the Eastwick community, prompting reinforcement specifically to Cobbs Creek and associated historic overflow.

1 EASTWICK CONTEXT
COMMUNITY ASSETS

The proposed levee design is within the Eastwick Regional Park, one of several parks along Cobbs Creek. The park is active within the community, serving immediate neighborhood residents, day camp participants, and the adjacent Penrose Elementary School children. Opportunities exist to connect Eastwick Park to nearby recreational assets like Cobbs Creek Trail and John Heinz National Wildlife Refuge (NWR), the largest wetland complex in Philadelphia. Cobbs Creek Trail ends north of the project, but the proposed plans involve the connection of the established four-mile trail to the Eastwick Regional Park trail and south to John Heinz NWR.



1 EASTWICK CONTEXT
SITE

The levee's proposed location and surroundings are a complex mixture of riparian wetlands, recreational parklands, and a landfill. The proposed levee would tie into two high points on site: to the north, baseball fields in the William A. Cibotti Recreation Center, and to the south, the Clearview Landfill. Eastwick Park hosts recreational amenities like playgrounds, grills, and tennis and basketball courts. Currently, the EPA is in the process of cleaning up, capping, and replanting Clearview Landfill. EPA also recently underwent remedial action to clean up waste and restore residential areas with contaminated soil from the Clearview Landfill. This remediation project impacted an established path, thus necessitating a replacement bike path planned to run from 84th Street to 80th Street. Additional EPA on-site improvements include two newly constructed, large bioswales that capture water runoff from the landfill and creek-side stabilization projects along the western bank of Cobbs Creek. The bioswale to the north of the landfill is located within the proposed boundary of the levee. In addition to the bioswales, the site supports a 2-acre riparian forest adjacent to Cobbs Creek.

2 EASTWICK LEVEE CONCEPT
LEVEE ALIGNMENT

USACE presented two potential alignments during the tentatively selected plan (TSP) Milestone meeting held on January 31, 2023. After additional consideration and modeling, a preferred alignment was designated in the Draft Integrated Feasibility Report & Environmental Assessment. For this EWN project, the team worked to design with both alignments as they were initially proposed.

For this EWN project, the team worked to design with both alignments as they were initially proposed.

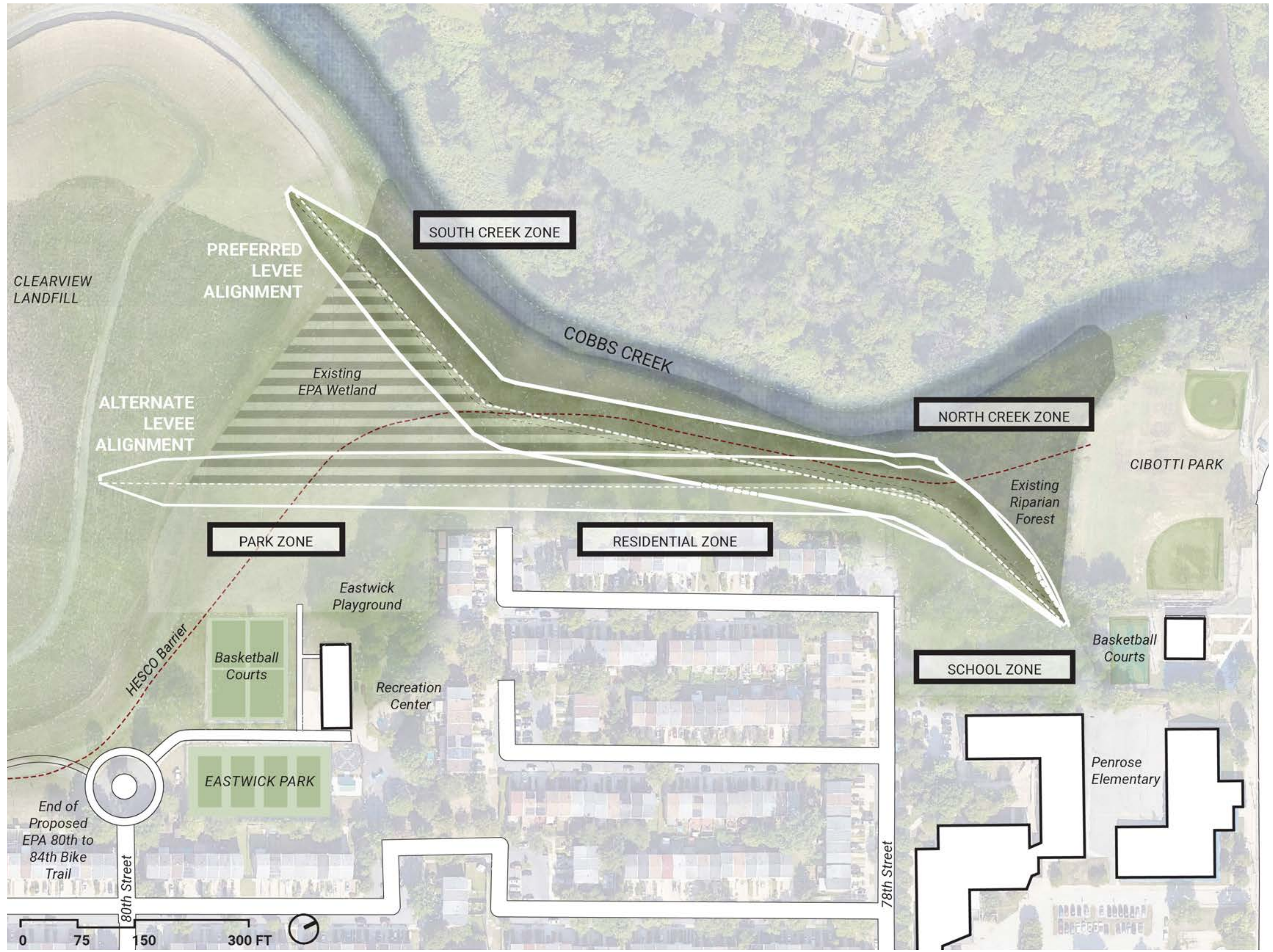
PARK ZONE: Located between the levee and the playground, this zone contains Eastwick Park, Recreation Center, Tennis Courts, Basketball Courts, and Playground, as well as the start of the proposed EPA bike trail.

RESIDENTIAL ZONE: This zone exists between the Saturn Place residential properties and the levee toe.

SCHOOL ZONE: Located between the levee and Penrose Elementary School, this zone is accessible by 78th street, and characterized by the existing maintained meadow.

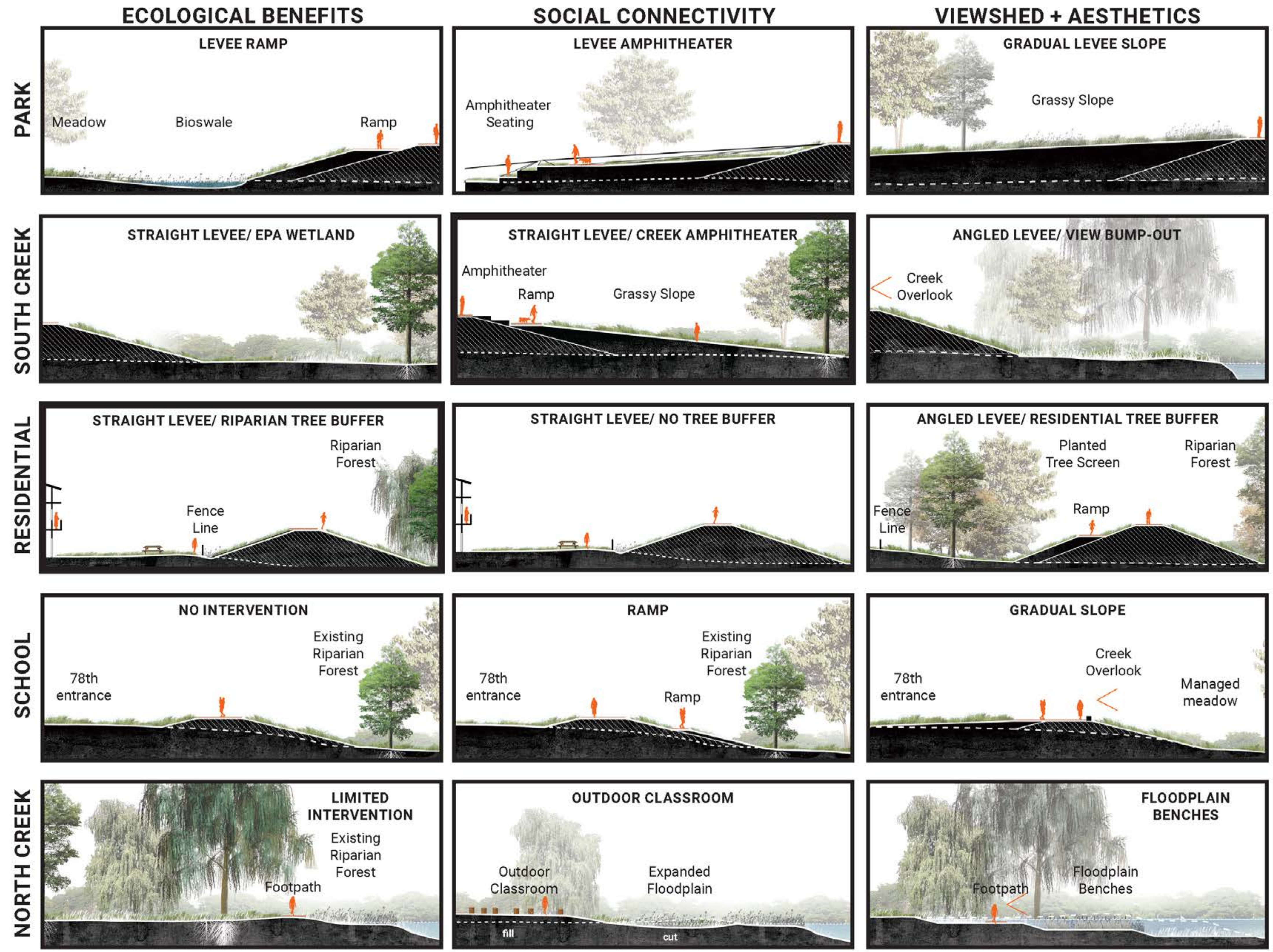
SOUTH CREEK ZONE: Located between the levee and the south side of the creek, this zone includes an EPA wetland, several EPA bank stabilization projects, and a small riparian buffer.

NORTH CREEK ZONE: Located between the levee and the north side of the creek, this zone includes the 2-acre riparian forest.



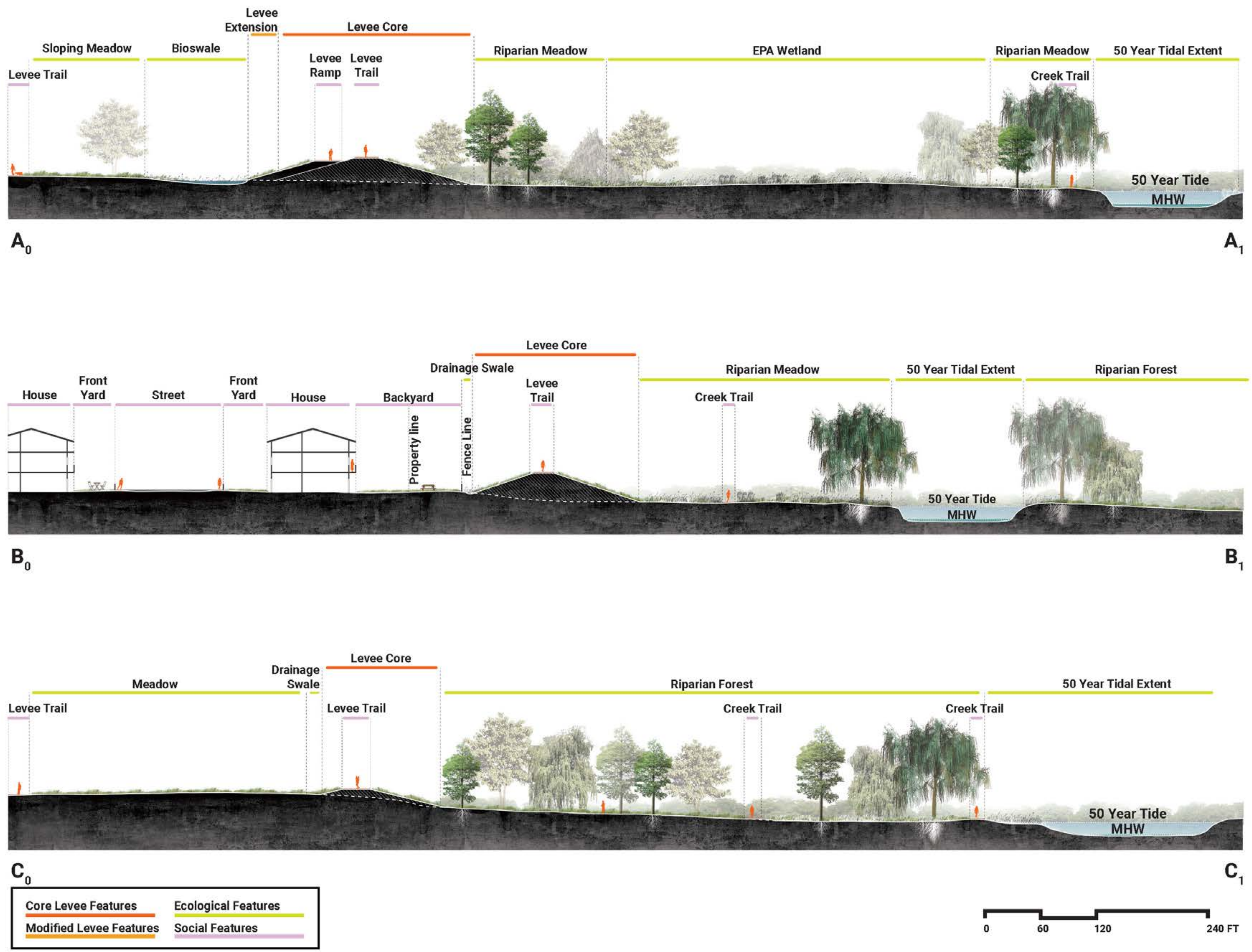
2 EASTWICK LEVEE CONCEPT
SECTION STUDIES

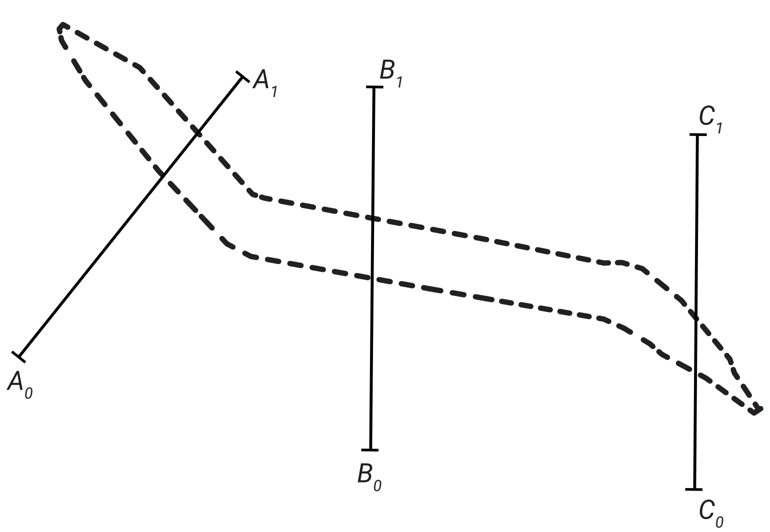
The combination of a traditional FRM strategy with natural and nature-based features in addition to USACE's structural levee can increase the ecological, social, and aesthetic benefits of the protection system. Three complimentary approaches to the standard levee design are presented, each focused on increasing one of these primary benefits to encourage and prioritize different values in the decision-making process. In the section studies drawing, these approaches (ecological, social, and aesthetic) are applied to five zones (park, residential, school, south creek, and north creek). These designs are not comprehensive or independent; instead, components are to be considered and implemented where feasible in the final design of the levee system. The following plans use these section studies to develop a design that will further discuss potential benefits and limitations.



2 EASTWICK LEVEE CONCEPT
ECOLOGICAL SECTIONS

In a plan that maximizes ecological benefits, the straight levee alignment setback from the shoreline allows for creek-adjacent wetlands and riparian buffers. This increased riparian space would improve overall river connectivity and provide increased flood protection. Complimentary measures with this alignment would preserve, as much as is feasible, the upland wetlands previously constructed during the EPA restoration efforts, minimize impacts to the existing riparian forest habitat to the north, and encourage minimization of the overall levee footprint. Minimal bioswale grading along the toe of the proposed levee would improve drainage and direct water to the constructed and existing wetland systems. Increasing the ecological value of the levee system adds an additional layer of defense against flood risk, improves resilience for the community prone to flooding, and enhances the sustainability of a natural system in an urban environment.





2 EASTWICK LEVEE CONCEPT
ECOLOGICAL PLAN

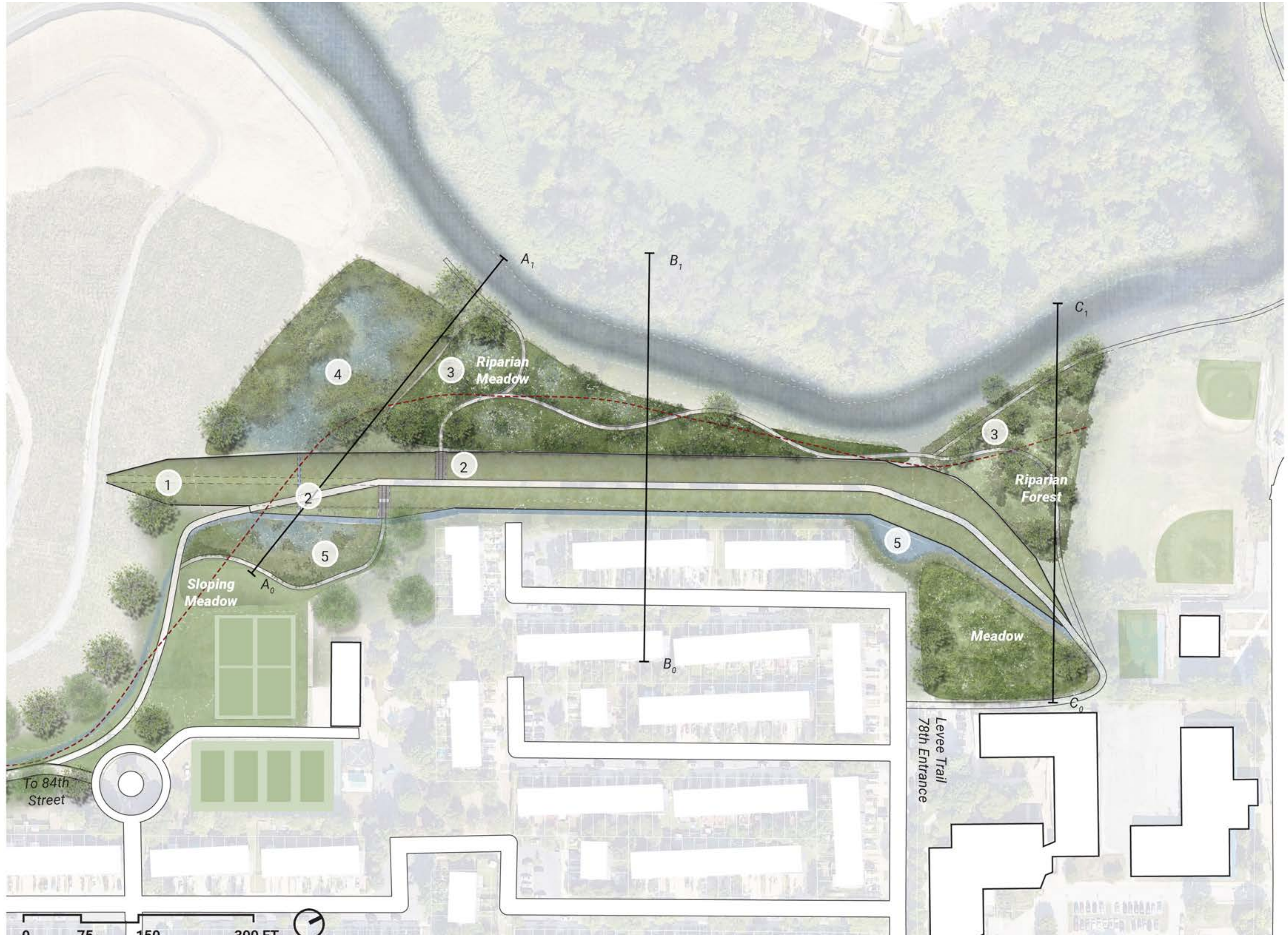
① **STRAIGHT LEVEE ALIGNMENT** Maximizes the creek-adjacent wetlands and flood lands.

② **LEVEE RAMPS AND STAIRS** Provide accessibility while minimizing levee footprint.

③ **MANAGED RIPARIAN HABITAT** Preserves, enhances, and diversifies of valuable riparian habitat.

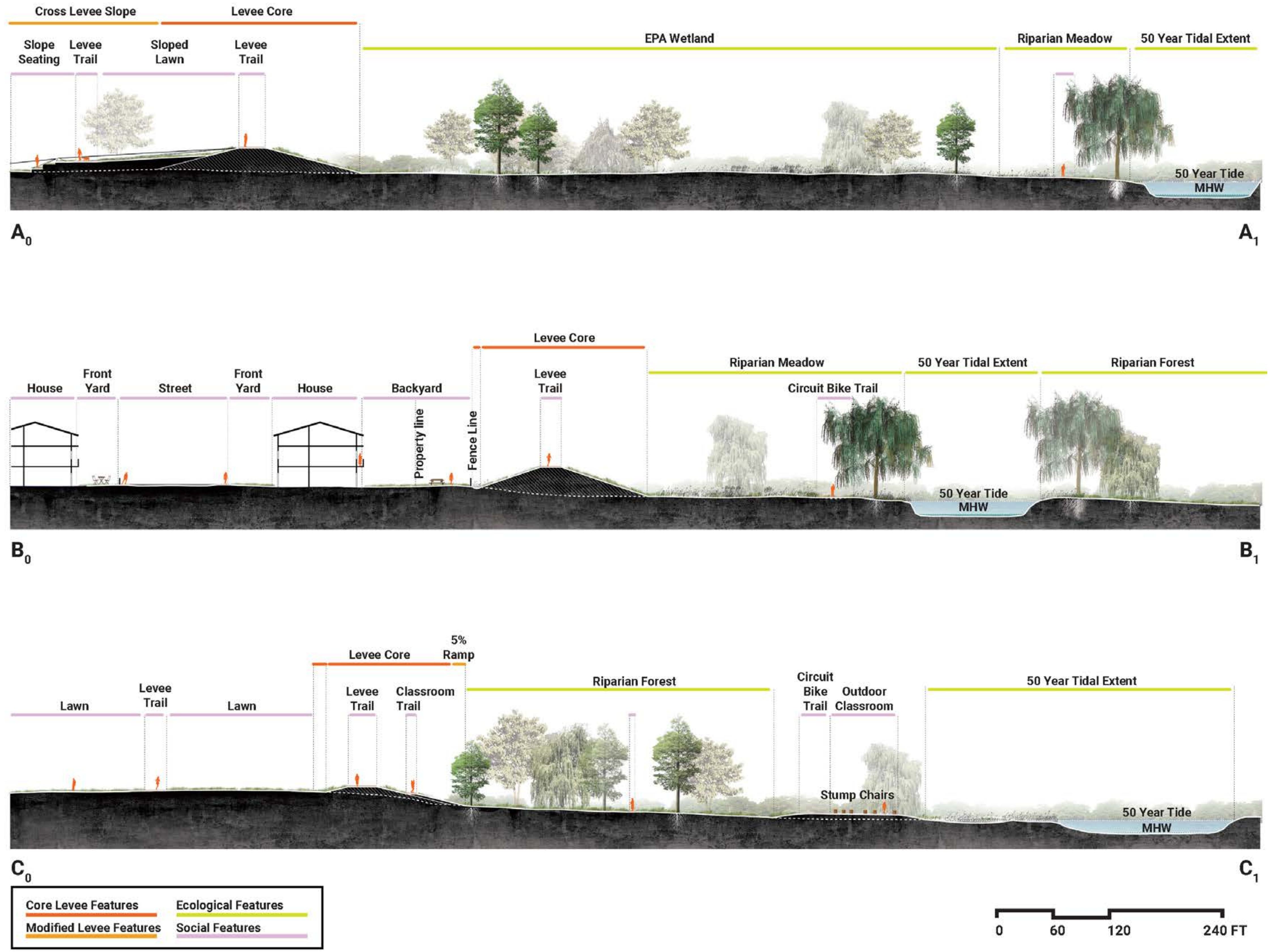
④ **EPA WETLANDS** Captures runoff from the landfill.

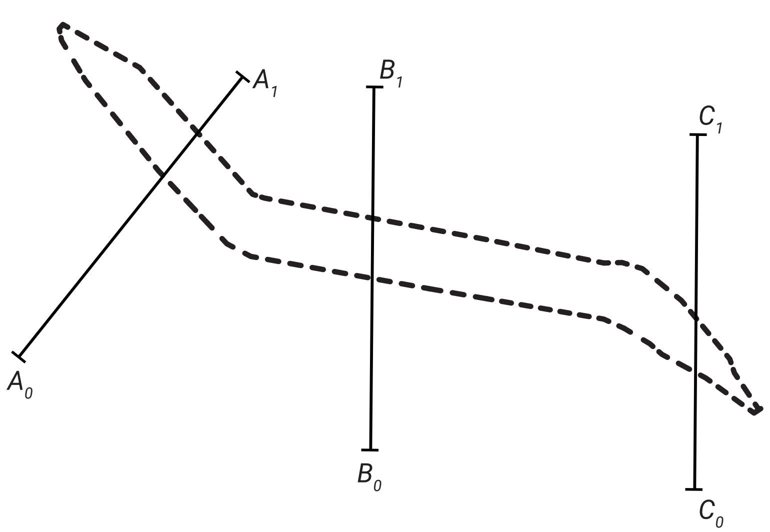
⑤ **BIOSWALES** Incorporates stormwater management into the levee design, and drains into the existing EPA wetlands on site.



2 EASTWICK LEVEE CONCEPT
SOCIAL CONNECTIVITY SECTION

This design concept is intended to incorporate and extend the use of the current site through trails and open space. Accessibility through measures including Americans with Disabilities Act-compliant ramps, bicycle paths, and pedestrian trails, as well as diversification of spaces for public use (e.g., amphitheater, lawn, or living classrooms), could be integrated and built around the levee system to encourage public access and use to support overall social connectivity, accessibility, and integration to existing trail networks. The trail network would connect to current and proposed trails, including the new trail constructed along the EPA landfill restoration from 80th to 84th Street and the Cobbs Creek Trail. This system could be expanded to connect to existing points of interest, including the John Heinz Wildlife Management Refuge, Eastwick Park and Playground, Cibotti Recreation Center and Ballfields, and Penrose Elementary School. Connection to these points of interest will also extend existing social spaces. For example, on the southern side, the lawn space and modified grassy slope could extend the current Eastwick Park and Playground space, and a living classroom on the northern side would provide an extension to the nearby Penrose Elementary School.





2 EASTWICK LEVEE CONCEPT
SOCIAL CONNECTIVITY PLAN

① **STRAIGHT LEVEE ALIGNMENT** Allows for graded slope on both sides of levee which increases connectivity and access.

② **CROSS LEVEE SLOPE** Modifies levee form to allow for a gradual slope across the levee.

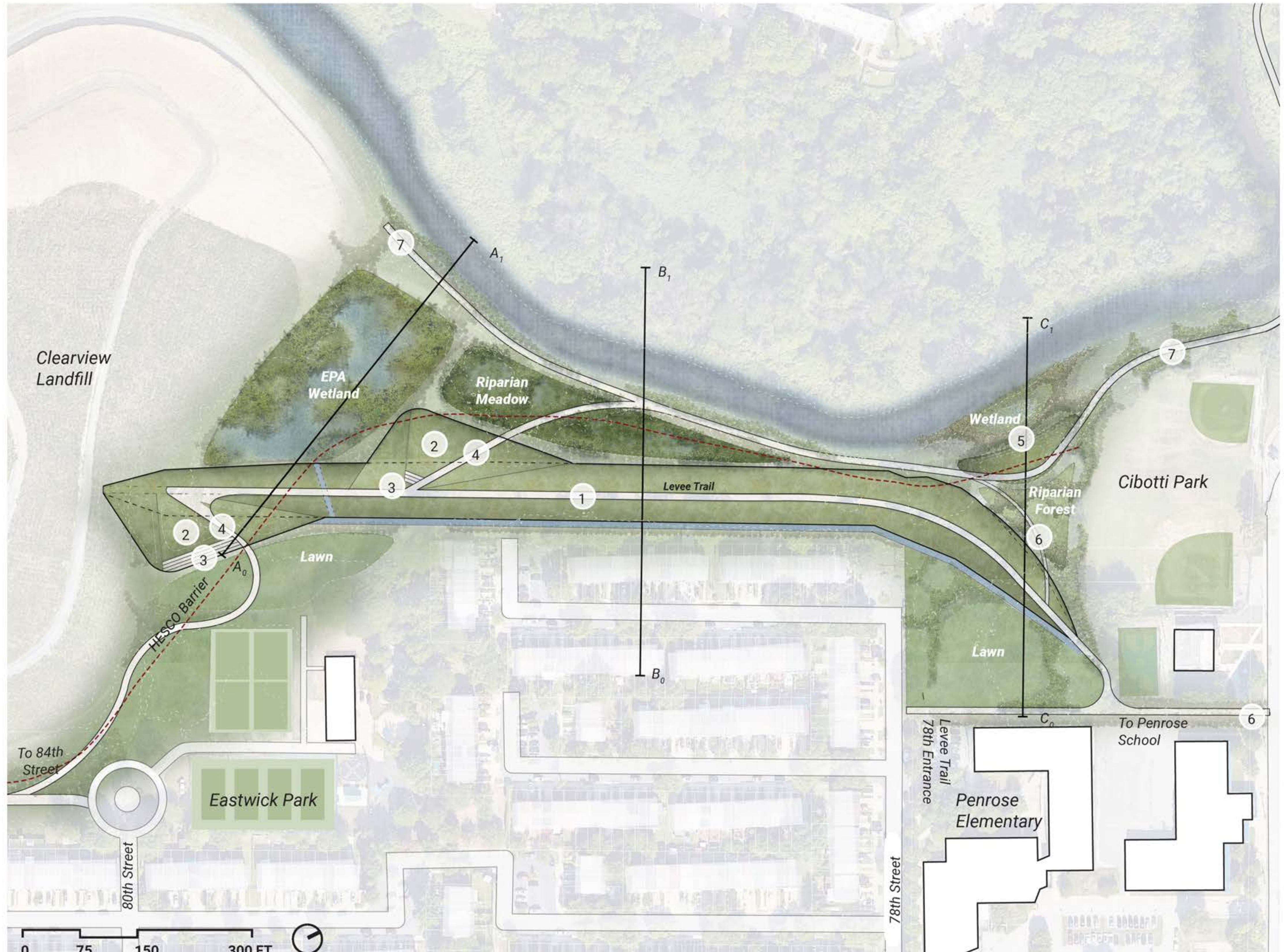
③ **SLOPE SEATING** Grades into the modified levee slope to create amphitheater type views of the river on the west, and the Eastwick park on the east.

④ **LEVEE RAMP** Allows for ADA Accessibility.

⑤ **OUTDOOR CLASSROOM** Extends Penrose School to the creek. The classroom can be graded and built up on higher ground with fill from adjacent wetland excavation.

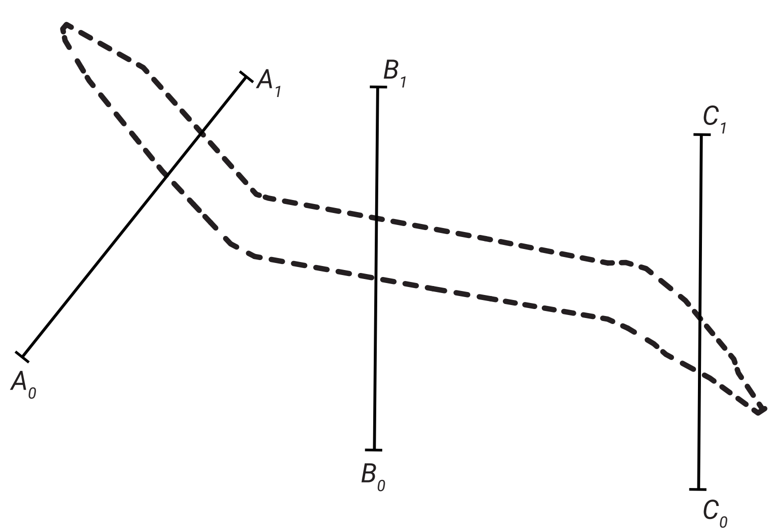
⑥ **CLASSROOM TRAIL** Connects Penrose Elementary School and Cibotti Park to the levee and outdoor classroom.

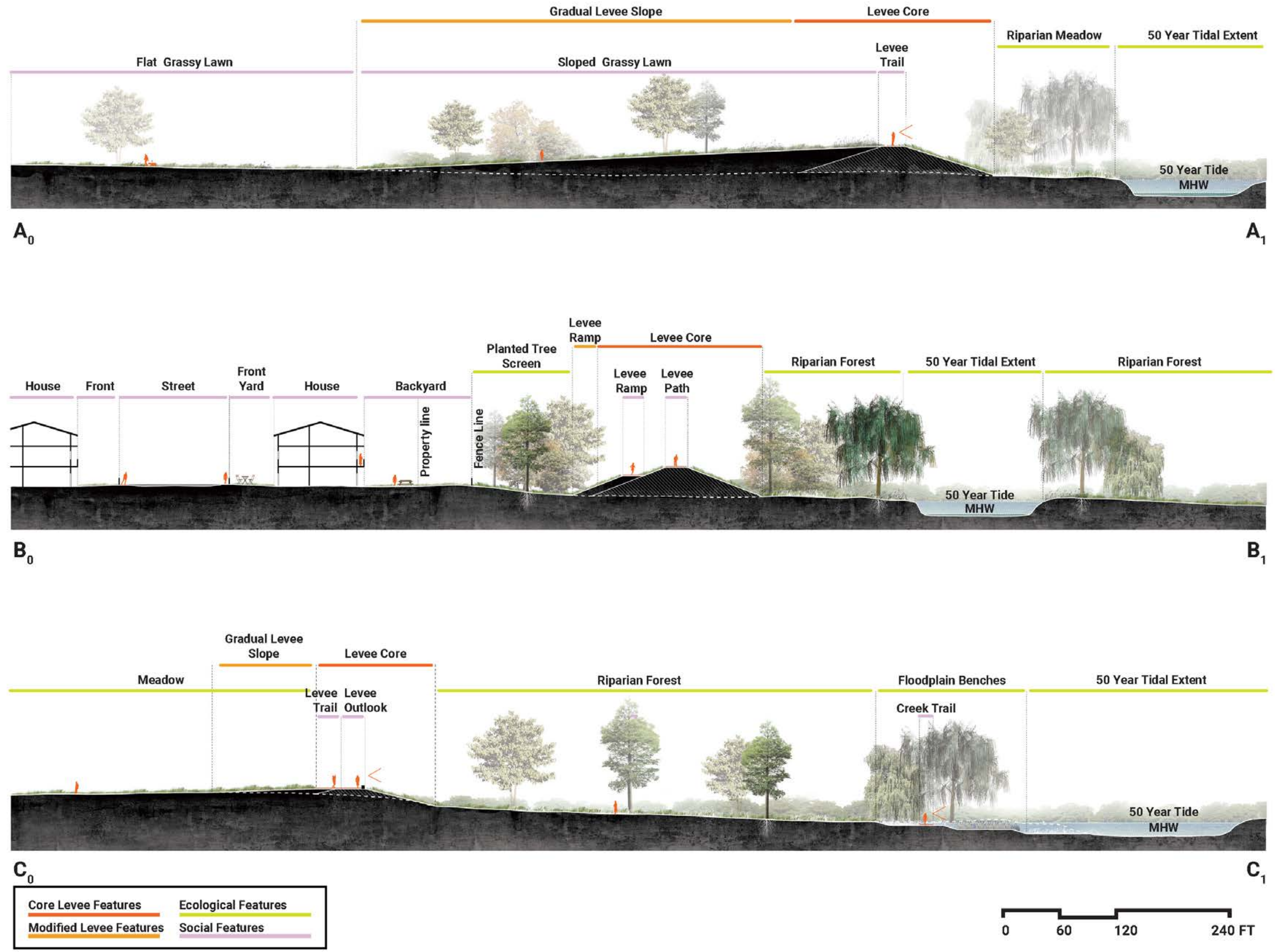
⑦ **CREEK BIKE TRAIL** Borders Cobbs Creek and extends into future Cobbs Creek Circuit Trail.



2 EASTWICK LEVEE CONCEPT
VIEWS + AESTHETICS SECTIONS

Levees, by function, involve an increase in elevation to protect the land behind from rising water during storm events. Levees are also traditionally uniform and monolithic in shape and form. This increase in height and uniformity in structure consequently impacts the viewshed and isolates the community from the aesthetic value of the creeks and surrounding habitat (Nguyen, 2021; Donovan, 2022). Complimentary measures to the proposed levee could blend the levee into the surrounding landscape while improving the visual interest of the system.





2 EASTWICK LEVEE CONCEPT
VIEWS + AESTHETICS PLAN

① **CURVED LEVEE ALIGNMENT:** Allows for expanded space to grade levee into landscape.

② **GRADED LEVEE SLOPES:** Allows for easier access and helps blend the levee form into the surrounding landscape.

③ **TREE SCREENS:** Provide privacy to the adjacent residential houses and backyards from the levee trail.

④ **FLOODPLAIN BENCHING:** Provides ecological and visual interest.

⑤ **LEVEE OVERLOOK:** Provides area for visual overlook out over the creek.

2 EASTWICK LEVEE CONCEPT COMMUNITY DAY

EWN representatives participated in a Philadelphia OOS-organized community day on June 10, 2023. The event provided a platform for residents to discuss the neighborhood's various ongoing and planned flood and environmental protection initiatives. During the event, our EWN team representatives presented potential additional features to the levee plan and heard from residents about desired and undesirable design elements. This feedback was incorporated into the second design round, described on the following page.

POTENTIAL LEVEE MODIFICATIONS AND/OR ADDITIONS

These potential modifications and/or additions are to increase social and ecological benefits of the site. They would not interfere with the integrity of the levee itself.

On the Eastwick Levee map:

1. Please use the colored post-its to write any desired modifications and/or additions to the proposed levee plan using the KEYWORDS in parenthesis next to the descriptions below.
2. On a scale of 1-10, 1 being the most important, and 10 being the least important, please include number next to the KEYWORD to indicate the importance of that potential modification/addition to you.

For example:

If maintaining open lawn areas were very important to you, use a yellow post-it to write LAWN #1 and place the post-it in an area where you would like to see lawn space.

Access (pink post-its)

1. Access to the Shoreline of Cobbs Creek (RIVER)
2. Trail on top of the levee
   - ADA (ADA)
   - Bike Access (BIKE)
   - Pedestrian Access (WALK)
3. Connections to Penrose School (PENROSE)
4. Connections to the Eastwick Playground (PLAYGROUND)
5. Connections to 80th, 82nd, 83rd, or 84th Streets (STREETS)
6. Connections to EPA walking/biking trail (EPA TRAIL)

Programs/spaces (yellow post-its)

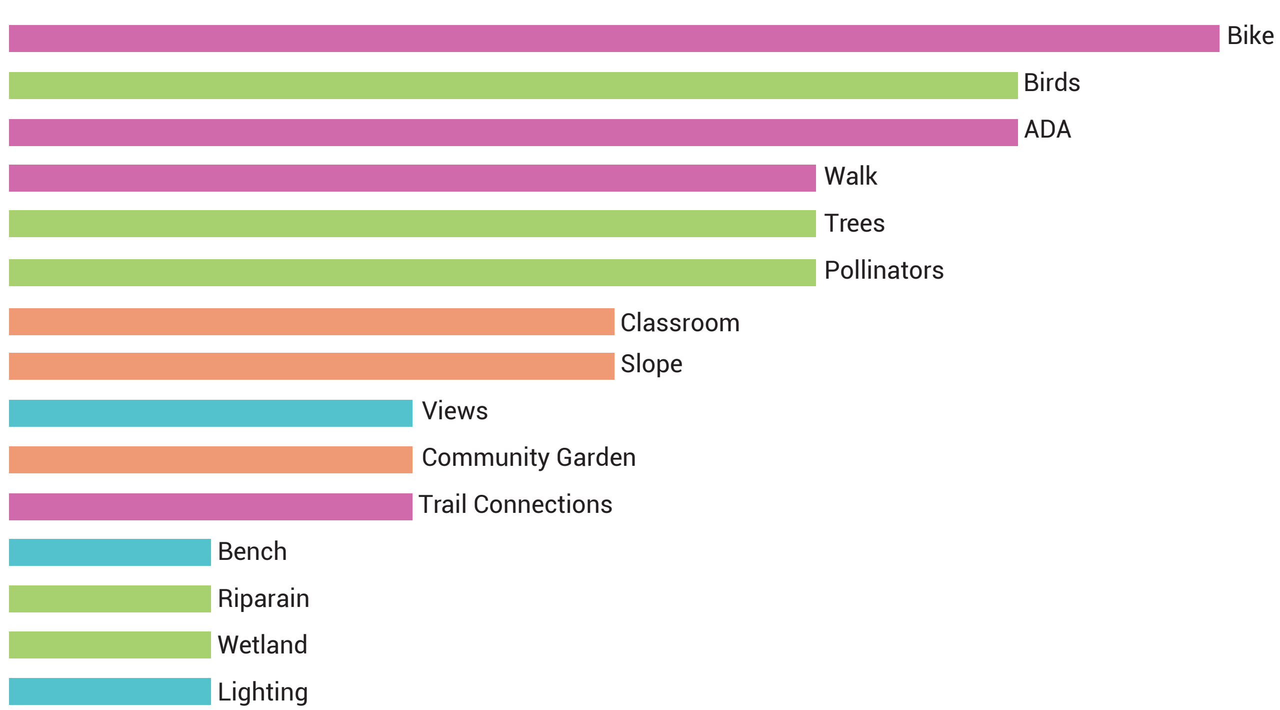
1. Levee slopes that can be used as seating (SLOPE SEATING)
2. Places to sit (BENCH SEATING)
3. Open lawn areas (LAWN)
4. Spaces for specific outdoor sports (list them) (SPORTS)
5. Creekside Living classroom for Penrose School (CLASSROOM)
6. Public art (ART)
7. Shady areas (SHADE)

Habitat (green post-its)

1. More or improved habitat along Cobbs Creek (RIPARIAN)
2. Vegetation that attracts pollinators (POLLINATORS)
3. Vegetation that attracts bird for birdwatching (BIRDS)
4. New wetland areas (WETLAND)

View (blue post-its)

1. Viewing areas from the levee to see the creek and surrounding neighborhood (VIEWSHED)
2. Vegetation that would block the view from the levee to the homes in the community (TREE SCREEN)
3. Areas cleared of tall trees to allow visibility (VISIBILITY)
4. Grading levee into existing landscape (GRADUAL LEVEE)



2 EASTWICK LEVEE CONCEPT
PREFERRED SECTION

Our EWN team designed a new potential plan that integrated the USACE's preferred alignment with many of the desired features and attributes, as discussed on community day.

The existing creekbank would be preserved and enhanced with additional vegetation to support wetland habitat and riparian buffer development. The creekbank up to the levee and levee itself would be planted with vegetation strategically selected to minimize structural risk to the levee while providing a diversity of both riparian and non-riparian habitats, such as riparian forest, riparian grasslands, wetlands, and meadows, specifically to attract bird and pollinator species.

Grading the levee gradually into the surrounding landscape is proposed, providing a more natural aesthetic and allowing easier public access. The lawn space and modified grassy slope could extend the current Eastwick Park and Playground space. In contrast, a living classroom on the northern side would extend to the nearby Penrose Elementary School. This intentional grading of the levee into land will connect open space along the existing trail network while accommodating different forms of accessibility (e.g., ramps or stairs). Creating specific moments of visual interest from the levee could be designed to provide views of the surrounding area, including floodplain bench views, creek views, and city skyline views that take advantage of the increased elevation. Both vegetation and levee bump-outs would direct visual interest to direct the viewer's orientation and enhance active and passive pause points of interest.

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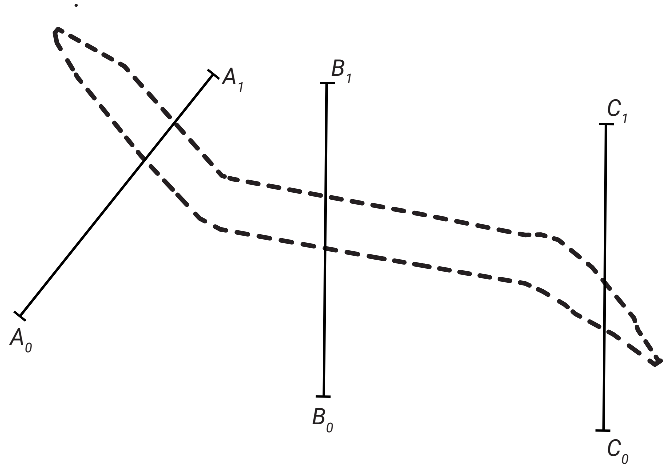
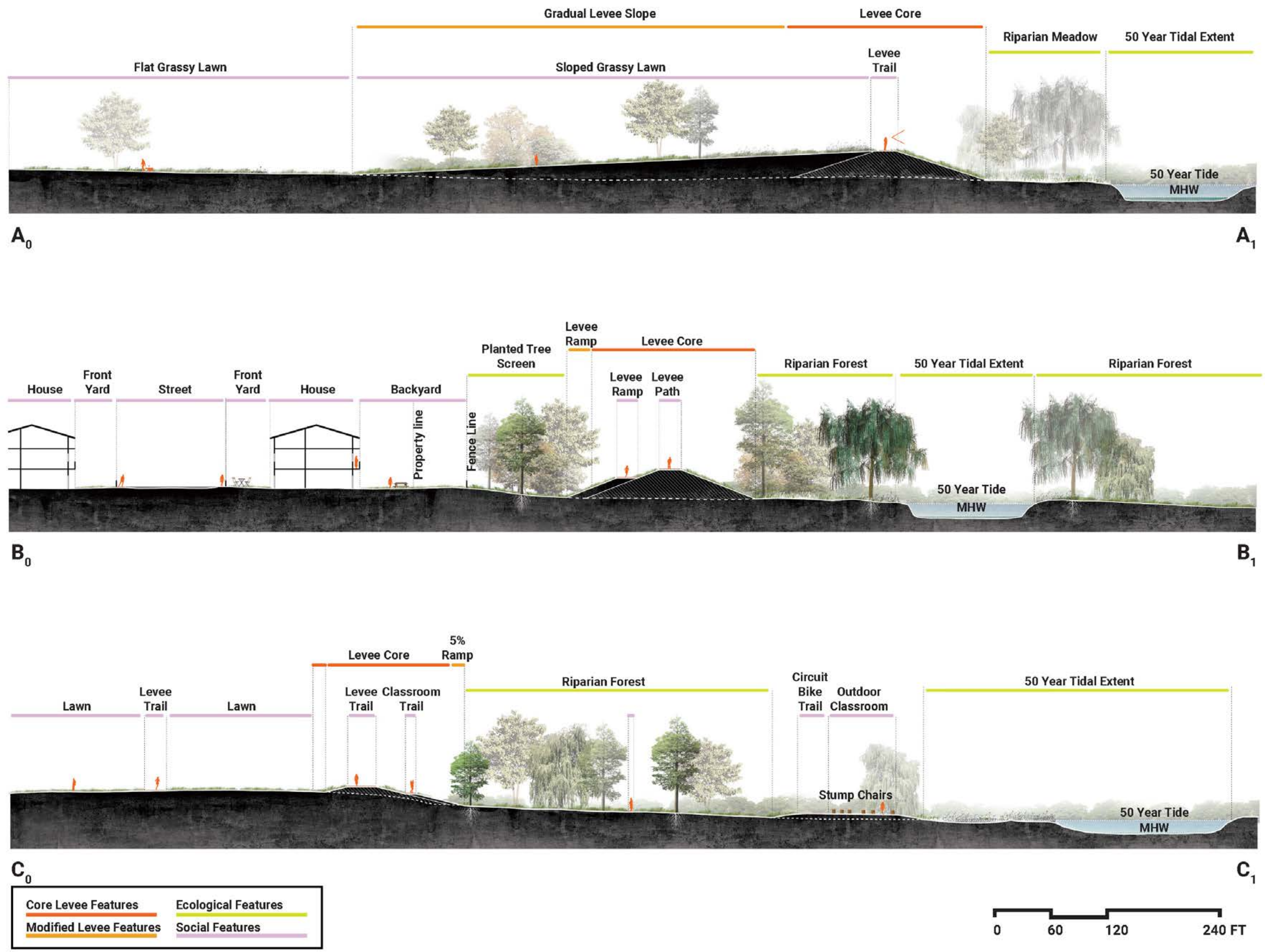




EASTWICK LEVEE CONCEPT
PREFERRED PLAN

① **TRAIL CONNECTIONS** Enhance connections to current and future trails and places, including the EPA bike trail, Cobbs Creek Circuit Trail, and Penrose Elementary School.

② **GRADED LEVEE SLOPE:** Allows for easier access and helps blend the levee form into the surrounding landscape.

③ **BIRD AND POLLINATOR PLANTINGS** Establish bird and pollinator-attracting plants on the levee slopes.

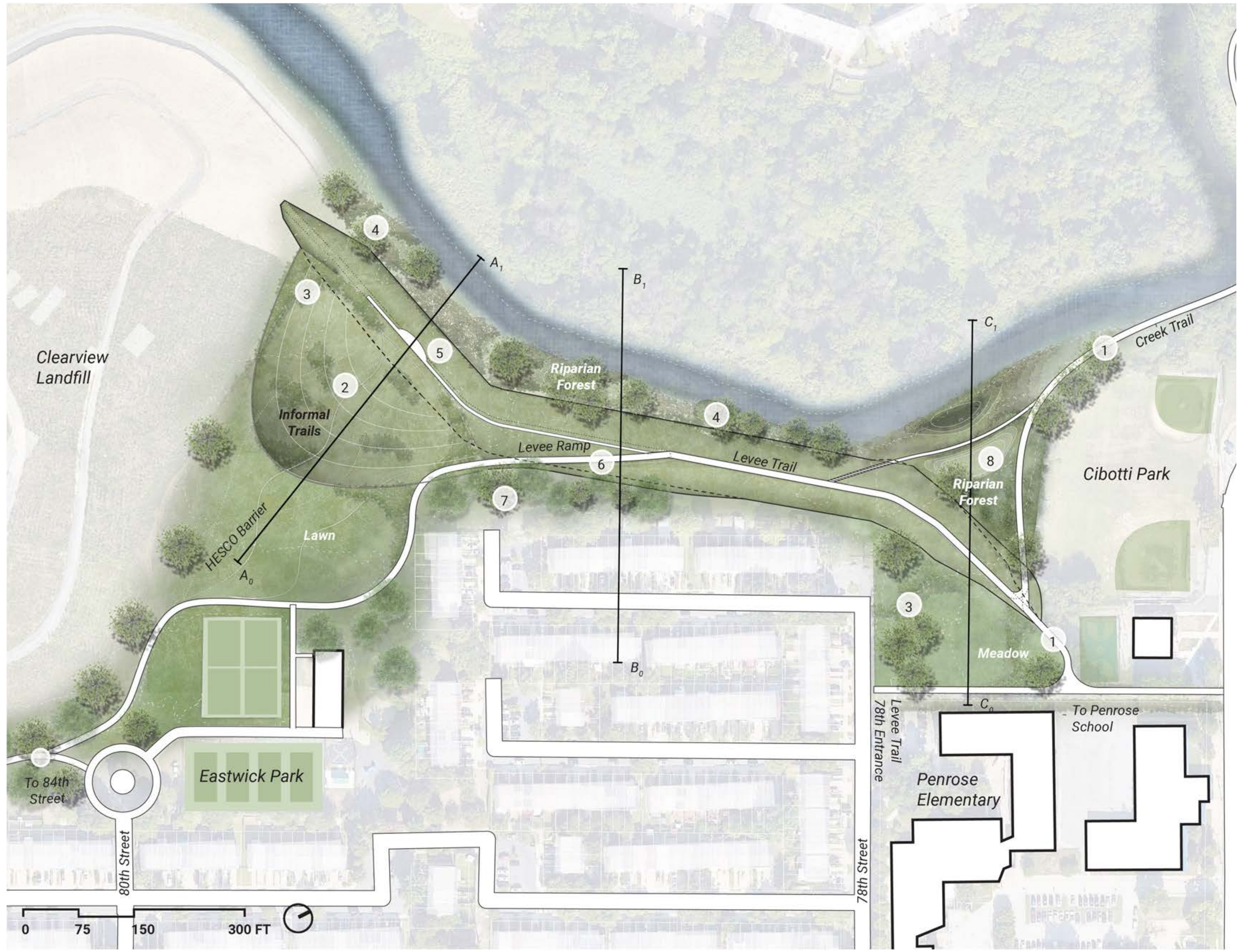
④ **MANAGED RIPARIAN HABITAT :** Preserves, enhances, and diversifies of valuable riparian habitat.

⑤ **CREEK OVERLOOK:** Provides area for visual overlook out over the creek.

⑥ **ADA/BIKE ACCESSIBLE TRAILS:** Design ramps and stairs into levee to provide accessibility while minimizing levee footprint.

⑦ **TREE SCREENS:** Provide privacy to the adjacent residential houses and backyards from the levee trail.

⑧ **OUTDOOR CLASSROOM:** Extends Penrose School to the creek. The classroom can be graded and built up on higher ground with fill from adjacent wetland excavation.




1
Trail Connections to Nearby Attractions
2
Graded Levee Slope
3
Bird and Pollinator Plantings
4
Managed Riparian Habitat
5
Creek Overlook
6
ADA/Bike Accessible Trail
7
Tree Screen
8
Outdoor Classroom
78th Entrance
Penrose Elementary
Recreation Center
Eastwick Park
Clearview Landfill
To 84th st.

PART 3

DELAWARE BAY

DELAWARE BAY
OVERVIEW

The Delaware Bay is the estuary of the Delaware River as it disperses into the Atlantic Ocean. Within the bay, freshwater mixes with salt water, creating both a tidal and salinity gradient. The bay shores are almost entirely composed of an extensive network of protected fringe marshland and beaches interrupted only by scattered small bayside communities. These tidal marshes, which are influenced by rivers that drain into the bay, support breeding grounds for many important aquatic species, including the largest population of Horseshoe crabs in the world. Over thirty species of migrating shorebirds, including Red Knots, utilize the beaches and associated marshes for stopover habitat, while oysters inhabit reefs throughout the bay.

Recreationally, these wildlife areas support excellent conditions for birding and fishing, while the artificial reefs within the bay provide ample fishing and scuba diving opportunities. Though less popular than the state's ocean-front beaches, there are also swimming beaches on the Delaware side of the Bay.

In recent years, USACE has studied innovative methods for the management and beneficial use of dredged material to improve flood risk management in the area, specifically targeting the use of coarser material found in the Delaware Bay portion of the Philadelphia-to-Sea channel to nourish bayside beaches and protect marshes (New Jersey and Delaware Beneficial Use of Dredged Material for the Delaware River Feasibility Report and Integrated Environmental Assessment 2016, 2017). In addition, while immediate plans to do so are limited, this region could also support more beneficial use of fine-grained material and beneficial reuse of CDF material.

1 DELAWARE BAY PROJECT FOCUS

The following map seeks to examine the relationship between areas of social and ecological vulnerability to identify USACE projects that have the potential to mitigate those vulnerabilities. Highlighted are two focus projects: a beneficial reuse project in the mosquito-ditched marshes along the Murderkill River in Delaware and a Habitat-Producing Facility project in Cape May, New Jersey.

ECOLOGICAL + SOCIAL VULNERABILITY

- FEMA 100 YR Floodplain
- CAT 1-4 SLOSH Model
- Vulnerable Wetlands* *According to TNC Resiliency Study*

Social Vulnerability Index

- 0-20% Poverty
- 20- 40%
- 40-60%
- 60-80%

Center for Disease Control Agency for Toxic Substances and Disease Registry. 2018. Social Vulnerability Index-Overall.

ECOLOGICAL + SOCIAL ASSETS

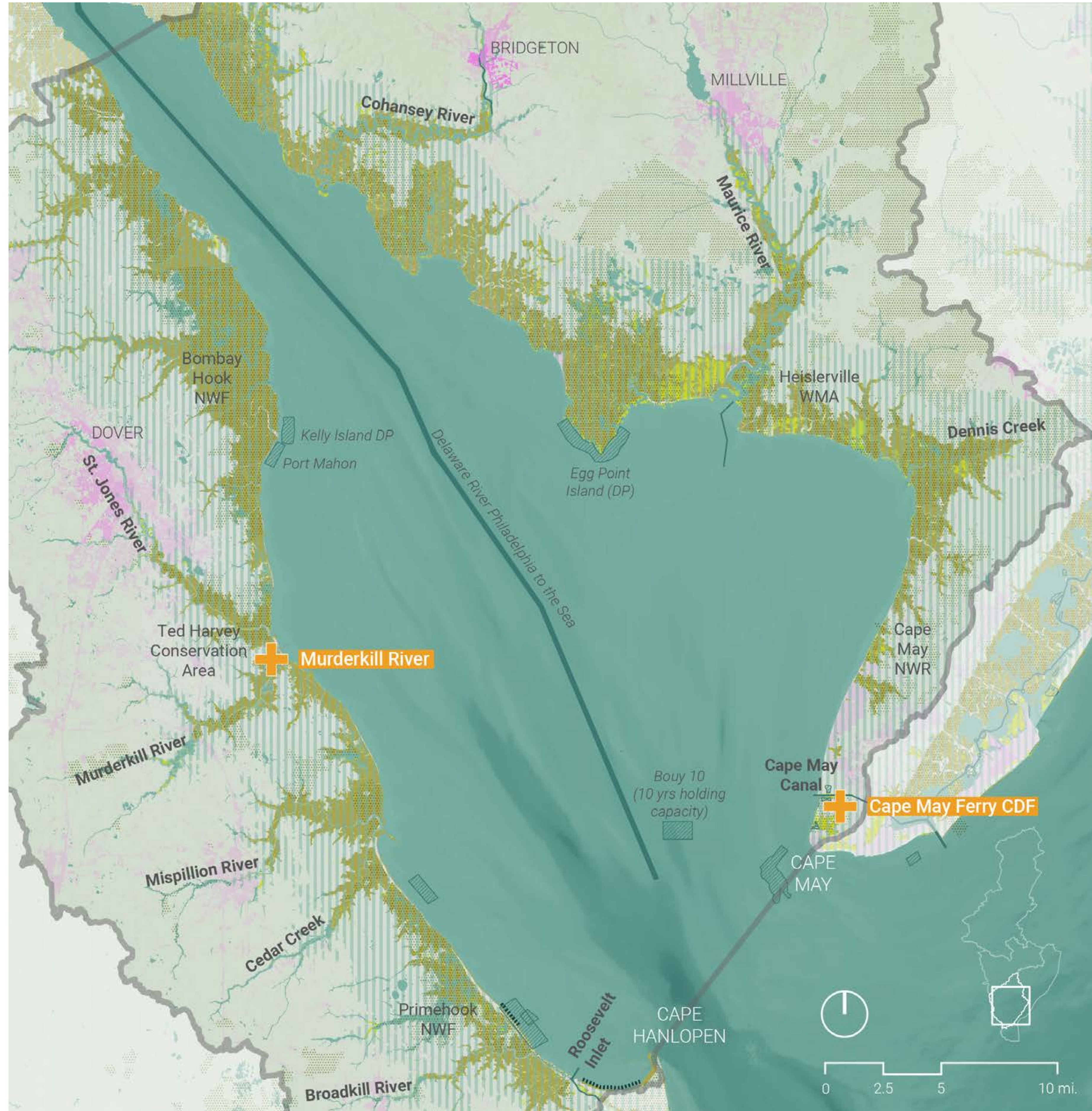
- Wetlands
- Parks and Protected Areas *National, State, and Local Parks*

EWN-LA FOCUS AREAS

- Murderkill River — Beneficial Use Marsh Restoration
- Cape May Ferry CDF — Habitat-Producing CDF

USACE PROJECTS + OPERATIONS

- USACE Channel Areas
- USACE Placement Areas
- Federal Shoreline Projects



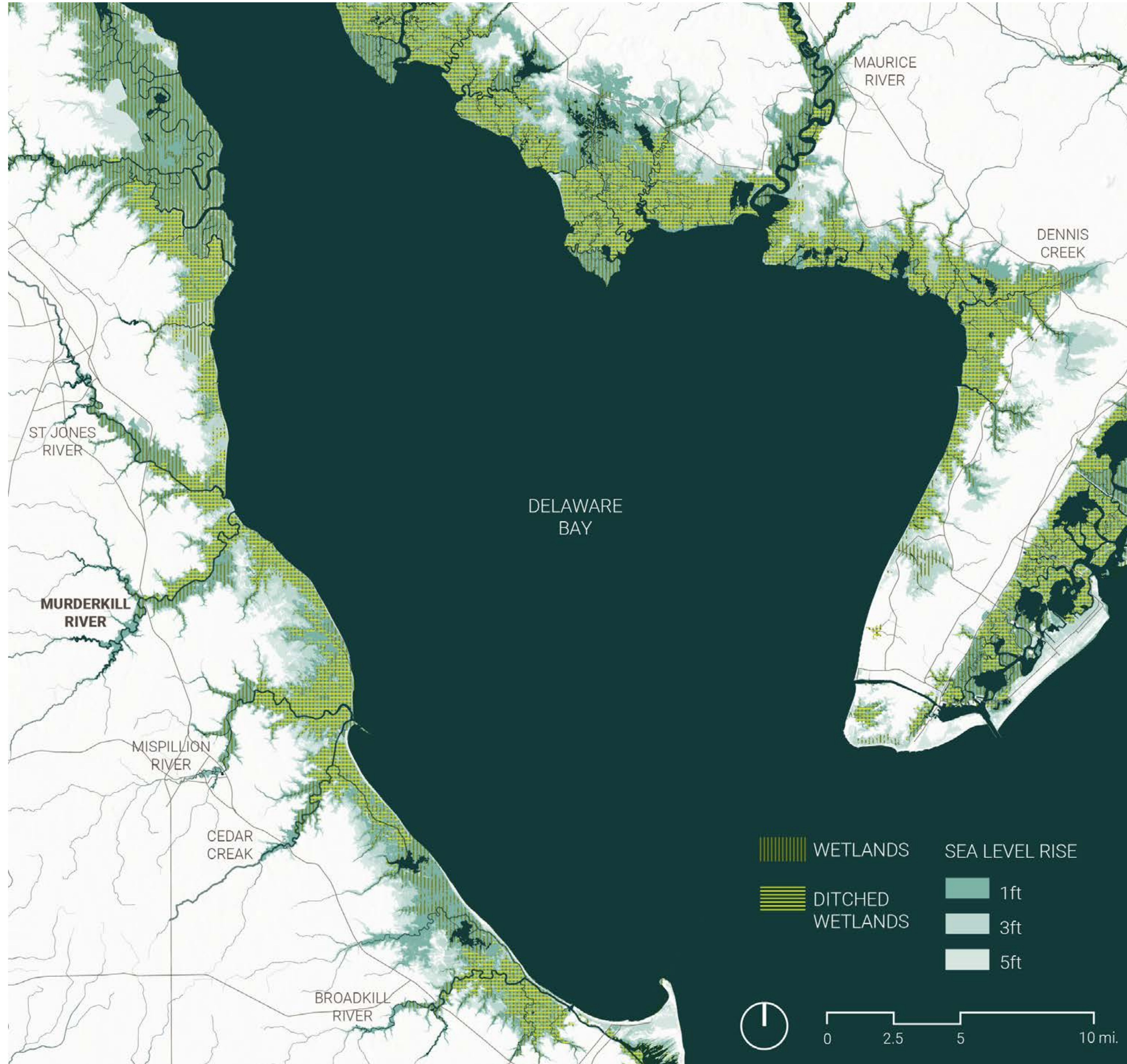
BENEFICIAL USE MARSH RESTORATION
MURDERKILL MOSQUITO DITCHES

Due to subsidence and rising sea level rise, mosquito-ditched wetlands in the Delaware Bay are increasingly vulnerable to open-water conversion. Murderkill River, a federally authorized navigation project, runs alongside several large parcels of state-owned mosquito-ditched marshes. First constructed around the 1930s, mosquito ditches were subsequently found to have many adverse effects, such as altering tidal exchange, lowering the water table and salinity, changing plant communities, and altering habitat preferred by fish and waterfowl species. They were also found to accelerate marsh degradation and die-off. The proximity of the maintained channel to a ditched wetland marsh provides the opportunity to use dredged material to restore the marshes to a more natural tidal regime. In doing so, the project can support local species, increase tidal sediment supply, mitigate sea level rise, and attract recreational boaters and fishermen. Due to the high concentration of mosquito ditches in salt marshes on the Atlantic coast, this nature-based strategy of reclaiming dredged sediment for marsh buildup could be applied to other ditched areas experiencing similar sediment buildup, manufactured flow, and nearby erosion events. The Coastal Resilience Design Studio at the University of Delaware developed a Conceptual Resilience Plan for the town of Bowers; The plan recommended restoring the natural hydrology of the FWS marsh by creating meandering channels, runnels, tidal pools, and mudflats (CRDS, 2022). Our EWN team expanded upon this study to explicitly find ways to restore a mosquito-ditched marsh with beneficial use material, using Murderkill River and the adjacent Milford Neck Conservation Area as a case study.

1 REGIONAL OPPORTUNITIES
MITIGATING DROWNED MARSHES

In the 1930s, as a method of mosquito control and disease prevention, "mosquito ditches" were hand-dug through salt marshes to mitigate the extreme mosquito populations in coastal regions. These ditches were constructed in tidal marshes "to allow drainage via tidal circulation and flush the marsh interior daily […] to reduce habitat for mosquito larvae (Hardenburg, 1922; Resh & Balling, 1983)." By the 1940s, 90% of salt marshes on the Atlantic coast were ditched for mosquito control (Walsh, 2019). As new mosquito control methods increased and the use of these ditches fell, the negative impact the ditches had on the surrounding marsh ecosystem became more apparent.

The hand-dug ditches altered the natural water movement through the marsh and adjacent riverine system. This irregular water movement led to habitat degradation, food depletion, and marsh plant die-offs in salt marshes in surrounding areas (Walsh, 2019). Impoundments and mosquito channels are extensive in tidal and nontidal wetlands and have changed wetland hydrology, created a fill source, and altered natural wetland functions in the watershed (DE DNREC 2005). Importantly, these mosquito-ditched wetlands are less resilient to rising sea levels, as the mosquito ditches alter the natural sediment accretion in tidally influenced marshes.



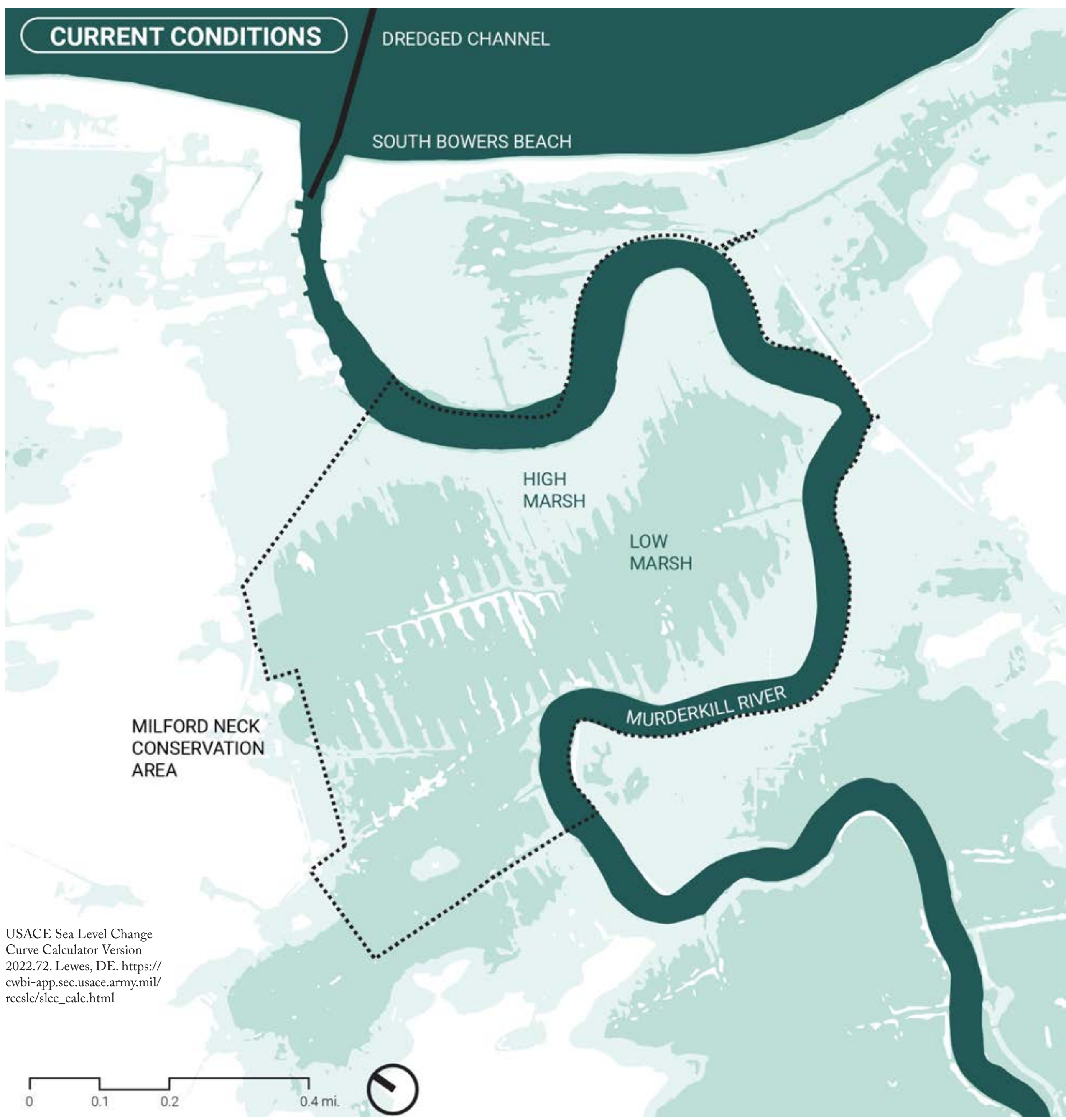
Fish and Wildlife Service. National Wetlands Inventory. https://fwsprimary.wim.usgs.gov/wetlands/apps/wetlands-mapper/. Accessed January 2022

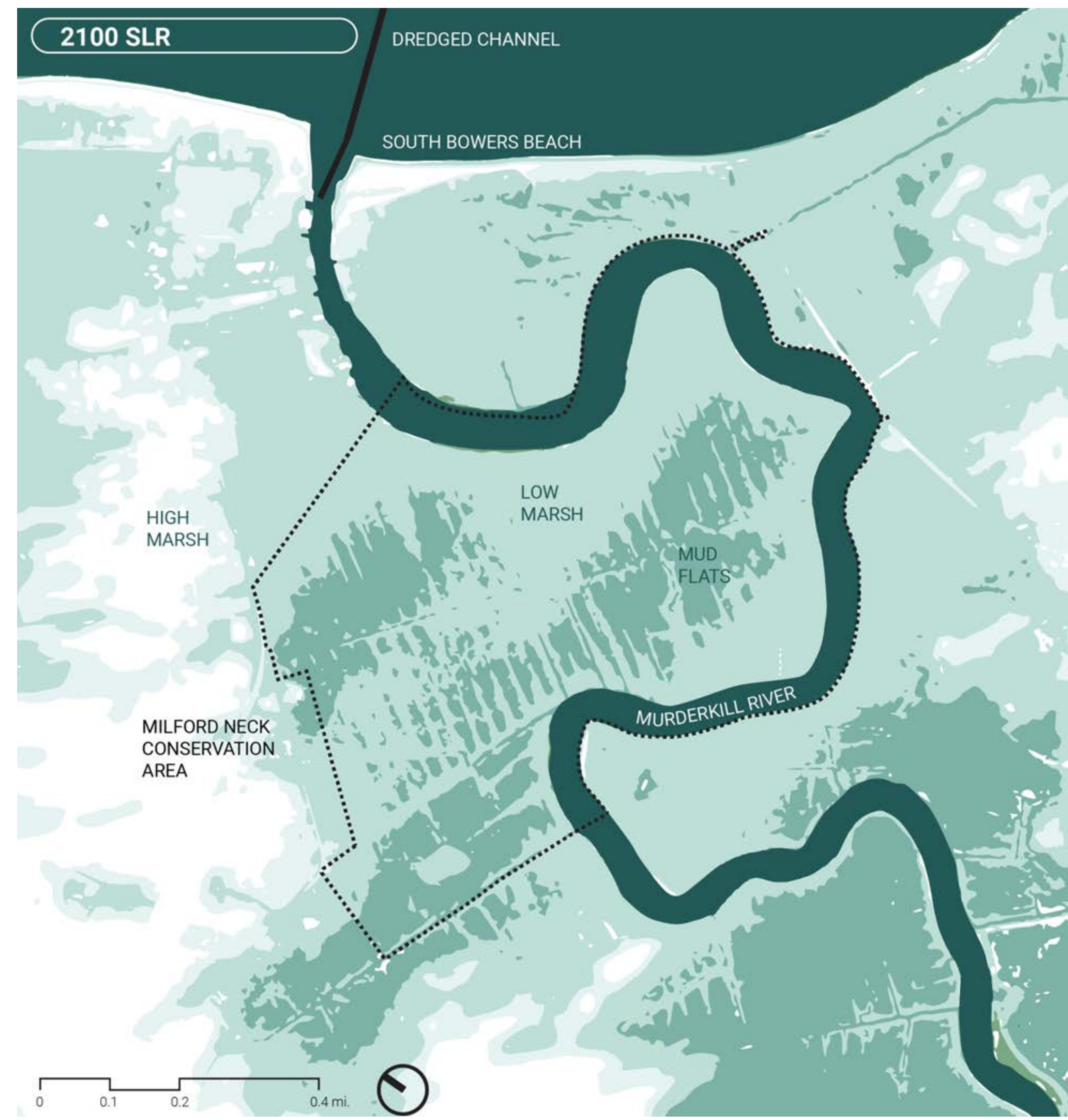
2 **MURDERKILL CONTEXT**
MURDERKILL RIVER

The Murderkill River federal navigation channel requires periodic dredging to maintain safety and navigable access to the river, which is critically important to commercial, recreational, and emergency vessels. The navigation channel, which runs eight miles from Frederica and extends a mile beyond the shoreline, passes through valuable tidal marsh habitat, most of which has been ditched. This marsh habitat includes several parcels of the protected Milford Neck Conservation Area, the northernmost one selected as the site for the project. As the river flows past this Milford Neck parcel, it forms the southern boundary of the Town of Bowers—a popular boating area with its docks, Delaware Natural Resources and Environmental Control (DNREC) Division of Fish and Wildlife-owned boat launch and large parking area—before discharging into the Delaware Bay. Most recently, an emergency dredging project was undertaken by DNREC, which removed 52,000 cubic yards of sediment from the river's navigation channel. DNREC used the dredged sand to nourish the eroding shoreline at South Bowers Beach and placed the finer-grained material offshore.

2 MURDERKILL CONTEXT
CURRENT HABITAT

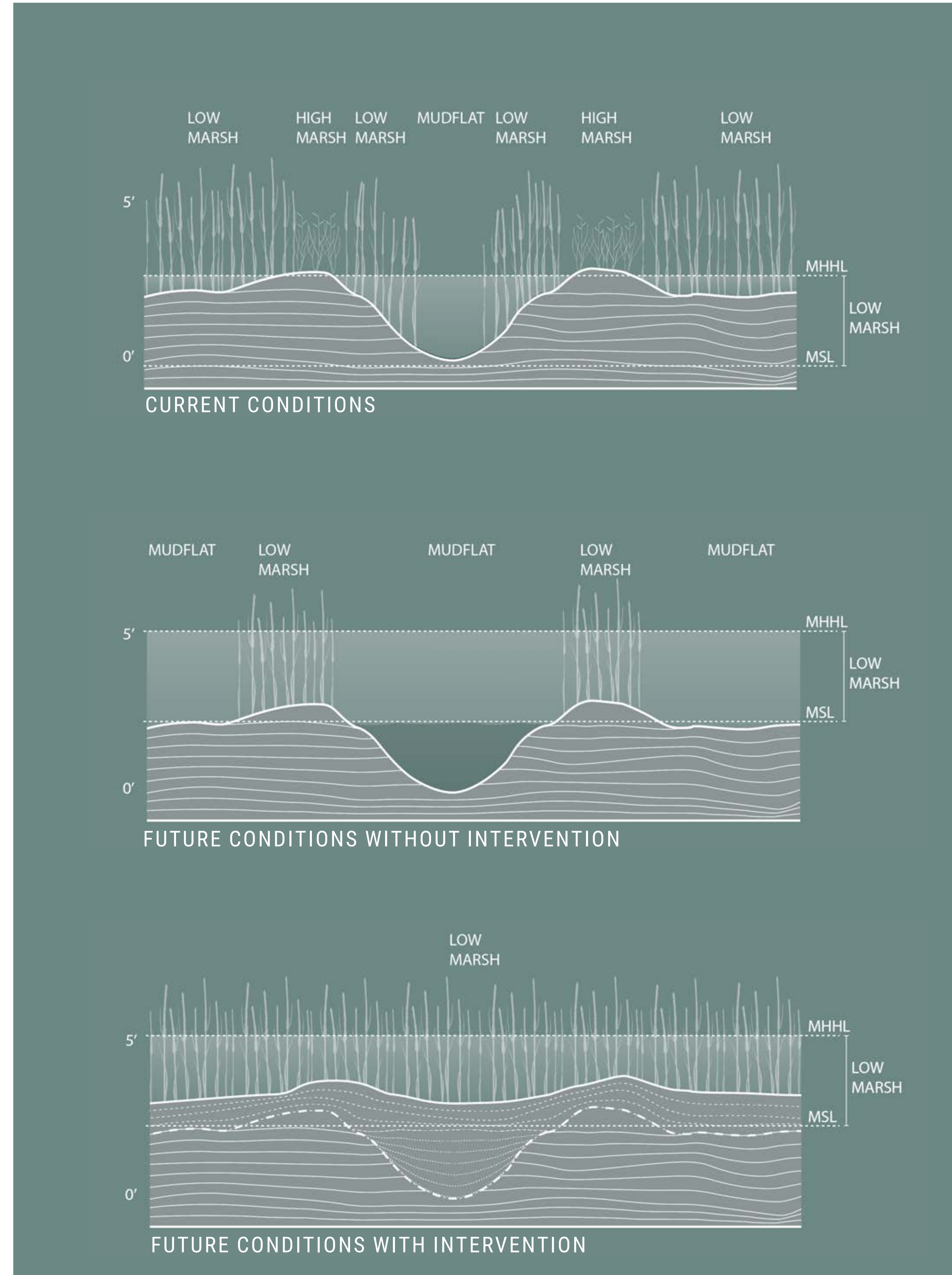
The tidal marshes within Milford Neck Conservation Area are susceptible to rising sea levels. Based on the current estimates for wetland platforms (McKenna, 2018) and future sea level change scenarios developed by the USACE (NACCS, Appendix D-Delaware, 2015), by 2100, in the intermediate USACE SLR scenario, high tidal marsh is at risk for low tidal marsh conversion, and low tidal marsh is at risk for mudflat or open-water conversion.





2 MURDERKILL CONTEXT
SLR RISE

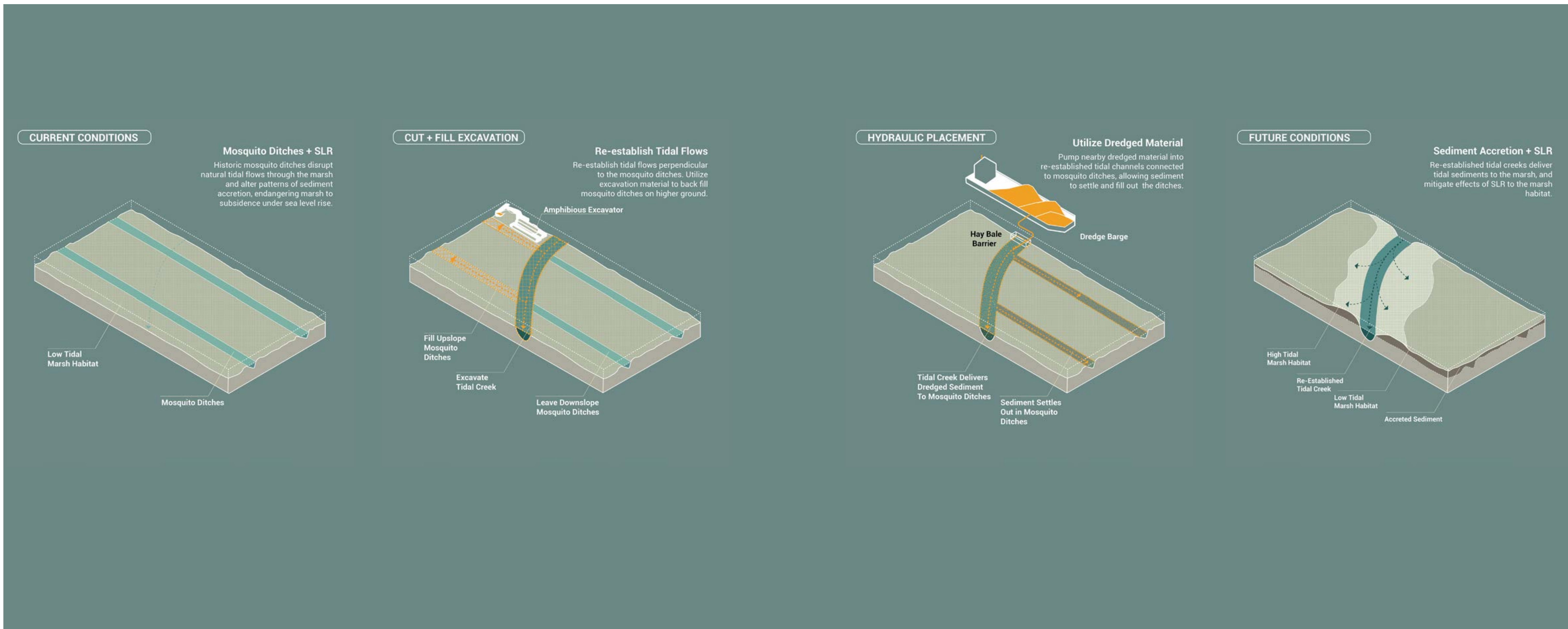
As shown in the section, as the sea level rises, the mosquito ditches prevent natural tidal sedimentation accumulation, leading to a subsided marsh that cannot combat rising waters. With the following intervention, newly excavated channels will pump dredged material from the nearby channel into the mosquito ditches. The filled mosquito ditches and newly excavated tidal channels will restore a more natural tidal regime, encourage the natural accumulation of sediment over time, and help mitigate the deleterious effects of rising sea levels.



3 MARSH RESTORATION CONCEPT
OPERATIONS

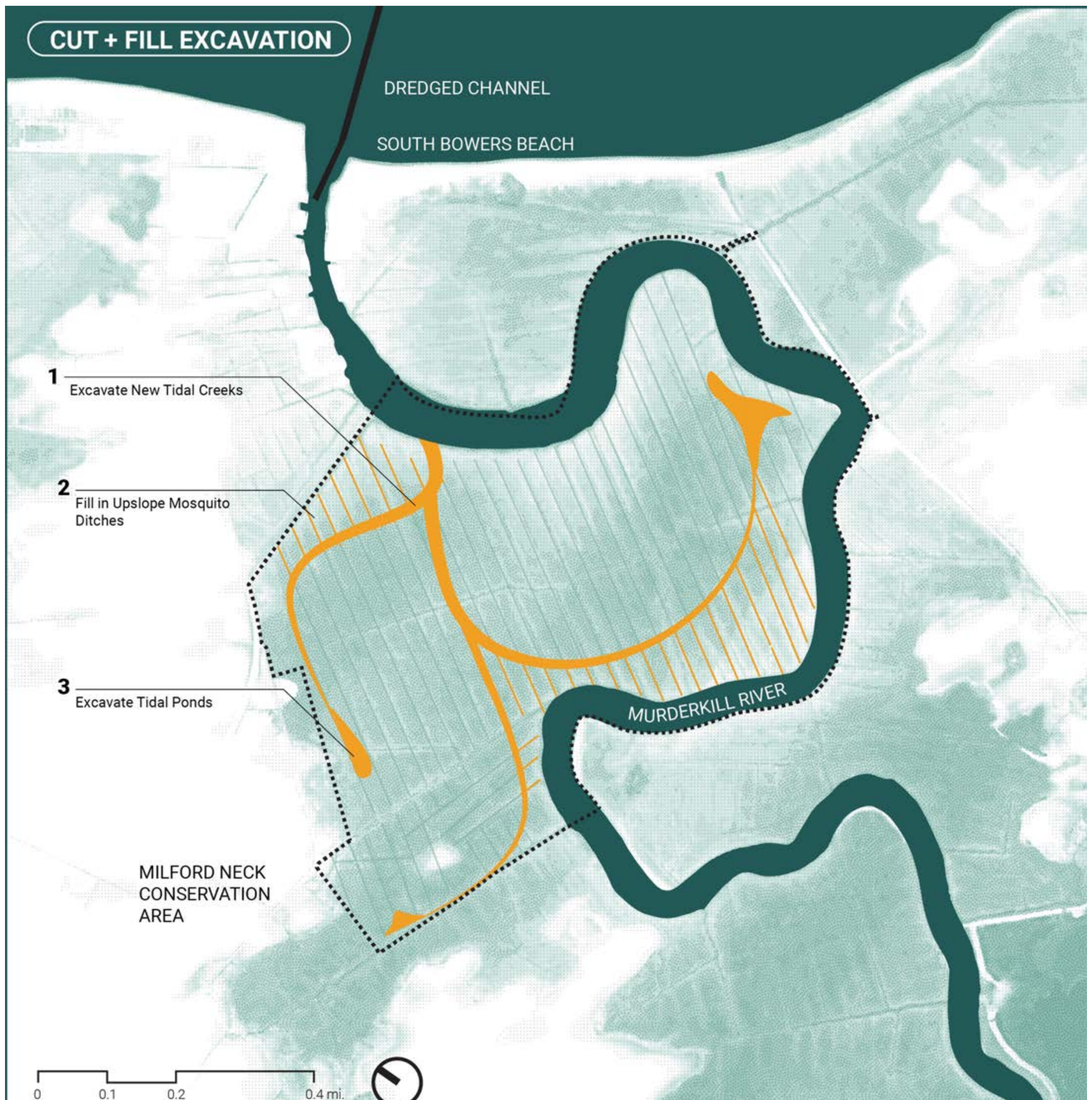
Through a series of operations, this plan proposes to use the pattern and form of mosquito ditches to pump and distribute dredged material throughout the marsh and restore a more natural system to the marsh. First, tidal creeks, designed perpendicular to the mosquito ditches, will be established in the marsh. Modeled after Open Marsh Water Management methods utilized regionally, each tidal creek will end in a terminal shallow tidal pond to create an aquatic habitat and aid in mosquito control (NJDEP Office of Mosquito Control Coordination). The excavation material will be used to backfill the portion of mosquito ditches located topographically higher than the excavated tidal creeks.

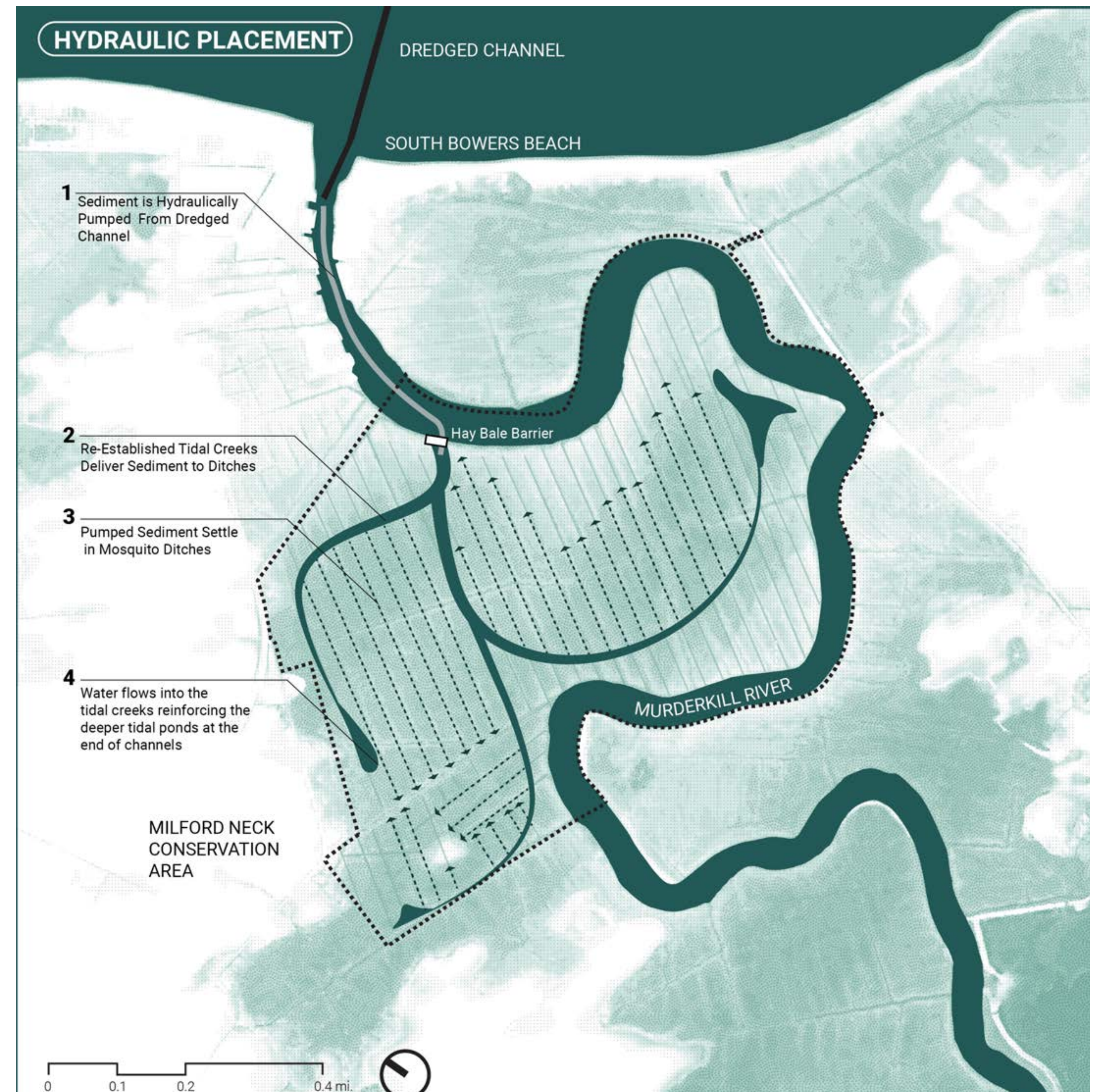
Second, dredged fines from the adjacent river and the river mouth will be pumped into the established creeks after creating a barrier at the start of the tidal creeks. The material will then move from the channels into the connected mosquito ditches, allowing the sediment to settle and fill. After operations are completed, the barrier to the tidal channel will be removed, allowing for a more hydrologically connected system that can more adequately promote sediment accretion.



3 MARSH RESTORATION CONCEPT
OPERATIONS PLAN

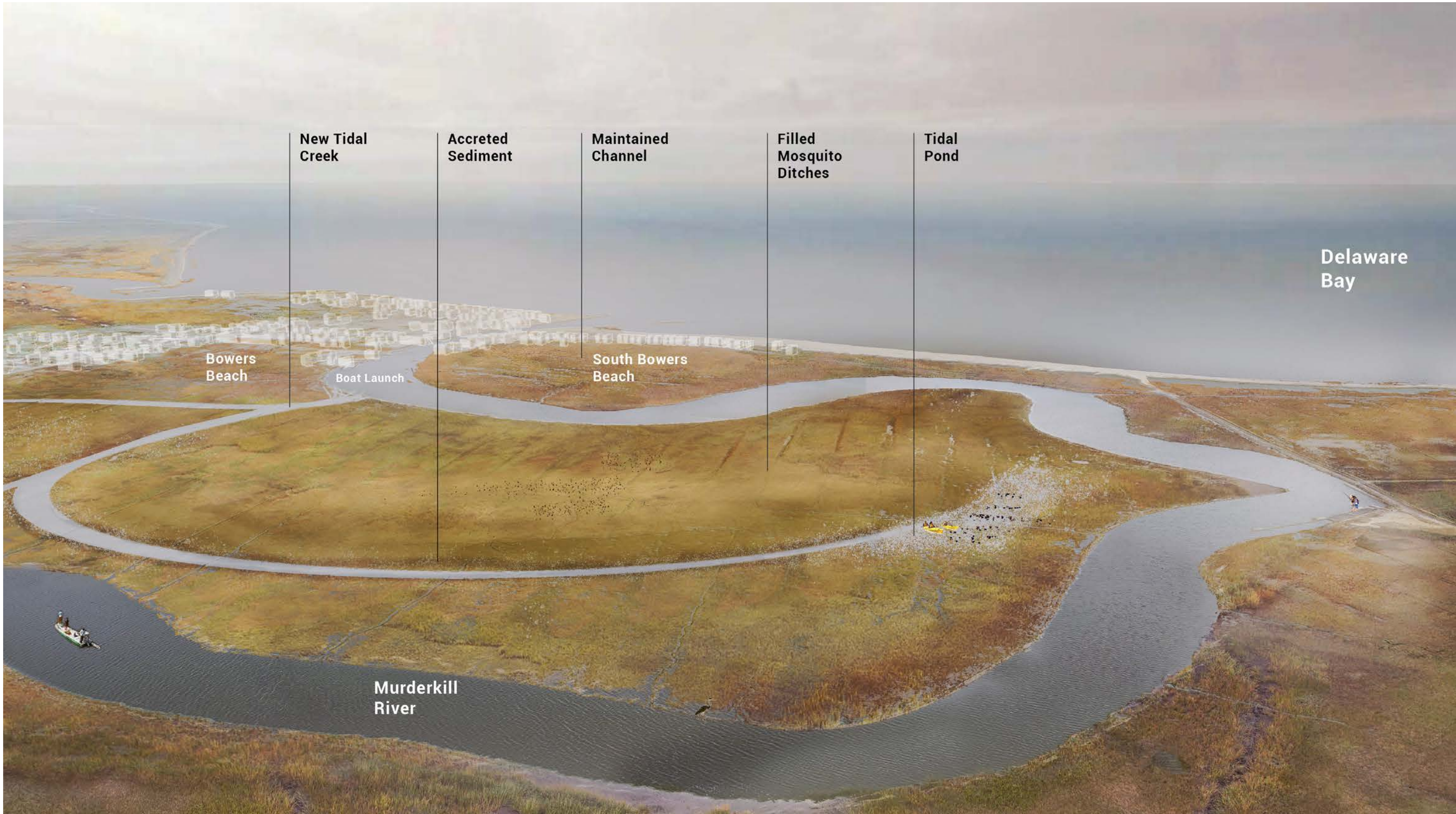
The following plan offers one potential layout that can be used to restore Milford Neck marshes with the tidal excavation and hydraulic placement of sediment. In this plan, the newly excavated tidal creeks are located at the border of low marsh and high marsh areas, with the expectation that the high marsh area will be filled manually with excavation material and the low marsh areas will be gravitationally filled with hydraulically pumped material. Additionally, as much as possible, while still aiming to mimic a natural system, the excavated channels are designed to run perpendicular to the mosquito ditches. A few small, shallow tidal ponds will be constructed at the end of each tidal creek to provide additional aquatic habitat and help with mosquito control.

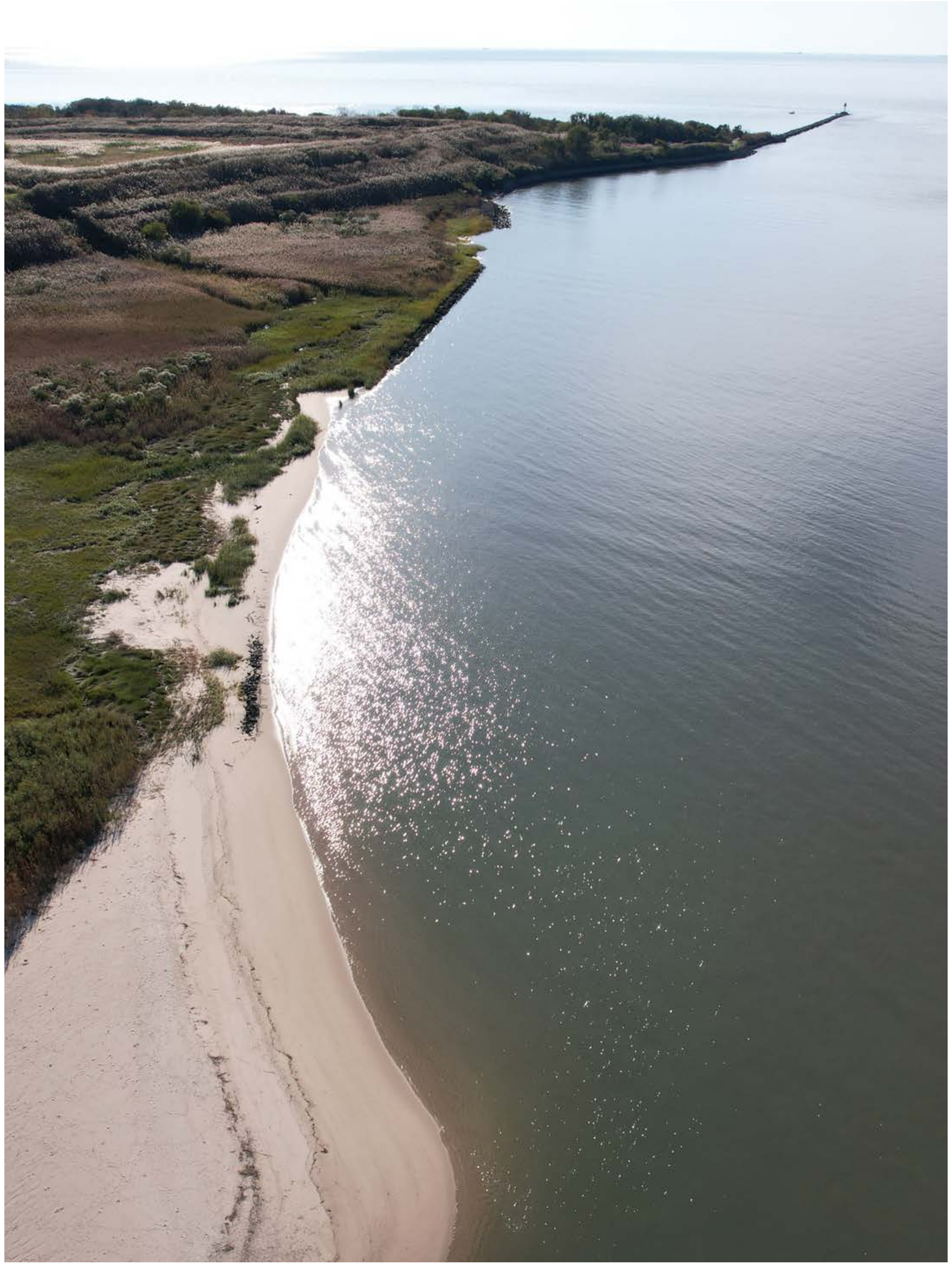




3 MARSH RESTORATION CONCEPT
FUTURE VISION

Over time, the layers of sediment will accumulate on the banks of the established tidal creeks. Species of fish and birds will utilize the restored tidal creeks, ponds, and marshlands. Additionally, the creeks are sized for kayak access, allowing for easy access from the boat launch through the marsh.





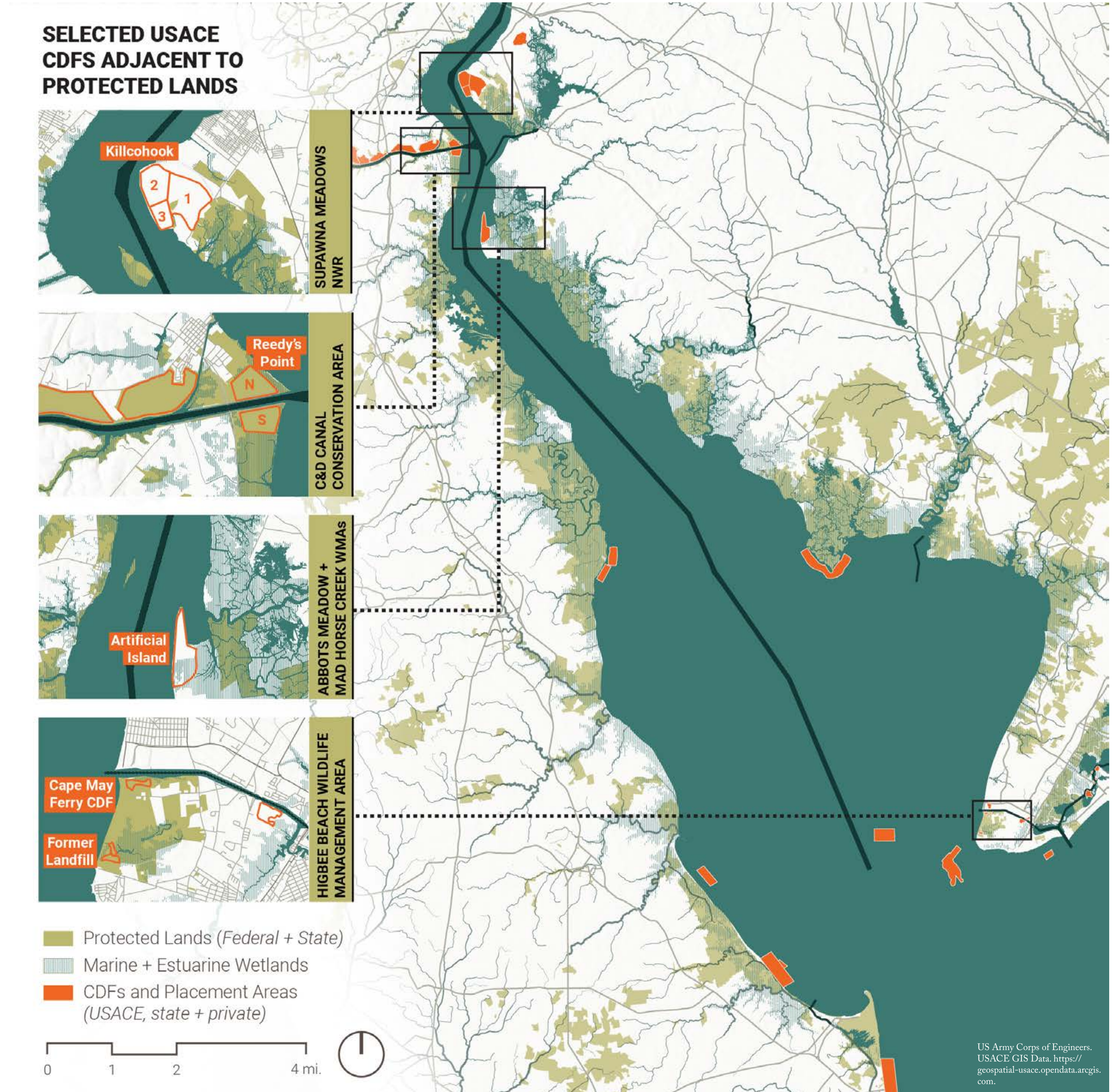
HABITAT-PRODUCING CDF

CAPE MAY FERRY CDF

While the Delaware River and Bay CDFs currently have varying levels of future capacity, as sediment sits in the CDFs indefinitely, the threat of these facilities reaching capacity increases. Rather than creating new CDFs, which is expensive and not sustainable in the long term, and as water-front real estate is limited, beneficial re-use of dredged material reclaimed from within the CDFs can be utilized to enhance the habitat and ecosystem while also providing educational and recreational opportunities in the area. For example, the USACE-owned Cape May Ferry CDF, located along the Cape May Canal, is well-positioned to reclaim dredged material to enhance the surrounding habitat and recreational opportunities. By leveraging its built form to sort and store sediment for later habitat and shore protection use, the CDF can be a “habitat-producing facility,” one that could build up and maintain nearby marshes, create protective sandy beaches, and create transitional habitat. This change in focus from sediment as a waste product to sediment as a habitat resource could help encourage and inspire similar approaches to be implemented for traditional upland containment facilities, particularly in areas that would benefit from shoreline restoration and habitat creation.

1 REGIONAL OPPORTUNITIES
CDFS + HABITAT

The federal facilities located south of Philadelphia on the Delaware River have varying capacities but, by their original design and nature, have a finite life span. One way to increase capacity would be to reuse the de-watered and settled material. However, this method can be cost-prohibitive as it requires double-handling the sediment and often necessitates transporting the material off-site. Considerable cost savings could be achieved if material was reused for nearby shoreline protection or habitat projects rather than containment or transporting it to a more remote or distant location. Located along major waterways, CDFs are often situated near valuable coastal habitats, which could benefit from more sediment, either in shoreline protection, sea level rise mitigation, or for developing topographically variable habitats. The map to the right examines the pattern of CDFs situated around protected and important habitats, providing an opportunity for beneficial use. Our team will further explore this opportunity by modifying a current CDF along the Cape May Canal into a "habitat-producing facility."



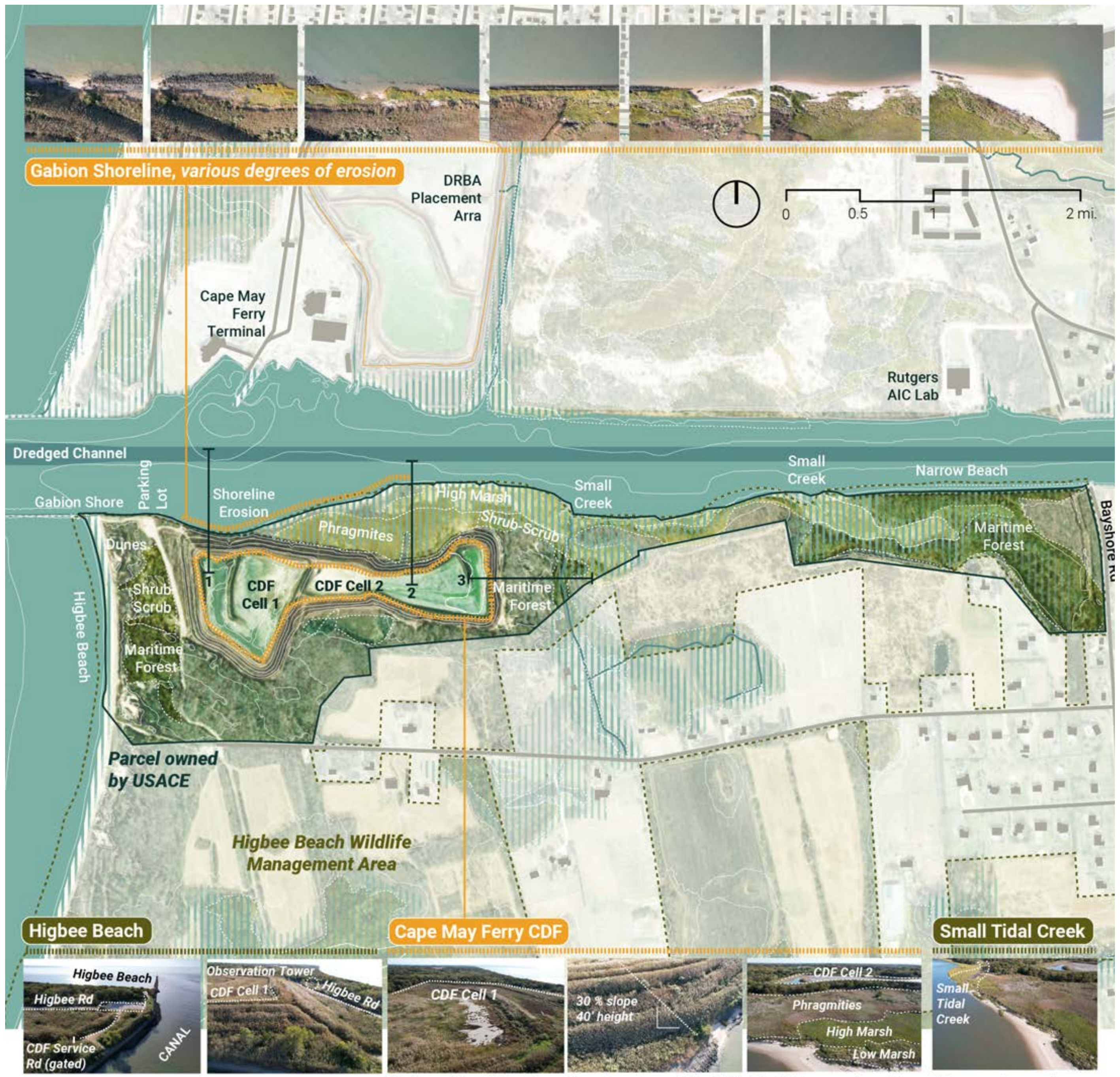
2 CAPE MAY FERRY CDF
SITE DESCRIPTION

The current USACE-owned Cape May Ferry CDF is used for NJIWW sediments dredged from the Cape May Ferry channel, ensuring that this critical access point from the Delaware Bay is kept navigable and open while providing containment for approximately 50,000 cy of material annually (pers. comm. Monica Chasten). Recreationally, the area is close to several popular attractions, such as Cape May National Wildlife Refuge, Rutgers Aquaculture Innovation Laboratory, and the Delaware River and Bay Authority's Cape May to Lewes ferry landings. Higbee Beach Wildlife Management Area, managed by the NJ Department of Environmental Protection, is directly adjacent to the Cape May Ferry CDF. It includes over 1000 acres of protected dune, forest, and scrub-shrub habitat, which helps support millions of migrating birds that stop through the Cape May peninsula yearly. More than 20 shorebird species frequent the area, including the piping plover, an endangered species, raptors, and members of the neotropical songbird species.

2 CAPE MAY FERRY CDF CURRENT CONDITIONS

The current configuration of the Cape May Ferry CDF consists of two cells that will be referred to as cell 1 and cell 2, both of which are currently fully operational and receive dredged material. The CDF has continued to expand upwards by building upon the diked walls to accommodate the need for additional capacity.

Increased height of the walls and erosion from the ferry wake have led to slopes that continue to steepen. The current shoreline erosion control consists of gabions, which structurally look degraded but functionally are performing for shoreline stabilization, and as such, the degraded wire baskets are a potential trapping hazard to egg-laying horseshoe crabs, which valuable themselves, also serve as an essential food for red knots. The adjacent nearshore environment and tidal habitat could benefit from increased sediment supply, while the CDF could benefit from increased capacity and shoreline protection. The current conditions of the CDF and surrounding areas are further documented in the following plan view and series of sections.



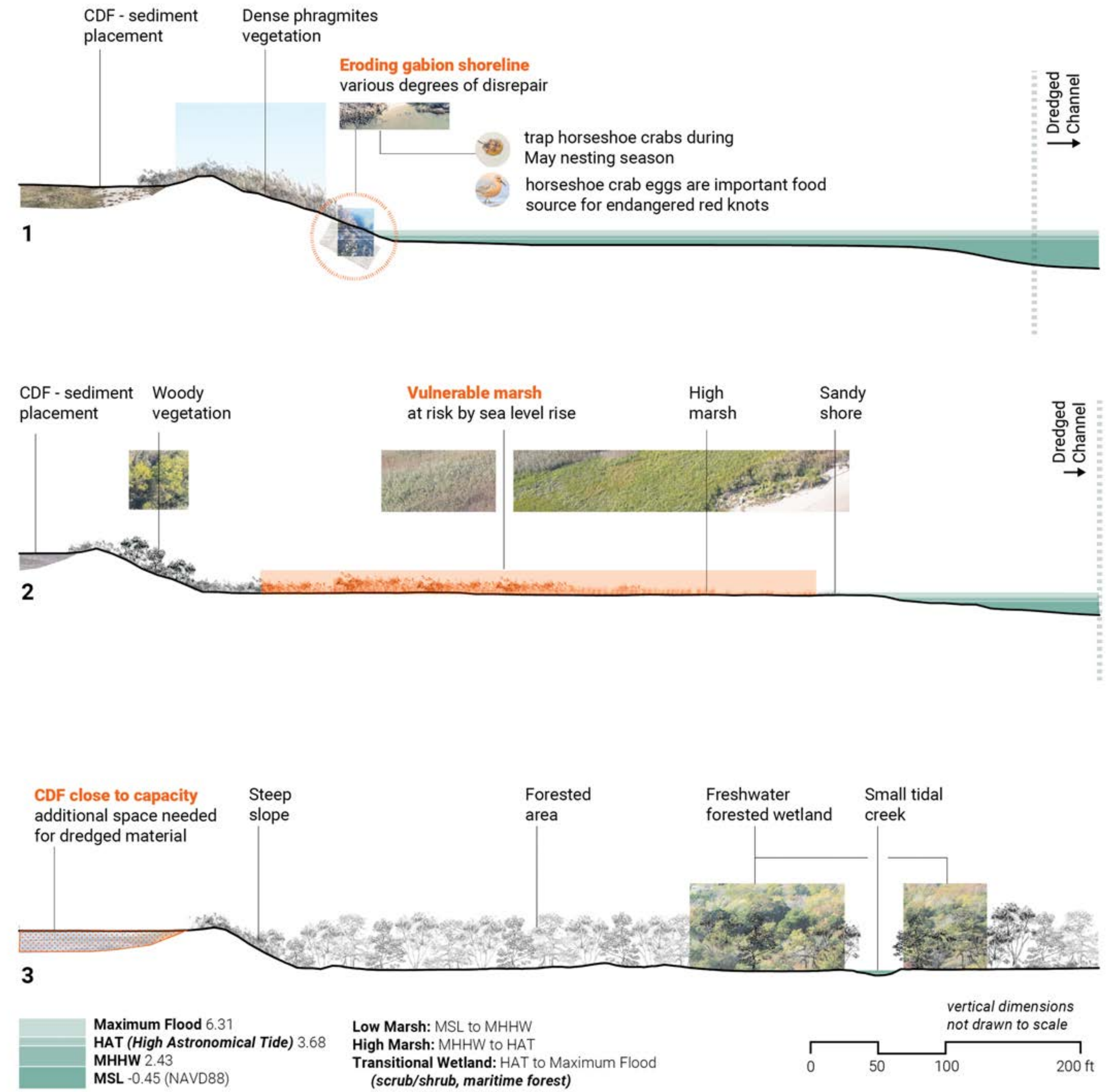
Higbee Beach has established dunes and scrub/shrub habitat. This area nearby the CDF is a popular birding hotspot. The observation tower marks a location in which over 300 species of birds have been counted.

The top of the CDF cells feature concentrations of sand and growth of wetland plant species.

The steep slope of the CDF is primarily a monoculture of phragmites.

The tidal area adjacent to the CDF supports a sandy beach, high marsh habitat, and phragmites.

This parcel supports one of two small tidal creeks, the western one at the eastern end of the CDF.



3 CAPE MAY FERRY CDF CONCEPT
CDF + HABITAT INTERGRATION OPPORTUNITIES

Using the same three sections, located on the west, middle, and east sides of the CDF, different strategies are explored to solve current operational and ecological issues with integrated solutions.

Shoreline Protection

As outlined in Section 1, the sand extracted from the CDF aims to create a feeder berm positioned north of cell 1. Once initially placed, this feeder berm will provide enhanced protection to the Cape May Ferry CDF. Designed to migrate westward, the feeder berm serves as a sediment source for continuous shoreline protection.

Preliminary observations, noting sedimentation patterns and the formation of a sand spit west of the CDF, indicate a potential western longshore transport. However, it is essential to conduct a modeling or pilot study to definitively ascertain whether the extracted material is susceptible to erosion back into the channel, potentially requiring increased maintenance dredging.

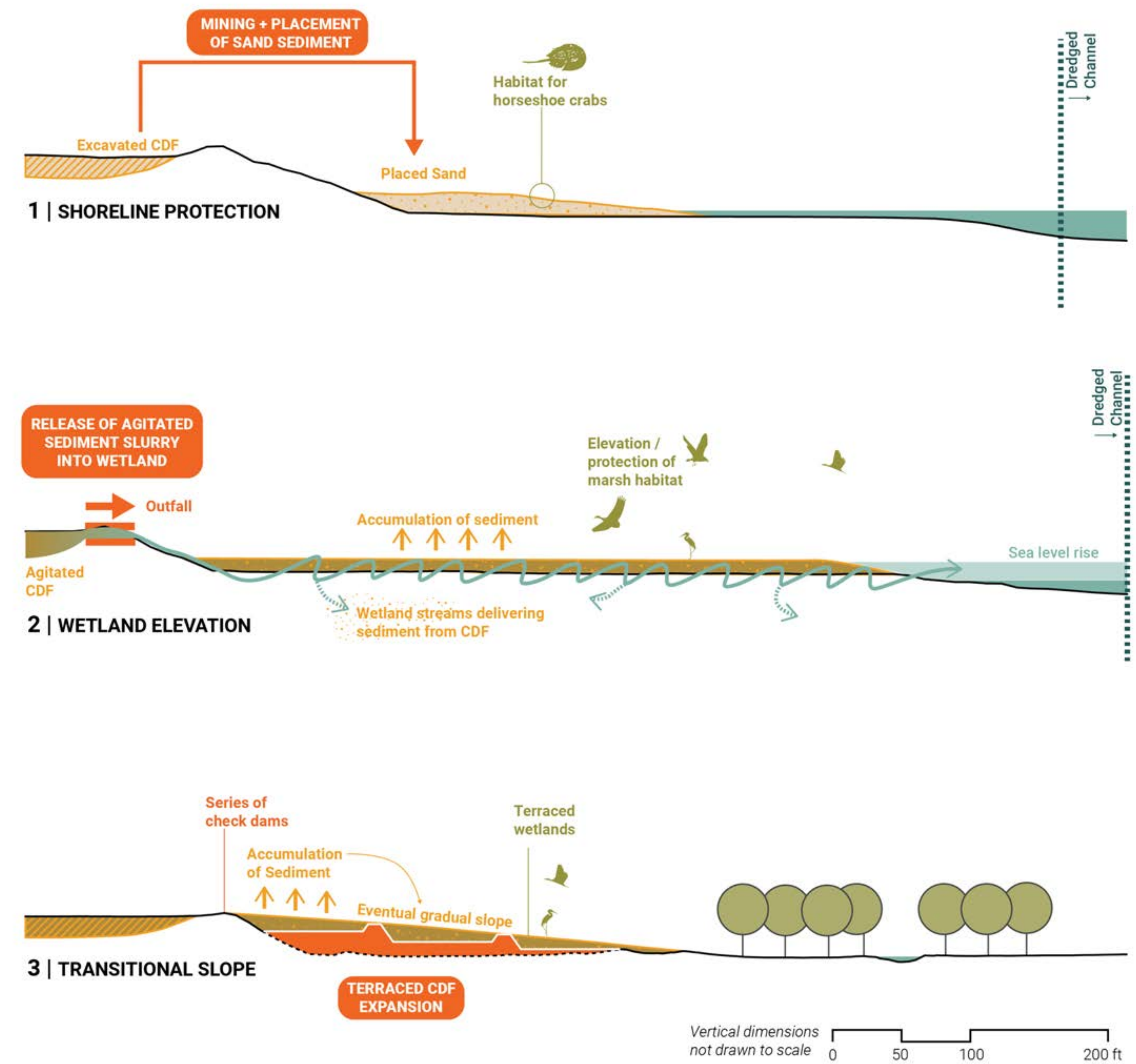
As the material from the feeder berm erodes and moves westward, it will contribute to shoreline protection for the wetlands against oncoming waves. Additionally, the berm will establish a beach connection from the jetty, provide a habitat for shorebirds, and prevent the entrapment of horseshoe crabs. The chosen placement site for the feeder berm presents an opportunity to continue reusing the coarser material from the CDF in the nearshore.

Wetland Elevation

As shown in Section 2, the existing spillway in each cell would transport suspended fine sediment created by either direct agitation or, through the process of placement, downslope into the adjacent tidal wetland. This system would be designed such that the fine material would nourish the tidal wetland at a sea-level rise mitigation rate. Expected enhancements to the wetland area include increased material deposition, habitat creation, and encouragement for more ecological diversity. Not only will the discharge points introduce sediment into the wetland area, but they will also increase the CDF's capacity, increasing the facility's overall operational life. Furthermore, as the feeder berm migrates westwards, sand will form a protective barrier along the outermost edge of the tidal wetland, providing additional protection for the sediment to move and stay within the system.

Transitional Slope

As shown in Section 3, a series of check dams on the outermost side of Cell 2 could expand the footprint of the CDF, thus increasing the long-term capacity. The terraces will fill with sediment, creating a more gradual CDF slope. This gentler slope could support an additional access road that would, in turn, improve the ability to transport sediment out of the CDF or maintain the facility. Eventually, in the future, if one or more cells of the CDF close, the slope could also provide a more accessible access point for birders and hikers, as well as create wetland terraces for flora and fauna.



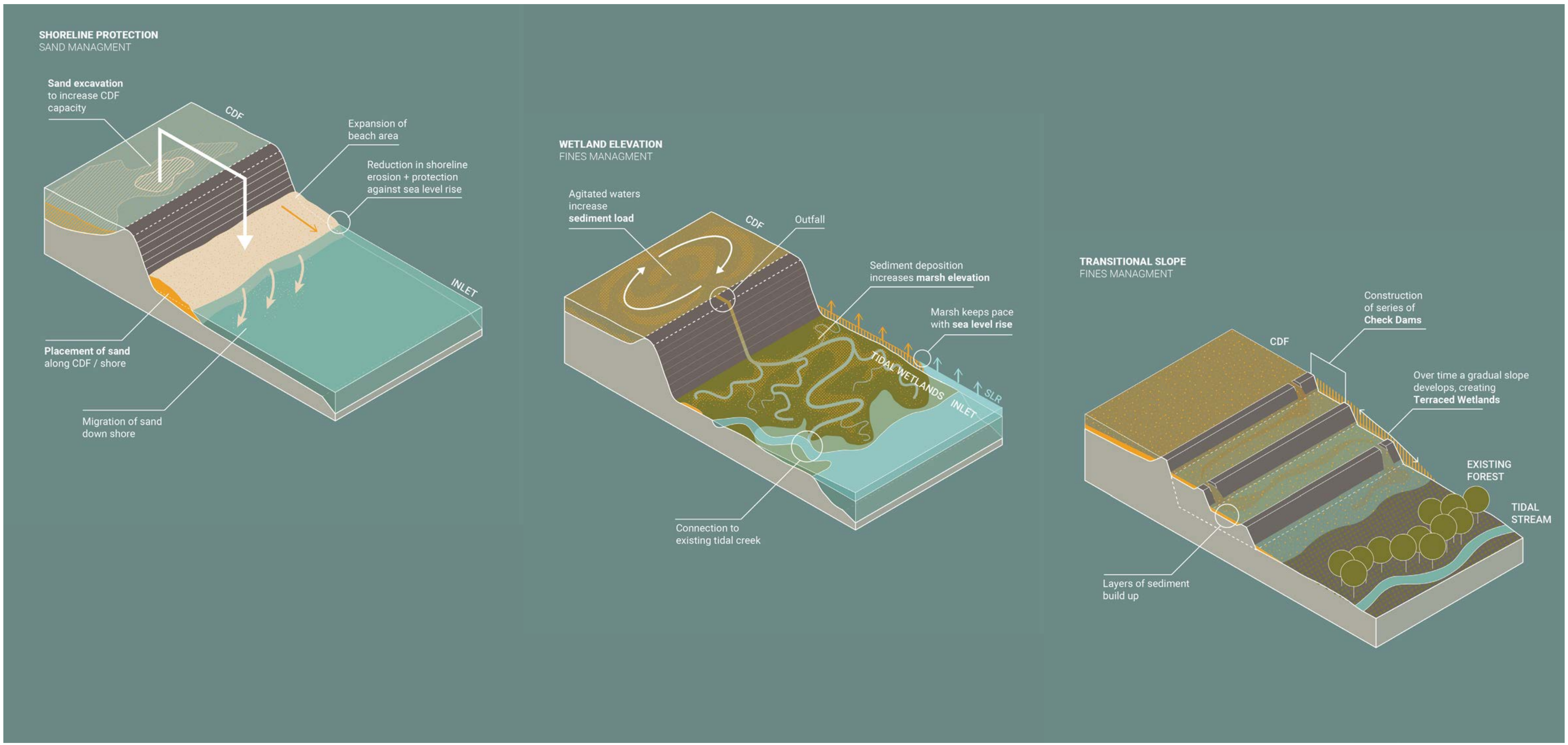
3 CAPE MAY CDF CONCEPT
CDF + HABITAT INTERGRATION OPPORTUNITIES

These axons explore the objectives of each of the three strategies in more detail.

+ **Shoreline Protection:** Uses coarser CDF sediment to build a feeder berm north of the cell 1, softening the dike line along the eastern cell

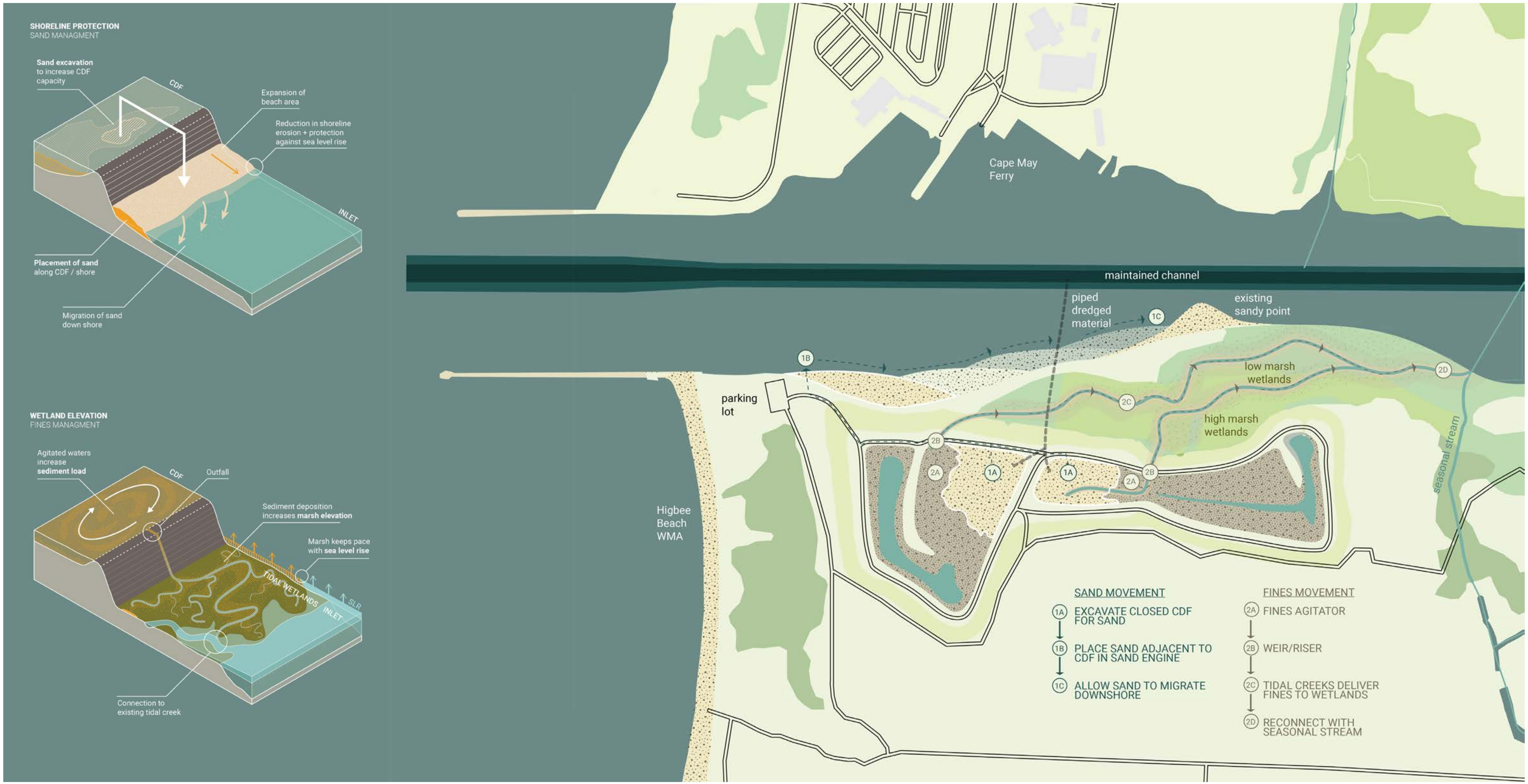
+ **Wetland Elevation:** Adds discharge points so that finer CDF sediment can enhance adjacent wetlands.

+ **Transitional Slope**: Implements a series of check dams to soften the slope and create wetland terraces. Further research would be necessary to determine that there is enough retention time for the check dams to work on the hydraulically placed material.



3 CAPE MAY FERRY CDF CONCEPT

The Habitat-Producing CDF Plan utilizes shoreline protection and wetland elevation strategies to increase capacity, protect the shoreline, and augment nearshore and tidal habitat. Both cells remain operational and each contributes fine sediment to the adjacent wetland through an outfall located to maximize the sediment contribution load. Using the coarser material for the nearshore and the finer material for the wetland, the CDF could conceivably process as much sediment as is placed. In doing so, the CDF would use its built form to both sort the sediment and, in the case of the finer sediment, distribute it via gravitational forces.



3 CAPE MAY FERRY CDF CONCEPT

As envisioned, this rendering shows the **Habitat-Producing CDF Plan** as it would integrate operational, ecological, and recreational benefits to the Cape May Ferry CDF and surrounding areas.

PART 4

DE + NJ COAST

DELAWARE + NEW JERSEY COAST
OVERVIEW

The Philadelphia District encompasses most of the New Jersey coast, spanning south of Manasquan Inlet to Cape May, as well as the entirety of the Delaware Coast. This coast region is a major tourist attraction during the summer months, known for its wide beaches, boardwalks, restaurants, and casinos. Over recent years, increased demand for housing on the island has led to soaring property values and gentrification. Despite this, significant portions of the coast, wetlands, and forest have been preserved as parkland, allowing visitors to hike, kayak, fish, spot birds, and enjoy the natural scenery.

These shorelines are composed of beaches, dunes, tidal salt marshes, brackish bays, river estuaries, and barrier islands. These vital ecological habitats support important aquatic and wetland ecosystems, including the many migratory bird species that pass through, feed, or breed in these areas as part of the Mid-Atlantic Flyway. These ecological habitats, particularly the backbays and dune landscapes, also protect and buffer the interior of the islands and mainland from large storms.

Historically, the area has been hit by large coastal storms, the largest in recent history was Hurricane Sandy in 2012, which demolished entire neighborhoods in some regions. After this devastating event, the Philadelphia District repaired significant natural infrastructure under their robust Coastal Storm Risk Management Program, mainly in the form of dunes and beach nourishment along much of the coast. Other notable resiliency efforts include the New Jersey Back Bays (NJBB) Coastal Storm Risk Management (CSRM) Study, which has been examining different approaches to reduce the impacts of waves and water levels along these bodies of water inlets, and the Seven Mile Innovation Laboratory, which advances the use of dredged sediment to beneficially nourish degraded marsh and shorelines in the back bay environment. Additionally, the USACE maintains navigation of the New Jersey Intracoastal Waterway (NJIWW), as well as numerous rivers, inlets, and man-made reservoirs within this region.

1 DE + NJ COAST USACE PROJECTS

The following map seeks to examine the relationship between areas of social and ecological vulnerability and identify relevant USACE projects that could potentially mitigate those vulnerabilities. Highlighted as focus EWN projects in this area are a storm-surge mitigation modeling project on Holgate Peninsula and a dune resiliency research study.

ECOLOGICAL + SOCIAL VULNERABILITY

- FEMA 100 YR Floodplain
- CAT 1-4 SLOSH Model
- Vulnerable Wetlands* *According to TNC Resiliency Study*

Social Vulnerability Index

- 0-20% Poverty
- 20- 40%
- 40-60%
- 60-80%

Center for Disease Control Agency for Toxic Substances and Disease Registry. 2018. Social Vulnerability Index-Overall.

ECOLOGICAL + SOCIAL ASSETS

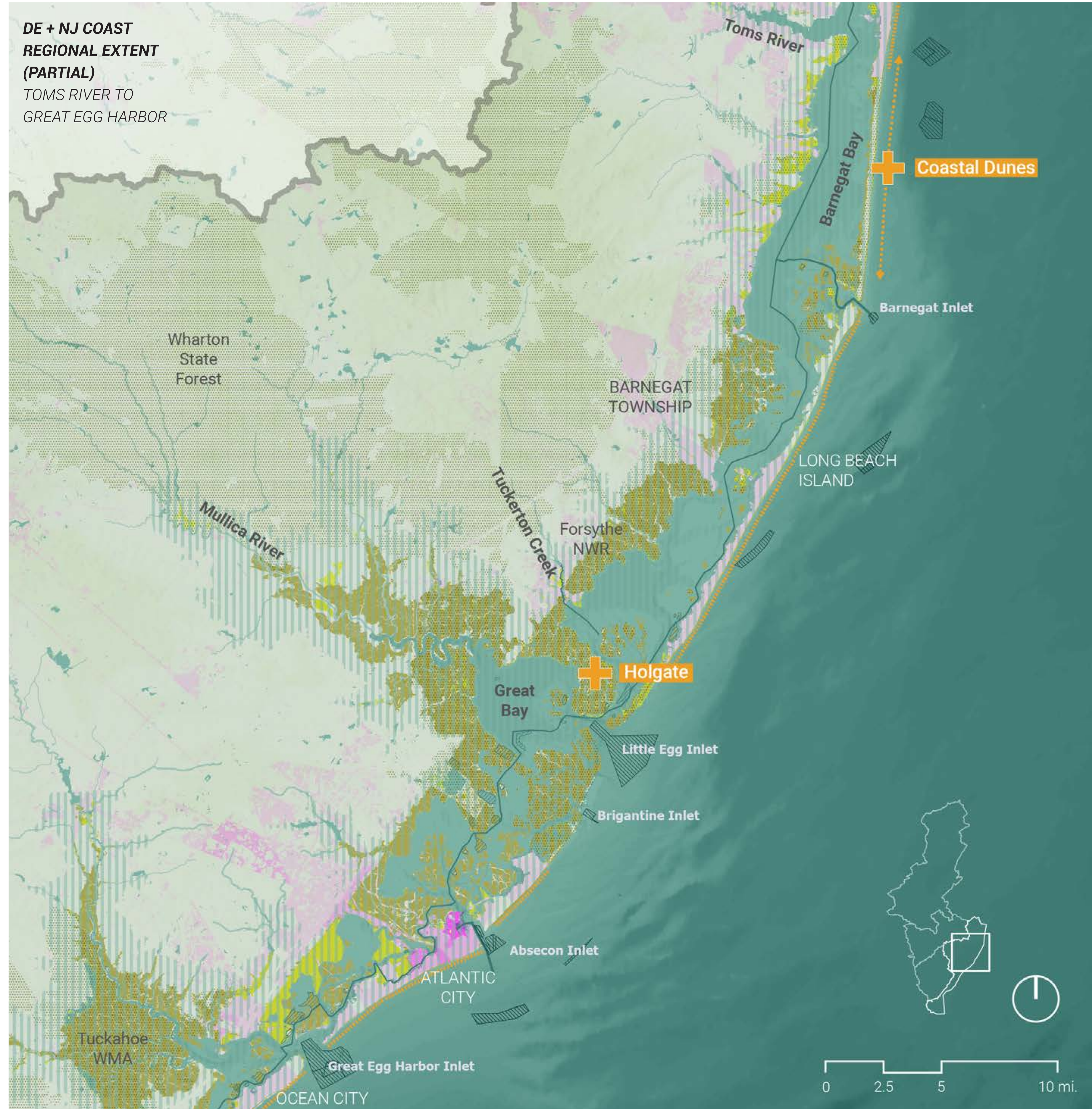
- Wetlands
- Parks and Protected Areas *National, State, and Local Parks*

EWN-LA FOCUS AREAS

- Holgate Peninsula Storm Surge Mitigation
- Coastal Dunes Dune Resiliency Research
- Federal Shoreline Projects

USACE PROJECTS + OPERATIONS

- USACE Channel Areas
- USACE Placement Areas
- USACE Sediment Borrow Areas



STORM SURGE MITIGATION
HOLGATE PENINSULA

The NJBB CSRM Study proposed a variety of mixed structural and non-structural options to protect against storm events. In the NJBB CSRM Tentatively Selected Plan (TSP), the initial structural strategies identified include storm surge barriers or inlet closures at Manasquan Inlet, Barnegat Inlet, and Great Egg Harbor Inlet, and cross-bay barriers at Absecon Boulevard and southern Ocean City (NJBB 2021). Non-structural strategies call for the elevation and floodproofing of 18 thousand structures, mainly concentrated along the mainland shoreline of Beach Haven West, Long Beach Island, the mainland of Northern Atlantic County, Brigantine, and large swaths of Cape May County. For these latter areas, there may be opportunities to supplement the non-structural strategies with NNBFs. Little Egg Inlet was chosen as a study site to further study NNBFs that would help accompany the non-structural strategies in the region. Additionally, the work would build upon the research done around Little Egg Inlet in the earlier EWN + LA bay report.

In the initial EWN + LA Back Bay report, designs studied the use of strategic, large-scale NBS + NNBFs in place of the tidal gates. Although the report found that the storm surge reduction attributable to NNBF was relatively modest, there were some promising areas to test the benefits of NNBFs further.

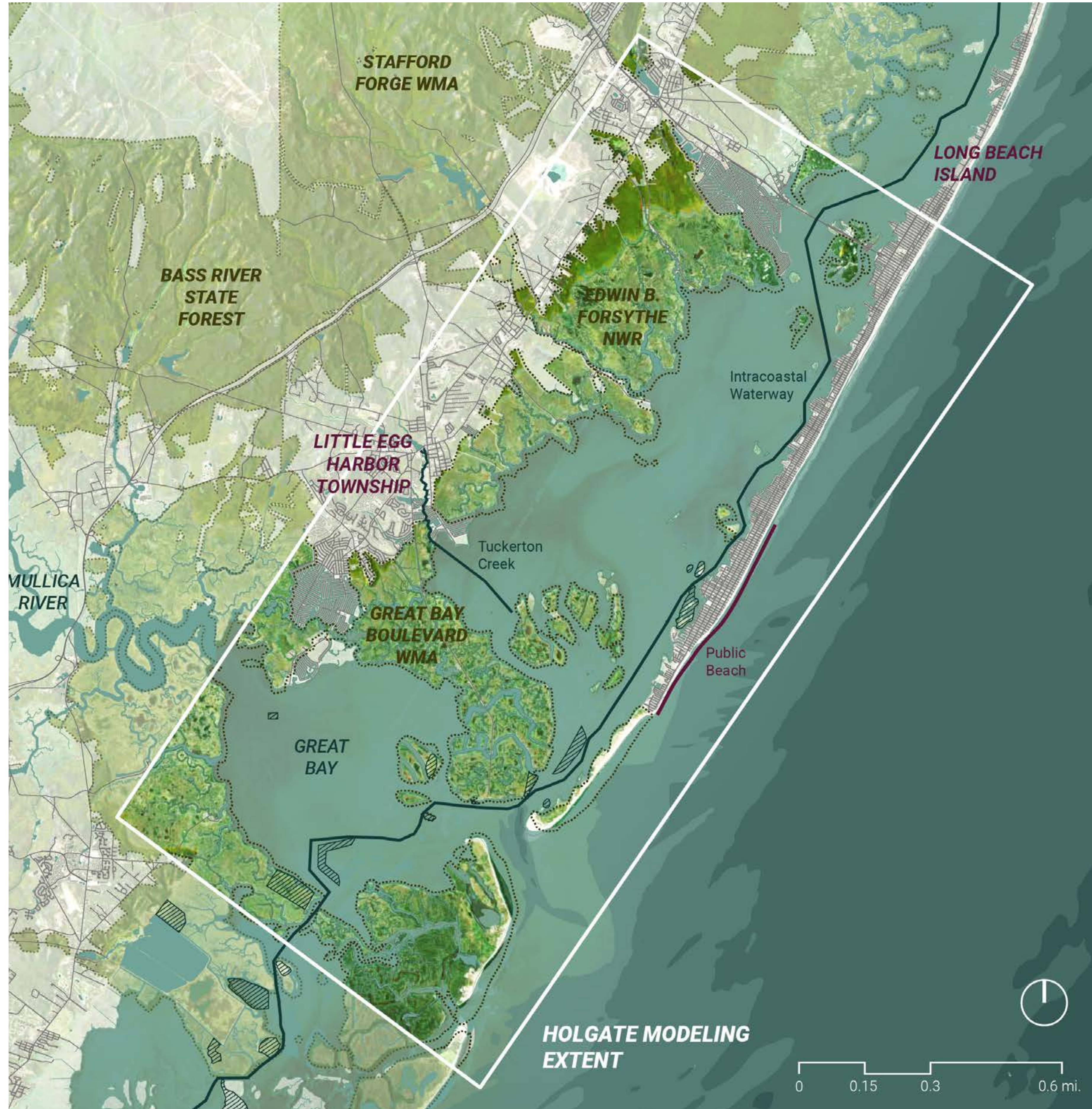
The first area of potential interest would be to leverage NNBF size with potential risk management benefits. As mentioned in the NNBF report, "some areas like Brigantine showed water level reductions attributable to NNBFs even under conditions where the NNBFs were inundated, lower elevation NNBFs may still potentially provide CSRM benefits with significantly less required sediment" (NJBB 2021). Specifically, can NNBFs be utilized in areas designated in the NJBB CSRM TSP plan that forgo structural operations instead of non-structural strategies? Moreover, if so, what is the trade-off point where maximum benefits are achieved with the minimum amount of sediment volume?

The second area of inquiry concerns NNBFs causing increased water levels during specific storm direction scenarios. "In some areas, the NNBFs increased water levels, especially in situations that created strong north to south winds; additional analysis with re-designed NNBF should be considered to determine if the amplification of water levels attributable to the NNBF could be reduced" (NJBB 2021). Is it possible to further tune the NNBFs to reduce storm surge while allowing water to leave the system? In a sense, can a directional wetland be designed?

These two areas of inquiry led to a second round of NNBF design in the areas surrounding the Holgate Peninsula.

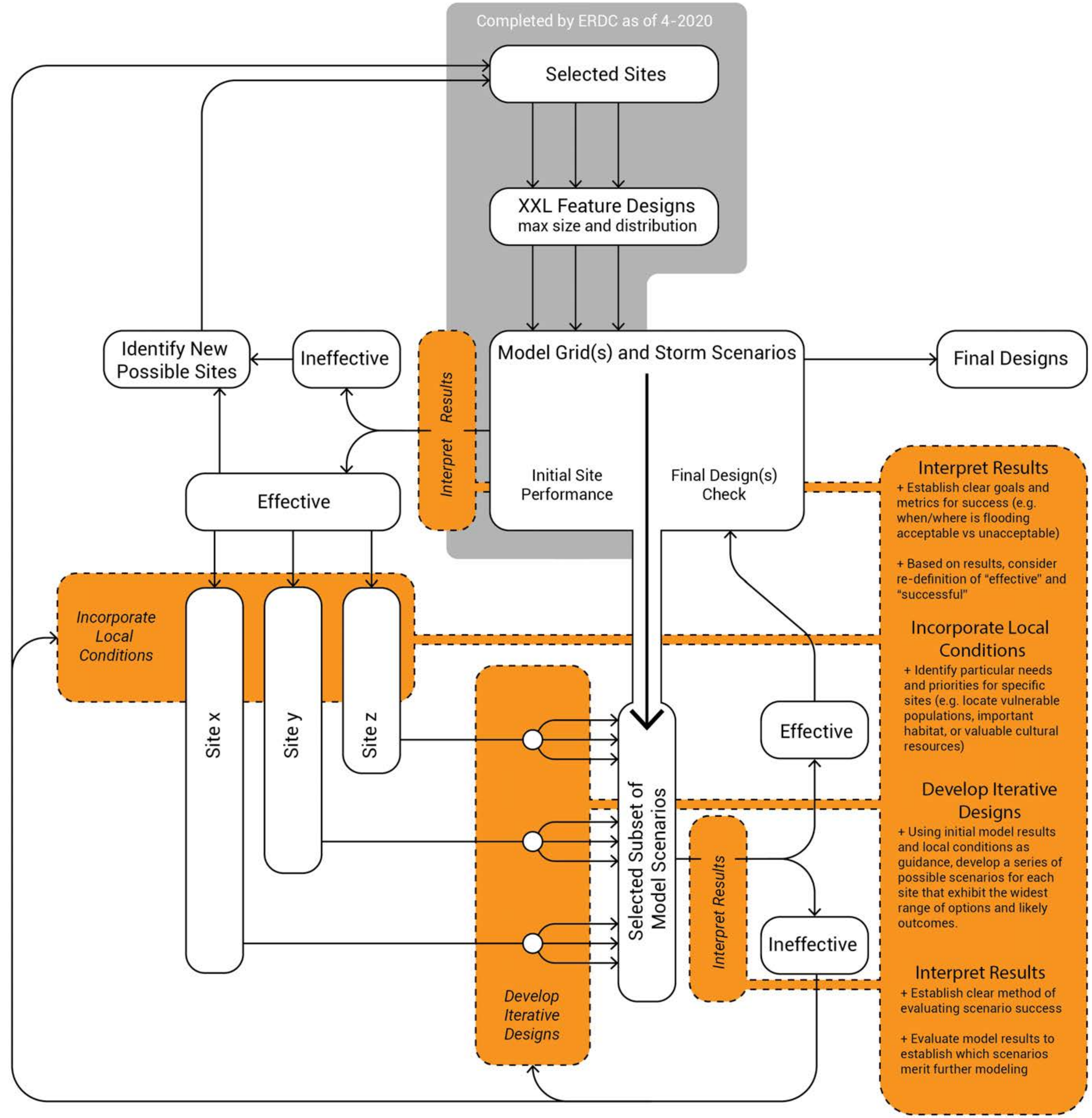
1 HOLGATE PENINSULA CONTEXT
PROJECT DESCRIPTION

The study area included the two large shallow back bays of Great Bay and Little Egg Harbor, both flowing out of the Little Egg Inlet. Dividing the two bays, Holgate Peninsula), is a large habitat complex comprising over 5000 acres of valuable tidal salt marsh. Situated on the easternmost tip of Holgate Peninsula, Rutgers University Marine Field Station is accessible via a single road that bisects the island. This field station serves as a potential hub for collaborative efforts in conducting beneficial use field studies. Little Egg Harbor is protected by Long Beach Island, primarily developed except for a natural spit 3 miles long at the southeast end. Tidal marshes, part of Edwin B. Forsythe NWR, also fringe the mainland of the Little Egg Harbor. Development in this area is mainly concentrated in three finger canal communities: Mystic Harbor, Tuckerton Beach, and Beach Haven West. Beach Haven West is the largest of the three, shoring up 5,000 residential structures with 50 miles of bulk-headed shoreline. On Long Beach Island, Beach Haven, Brant Beach, and Ship's Bottom are popular seasonal and year-round communities.



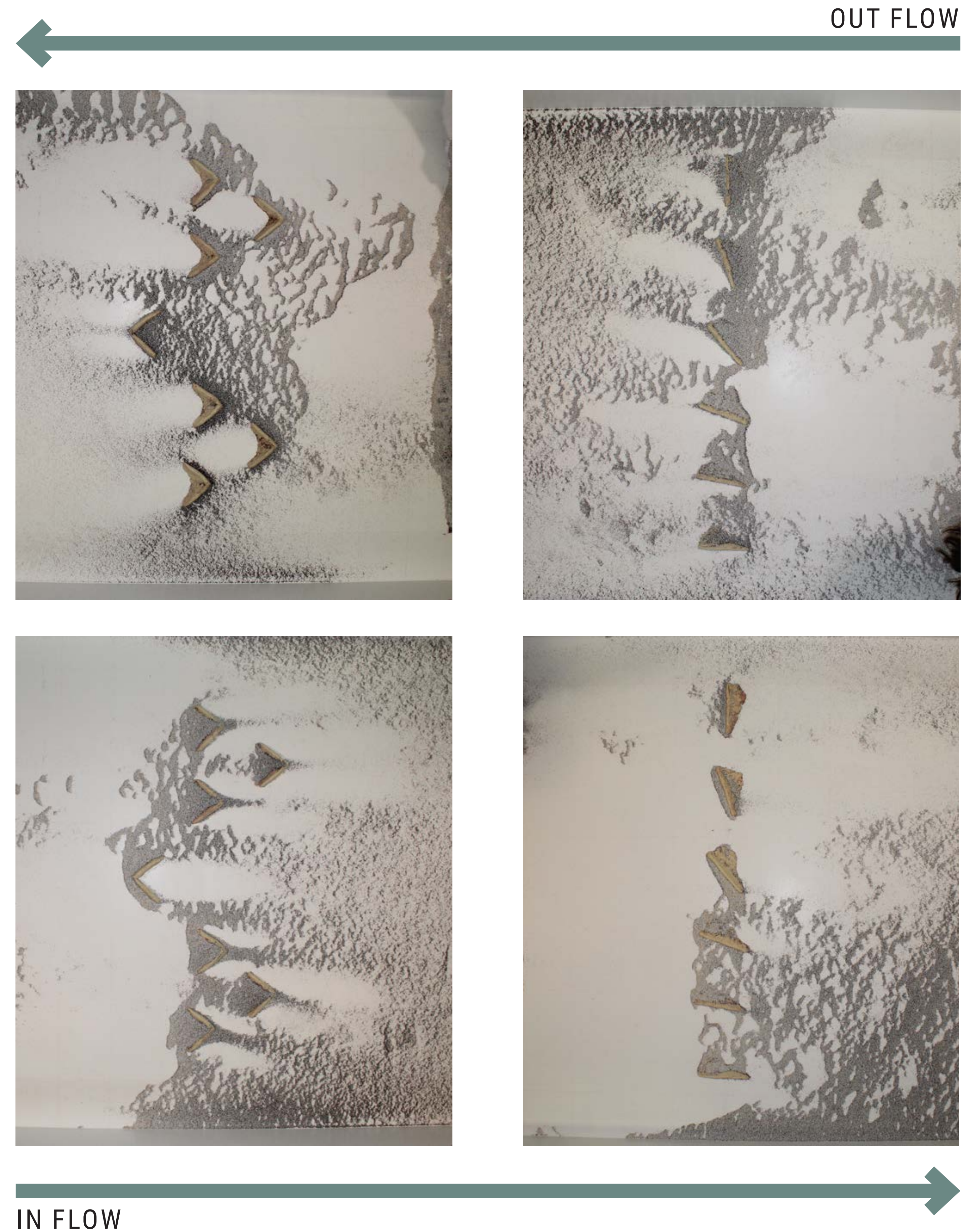
1 HOLGATE PENINSULA CONTEXT
PROJECT APPROACH

This project will reference the proposed design and modeling method outlined in the EWN + LA Back Bay report (EWN + LA NJBB, 2020). This series of feedback loops integrates information gleaned from past modeling results to direct new design directions. As indicated above, the first round of modeling showed that while some storm surge reduction was observed, the modeled features also prevented water from leaving the bay (NJBB 2021). Our team acknowledged the complexity of the inlet hydrodynamics and the difficulty of modeling sediment and storm interactions accurately over the time frame of the project. To address this difficulty, the team developed a modeling process that simply tested the possible performance of a "directional" wetland feature that could potentially maintain the storm surge protection observed in the initial model while mitigating the negative effects that were also observed when water direction changed. In this way, the team used an iterative process of hydrodynamic modeling and feature designs to test the directional performance of a range of possible scenarios. The rapid iteration of possibilities required overlooking or generalizing many of the complexities of the inlet in favor of a simpler assessment of whether the sole objective of directionality was met or not with each scenario.



2 HOLGATE PENINSULA CONCEPT
DIRECTIONAL WETLANDS

Based on the previous models of NNBF in the region, it was clear that the directionality of the storm surge had implications on the “success” of the features. Water piling up at the inlet and reducing the surge into the bay was seen as a productive outcome of the feature. However, this performance also hindered the ability of the surge to exit the bay when it came from the north, leading the team to consider whether NNBFs could be directional: to block storm surge from the ocean while allowing water passage from the bay.

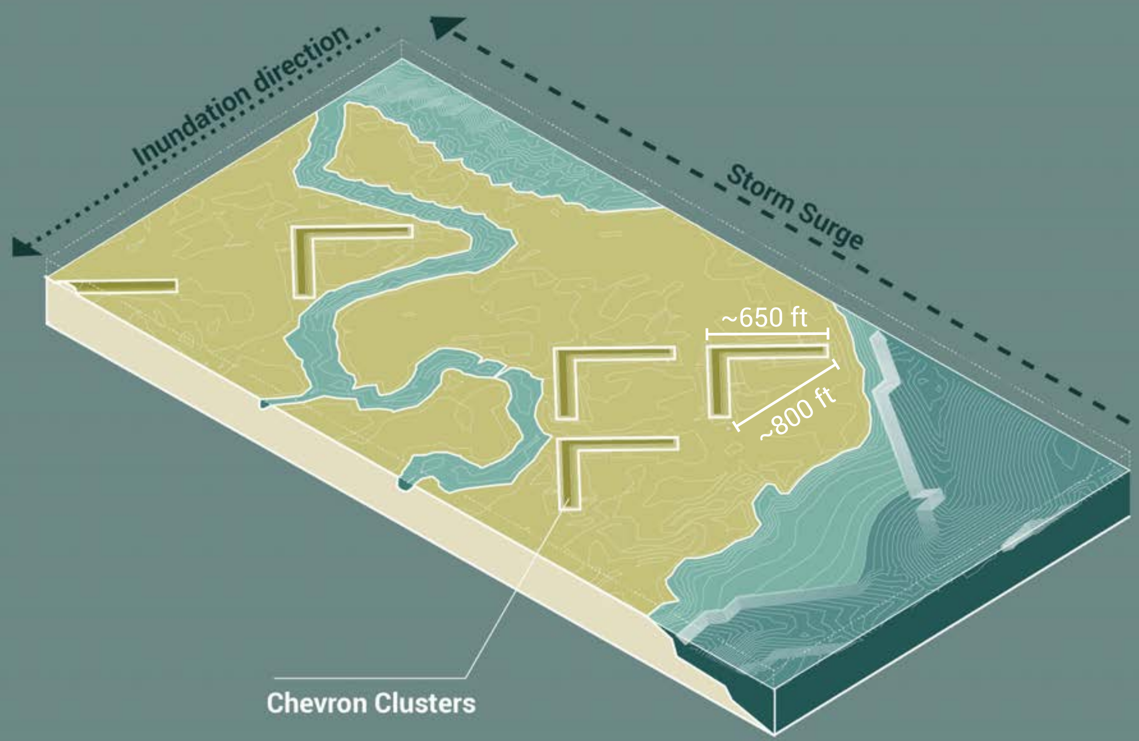


2 HOLGATE PENINSULA CONCEPT
DIRECTIONAL WETLAND OPTIONS

The following concepts were developed to investigate the possibility of using smaller-scale, more highly tuned NNBFs to reduce storm surge and decrease flooding. The conceptual idea behind the interventions was to create "directional wetlands," or wetland forms that would mitigate storm surges on the front side and allow water passage on the backside. The chevron design reaches an elevation 6ft while the wetland slopes reach an elevation of 8ft.

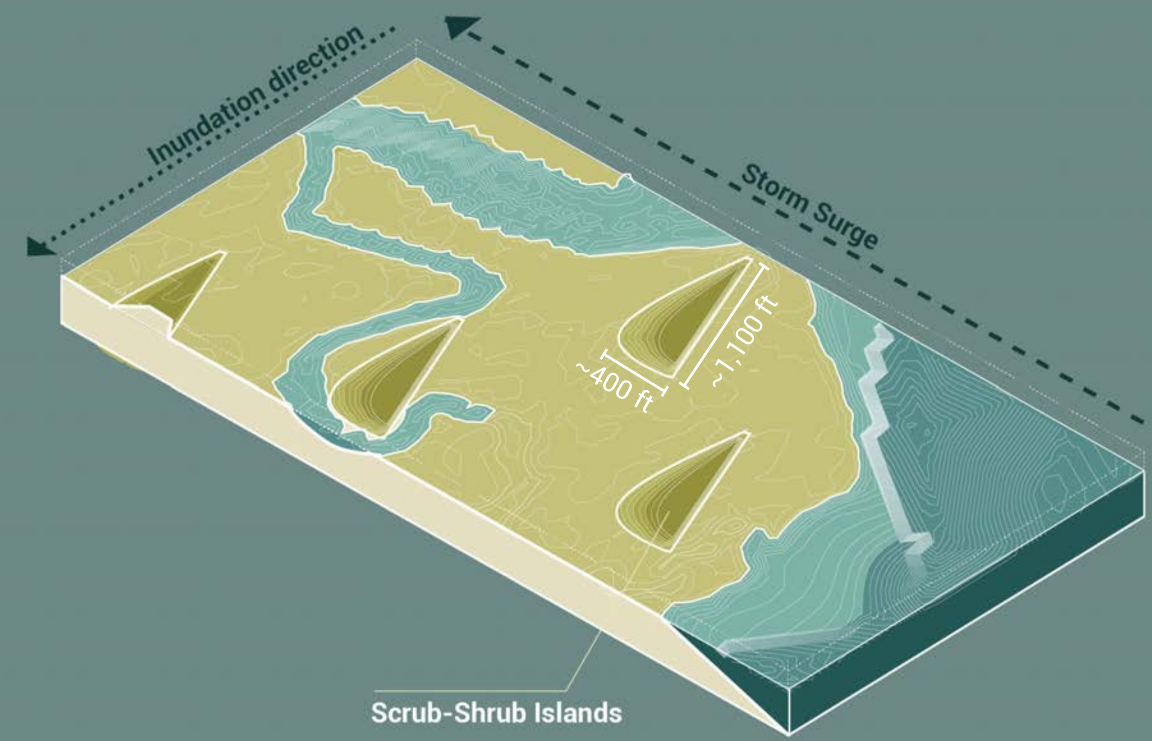
CHEVRON

Chevrons are designed to both capture sediment and reduce storm surge. The angle of the centerline of the chevron is perpendicular to the predominant storm surge angle. Chevrons are grouped in triangle clusters, which are offset from one another.



WETLAND SLOPES

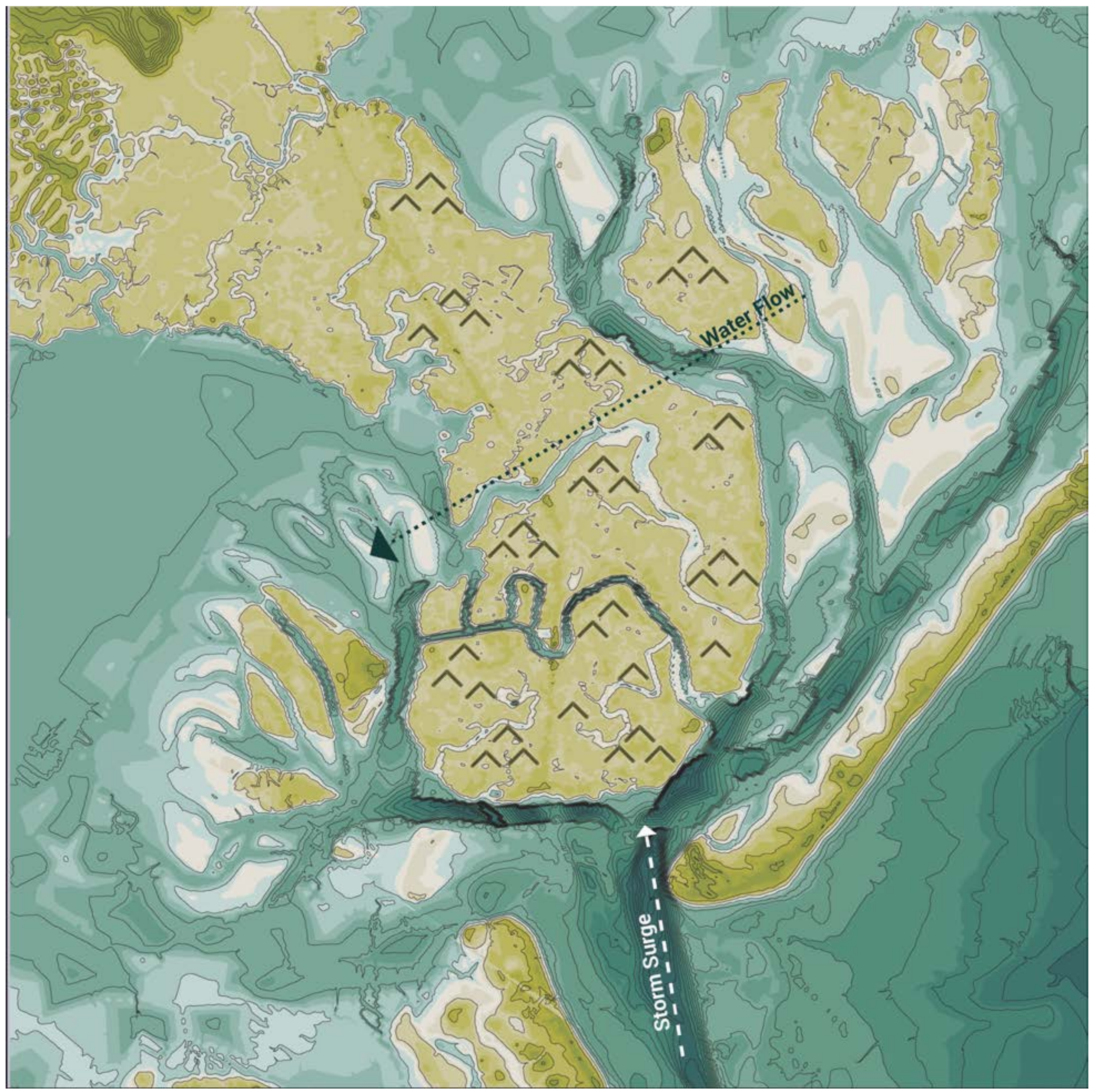
Wetland slopes are placed throughout the Holgate Peninsula, perpendicular to storm surge, allowing for scrub-shrub habitat to colonize and inhabit.



3 COMPUTATIONAL MODELING
PLAN SETUP

Two "directional" interventions were designed, modeled, and described below. The following two interventions are placed on Holgate Peninsula to increase the wetland's efficiency in mitigating storm surges. These features were oriented perpendicular to the predominant wave direction (which was anticipated to be the predominant storm surge direction) while attempting to design enough space between the features to allow for flow.

CHEVRON



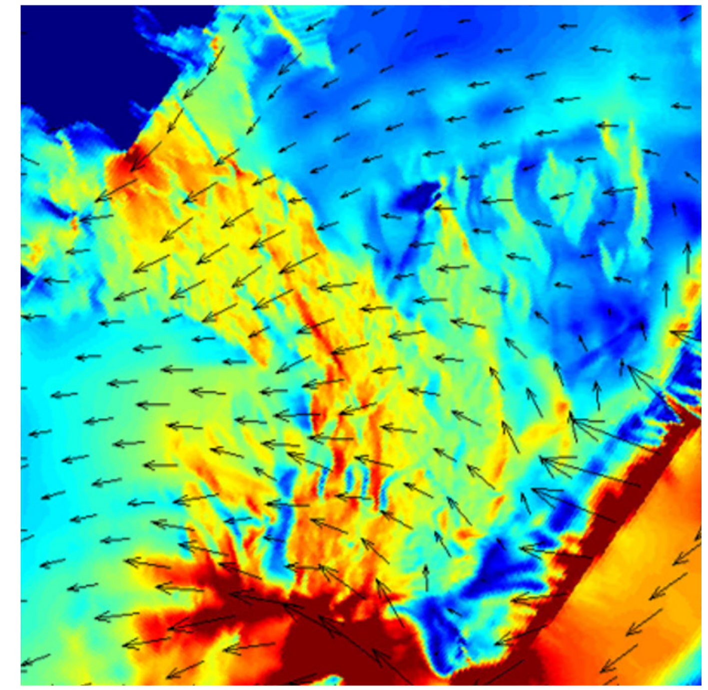
WETLAND SLOPE

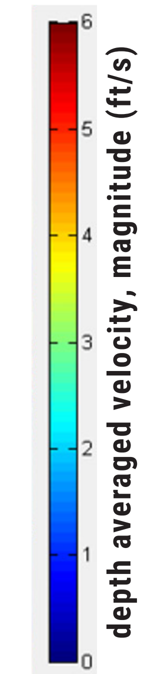
3 COMPUTATIONAL MODELING
RESULTS

The two concepts were modeled against existing conditions to evaluate the interventions' impacts on water levels, flow velocity magnitude, and direction during storm surges. As shown in the figures, while the Chevron and Wetland Slope features cause localized differences in flow velocities adjacent to the features, there is not a significant difference in flow velocity magnitudes or directions across the Holgate Peninsula. However, there was no significant difference in flow velocity magnitudes or directions across Holgate Peninsula. Finally, there were no significant differences in water level elevations between existing conditions and the conceptual design alternatives. Since the scenarios modeled were representative of extreme storm events, it is possible that the designs could have a more significant impact on more moderate storm events. However, based on the preliminary results, the types and scales evaluated did not achieve the desired project objective of reducing extreme storm surges in the area, and other intervention types should be considered.

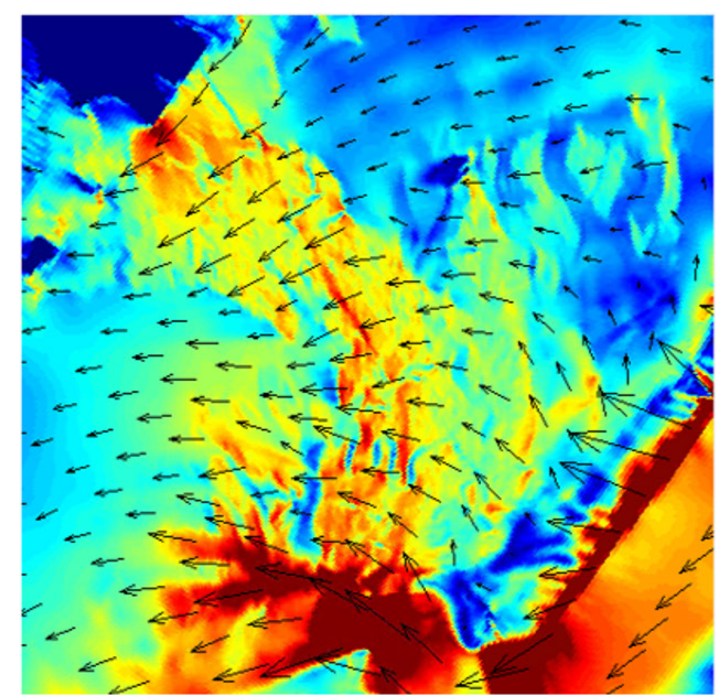
VELOCITY RESULTS: STORM 350

EXISTING CONDITIONS

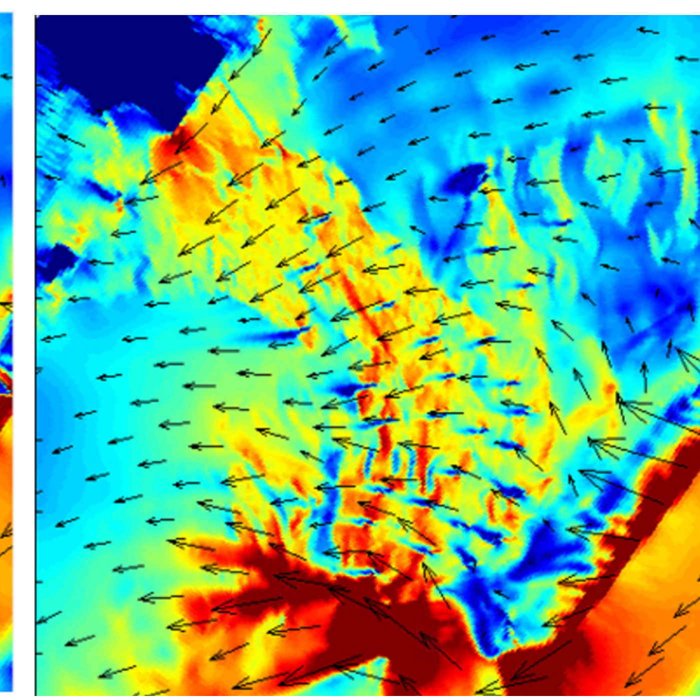




CHEVRON

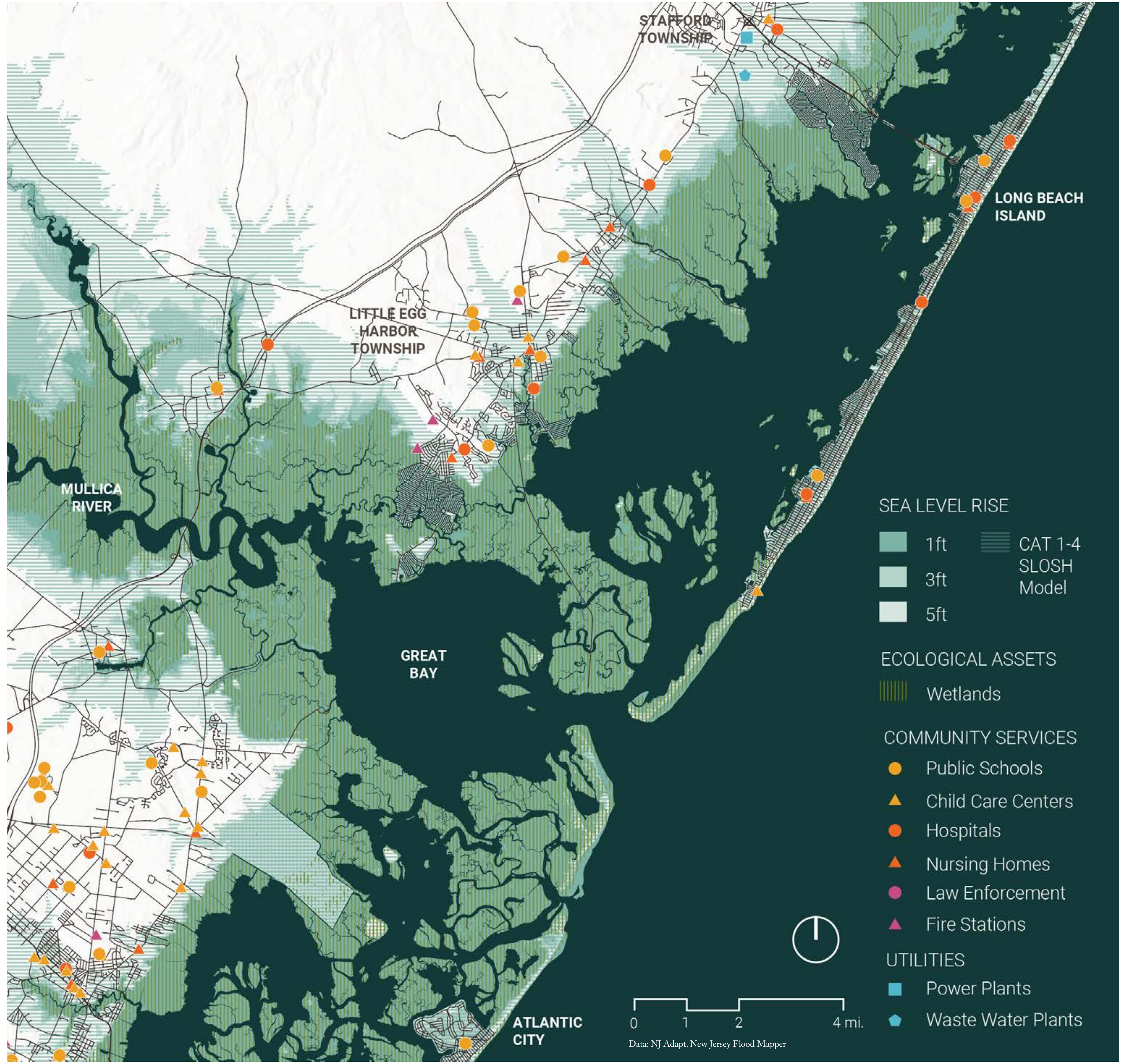


WETLAND SLOPE



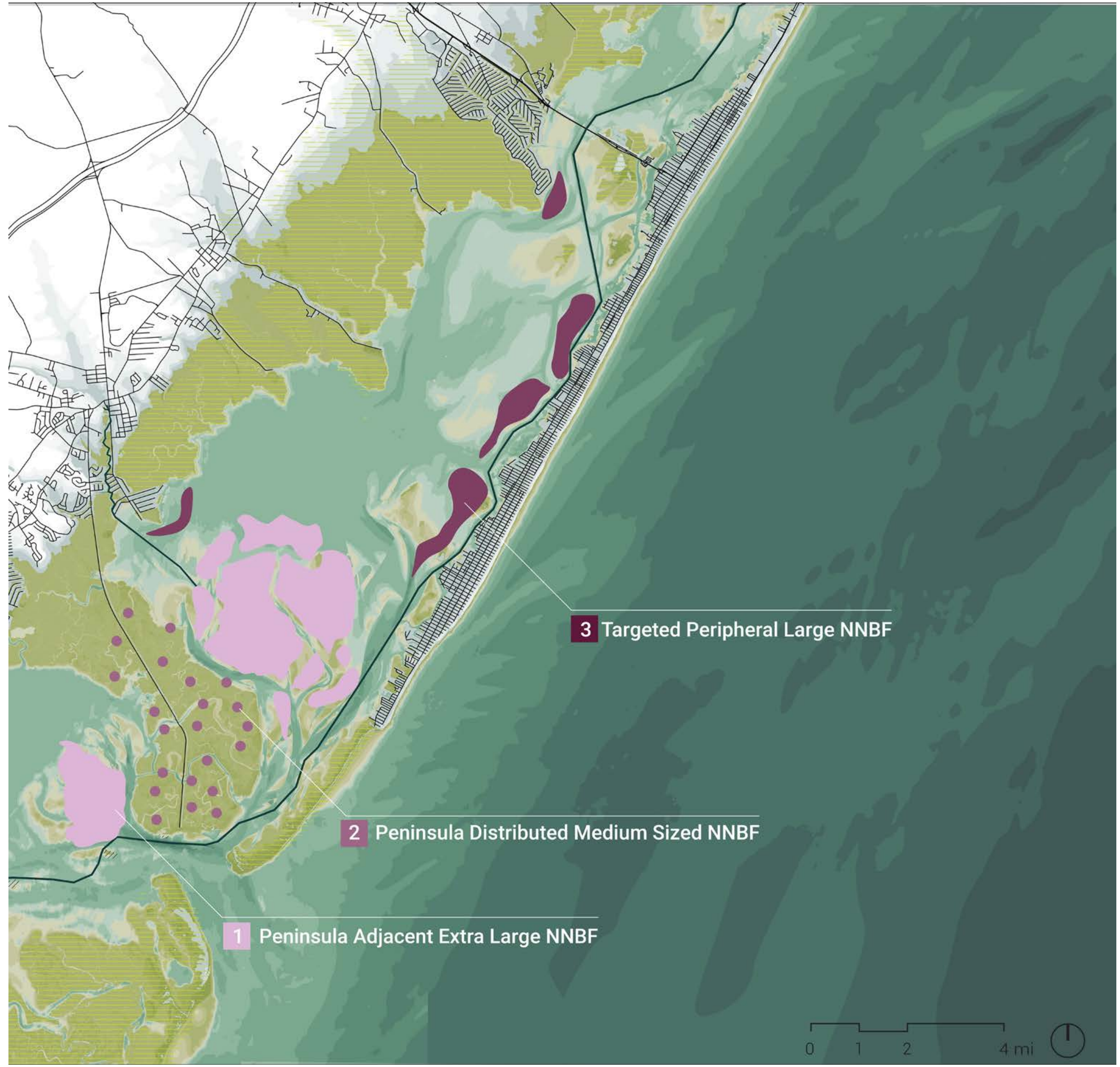
4 NEXT STEPS
VULNERABILITY ANALYSIS

Based on the results of the modeling, the smaller NNBF features were not found to be effective against large storm scenarios. Instead, based on the results of the first and second rounds of modeling, it was speculated that reducing storm surge through NNBFs at and around Holgate Peninsula was ineffective. Instead, our EWN team hypothesized that targeted NNBFs closer to shore could be a better use of sediment and effort. Further mapping was conducted to highlight areas of risk to communities and infrastructure along the island and mainland communities in Little Egg Bay, which could benefit from a targeted NNBF approach. Through this analysis and the results from the modeling, our team sketched out the next conceptual set of features to test via the design-model feedback loop.



4 NEXT STEPS
FUTURE QUESTIONS

This model-design project, which tested the effectiveness of smaller directional wetlands on Holgate Peninsula, followed the previous model-design project explored in the EWN+ LA NJBB report, which tested the effectiveness of extra-large NNBFs surrounding Holgate Peninsula (EWN + LA NJBB, 2020). Based on the results of this modeling round, the following hypothesis to test would be the efficacy of medium to large NNBFs in targeted nearshore locations. NNBFs around the Holgate Peninsula were ineffective against the most significant storms. Instead of aiming to decrease storm surge across the bay, the NNBFs could be positioned closer to the coastal communities at risk. In turn, this would remove the NNBFs from the natural water outlets, thus removing the obstructions that caused increased flooding, and place more emphasis on selecting specific locations for maximum protective benefit. The figure on the following page offers a highly conceptual example of this approach and would require a good deal of future study to calibrate in terms of scale and specific location.

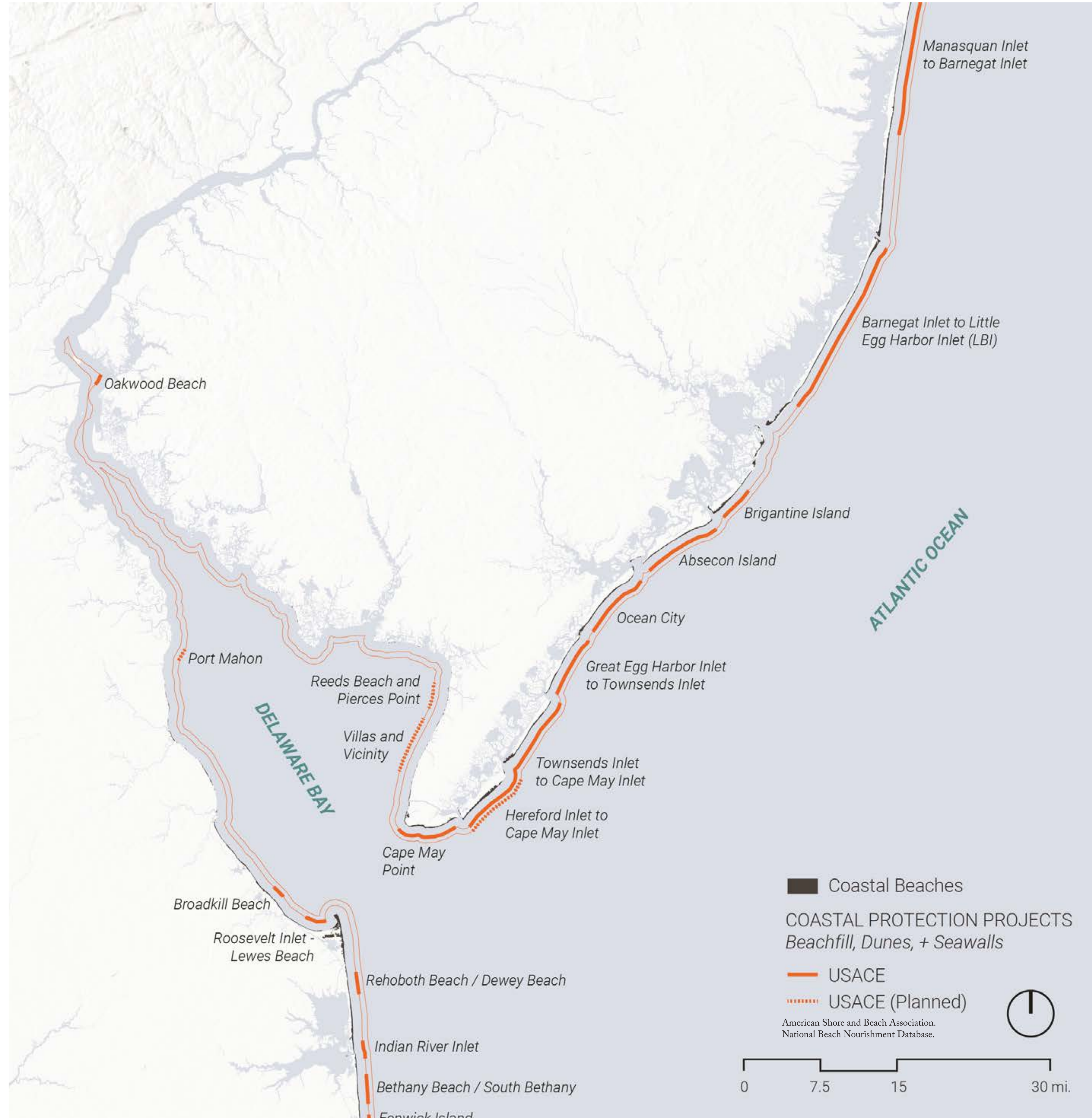


RESILIENT DUNE RESEARCH
NEW JERSEY + DELAWARE COAST

The USACE oversees the construction and maintenance of over 80 miles of constructed dunes along the New Jersey and Delaware coastline (USACE NAP District NJ and DE Factsheets, see table page 138). However, many practices used for beach placement, dune creation, and dune management (including planting) are well-poised for innovative reconsideration in the face of climate and financial challenges. This project catalogs and speculates on new possibilities in the construction and maintenance of features in the nearshore and dune regions of the coast, looking specifically at what technologies could be employed to maintain a protective, resilient, and ecologically diverse nearshore, beach, and dune system. Dunes provide natural coastal protection against storm surges and wave attack events. In addition to being regarded as the most economical and aesthetically pleasing coastal protection measure, dunes are often vastly preferred over seawalls, rock revetments, or other 'hard' shoreline stabilization structures due to their ability to dissipate wave energy rather than reflect waves onto beaches or neighboring properties.

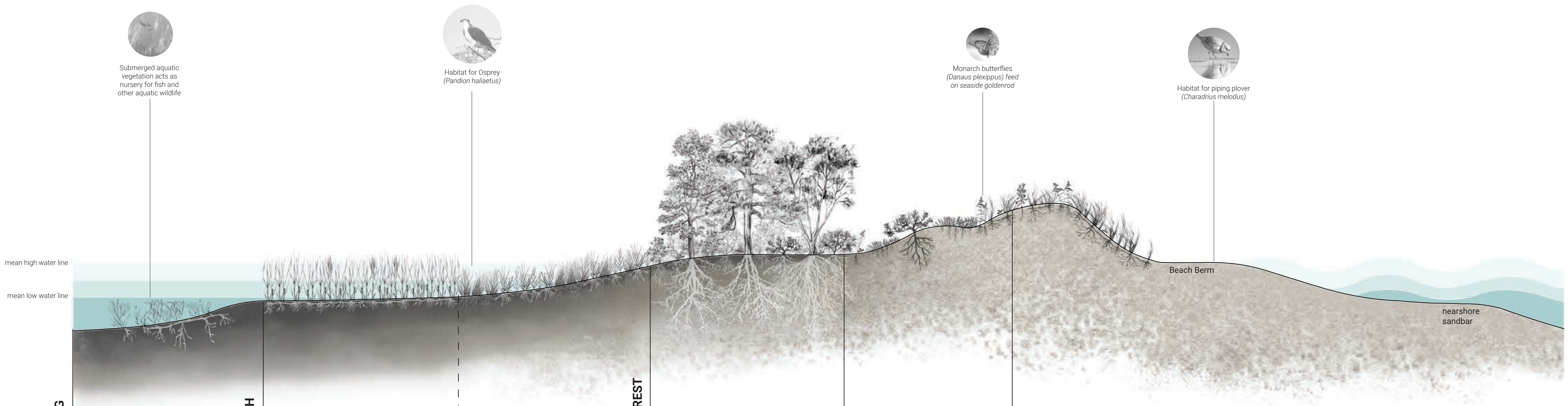
1 REGIONAL OPPORTUNITIES
SHORELINE PROTECTION

The Philadelphia District plays a key role in the protection of the New Jersey and Delaware coastline, from Manasquan Inlet south to Fenwick Isle. Since the 1990s, sixteen federally authorized coastal storm risk management projects have been constructed along the district's New Jersey and Delaware coastline, providing over 80 miles of protection (USACE NAP District NJ and DE Factsheets). The majority of these projects are dune and berm systems intended to reduce risk of storm damages of adjacent infrastructure. Additional details regarding these projects are listed in the USACE NAP District Coastal Projects table on page 138 of this report.



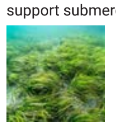
2 PRECEDENT RESEARCH
NATURAL DUNE RESILIENCY

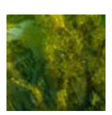
Dunes provide natural protection against storm surges on the coast. A natural dune system is complex and ever-changing, formed and shaped by the wind and the waves. As a dune grows, its seaward face becomes steeper as its landward tail is gentler, creating an asymmetrical shape. As the dune and vegetation increase in height and density, the back dune becomes more sheltered, hosting multiple species of plants like Rugosa Rose, Bayberry, and Goldenrod. The shoreface of the dune typically hosts American Beach Grass. A dune field may develop in coastal areas wide enough to support it, with each subsequent line of dunes separated by interdunal habitat. These varied microhabitats support a diverse plant community, which in turn helps support dune resiliency and stabilization, as each plant species plays a different role in above and below-ground sand retention (Sea Grant, 2016).



AQUATIC VEG

The nearshore aquatic environment support submerged sea grasses

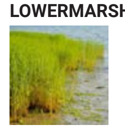

Eelgrass
Zostera marina


Widgeon Grass
Ruppia cirrhosa

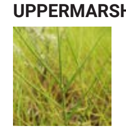
TIDAL MARSH

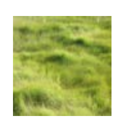
Tidal marshes are densely vegetated with stands of grasses tolerant of saltwater, tidal changes, and water movement. Though they only support a few species of grasses, they are some of the world's most productive environments in the world, thanks to access to sunlight and sediment.

LOWERMARSH


Smooth Cord Grass
Spartina alterniflora

UPPERMARSH


Spike Grass
Distichlis spicata

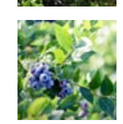

Salt Hay
Spartina Patens

THICKET/FOREST

Thickets and forests support an unusual amount of biodiversity for the barrier island and feature a large variety of slow-growing and salt-tolerant shrubs and trees

Shrubs

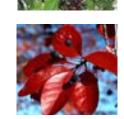

Northern Bayberry
Myrica pensylvanica


High Bush Blueberry
Vaccinium corymbosum

Trees


Pitch Pine
Pinus rigida


Black cherry
Prunus serotina


Sourgum
Nyssa sylvatica

Additional species

Eastern red cedar
Juniperus virginiana

American holly
Ilex opaca

Hackberry
Celtis occidentalis

Shadbush
Amelanchier canadensis

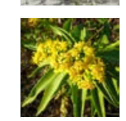
Red maple
Acer rubrum

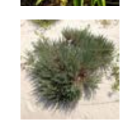
Northern red oak
uercus rubra

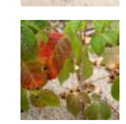
BACKDUNE

The backdune community features species well adapted to dry conditions, but less tolerant to the impacts of wind.


Beach Plum
Prunus maritima
- Produces commercially valuable fruits


Seaside Goldenrod
Solidago sempervirens
- Flowers provide food for migrating monarchs

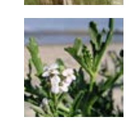

Beach Heather
Hudsonia tomentosa

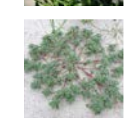

Poison Ivy
Toxicodendron radicans

FOREDUNE

The vegetation of the foredune helps build the dune and must be tolerant to salt spray, strong winds, and some burial by wind-blown sand. These species collect sand around themselves and are essential to building dunes.

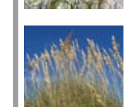

American Beachgrass
Ammophila breviligulata
- Vigorous, upright grass that grows in dense clumps and is capable of rapid lateral spread by runners
- Quick establishment and effective trapping of sand the first growing season
- Grows through as much as 4 feet of sand accumulation during one season


Sea Rocket
Cakile edentula
- Annual plant species that spreads seed pods using ocean waters
- Puts down deep tap roots, creating structure for sand dune
- Features attractive four-petal flower


Seabeach Amaranth
Amaranthus pumilus
- Reappeared in New Jersey after period of disappearance in state-currently considered endangered
- Grows low to ground, with long horizontal rhizomes roots that enable stability and spread

Potential future species *(non-native / southern)*

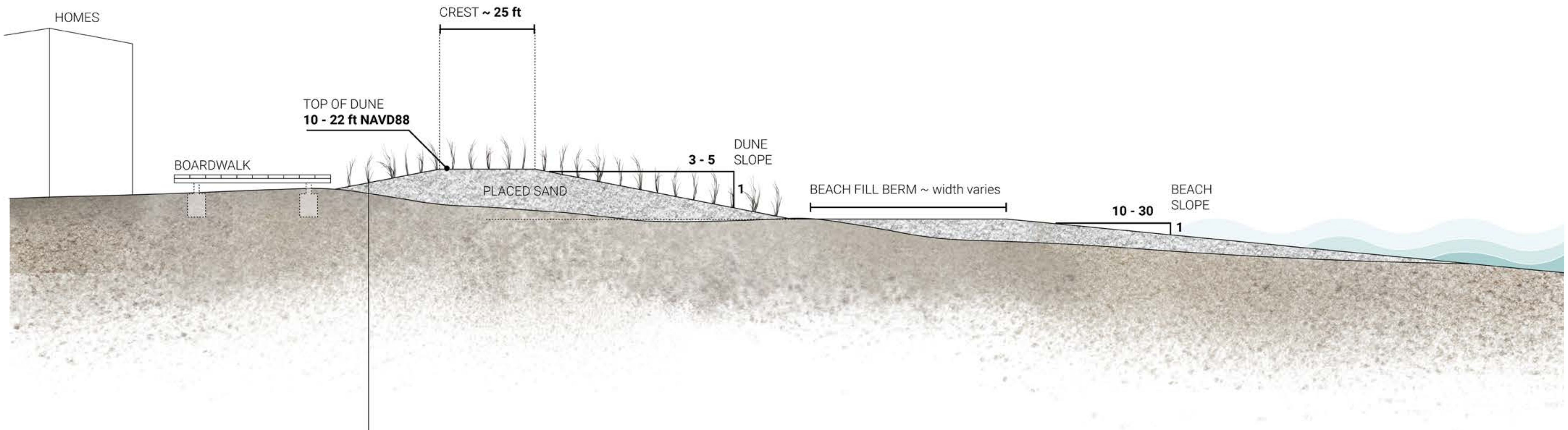

Asiatic Sand Sedge
Carex kobomugi
- Native to Asia, but commonly found along the Jersey Shore
- Grows in stands separate from American beachgrass
- 2017 study found that it preventing dune erosion during superstorm Sandy better than native American beachgrass


Sea Oats
Uniola paniculata
- Native along southern east coast, Virginia to Texas
- Extensive root system enables survival in foredune
- Does not spread as rapidly as American beachgrass, and its
- Most effective when planted with American beachgrass due to its slow lateral spread


Seashore elder
Iva imbricata
- Native along southern east coast, Virginia to Texas
- Low-growing, woody shrub adapted to foredunes
- Useful for planting where American beachgrass has died out

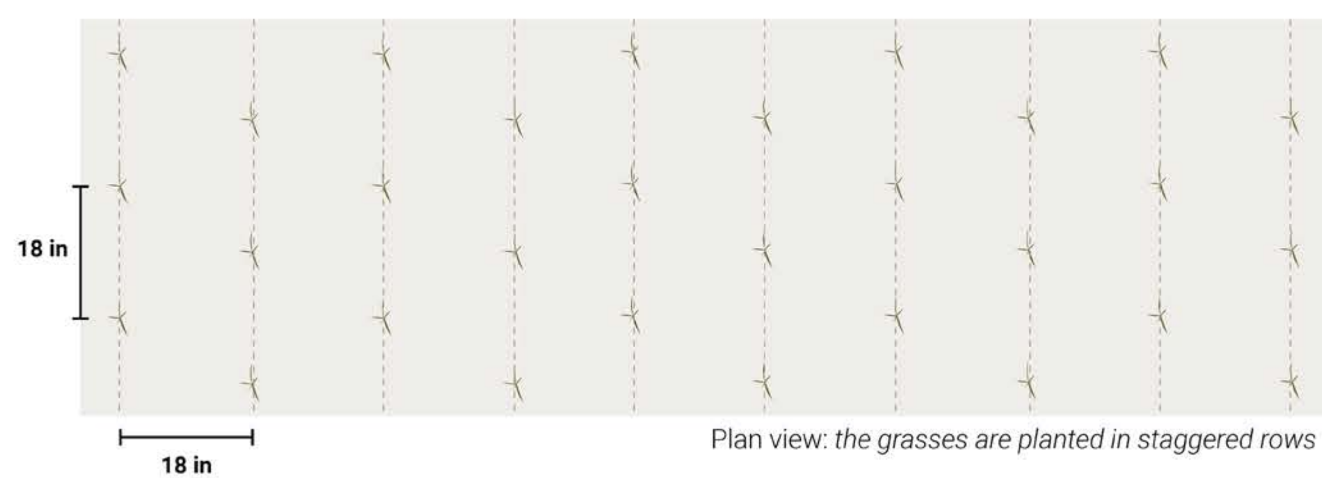
2 PRECEDENT RESEARCH
ACE CONSTRUCTED DUNE

The typical dune is constructed to an elevation of +12.8 to +22.0 feet (NAVD88) with a 5:1 slope and planted with American Beach grass (USACE NAP Civil Works Factsheets). When working with dunes, the height and width of the dune and adjacent berms are primary considerations. Studies have shown that a seaward slope of a dune should be less than a 5:1 (base: height) ratio to be stable for this region. While a taller and



American Beachgrass
Ammophila breviligulata

American Beachgrass (*Ammophila breviligulata*) is the primary species planted by the USACE on the front and back of constructed dunes. The species is considered the most reliable and commercially available option.



Plan view: *the grasses are planted in staggered rows*

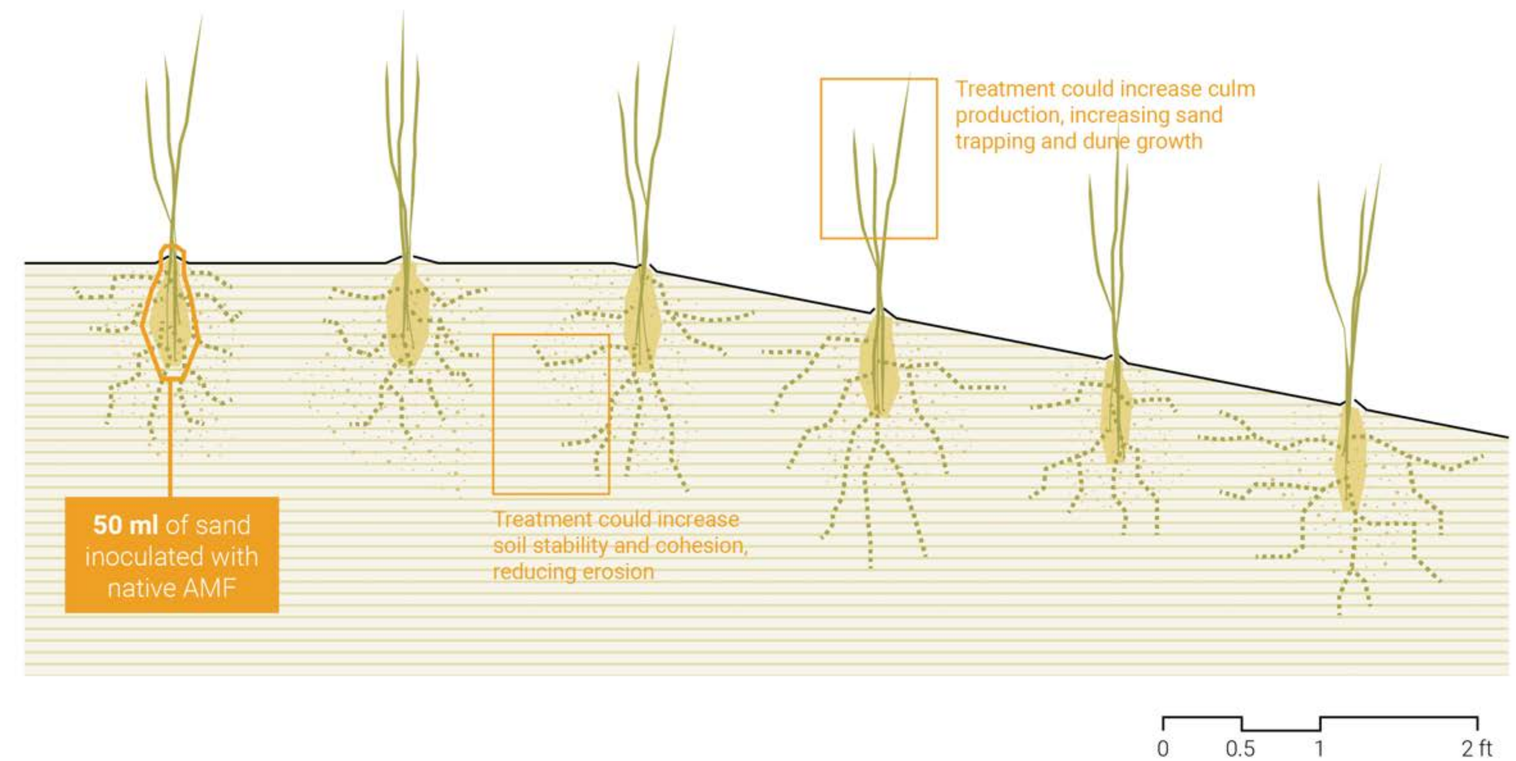
3 RESILIENT DUNE RESEARCH QUESTION
MYCORRHIZAL FUNGI

How would bolstering AMF populations through the inoculation of soil during American beachgrass planting impact plant survival + density and dune soil stability?

The growth of several dune species, including the commonly planted American Beachgrass (Ammophila breviligulata), relies on mutualistic relationships with tiny organisms called Arbuscular Mycorrhizae Fungi (AMF). The fungi live on plant roots, using their hyphae networks to funnel nutrients to their host plants in return for plant sugars. While AMF are extremely abundant and play an essential role in many ecosystems, they are critical in the harsh conditions of dune environments where they increase their host plant's tolerance to salt and drought, reduce the incidence of root parasites, and improve soil stability. As a resWWult, the success of Beachgrass plantings depends on the presence of AMF in the soil. However, as obligate symbionts, the fungi cannot survive or reproduce in barren landscapes such as constructed dunes.

A 1996 field study in a barren region of Cape Cod National Seashore (Gemma & Koske, 1997) tested the impact of planting beachgrass culms into 50-milliliter pockets of soil inoculated with native AMF. Though AMF eventually became present in the soil of both the uninoculated control area and inoculated test area, the inoculated plants produced 14% more culms and 67% more inflorescences than the control plants after 42 weeks. The difference between the number of culms produced increased to 31% by 81 weeks, indicating a sustained benefit of AMF inoculation. A more recent study of Texas Coastal Dunes (Sigren et al., 2014) found that vegetated dunes had more than 50 times the potential of AMF colonization, with an average of 94.4 spores per 100 grams of sediment than degraded unvegetated dunes, with just 1.7 spores per 100 grams sediment. These results suggest that incorporating AMF inoculation into dune planting practices could improve restoration effort successes.

Interestingly, AMF also has been shown to increase soil stability. On the microscopic level, AMF mechanisms for influencing soil aggregation include biological, biochemical, and physical processes (Rillig et al., 2006). A greenhouse experiment completed in 2016 (Mardhiah et al., 2016) found hyphal length in inoculated soils to correspond with reduced soil loss under shear stress, reinforcing the understanding of AMF as soil stabilizers. While some recent studies have focused on chemically increasing sand stability through microbial and enzymatic-induced carbonate precipitation (Liu et al., 2020) or colloidal silica-based consolidation techniques (D'Alessandro et al., 2021), increasing AMF populations could be a more ecologically beneficial approach to bolstering sand strength and cohesion. Though commercial inoculums exist for purchase, a natively derived AMF would likely be most beneficial.



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Gemma, J. N., & Koske, R. E. (1997). Arbuscular Mycorrhizae in Sand Dune Plants of the North Atlantic Coast of the U.S.: Field and Greenhouse Inoculation and Presence of Mycorrhizae in Planting Stock. Journal of Environmental Management, 50(3), 251–264. https://doi.org/10.1006/jema.1996.9985

Liu, K.-W., Jiang, N.-J., Qin, J.-D., Wang, Y.-J., Tang, C.-S., & Han, X.-L. (2020). An experimental study of mitigating coastal sand dune erosion by microbial- and enzymatic-induced carbonate precipitation. Acta Geotechnica, 16(2), 467–480. https://doi.org/10.1007/s11440-020-01046-z

Mardhiah, U., Caruso, T., Gurnell, A., & Rillig, M. C. (2016). Arbuscular mycorrhizal fungal hyphae reduce soil erosion by surface water flow in a greenhouse experiment. Applied Soil Ecology, 99, 137–140. https://doi.org/10.1016/j.apsoil.2015.11.027

Rillig, M. C., & Mummey, D. L. (2006). Mycorrhizas and soil structure. New Phytologist, 171(1), 41–53. https://doi.org/10.1111/j.1469-8137.2006.01750.x

Sigren, J. M., Figlus, J., & Armitage, A. R. (2014). Coastal sand dunes and dune vegetation: Restoration, erosion, and storm protection. Shore and Beach, 82(4), 5–12. ResearcgGate.net.

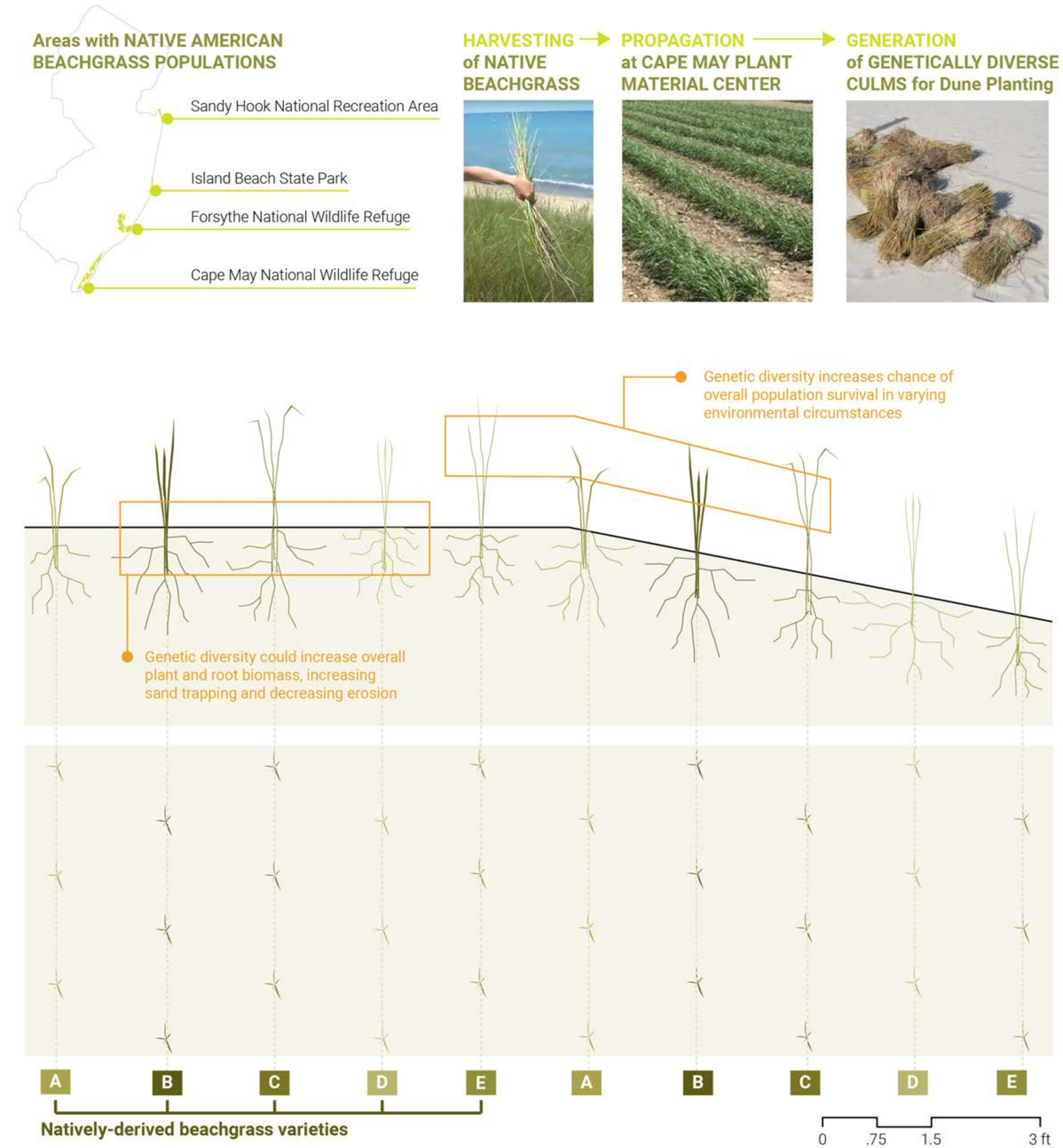
3 RESILIENT DUNE RESEARCH QUESTION
GENETIC DIVERSITY

How would increasing the genetic diversity of American beachgrass plantings impact a dune's stability and resilience to erosive weather events?

As one of the few species adapted to the frontal dune environment, American Beachgrass (*Ammophila breviligulata*) is the primary plant used to stabilize and restore dunes along the Mid-Atlantic coast. In most instances, a specific variety of the species named "Cape" is planted. This plant material originated on Cape Cod, Massachusetts. It was selected by the United States Department of Agriculture's Natural Resources Conservation Service in the 1970s for its wide leaf surface area and dense stems, both of which help efficiently trap wind-blown sand and grow dunes. The variety is currently one of just three commercially available varieties of American Beachgrass and the one best suited to the coasts of New Jersey and Delaware.

However, the common practice of planting a single asexually propagated cultivar results in a clonal monoculture, which can affect a dune's long-term performance and ecological health. Genotypic diversity has been found to increase plant population's biomass production, survival time, and rate of spread as well as improve ecological communities' resistance to disturbance. Additionally, it has been found that using non-local genotypes for restoration can threaten local genotypes and decrease community-level biodiversity. While the failure of beachgrass plantings is traditionally attributed to a lack of sand movement and/or disease, monotypic and non-local genotypes could be part of the problem.

A 2015 study (Slaymaker et al., 2015) used Inter Simple Sequence Repeat markers to survey the genetic diversity of four native and restored dunes along the coast of New Jersey. The results indicated that more genotypic diversity exists within the native beach grass populations than restored populations and found that commercial beach grass varieties used in restoration were absent from native populations. These findings suggest that the native beach grass populations surveyed, located at Sandy Hook National Recreation Area, Island Beach State Park, Forsythe National Wildlife Refuge, and Cape May National Wildlife Refuge, could be sources of genotypically diverse beachgrass for local dune stabilization and restoration efforts.



REFERENCED PAPERS:

Slaymaker, D. H., Peek, M. S., Wresilo, J., Zeltner, D. C., & Saleh, Y. F. (2015). Genetic Structure of Native and Restored Populations of American Beachgrass (Ammophila breviligulataFern.) along the New Jersey Coast. Journal of Coastal Research, 31(6), 1334–1343. https://doi.org/10.2112/jcoastres-d-13-00157.1

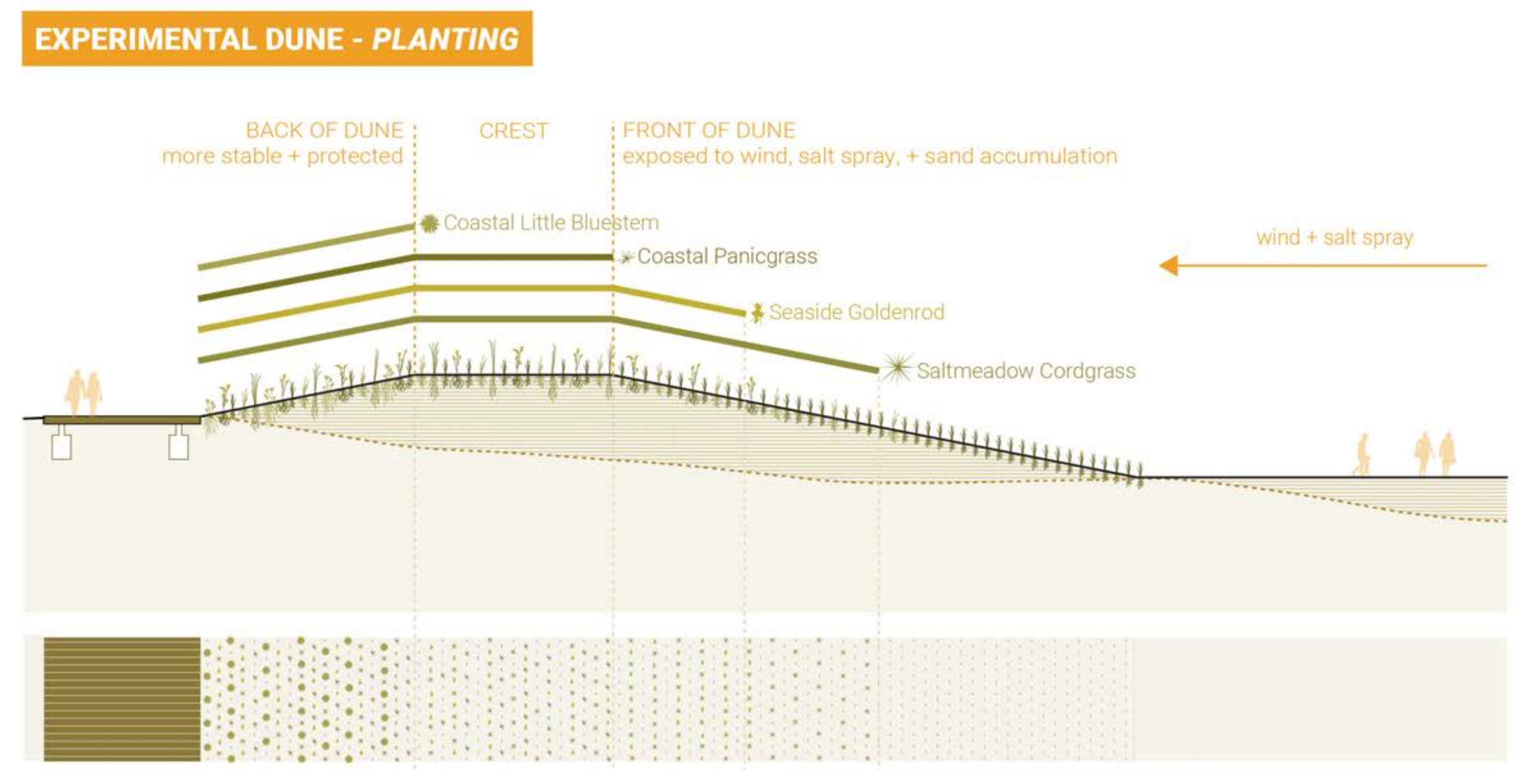
3 RESILIENT DUNE RESEARCH QUESTION
PLANT DIVERSITY

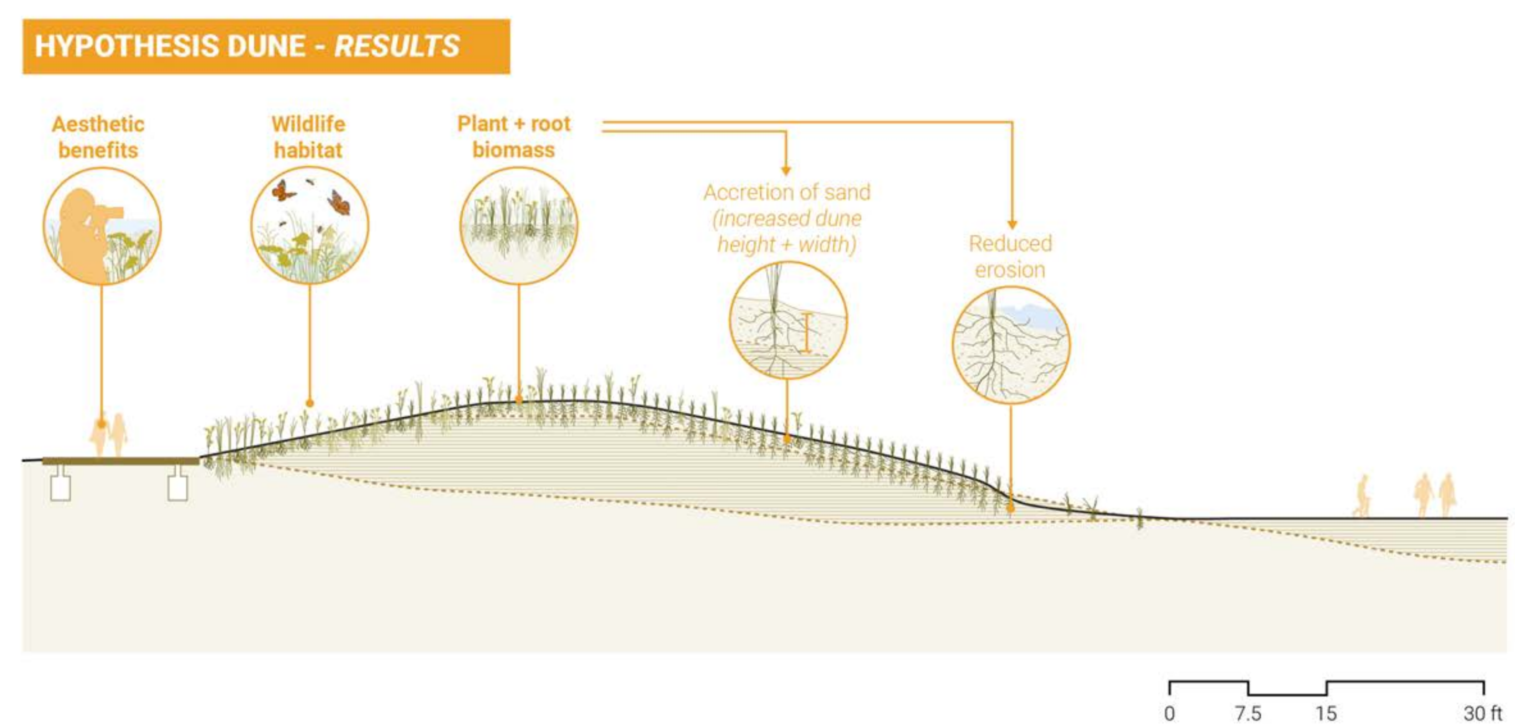
How would increasing plant species diversity on constructed dunes impact ecological health, long-term sand stabilization, and resilience to erosive weather events?

The USACE Philadelphia district primarily plants American Beachgrass (*Ammophila breviligulata)* on the dunes they construct. This species is one of the few plants adapted to the frontal dune's harsh, windy, and salty environment. Additionally, it is the most effective planting option for trapping sand and growing dunes. A recent study (Hacker et al., 2019) compared the sand accretion of the four most common dune grass species present on the Outer Banks islands of North Carolina. American Beachgrass was found to be most effective, accreting 42% more sand than Sea Oats (*U. paniculata*), which was found to be the second-best sand accretor. The authors attributed American Beachgrasses' capacity for efficiently trapping sand to its growth of densely clumped shoots and speedy lateral spread. Another recent study of the North Carolina Outer Banks barrier islands (Jay et al., 2022) found that American Beachgrass density correlated to changes in foredune morphometrics over the course of a year. Considering the significant annual fluxes in sediment supply and the frequency of hurricanes, this finding was surprising and pointed to the species' impressive ability to quickly spread, accrete sand, and build dunes.

However, American Beachgrass populations have been found to decline in the years following planting. One manifestation is the emergence of circular patches of dead American Beachgrass, called "fairy rings," commonly observed after 4 to 7 years. The plant's gradual loss in vigor is related to its unique growing requirements; the species performs best when it is continually buried by sand because it becomes susceptible to disease when its base and roots are exposed to air. When American Beachgrass plantings die, and no other species replace them, dunes are left highly vulnerable to erosion.

To combat the failures and risks associated with monocultural American Beachgrass plantings, the New Jersey Sea Grant Consortium has recommended incorporating more species diversity into dune plantings, especially on the backside of dunes. Somewhat shielded from wind, salt spray, and shifting sand, the back dune can typically support a broader range of species than the frontal dune. As sand stabilizes over time and American Beachgrass consequently dies off, back dune species have the potential to migrate and replace the dead grasses, helping keep the dune stabilized. By implementing this concept with four additional native dune plant species, we hope to study how increasing plant species diversity could impact overall ecological health and dune stabilization.





REFERENCED PAPERS:

Hacker, S. D., Jay, K. R., Cohn, N., Goldstein, E. B., Hovenga, P. A., Itzkin, M., Moore, L. J., Mostow, R. S., Mullins, E. V., & Ruggiero, P. (2019). Species-Specific Functional Morphology of Four US Atlantic Coast Dune Grasses: Biogeographic Implications for Dune Shape and Coastal Protection. Diversity, 11(5), 82. https://doi.org/10.3390/d11050082

Jay, K. R., Hacker, S. D., Hovenga, P. A., Moore, L. J., & Ruggiero, P. (2022). Sand supply and dune grass species density affect foredune shape along the US Central Atlantic Coast. Ecosphere, 13(10). https://doi.org/10.1002/ecs2.4256

Wootton, L., Miller, J., Miller, C., Peek, Dr. M., Williams, A., & Rowe, P. (2016). New Jersey Sea Grant Consortium Dune Manual. In njseagrant.org. https://njseagrant.org/wp-content/uploads/2016/07/Dune-Manual-Pgs-compressed.pdf

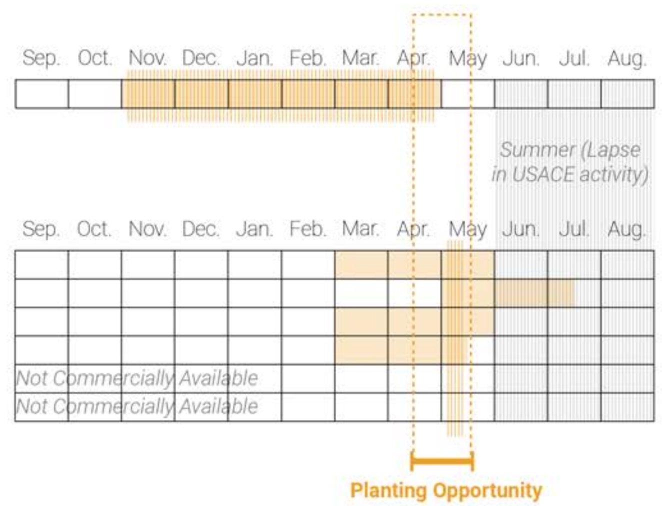
3 RESILIENT DUNE RESEARCH QUESTION
PLANT DIVERSITY: DETAILS

PLANTING CONSIDERATIONS

SCHEDULING

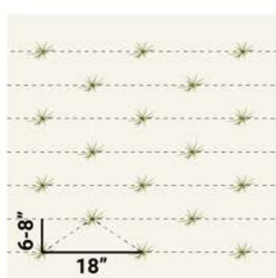
Currently Planted Species
'Cape' American beachgrass (Ammophila breviligulata)

Additional Species
coastal panicgrass (Panicum amarum var. amarulum)
saltmeadow cordgrass (Spartina patens)
coastal little bluestem (Schizachyrium littorale)
seaside goldenrod (Solidago sempervirens)
beach pea (Lathyrus maritima)
trailing wild bean (Strophostyles helvola)

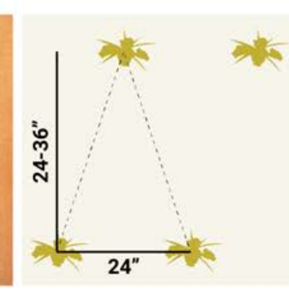


GROWTH + SPACING

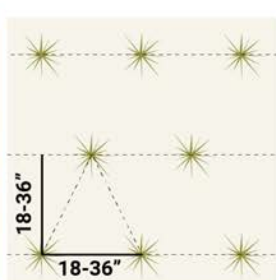
Coastal Panicgrass
Panicum amarum
Height: up to 4 ft
Roots: extensive fibrous roots and rhizome system

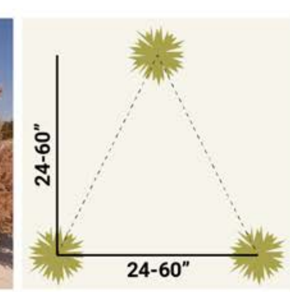
Seaside Goldenrod
Solidago sempervirens
Height: 3-4 ft near the ocean
Roots: large root systems

Saltmeadow Cordgrass
Spartina patens
Height: 2-3 ft
Roots: rhizomatous

Coastal Little Bluestem
Schizachyrium littorale
Height: most commonly 1-2 ft
Roots: Extensive lateral growth, fibrous

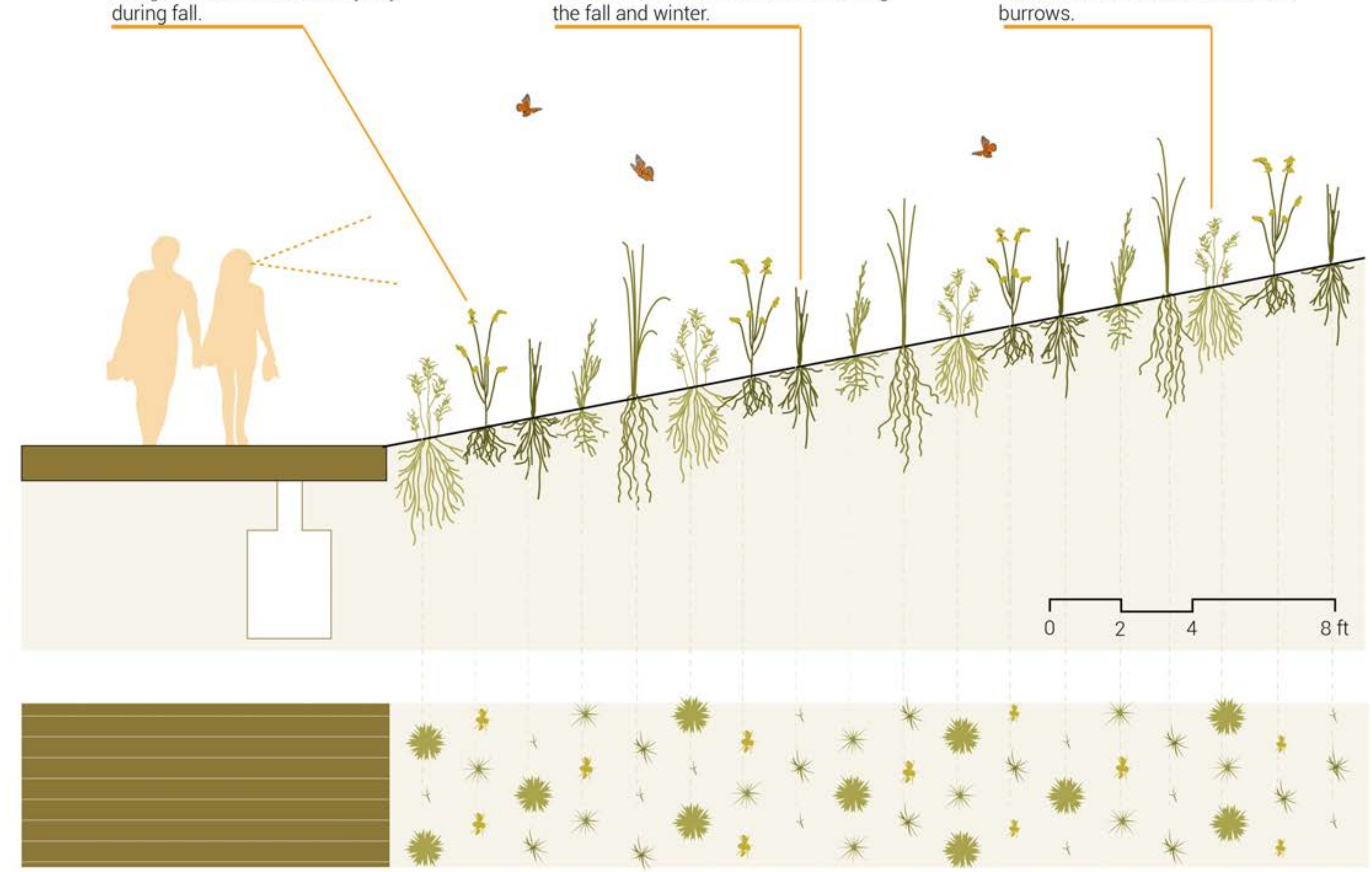



WILDLIFE BENEFITS

Seaside Goldenrod is an important food source for **monarch butterflies** migrating along the Atlantic Coastal Flyway during fall.

Coastal Panicgrass produces calorie-dense seeds that are an important food source for **songbirds, waterfowl, and small mammals** during the fall and winter.

Coastal Little Bluestem has a symbiotic relationship with **ghost crabs**, who collect and store little bluestem seed heads in their dune burrows.



3 RESILIENT DUNE RESEARCH QUESTION
SEABALE CORES

How would adding a seabale core to the dune affect long-term sand stabilization, and resilience to erosive weather events?

While planting vegetation atop dunes has become an accepted form of extending dune longevity, variations in the core construction of the dune can be considered. The dynamic and adaptive nature of dune morphology should be considered and further assessed in these core variation designs.

A pilot study performed by Texas A&M University at Galveston investigated the benefits of implementing vegetation, specifically sargassum, as a core in reinforced dunes to improve overall resilience. They found that in addition to finding a use for the heavy Sargassum buildup local to the area, benefits from the seabales included increased erosion resistance of the dunes as seabales absorbed incoming wave energy, enhanced capture of aeolian sediment transport, and an overall increase in dune resilience to drought and erosive conditions (Figlus et al., 2015)). The findings were that sealable-enhanced dune cores with vegetative planting on top performed the best in an actual storm scenario (Tropical Storm Bill). This study also found that "vegetated dunes including seabales were able to develop strong root systems quicker than their counterparts without seabale cores" (Figlus et al., 2015). It was, therefore, anticipated that the long-term effect of sargassum cores might spur the growth of other dune vegetation as the seabales decay, further providing stability and biomass to the dune.

Further development of the seabale core technique may lead to additional cost savings in coastal management practices, decreasing the volume of sand needed for dune nourishment and providing an on-site alternative to the costly removal of seaweed from the beach, in addition to any protection of infrastructure and property flood damage it may provide.

REFERENCED PAPERS:

Figlus, J., J. Sigren, R. Webster & T. Linton, 2015. Innovative Technology Seaweed Prototype Dunes Demonstration Project: Final technical Report. CEPRA Cycle 8 Project 1581 (Contract N. 14-24-000-8334)

4 SUMMARY OF DUNE RESEARCH / SOURCES

COASTAL PROJECTS + DUNE RESEARCH

USACE NAP DISTRICT COASTAL PROJECTS

All information derived from USACE NAP District New Jersey Factsheets and Delaware Factsheets.

PROJECT NAME	LOCATION	STATUS	APPX DATE	BEACHFILL	DUNE	SEAWALL	LENGTH	ADDITIONAL NOTES
Barnegat Inlet to Little Egg Inlet, (Long Beach Island, NJ)	Coast	Completed	2006	x	x		approximately 20 miles	
Bethany & South Bethany	Bay	Completed	2008	x	x		2.8 miles	
Brigantine Inlet to Great Egg Harbor Inlet, Absecon Island	Coast	Completed	2018	x	x	x	approximately 8.1 miles	storwater management system in Margate (5 oceanfront outfalls)
Brigantine Inlet to Great Egg Harbor Inlet, Brigantine Island	Coast	Completed	2006	x	x		6.5 miles	
Broadkill Beach	Bay	Completed	2016	x	x		14,600 feet	
Cape May Inlet to Lower Township	Coast	Completed	1990s	x			southwest jetty of Cape May Inlet to 3rd Ave. in Cape May City	extension of 17 storm water outfalls, reconstruction of 7 groins and construction of two new groins, and a shoreline monitoring program
Fenwick Island	Bay	Completed	2005	x	x		6,500 feet	
Great Egg Harbor and Peck Beach, (Ocean City), NJ	Coast	Completed	1992	x			about 8 miles	extension of 38 storm drain pipes
Great Egg Harbor Inlet to Townsends Inlet, NJ	Coast	Completed	2016	x	x		approximately 16 miles	
Hereford Inlet to Cape May Inlet, NJ	Coast	Not Completed	N/A	x	x			
Indian River Inlet Sand Bypass	Bay	Completed	1988	x			3,500 feet of feeder beach	sand bypass plant + feeder beach
Lewes-Roosevelt Inlet	Bay	Completed	2004	x	x		1,400 feet	
Lower Cape May Meadows – Cape May Point, NJ	Coast	Completed	2020	x	x		approximately 2.5 miles	wetland restoration
Manasquan Inlet to Barnegat Inlet, NJ	Coast	Completed	2019	x	x		approximately 14 miles	
Oakwood Beach, NJ	Bay	Completed	2014	x			approximately 2 miles	
Port Mahon	Bay	Not Completed	N/A	x			5,200 foot long beachfill	raising road, rip-rap along rode, and wetland restoration
Reeds beach + pierces point	Bay	Not Completed	N/A	x			6,800 feet	ecosystem restoration (not shore protection)
Rehoboth & Dewey	Bay	Completed	2006	x	x		13,500 linear feet	
Townsends Inlet to Cape May Inlet, NJ	Coast	Completed	2009	x	x	x	12m study area (4.3 miles of beachfill + dune, 2.2 miles of seawall construction, and 116 acres of natural barrier island habitat including beach fill and dune construction)	ecosystem restoration
Villas + vacinity	Bay	Not Completed	N/A	x			29,000 feet	ecosystem restoration (not shore protection)

DUNE RESEARCH

This table was developed as a working document to gather information related to dune fabrication based on research from the past 30 years. Final proposals drew heavily from existing research on dune vegetation collected within this table.

Dune research table continued (right-hand part of the page; combined into the table below)

FACTORS	Variables	Potential Impact	Existing / Relevant Research
Site / Physical Properties	beach berm width	Dune development relies on wind processes acting on dry beach and requires a minimum width of dry beach. Increases in beach width (potentially requiring easement agreements) could increase rate of dune regrowth after storm events.	**Itzkin, M., Moore, L. J., Ruggiero, P., Hacker, S. D., & Biel, R. G. (2021). The relative influence of dune aspect ratio and beach width on dune erosion as a function of storm duration and surge level. Earth Surface Dynamics, 9(5), 1223–1237.** https://doi.org/10.5194/esurf-9-1223-2021 XBeach numerical model found that a wide beach offers the greatest protection from erosion in all circumstances suggesting that efforts to maintain a wide beach may be effective at protecting coastal communities from dune loss. **Grafals-Soto, R. (2012). Effects of sand fences on coastal dune vegetation distribution. Geomorphology, 145-146, 45–55. https://doi.org/10.1016/j.geomorph.2011.12.004** This study also concludes that increasing beach width could lead to naturally forming dunes, however appropriate beach width is dependent on site specifics and should be determined by reviewing historical images.
	quantity of sand supply/ height of dune	Sand supply is essential for dune development, and increasing a beach's sand supply increases height and width of dunes, potentially reducing overwash/inundation risks for nearby communities	**Jay, K. R., Hacker, S. D., Hovenga, P. A., Moore, L. J., & Ruggiero, P. (2022). Sand supply and dune grass species density affect foredune shape along the US Central Atlantic Coast. Ecosphere, 13(10). [DOI]** Study found relationship between beach sand supply and dune morphology (particularly overall height and width).
	sand compaction	Sand compaction can reduce dune erosion, though can also harm vegetation if it occurs after vegetation is established (such as by driving on dunes)	**Nishi, R., & Kraus, N. C. (1997). Mechanism and Calculation of Sand Dune Erosion by Storms. Coastal Engineering 1996. https://doi.org/10.1061/9780784402429.235** The degree of compaction was found to be a significant parameter that decreases the potential for dunes to erode
	dune morphology (height & slope)	Dune height and slope can impact the dune's ability to withstand different types of storm events. This is important to consider not just for USACE dune designs, but also because vegetation impacts slope and dune plant species may change with climate change.	**Itzkin, M, et. al. (2021)** XBeach numerical model found that lower aspect ratio dunes erode less than higher aspect ratio dunes when both are in the collision regime (the study modeled dunes with aspect ratios ranging from 0.02 to 0.27) **Jay, K. R., et. al., (2022)** Vegetation can impact dune slope, and climate change induced fluctuations in vegetation may change dune morphology and its performance in storm events.
	number of dunes/ topographic diversity	The layering of two dunes can provide additional coastal protection. Additionally, topographic diversity (ie multiple peaks and valleys) may lead to more vegetation diversity.	**Figlus, J., & Jonkman, B. (2021). Response to USACE Texas Coastal Study (pp. 23–37). The Center for Texas Beaches and Shores, Texas A&M University at Galveston .** https://idrt.tamug.edu/wp-content/uploads/2021/01/USACE-Response-Report-Ike-Dike.pdf Analysis of double-dune system designed for West Galveston Island **Grafals-Soto, R. (2012)** Study explored how topographic diversity caused by sand fences could lead to species diversity within dune ecosystem.
Vegetation	plant density	Plant density impacts dunes in two ways: 1.) spurring dune growth through natural aeolian processes, and 2.) reducing dune erosion by stabilizing dune.	**Jay, et. al., 2022** Recent study on central Atlantic coast found that an increase in A. breviligulata density was strongly associated with foredune height and width
	root depth & mass	Plant roots stabilize dunes and help prevent erosion during storm events. Root depth is an important factor, as well as a root's lateral extent which can impact the dune's slope development	**Charbonneau, B. R., Wnek, J. P., Langley, J. A., Lee, G., & Balsamo, R. A. (2016). Above vs. belowground plant biomass along a barrier island: Implications for dune stabilization. Journal of Environmental Management, 182, 126–133.** https://doi.org/10.1016/j.jenvman.2016.06.032 Recognizing that root density likely translate to variability in coastal erosion prevention, researchers directly compared stabilizing factors (depth and density) of the root systems of native American beach grass (Ammophila breviligulata) and invasive Asiatic sand sedge (Carex kobomugi), surprisingly finding that Carex has deeper, more complex root system
	species	With climate change, new southern or non-native species may provide better protection against dune erosion, such as asianic sand sedge (Carex kobomugi), sea oats (Uniola paniculata) and seashore elder (Iva imbricata).	**Charbonneau, B. R., Wootton, L. S., Wnek, J. P., Langley, J. A., & Posner, M. A. (2017). A species effect on storm erosion: Invasive sedge stabilized dunes more than native grass during Hurricane Sandy. Journal of Applied Ecology, 54(5), 1385–1394. https://doi.org/10.1111/1365-2664.12846** Paper by a Penn PhD student found that Carex kobomugi had performed better at preventing dune erosion during Superstorm Sandy than native American beachgrass **Hacker, S. D., Jay, K. R., Cohn, N., Goldstein, E. B., Hovenga, P. A., Itzkin, M., Moore, L. J., Mostow, R. S., Mullins, E. V., & Ruggiero, P. (2019). Species-Specific Functional Morphology of Four US Atlantic Coast** Study looking at geomorphological impact of 4 common dune grass species along the Atlantic Coast (Ammophila breviligulata, Panicum amarum, Spartina patens, Uniola paniculata). Found that American Beachgrass was most effective at accretting sand and accreted 42% more sand than Sea Oats (U. paniculata), which was found to be the second-best sand accretor. American Beachgrasses' capacity for efficiently trapping sand was attributed to its growth of densely clumped shoots and speedy lateral spread.
	genotypic diversity	Genotypic diversity has been found to increase plant population's biomass production, survival time, and rate of spread as well as improve ecological communities' resistance to disturbance. However, most beachgrass planting is the "cape" variety, producing clonal monocultures on constructed dunes.	**Slaymaker, D. H., Peek, M. S., Wresilo, J., Zeltner, D. C., & Saleh, Y. F. (2015). Genetic Structure of Native and Restored Populations of American Beachgrass (Ammophila breviligulata) along the New Jersey Coast. Journal of Coastal Research, 31(6), 1334–1343. [DOI]** Study used Inter Simple Sequence Repeat markers to survey the genetic diversity of native and restored dunes in New Jersey. Found more genotypic diversity within the native beachgrass populations than restored populations that commercial beachgrass varieties used in restoration were absent from native populations
	fertilizers	Nutrient availability can greatly impact species growth and root structure, and thus a plant community's ability to prevent dune erosion. Nitrogen and phosphorus fertilizers can help speed up establishment of transplants, though if used in excess could damage plants, increase diseases, and pollute groundwater.	**New Jersey Sea Grant Consortium. (2016). Dune Manual. https://njseagrant.org/wp-content/uploads/2016/07/Dune-Manual-Pgs-compressed.pdf [Accessed September 2023]** Seagrant recommends that a small amount of fertilizer be applied during plant installation:
	species diversity	Dune species diversity could increase plant density and plant root mass, both of which have been shown to reduce dune erosion during storms. Diversifying dune plantings (polycultures instead of monocultures) could therefore potentially reduce dune erosion.	**Stallins, J. A. (2003). Dune Plant Species Diversity and Function in Two Barrier Island Biogeomorphic Systems. Plant Ecology, 165(2), 183–196. https://www.jstor.org/stable/20146380** Overwash play a nuanced role in shaping species diversity. Study of two barrier island communities found that in some instances overwash could increase plant diversity by reducing the competitive dominance of certain plants, while in others overwash reduced plant diversity by reducing topographic diversity
	arbuscular mycorrhizae fungi (AMF)	AMF are tiny fungal organisism that live on plant roots. They use their hyphae networks to funnel ntrients to their host plants in mutualistic relationships. AMF are beneficial to may plants but are particularly crtical for dune grasses which must survive in the harsh environment of coastal dunes. AMF are obligate symbionts, so the fungi cannot survive or reproduce in the barren landscapes of a recently constructed dune from dredged material.	Gemma, J. N., & Koske, R. E. (1997). Arbuscular Mycorrhizae in Sand Dune Plants of the North Atlantic Coast of the U.S.: Field and Greenhouse Inoculation and Presence of Mycorrhizae in Planting Stock. Journal of Environmental Management, 50(3), 251–264. Field study in Cape Cod found that beachgrass inocculated with AMF produced 14% more culms and 67% more inflorescences than the control plants after 42 weeks. Sigren, J. M., Figlus, J., & Armitage, A. R. (2014). Coastal sand dunes and dune vegetation: Restoration, erosion, and storm protection. Shore and Beach, 82(4), 5–12. [ResearchGate.net] Study of Texas Coastal Dunes found that vegetated dunes had more than 50 times AMF colonization, with an average of 94.4 spores per 100 grams of sediment, than degraded unvegetated dunes, with just 1.7 spores per 100 grams sediment. Mardhiah, U., Caruso, T., Gurnell, A., & Rillig, M. C. (2016). Arbuscular mycorrhizal fungal hyphae reduce soil erosion by surface water flow in a greenhouse experiment. Applied Soil Ecology, 99, 137–140. [DOI] Greenhouse experiment found hyphal length in inoculated soils to correspond with reduced soil loss under shear stress, reinforcing the understanding of AMF as soil stabilizers.
	disturbance regime	Disturbance of dune systems can impact dune function in a variety of ways. Dune vegetation is very sensitive, so walking on dunes is generally prohibited. However, studies have found that disturbance can increase biodiversity, which could benefit long-term dune health.	**Brunbjerg, A. K., Svenning, J.-C., & Ejrnæs, R. (2014). Experimental evidence for disturbance as key to the conservation of dune grassland. Biological Conservation, 174, 101–110. https://doi.org/10.1016/j.biocon.2014.04.002** Researchers tested the effects of disturbance on Danish dune vegetation by simulating trampling, grazing, blowouts and N-deposition and concluded that anthropogenic suppression of disturbances by wind, coastal erosion or grazing animals could threaten dune biodiversity
Physical Installations	fence material	Material of fence can impact the growth rate of dunes, by controlling the amount of sand that gets trapped and its own ability to withstand wind pressures. Material (wood vs fabric) can impact the fence function, as well as size of spaces between slats.	**Quan, R., & Kobayashi, N. (2015). Pile Fence to Reduce Wave Overtopping and Overwash of Dune. Journal of Waterway, Port, Coastal, and Ocean Engineering, 141(6).** https://doi.org/10.1061/(asce)ww.1943-5460.0000308 Experiments performed to examine the utility of a pile fence in reducing dune erosion and overwash during a storm. Article concludes that pile fence appears promising but will need to be further tested at a field site.
	fence position	Height and position of fence can impact sand accumulation (an initial dune crest can be produced by installing a 2-foot-high sand fence several hundred feet behind and parallel to the high tide line).	**Broome, S. (2015, March 17). Restoration and Management of Coastal Dune Vegetation | NC State Extension Publications. Content.ces.ncsu.edu; N.C. Cooperative Extension.** https://content.ces.ncsu.edu/restoration-and-management-of-coastal-dune-vegetation Summary of coastal dunes in North Carolina and construction of new dunes using vegetation.
	fence configuration	Double rows of fences can increase sand accumulation and overall dune volume. Alternative configurations of sand fences could consider their potential to create a protective dune that has morphological and vegetation diversity.	**Lima, I. A., Araújo, A. D., Parteli, E. J. R., Andrade, J. S., & Herrmann, H. J. (2017). Optimal array of sand fences. Scientific Reports, 7(1).** https://doi.org/10.1038/srep45148 Study found that for typical sand-moving wind velocities, the optimal fence height (which minimizes this cost function) was around 50 cm, while using fences of height around 1.25 m leads to maximal cost.
	placement of christmas trees / woody vegetation	Strategic additions of christmas trees to fencing configurations can increase impact of fence system. Adding trees landward of fence can imitate effect of double row of fences. Arranging trees in a spur formation can reduce wind speeds from all directions.	**Berman, G. (2020, January). To Tree or Not to Tree: The use of discarded Christmas trees for dune stabilization. Marine Extension Bulletin ; WOODS HOLE SEA GRANT and CAPE COD COOPERATIVE EXTENSION.** https://seagrant.whoi.edu/wp-content/uploads/2020/12/Xmas-tree_web.pdf Review of history, mechanics, and Best Management Practices for using discarded Christmas trees for dune stabilization in Massachusetts, concluding that use of christmass trees can relatively cheaply and efficiently accumulate sand if installed properly in one of the rare locations suitable for the technique.
Internal Dune Material	sediment type	Percentage of sand, gravel, and cobble - sized sediment should match, or be slightly coarser than, the existing beach/dune sediments. Using sediments with slightly larger grain sizes can provide improved erosion control and storm damage protection. More energy is needed to move this larger material, absorbing wave energy more effectively and eroding less readily. However if coarser sediment moves seaward it can cause harm to the beach environment.	**StormSmart Properties Fact Sheet 1: Artificial Dunes and Dune Nourishment What Are Artificial Dunes and Dune Nourishment? (2013).** https://www.mass.gov/files/documents/2018/05/29/ssp-factsheet-1-dunes-new.pdf Document outlines guidance for use of "compatible" sediments for dune projects, including factors such as ssediment size, shape, color, and texture.
	wrack	Incrementally adding beach wrack into dune mimics natural cycle of dune and could help stabilize dune by providing nutrients for dune plants.	**Working with nature to create a stronger, more resilient dune system. (2021, June 24). Www.usm.edu. https://www.usm.edu/news/2021/release/dune-system-research.php** Researchers at the U.S. Army Engineer Research and Development Center (ERDC), along with partners at the U.S. Army Corps of Engineers (USACE) Mobile District and the University of Southern Mississippi (USM), are developing methods to use wrack to build coastal dunes.
	microbial-induced carbonate precipitation (MICP) and enzymatic-induced carbonate precipitation (EICP)	Microbes/enzymes can modify engineering properties of soils and sediments. Specifically, induced carbonate precipitation can make dune soil more stable and less vulnerable to erosion during storm events.	**Liu, K.-W., Jiang, N.-J., Qin, J.-D., Wang, Y.-J., Tang, C.-S., & Han, X.-L. (2020). An experimental study of mitigating coastal sand dune erosion by microbial- and enzymatic-induced carbonate precipitation. Acta Geotechnica, 16(2), 467–480. https://doi.org/10.1007/s11440-020-01046-z** Study tested effectiveness of MICP and EICP treatment on mitigating coastal sand dune erosion in a small-scale laboratory model. Found that MICP and EICP treatment was generally found to be effective in mitigating sand dune erosion, however their effectiveness diminished under adverse conditions including steep dune slope, large wave intensity, and long period of wave attack
	mineral colloidal silica	Injection of dunes with a colloidal silica-based mixture increases the mechanical strength of non-cohesive sediments, reducing dune erosion. The material is non-toxic and is already present within the dunes.	**D'Alessandro, F., Tomasicchio, G. R., Francone, A., Leone, E., Frega, F., Chiaia, G., Saponieri, A., & Damiani, L. (2020). Coastal sand dune restoration with an eco-friendly technique. Aquatic Ecosystem Health & Management, 23(4), 1–8.** Researchers have experimented with mineral colloidal silica techniques at two dunes in Italy
	seabales	Embedding seaweed into dunes can improve dune vegetation growth through the seaweed's retention of moisture and release of nutrients during its decomposition. The resulting increase in plant biomass and density can in turn increase the capture of wind-blown sediment and reduce dune erosoion.	**Figlus, J., J. Sigren, R. Webster & T. Linton, 2015. Innovative Technology Seaweed Prototype Dunes Demonstration Project: Final technical Report. CEPRA Cycle 8 Project 1581 (Contract N. 14-24-000-8334)** Demonstration project based in Texas concluded that including seabales made of sargassum in the cores of dunes could have several short term and long term benefits related to sargassum wrack management and dune vegetation health.
Core - Enhancements	geotubes	Geodubes can enhance core of dunes and reduce their erosion. The diameter of geotubes, as well as their internat material (whether sand or more long term, solid materials) will have an impact on geotube function.	**Trierweiler, D. J. (2010, June). Slowing the swelling seas - An in depth look at the geotextile installed in the Grand Isle. Louisiana Hurricane Rehabilitation Project. Western Dredging Association Technical Conference. 30th 2010. (and the 41st Texas A&M Dredging Seminar).** Presentation paper discusses Geotubes used in Louisina Hurrican Rehabilitation Project in Grand Isle, Louisian. Geotubes filled with sand were replaced by chain of TenCate Geotube® units with erosion mats in front and behind. The tubes are filled with a mixture of sand and water that will harden and last 100 years.
	hybrid dunes	Structures made from clay, reinforced concrete T-wall elements, rubble mound material, or combinations thereof can provide a core for a constructed dune and then be covered with sand to a certain thickness. This can increase the durability and flood prevention ability of dunes.	**Figlus, J., & Jonkman, B. (2021). Response to USACE Texas Coastal Study (pp. 23–37). The Center for Texas Beaches and Shores, Texas A&M University at Galveston . https://idrt.tamug.edu/wp-content/uploads/2021/01/USACE-Response-Report-Ike-Dike.pdf** Analysis of West Galveston Island double dune system advocated for alternative approach using hybrid/core-enhanced dunes

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APPENDIX 1

HOLGATE FLOOD RISK MANAGEMENT STUDY–HYDRODYNAMIC MODELING ANALYSIS

Prepared for:

US Army Corps of Engineers
ERDC
EWN

Prepared by:

ANCHOR QEA
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1 INTRODUCTION

This report describes the hydrodynamic modeling analysis performed by Anchor QEA, LLC, to support the evaluation of conceptual design alternatives developed in conjunction with the Dredge Research Collaborative (DRC) as part of the Engineering with Nature (EWN) initiative funded by the U.S. Army Engineer Research and Development Center. The objective of this EWN project was to research and conceptualize the potential for natural and nature-based features (NNBF) to provide flood risk management benefits to complement the New Jersey Back Bay (NJBB) Coastal Storm Risk Management Study (CSRM) being implemented by the U.S. Army Corps of Engineers (USACE) in Monmouth, Ocean, Atlantic, and Cape May Counties in New Jersey. As part of the project, the DRC and Anchor QEA worked closely with the USACE Philadelphia District to review ongoing and planned projects, with a view to incorporate EWN, NNBF, and beneficial use features into them. Several concepts were developed, as discussed in the EWN Proving Ground report (DRC and AQ, 2023). In this supplement to the DRC and AQ (2023) report, we discuss results of a hydrodynamic study to review the Holgate Peninsula in New Jersey. Specifically, the goal of our study was researching the potential for using NNBF on and near the Holgate Peninsula between Great Bay and Little Egg Harbor in New Jersey to create directional wetlands that reduce storm surge while allowing water to leave the system.

2 COASTAL SETTING

The study area included two large, shallow New Jersey back bays, Great Bay, and Little Egg Harbor, in southern New Jersey within the Jacques Cousteau National Estuarine Research Reserve and connected to the Atlantic Ocean via the Little Egg Inlet. Great Bay encompasses approximately 10 square miles and connects to the Mullica River system. Receiving influxes from both land and seaside, Great Bay is a relatively high-salinity, well-mixed estuary (Able and Grothues 2021). Little Egg Harbor spans approximately 25.3 square miles, connecting to Manahawkin Bay approximately 9.3 miles northeast of the project area. Between the two bays is Holgate Peninsula, an approximately 4,000 acre coastal wetland complex consisting primarily of tidal salt marsh that is part of the Great Bay Boulevard Wildlife Management Area. Figure 1 shows the location of the study area.

2.1 Water Levels

Great Bay and Little Egg Harbor surrounding Holgate Peninsula have a mean diurnal tide range of approximately 2.9 feet as shown at National Oceanic and Atmospheric Administration (NOAA) tidal station 8534319, Great Bay, Shooting Thorofare, New Jersey (NOAA 2023a). This tidal station is located at the southern end of Holgate Peninsula and has water level data available from 2017 through 2023. Tidal datum elevations published at NOAA station 8534319, relative to North American Vertical Datum of 1988 (NAVD88) and the 19-year tidal epoch from 1983 through 2001, are as follows:

- Mean Higher High Water is 1.50 feet NAVD88
- Mean High Water is 1.17 feet NAVD88
- Mean Tide Level is -0.26 foot NAVD88
- Mean Low Water is -1.69 feet NAVD88
- Mean Lower Low Water is -1.83 feet NAVD88

For comparison, a tidal station with a longer data record, NOAA tidal station 8534720 Atlantic City, New Jersey, in the Atlantic Ocean approximately 10 miles south of Little Egg Inlet (see Figure 1; NOAA 2023b), has a mean tidal range of approximately 4 feet. Figure 2 shows a cumulative frequency distribution of hourly water level measurements from the NOAA Atlantic City station from 1911 through March 2023. The 95th percentile water level (i.e., the water level greater than 95% of the measurements) from this data record is approximately 2.0 feet NAVD88.

2.2 Wind

Wind data in the vicinity of the study area was gathered from the National Centers for Environmental Information (NCEI) Atlantic City International Airport, New Jersey station, located approximately 13 miles southwest of the site (see Figure 1; NOAA 2023c). The available wind data record contained hindcasted hourly wind speed and direction measurements for 76 years (1947 through 2023). A wind rose of the NOAA NCEI data at Atlantic City is shown in Figure 3. The prevailing winds are from the south and west; however, winds from along the fetches in the bays from the southwest and northeast, although less frequent, can also generate waves that impact the site.

A statistical analysis of the wind data was performed to estimate various return interval wind speeds from the southwest and northeast. To compute the return interval wind speeds (extreme wind events), first the maximum yearly wind speeds in each directional bin was computed for the wind data record. A statistical analysis was performed using the maximum yearly wind speed in each direction to estimate the return period wind speeds. Five candidate probability distribution functions (Fisher-Tippet Type I and Weibull distributions with exponent k varying from 0.75 to 2) were fitted to the maximum yearly wind speed data in each direction. The return period wind speeds were calculated by applying the best fit distribution. Table 1 summarizes the estimated return period wind speeds from the northeast and southwest.

Table 1
Return Interval Wind Speeds at Atlantic City, New Jersey

Wind Direction	Return Period	Wind Speed (mph)
Northeast	1-year	20.4
	20-year	40.4
	100-year	45.2
Southwest	1-year	18.1
	20-year	36.1
	100-year	40.4

Notes: Wind direction notes direction winds are "blowing from" mph: miles per hour

2.3 Coastal Flooding

As described in the USACE Coastal Hazards System North Atlantic Coast Comprehensive Study (NACCS; USACE 2015)), New Jersey's 210-miles of low-lying coastline, stretching from Raritan Bay in the north, along the Atlantic Coast to Delaware Bay is highly susceptible to coastal flooding. This region has experienced frequent coastal flooding events over the years, causing extensive beach erosion, marsh loss, damage to dunes and other coastal flood risk management structures, as well as tidal flooding impacts. The shorelines of most of New Jersey's Back Bays are characterized by low elevation areas, developed with residential and commercial infrastructure, and include undeveloped areas that provide ecological, fisheries and recreational benefits. Healthy marshes in back bay areas have the potential to dampen coastal flooding and storm surge. These areas are subject to erosion, loss and alteration due to coastal storms. Back Bay dune, beach, marsh and estuarine ecosystems are quite fragile in some locations and are threatened by sea level change (USACE, 2015).

3 HYDRODYNAMIC MODELING

A hydrodynamic modeling analysis was performed to assess how the proposed NNBF conceptual design alternatives may affect storm surge elevations and current velocities in the study area. The hydrodynamic modeling analysis was performed using the Delft 3D-FLOW (FLOW) model in a two dimensional configuration. The FLOW model simulates steady and unsteady flows in two dimensions (depth-averaged), incorporates the effects of drying and flooding, and can represent hydraulic structures. The FLOW model was used to provide computed hydrodynamic information resulting from water level fluctuations and wind forcing to evaluate changes in water level and current velocity, if any, compared to existing conditions. This industry-accepted model was developed and supported by the Deltares Institute (Delft, the Netherlands) and validated for use in riverine, estuarine, and open coast hydrodynamic systems.

3.1 Model Grids

A site-specific FLOW model grid was developed, encompassing Great Bay, Little Egg Harbor, Little Egg Inlet, and a portion of the Atlantic Ocean along the eastern shoreline of the barrier islands in the study area. The resolution of the model grid was spatially variable, with local refinement on Holgate Peninsula and in Little Egg Inlet to represent the detail and key site features of the project area and the conceptual design alternatives. The spatially variable model grid resolution increases computational efficiency. The resolution of the model grid is approximately 107 feet by 272 feet along the boundary in Manahawkin Bay, farthest north from the site, and approximately 100 feet by 100 feet on Holgate Peninsula and in Little Egg Inlet. Figure 4 shows the flow model grid extents and resolution on and near Holgate Peninsula.

3.2 Model Elevation Data

Detailed elevation data were incorporated into the model grid to represent the bathymetry and topography within the model grid extents and to distinguish local bathymetry near the project area and more accurately predict water levels and current velocities in the study area. The elevation data were projected horizontally to the North American Datum of 1983, 2011 (NAD83/2011) New Jersey State Plane (meters), and vertically to North American Vertical Datum of 1988, meters (NAVD88).

The model surface was constructed primarily using data from NOAA's Continuously Updated Digital Elevation Model and supplemented with NOAA Navigation Chart Soundings within deeper navigation channels in Little Egg Inlet and the back bays in the study area (NOAA 2023d, NOAA 2023e, and NOAA 2023f). Figure 5 shows a comparison of the elevations within the model domain for this study compared to the model elevations used in a previous modeling evaluation of the study area performed by USACE (Piercy et al. 2020). As shown in Figure 5, the elevations within each model domain were similar.

3.3 Modeling Approach

To evaluate two different storm surge conditions, model boundary conditions for two extreme storm events were sourced from the USACE NACCS consistent with previous USACE modeling projects performed in the area (USACE 2015; Piercy et al. 2020). Storm 350 and Storm 636 were selected from the 1,050 synthetic tropical cyclones in the NACCS storm suite based on previous USACE modeling of the study area, which had focused on these storms because "Storms 350 and 636 showed two typical patterns of water level response to storms for most NNBF and surrounding areas..." (Piercy et al. 2020). Based on Piercy et al. (2020), Storm

350 was considered representative of an extreme storm event that drives storm surge from the Atlantic Ocean through the Little Egg Inlet and into Great Bay and Little Egg Harbor. Storm 636 was considered representative of an extreme storm event that pushes water out of the back bays and through Little Egg Inlet into the Atlantic Ocean.

The water level and wind data model inputs for each storm were taken from USACE Coastal and Hydraulic Laboratory (CHL) Station 5677 from NACCS, located approximately 3 miles offshore of Little Egg Inlet at the approximate location of the offshore FLOW model grid boundary (see Figure 1). The duration of each storm simulation varied with Storm 350 simulated over a 6-day period (July 10 to 16, 2000) and Storm 636 simulated over a 13-day period (July 6 to 19, 2000). The timeseries of water level and wind magnitudes and directions for Storm 350 and 636 at Station 5677 were applied to the model grid to simulate the extreme storm conditions. Figure 6 shows the timeseries of water levels for each storm at CHL Station 5677. As shown in the figure, the peak water level elevation for Storm 636 of 4.9 feet NAVD88 was equal to the estimated 10-year water level from NACCS at CHL Station 5677. The peak water level elevation for Storm 350 of approximately 8.7 feet NAVD88 exceeded the estimated 100-year water level from NACCS at CHL Station 5677. Table 2 summarizes the estimated return interval water levels at CHL Station 5677 from the NACCS. The maximum wind speeds at CHL Station 5677 during the simulations for Storm 350 and 636 equaled approximately 81 and 76 miles per hour (mph), respectively.

Table 2
Return Interval Water Levels

NACCS Station 5677	Water Level (feet, NAVD88)
1-year	2.2
2-year	3.2
5-year	4.2
10-year	4.9
20-year	5.5
50-year	6.6
100-year	7.9

4 CONCEPTUAL DESIGN ALTERNATIVES MODELING

The DRC and Anchor QEA team developed several initial conceptual design alternatives to evaluate potential for incorporating smaller scale, more highly tuned NNBF into the USACE NJBB CSRM project to reduce storm surge and decrease flooding in the study area. The objective was to have the NNBF create directional wetlands that would mitigate storm surge on the front side while allowing water passage on the backside.

The DRC performed physical modeling of various forms and geometries in a laboratory setting to identify and select alternatives to be evaluated with the hydrodynamic model. Following are the names and a brief description of each alternative:

- **Chevrons**: angular features with a crest elevation of 6 feet NAVD88 installed individually or grouped in triangle-shaped clusters with gaps between them to both capture sediment and reduce storm surge
- **Wetland Slopes**: create upland scrub-shrub islands throughout the Holgate Peninsula to reduce storm surge

Figures 7 through 8 illustrate how each conceptual design alternative was represented in the hydrodynamic model and presents a comparison to the existing conditions model elevations. The hydrodynamic model was used to evaluate each alternative type for the same two storm events as the existing conditions model. The results of each conceptual design alternative flow simulation were compared to the existing condition results to evaluate how each alternative affected water levels and flow velocity magnitudes and patterns.

4.1 Model Results

To evaluate the effects of the conceptual design alternatives on storm surge, water level results from the existing conditions simulation were compared to the water level results from the conceptual design alternative simulations at select locations in Great Bay, on Holgate Peninsula, and in Little Egg Harbor. Figures 10 through 11 present the comparison of the existing conditions water level results to the water level results for each conceptual design alternative for Storm 350 and 636 and the location where the results were evaluated. As shown in the figures, for Storm 350, the peak storm surge elevation equaled approximately 9.9 feet NAVD88 in Great Bay, 9.3 feet NAVD88 on Holgate Peninsula, and 8.7 feet NAVD88 in Little Egg Harbor for all simulations. For Storm 636, the peak storm surge elevation equaled approximately 6.5 feet NAVD88 in Great Bay, 5.8 feet NAVD88 on Holgate Peninsula, and 4.9 feet NAVD88 in Little Egg Harbor for all simulations. There were no significant differences in water level elevations between existing conditions and the conceptual design alternatives.

Figure 12 presents a comparison of the maximum existing conditions flow velocity magnitude and direction results across Holgate Peninsula for Strom 350 and 636. Figures 13 through 14 present a comparison of the existing conditions flow velocity magnitude and direction results to the flow velocity results for each conceptual design alternative for Storm 350. Figures 15 through 16 present the same comparison for Storm 636. The flow velocity magnitudes and directions shown correspond to the timestep of maximum velocity at a point located centrally on Holgate Peninsula to evaluate how the conceptual design alternatives affect flow velocities and patterns across the peninsula. As shown in the figures, although the chevron and wetland slope features cause some localized differences in flow velocities adjacent to the features, there is not a significant difference in flow velocity magnitudes or directions across Holgate Peninsula. Similarly, the Channel Re-Orientation feature causes some localized differences in flow velocities near the modified channel features around Holgate Peninsula, but there was not a significant difference in flow velocity magnitudes or directions across Holgate Peninsula.

5 SUMMARY

A hydrodynamic modeling analysis was performed to support the evaluation of conceptual design alternatives developed by the DRC to research the potential for NNBF on and near the Holgate Peninsula between Great Bay and Little Egg Harbor in New Jersey to create directional wetlands that reduce storm surge while allowing water to leave the system. Three types of NNBF were evaluated, including chevron and wetland slope features placed on Holgate Peninsula and a re orientation of the Little Egg Inlet channel to encourage storm surge to flow south of Holgate Peninsula into Great Bay. Two extreme storm events from the NACCS suite of synthetic tropical storms were simulated based on previous USACE modeling performed at the project study area. One event was considered representative of an extreme storm event, driving storm surge from the Atlantic Ocean through the Little Egg Inlet and into Great Bay and Little Egg Harbor. The other storm event was considered representative of an extreme storm event, pushing water out of the back bays and through Little Egg Inlet into the Atlantic Ocean. The preliminary model results showed that there were not significant differences in storm surge elevation or flow velocity magnitudes and patterns in Great Bay, on Holgate Peninsula, or in Little Egg Harbor between the existing conditions results and conceptual design alternatives results. Therefore, the results of the modeling analysis indicate placing NNBF on Holgate Peninsula at the types and scale evaluated would not achieve the desired project objective of reducing storm surge in the study area.

We recommend additional studies to evaluate the storm surge and velocity reduction benefits of larger NNBF features that may break up the flow more effectively during future EWN Proving Ground or USACE District studies. Conceivably, as the features get larger, they could offer improved storm resiliency benefits (for example, construction of a larger island near the inlets to alter the flow patterns).

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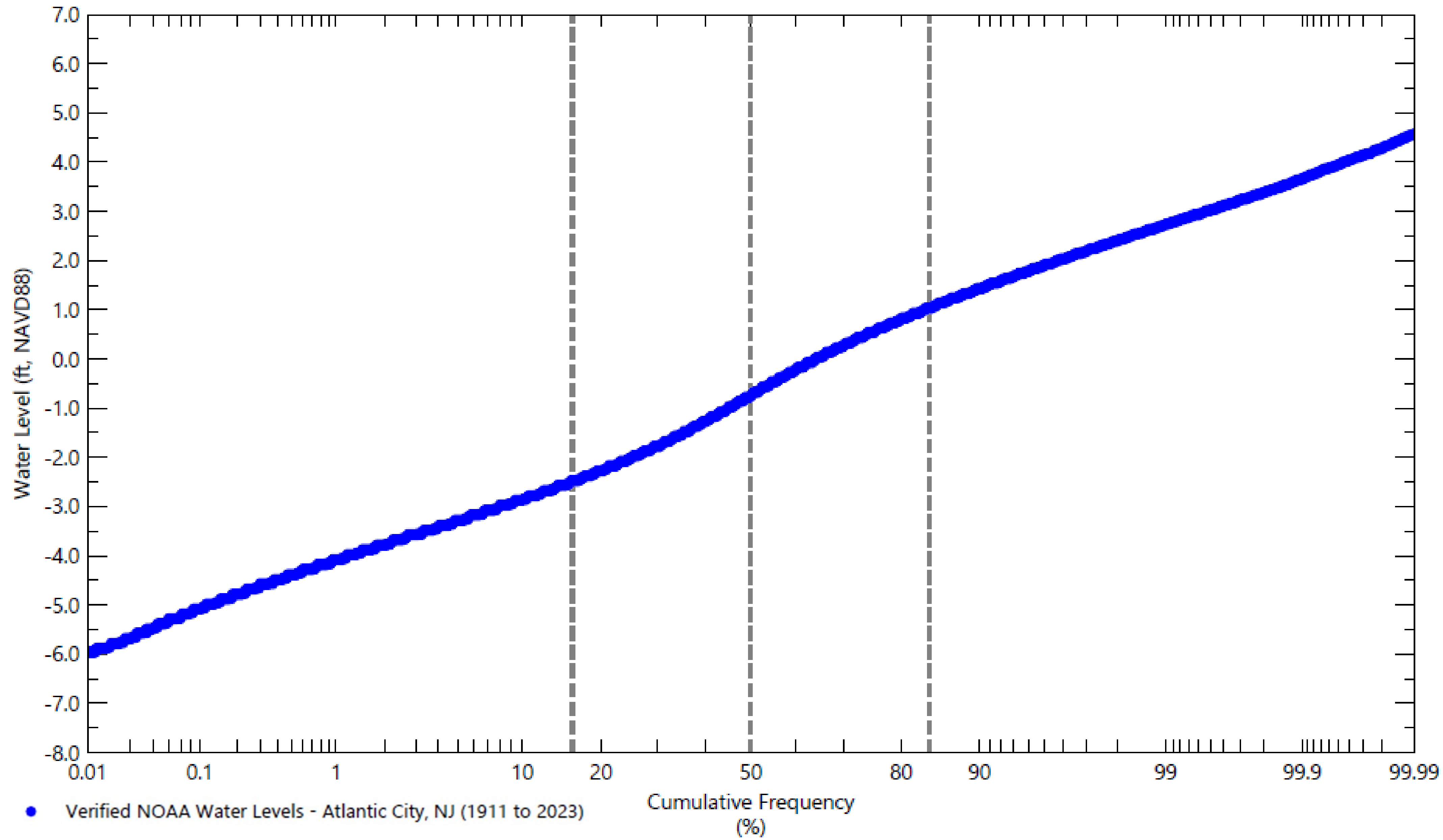
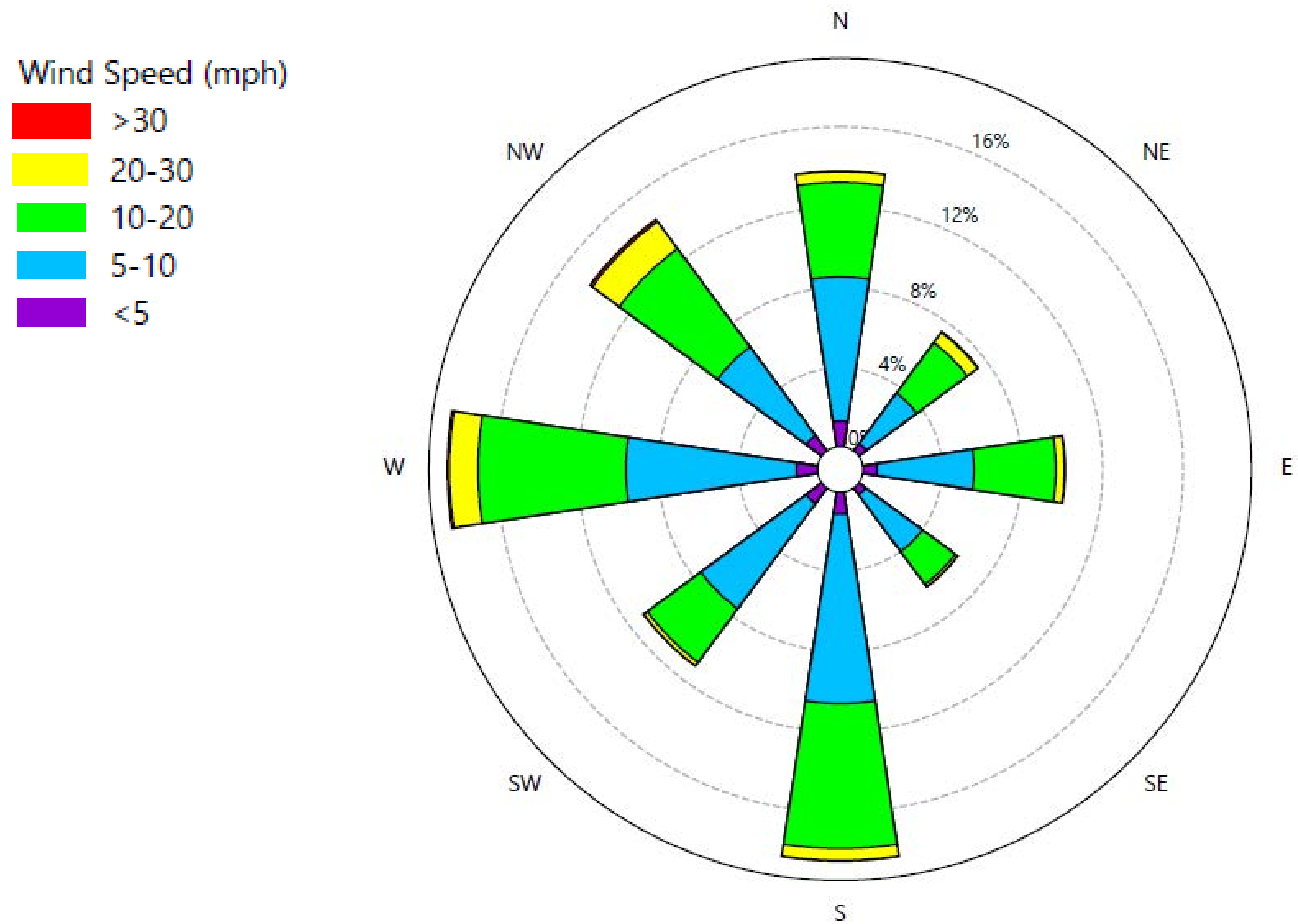
7 FIGURES

Figure 1
Site Vicinity Map



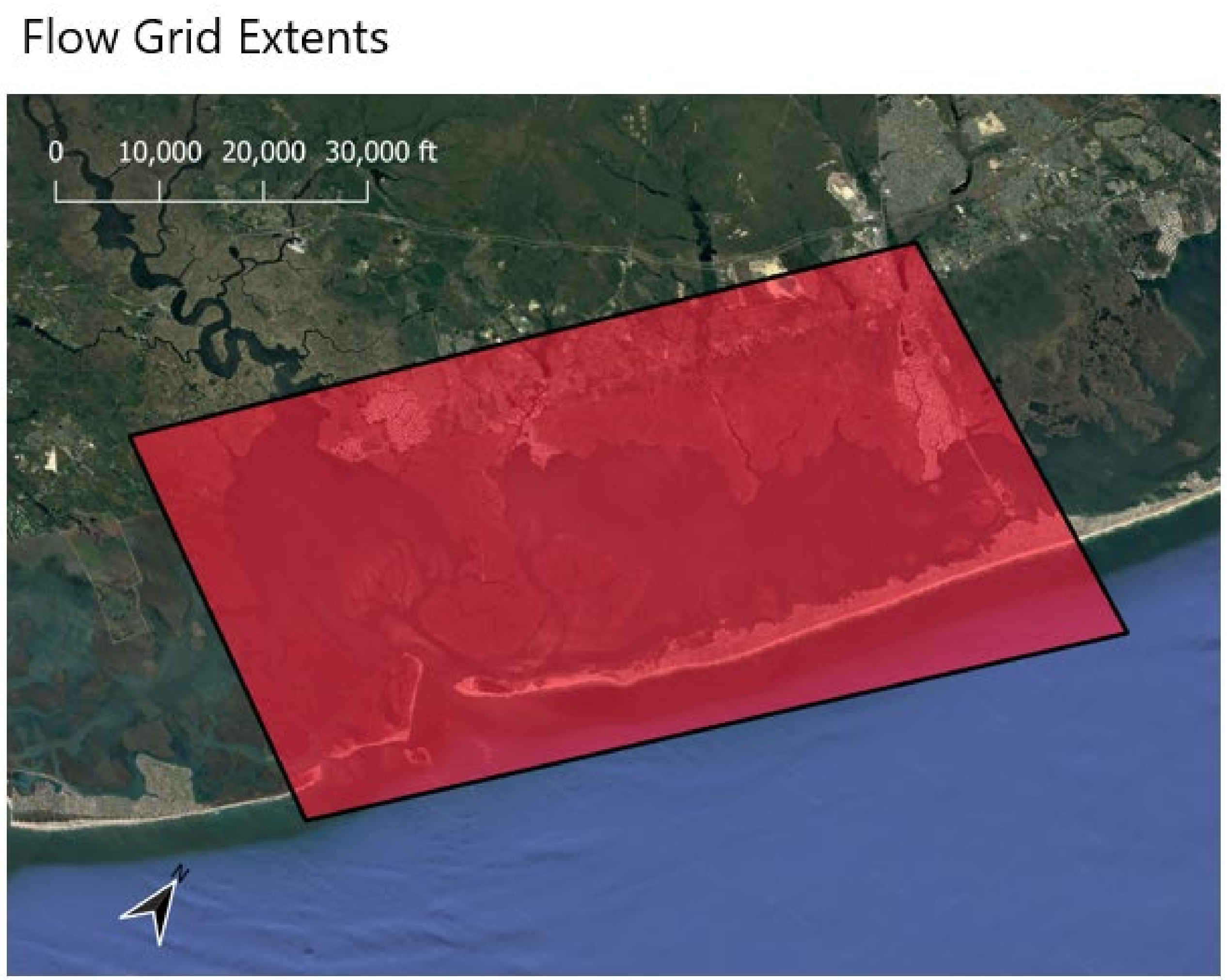
Notes
1. NAVD88: North American Vertical Datum of 1988
2. NOAA: National Oceanic and Atmospheric Administration

Figure 2
Cumulative Frequency Distributions of Measured Hourly Water Levels near the Project Site



Notes:
1. Hourly wind Data Obtained from NOAA NCEI Station WBAN 93730 at Atlantic City, NJ for years 1947 through 2023
2. Calm and Variable Winds 8.4%
3. Maximum Recorded Wind Speed: 84 mph
4. Wind Data are presented as the "blowing from" direction

Figure 3
Wind Rose for Atlantic City International Airport, NJ



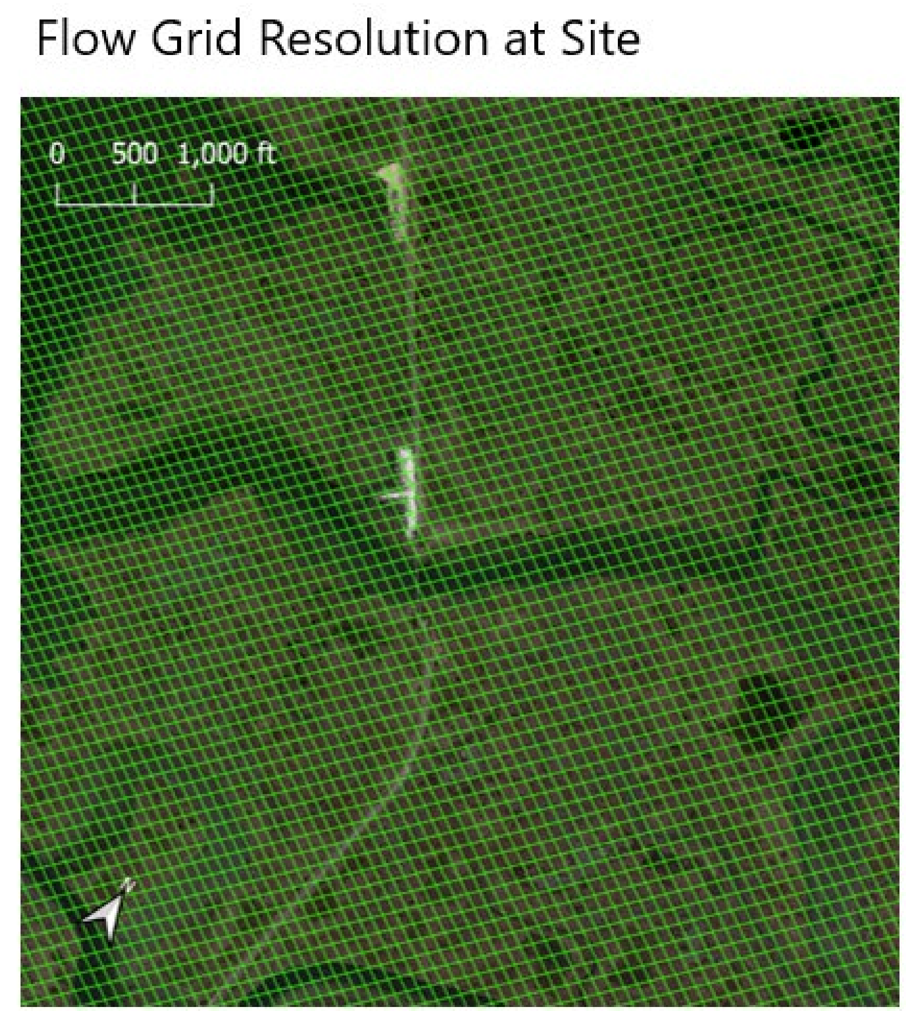
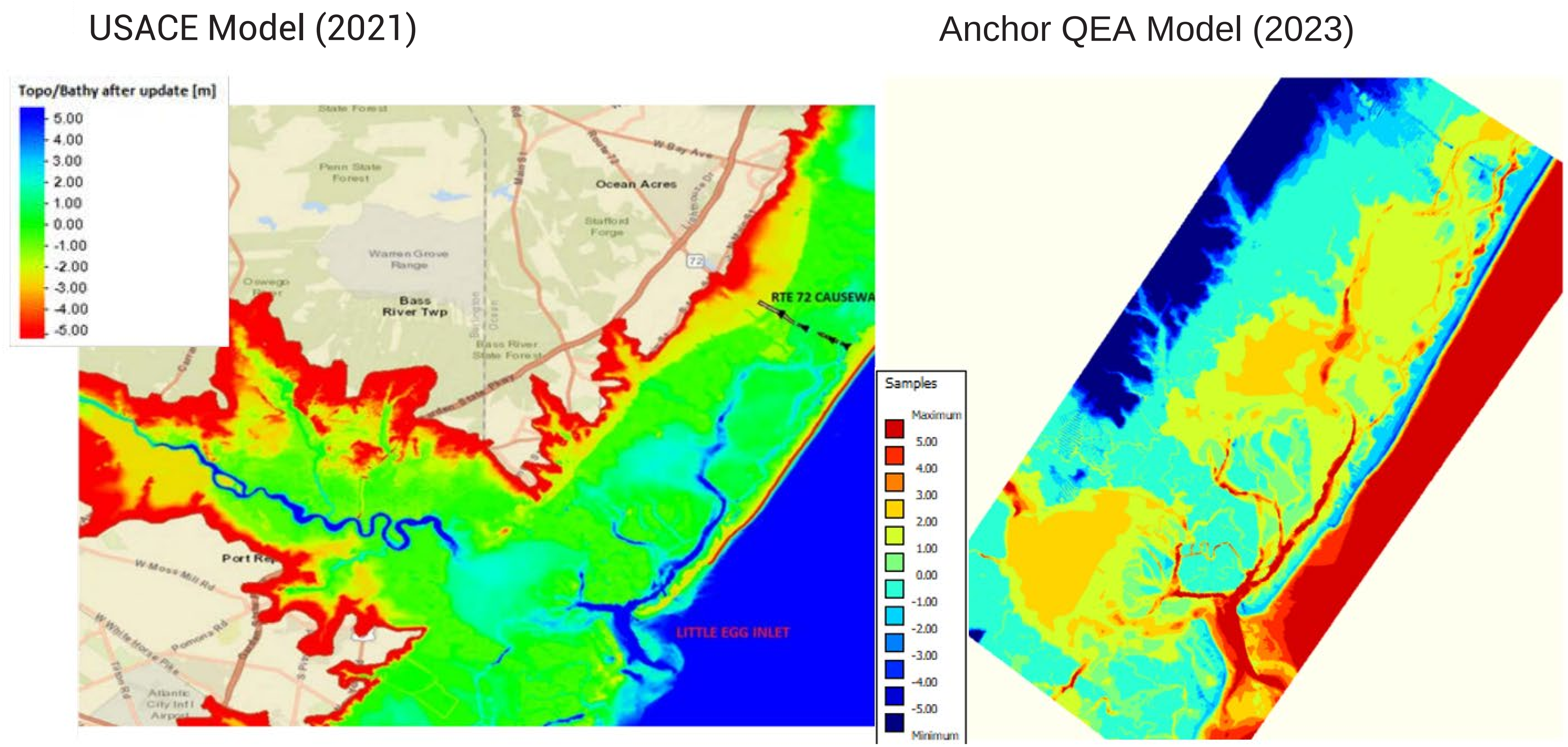


Figure 4
Hydrodynamic Flow Model Grid



Note: Sign convention is depths below 0 meters NAVD888 are positive.

Figure 5
Comparison of Hydrodynamic USACE and Anchor QEA Model Bathymetry

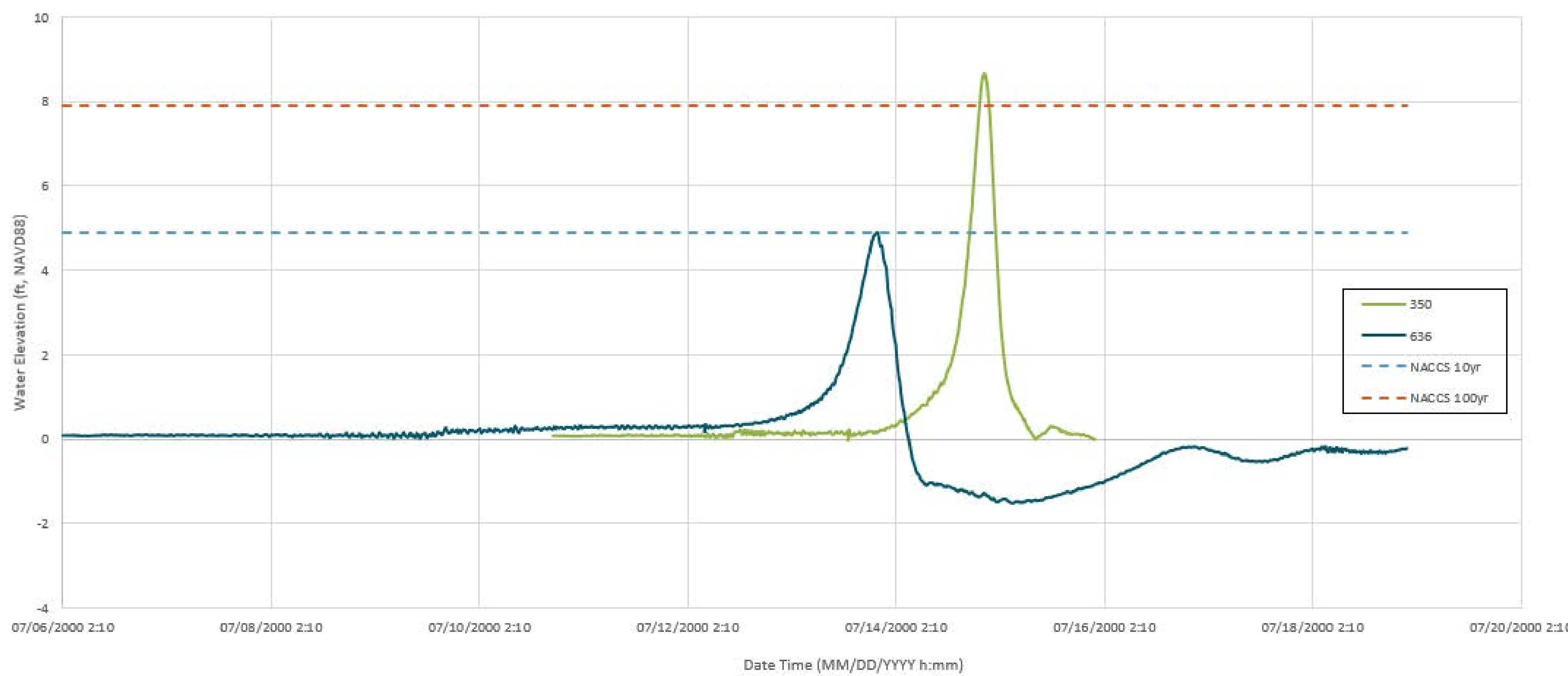
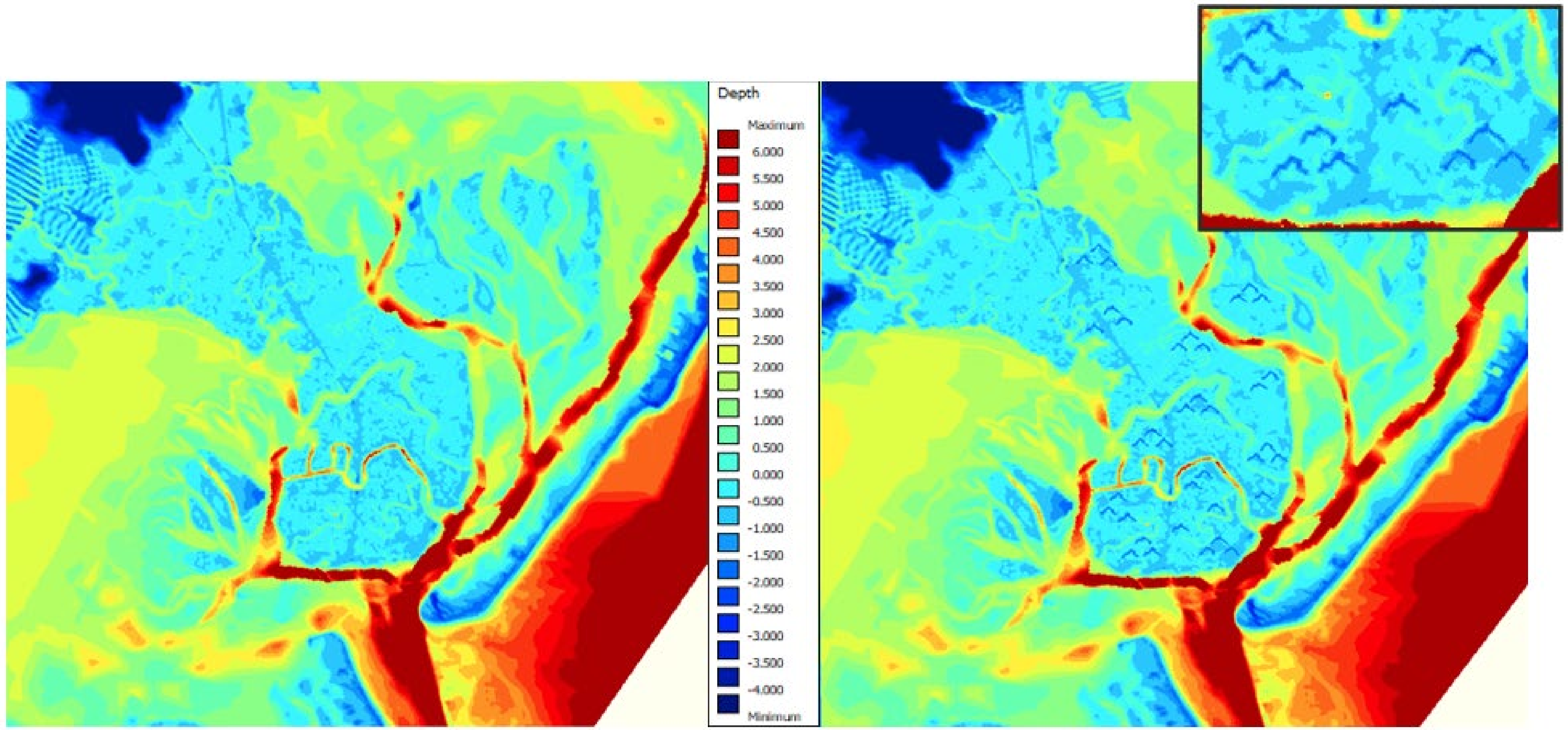


Figure 6
Water Levels at NACCS Station 5677 During Storm 350 and Storm 636

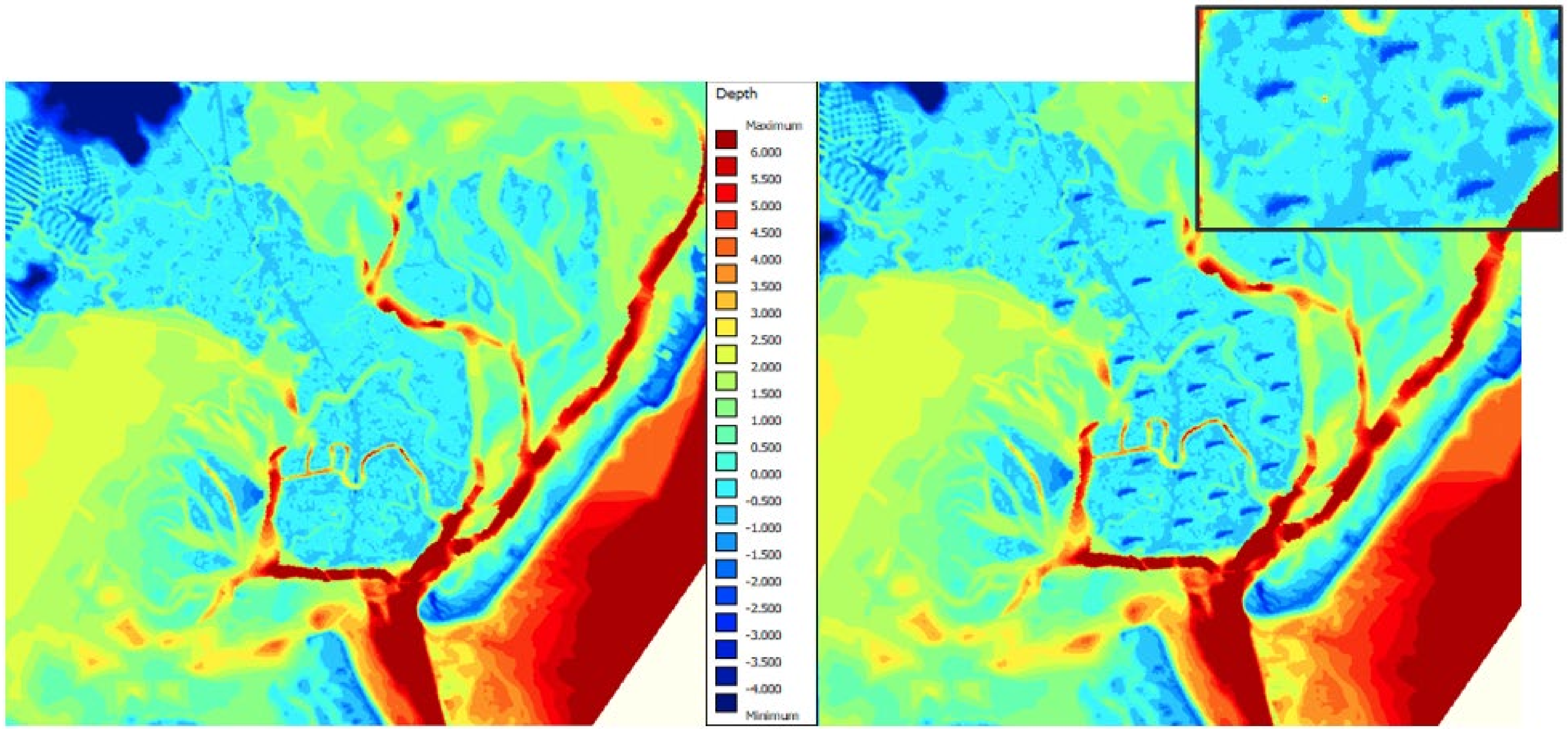


Notes:

1. Sign convention is depths below 0 meters, NAVD88
2. Crest elevation of Chevron features was set to 6 feet, NAVD88

Figure 7

Comparison of Hydrodynamic Model Elevations for Existing Conditions and Chevron NNBF



Notes:

1. Sign convention is depths below 0 meters, NAVD88
2. Crest elevation of Wetland Slope features was set to 8 feet, NAVD88

Figure 8

Comparison of Hydrodynamic Model Elevations for Existing Conditions and Proposed Wetland Slopes NNBF

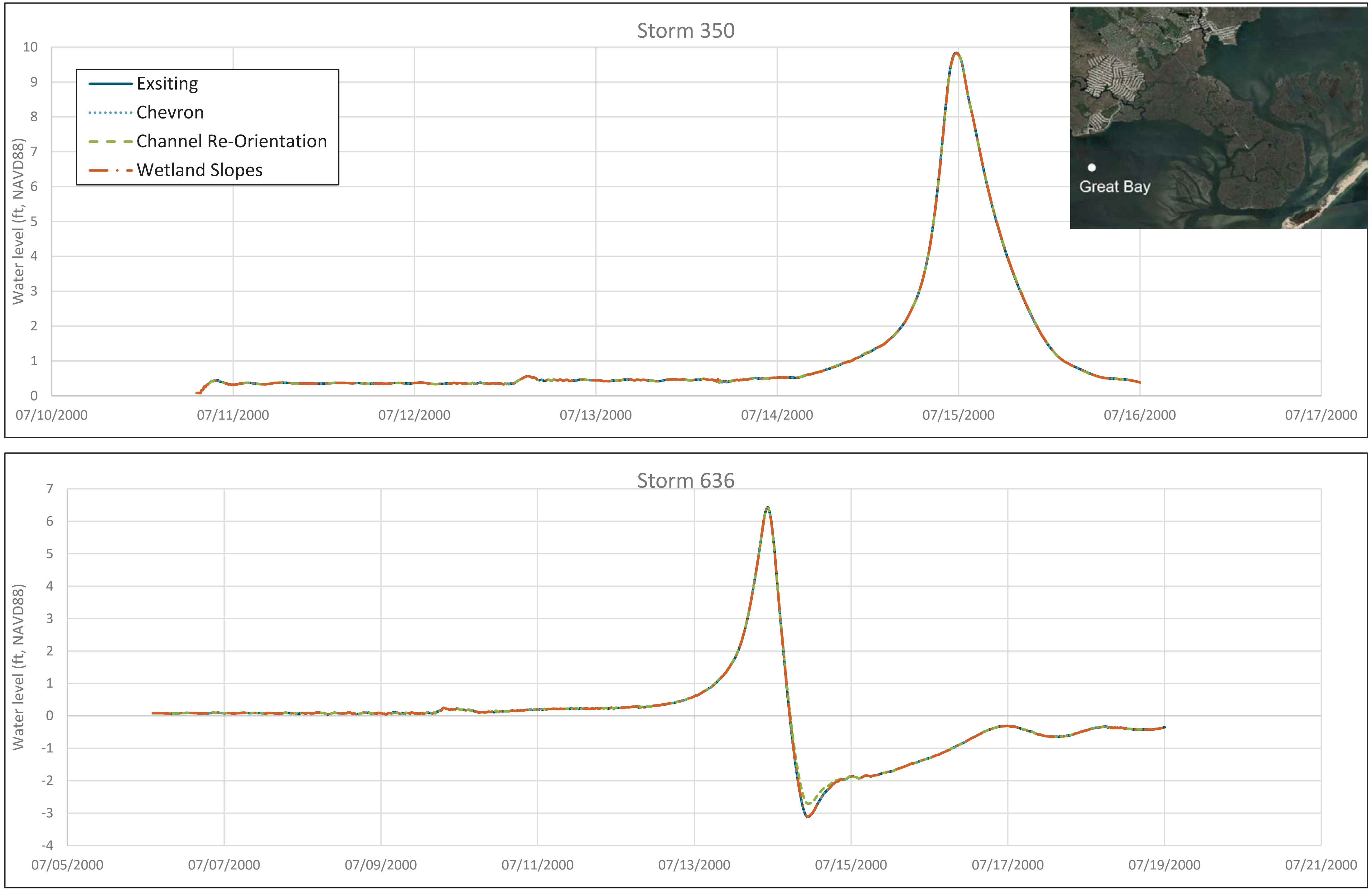


Figure 9
Comparison of Water Level Results for Existing Conditions and NNBF Simulations in Great Bay

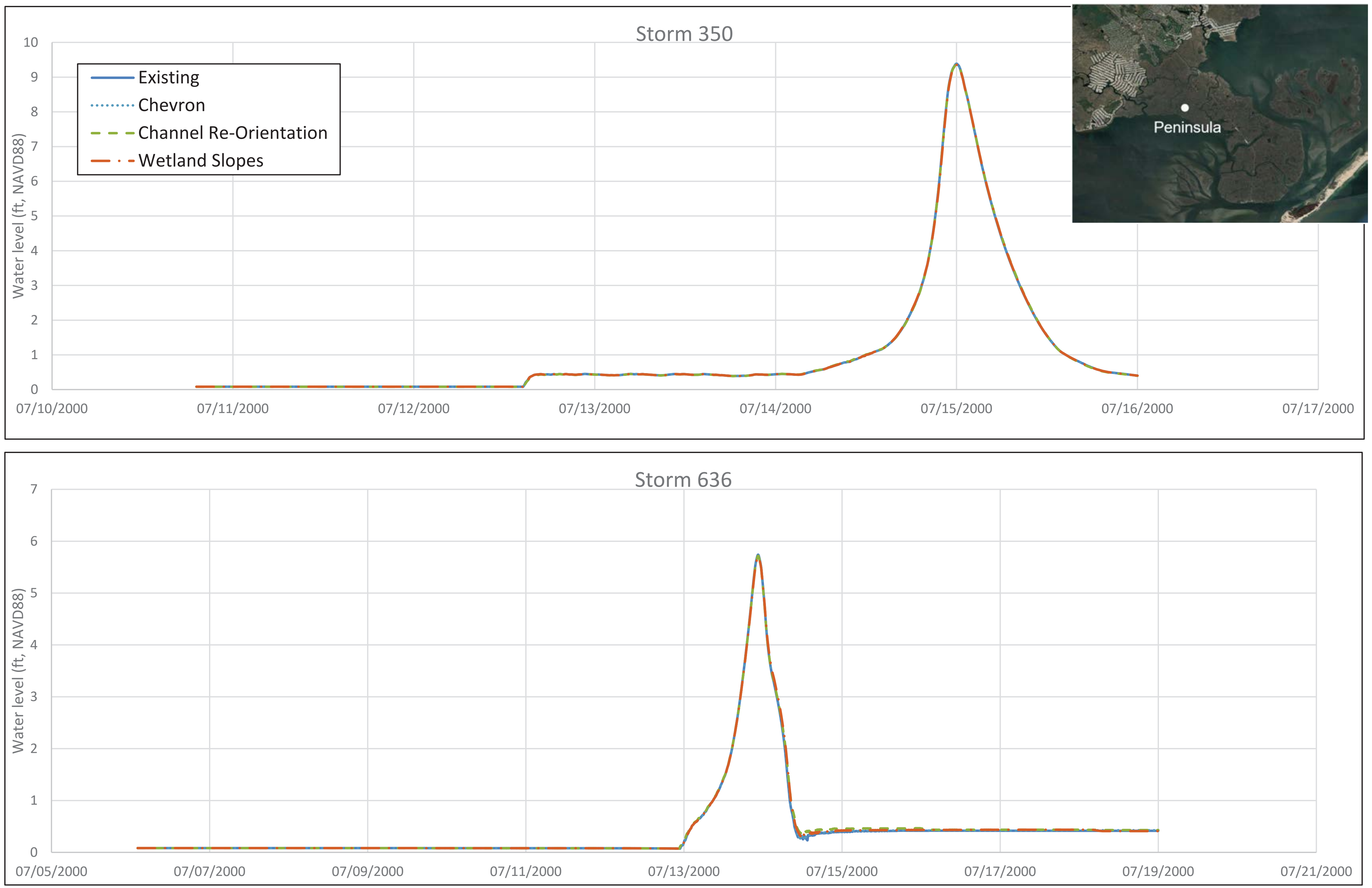


Figure 10
Comparison of Water Level Results for Existing Conditions and NNBF Simulations on Holgate Peninsula

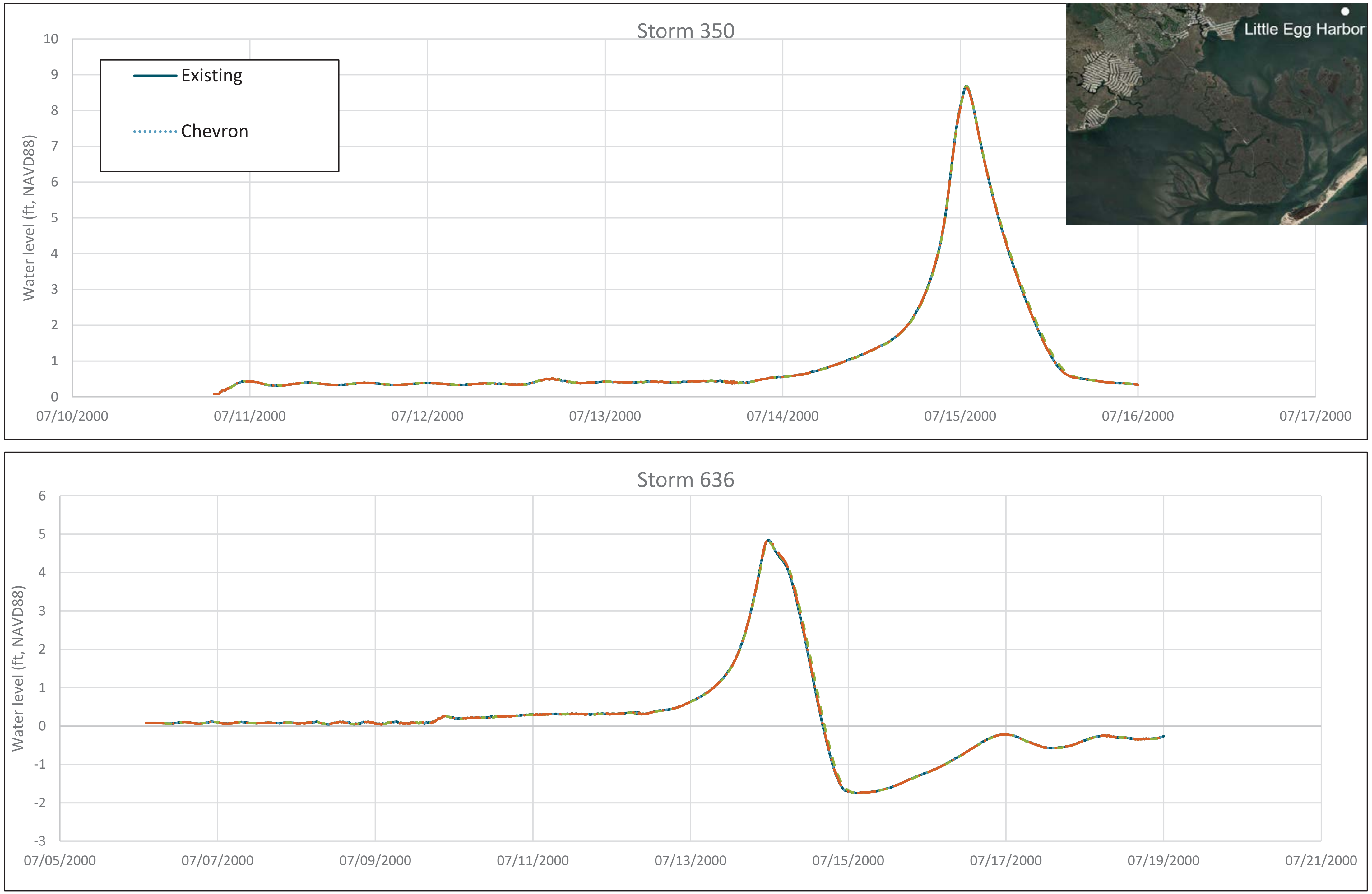
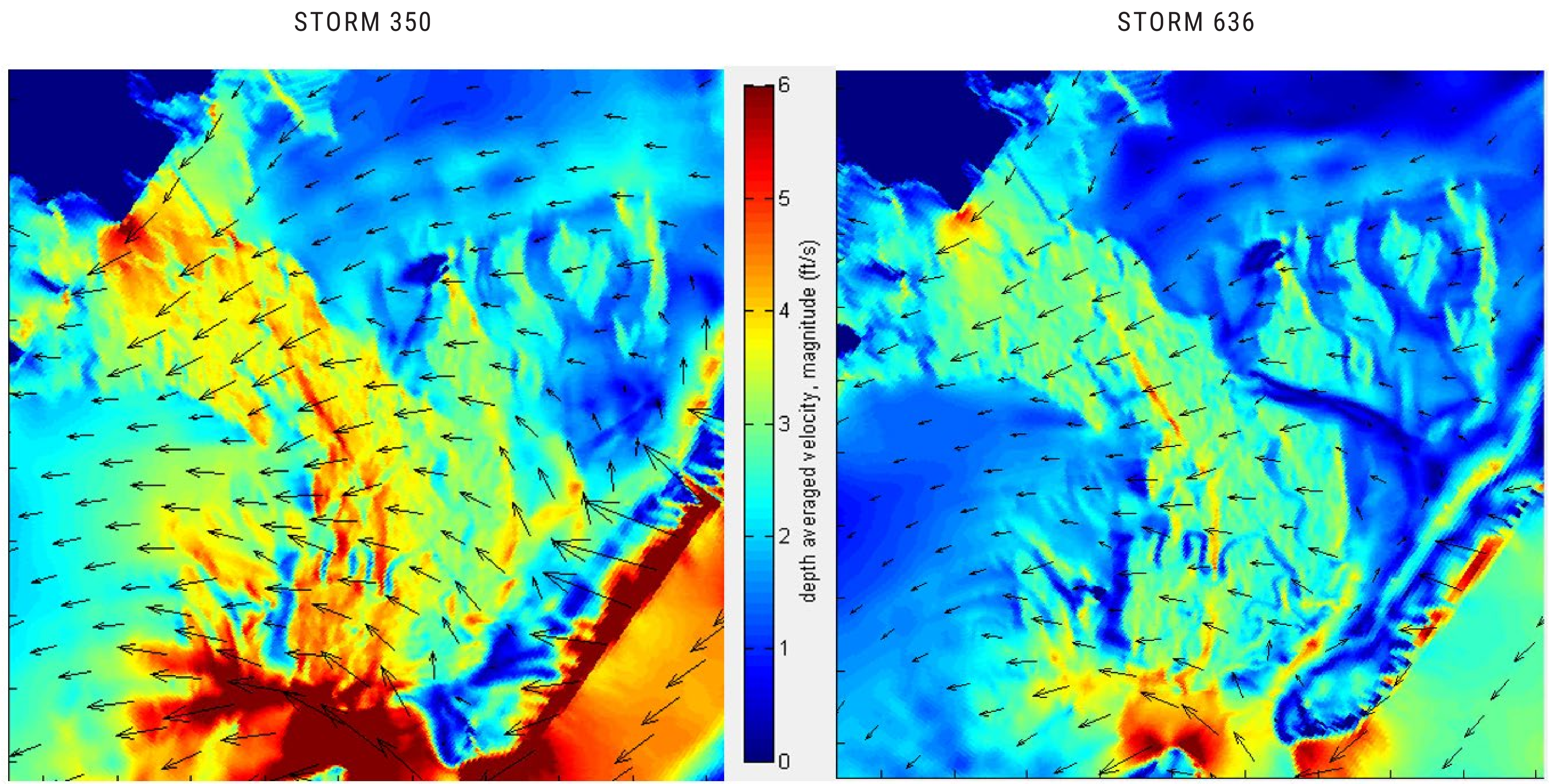


Figure 11

Comparison of Water Level Results for Existing Conditions and NNBF Simulations in Little Egg Harbor

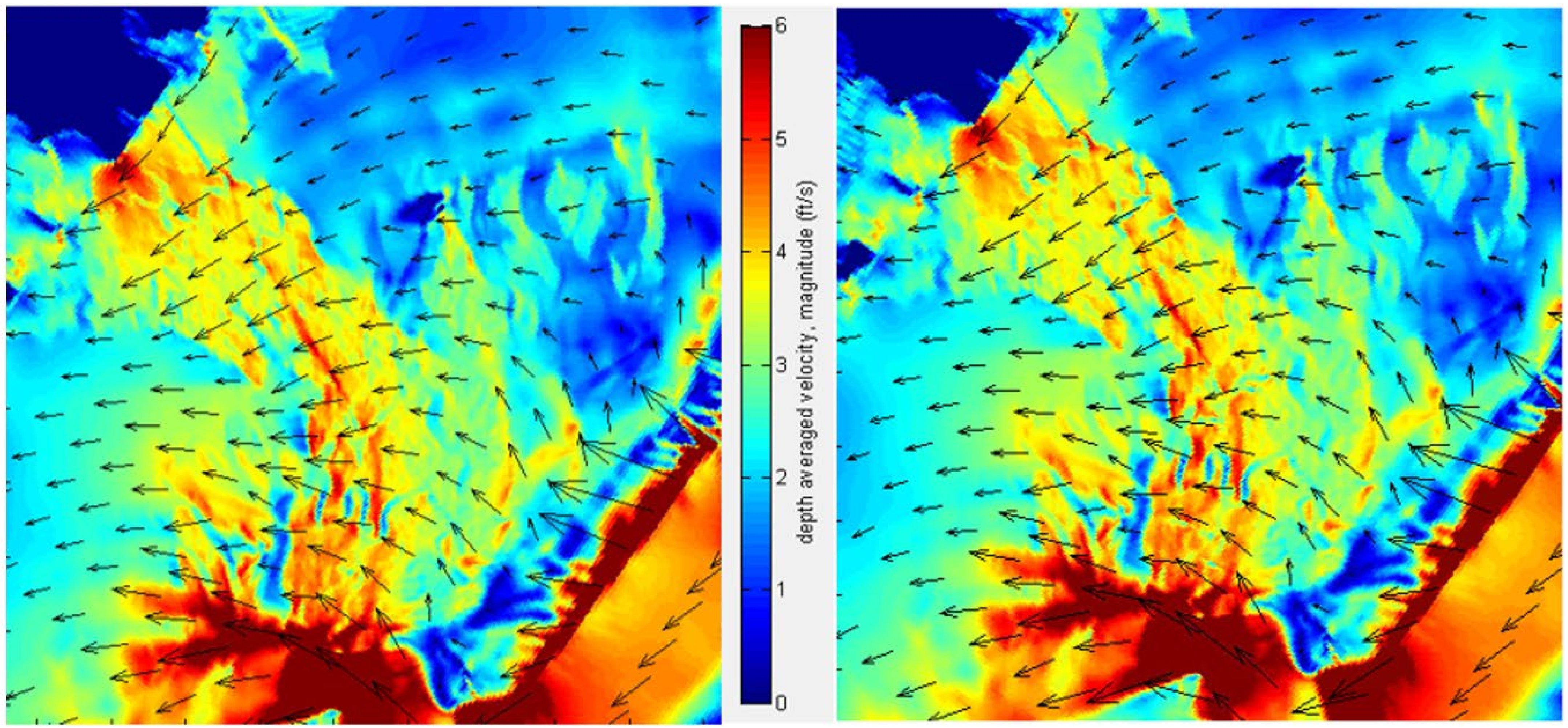


Notes:
1. Velocity vectors shown in black indicate flow direction
2. Depth averaged velocities shown correspond to the timestep of maximum velocity at a point located centrally on Holgate Peninsula

Figure 12
Comparison of Existing Conditions Maximum Flow Velocities on Holgate Peninsula for Storm 350 and 636

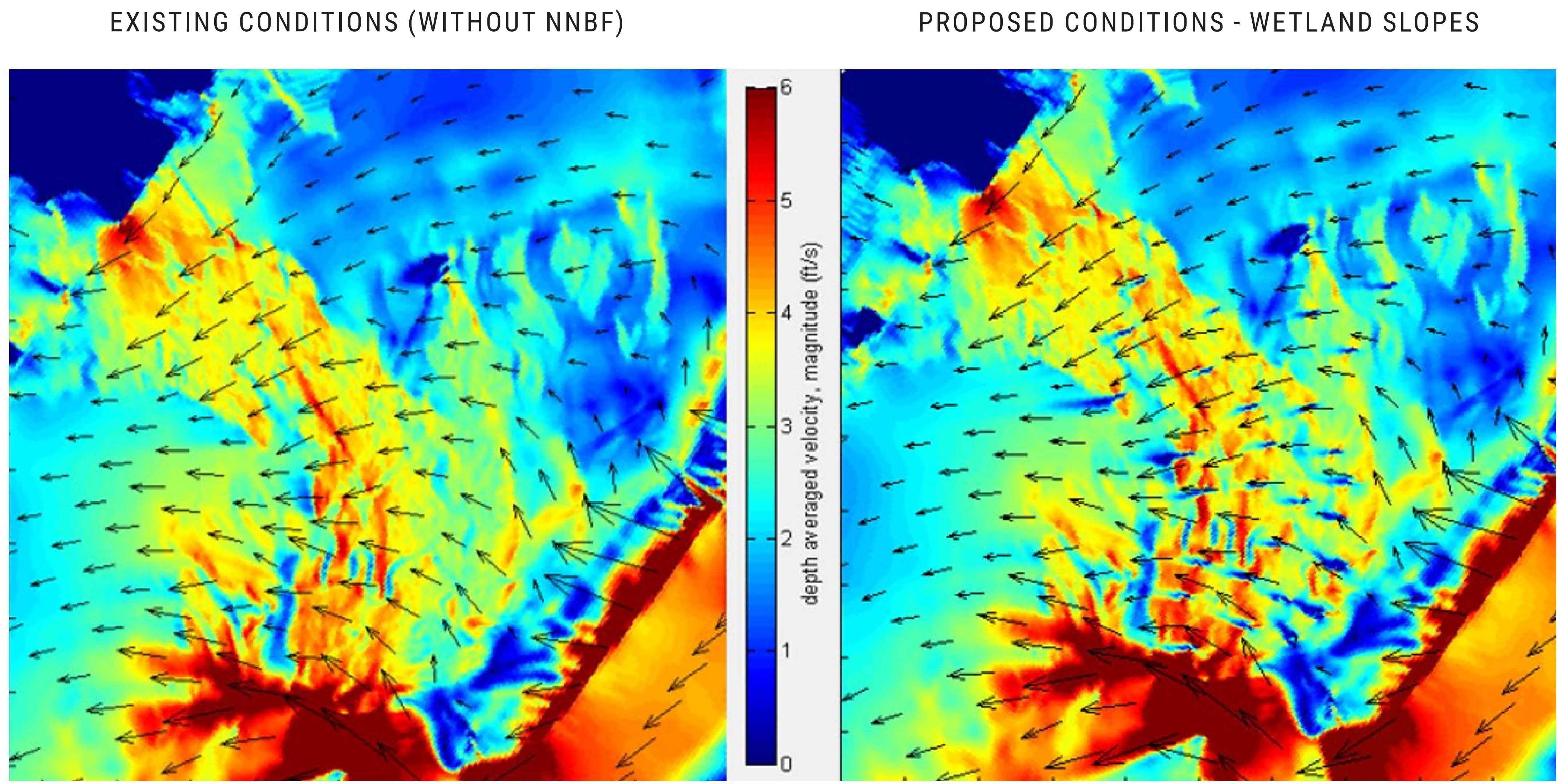
EXISTING CONDITIONS (WITHOUT NNBF)

PROPOSED CONDITIONS - CHEVRONS



Notes:
1. Velocity vectors shown in black indicate flow direction
2. Depth averaged velocities shown correspond to the timestep of maximum velocity at a point located centrally on Holgate Peninsula

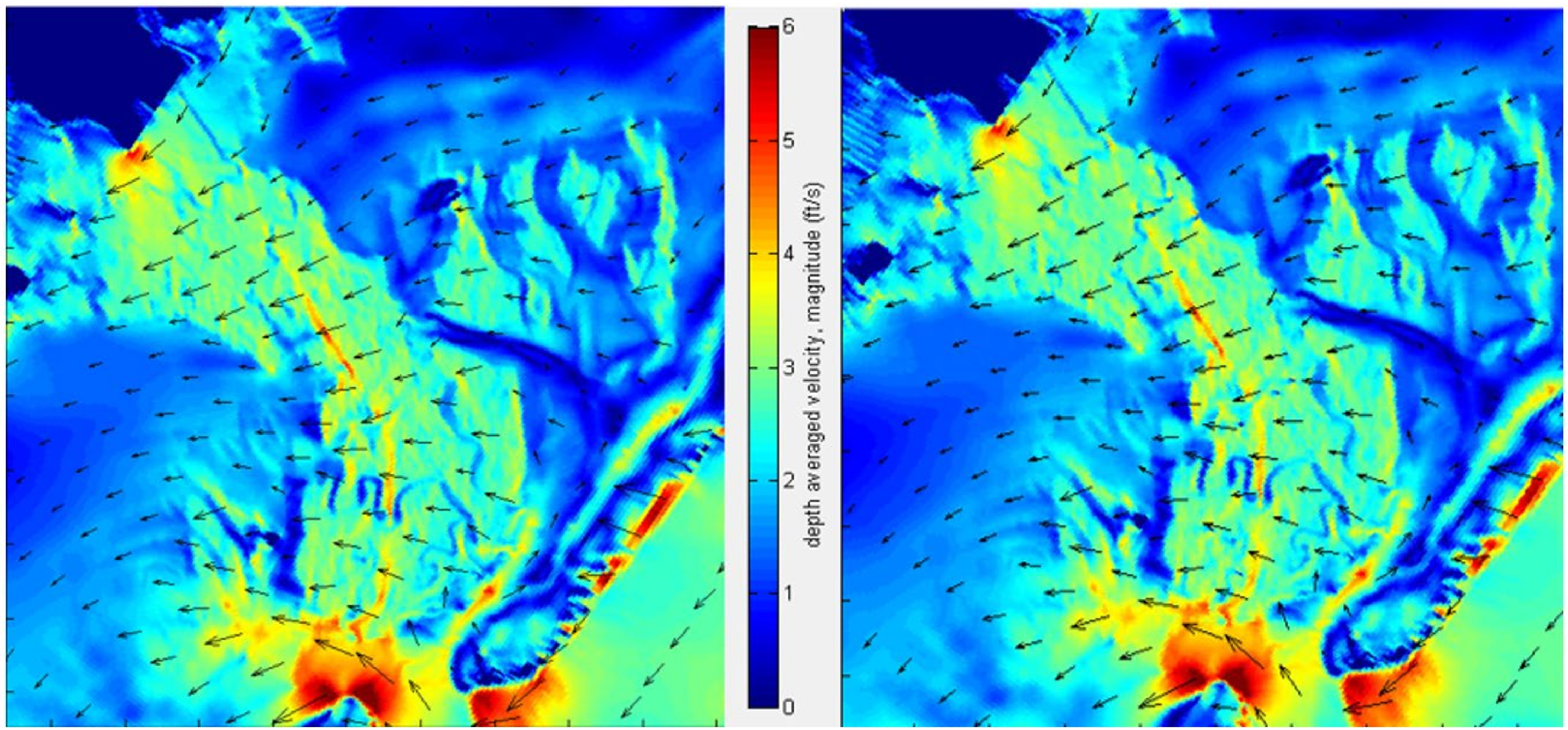
Figure 13
Velocity Results: Storm 350



Notes:
1. Velocity vectors shown in black indicate flow direction
2. Depth averaged velocities shown correspond to the timestep of maximum velocity at a point located centrally on Holgate Peninsula

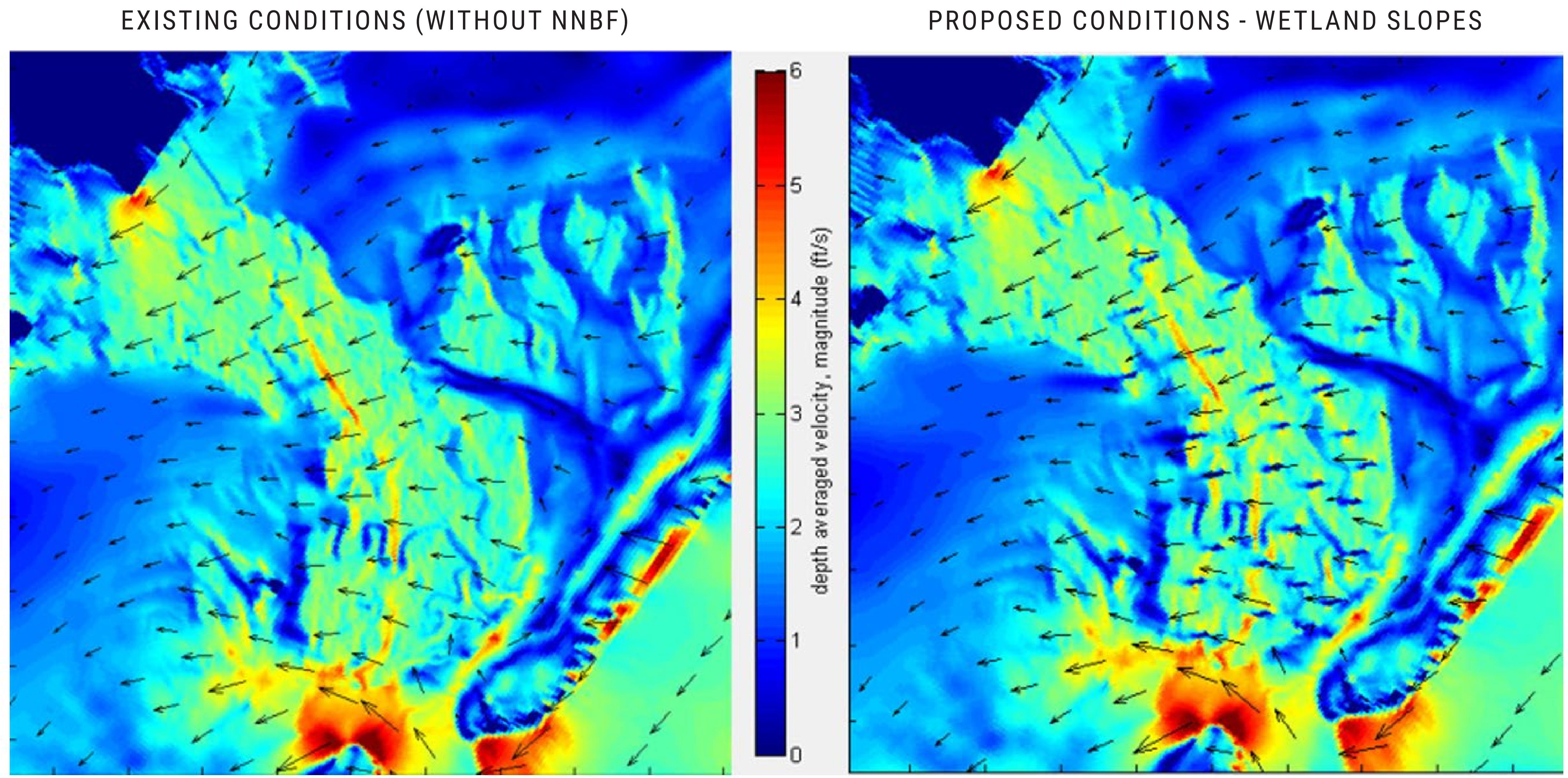
Figure 14
Velocity Results: Storm 350

EXISTING CONDITIONS (WITHOUT NNBF) | PROPOSED CONDITIONS - CHEVRONS



Notes:
1. Velocity vectors shown in black indicate flow direction
2. Depth averaged velocities shown correspond to the timestep of maximum velocity at a point located centrally on Holgate Peninsula

Figure 15
Velocity Results: Storm 636



Notes:
1. Velocity vectors shown in black indicate flow direction
2. Depth averaged velocities shown correspond to the timestep of maximum velocity at a point located centrally on Holgate Peninsula

Figure 16
Velocity Results: Storm 636