NATURAL AND NATURE-BASED FEATURES APPENDIX

NEW JERSEY BACK BAYS COASTAL STORM RISK MANAGEMENT FEASIBILITY STUDY

PHILADELPHIA, PENNSYLVANIA

APPENDIX G

August 2021

U.S. Army Corps of Engineers
Philadelphia District

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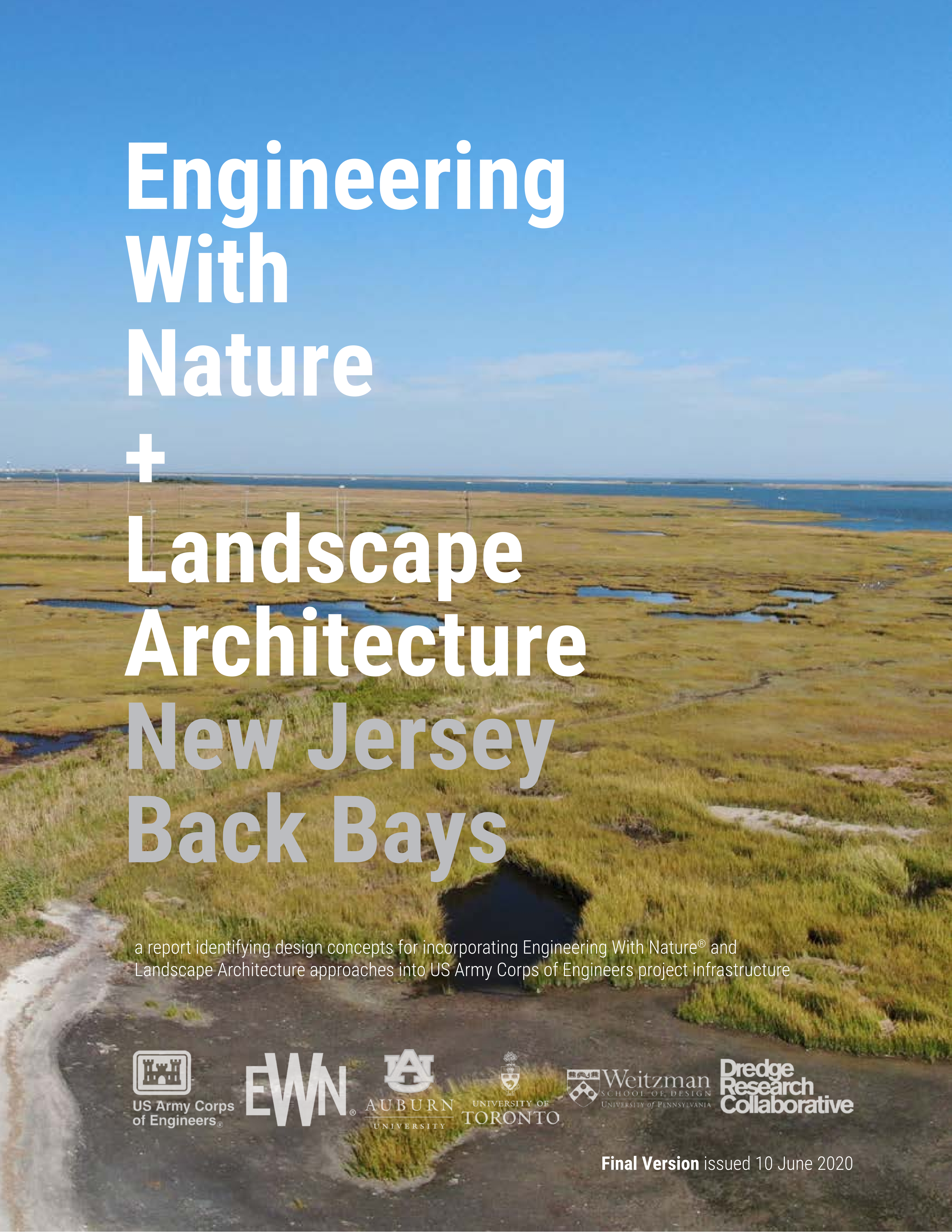

Engineering With Nature + Landscape Architecture

New Jersey Back Bays

a report identifying design concepts for incorporating Engineering With Nature® and Landscape Architecture approaches into US Army Corps of Engineers project infrastructure

US Army Corps of Engineers®
EWN®
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University of Toronto
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Dredge Research Collaborative

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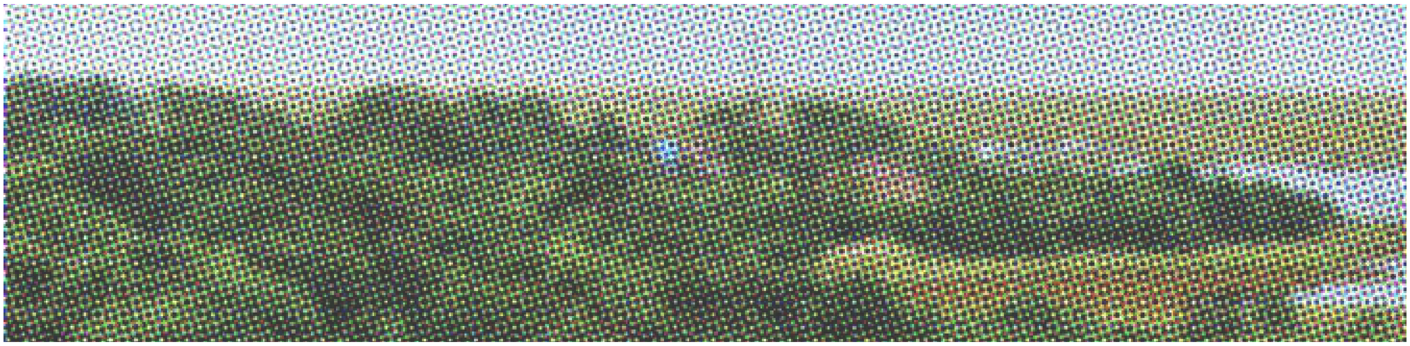

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This report covers findings from cooperative agreement W912HZ-18-2-0008 **Incorporating Engineering With Nature® (EWN®) and Landscape Architecture (LA) Designs into Existing Infrastructure Projects**, an agreement between the **U.S. Army Engineering Research Development Center** (ERDC) and **Auburn University** (AU) for FY2020.

This report has been prepared by the investigators at **Auburn University**, the **University of Pennsylvania**, and the **University of Toronto** and consultants from the **Dredge Research Collaborative**; it also incorporates concepts and text from ERDC's **Engineering With Nature®** project team.

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

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

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

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

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Executive Summary

The five counties of the New Jersey Back Bays region, Monmouth, Ocean, Atlantic, Burlington, and Cape May, are home to nearly two million people. Many of these people live in communities that are on or near the edge of the tidal waterbodies,that lie between the Atlantic Ocean barrier islands and the New Jersey mainland, such as Barnegat Bay, Great Bay, and Great Egg Harbor Bay. While the oceanward edges of the barrier islands are well-protected by existing Coastal Storm Risk Management (CSRM) features, the back bay region lacks a comprehensive CSRM program. Consequently, the region has proven vulnerable to impacts from storms, including the recent Hurricane Sandy. On-going sea level rise, the degradation of coastal ecosystems, and aging infrastructure systems make addressing the region's vulnerabilities urgent.

The US Army Corps of Engineers' (USACE) New Jersey Back Bays CSRM Feasibility Study (NJBB CSRM FS) is intended to address this need. This Engineering With Nature and Landscape Architecture (EWN-LA) New Jersey Back Bays document summarizes work done within the context of that study to develop design concepts for Natural and Nature-Based Features (NNBF) that can contribute to the larger Feasibility Study's holistic CSRM objectives. NNBF such as constructed marsh islands, 'living breakwaters', and horizontal levees have the potential to provide CSRM value while also providing valuable habitat, strengthening ecosystem function, offering recreational opportunities, and contributing to the aesthetic quality of the Back Bays. Depending on local circumstances, NNBF can be deployed in place of other CSRM measures, such as structural measures, or to augment them.

The work summarized in this EWN-LA NJBB document has taken place between July 2019 and April 2020. The process launched with a workshop hosted by the Philadelphia District (NAP), in which an array of potential design concepts were developed for further consideration. These concepts are summarized in *Part I: Regions and Initial NNBF Applications*, which includes tables listing all of these concepts and maps locating their potential locations within the four study regions defined in the NJBB CSRM FS.

Part II: Design Concepts describes in greater detail seven of the design concepts that were prioritized for further study: the (1) Ocean City Horizontal Levee, (2) Lagoon Community Protection, (3) Coastal Lakes Terracing, (4) Tuckerton Peninsula Barrier, (5) Beach Haven Surge Filter, (6) Seven Mile Island Innovation Lab (SMIIL), and (7) Barnegat Bay Shallowing. SMIIL is a current initiative between the State of New Jersey, The Wetlands Institute, and the USACE. The Barnegat Bay Shallowing design concept considers a broad scale application of NNBF for combined CSRM benefits.

The third section of this report, *Part III: NNBF Performance and Suitability: Linking Modeling to Design*, provides a brief overview of the work of the modeling team, which studied in depth three model areas, Holgate, Brigantine, and Great Egg. Two of the features from Part II, the Tuckerton Peninsula Barrier and Beach Haven Surge Filter, compose the Holgate model area. The model results indicate that NNBF can have significant CSRM effects, but these effects have the potential to be positive in some cases and negative in others. Further modeling and design is needed to explore alternatives and select NNBF configurations with the most beneficial effects. For in-depth presentation and discussion of the modeling results, see the separate report by the modeling team, “Enhanced Modeling in Support of Recommended EWN/NNBF Measures and Efficacy ini Providing Flood/Storm Risk Reduction”. Part III also builds on those results to recommend a potential method for linking modeling to design efforts in future study of NNBF opportunities.

Part IV: Pairing Nonstructural Measures with NNBF explores the potential CSRM and ecological benefits of linking physical nonstructural measures, such as building retrofits or relocation, with NNBF. NNBF and nonstructural measures can often be mutually supportive. Acquisition, for instance, could be strategically deployed in flood-prone areas to provide upland migration space for marsh buffers. Part IV also discusses potential opportunities and pitfalls in planning such linkages.

The fifth section of the report, *Part V: Initial Qualitative Cost Investigations*, describes a general approach to cost estimation for NNBF. As most NNBF require large quantities of sediment for their construction, the core challenges to cost estimation identified center on the highly variable availability of sediment, associated variations in cost, and the logistical coordination of construction projects such as NNBF with on-going navigational maintenance dredging in the region. NNBF are an emerging category of CSRM measure, and practices for planning, constructing, and evaluating them are still evolving. Nonetheless, their capacity to deliver multiple benefits, potential to be integrated with on-going O&M work (navigational dredging), and ability to adapt dynamically over time to changing environmental conditions make them wroth considering within the suite of available CSRM measures.

As a whole, this report is indicative of the range of types of NNBF that could be viable in the NJBB region and of the scales at which those features might be constructed. Further work should build on this report to refine, test, and design in greater detail. Potential next steps include:

- Linking modeling to design in the iterative development, selection, and refinement of NNBF, as described in Part III
- Further modeling to continue to establish CSRM benefits and prioritize NNBF; very large-scale strategies such as comprehensive Barnegat Bay shallowing could be examined
- Holistic planning to link NNBF with non-structural measures in a fashion that respects the varying needs, situations, and desires of communities throughout the Back Bays
- Analysis of the range of NNBF-like work underway in the Back Bays by other federal and state agencies, non-governmental organizations, and local entities including the examination of CSRM value and the potential for coordination
- Establishing linkages between NNBF strategies and ongoing O&M projects
- Further analysis of the ecological systems of the Back Bays, together with study of how short-term impacts of NNBF construction might be mitigated and how long-term benefits might be maximized; this could be done in consultation with resource agencies and the local scientific research community
- Analysis and prioritization of NNBF relative to spatialized Relative Sea Level Rise (RSLR) projections, with particular attention to marsh migration capacity
- Coordination with and outreach to local communities

Introduction

This report concerns the development of innovative design concepts for the New Jersey Back Bays Flood Risk Management Feasibility Study (NJBB), which is a project of the Philadelphia District (NAP) of the US Army Corps of Engineers (USACE). These design concepts combine Engineering With Nature® (EWN®) approaches to infrastructure design with landscape architectural (LA) approaches to infrastructure design in order to identify opportunities to incorporate "Natural and Nature-Based Features" (NNBF) into proposed NAP project infrastructure.

As described by the EWN® initiative, NNBF "are landscape features that are used to provide engineering functions relevant to flood risk management, while producing additional economic, environmental, and/or social benefits. These features may occur naturally in landscapes or be engineered, constructed and/or restored to mimic natural conditions. A strategy that combines NNBF with nonstructural and structural measures represents an integrated approach to flood risk management that can deliver a broad array of ecosystem goods and services to local communities."

The described in this report has focused on NNBF that can offer coastal storm risk management (CSRM) value in the context of the alternatives defined in the NJBB CSRM Interim Feasibility Study and Environmental Scoping Document, which was issued on March 1, 2019. These NNBF have been evaluated and selected for their potential to combine CSRM value with additional ecological and social benefit, such as the provision of marsh habitat and opportunities for recreational use.

Background

This report has been produced as part of a larger collaborative project, which we refer to as the Engineering With Nature®-Landscape Architecture (EWN-LA) initiative. This initiative emerged in response a workshop held at the USACE Engineering Research and Development Center (ERDC) in Vicksburg, Mississippi in Summer 2017. In that workshop, personnel from the USACE, members of the Dredge Research Collaborative, and a diverse group of landscape architects identified opportunities to integrate EWN® and LA approaches into new and existing water infrastructure projects and operations.

Engineering With Nature® is an initiative of the US Army Corps of Engineers. It is the intentional alignment of natural and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaborative processes.

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, in order to achieve "innovative and resilient solutions" that are more socially acceptable, viable, and equitable, and, ultimately, more sustainable.

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 in particular the re-imagination of existing infrastructure to meet more diverse criteria encompassing engineering functions, ecological value, recreational opportunities, and aesthetic benefits (Spirn 1984, Mossop 2006, Orff 2016, Belanger 2017). This overlap in concerns suggests that the design principles and precedent knowledge summarized as EWN® approaches may be beneficially combined with the design principles and precedent knowledge that has been accumulating in landscape architectural approaches to infrastructure, such as the work of landscape architects on recent international design competitions that deal with issues of coastal storm protection, public space, and ecological performance, like Rebuild by Design NYC and the Resilient by Design Bay Area Challenge. Moreover, landscape architects bring additional methods and expertise, including design, representation, and communication skills, that can aid in achieving the shared goals of EWN® and landscape architecture.

The members of the Dredge Research Collaborative, including the DRC-associated faculty from Auburn, Toronto, and Penn working on this project, work in precisely this area of contemporary landscape architecture, with a particular focus on coastal and riverine infrastructures that interact with sediment systems, and are correspondingly able to bring familiarity with both the challenges and the opportunities inherent in deploying EWN® approaches to water infrastructure.

Context

NJBB CSRM context

This draft report is intended to demonstrate the scope and breadth of NNBF possibilities within the context of the *NJBB CSRM Interim Feasibility Study and Environmental Scoping Document*. Because of this, it has focused on NNBF that combine the potential for strong CSRM benefits with ecological and social benefits.

The CSRM value provided by NNBF (and by features that hybridize NNBF and structural approaches) does differ from the value provided by traditional structural measures. NNBF have the advantage of providing multiple kinds of benefits and, because they incorporate dynamic natural processes, are in some cases capable of adapting to changing environmental conditions. Marshes, for instance, can accrete, potentially keeping pace with relative sea-level rise (RSLR). However, NNBF typically perform best when paired with non-structural measures such as buyouts and relocation, as NNBF require migration space over time to perform their natural adaptations.

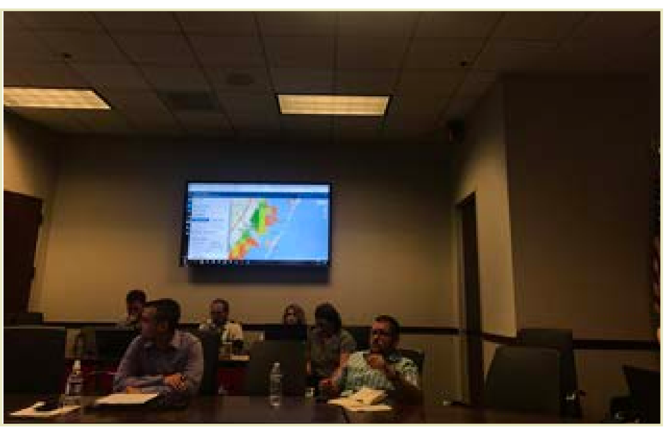
In the context of the NJBB region, some of the most valuable CSRM benefits that are possible through NNBF come by way of creating, enhancing and/or bolstering the existing systems of islands and marshes. The scientific literature supporting the CSRM benefits of vegetated coastal systems has been growing both in the United States and in Europe. This literature is aided by field-verified observations from well-monitored storms. Work done in the United States, led primarily by researchers with the USACE has both modeled and observed storm-associated water-level reductions of 1 meter across marsh expanses ranging from 6 to 60km depending on local conditions and storm type (Wamsley et al., 2010). Another report (Wu et al., 2015) concluded that, while highly variable, vegetation in their numerical tests provided as much as 37% reduction in storm surge water levels. In Europe, a physical flume was used to study the effects of salt marsh on wave reductions and concluded that up to 60% of the reduction they saw in their test could be attributed to vegetation. They stated that their findings "support the incorporation of salt marshes into coastal protection schemes" (Moller et al., 2014). Studies in Holland have also concluded that vegetated foreshores on dikes could reduce wave height between 25 to 50% and serve as a natural reinforcement (Vuik et al., 2016). Studies in New Jersey regarding the cumulative reductions in property damage related to the presence of wetlands estimated that damage during Hurricane Sandy was reduced by 27%, equating to $430 million (Narayan et al., 2017). While the results of these studies are all prefaced with considerable contextual assumptions and thus do not provide the ability to extract specific generalizable predications as to how effective vegetated marshes are at reducing storm surge and wave risk, as a body of research they do all confirm that there is some reduction and that marshes are clearly valuable to some degree as a CSRM strategy.

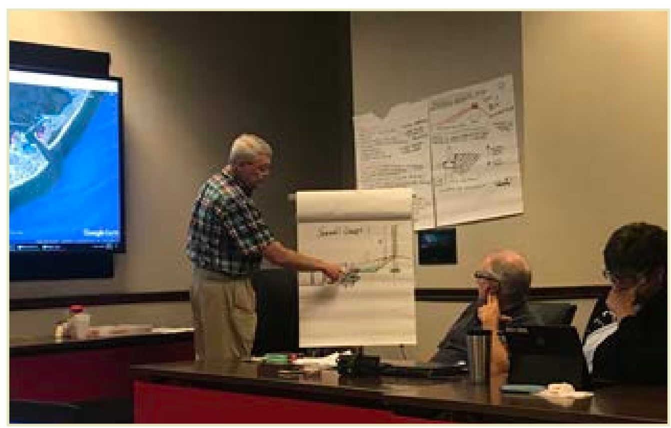
The Interim Feasibility Study describes and evaluates a range of structural measures for the New Jersey Back Bays, including inlet storm surge barriers, levees, floodwalls, seawalls, and revetments. This draft report refers to these measures in a number of places, and the NNBF described within it have been developed within the context of these proposed measures. The study of non-structural measures, particularly as they can be paired with NNBF, would help to round out the full range of possibilities being considered.

<u>Workshops and process</u>

This EWN-LA study has been a collaborative effort by the members of the project delivery team (PDT), which includes personnel from NAP, EWN, the grant investigators, their staff, and consultants.

The PDT's first stage of work was a workshop, hosted by NAP, which took place on July 30 and 31, 2019. During the workshop, the PDT worked to identify issues and opportunities associated with each of the project regions, as well as general NNBF strategies that might respond to those issues and opportunities. (These strategies are summarized on pages 18-31.)





A follow-up workshop took place from September 20-23, 2019. During this workshop, the PDT reviewed a matrix of strategies in order to prioritize key strategies for advancement as design concepts, discussed on-going modeling efforts, made a series of visits to potential NNBF sites in the Back Bays, and worked to refine the prioritized design concepts. Based on this prioritization, the EWN-LA team produced a series of draft products, which were presented to the full PDT via webinar on October 16, 2019. A draft report was issued in February 2020, followed by this final report in May 2020.

Report Contents

The pages that follow in this report summarize the current state of this NNBF R&D study. First, a series of spreads describe the ecological context of the New Jersey Back Bays, organized by the plant communities and significant animal species that NNBF have the potential to positively impact. This ecological context is followed by a NNBF Glossary, which describes via text and diagram key types of general NNBF strategies, such as "horizontal levees", which are relevant to the Back Bays.

Specific NNBF recommendations follow in five parts. Part I is a summary of strategies considered in the July and September workshops, organized by the four study regions of the feasibility study. Part II is a detailed exploration of some of the NNBF that have been prioritized by the PDT and selected for advancement as design concepts, including in particular NNBF that are also being explored through modeling at ERDC. Part III covers the remainder of the prioritized NNBF, which were studied by the modeling team. Part IV explores potential opportunities for linking nonstructural measures to NNBF. Finally, Part V discusses initial qualitative cost estimate procedures, provides area takeoffs for the NNBF in Part II, and helps to define the habitat creation value of those NNBF.

Ecological Context

Ecologically, the study area of the *NJBB CSRM Interim Feasibility Study and Environmental Scoping Document* is composed primarily of the Coastal Salt Marsh plant community, although portions of the area also include Coastal Sand Dune and Upland Forest communities. The continued existence of these plant communities, and the affiliated animal communities who depend on them, is threatened by sea level rise and strengthened storms associated with climate change. The coast of New Jersey already shows signs of these changes. For instance, "ghost forests" of dead trees, unable to tolerate the intrusion of saltwater, are prevalent in many locations. Similarly, Saltmarsh Sparrow (*Ammodramus caudacutus*) populations are declining rapidly due to unpredictable water levels drowning hatchlings and the disappearance of healthy continuous stands of marsh in many regions of the Back Bays.

Healthy ecosystems and plant communities like the Coastal Salt Marsh are important for their economic value in tourism revenue and food production, their ability to mitigate and buffer storms from reaching coastal homes, and their intrinsic value. Engineered solutions to combat sea level rise and protect against natural disasters like hurricanes should therefore strive to incorporate and consider NNBF in their future projects in order to protect and bolster the important habitats these marshes represent.

FLORA

Coastal Salt Marsh

Coastal Salt Marsh is a plant community always on the move, expanding from the accretion of dead plant materials, and now more commonly shrinking from erosion by sea level rise. The vegetation of coastal salt marshes is dominated by halophytes – plant species that can tolerate the constant or temporary inundation of salt water in soil. Though plant cells normally wither in the presence of salt, halophytes are extremely adapted to this difficult growing condition. Below the mean tide level, Sea Lettuce, *Ulva lactuca,* can be established in mudflat conditions and deeper still, in waters up to 3 meters, Eel Grass, *Zostera marina*, can be found. The number of terrestrial halophytic species are not numerous and two species tend to dominate this niche: Smooth Cordgrass, *Sporobolus alterniflorus* (previously known as *Spartina alterniflora*), and Saltmeadow Cordgrass or Salt Hay, *Sporobolus patens* (previously *Spartina patens*). The two grasses look relatively similar to the untrained eye, and the coastal salt marsh tends to look like a monoculture of a green grass. However, the two grasses can be easily identified by their location in the Coastal Salt Marsh and their height. *Sporobolus alterniflorus* is generally found closer to the water's edge and tends to grow to a height of 3 to 8 feet. *Sporobolus patens* is found at a higher marsh elevation and has less contact with the faster moving water. This species height never exceeds more than two feet.

At higher elevation points within the marsh where salt intrusion is less constant, other less numerous species can be found including Spike Grass, Black Grass, Sea Lavender, Seaside Mallow, Slender Glasswort, Woody Glasswort, Salt Marsh Fleabane, Orache, Perennial Salt Marsh Aster, Tall Sea-Blite, Low Sea-Blite, and Salt Marsh Sand Spurrey. Towards the coast and on more elevated islands, the presence of native Cattail and the invasive Phragmites can be found in large stands when salt water is mostly out of the reach of roots, aside from rare inundation.

At the border of Coastal Salt Marsh and the neighboring plant community, shrubs and vines can be found, including Marsh Elder, Groundsel Bush, and Bay Berry. Additional herb species in this zone include Seaside Goldenrod, Salt Marsh Bulrush, Salt Marsh Cockspur Grass, Sea-Pink, Seaside Gerardia, and Beaked Spike Rush.

With changing salt concentration in the Back Bays, higher water levels, and more constant storm surge into areas not evolved for high salt concentrations, this plant community is in flux and species are attempting to adjust to unprecedentedly rapid change in environmental conditions. Aiding species movement and rebuilding soil heights in future projects will be imperative to maintaining a healthy Coastal Salt Marsh plant community.

Coastal Sand Dune

Almost exclusively found on barrier islands, Coastal Sand Dunes are created and modified daily by wind, tides, and storms. Due to the creation of ridges and hollows between dunes, a wide range of environmental stresses of salt spray, saltwater, moisture, and wind is found within this plant community. Consequently, it is further broken down into four general vegetation types: Dunegrass, Beach Heather, Shrub Thicket, and Dune Woodlands.

Dunegrass Community

This community is found on the primary foredunes facing the ocean. Environmental stresses like salt spray, sand movement and extreme wind make it very hard for many plant species to thrive here. Only around 10% of the foredune is typically vegetated with Dunegrass, *Ammophila breviligulata*, being the most common native species. The Asiatic Sedge, *Carex kobomugi*, has begun to rival dunegrass and also characterize this community. Less common species include Sea Rocket, Sea-Beach Panic-Grass, Seaside Spruge, Sandbur, Beach Pea, Long-Spined Sandburg, Cocklebur, Saltwort, Sand Grass, Seaside Goldenrod, and the introduced Dusty Miller.

This community is important for combating storm surge. While many of the remaining habitats in the Coastal Sand Dune have been lost due to development, the Dunegrass Community is recognized for its ability to mitigate flooding. Efforts are constantly being made to replant these dunes and keep people from walking on them. Healthy stands of Dunegrass help trap even more sand, leading to taller dunes and more protection during storms.

The following communities, Beach Heather, Shrub Thicket, and Dune Woodlands are now quite rare due to the development of the barrier islands. These communities are almost entirely found within nature preserves.

Beach Heather

Found on the backside of the primary and secondary dune Beach Heather the most abundant species in this area can occur in great stands. Sea Beach Three-awn, Switch Grass, Little Bluestem, Sandgrass, Beach Pinweed, Prickly Pear, Sedge spp., Virginia Creeper, and Poison Ivy are also common in this area alongside the Dunegrass community.

Shrub Thicket

With an increase in moisture and decrease in salt spray, a shrub thicket is the first community of woody plants from the ocean. The shrub thicket community can vary greatly depending on amount of moisture. True to its name, the thicket is composed of vines, shrubs, and small trees, growing in a dense tangle of plants. It is quite rare due to development. Common tree species include Red Cedar, Black Cherry, and American Holly. Stunted Red Maples can also be found. Shrub and vine species include: Scrub Oak, Bay Berry, Shadbush, Highbush Blueberry, Arrowwood, Virginia Creeper, Greenbrier, Poison Ivy, Highbush Blue Berry, and Beach Plum. Herbs include many from the Beach Heather community and Dunegrass community. Additionally, Prickly Pear and even fern species can be found here.

Dune Woodlands

In the most protected areas of the barrier islands, Dune Woodlands exist. With freshwater, a lack of salt spray, and less wind, tall trees start to appear. This community consists of American Holly, Black Cherry, Sassafras, Red Cedar, Red Maple, Pitch Pine, and Hackberry, which can all grow to impressive heights. Vines can grow to the tree tops, creating a dense forest. These woodlands are susceptible to salt water intrusion and Hurricane Sandy transformed many Dune Woodland Communities into ghost forests.

Upland Forests

Moving upland from the Coastal Salt Marsh, Upland Forest will generally be the next community present. Two upland communities that are common in the inner coastal plain are Sweetgum Successional Forest and Virginia Pine Successional Forest, which are both named for their most dominant tree species. While these are both successional forest and will likely mature into a mixed oak plant community, they are currently the most dominant types as much of the inner coastal plain was originally used for agricultural land and is just now returning to forest. In both of these successional communities, pines, hickories, oaks, American Holly, and Sassafras are quite common.

FAUNA

The New Jersey Back Bay is home to many species. Fish, bivalves, crustaceans, insects, mammals, reptiles, and birds all call this area home. Many migrating species of birds can also be found feeding, resting, or nesting here at some point in the year. A few species of key concern are noted below.

Black Skimmer

A unique seabird with an identifiable flying pattern and odd beak shape which skims the surface of the water in search of fish. This species is of concern due to its decreasing population from habitat loss. This species breeds on gravel and sandy bars and beaches. This species is listed as endangered in New Jersey.

Saltmarsh Sparrow

A sparrow which are restricted to tidal saltmarshes. These birds are in rapid decline due to predation of eggs by the introduced red fox. Additionally, these species lay their nest just 2 to 10 cms above the tide level in Sporobolus patens to hide from predators. However, with sea level rise and a new frequency of storms, the offspring are drowning. It is predicted that a threshold of sea level rise will soon be reached and these birds will become extinct in less than 20 years following that threshold.

Red Knot

A beautiful bird considered a near-threatened species. This species eats horseshoe crab eggs. The new stricter fishing regulations on horseshoe crabs in New Jersey in place may help this species rebound. Climate change, sea level rise, and hunting for both food and sport are reasons for this species' decline.

American Oystercatcher

While the population of American Oystercatchers are considered stable, they are in decline and listed as a species of "special concern" in New Jersey, one of their most important habitats. These birds nest in the back bay marshes of New Jersey and similar habitats on the East Coast.

Piping Plover

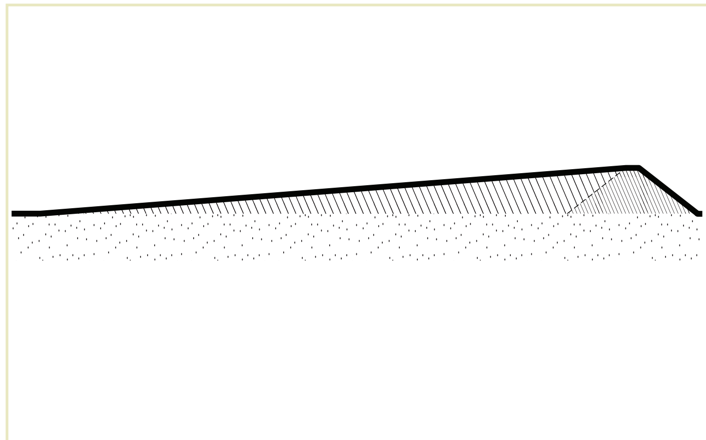
This charismatic bird is often seen at the waters edge running up and down the beach and back bay. They nest on bare sand and are therefore under great pressure from coastal development and tourists. Listed both in New Jersey and federally as endangered.

NNBF GLOSSARY

A collection of NNBF strategies are being considered and developed for this report. These strategies have come about through discussions of performance, cost, and location preference by the PDT. While the following list is not exhaustive of all possible NNBF strategies, they are representative of many of those under consideration in this report. These are not proposals for specific projects but are general descriptions of terms and concepts used elsewhere in this report.

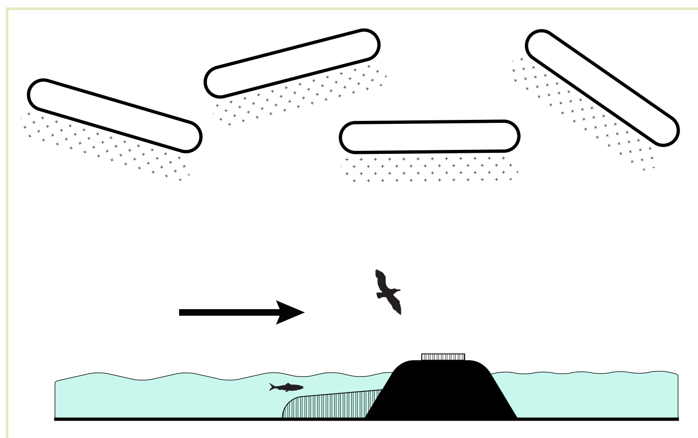
HORIZONTAL LEVEE

A levee with an expansive slope (e.g. 1:30) that permits habitat to migrate upland while also possibly incorporating social uses. See (1) Ocean City Horizontal Levee, and (4) Tuckerton Peninsula Barrier in Part II.



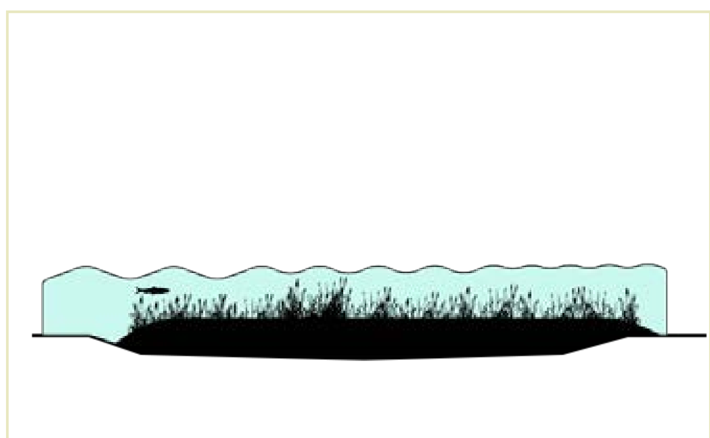
LIVING BREAKWATERS

Living Breakwaters are emergent breakwater structures designed to incorporate various forms of desired habitat. In the NJBB, these could include oyster beds, mudflats, nesting areas for birds, and/or locations for emergent vegetation. See (2) Lagoon Community Protection, (4) Tuckerton Peninsula Barrier, and (7) Bernegat Bay Shallows in Part II.



SHALLOWS

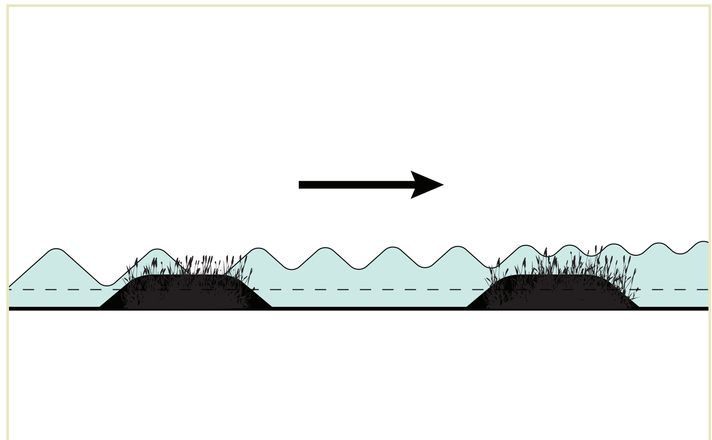
Shallows are areas that were once deeper water, that are filled to an elevation that can accommodate sub-aquatic vegetation such as Eel Grass. See (7) Barnegat Bay Shallows in Part II.



diagrams not to scale

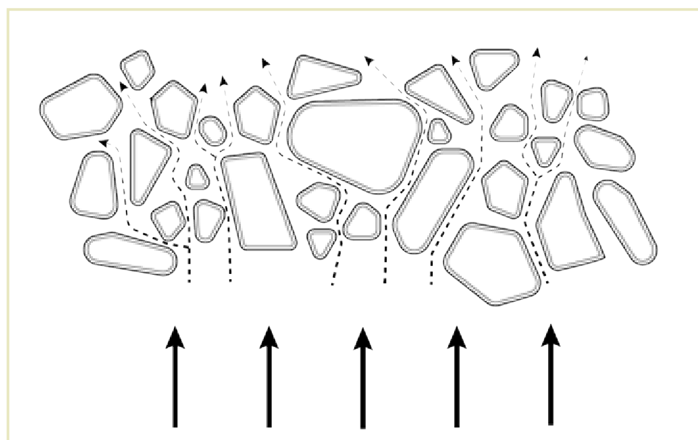
SPEED BUMPS

Speed bumps are linear, elevated islands, designed to reduce wave energy while providing a variety of subaqueous, intertidal, emergent, and even upland habitats. See Abesecon/Brigantine speed bumbs in Central Region, Part I as well as modeling efforts.



SURGE FILTER

The surge filter is a wetland complex designed or modified in order to create a thick collection or field of vegetation and soil. This field acts like a sponge or buffer, absorbing and dissipating wave energy as water passes through it. See (5) Beach Haven Surge Filter in Part II.



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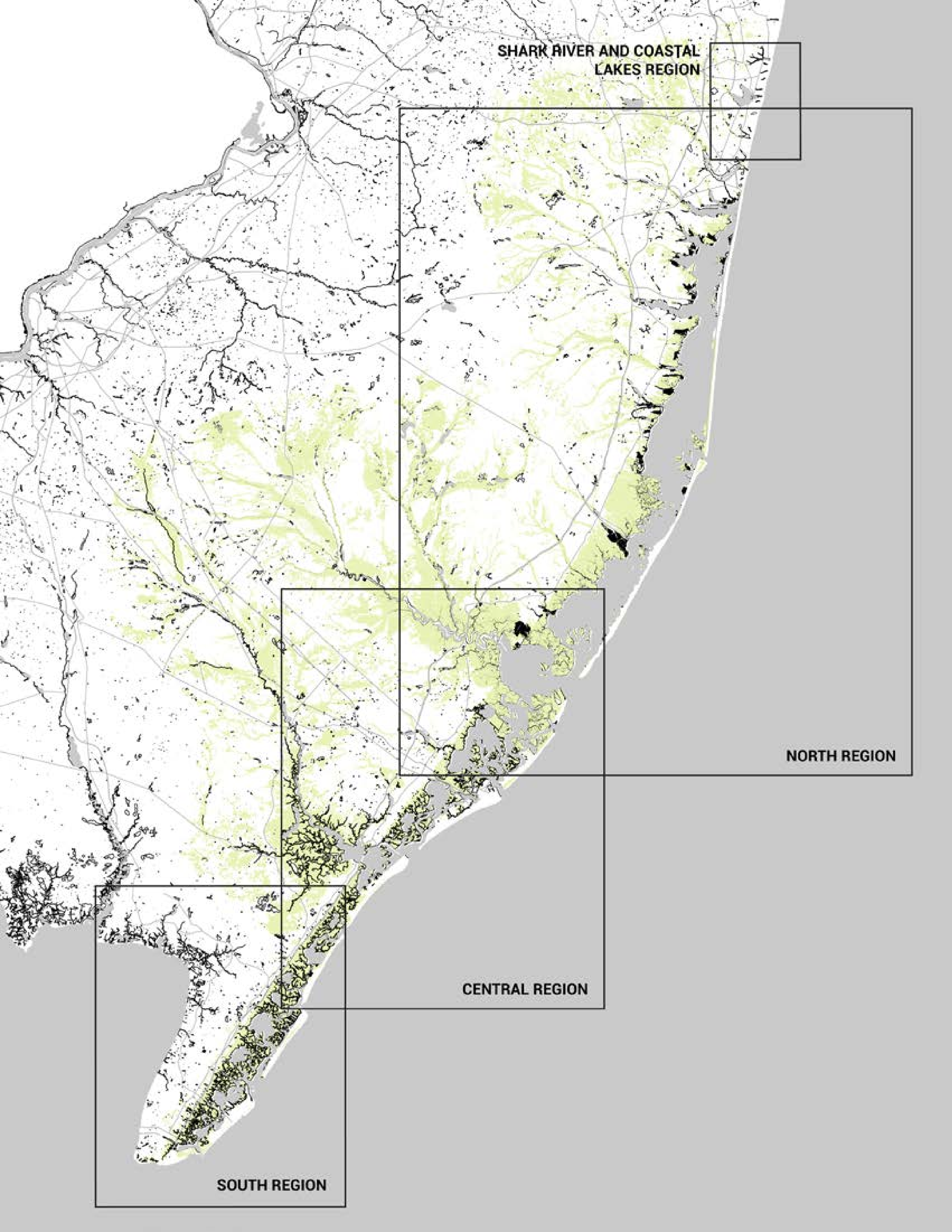
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NORTH REGION
CENTRAL REGION
SOUTH REGION

Part I

REGIONS AND INITIAL NATURE AND NATURE BASED FEATURES (NNBF) APPLICATIONS

This section contains an overview of the initial suite of NNBF opportunities identified by the PDT during the workshops. It is organized along the lines of the geographic study area regions from the NJBB CSRM Feasibility Study: Shark River and Coastal Lakes Region (grouped); North Region; Central Region; and South Region. The initial NNBF application concepts discussed in the workshops are listed by region, incorporating the entire range of NNBF strategies considered. The list is supplemented by maps outlining location specific concepts. The features shown on the map are drawn to locate the general area an NNBF might be considered, and are not representative of a specific design. From this full suite, key NNBF have been advanced to study as design concepts, documented in Parts II and V of this report. Other key NNBF were advanced through study by the modeling team; that work is briefly described in Part III of this report, and is documented in more depth by the modeling team's report.

Shark River/Coastal Lakes

Project Idea	*Description*	*General Vicinity*	*Comments*
Dune Enhancement	Not sure of existing dune height in this area - consider up to 20'	Belmar and Bradley Beach Area	Although not part of NJBB study per se; building up dunes on ocean-side of barrier islands represents another potential defense strategy.
Expand Shark River Island	Buy out residences located on Shark River Island; Create larger island with more complex topography	Shark River Island	Create more complex topography on the island w/ diverse habitat to slow surge at Shark River Inlet.
Improve shoreline for lakes	Create naturalized shoreline with shallower slopes or terraced shoreline to provide habitat benefits	Examples: Wesley Lake, Sunset Lake, Deer Lake, and Sylvan Lake	Lakes become part of strategy to deal with compound flooding during coastal storms (stormwater runoff+surge); Dredge out lakes to ~water table for additional storage capacity; Add pumps to draw down lake water levels prior to storms to provide flood storage (a la Harvey) Consider maintaining some at lower normal water levels to provide more opportunity for community interactions with lakes, i.e., parkland
Improve tidegates/culverts for Lakes	Modify tide gates/culverts to provide better circulation to lakes during calm conditions and block surge during storms	Examples: Wesley Lake, Sunset Lake, Deer Lake, and Sylvan Lake	Need to think more about EWN strategy here, if this is prioritized.

North Region (north of Great Bay Blvd to Manasquan Inlet)

Project Idea	*Description*	*General Vicinity*	*Comments*
Cross Bay Barrier (Great Bay Barrier Blvd) - Transformed into Horizontal Levee	Modify existing area to resemble horizontal levee configuration that includes mixture of extensive high/low marsh system abuting existing infrastructure	Cross Bay Barrier/Great Bay Blvd.	Large Approach to NNBF -proposed modeling Task 7; Consider adding rails-to-trails type feature to cross-bay barrier
Beach Haven/Holgate Surge Filter Islands [PROPOSED MODELING]	Restore/expand marsh and island complex; Serve as "surge filter" and dampening surge.	Just North of Great Bay Blvd. In vicinity of Story Island, Goodluck Sedge, Barrel Island, West Sedge, and Goosebar Sedge	Large Approach to NNBF -proposed modeling Task 7; Restore and expand island complex to serve as surge filter; incorporate mosaic of elevations and habitats to increase surge attenuation value; likely in combination with intervention at Great Bay Blvd
Bio-Block or some type of Goliath Reef Ball - NNBF Features	Large, Eco-Friendly "hard-type" structure designed to withstand more energy than traditional reef balls and geotubes	On the North side of Barnegat Inlet in the general vicinity of degraded geotubes	Considerable energy in this area, which has resulted (and continues to result) in erosion.
Sedge Islands Restoration	Restore and build out Sedge Islands to prevent flanking of Barengat Island SSB and to minimize closure frequency.	North of Barnegat Light and south of Barnegat Bay	Restore and build out Sedge Islands to prevent flanking of Barengat Island SSB and to minimize closure frequency.
Thorofare Island Expansion	Significantly expand island to include upland, highmarsh, low marsh reef complex.	At Thorofare Island adjacent to large community (Mill Creek Park)	Island complex wraps around community towards Henderson Memorial Bridge
Manasquan Inlet	Consider reshaping of Gull Island to prevent wave propagation across shoal	Gull Island adjacent to Masasquan Inlet	Ideas in vicinity of Manasquan Inlet may also include: Parallel island to protect communities and shoreline to the north. Add dunes to beachfront, perhaps consider alternate vegetation approaches (naturally build, biomass incorporation, alternate planting
Barnegat Bay Living Breakwaters	Large bay of water that results in substantial fetch and wave energy. Dampen those forces through strategic integration of living breakwaters.	Placement would occur in Barnegat Bay. Modeling could help inform placement strategies	This NNBF approach could reduce sometimes subdtantail fetch that is eroding north bay shorelines. The living breakwaters would also offer habitat and recreation functions.
Butler's Beach Community	Develop created island or island complex to include upland, high/low marsh complex w/ reef in front of community to protect from surge, wave energy, etc.	Immediately adjacent to Butler's Beach Community in Barnegat Bay Area	Island complex wraps around community like "half-moon" and/or constructed as multiple island network that offers CSRM benefits and added ecological benefits.
Berkeley's Shores Community	Develop created island to include upland, high/low marsh complex w/ reef in front of community to protect from surge, wave energy, etc.	Immediately adjacent to Berkeley's Shores Community in Barnegat Bay Area	Island complex wraps around community like "half-moon" and/or constructed as multiple island network that offers added protection.
Sunrise Beach Community	Develop created island to include upland, high/low marsh complex w/ reef in front of community to protect from surge, wave energy, etc.	Immediately adjacent to Sunrise Beach Community in Barnegate Bay Area.	Island complex wraps around community like "half-moon" with potential nexus to adjoining marsh system.
Tuckerton Beach Community	Develop created island to include upland, high/low marsh complex w/ reef in front of community to protect from surge, wave energy, etc.	at Tuckerton Beach	Island complex wraps around community like "half-moon" and/or a series of multiple islands that offer additional CSRM and ecological benefits.
Other exposed communities immediately adjacent to bay area(s) and prone to storm surge, etc.	Similar to previous communities, there is an opportunity to introduce large NNBF island features (diverse composition, scaling, etc.) that offer added CSRM benefits.	Other example areas include, but are not limited to, Long Point Island; Green Island, Windor Park; Coates Point; Berkely Shores; and Laurel Harbor	Island complex wraps around community like "half-moon" and/or a series of multiple islands that offer additional CSRM and ecological benefits.

Central Region (from Corson's Inlet including Great Bay Blvd)

Project Idea	*Description*	*General Vicinity*	*Comments*
Horizontal or Ecotone Levees	In addition to traditional 3:1 Levee; propose placement of material to construct 30:1 or 50:1 slope for horizontal levee; replace flood walls with levees	Ocean City, Atlantic City, and other possible locations; Where traditional levees or floodwalls must remain - pursue environmental enhancement of traditional infrastructure	Locations where traditional levee or flood wall has been proposed, but there is available space on the degraded marsh/water interface side; combine levee/flood wall with wetland to reduce overall height of ectone levee
Absecon/Brigantine Island/Wetland Creation and Restoration [PROPOSED MODELING	Construction of large island(s) complex that serve as "speed bump" and dampening surge.	Includes vicinity of Brigantine, Dog Island, Weakfish Island and Shad Island	Large Approach to NNBF -proposed modeling Task 7; Work with Forsythe NWR to support existing wetlands behind Brigantine
Dunes / I-Wall Complex	Pile up "sand" /sediment abuting I-Wall Complex	Where I-Flood Walls are still required because of limited space.	Possible to reduce overall height of flood wall with added sand
Dune Enhancement	Current dunes are between 12-14' in height (ie. Absecon Island) - consider up to 20'	On barrier islands; Brigantine area	Although not part of NJBB study per se; building up dunes on ocean-side of barrier islands represents another potential defense strategy.
Great Egg Harbor Inlet Island [PROPOSED MODELING]	Restore/expand marsh islands in vicinity of Great Egg Harbor Inlet to replace or reduce operation of proposed SSB	Vicinity of Great Egg Harbor	Large Approach to NNBF structure - proposed modeling Task 7; Restore/expand marsh islands in vicinity of Great Egg Harbor Inlet to replace or reduce operation of proposed SSB
Mystic Island and Osborne Island Communites	Develop created islands to include upland, high/low marsh complex w/ reef in front of community to protect from storm surge and dampen wave energy, etc.	Mystic Island and Osborne Island Communities	Island/Marsh complex wraps around Mystic Island in "half-moon" shape with nexus to adjoining marsh. Osborne Island already somewhat protected, but additonal island features from Mystic and Tuckerton Beach Community provide additional protection.

South Region (Cape May to Corson's Inlet)

Project Idea	*Description*	*General Vicinity*	*Comments*
Horizontal or Ecotone Levees	In addition to traditional 3:1 Levee; propose placement of material to construct 30:1 or 50:1 slope for horizontal levee; replace flood walls with levees	North Wildwood, Wildwood Crest, Wildwood, Stone Harbor & Seven Mile Island area (other possible locations); Where traditional levees or floodwalls must remain - pursue environmental enhancement of traditional infrastructure	locations where traditional levee or flood wall has been proposed, but there is available space on the degraded marsh/water interface side; combine levee/flood wall with wetland to reduce overall heigh of ectone levee
Speed Bump Islands	Speed bump islands to knock down hydrograph—more of a surge filter and barrier		Construct islands using maintenance dredge material or dreding NJIWW back to original project depth
Dunes / I-Wall Complex	Pile up "sand" /sediment abuting I-Wall Complex	Where I-Flood Walls are still required because of limited space.	Possible to reduce overall height of flood wall with added sand
Strategic Placement of sediment on/adjacent to existing wetlands	Support existing wetland complexes given their existing function		existing wetlands because they are already providing some measure of risk management, can use navigational DM to do this in some areas

SHARK RIVER AND COASTAL LAKES REGION

The Shark River and Coastal Lakes region combines two of the study area regions from the NJBB CSRM Feasibility Study into one area. This area stretches from Lake Takanassee in Monmouth County south across the Shark River to Wreck Pond in Ocean County. It contains 16 freshwater and brackish lakes, many of which are non-tidal yet nonetheless connected to the Atlantic Ocean in some way. Historically, many of these lakes were estuaries, but today they exhibit a range of conditions that subject them to different types of flood risk. Much of this region is highly urbanized and the water quality of the lakes is compromised by stormwater runoff. This region is unique to the study as it does not have any back bay wetlands protected by sand bars, as is the condition in most of the study area south of the Coastal Lakes Region.

NNBF Opportunities

Due to the highly variable conditions of the various lakes, very few generalizable NNBF responses are possible within this region. The reduction of flood risk is something that must be considered on a lake-by-lake basis. However, the opportunity of terracing or lining lakes with vegetation that could serve as stormwater filters, habitat, and increased recreational amenities is one overall strategy that may be applicable (see (2) in Part II). Other possibilities include the creation of islands within the river itself in order to reduce storm effects to the surrounding coastlines.

Legend

- Tidegate Improvements
- Shoreline Enhancement
- Island Expansion
- Dune Enhancements

0 0.75 1.5 3 mi.


Deal Lake
Sunset Lake
Lake Wesley
Fletcher Lake
Sylvan Lake
Silver Lake
Lake Como
Spring Lake

NORTH REGION

The north region of the study area extends from the Manasquan Inlet south to Little Egg Harbor Inlet and the Great Bay estuary. It is the largest region of the analysis and includes areas in Ocean, Burlington and Atlantic Counties. This region is characterized by large bays with very few openings or inlets to the Atlantic and includes Barnegat Bay, Manahawkin Bay, Little Egg Harbor, and Great Bay. The typical conditions here include barrier beaches or spits that separate the Atlantic from the bays behind them. Most of the spits are highly developed on both the ocean and bay sides. The western coast of the bays are more diverse with urban development, single family homes, wetlands, and a collection of lagoon communities.

There are several structural CSRM alternatives being considered for this region within the feasibility study, including gated storm surge barriers (SSB) at Barnegat Inlet and Manasquan Inlet and bay closures at the Point Pleasant Canal and Holgate. As of this writing, the viability of each of these and/or their combination is still under review. However, the proposed Holgate bay closure would significantly impact the potential of particular EWN strategies within this region. Additionally, because options that included this strategy (3F in the NJBB CSRM IFS) failed the environmental quality (EQ) screening in the feasibility study, the work included in this report assumes that a bay closure in this area is infeasible due to ecological concerns. The feasibility study also indicates that the proposed SSB that would be constructed between Little Egg Inlet and Brigantine Inlet at the southern end of this study area is likely not feasible due to the combination of financial and environmental costs. Storm surge barriers at Barnegat and Manasquan would have varied effects on the EWN potential of the strategies included in this report, but it is believed that, with the exception of the Holgate bay closure, none of these are completely incommensurable.

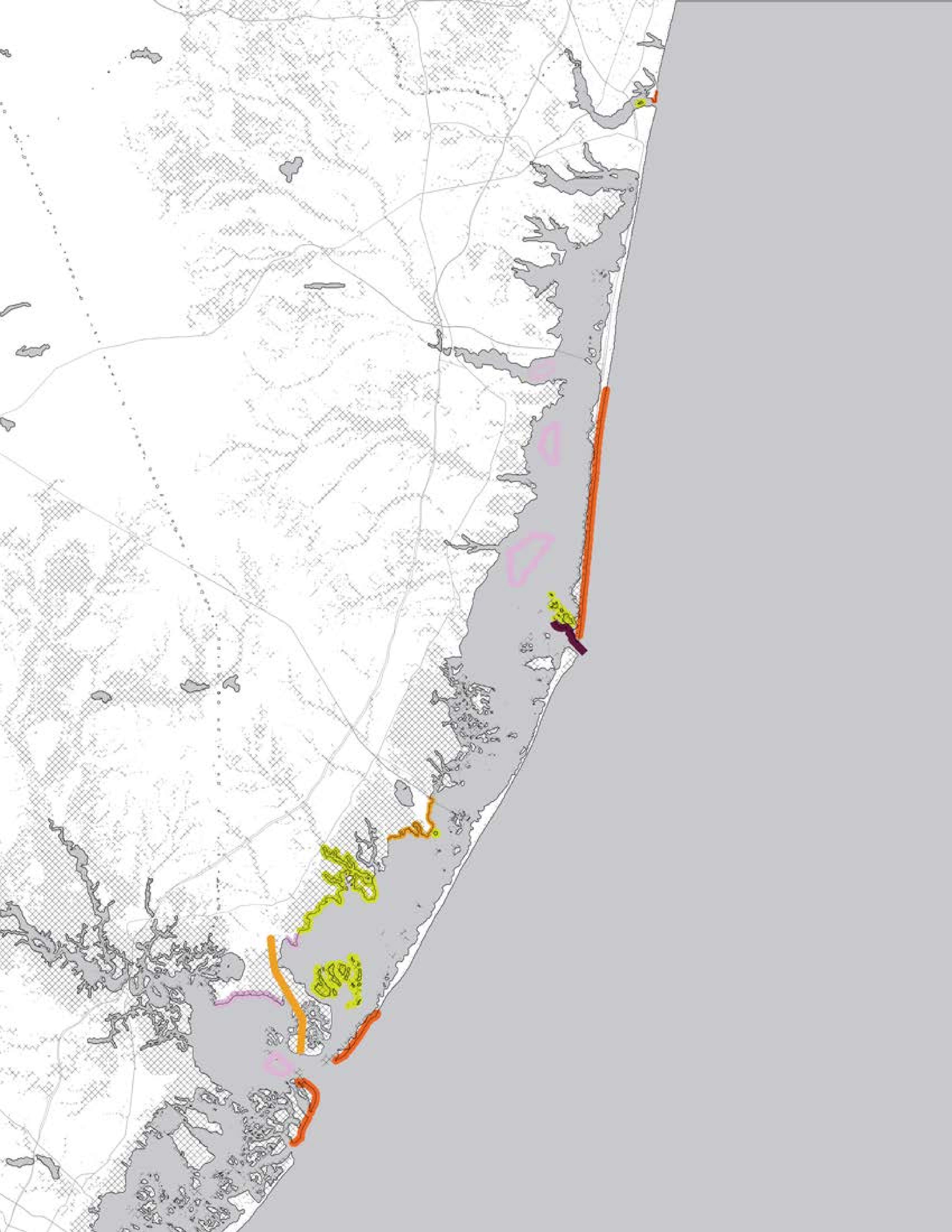
NNBF Opportunities

As the largest region of the study, and a collection of somewhat similar conditions, this region provides the opportunity to study a series of strategies that could be repeatedly deployed at large scale, calibrated to specific conditions. For this report, we have used Barnegat Bay as our example for this approach, demonstrating the range of NNBF strategies that could be used at a bay-wide scale to address some of the more ubiquitous conditions there. If the Holgate barrier option and the Little Egg-Brigantine Storm Surge Barrier are not included in the TSP, then this will place significant importance on the performance of the Tuckerton Peninsula/Great Bay Boulevard wetland complex and the system of sedge islands to the northeast of the peninsula. This report covers two possible NNBF in this area, including possibilities for the Tuckerton Peninsula (see page 54) and the modifications of the sedge islands to enhance their performance as a surge filter (see page 70).

Legend

- Horizontal or Ecotone Levee
- Island Expansion
- Dune Enhancements
- Bio-block or Goliath Reef Bal
- Island Creation

0 5 10 20 mi.



CENTRAL REGION

The Central Region extends from Little Egg Harbor and extends south to the Corson Inlet. This area contains many more inlets than does the North Region and has large urban populations on the barrier islands in Atlantic City, Brigantine, and Ocean City. Like the North Region, the western coast of the bay is a mixture of single family residential, wetlands, and small urban developments, including lagoon communities.

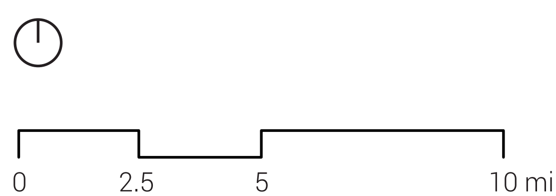
Structural CSRM strategies under consideration in the IFS for the Central region include SSB at the Absecon and Great Egg Harbor inlets and bay closures at either North Point or Absecon Boulevard. The viability of these strategies is still under consideration, but if bay closures are deemed necessary, the Absecon closure has been described as preferable from both an economic and ecological perspective, because it maintains the highest level of connectivity between the ocean and the bays.

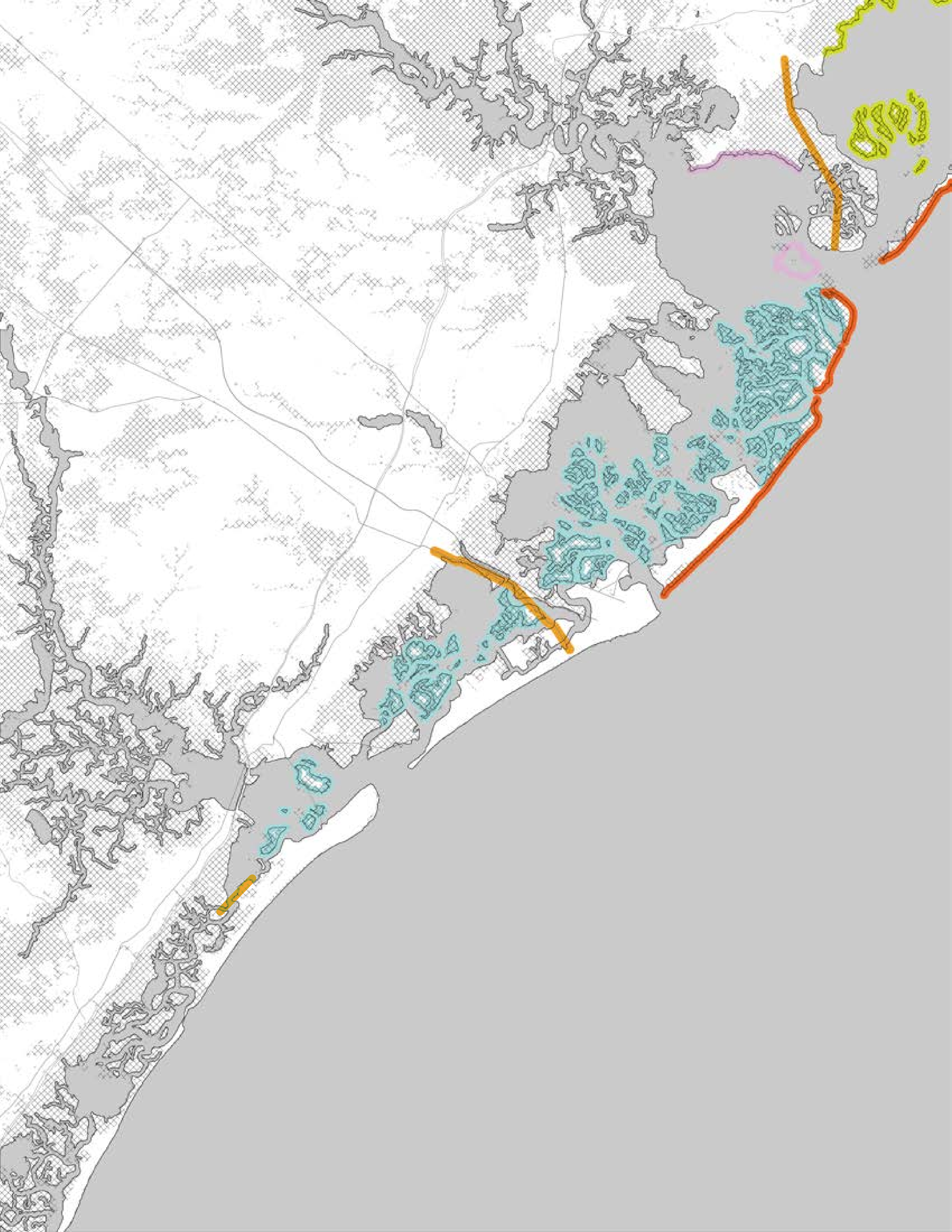
NNBF Opportunities

One of the significant challenges of this region is the flooding of urban areas from the bay during periods of high water. In addition to the aforementioned SSB and bay closures, there is likely to be some consideration of flood wall or levee construction to protect urban populations on the barrier islands. This report discusses one such condition in Ocean City, looking at how it can be developed as a NNBF (see page 40). Many of the previously discussed possibilities for wetland creation and bayfloor shallowing may have application in this region as well, particularly in and around Reed's Bay in the event of the bay closure moving to Absecon. The CSRM effects of such wetland enhancements are currently under consideration by the modeling team.

Legend

- Horizontal or Ecotone Levee
- Island Expansion
- Dune Enhancements
- Island Creation
- Wetland Creation or Restoration
- Wetlands





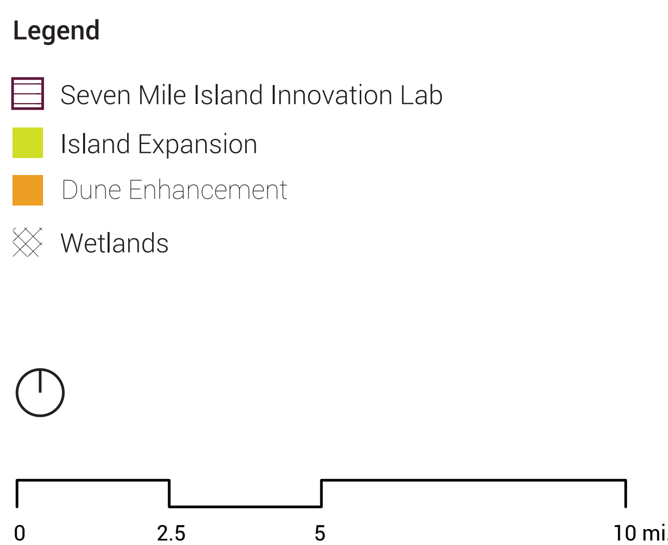
SOUTH REGION

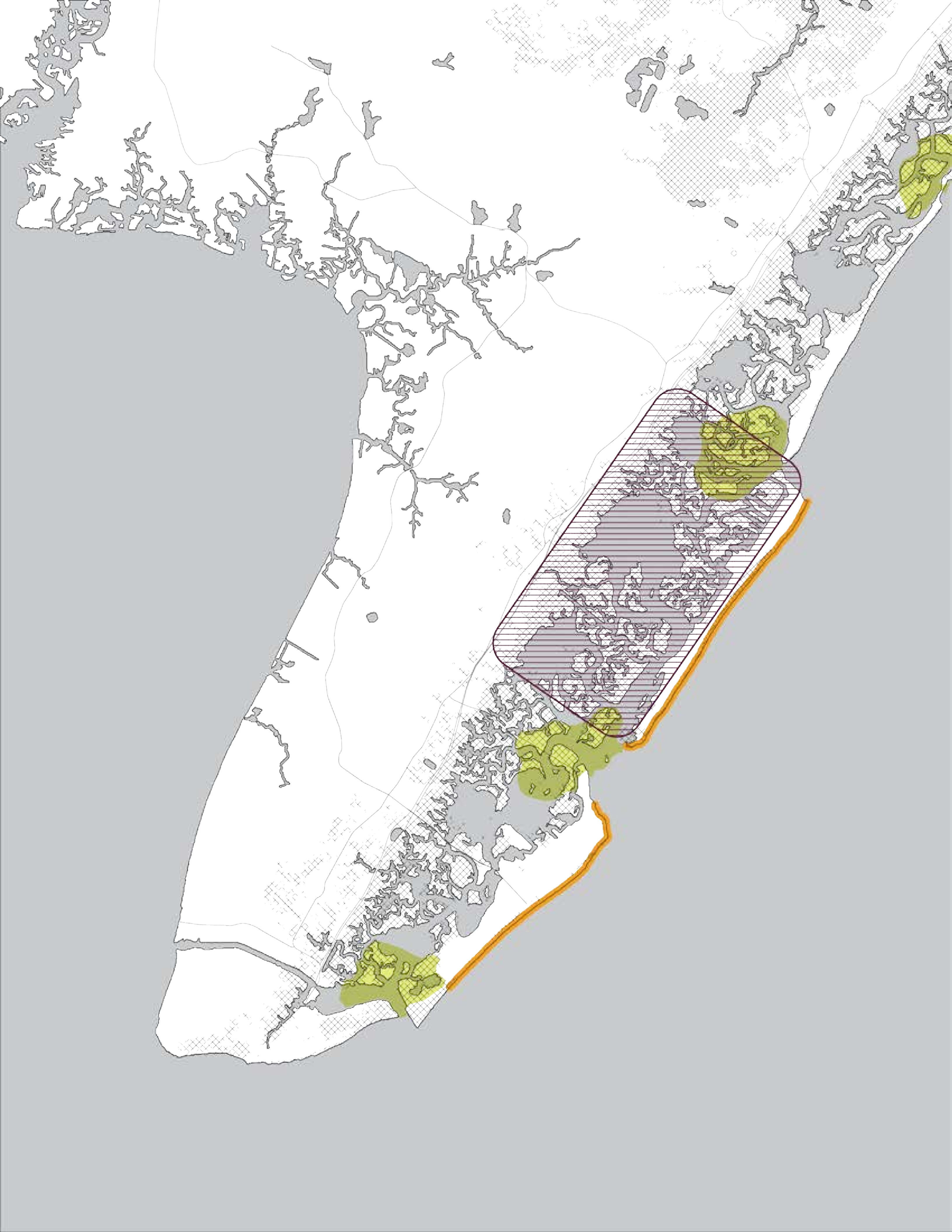
The South Region extends from Corson Inlet south around Cape May. This region is characterized by a large number of inlets and developed urban regions on the barrier islands. Many significant urban areas exist in the region, including Avalon, Stone Harbor, Wildwood and Cape May. However, the western edges of the bay are notably less developed than in other regions.

According to the Interim Feasibility Study, the only alternatives that are feasible in the southern region are nonstructural options, with or without a perimeter plan to protect the western side of the barrier communities.

NNBF Opportunities
Due to the suggested infeasibility of structural CSRM measures, the South Region will likely require significant investments in both nonstructural strategies and strategies that enhance wetlands in order to provide enhanced storm protection. While the decision was made for this study to focus NNBF development in the Central and North regions, the perimeter plan that will likely be necessary for this region could benefit from NNBF similar to those described for Ocean City (see page 40) or the wetland enhancement projects described elsewhere in this report. Dune enhancement and beach nourishment is also possible in this region as a method of protecting barrier island communities.

Finally, the Seven Mile Island Innovation Lab (see page 74) is a collaborative project between the USACE, the Wetlands Institute, and the State of New Jersey, began in 2019. It is developing innovative methods of sediment management that have significant potential to contribute to CSRM.





Part II

DESIGN CONCEPTS

Drawing on the broad range of NNBF opportunities identified during the workshops (as described in Part I), the PDT has collaboratively selected a subset of NNBF for further advancement as design concepts. These NNBF have been selected first for their potential to combine CSRM value with ecological and social benefits.

They have also been selected to demonstrate the range of scales that NNBF can be deployed at within the larger study area. These scales range from a comprehensive regional scale (XXL) to the scale of discrete landscape interventions (M-S). A given type of NNBF, such as a "surge filter", can be deployed at any of these sizes: a single or small grouping of marsh islands might constitute a "S" or "M" surge filter; a dense archipelago of marsh islands at one particular inlet could be an "XL" deployment of surge filters; and the strategic placement of marsh islands throughout the breadth of a bay could be an "XXL" use.

It is also important to note that these design concepts are potentially applicable in multiple geographic circumstances. The Ocean City horizontal levee/wall, for instance, has been developed to suit the particular circumstances of one stretch of proposed seawall in Ocean City, but the general concept that it represents could likely be deployed in other locations where bayside perimeter protection is required. Similarly, the Beach Haven Surge Filter is representative of several potential surge filter locations that have been identified in Part I. Finally, the concepts described under the rubric of the XXL approach to Barnegat Bay, are presented as a toolkit of NNBF that could be deployed in a variety of circumstances. Mappings of both the Great Bay/Little Egg Inlet Region and of Barnegat Bay delineate opportunities for such deployments as well as conditions like marsh loss that should inform their placement.

The advancement of these NNBF has been shaped by collaborative discussions that have included both the EWN-LA project team and personnel from NAP. For several of the features in this section (as well as additional features not described in this section), their CSRM value was also evaluated by the modeling team. That evaluation is described in Part III of this report, and in more detail in the modeling team's report.

The design concepts in this report are arranged by scale, from small to large. The adjacent map shows the overlap between the selected areas for modeling and the design concepts that follow. See Part III for more detail on modeling areas.

Scale S-M

1 **Ocean City Horizontal Levee/Wall**
2 **Lagoon Communities Protection**
3 **Coastal Lakes Terracing**

Scale L

/ Great Bay and Little Egg Inlet Region [Mappings]
4 **Tuckerton Peninsula Barrier**
/ Great Bay Blvd Horizontal Levee [Model Area]

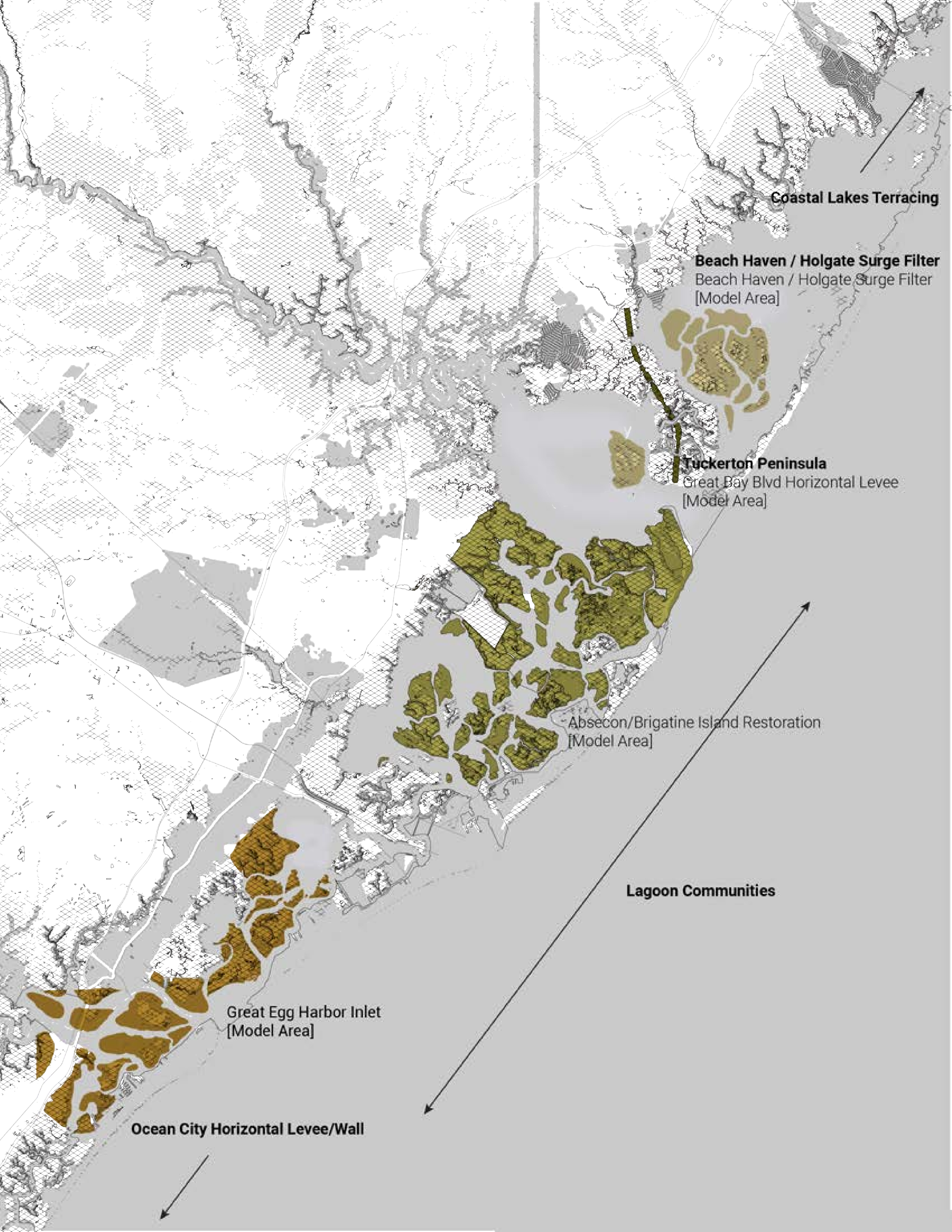
Scale XL

5 **Beach Haven Surge Filter**
/ Beach Haven/Holgate Surge Filter [Model Area]
6 **Seven Mile Island Innovation Lab**

/ Absecon/Brigatine Island Restoration [Model Area]
/ Great Egg Harbor Inlet [Model Area]

Scale XXL

7 **Barnegat Bay Shallows**
/ Barnegat Bay Region [Mappings]
/ 3 XXL Opportunities



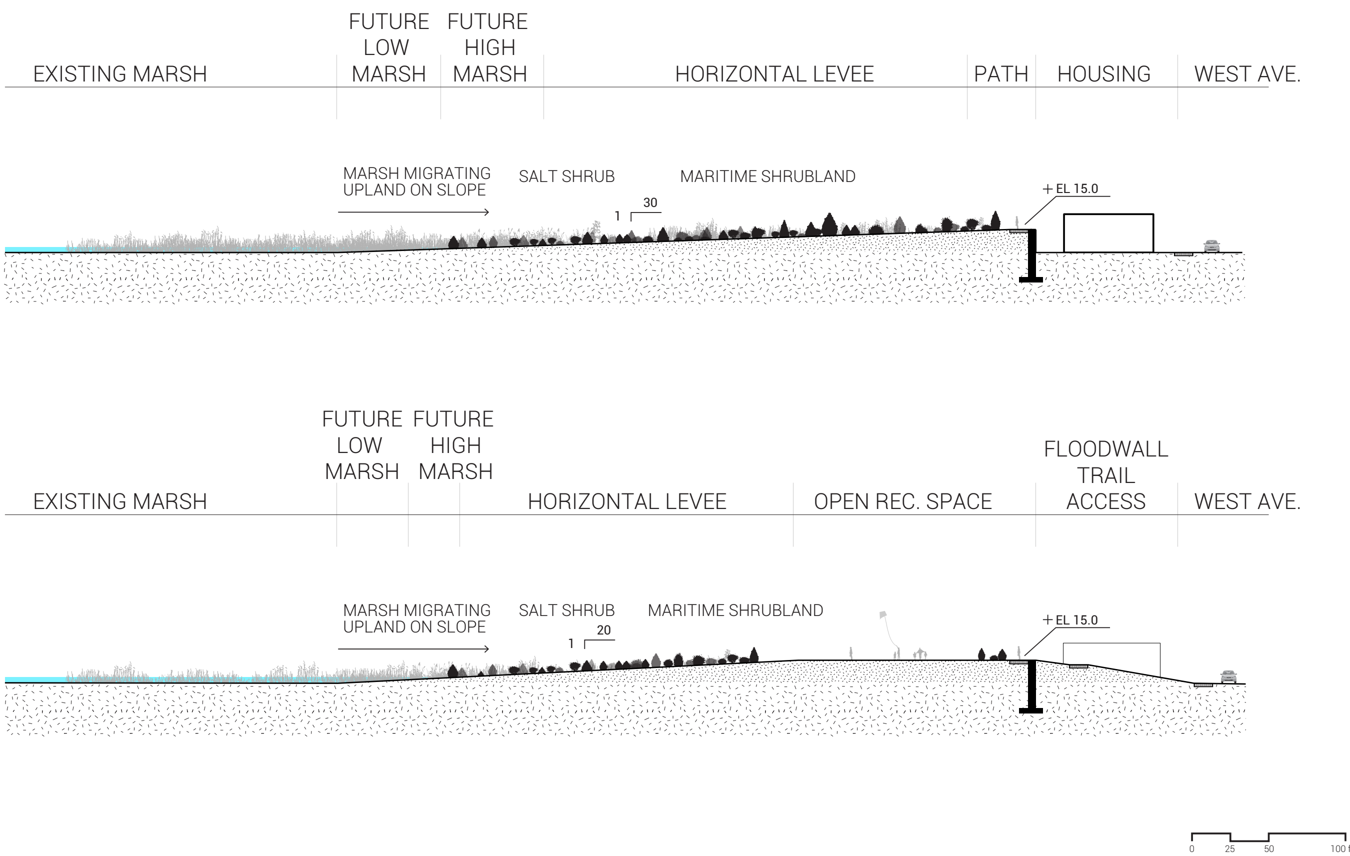
Coastal Lakes Terracing
Beach Haven / Holgate Surge Filter
Beach Haven / Holgate Surge Filter
[Model Area]
Tuckerton Peninsula
Great Bay Blvd Horizontal Levee
[Model Area]
Absecon/Brigatine Island Restoration
[Model Area]
Lagoon Communities
Great Egg Harbor Inlet
[Model Area]
Ocean City Horizontal Levee/Wall

1 OCEAN CITY HORIZONTAL LEVEE/ WALL

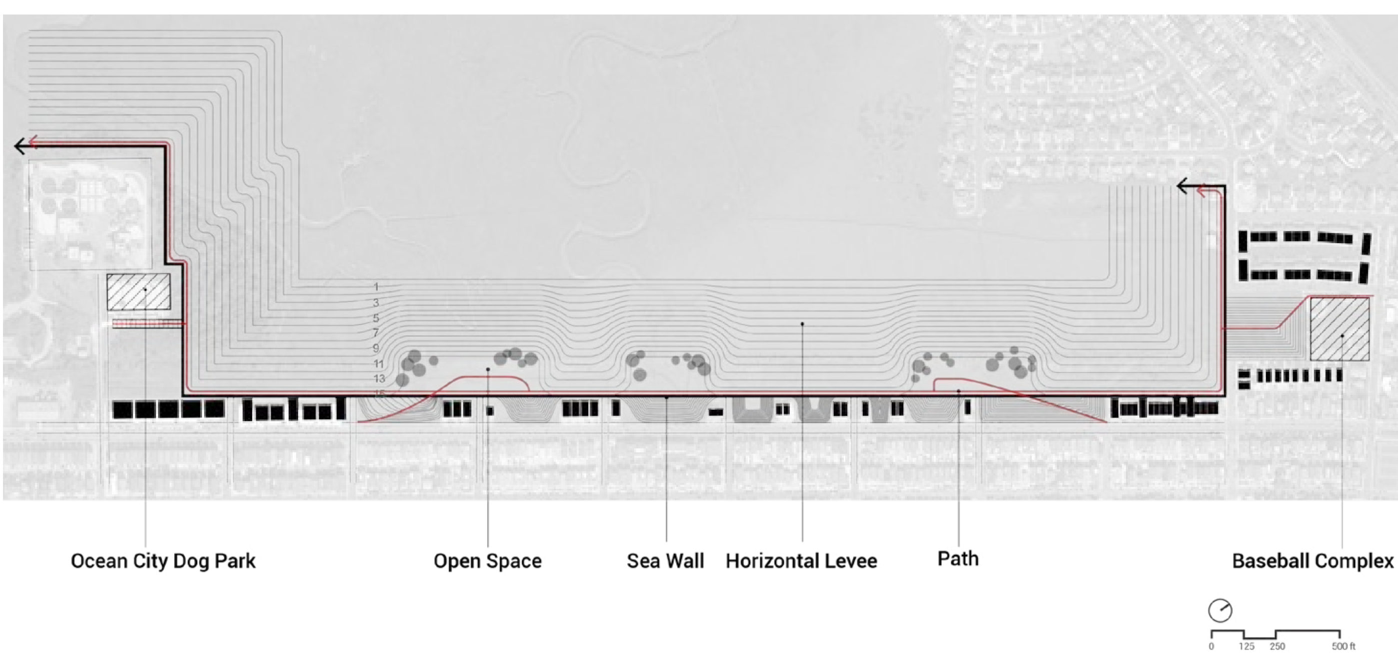
The feasibility study includes a large number of perimeter plan locations that would protect bayside communities from storm surge and rising waters. The features most typical in these protections are the levee and the seawall. In areas with dense populations, seawalls are less disruptive and take up less space. According to the feasibility study, the costs between the two strategies are comparable.

Levees could be modified in order to achieve NNBF objectives. The creation of a more horizontal levee with less steep (1:20-1:30) sides would allow for areas of elevated vegetation and possible social amenity that are not possible on the standard 1:2 slope levee. In the Central Region, where urban populations are dense, the ability to achieve both the space-saving qualities of the sea-wall and the ecological and social benefits of the horizontal levee could be desirable. Looking specifically at the community of Ocean City facing into the back bay wetlands, the hybrid "levee/ wall" design concept described here would modify the seawall that is under consideration between the Ocean City Dog Park and the Harry D. Vanderslice Baseball Complex.

The design concept for this Ocean City levee/ wall is intended to provide connectivity between two public resources in the city (the dog park and the ball fields) while also providing open space for residents and enhanced elevated habitat. Instead of the proposed zig-zagging of the seawall around properties, this design concept straightens, and thus shortens, the length of the wall in this area, filling in the spaces between homes with either elevated habitat or accessible routes to the top of the levee/ wall and a trail there. Slopes of the levee/wall vary along its length between 1:20 and 1:30 in order to accommodate the creation of more open space at the crest of the levee/wall.



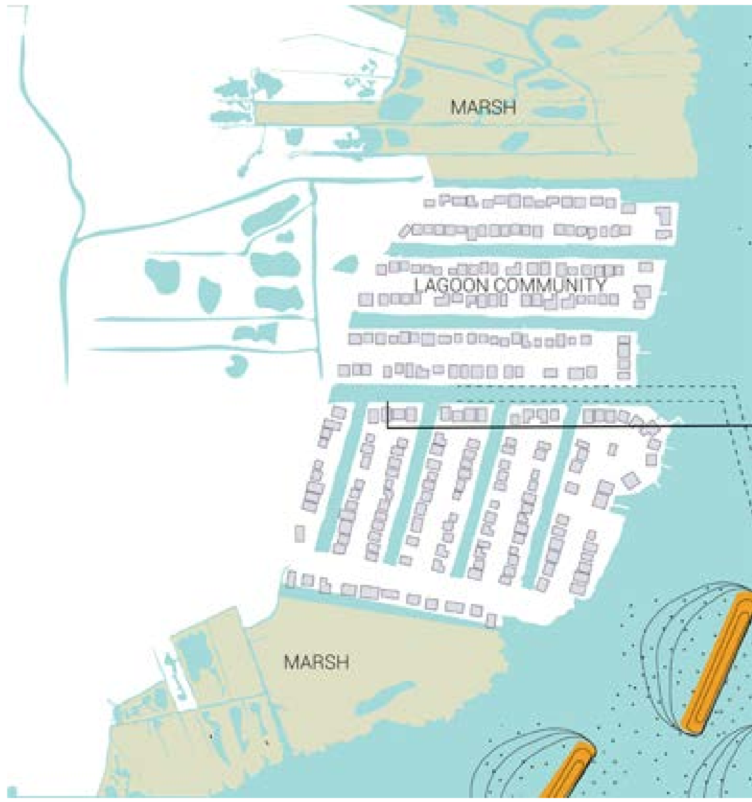
Ocean City Section

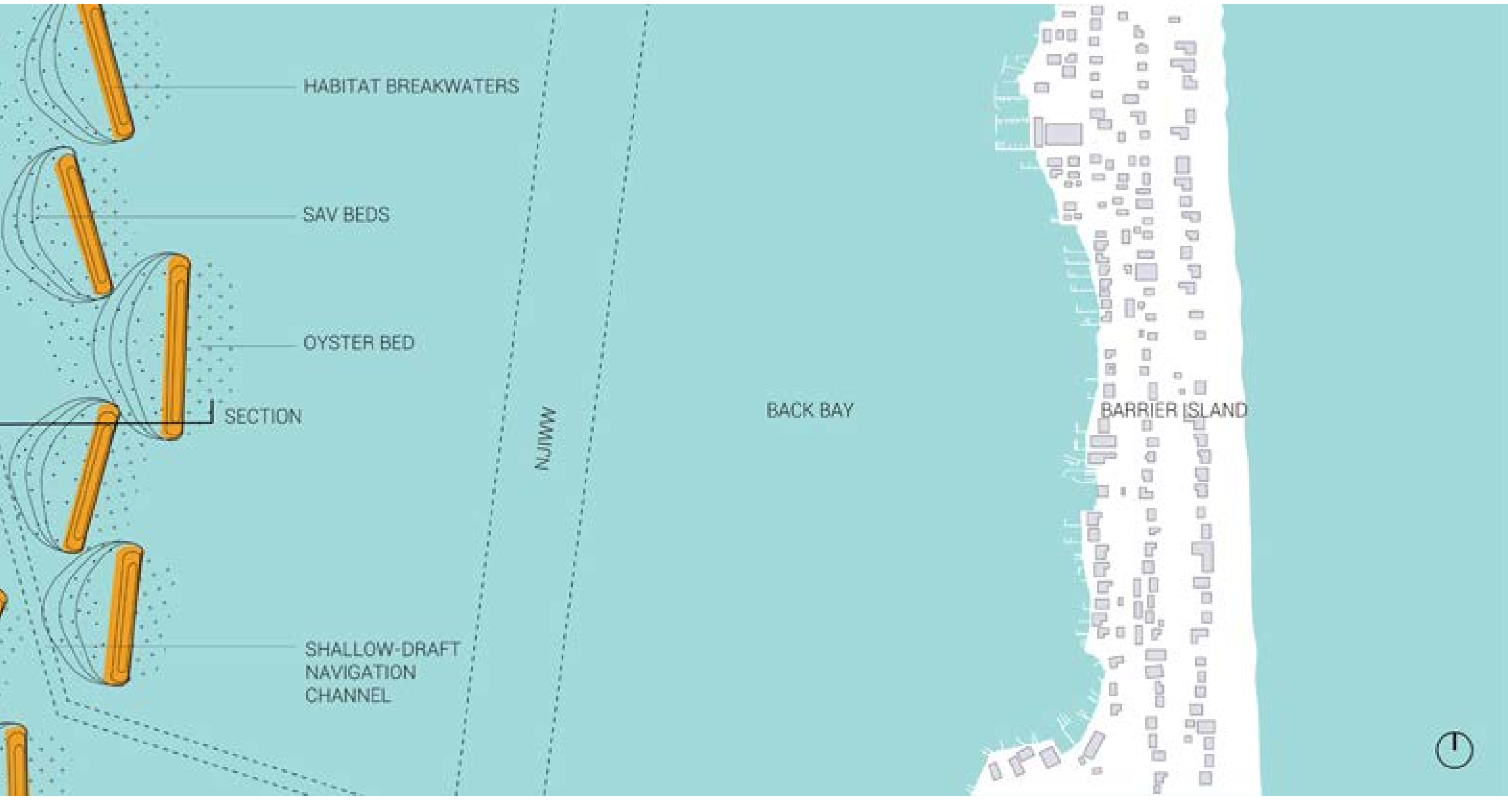


Ocean City Plan

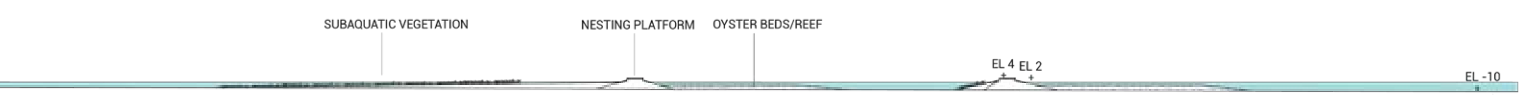
2 LAGOON COMMUNITY PROTECTIVE ISLANDS

One of the more characteristic conditions of interest within the north region is the collection of lagoon communities that exist along the western shore of the bay. Building traditional structural measures is infeasible in these circumstances, as the viability of these communities depends on their extensive shoreline and water access, but linear islands could be constructed in the bay to provide wave energy reduction, habitat, and recreational opportunities for them. As shown in the plan and section, 'habitat breakwaters' constructed of stone could form the core of these islands, with constructed oyster reefs on the eastern (bay) sides of the islands, and underwater slopes planted with SAV on the protected western sides. (These drawings are of a hypothetical location that has been collaged together from multiple actual locations, and should not be taken to represent a specific community.)





HABITAT BREAKWATER ISLANDS



3 COASTAL LAKES TERRACING

The wide range of conditions that exist within each of the coastal lakes of the study's northernmost region means that specific NNBF designs would need to be calibrated for each of the lake's particular features and flooding concerns. However, some generalized strategies are possible. Terrace construction around the lakes could be a method for creating habitat and filtering stormwater that continually compromises water quality. The CSRM value of this strategy would vary based on individual lake conditions, but, in many cases, the lakes serve as important flood storage areas during storms. Methods to increase flood capacity could include excavation of the lakes themselves, but would require specific knowledge of the Lake's hydrology and relationship to tidal versus overland flow. Using the Lakes as effective flood control might require updates to or the installation of tidal gates.

DEAL LAKE
Perimeter: 11.48m
Area: 0.26m²

SUNSET LAKE
Perimeter: 1.04m
Area: 0.02m²

LAKE WESLEY
Perimeter: 1.32m
Area: 0.02m²

FLETCHER LAKE
Perimeter: 0.86m
Area: 0.01m²

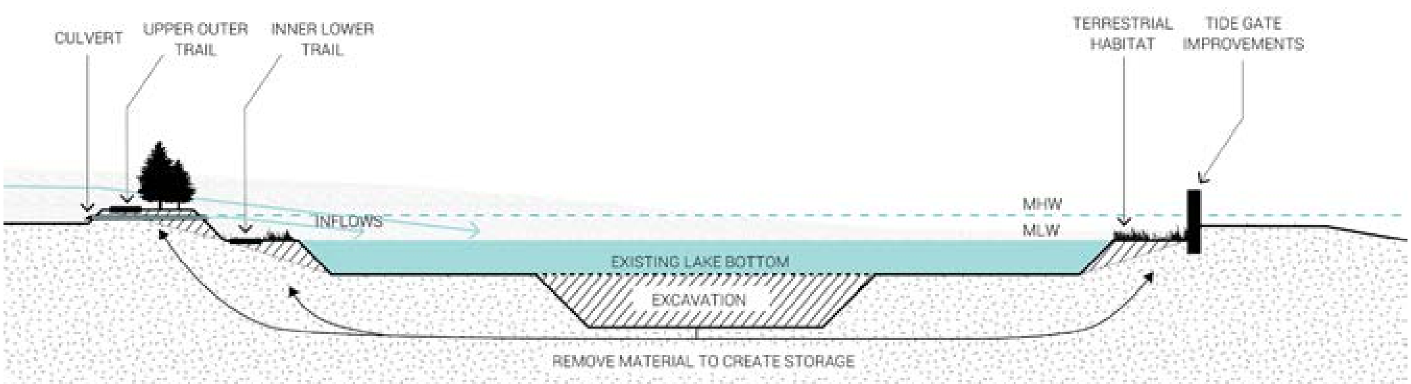
SYLVAN LAKE
Perimeter: 1.26m
Area: 0.03m²

SILVER LAKE
Perimeter: 0.89m
Area: 0.02m²

LAKE COMO
Perimeter: 1.17m
Area: 0.06mi²

Dimensions of coastal lakes that might benefit from terracing NNBF

Diagrammatic vision for Lake Como with excavated lake bottom, terraced perimeter with planted ecological communities, and trails.



Diagrammatic section of coastal lake NNBF concept with excavated lake bottom, terraced perimeter with planted ecological communities, and trails.

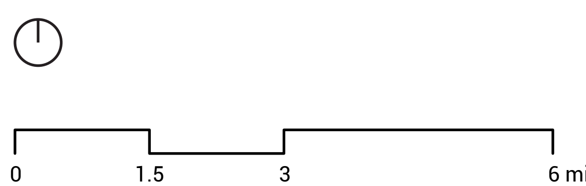
GREAT BAY AND LITTLE EGG INLET REGION

There are several L- and XL-scaled areas in this region that were studied by ERDC's modeling team. The results of these model studies are briefly addressed in Part III of this report. Full results are detailed in the modeling team's report. The modeling areas cconsidered by ERDC include the Beach Haven Surge Filter, the Tuckerton Peninsula Barrier, Wetland and Island creation around Absecon and Brigantine, and Marsh Island creation around Great Egg Harbor.

The following four maps of the Great Bay and Little Egg Inlet Region provide broader context for the two design concepts in this report—(4) Tuckerton Peninsula Barrier and (5) Beach Haven Surge Filter—which were part of ERDC's modeling studies. As projects that would require substantial material to contribute to CSRM benefits by creating and expanding existing islands and marshes, their proximity to potential sediment sources such as the NJIWW, historic dredged material placement areas, and CDFs are highlighted here. Marsh loss is shown to indicate possible areas for restoration used to inform the location and shapes of NNBF in the following two design concepts.

Legend

- Existing Marshlands
- Wetland Lost
- Reclaimed Land
- Beneficial Use Project
- CDFs and Historic Placement Areas
- Submerged Placement Areas (incl. Historic)
- NJIWW
- Drainage Ditch




Tuckerton Bay
Great Bay
Mordecai
Island

GREAT BAY AND LITTLE EGG INLET REGION

This map shows marsh loss, expected marsh erosion, and potential areas of marsh migration with one, two, and three feet of sea level rise. The prioritization and location of NNBF in this region should respond to sea level rise projections and the viability of maintaining marsh elevations and/or assisting marsh migration.

Legend

- Lost Wetland
- Salt Marsh Erosion
- Salt Marsh Conversion with 1′ SLR
- Salt Marsh Conversion with 2′ SLR
- Salt Marsh Conversion with 3′ SLR
- Marsh Migration Area with 1′ SLR
- Marsh Migration Area with 2′ SLR
- Marsh Migration Area with 3′ SLR
- Inhibited Marsh Migration Area

0 1.5 3 6 mi

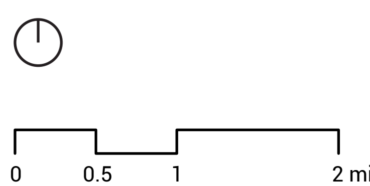

Tuckerton Bay
Great Bay

GREAT BAY AND LITTLE EGG INLET REGION

This map provides a closer view of the areas where the Tuckerton Peninsula Barrier and Beach Haven Surge Filter features are located.

Legend

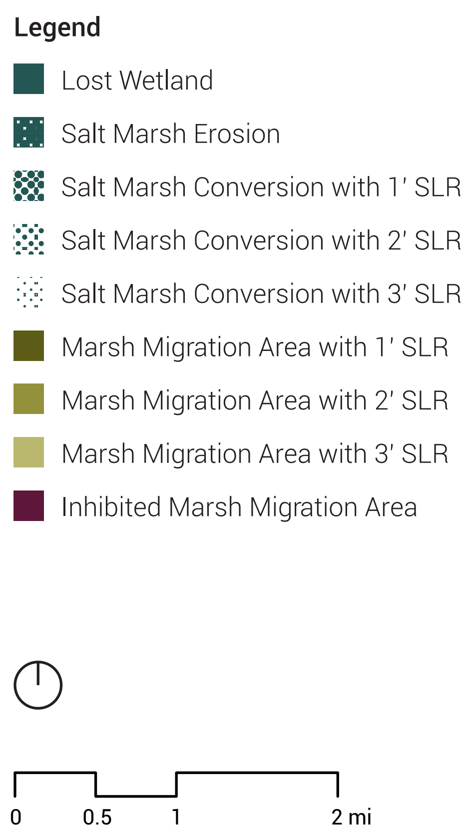
- Existing Marshlands
- Wetland Lost
- Reclaimed Land
- CDFs and historic placement areas
- NJIWW
- Drainage Ditch




Tuckerton Bay
Great Bay

GREAT BAY AND LITTLE EGG INLET REGION

This map provides a closer view of the areas where the Tuckerton Peninsula Barrier and Beach Haven Surge Filter features are located.



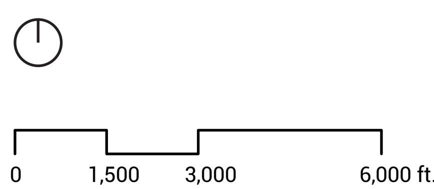
Tuckerton Bay
Great Bay
Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS

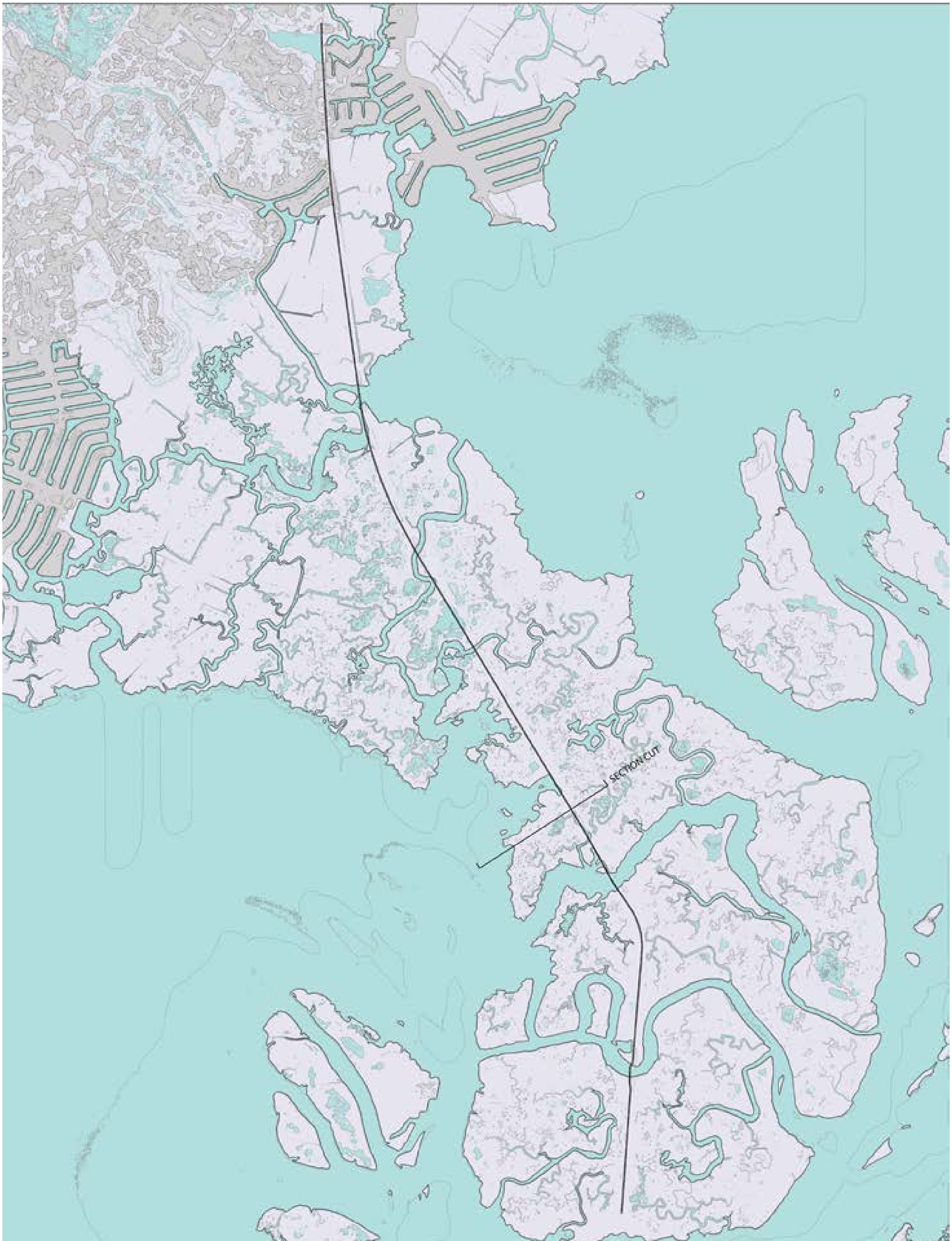
4 TUCKERTON PENINSULA BARRIER

The Tuckerton Peninsula, and the Great Bay Boulevard that serves as its spine, provide access to a large wetland complex that stretches across most of the southern end of Barnegat Bay, buffering it from Great Bay to the south. While the feasibility of the Holgate Bay closure feature (that would have included the Great Bay Boulevard structure) was not preferred due to environmental concerns, the use of the peninsula as a CSRM feature is still under exploration, as it spans the majority of the bay.

This report looks at three possible options for a NNBF/CSRM feature located on or near the peninsula. These include a horizontal levee (which is the option that was modeled by ERDC), a series of offshore breakwaters, and an expanded marsh complex. Each concept is intended to provide some level of CSRM value while also enhancing local ecological conditions.

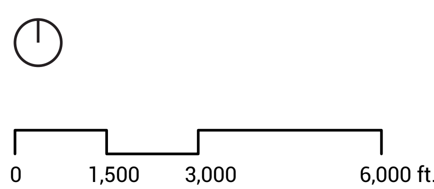
These options are not mutually exclusive. Any two options or even all three options could potentially be combined into a preferred alternative.

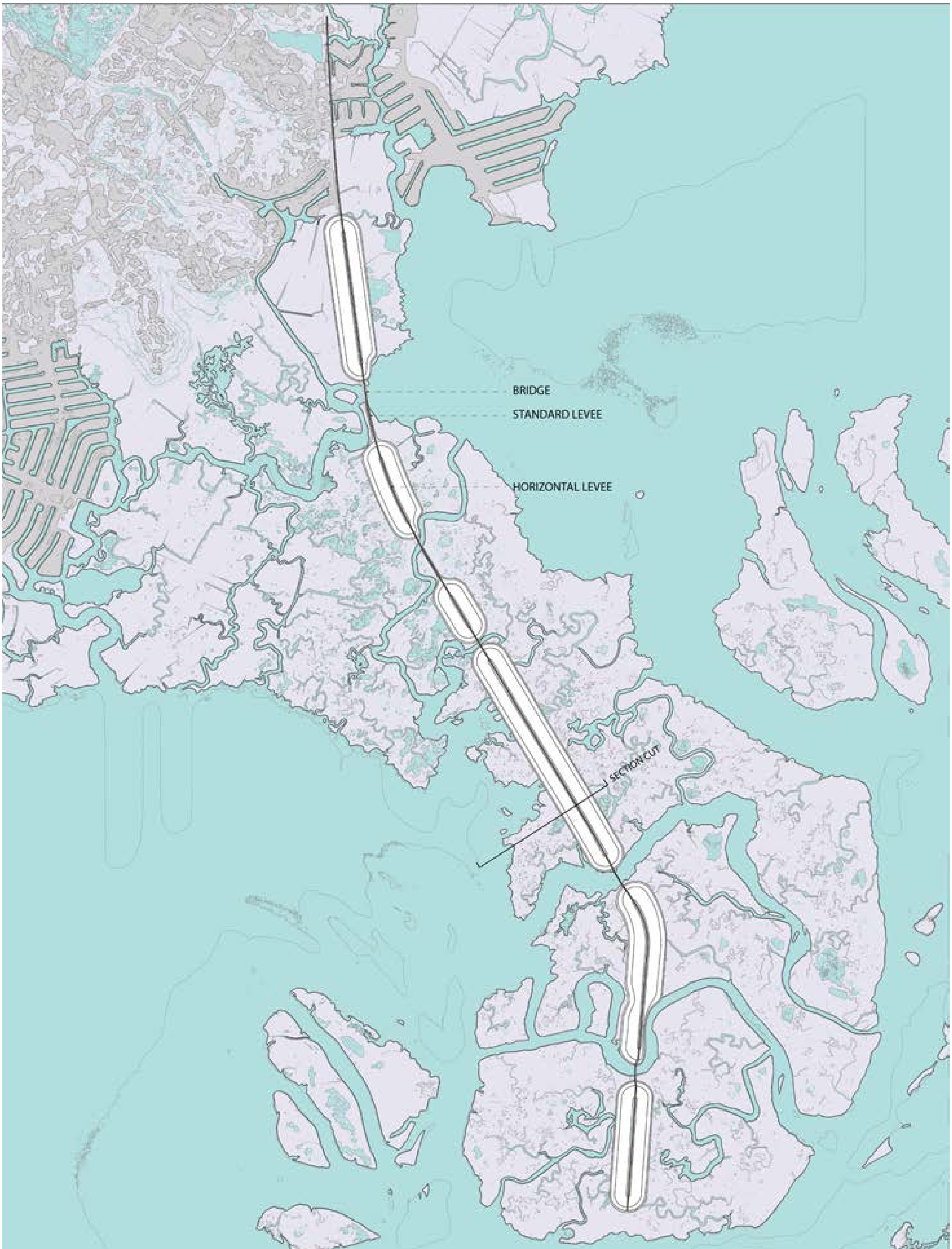



SECTION CUT

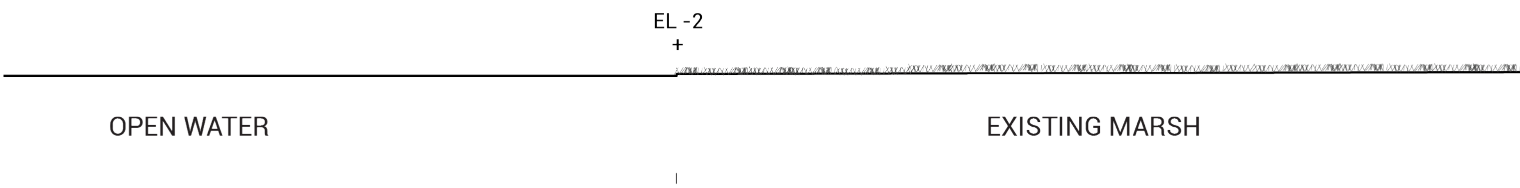
4a TUCKERTON PENINSULA: HORIZONTAL LEVEE OPTION

The horizontal levee option shows the elevation of Great Bay Boulevard to approximately +15 NAVD88, with shallow slopes (1:30) extending away from it into the marshes on either side. These slopes could be planted with marsh species at their bases and then transition into shrubland for most of their flanks, before reaching a mowed meadow near the levee crest. This option would provide significant resistance to storm surge moving across the Tuckerton Peninsula, but it would require a large volume of fill to construct.

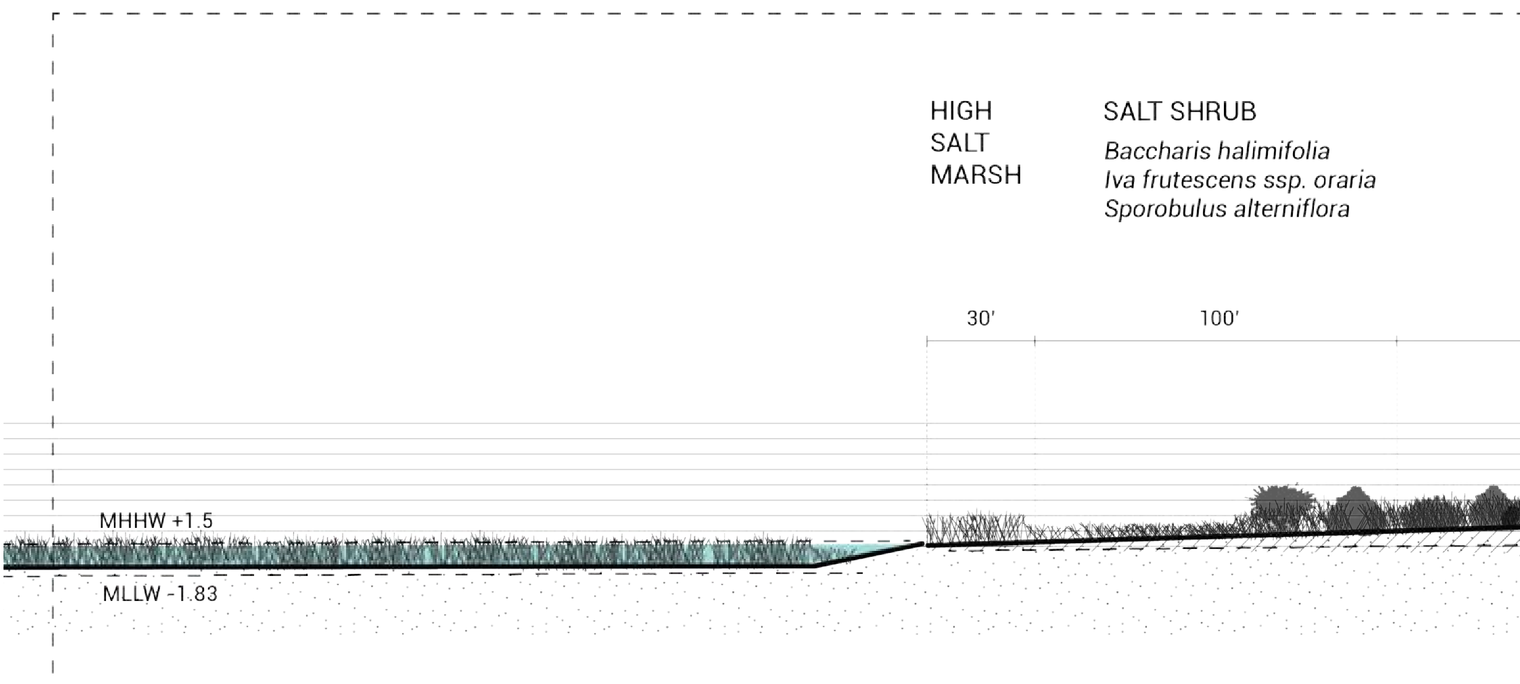



BRIDGE
STANDARD LEVEE
HORIZONTAL LEVEE
SECTION CUT

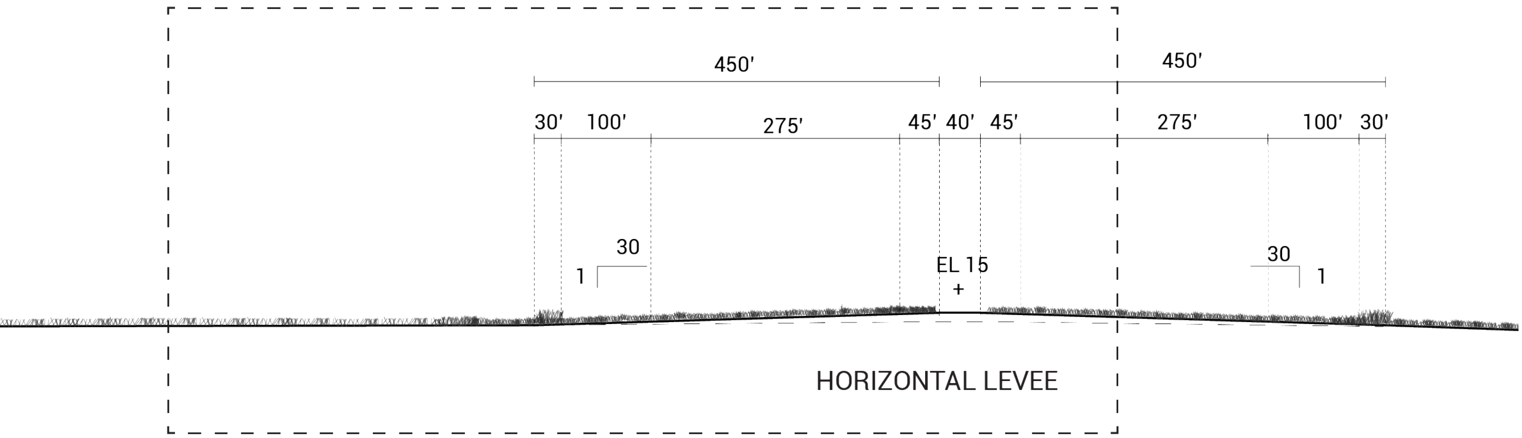
4a TUCKERTON PENINSULA: HORIZONTAL LEVEE OPTION



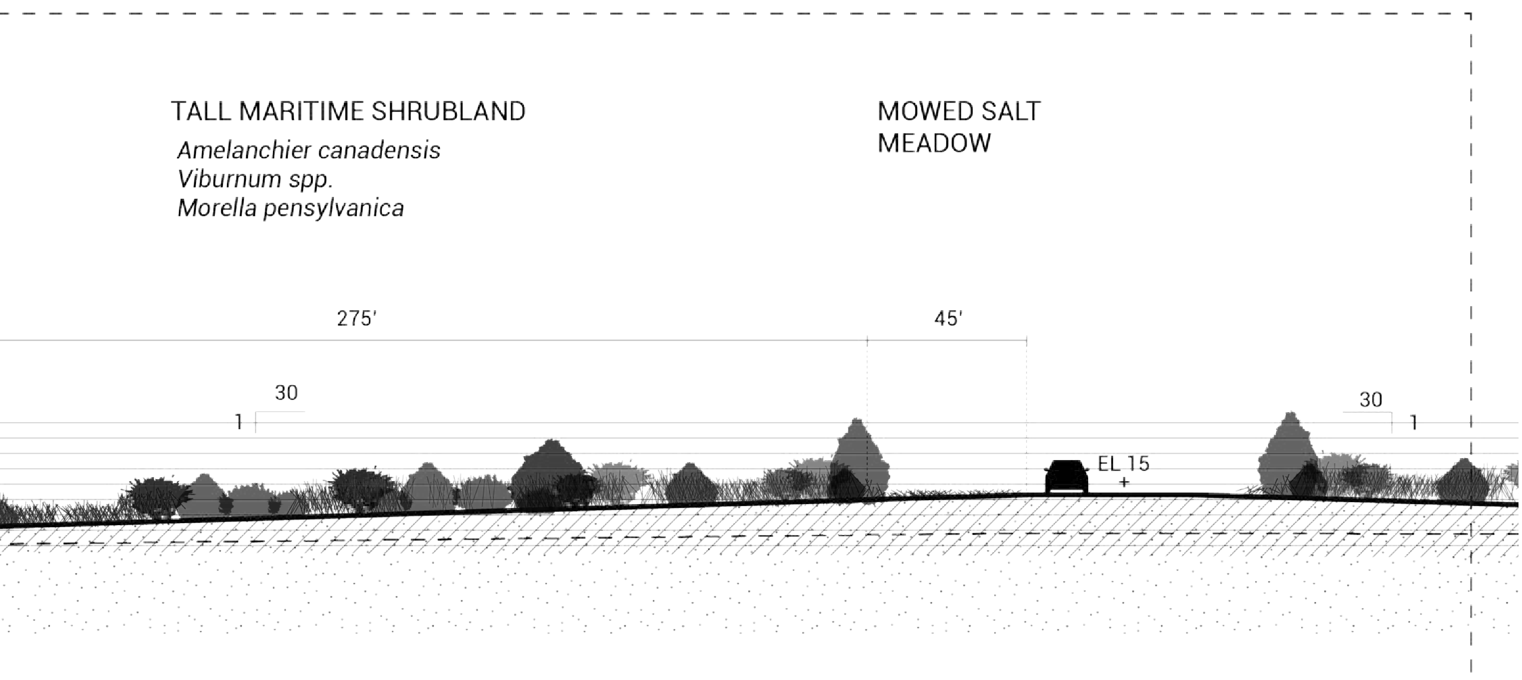
4a HORIZONTAL LEVEE



DETAIL 4a.1

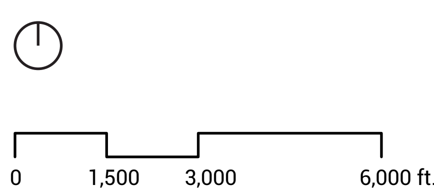

450'
450'
30'
100'
275'
45'
40'
45'
275'
100'
30'
30
1
EL 15
+
30
1
HORIZONTAL LEVEE

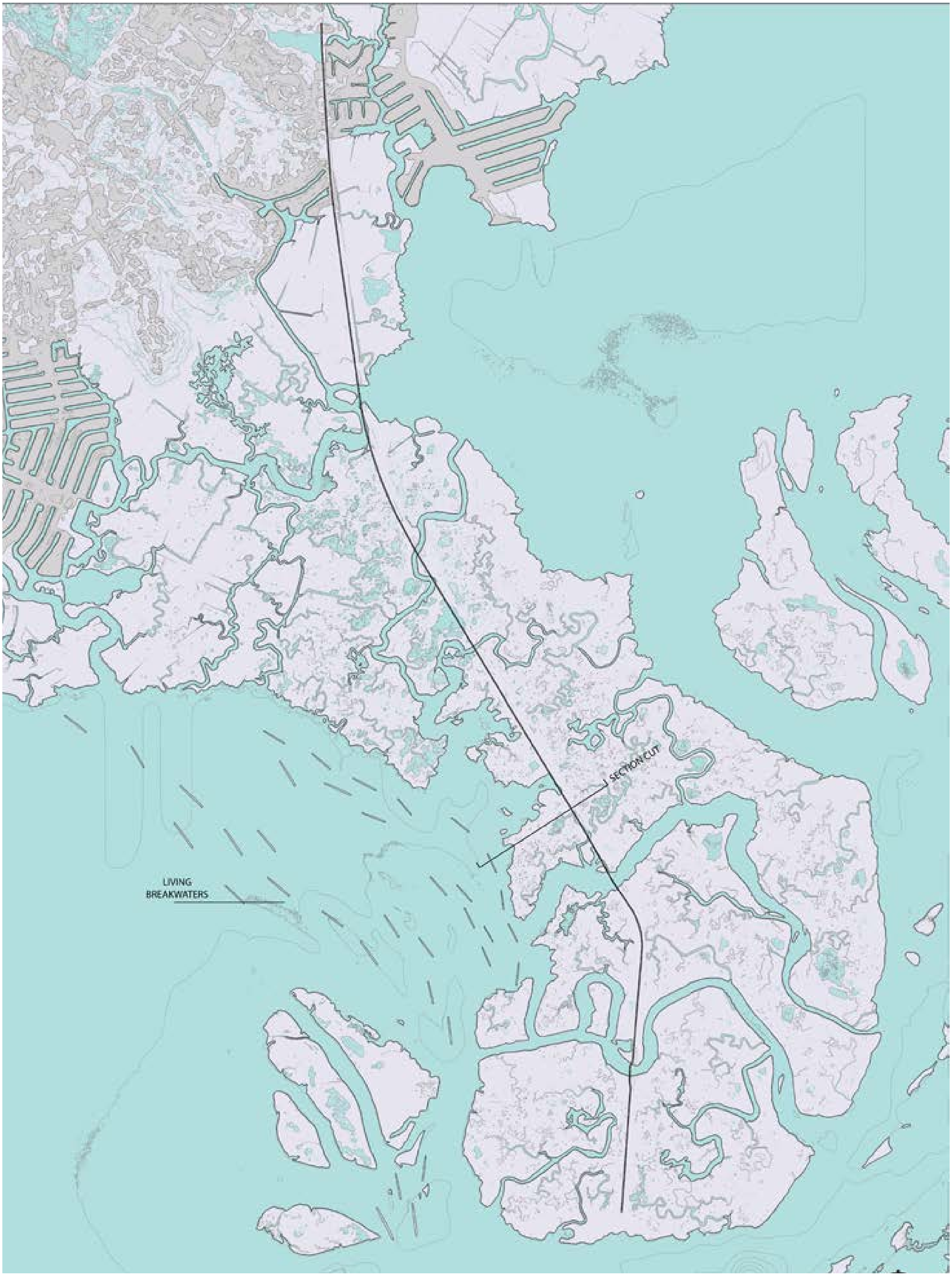
DETAIL 4a.1


TALL MARITIME SHRUBLAND
Amelanchier canadensis
Viburnum spp.
Morella pensylvanica
MOWED SALT
MEADOW
275'
45'
30
1
EL 15
+
30
1

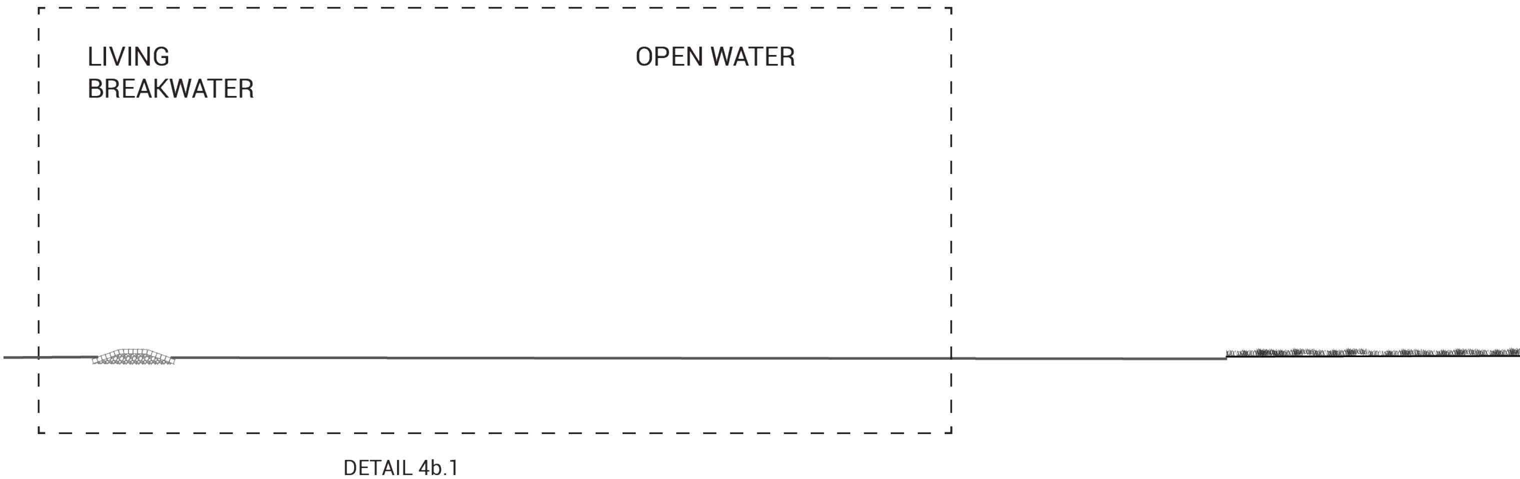
4b TUCKERTON PENINSULA: LIVING BREAKWATER OPTION

The living breakwater option moves the surge resistant features offshore and southwest into Great Bay, where a series of linear breakwaters could be designed to double as habitat features for shellfish, crustaceans, and fish. A case study of a similar project off Staten Island is noted in Appendix 2.

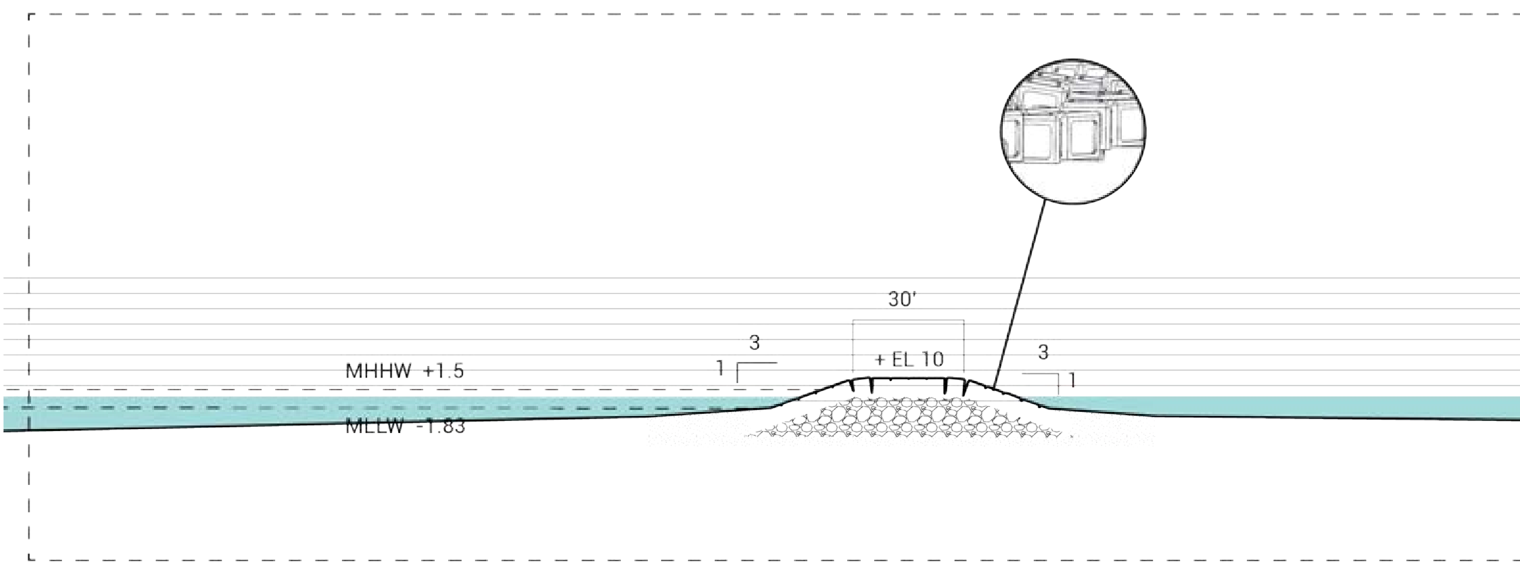



SECTION CUT
LIVING
BREAKWATERS

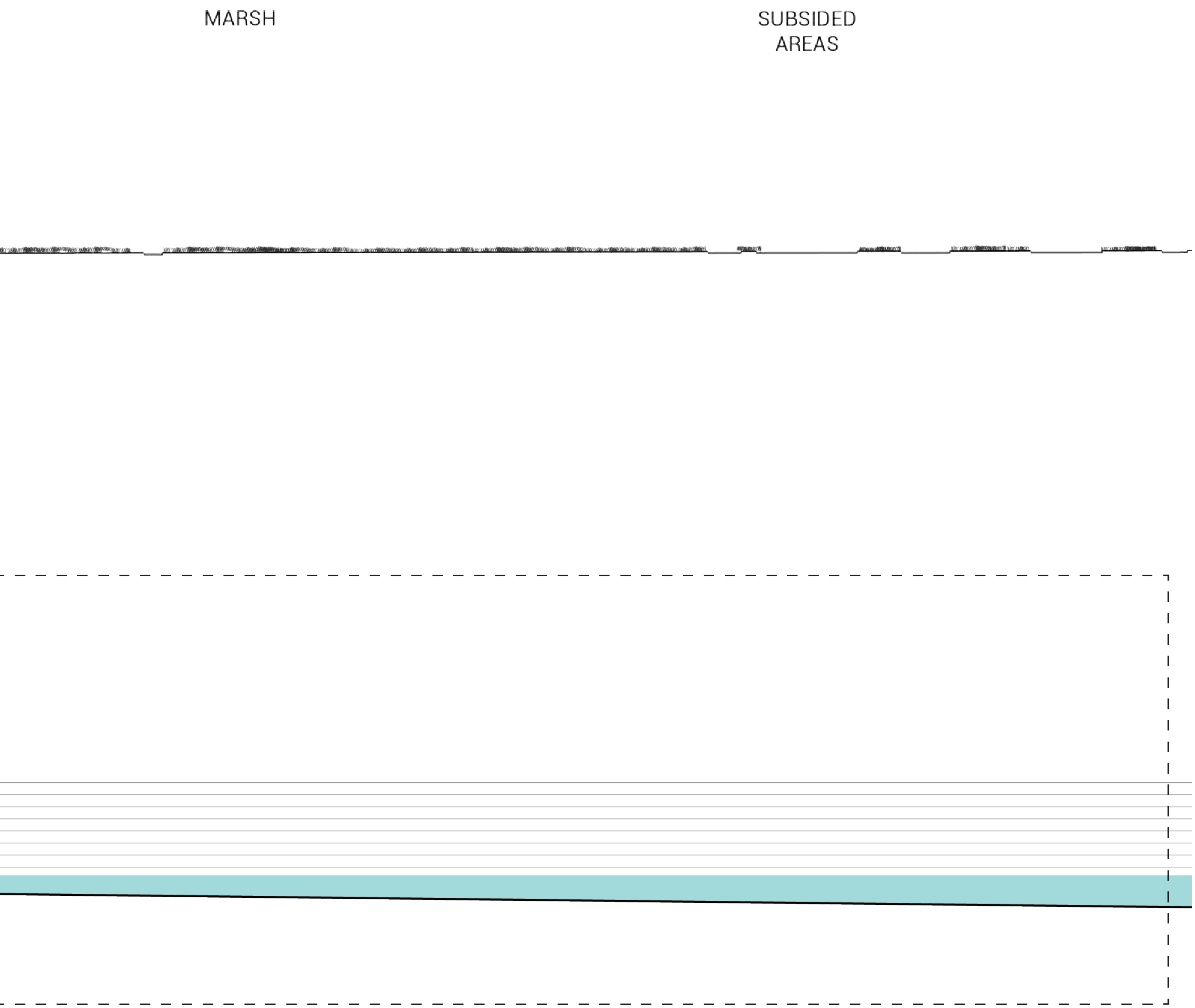
4b TUCKERTON PENINSULA: LIVING BREAKWATER OPTION



4b LIVING BREAKWATER



DETAIL 4b.1

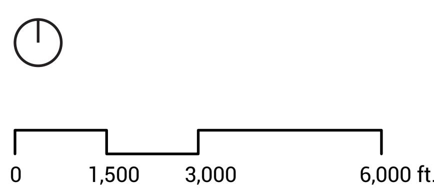

MARSH
SUBSIDED
AREAS

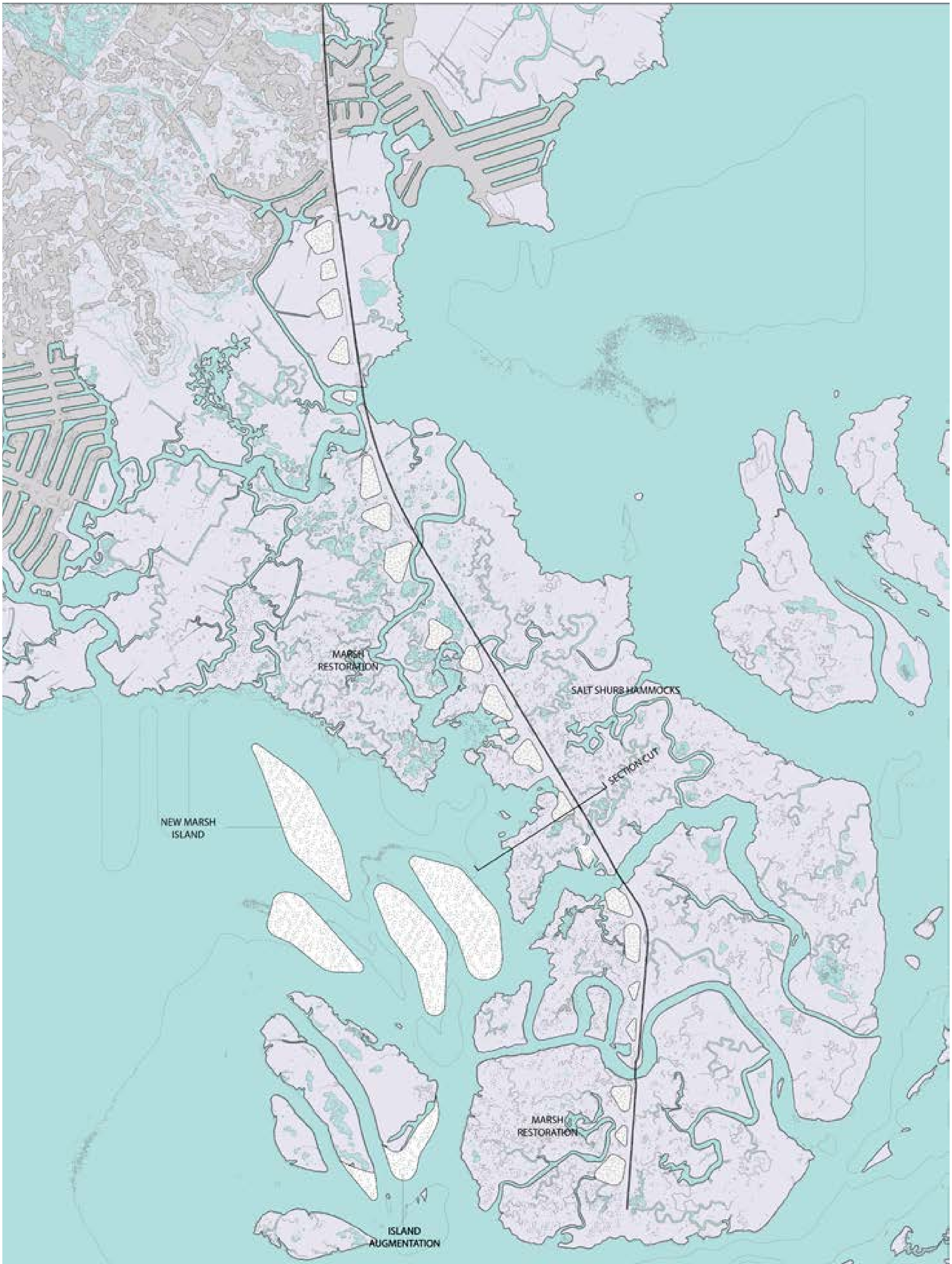
DESIGN CONCEPTS

4c TUCKERTON PENINSULA: MARSH AUGMENTATION OPTION

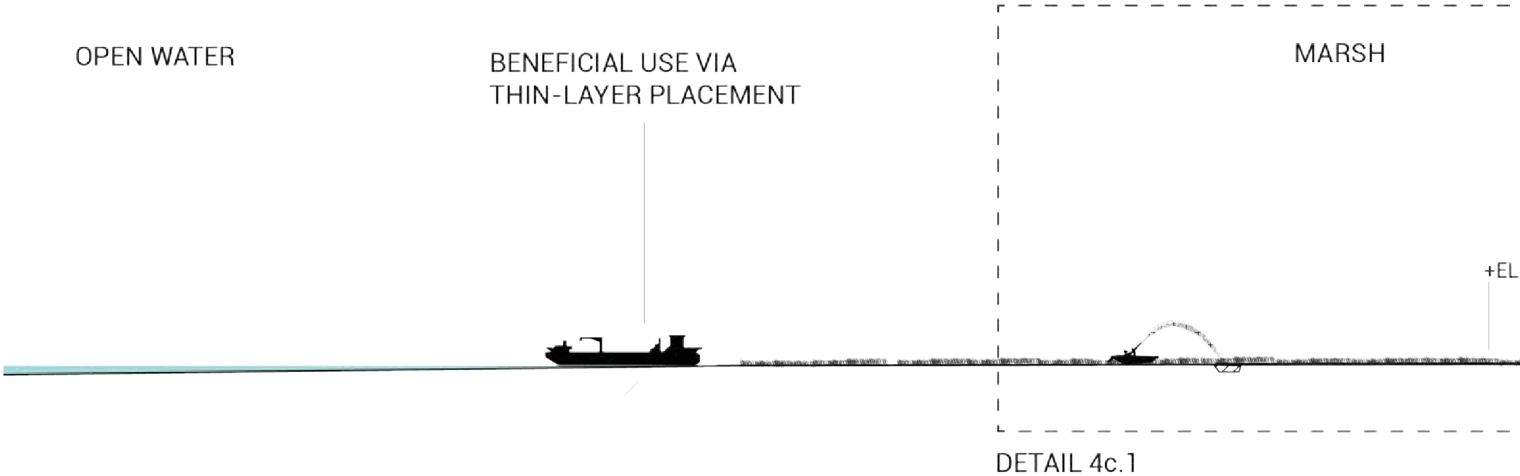
The third option, marsh augmentation, would involve expanding existing marsh islands, constructing new marsh islands, restoring subsided portions of the Tuckerton Peninsula marshes through thin-layer placement, and potentially constructing a series of small salt shrub "hammocks" to the southwest of the Great Bay Boulevard.

Like the Horizontal Levee Option, this option would require significant volumes of sediment. Possible sources for this sediment include the beneficial use of dredged material, mining of existing spoil islands and CDFs, and dredging of inlet shoals. These sources are indicated in the map on page 51.

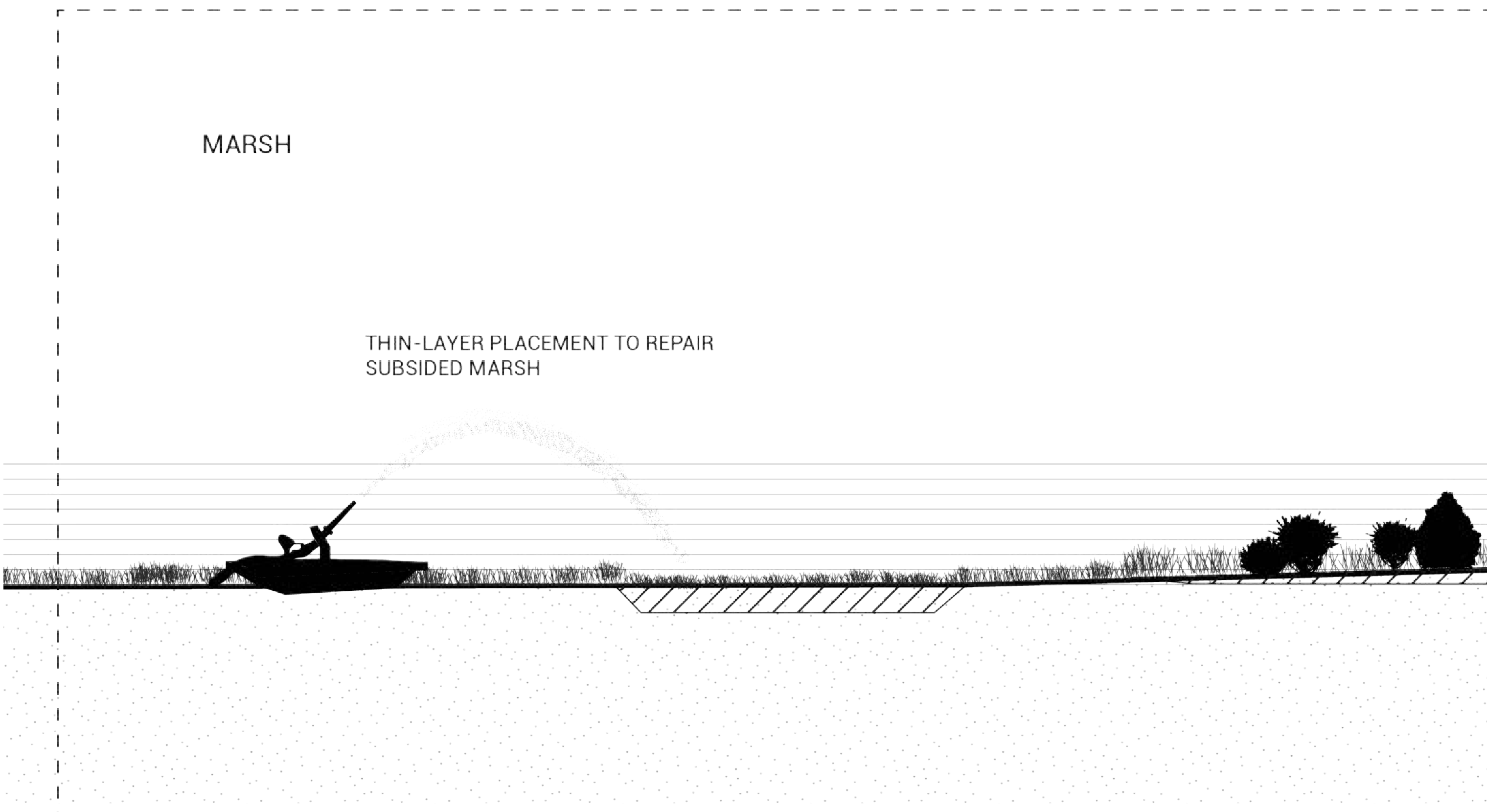



MARSH RESTORATION
SALT SHURB HAMMOCKS
SECTION CUT
NEW MARSH ISLAND
MARSH RESTORATION
ISLAND AUGMENTATION

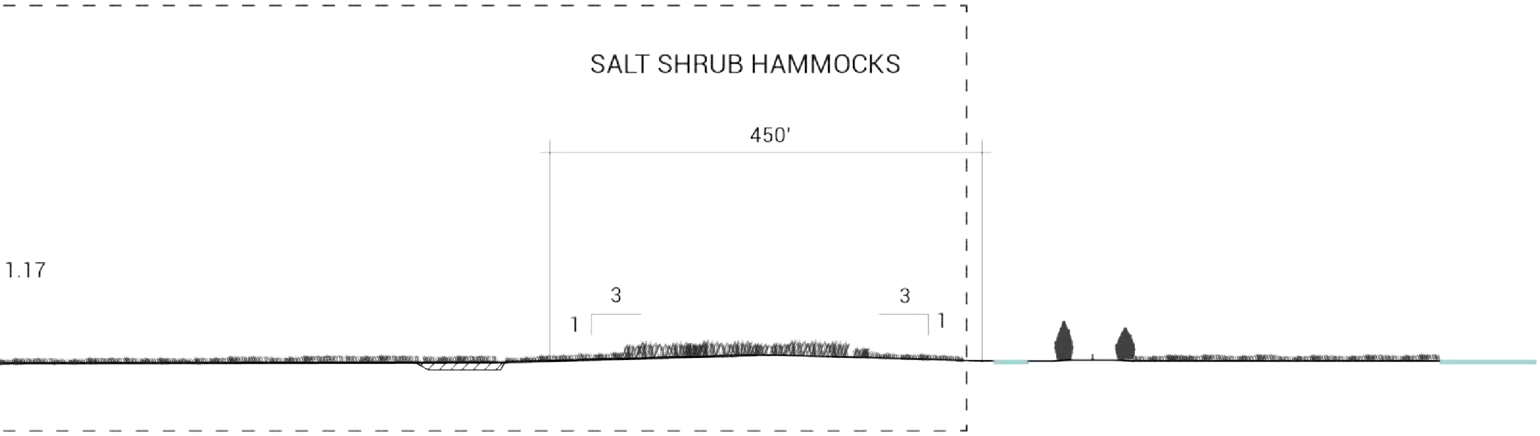
4c TUCKERTON PENINSULA: MARSH AUGMENTATION OPTION

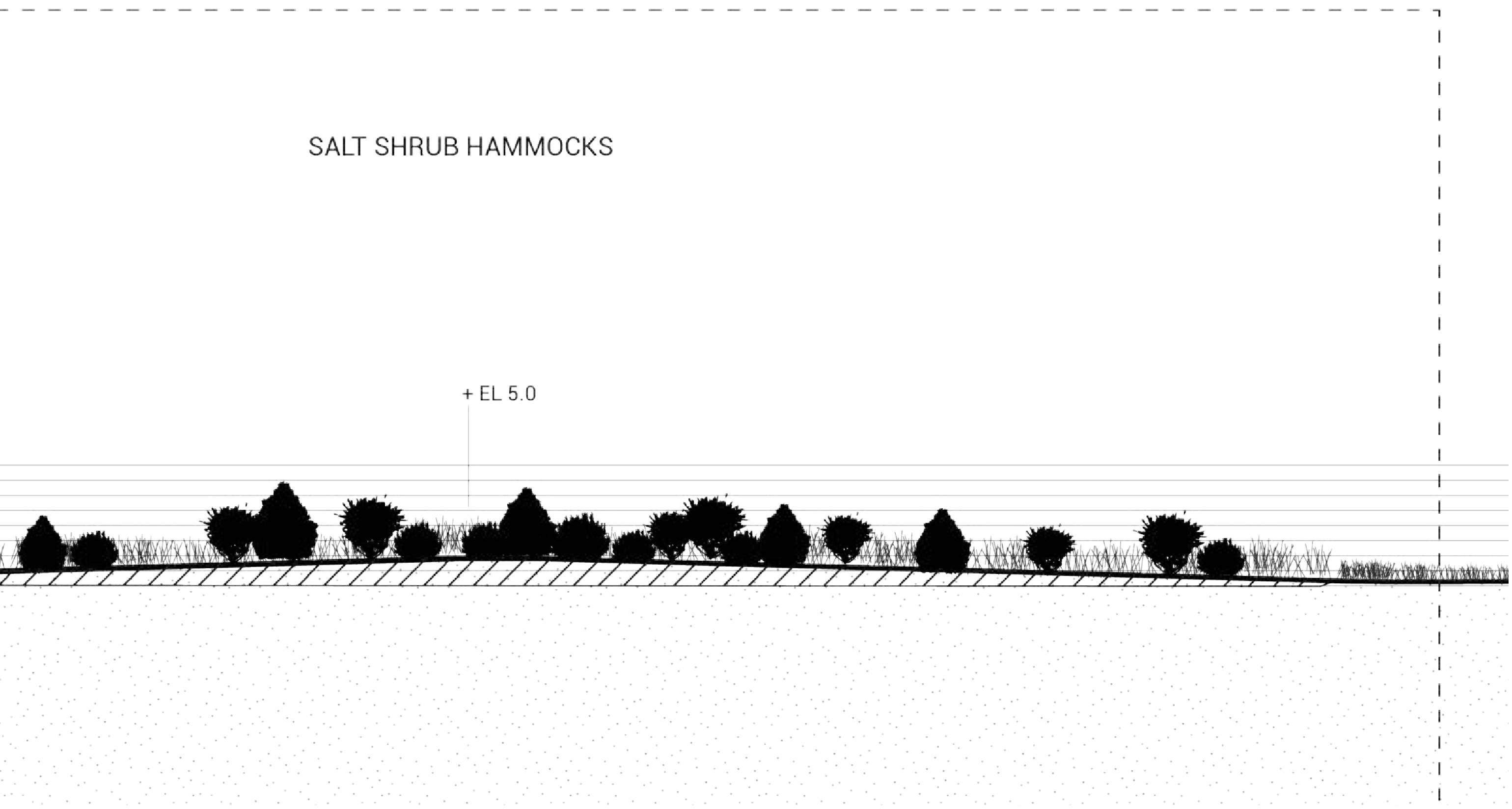


4c MARSH AUGMENTATION



DETAIL 4c.1


SALT SHRUB HAMMOCKS
450'
1.17
3
1
3
1


SALT SHRUB HAMMOCKS
+ EL 5.0

4c TUCKERTON PENINSULA: MARSH AUGMENTATION OPTION

View of marsh augmentation option from the southern end of the Tuckerton Peninsula, looking back into Great Bay

5 BEACH HAVEN SURGE FILTER

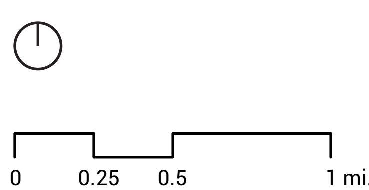
This report has focused attention on the design concept for the surge filter feature near Beach Haven as an example of the kind of NNBF that has been studied via modeling. The Beach Haven surge filter is somewhat smaller and more geographically prescribed compared with the other XL options being modeled. This geographic specificity provides a better opportunity to describe the spatial features of the marsh island creation project, and provides some specifics whose application could be imagined throughout the entire region.

The site of the Beach Haven surge filter is located northeast of the Tuckerton Peninsula and Great Bay Blvd wetland complex. The area is presently the location of a series of shifting sedge islands that vary in size from over 300 acres (Story Island) to intermittent exposed areas of well under 1 acre. The elevation of many of these islands does not exceed +3' NAVD88. The Intracoastal Waterway runs to the east of the islands, between them and the barrier island community of Beach Haven.

5 BEACH HAVEN SURGE FILTER

For the surge filter design concept, several assumptions have been made. The first and most significant of these was that the performance of the surge filter will increase as the density of islands and marshes increases. Consequently, the surge filter is, practically, a thickening of the density of the existing marshes. Following this, several other guiding principles were established. These principles are subject to future modification in light of further modeling. The principles that were established for the design concept were:

- Attempt to limit the volumes of sediment needed to generate results by focusing attention on areas that either are already shallow (-3.5' NAVD88 or less) or have been exposed in the past.
- Placement in deeper water might be justifiable in particular locations. For example, a recent report (McKenna 2018) suggested that significant marsh loss is occurring along the northeastern edge of the Tuckerton Peninsula due to northeastern storms, so increasing marsh and island locations to the west of the present sedge islands might provide protection and reduction in the observed marsh loss.
- The proposed design approximately doubles the quantity of land exposed during MLLW within Sedge Island area.
- Island and wetlands created would be planted with *Sporobulus alterniflora* in the zones between MTL and MHW (-.26 NAVD88 and 1.17 NAVD88). Over the next 50 years, sea-level rise estimates vary, but it seems safe to expect at least a 2' rise over this period (Miller 2014). Islands should provide elevation for high marsh and possibly upland planting in the present scenario, thus providing room for low spartina marsh to migrate up as sea levels rise.



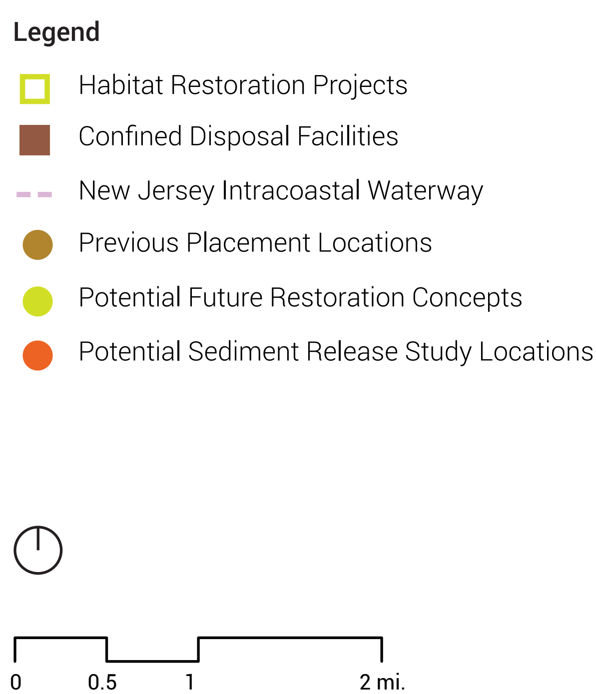
6 SEVEN MILE ISLAND INNOVATION LAB

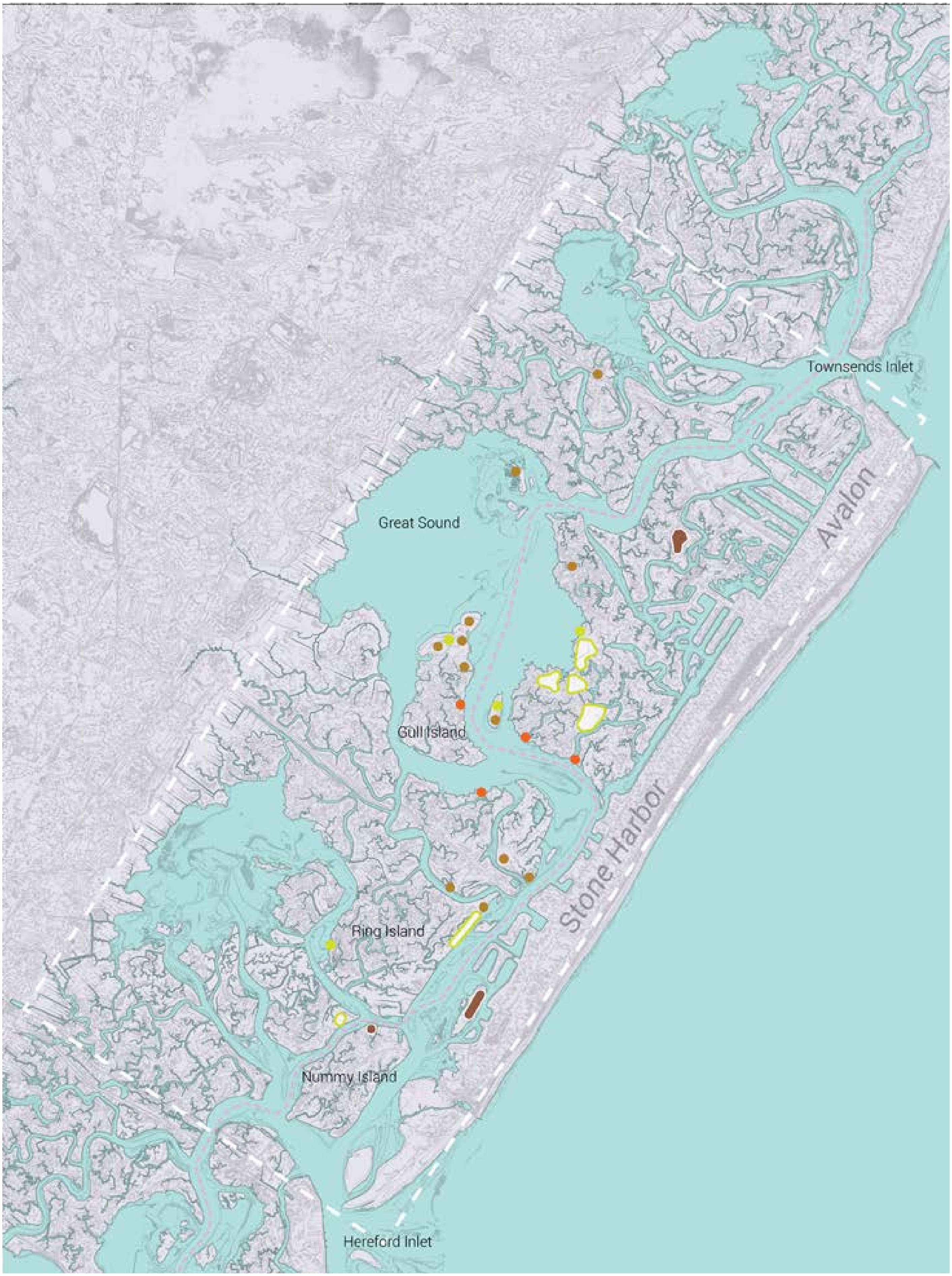
The Seven Mile Island Innovation Lab is a ~24 square mile collection of tidal salt marsh and barrier island communities located between the Townsends and Hereford inlets in the southern region of the Interim Feasibility Report. The Lab was announced in 2019 as a collaboration between the USACE, the Wetlands Institute, and the state of New Jersey. A large working group of over 30 individuals takes part in the development and design of the projects within the Lab.

The primary objective of the Lab is to develop and test innovative methods of sediment management that can not only address the continual management of shipping channels (the New Jersey Intracoastal Waterway runs through the Lab) but also develop processes that can capture multiple benefits of sediment within the back bay environment.

This work builds on a collection of projects that have been done in and around the Lab site that attempt to capture the benefits of EWN principles while undertaking sediment management projects, including the enhancement of marshes, the construction of elevated nesting areas and the development of new mudflats. Future projects will continue this trend and include a robust set of monitoring protocols to evaluate project performance. These include the likely expansion of Gull and Sturgeon Islands.

While the Lab is not fundamentally tasked with the development of strategies that address CSRM, the practices and procedures developed there do address questions of marsh flooding, edge erosion, and habitat establishment. The known ability for marsh density to aid in the reduction of storm damage thus makes the work being undertaken at the Lab considerably linked to CSRM topics.




Townsends Inlet
Great Sound
Avalon
Gull Island
Stone Harbor
Ring Island
Nummy Island
Hereford Inlet

7 BARNEGAT BAY SHALLOWS

The CSRM benefits of NNBF in shallow bays like the Back Bays generally compound as the scale and extent of features increase. For example, research suggests that one mile of vegetative wetland extent can reduce storm surge heights up to one foot (NOAA, 2020). While smaller vegetative wetland features may provide significant local CSRM benefits, there are larger scales of NNBF that should be considered to maximize regional CSRM benefits. This section explores this idea through a series of "projective mappings" that are suggestive of the largest feasible extent for these NNBF in a projective scenario, showcasing areas where further XXL scale studies and modeling could occur.

In the case of Barnegat Bay, the range of possible NNBF opportunities will vary across the bay, based on site conditions and local objectives. The bay-scale "projective mappings" show some of this complexity and identify sites that have experienced significant levels of human and ecological change over time, including areas of marsh change, significant filling, ditching, dredging operations, landcover, and developed areas. An investigation of these areas reveals three types of opportunities for NNBF with CSRM benefits at the XXL scale:

1. **Systems Approach** of implementing NNBF through the redesign of management practices of built and ecological systems over time, including sediment management, marsh enhancement, and resource protection. Systems approaches are well suited to adaptive management practices with the flexibility to change over time.

2. **Scaling Up** of previously identified NNBF identified in other sections of this report (S, M, L features). These features could be applied across larger extents or multiple geographic locations in the near term. Piloting and further study may be required to scale up these ideas.

3. **Linking with Nonstructural Measures** where the suite of applicable NNBF may expand as land uses change. With sea level rise and the implementation of non-structural CSRM measures like building elevation and relocation, today's highly vulnerable areas may become sites for future NNBF with additional CSRM benefits. This possibility is explored in more detailed in Part IV of this report.

The map shows sites of historic dredge material placement and dredge holes located and investigated by the Stockton University Coastal Research Center. The spatial parameters of dredge holes (subaqueous borrow pits) were acquired for future restoration. The team's data and report includes GPS elevation surveys, volume calculations, sediment samples, and a cataloguing and analysis of berms, vegetation, and site-specific features using photography of historic dredge material placement sites. Their work is an important resource for the strategies presented here.

Legend

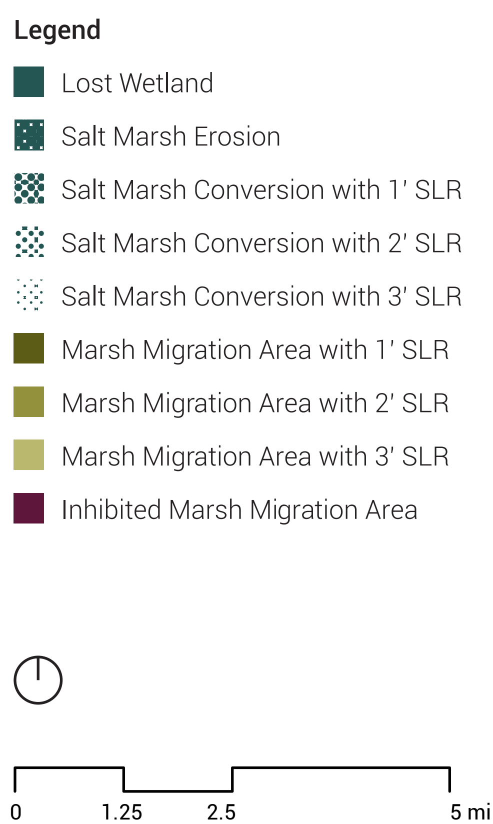
- Dredged Hole
- Unconfined Disposal Site
- Confined Disposal Facility
- Confined Disposal Site
- Other
- NJIWW
- Watershed

0 2.5 5 10 mi

The **Systems Approach** involves changes to the management practices that shape the bay, including sediment management, marsh enhancement, and resource protection.

One example of an XXL systems approach is a long-term plan to maximize the use of dredged sediment to create NNBF with ecological and CSRM benefits. The map at right identifies the navigable waterways, ditched wetland canals, and CDF placement sites which hold sediment extracted from previous dredging projects within central Barnegat Bay. An analysis of annual dredging volumes and locations, current CDF capacity, and dredge material quality and grain size could reveal the amount of material available for NNBF creation on annual or decadal cycles. A modeling study could evaluate the CSRM benefits and ecological impacts of this sediment applied across a range of scenarios at various locations, scales, and methods of application. For example, if the goal was to use dredge material for CSRM through the construction of NNBF, would it be most effective to focus on wetland construction directly adjacent to vulnerable Lagoon Communities or expand the number of Surge Filter landscapes within the Bay? While the scope of these questions exceeds the limits of this study, this XXL scale of design investigation is a logical next step to advancing NNBF within Barnegat Bay in a meaningful way.

The Systems Approach to XXL design has been pursued by other projects more extensively and suggest that this scale of thinking is worthy of further study. The SCAPE team's entry to the US Department of Housing and Urban Development competition "Rebuild by Design" developed an entry titled "The Shallows" that included an XXL scale approach to wetland restoration, living shoreline edge protection, and shallowing of portions of the Bay. Working with team partners at The Stevens Institute, preliminary modeling by the SCAPE team showed that two different NNBF XXL scale approaches may reduce flood water heights by 15-20% in surge events and reduce or eliminate wave damage within bay neighborhoods. While further research and refinement is required, this work suggests that XXL approaches may have more comprehensive CSRM benefits than individual interventions.



7 BARNEGAT BAY SHALLOWS

A second Systems Approach example of XXL NNBF would be to investigate and quantify the current CSRM value of today's coastal wetlands and upland forests. A study could be pursued that would model various storm events with and without today's vegetative wetland and forest cover, with varied rates of SLR. This study could analyze whether today's wetlands provide CSRM benefits in current and future conditions and could also isolate significant zones of wetlands that provide the most CSRM benefits to vulnerable populations. As vegetated wetlands are also vulnerable to sea level rise, this information, in combination with ecological and social goals, could help guide management and resource conservation decisions around wetlands. For example, it could be beneficial to use sediment resources to maintain existing wetlands at particular elevations (with thin-layer placement or other NNBF methods) to reduce risks to lagoon communities that benefit from wetland CSRM impacts today. Management and conservation practices around wetlands, including wetland migration planning and wetland augmentation, could shift to incorporate new research around the potential benefits of preserving these features.

Scaling Up involves the application of previously identified NNBF (S, M, L, and XL features) across multiple similar sites within the Bay. These features could be applied across larger extents within a single project area or multiple geographic locations that share certain environmental characteristics. For example, living breakwaters may be an appropriate strategy for many of the vulnerable lagoon communities that line the inland edge of Barnegat Bay. It is important to require physical piloting and monitoring at a small or medium scale to test the viability of these strategies before applying them more comprehensively to similar sites throughout the region. Strategies identified in this report with regional applicability for Scaling Up include:

- Living Breakwaters: Potentially applicable to inland edges with significant development vulnerable to wave action and erosion
- Upland Forest Restoration: Potentially applicable to vacant parcels or existing upland forest areas with poor vegetative cover along the upland edge of the Bay
- Augmentation of Existing Marshes: Potentially applicable to all areas of the bay that have existing vegetative wetlands depending on rates of sea level rise (includes thin layer placement and ditch filling)
- Shallowing: Potentially applicable to dredge holes and/or submerged portions of the bay with poor habitat value
- Horizontal Levees: Potentially applicable to sites where levees are planned adjacent to upland transition zones, and / or sites where wetlands have little migration space and fringe marsh habitat would

The projective mapping at right identifies area of Barnegat Bay where NNBF can be considered at a regional scale, including ditched wetlands, lagoon communities built on filled land, and upland forest areas.

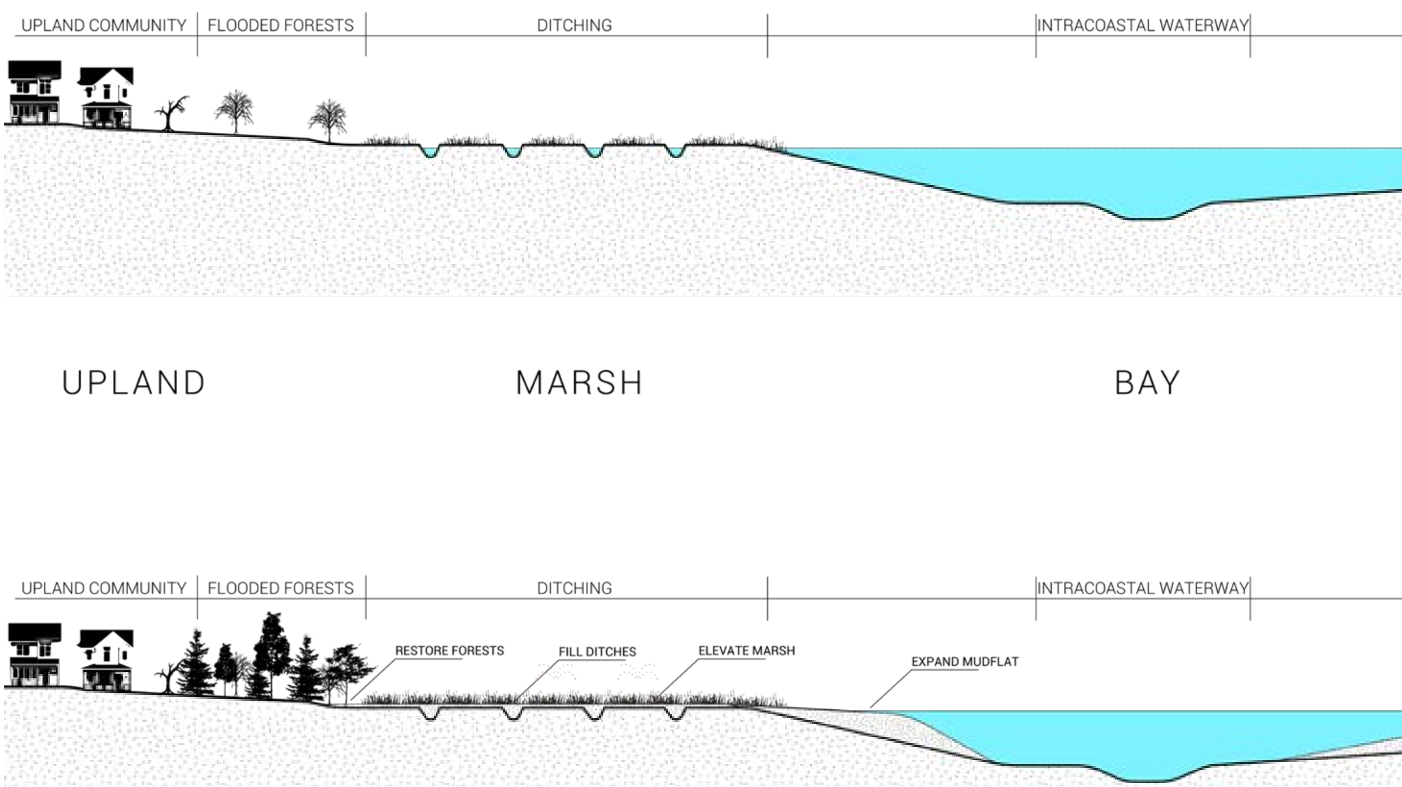
Legend

- Lost Wetland
- Canal Ditching
- Mudflats
- Historic Fill
- Historic Dredge Material Placement
- Submerged Dredge Material Placement
- NJIWW

0 1.25 2.5 5 mi

BARNEGAT BAY: STRATEGIES

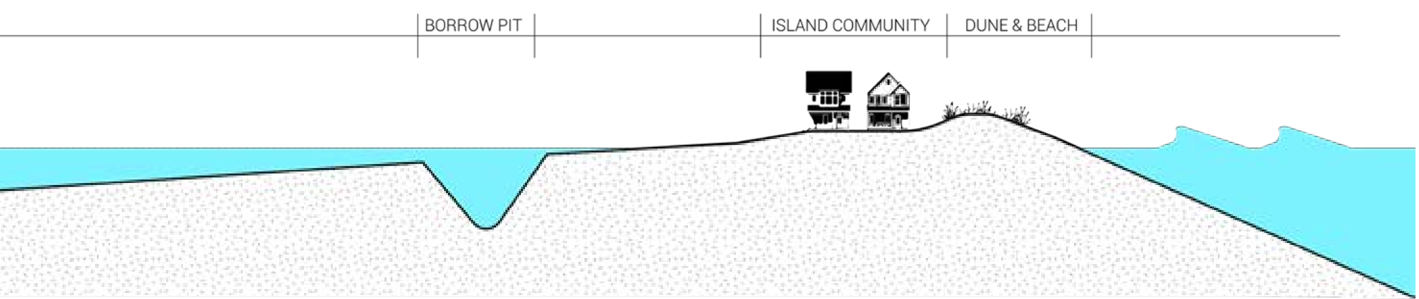
The most extensive NNBF strategy for the bay would include NNBF across a full transect from upland (reforestation of the maritime forest and shrublands), through existing marshes (augmented by ditch filling and thin-layer placement), to subaqueous habitat including mudflats (which could be expanded through further thin-layer placement) and SAV beds (which could be expanded through 'shallowing' and the filling of dredge holes). Living breakwaters could also be placed to complement these NNBF. Here, one typical section across Barnegat Bay collates this range of NNBF.



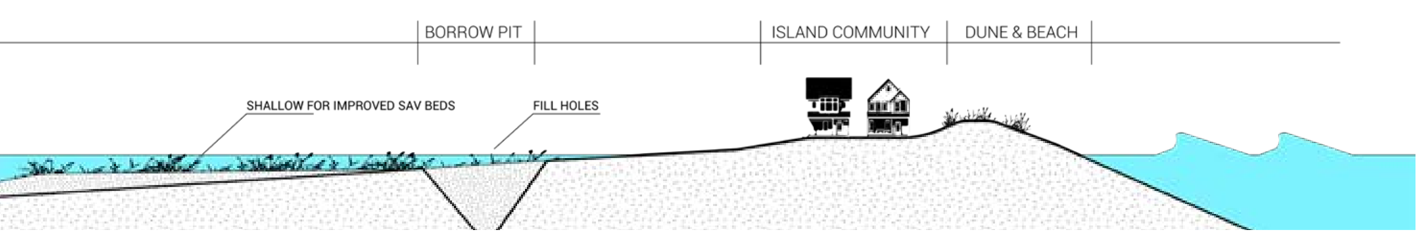
Diagrammatic sections showing the current condition (top) and general strategies applied (bottom) across a typical transect within Barnegat Bay.

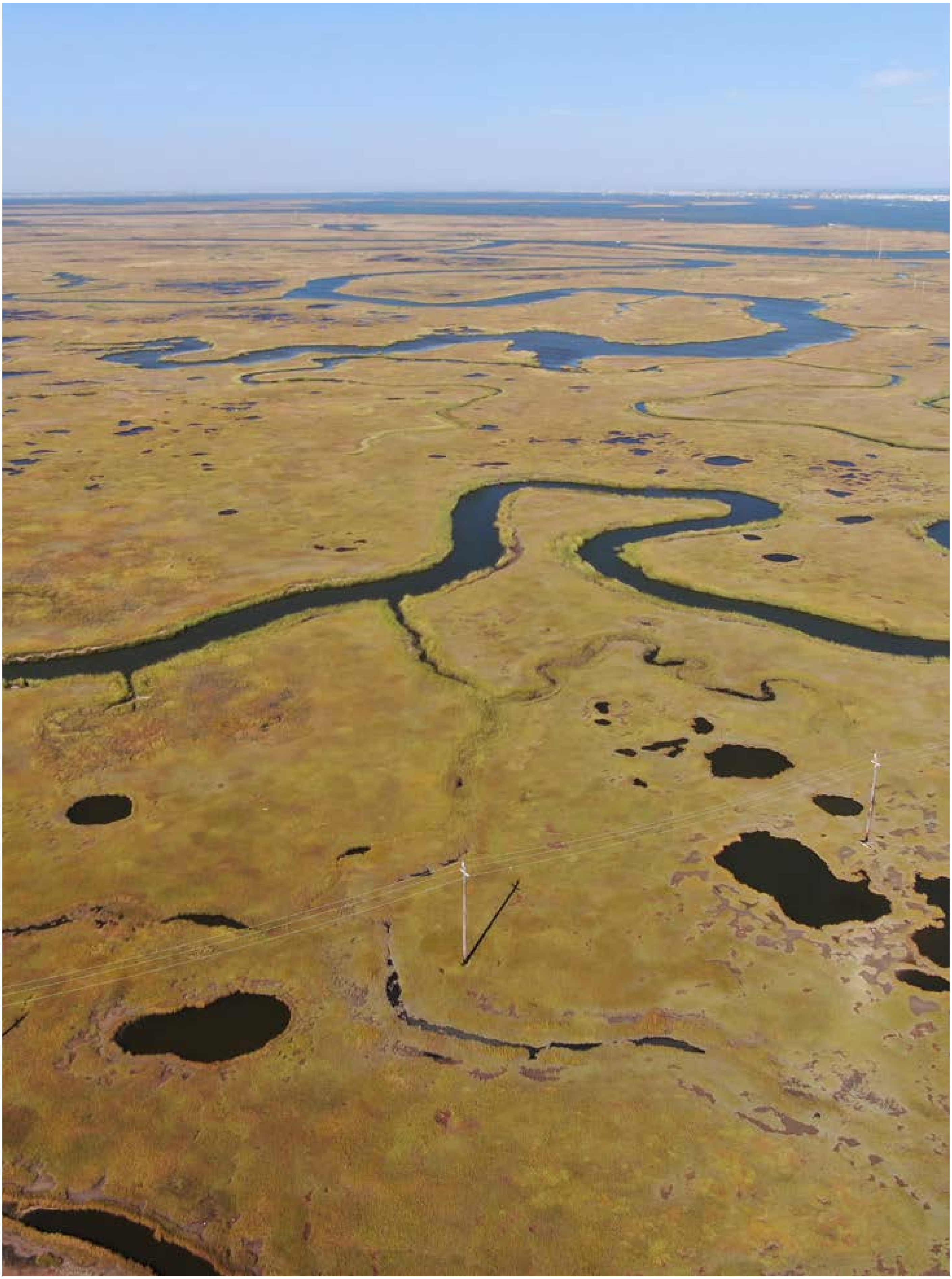
Linking with Nonstructural Measures involves the consideration of future threats of SLR and storm surge in highly vulnerable areas where repeat losses have occurred and nonstructural measures like building elevation and relocation may be implemented. The potential exists to expand implementation of NNBF in concert with non-structural solutions at the XXL scale, as significant zones of urban areas are likely to use non-structural strategies to respond to sea level rise and storm surge in the long term. For example, relocation is sometimes a viable strategy for communities that experience repetitive loss of property and assets. As a process, relocation requires community buy-in and thoughtful discourse, and should include a robust discussion of the future management of the remaining land. NNBF should be considered in these conversations, particularly when they provide ecological and CSRM benefits to the larger regional population at the XXL scale.

Part IV of this report disscusses the potential relationships between nonstructural measures and NNBF in more detail.



BARRIER ISLANDS





Part III

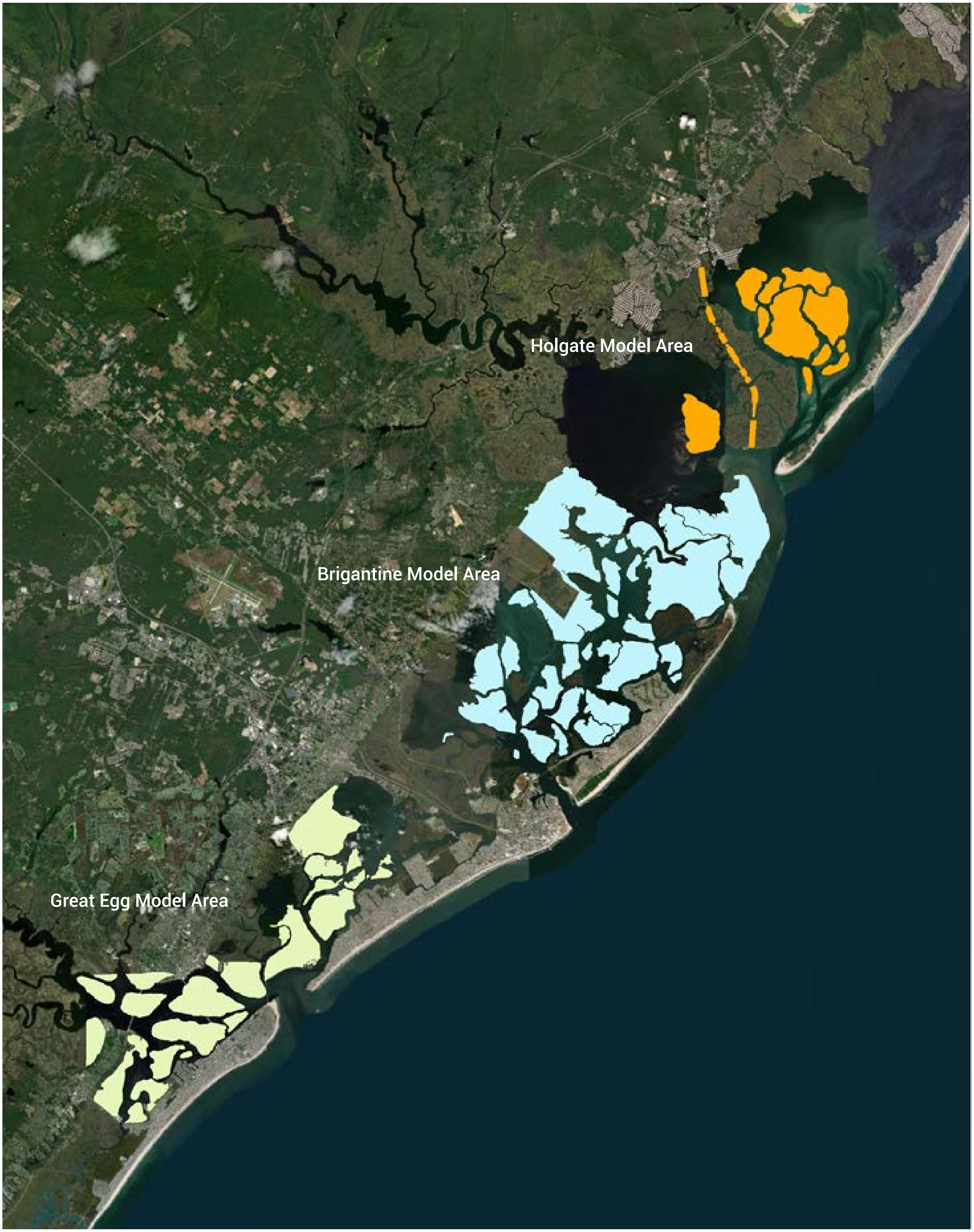
NNBF PERFORMANCE AND SUITABILITY: LINKING MODELING AND DESIGN

While this report was being developed, a concurrent modeling effort was being undertaken by a team at the Engineer Research and Development Center (ERDC) in Vicksburg. This section shows some of the results of this modeling and offers potential next steps for further integration of modeling and design. The full report on the ERDC modeling effort is entitled "Enhanced Modeling in Support of Recommended EWN/NNBF Measures and Efficacy in Providing Flood/Storm Risk Reduction".

As indicated on page 38 of this report, there were four distinct areas chosen for modeling. Two of these areas, the Great Bay Blvd Horizontal Levee and the Beach Haven/Holgate Surge Filter have been combined into one modeling region simply referred to as Holgate. Though done concurrently with the work described in this report, the selection of these areas and the morphologies of the NNBF modeled within them were developed independently by the modeling team, although we take no distinct issue with the sites, morphologies, or storm scenarios that were chosen. Our understanding is that, after site selection, these sites were 'filled' in the model with as much wetland soil and vegetation as was possible, taking standard slopes and necessary water movement into consideration. The footprints of these model areas and the morphologies of the modeled wetlands are shown on the following pages of this section.

The intention of this process was to demonstrate the efficacy that NNBF features (constructed marsh islands, in this case) could have in responding to storm surge and wave height so that designs could be located and scaled appropriately. Due to the assessment metrics established for the New Jersey Back Bay study, only benefits associated with Coastal Storm Risk Management (CSRM) were considered when evaluating the results of the models. This evaluation does not, as a result, incorporate or quantify the obvious ecological and potential social benefits that typically accompany NNBF strategies. Nonetheless, the modeling to date is an important step toward evaluating the potential performance of NNBF in the New Jersey Back Bays. It can and should be built on.

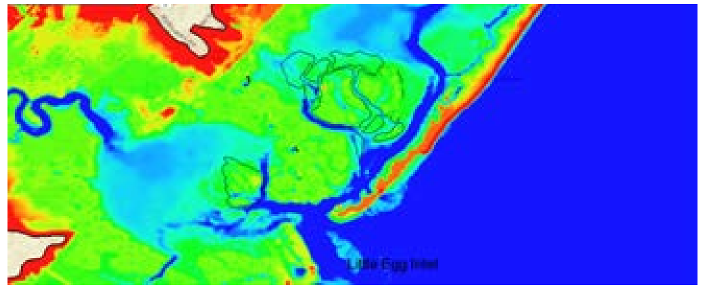
The enhanced wetlands proposed will augment the existing wetlands of the region



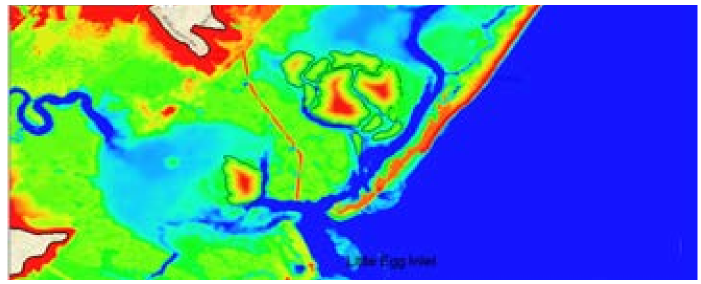
NJBB region with the three model areas identified by color

HOLGATE MODEL AREA

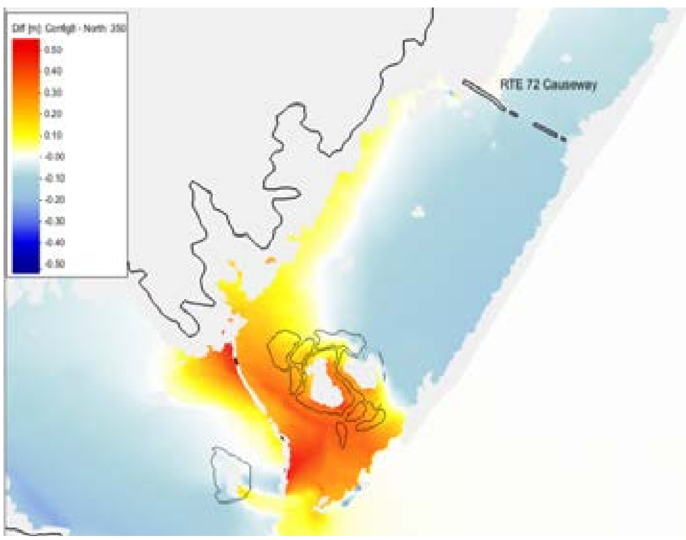
The Holgate model area consists of two NNBF features; the first is a collection of newly elevated marshes on either side of the Tuckerton Peninsula and the other is a horizontal levee constructed in concert with the raising of Great Bay Blvd. The images below and to the right were pulled from the ERDC report and were produced by the modeling team.



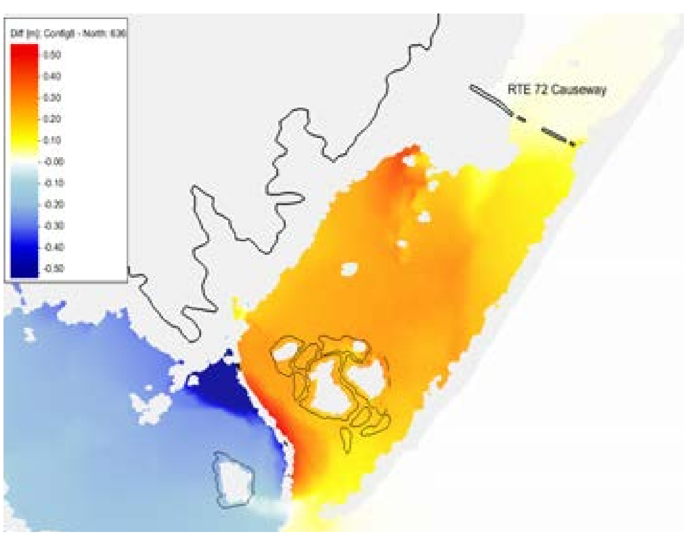
Holgate Model Area Existing Elevations



Holgate Model Area Modeled Elevations

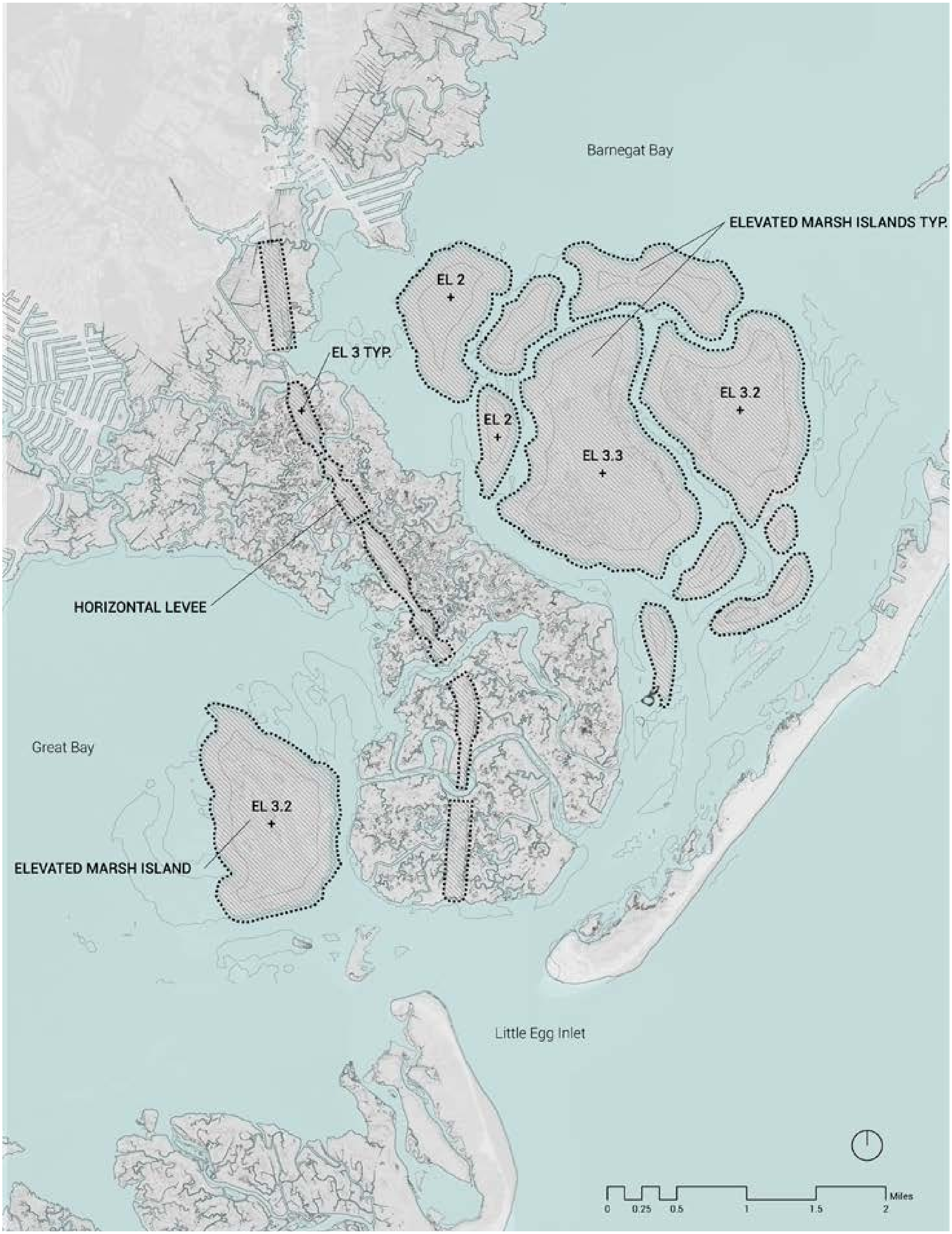


Water Surface Elevation Effect, Storm 350



Water Surface Elevation Effect, Storm 636

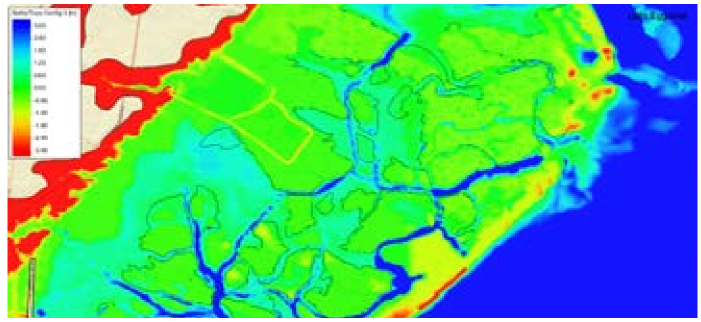
Footprints of Holgate model features



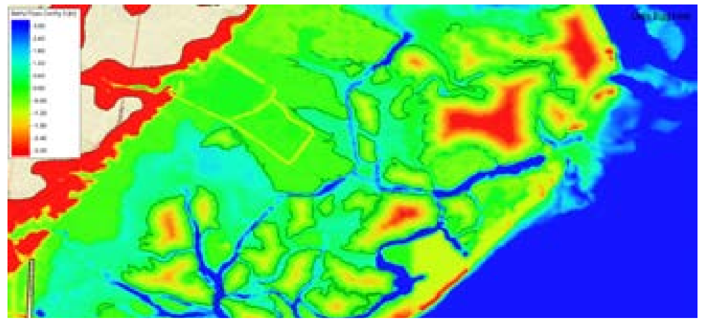
Holgate area as modeled in ERDC report

BRIGANTINE MODEL AREA

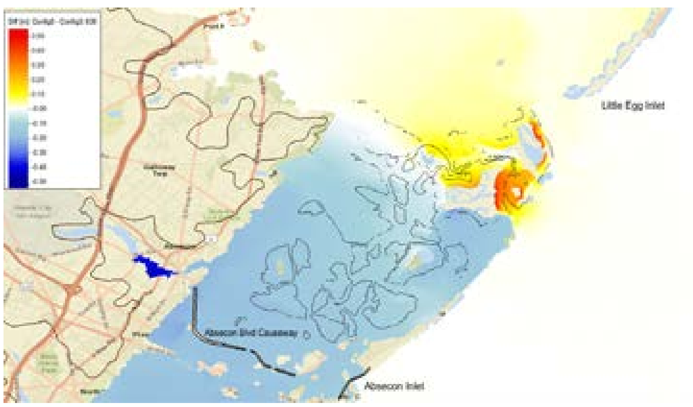
The Brigantine model area consists of an enhanced collection of elevated marsh islands between the Absecon and Little Egg Inlets. The images below and to the right were pulled from the ERDC report and were produced by the modeling team.



Brigantine Model Area Existing Elevations



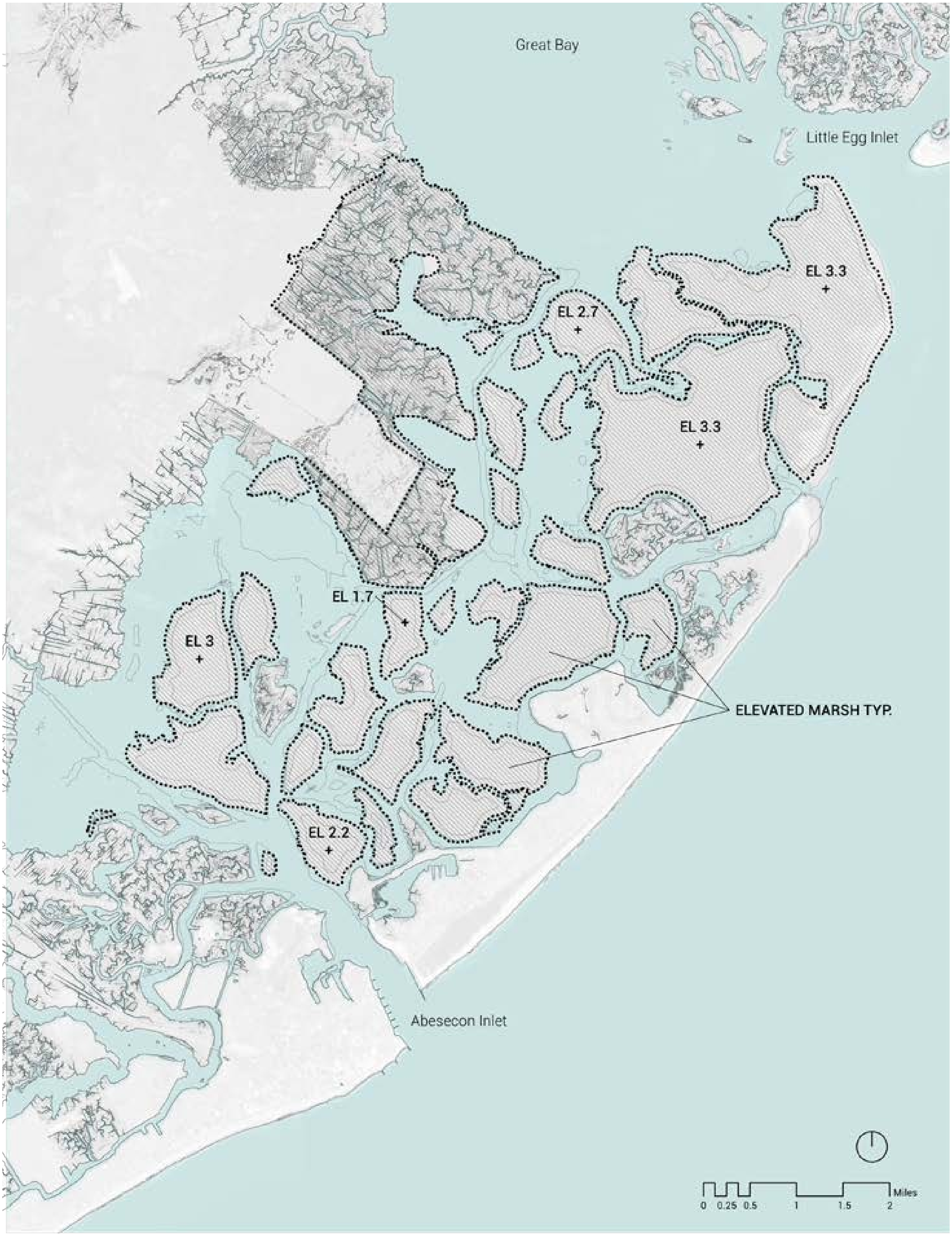
Brigantine Model Area Modeled Elevations



Water Surface Elevation Effect, Storm 350

Water Surface Elevation Effect, Storm 636

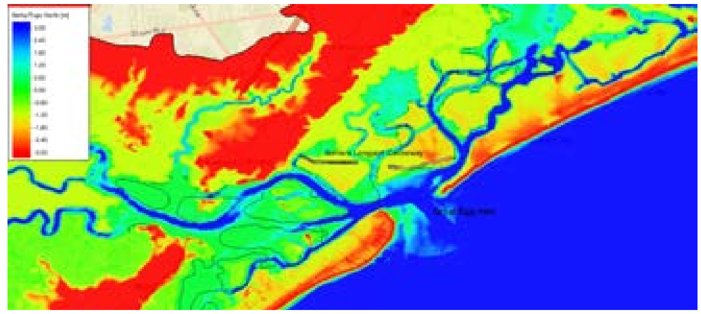
Footprints of Brigantine model features



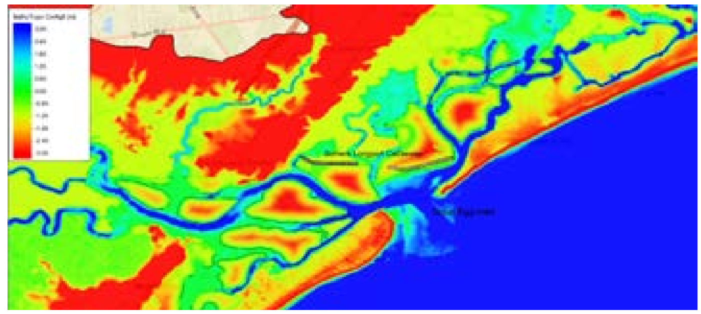
Brigantine area as modeled in ERDC report

GREAT EGG MODEL AREA

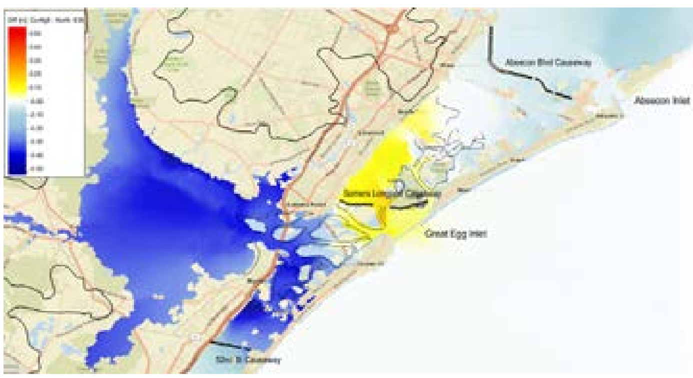
The Great Egg model area consists of a collection of enhanced and elevated marsh islands that span across Great Egg Harbor Inlet. The images below and to the right were pulled from the ERDC report and were produced by the modeling team.



Great Egg Model Area Existing Elevations



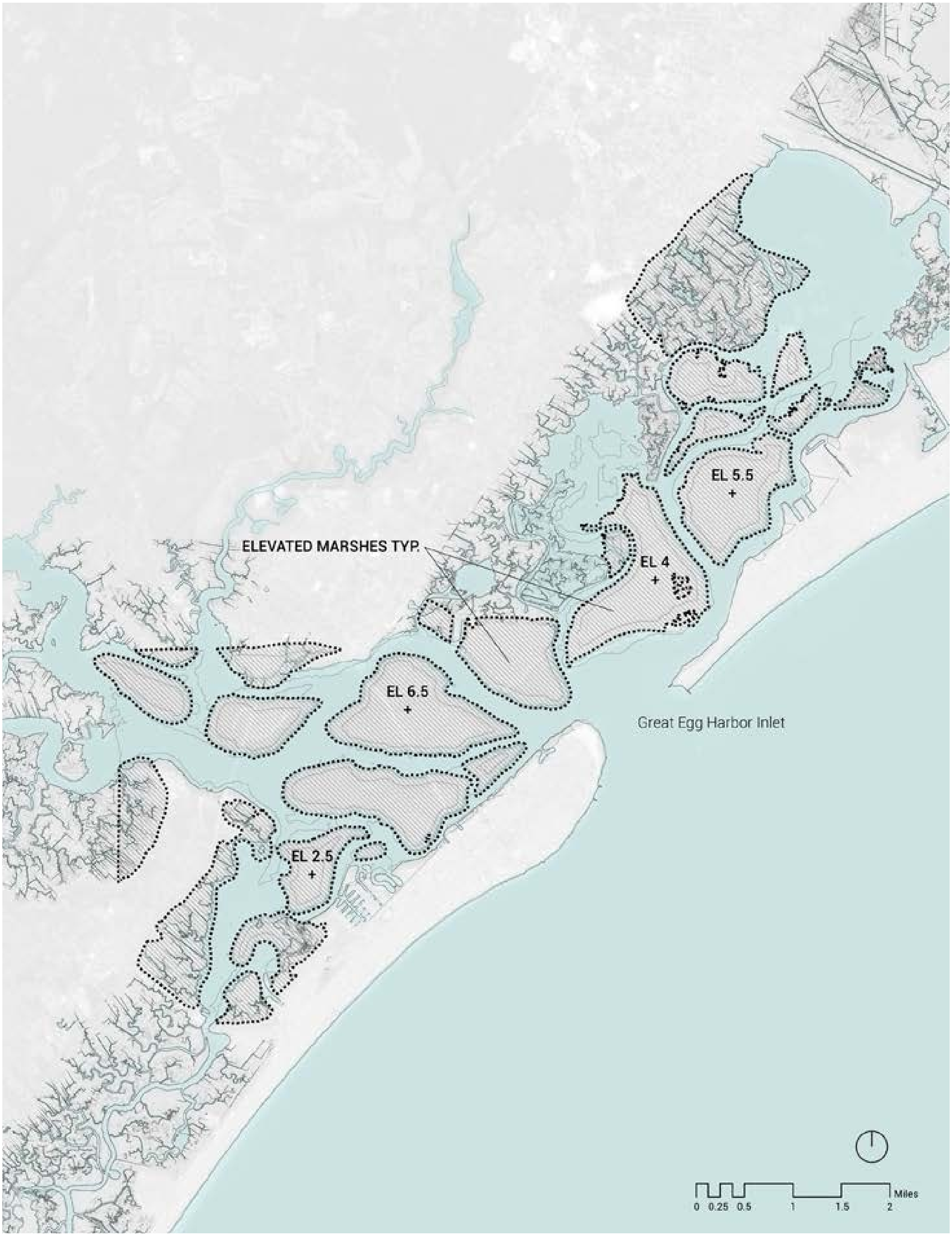
Great Egg Model Area Modeled Elevations



Water Surface Elevation Effect, Storm 350

Water Surface Elevation Effect, Storm 636

Footprints of Great Egg model features



Great Egg area as modeled in ERDC report

Interpretation of Results

From the modeling report, it is clear that the proposed NNBF do have significant effects on both storm surge and wave attenuation. However the results also demonstrate that not all effects are positive, as reductions in waves or storm surge in some locations are, at least under some storm scenarios, paired with increases in waves and surge in other locations. Additionally, different storm scenarios also prompted a wide range of effects from the various NNBF. Under at least some of the modeled conditions, features that would reduce storm surge in one location under one storm scenario were shown to increase storm surge under another storm scenario for the same location.

These are not surprising results, as any class of feature designed to reduce flooding or wave energy in one location has the potential to displace water to another location, depending on local circumstances. Consequently, this varied performance should not be interpreted as discrediting NNBF as CSRM strategies generally or in the Back Bays specifically.

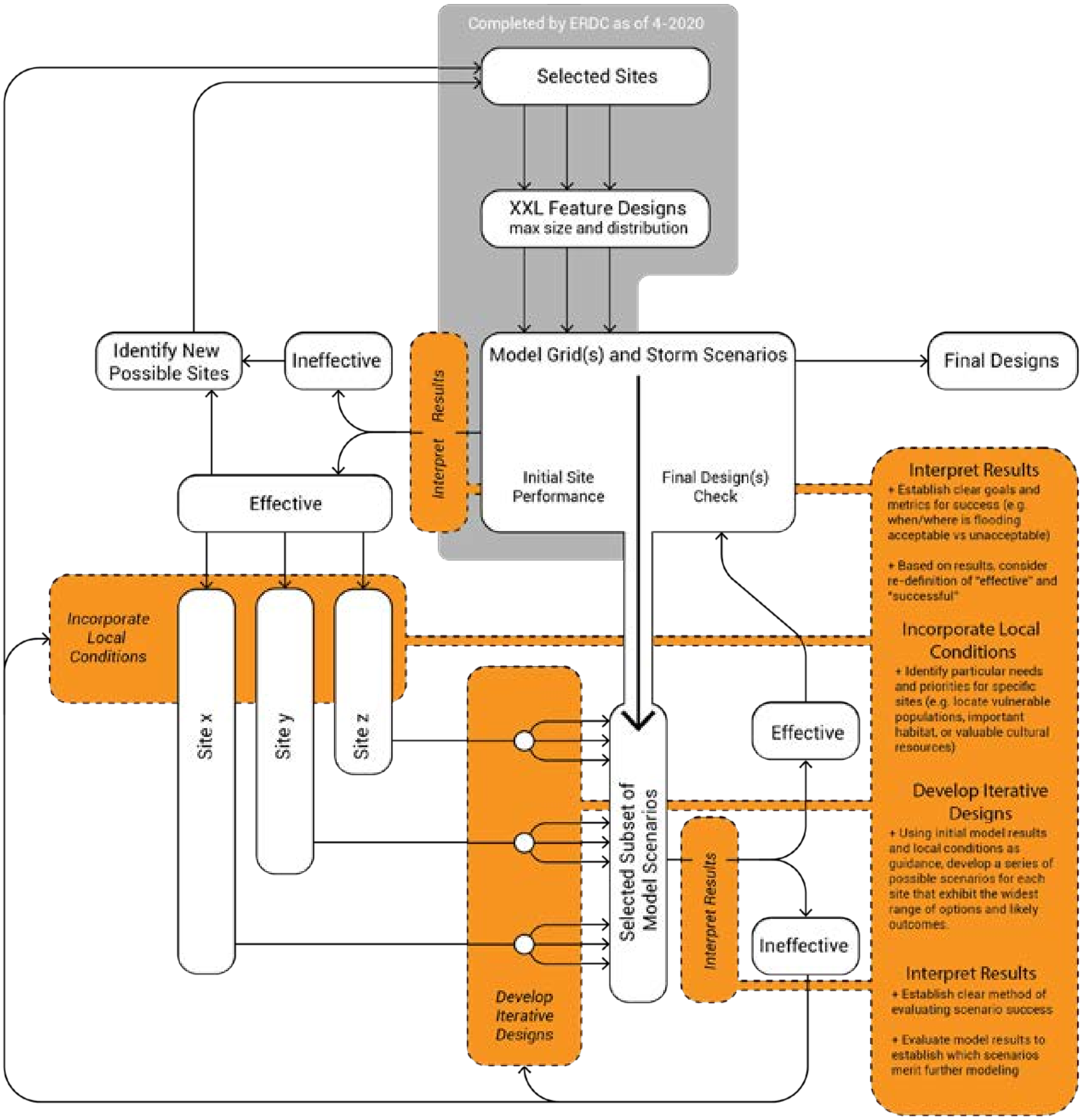
Moreover, not only are the reductions in storm surges found in the modeling variable across the bays and highly sensitive to storm characteristics, the reductions obtained from the modeled features were, as delineated in the modeling report, not sufficient to provide the desired level of protection on their own, suggesting that NNBF should be studied in combination with other structural and non-structural measures.

Ultimately, these results do, as the modeling report concludes, demonstrate that further design and modeling work is necessary in order to fully evaluate large-scale NNBF in the Back Bays. This further work should begin from the recognition that the modeling results clearly indicate that the size, location and form of proposed NNBF have significant effects on their CSRM performance. An extended modeling and design process should allow for the exploration of feature extents and configurations, aimed at maximizing the beneficial CSRM effects of the NNBF while minimizing the negative effects. Consequently, developing a system to design and test possible configurations will be necessary in order to complete a full study.

A Proposed Process Forward

We would suggest that the NNBF modeling efforts to date should be seen as the first steps in such a system, where modeling methods would be iteratively integrated with the larger design process. In many cases this requires iterative design and multiple model runs in order to establish the most effective designs. A systematic process like this moves beyond a simple binary of "effective" or "ineffective" and instead aims at discovering what works best based relative to a set of agreed-upon and explicitly-articulated goals. One example for how this would work can be seen in the modeling report, where it notes that the features as currently proposed for Great Egg Harbor "cause some surge amplification near the inlet mouth", which is relatively heavily developed, but that "reconfiguration and changes in the height of the features may allow this unavoidable amplification to be localized to well-protected or undeveloped areas". Modeling provides information about how a design performs; this suggests alternative configurations, which must then in turn be tested to understand their performance. Multiply this process of feedback between design and model across multiple bays and multiple iterations and the scope of the integrated process necessary to hone in on the most effective configurations starts to become clear.

The diagram at right is a simple schematic illustrating a possible working method. It outlines a process where the iterative exploration of alternatives and the explicit assessment of values (highlighted in orange) can be linked within an integrated design-and-modeling process in order to develop effective outcomes that span the widest possible range of benefits. It would build off the efforts already completed by the modeling team (shown in gray)



and use the established modeling grids and storm scenarios. Because models take considerable time to both set up and run, effort should be placed on the selection of the most essential subset of conditions under which to test different iterations before running them through the full gamut of scenarios that has been established. Iterative exploration also generates more "loops" within the larger process, allowing for results to feed back into upper levels of the process to reconsider starting assumptions and facilitate iteration which, ideally, grows increasingly intelligent in each "loop" through the integrated process. (Note that, in the diagram above, this reconsideration primarily happens in the "interpret results" step. This step (in orange) is shown as only partially overlapping with the modeling team work-

to-date (in gray), because, while the modeling has provided interpretation of results according their established scope, that scope did not include the tasks of determining whether the proposed features are effective or setting the criteria by which that effectiveness would be determined.)

In order to do this successfully, it is also necessary to clearly describe the value judgements that underlie both the model development itself and the assessments of the results. Returning to the example of the discussion of Great Egg Harbor may help clarify the role of value judgments in assessing model results. Modeling permits determining whether the proposed features increase or decrease surge in a given location, such as near the inlet mouth. In this localized fashion, modeling can be said to show whether the features are "effective" or "ineffective" for a bounded geography. However, modeling does not in and of itself determine whether it is more desirable to focus surge decreases around the inlet mouth or in some other location. That question, of what effects are desirable where, is ultimately what permits decisions to be made about whether a design is, as a whole, "effective" or "ineffective". Economic models can be one key input for this, feeding into the assessment of results by informing the goals that are set at each "loop" through the design-and-modeling process. Ideally, though, this process of assessment would be transparent, open-ended, and iterative, enabling criteria of effectiveness and ineffectiveness to be informed by what is learned through each step of an integrated design-and-modeling process.

Conclusion

Both model results and their interpretation are governed by sets of starting assumptions and, unfortunately, in many cases these assumptions are inaccurate or fail to take into consideration the compounding complexity of the natural world. It is also relatively easy to establish models that can clearly prove or disprove the success of any given design by adjusting the starting assumptions or the value system used to evaluate the results. We as a team are excited about the honesty in the ambiguity and range of the results generated by the ERDC modeling effort, as they point the way past these potential pitfalls. In our reading, the results demonstrate both the clear potential of NNBF as CSRM features and a need to test, design, and model a wide range of scenarios in order to capture the full potential of NNBF for CSRM in the New Jersey Back Bays.

Part IV

PAIRING NONSTRUCTURAL MEASURES WITH NNBF

This section of the report focuses on opportunities for linking nonstructural measures with NNBF to increase CSRM benefits and ecological value. Current nonstructural elements identified in the New Jersey Back Bays Coastal Storm Risk Management Interim Feasibility Study and Environmental Scoping Document: Main Report (USACE 2019) focus on building retrofits to residential structures by elevation. With further data and analysis, future recommendations for nonstructural measures in the New Jersey Back Bays may expand in scope and scale. In the Interim Feasibility Study, possible nonstructural measures are broadly identified within four categories: (1) managed coastal retreat (often facilitated by acquisition and/or relocation); (2) building retrofit (flood proofing, elevations, and ring levees); (3) land use management (zoning changes and undeveloped land preservation); and (4) early flood warnings (evacuation planning and emergency response systems). Within these categories, NNBF has the potential to increase CSRM benefits to buildings receiving retrofits, replace areas where buildings have been acquired and relocated that might offer CSRM benefits to adjacent areas, and establish larger interconnected NNBF through zoning changes and undeveloped land preservation that would support efforts to increase ecosystem resiliency and marsh migration with SLR.

In order to begin thinking through the potential benefits of linking nonstructural measures with NNBF, four community types were identified throughout the Back Bays based on their ecological context and physical urban form. Each of the four community types was then diagrammatically drawn to illustrate basic features that tend to appear throughout these communities. These "hypothetical communities" are arranged in this section of the report according to their location within the Bay from seaward to bayward, the Atlantic Ocean to upland. A range of nonstructural and NNBF strategies are diagrammatically illustrated according to potential applications along the cross-section of each community type.

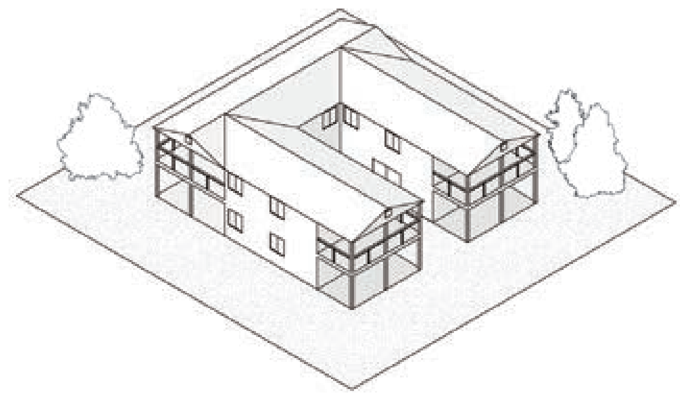
To evaluate the potential of combined nonstructural and NNBF measures (particularly managed retreat) in specific locations and communities within the Back Bays, in-depth data collection, analysis, and public engagement is necessary. The examples shown in this report do not address the range of vulnerabilities and inequities that particular communities currently experience or that might emerge with the implementation of these strategies, but it is important to do so through further study.

TYPICAL PHYSICAL NONSTRUCTURAL MEASURES

The following measures are based on current nonstructural measures for building retrofits as well as acquisition and relocation deployed by the USACE. Each drawing shows a hypothetical apartment building, similar in structure and scale to buildings found in Back Bay communities, in an abstracted context. There are no spatial diagrams in this report for non-physical measures, such as emergency response systems. Refer to the National Nonstructural Committee's Nonstructural Flood Risk Management Matrix for further information on the suitability of these measures to varying circumstances.

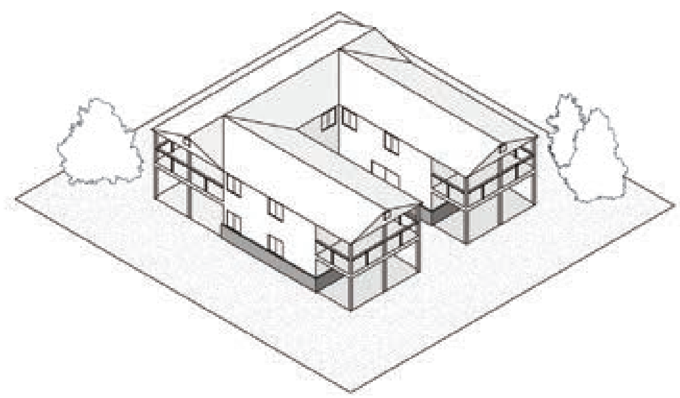
[BASE STRUCTURE]

The following diagrams are drawn to reflect nonstructural measures for this hypothetical apartment building.



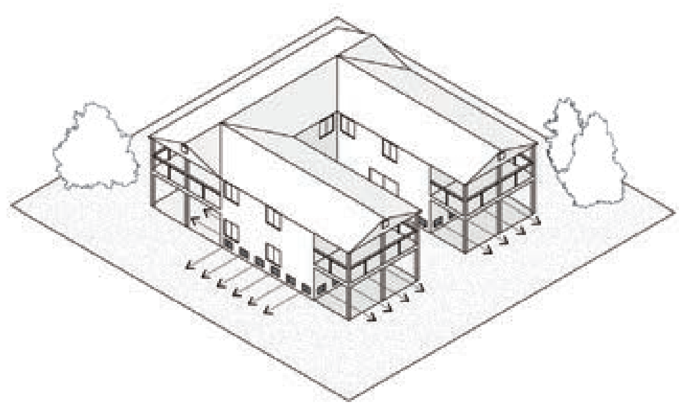
DRY FLOOD-PROOFING

Dry-flood proofing protects the building up to a certain elevation with flood shields and a protective membrane.



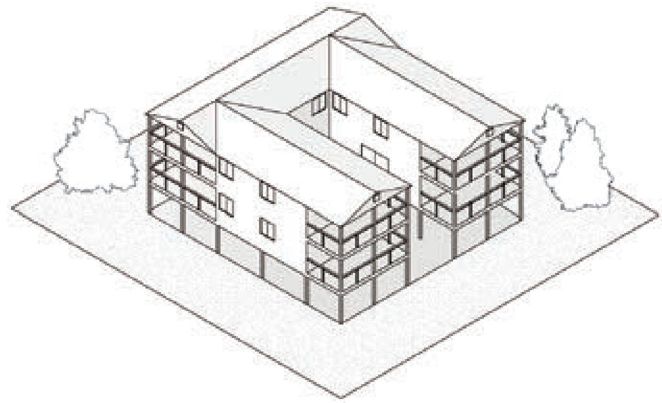
WET FLOOD-PROOFING

Wet-flood proofing allows the building to take on floodwater without sustaining major damages or compromising the integrity of the structure. In a flood event, the first floor would be evacuated and water would flow through.



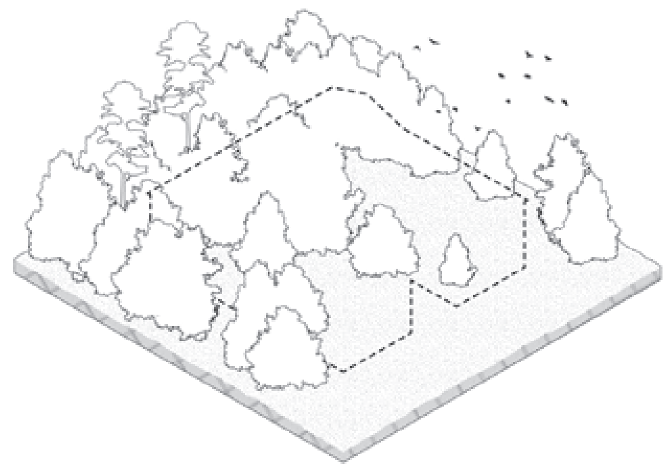
ELEVATION

Elevating the building to a particular height allows floodwater to pass underneath the structure without damaging the structure or needing to evacuate a ground floor.



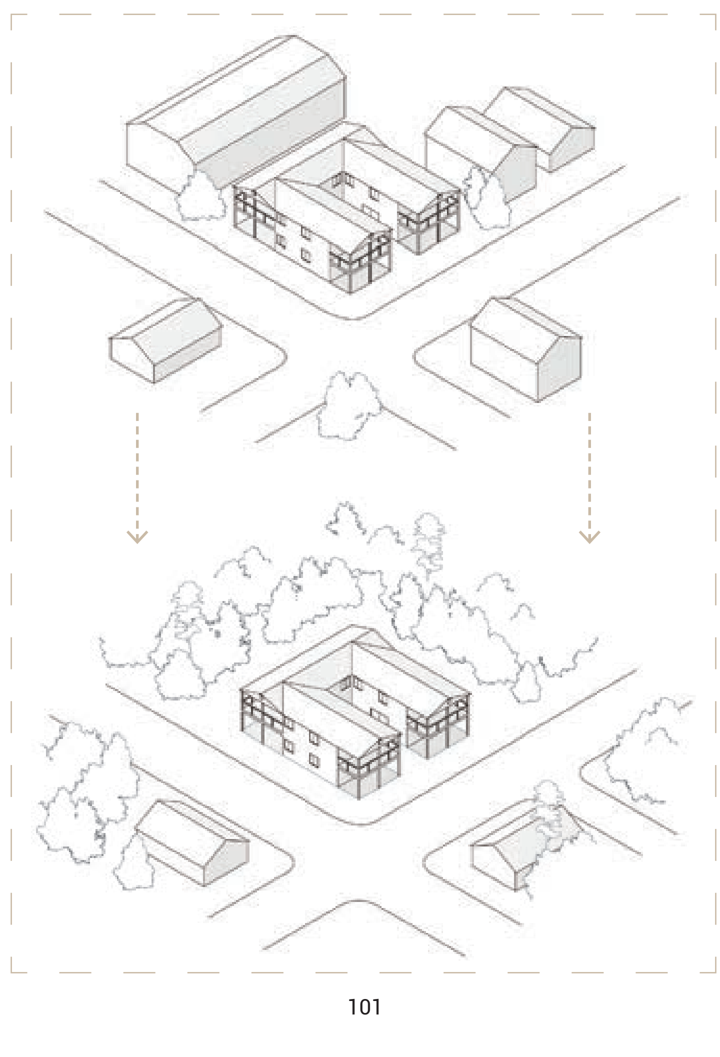
ACQUISITION

Acquisition is a process of purchasing a property that is at continued and unpreventable risk. This is accompanied by changing the land use of that property to prevent future settlement in hazardous areas.



RELOCATION

Relocation physically removes a building from a hazardous area and places it on a non-hazardous property. Similarly, the land use of the initial property is changed to prevent future settlement in hazardous areas.

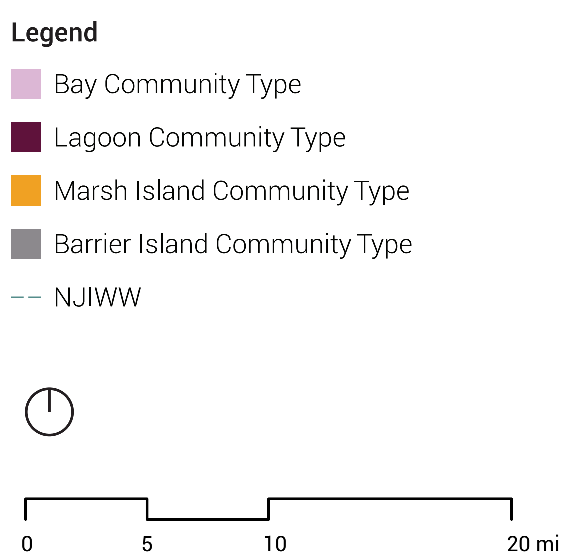


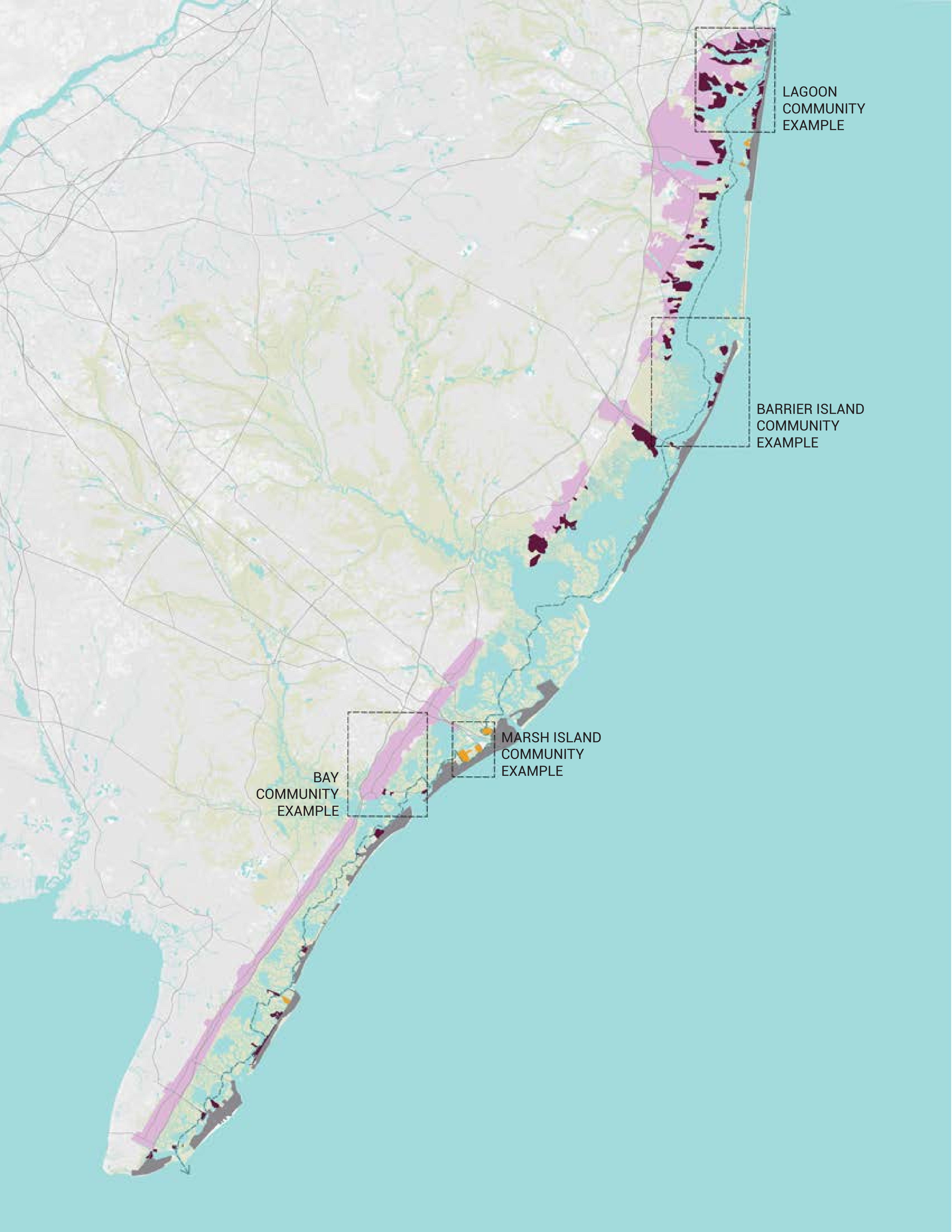
BACK BAY COMMUNITY TYPOLOGIES

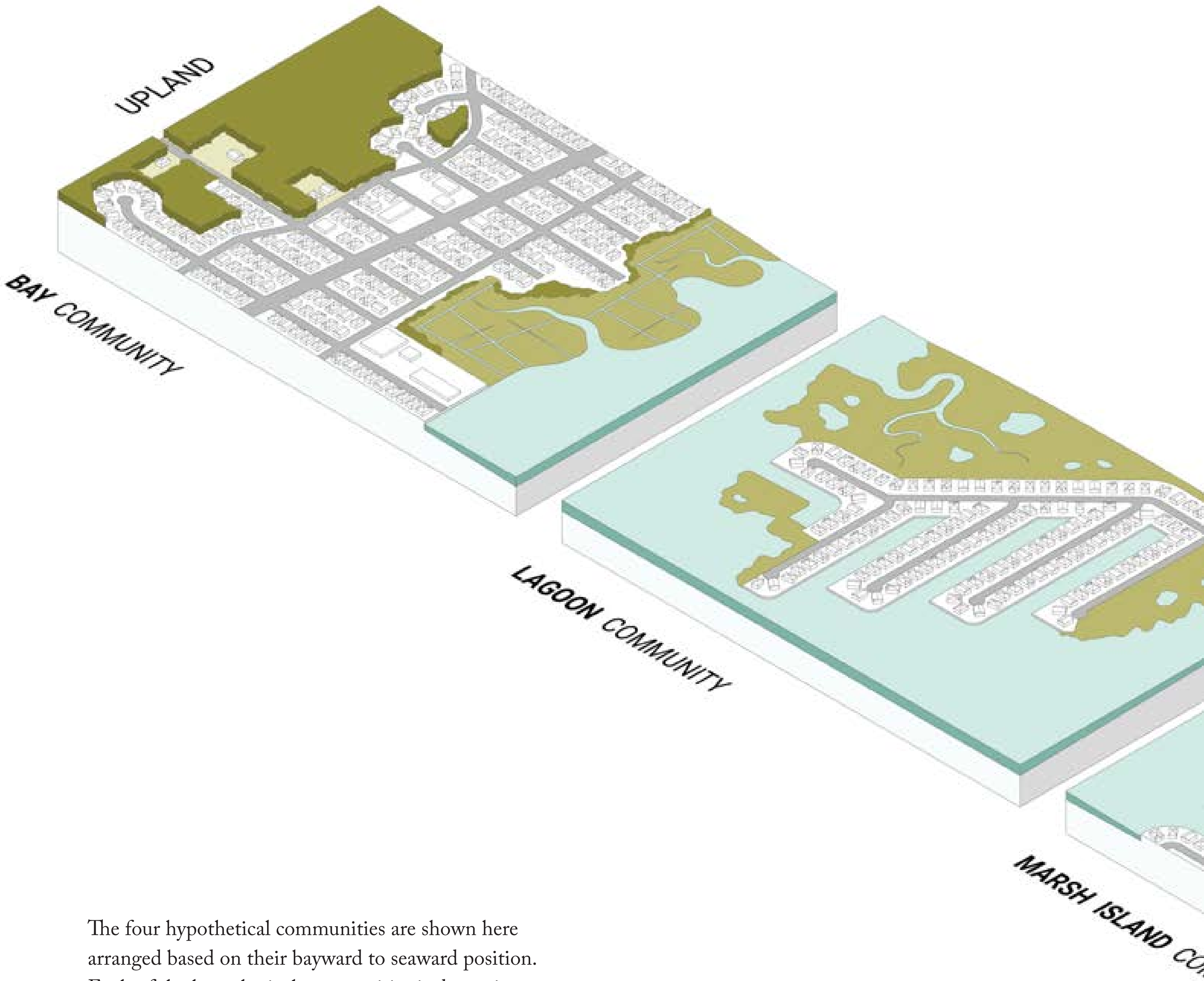
Four types of Back Bay communities were identified to structure this study of the potential benefits of combining nonstructural measures with NNBF. This approach suggests that the application of nonstructural measures be considered in relation to their ecological contexts and the CSRM benefits those contexts are able to provide. It also suggests important adjacencies throughout the bay, as alterations to one area have the potential to affect the ecological and hydrological dynamics of neighbouring areas.

This map (at right) identifies footprints for barrier island communities, marsh island communities, lagoon communities, and bay communities throughout the New Jersey Back Bays. Frames indicated with black dotted lines indicate examples of these communities that are shown in maps on subsequent pages of this report. For each of the four community types, the maps depicting these example communities are followed by sections and diagrams that use drawings of hypothetical communities to illustrate the potential combination of nonstructural measures and NNBF in that community type.

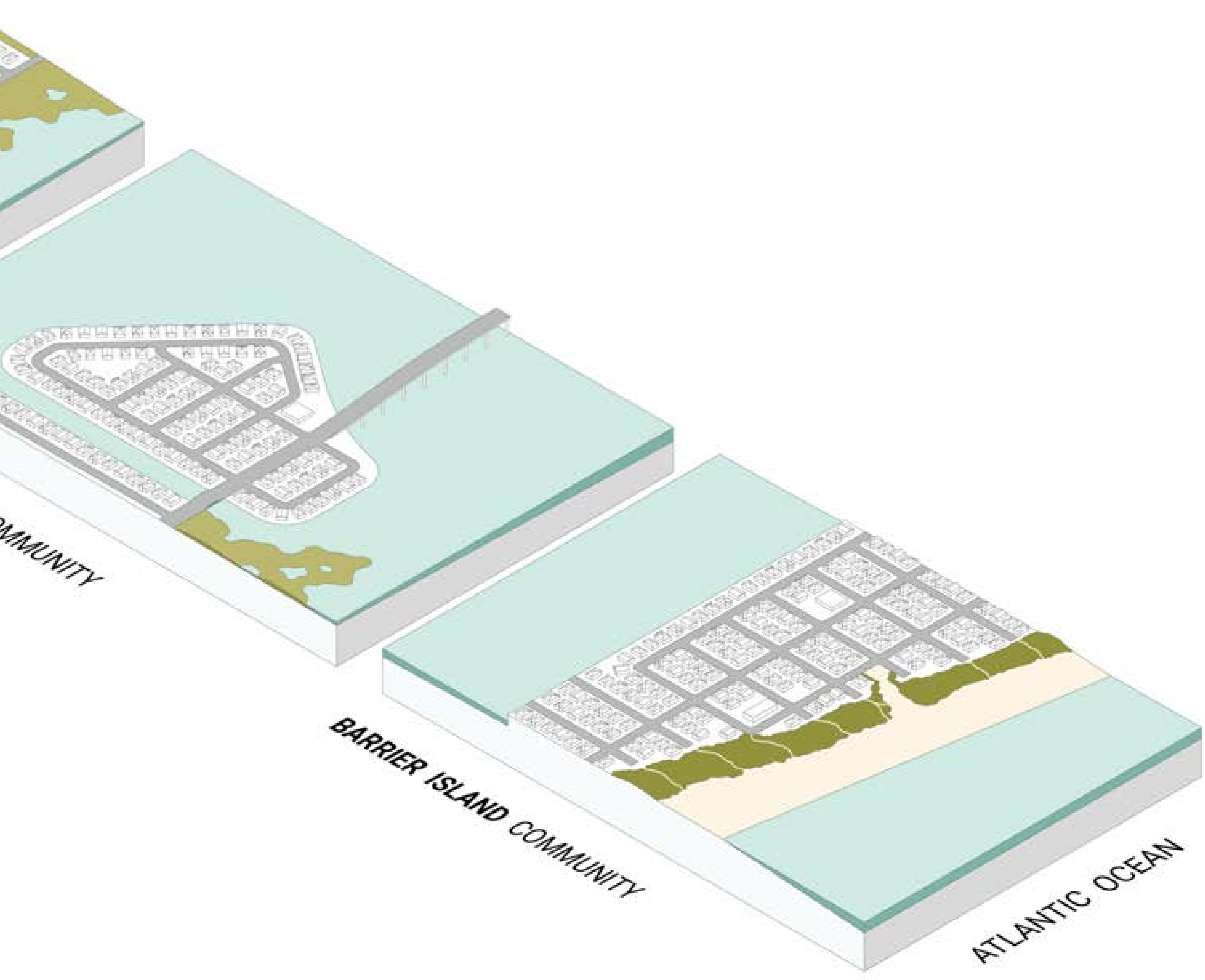
While the boundaries drawn here do not reflect the social, economic, jurisdictional, or infrastructural relations that constitute, create, and maintain community, they should be read in context of an understanding of the importance of community and social resilience to CSRM and the need to consider the specifics circumstances of individual communities in the planning and implementation of nonstructural measures, particularly when they are paired with NNBF.




LAGOON
COMMUNITY
EXAMPLE
BARRIER ISLAND
COMMUNITY
EXAMPLE
MARSH ISLAND
COMMUNITY
EXAMPLE
BAY
COMMUNITY
EXAMPLE



The four hypothetical communities are shown here arranged based on their bayward to seaward position. Each of the hypothetical communities is drawn in more detail on the coming pages, where they are shown in combination with potentially applicable nonstructural measures and NNBF. From these parts, a full cross-section of nonstructural measures and NNBF combinations can be stitched together that reflects possible beneficial relationships between the hypothetical communities within the larger back bay system.



OMMUNITY
BARRIER ISLAND COMMUNITY
ATLANTIC OCEAN

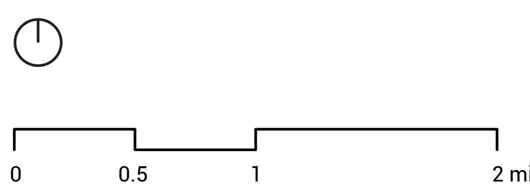
BARRIER ISLAND COMMUNITIES

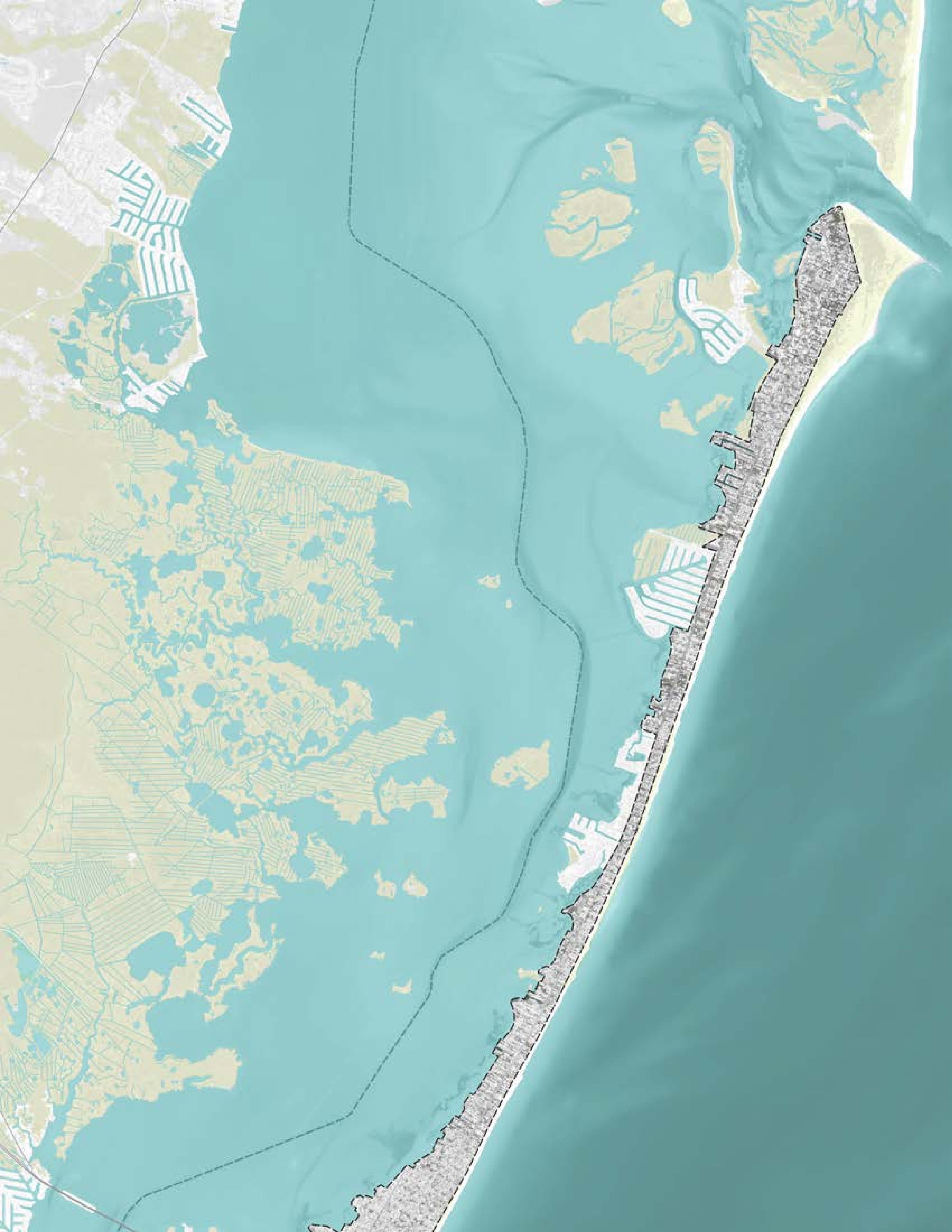
These communities sit on the outermost perimeter of the bays and are the furthest away from mainland New Jersey. Barrier islands are surrounded by water on all sides. Inlets occasionally cut through the islands, facilitating tidal exchange and forming entry points for navigation channels. Access to these communities is often limited and requires crossing over large bodies of water and navigation routes by way of a highway extension or bridge. In terms of urban form, barrier island communities are typically very dense, with small clusters of homes, commercial structures, and apartment buildings along gridded roads which extend seaward to bayard. The seaward side of the island is characterized by a beach and dune system. These communities have significant storm risk on the seaward edge along their length (though seaward CSRM lies outside the scope of this study) as well as storm surge waters that enter inlets from the bayward side.

The community represented on this map is an example of the many identified barrier island communities throughout the Back Bay system.

Legend

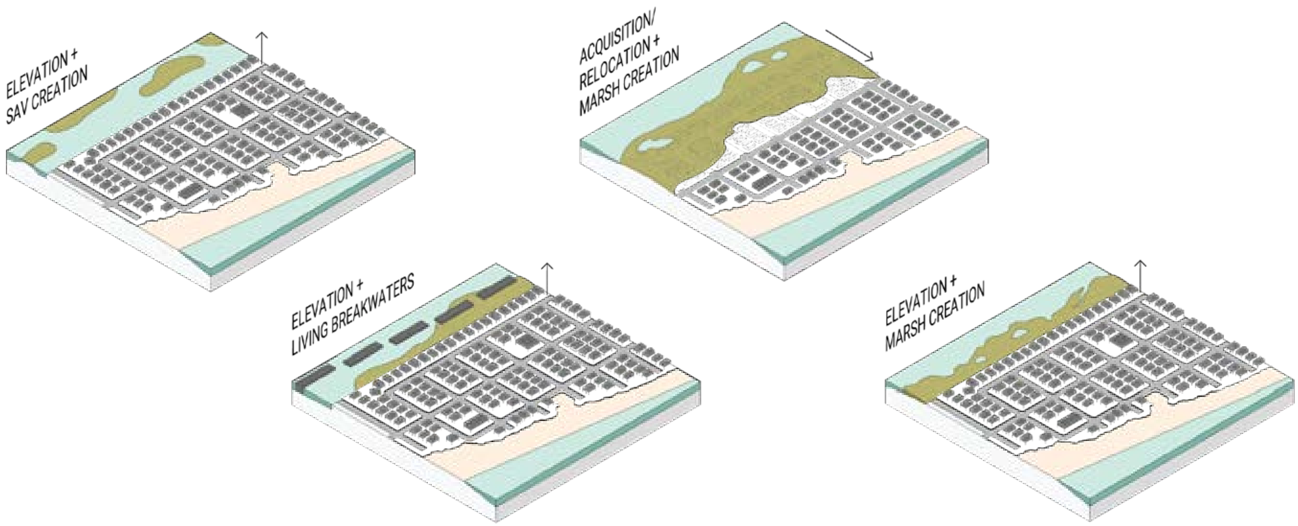
- Barrier Island Community Type
- Wetland
- NJIWW
- Major Road

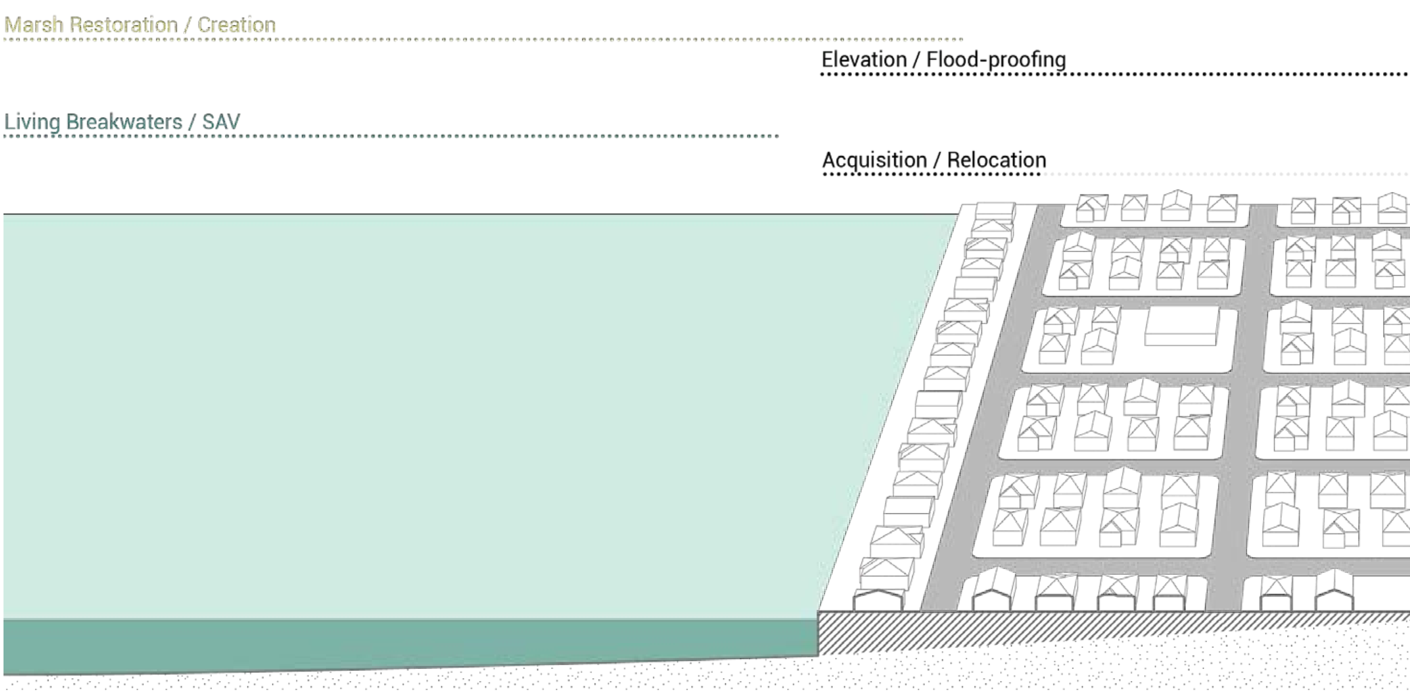




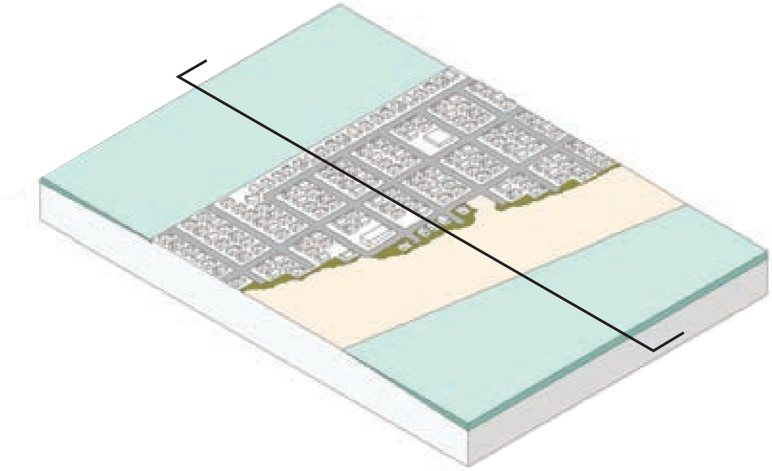
BARRIER ISLAND COMMUNITY: NONSTRUCTURAL WITH NNBF

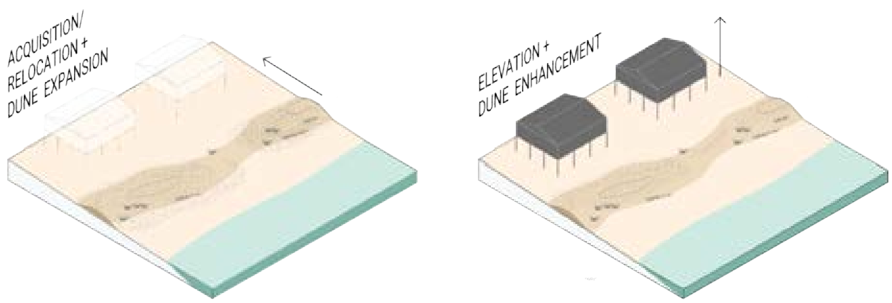
The potential of NNBF to provide CSRM benefits in combination with nonstructural measures can be considered on both the seaward and bayward sides of barrier island communities. (It should be noted that seaward CSRM lies outside the scope of the larger NJBB study, but ideally nonstructural measures would be paired with NNBF in a holistic fashion for a given community, and so seaward pairings are included here.) On the seaward side, enhanced dune systems paired with building retrofits and expanded dune systems with additional area allocated from acquisition/relocation can be considered. On the bayward side, improved and created marshes and SAV areas, living breakwaters, and ecotone levees can be considered to reduce storm surge energy and wave height.

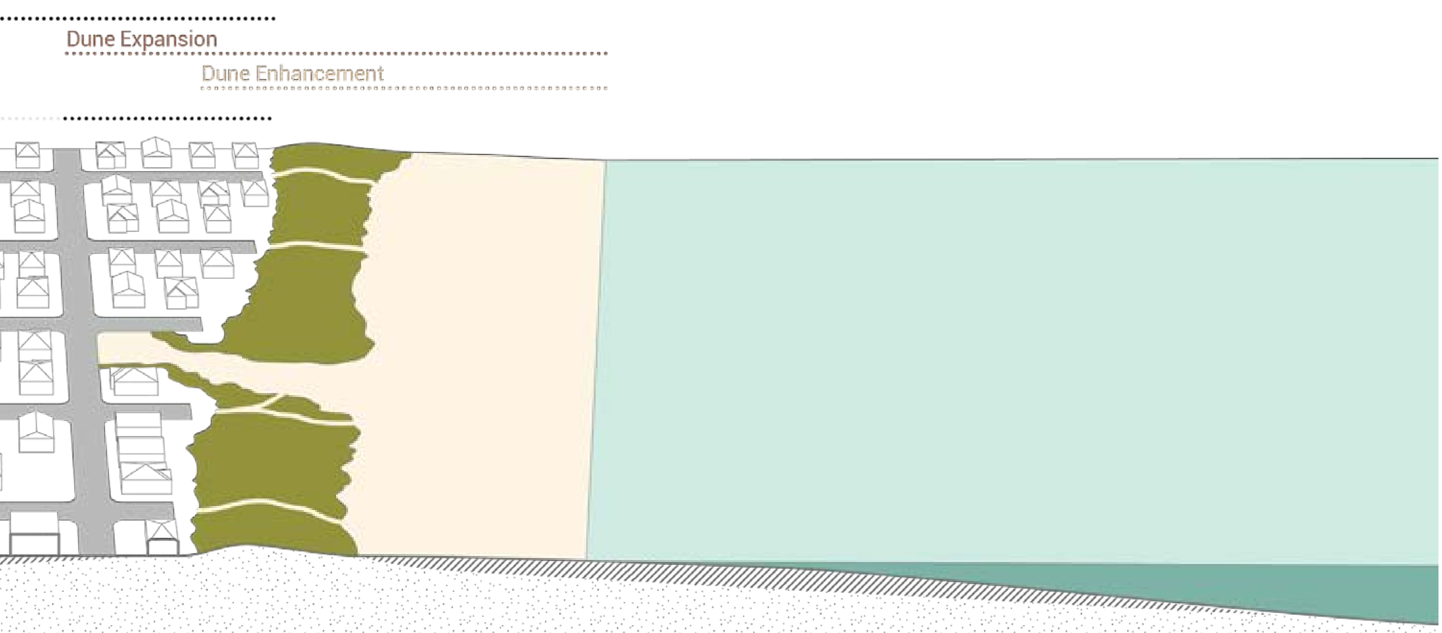




Diagrammatic section perspective of a hypothetical barrier island community



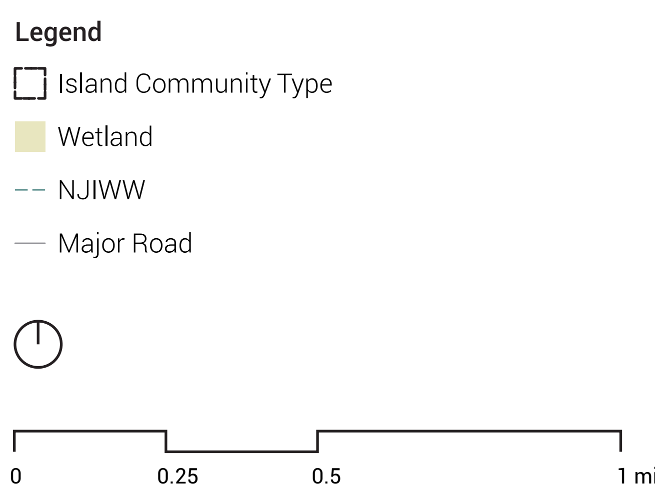

ACQUISITION/
RELOCATION +
DUNE EXPANSION
ELEVATION +
DUNE ENHANCEMENT


Dune Expansion
Dune Enhancement

MARSH ISLAND COMMUNITIES

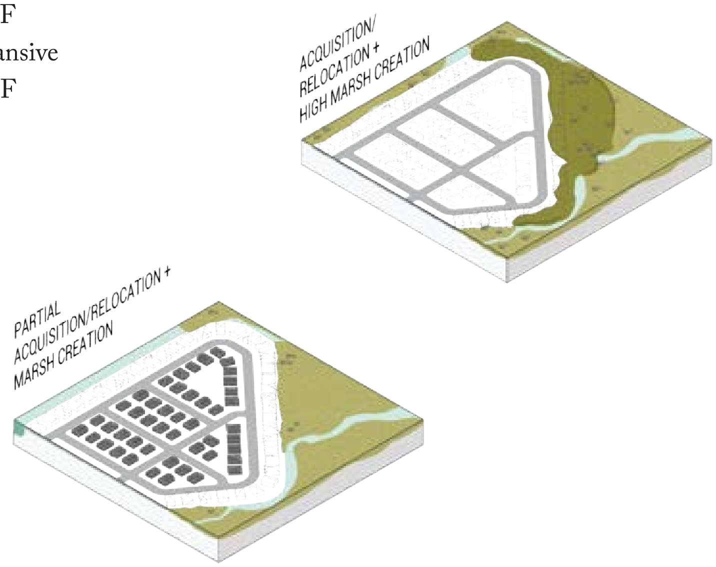
Marsh Island communities are located within the bays and are surrounded by water on all sides. Marsh Island communities are often smaller and segmented in comparison to long and continuous barrier island communities. These communities sit within the interior of the bays, replacing and often adjacent to intact marsh islands. These communities are the least prevalent of the four coastal community types identified in this report. Because of their size and separation from the east and west landforms of the bays, Marsh Island communities are accessible primarily by one or two roads or bridges. Similar to Barrier Island communities, homes on the islands are formed into dense clusters along gridded roads. The Marsh Island communities differ in that it does not have beach access on any side. Rather, they are surrounded by marsh, SAV, and open water habitat. Marsh Island communities throughout the Back Bays are primarily built on fill that extends urbanized areas from the barrier islands into the bays.

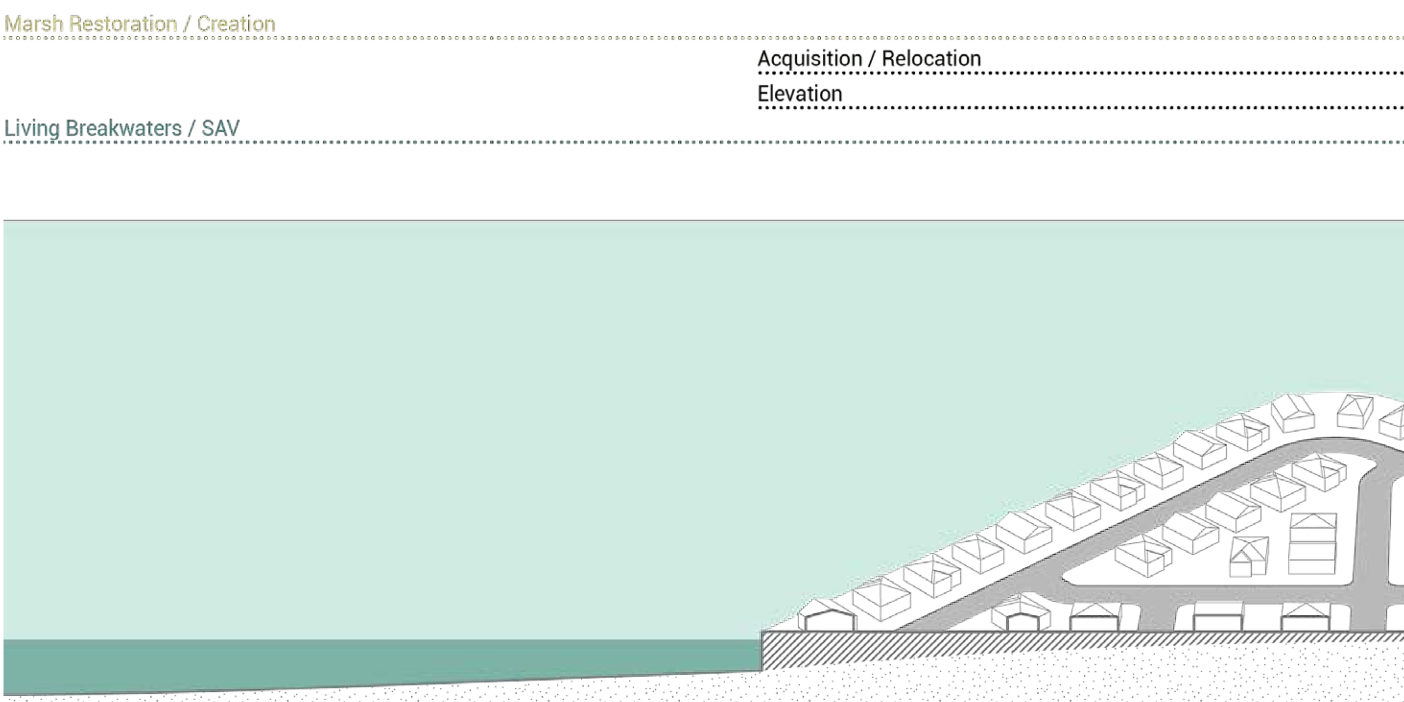
The communities represented on this map are a few examples of the many identified marsh island communities throughout the Back Bay system.



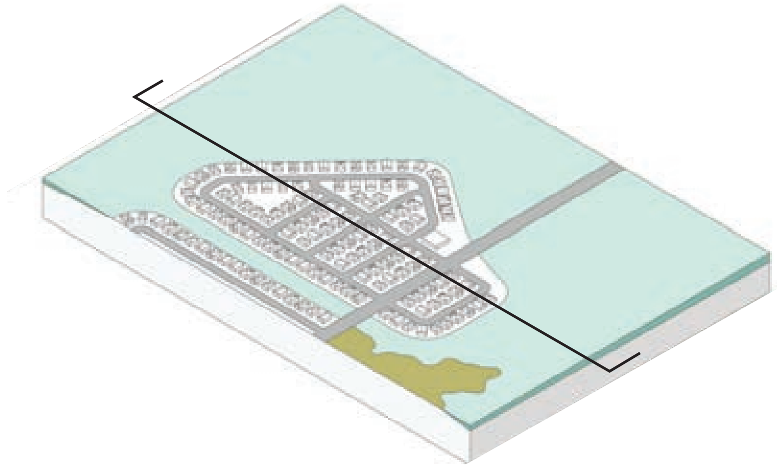
MARSH ISLAND COMMUNITY: NONSTRUCTURAL WITH NNBF

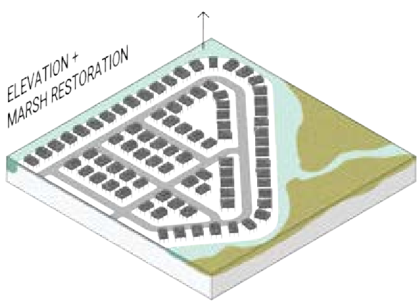
Paired nonstructural and NNBF measures should be considered for Marsh Island communities within the context of broader bay-wide initiatives, such as the "Barnegat Bay Shallows" depicted in Part II of this report. Marsh Island communities are densely inhabited with very little space for NNBF measures on the island. Surrounding marshlands in the bays have the potential to absorb and buffer storm surge and floodwaters. Relocation and acquisition along the edges of these areas could provide space for NNBF features to mitigate risk to the interior. More expansive relocation and acquisition of these areas for NNBF could provide CSRM to adjacent communities.

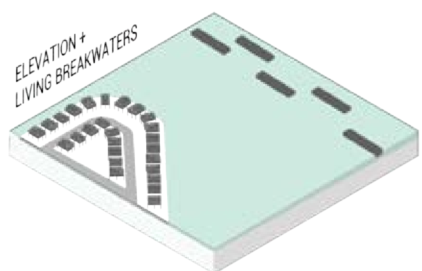


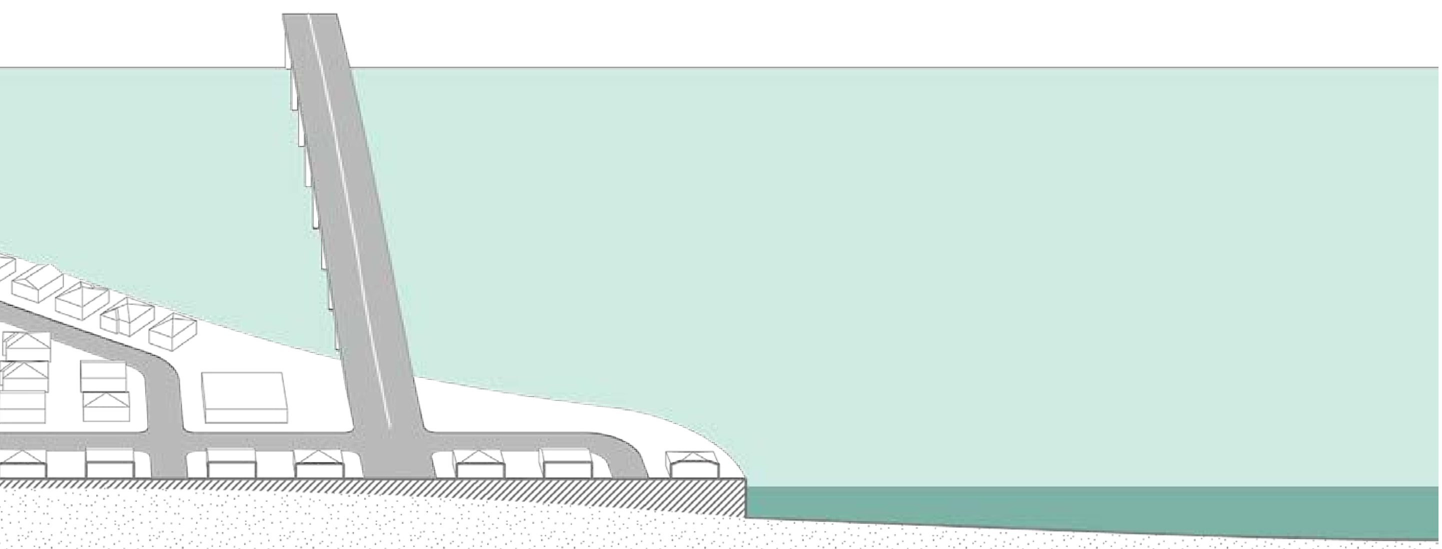


Diagrammatic Section perspective of a hypothetical marsh island community




ELEVATION +
MARSH RESTORATION


ELEVATION +
LIVING BREAKWATERS



LAGOON COMMUNITIES

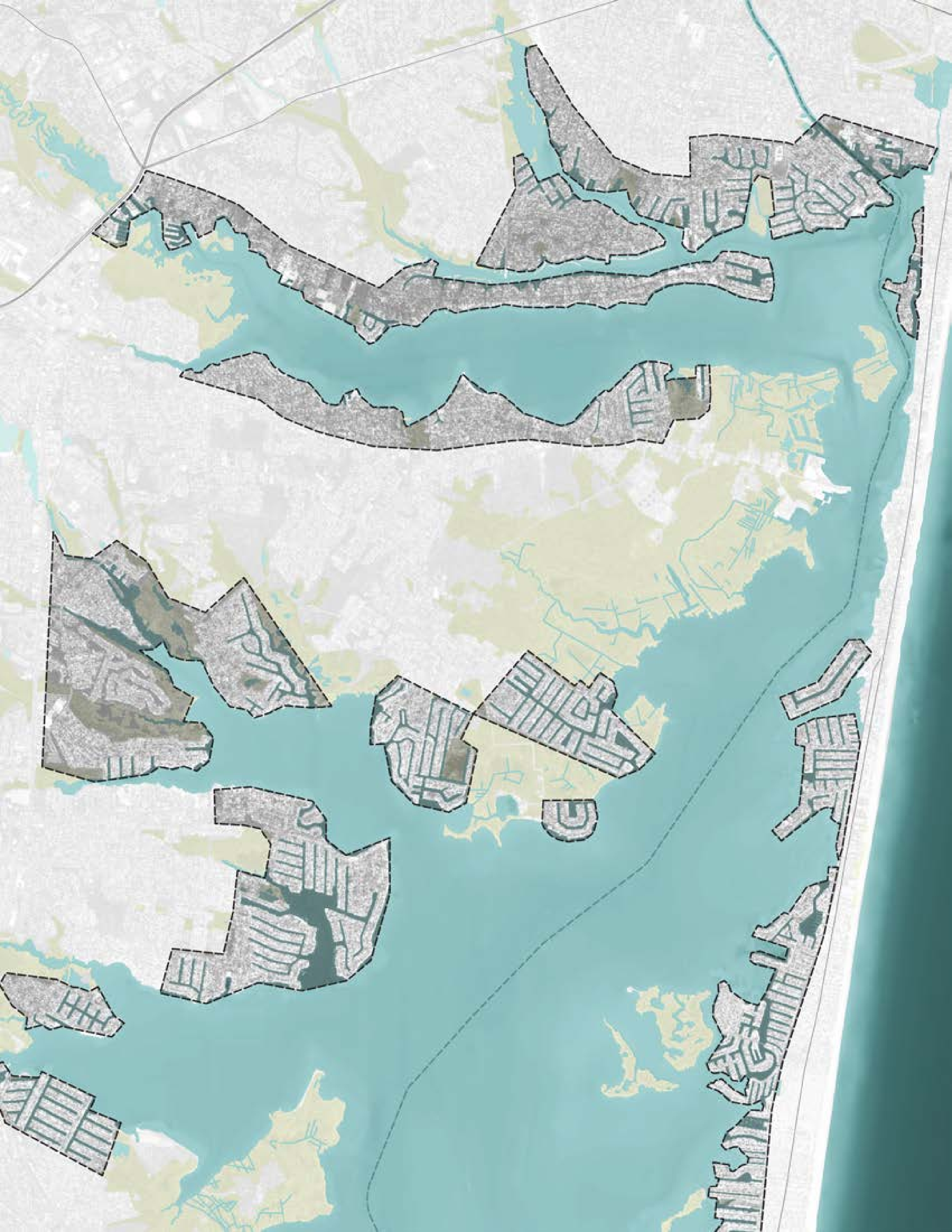
These communities are defined by canals, docks, and direct waterside access. They contain boat lanes that provide access to a row of homes on either side. Typically Lagoon communities were constructed by dredging "finger" canals into existing marshes and using the resulting dredged material to fill along either side of the canal. As a result, there are often large stretches of intact marsh on either side of Lagoon communities.

The communities represented on this map are a few examples of the many identified lagoon communities throughout the Back Bay system.

Legend

- Lagoon Community Type
- Wetland
- NJIWW
- Major Road

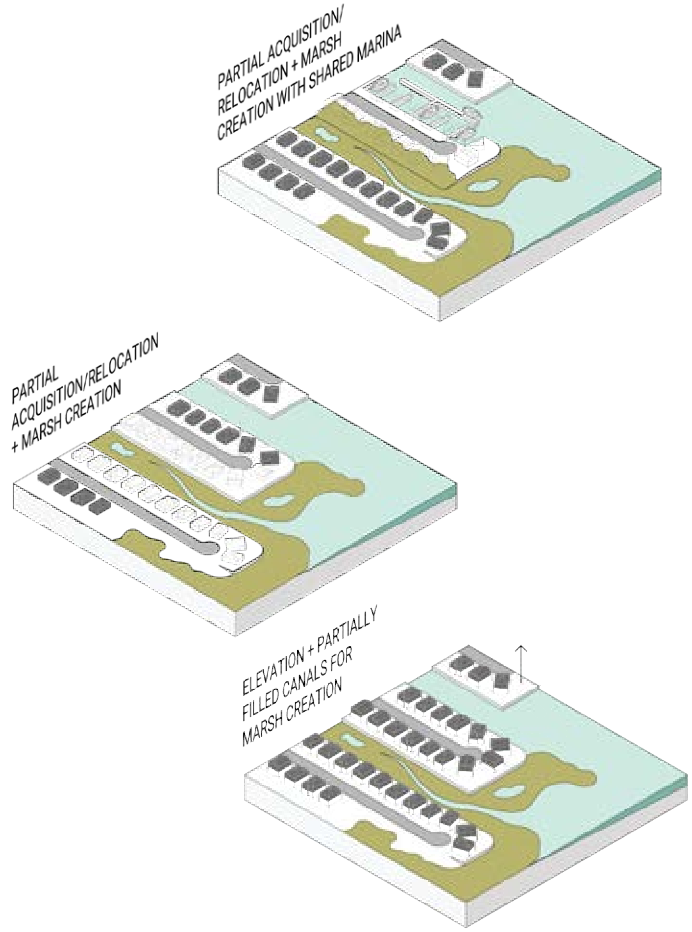
0 0.25 0.5 1 mi

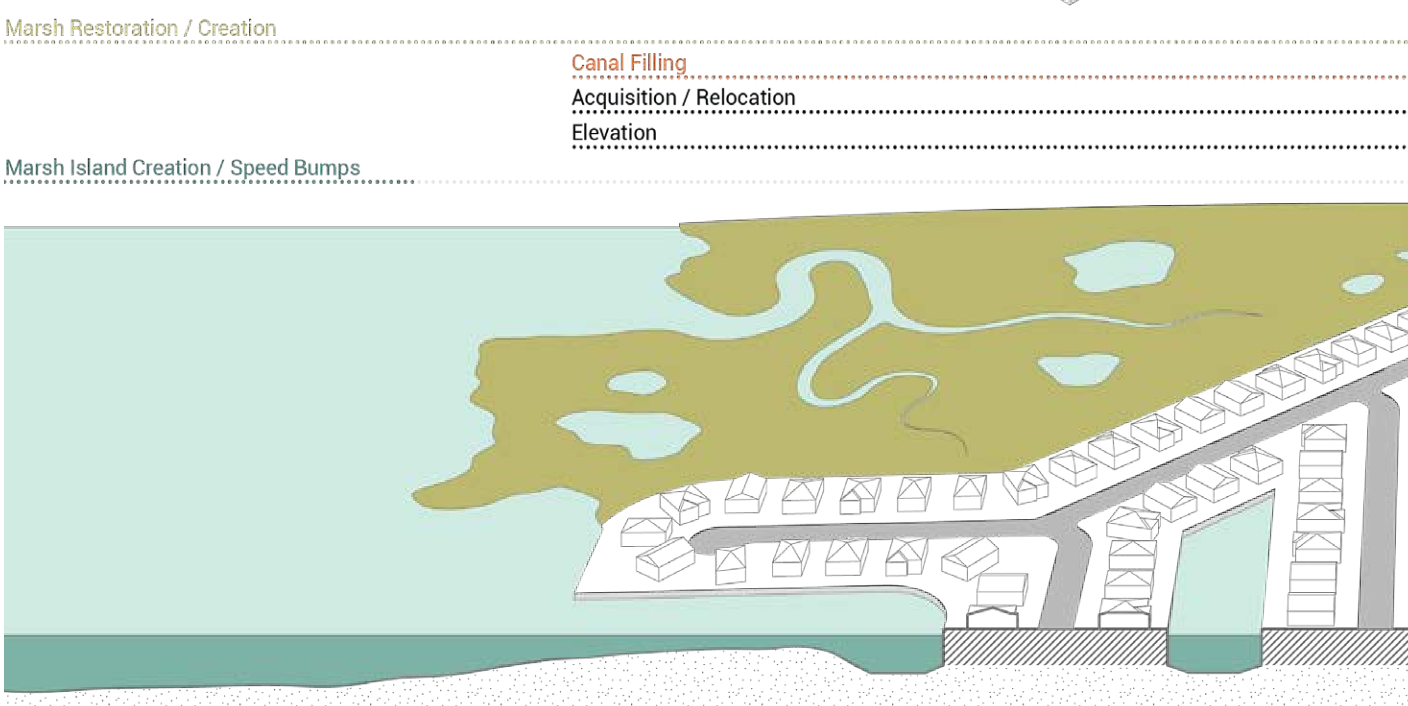


LAGOON COMMUNITY: NONSTRUCTURAL WITH NNBF

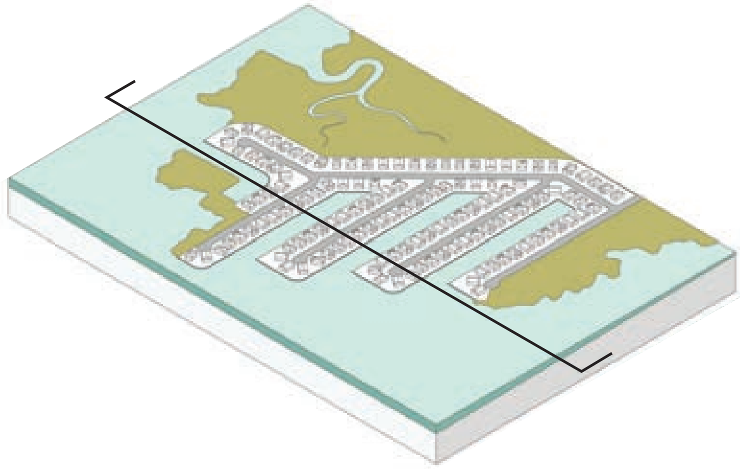
The finger canals are a key spatial constraint on the pairing of NNBF and nonstructural measures near and within Lagoon communities. Building elevation, acquisitions, relocations, and pier removal may be usefully paired with the development of NNBF such as constructed marshes either within (former) finger canals or along the perimeter of the Lagoon community. On the bayward side, improved and created marsh and SAV areas can be considered to absorb and buffer the community from rising waters. (NNBF options for Lagoon communities that would be located further into the bay are explored on pages 42-43 of this report.)

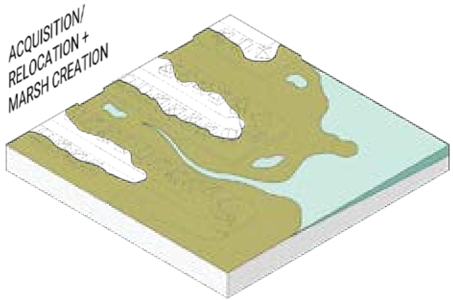
Most NNBF deployments for Lagoon communities would likely lead to a reduction in lots with boat access, making acquisition and/or relocation potentially key strategies. It is possible that community marinas could replace some lost individual lot access; community marinas would require less bay perimeter and facilitate the use of NNBF. This option would need to be explored in conversation with individual communities.

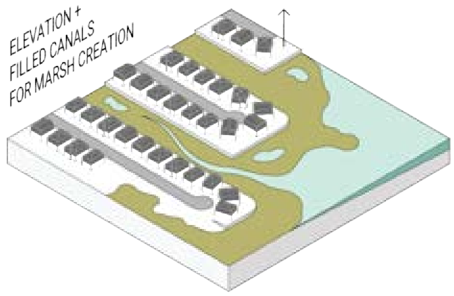


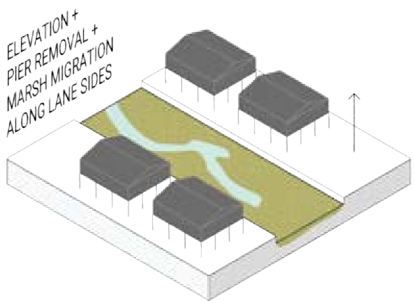


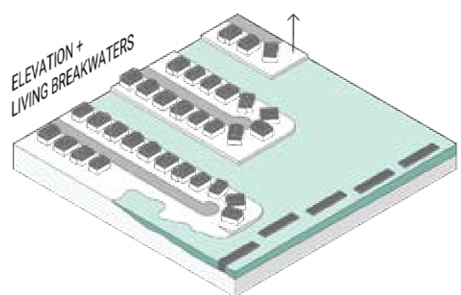
Diagrammatic section perspective of a hypothetical lagoon community

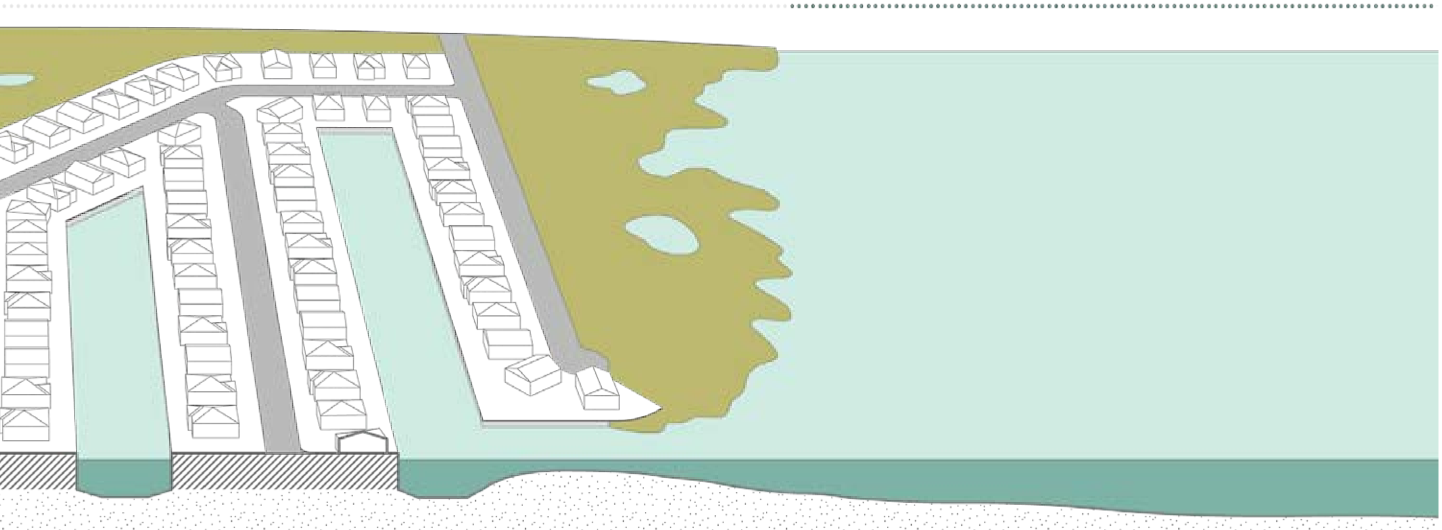



ACQUISITION/
RELOCATION +
MARSH CREATION


ELEVATION +
FILLED CANALS
FOR MARSH CREATION


ELEVATION +
PIER REMOVAL +
MARSH MIGRATION
ALONG LANE SIDES


ELEVATION +
LIVING BREAKWATERS



BAY COMMUNITIES

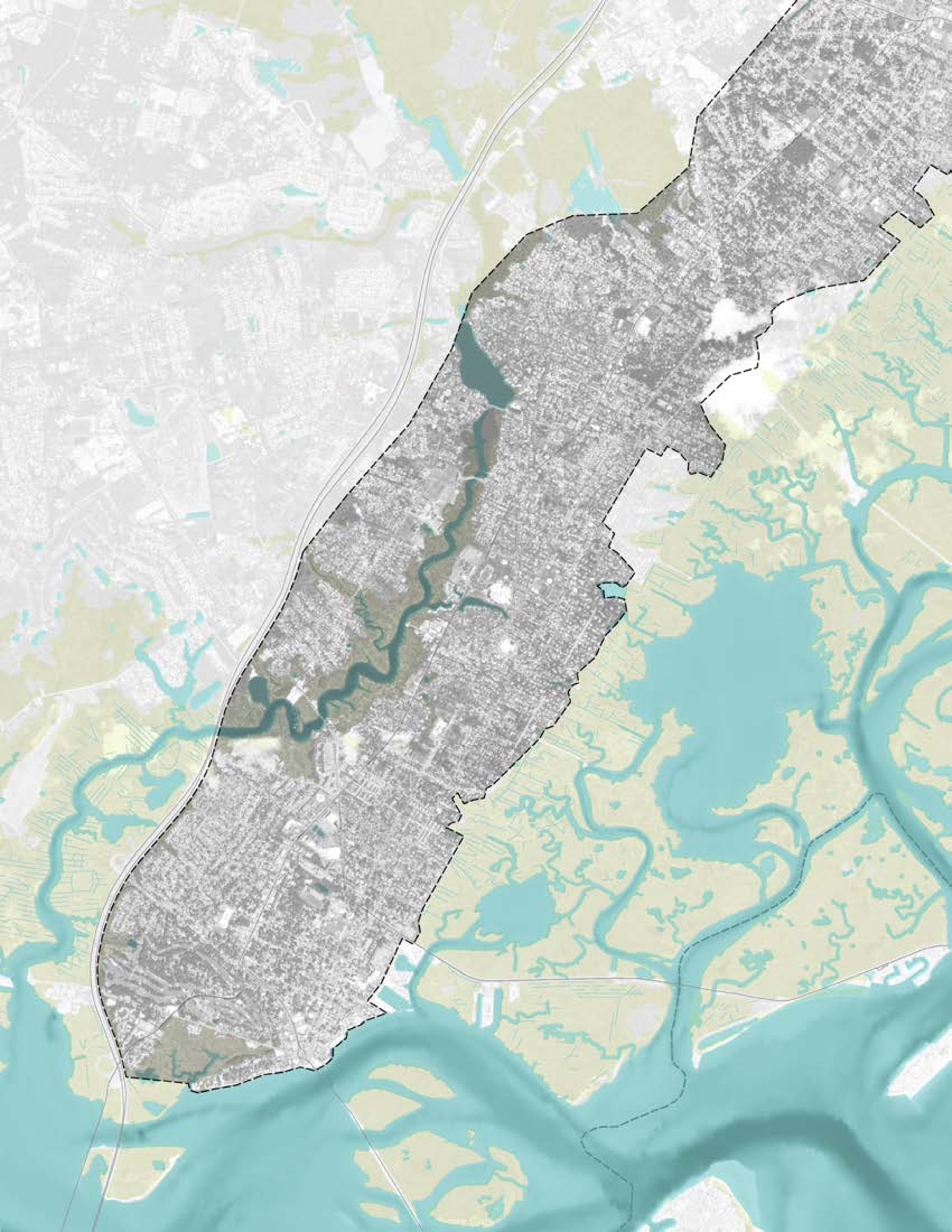
These communities are located along the Back Bays on the New Jersey mainland. Unlike Islands, Bay communities are defined by water only on one side. More than any of the other Back Bay community types, the urban form of Bay neighborhoods resembles non-coastal communities further inland. Bay communities typically include detached houses, sizeable backyards, gridded roads, cul-de-sacs, and extensive access to several highways and/or major roadways. Bay communities are larger than other coastal neighborhoods and have more defined city-centers as well as non-water related amenities, including wooded parks, golf courses, cemeteries and other non-developed community areas. In these communities, direct waterside access is less common than other neighborhood types.

The community represented on this map is one example of the many identified Bay communities throughout the Back Bay system.

Legend

- Bay Community Type
- Wetland
- NJIWW
- Major Road

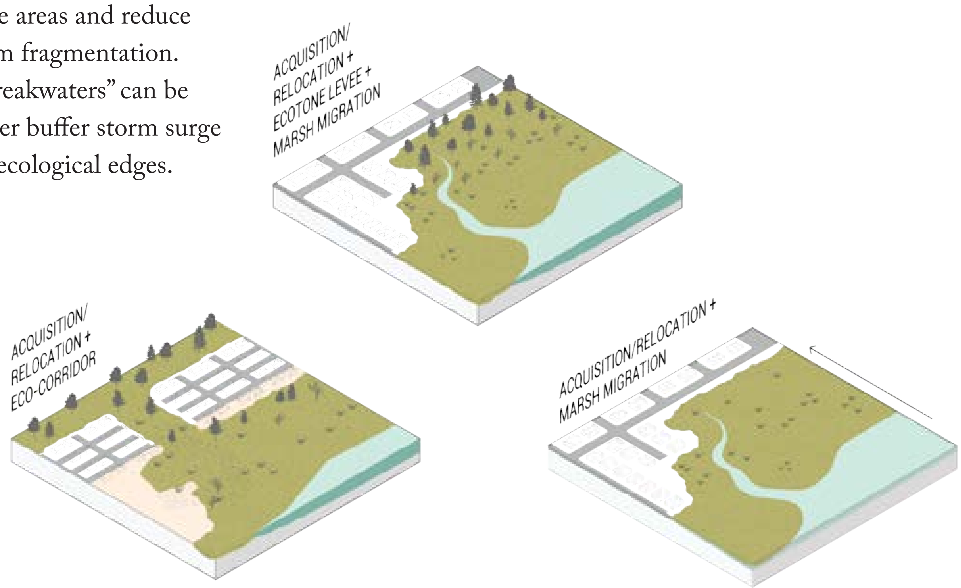
0 0.25 0.5 1 mi



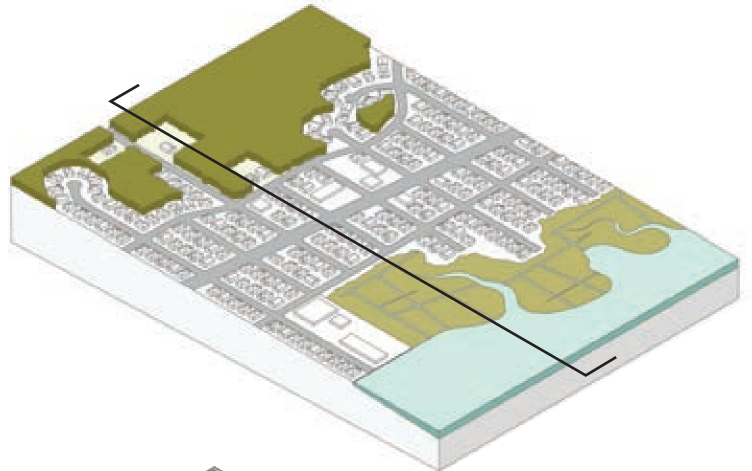
BAY COMMUNITY: NONSTRUCTURAL WITH NNBF

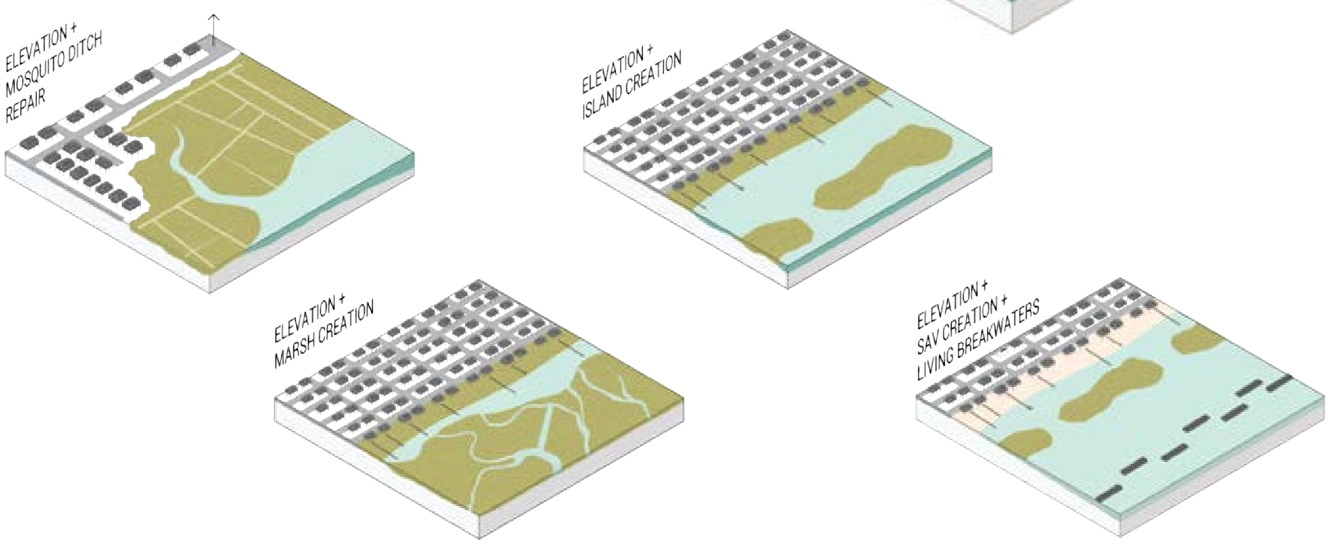
The combination of nonstructural and NNBF measures can be considered for Bay communities which are adjacent to marsh or have bulkheads and are adjacent to open water. In Bay communities which are adjacent to marsh, mosquito ditches are common. Filling and repairing mosquito ditches, as well as creating marshes in degraded areas, will help provide CSRM benefits in these areas and reduce further marsh deterioration from fragmentation. SAV beds paired with "living breakwaters" can be created within the bays to further buffer storm surge and reduce erosion to sensitive ecological edges.

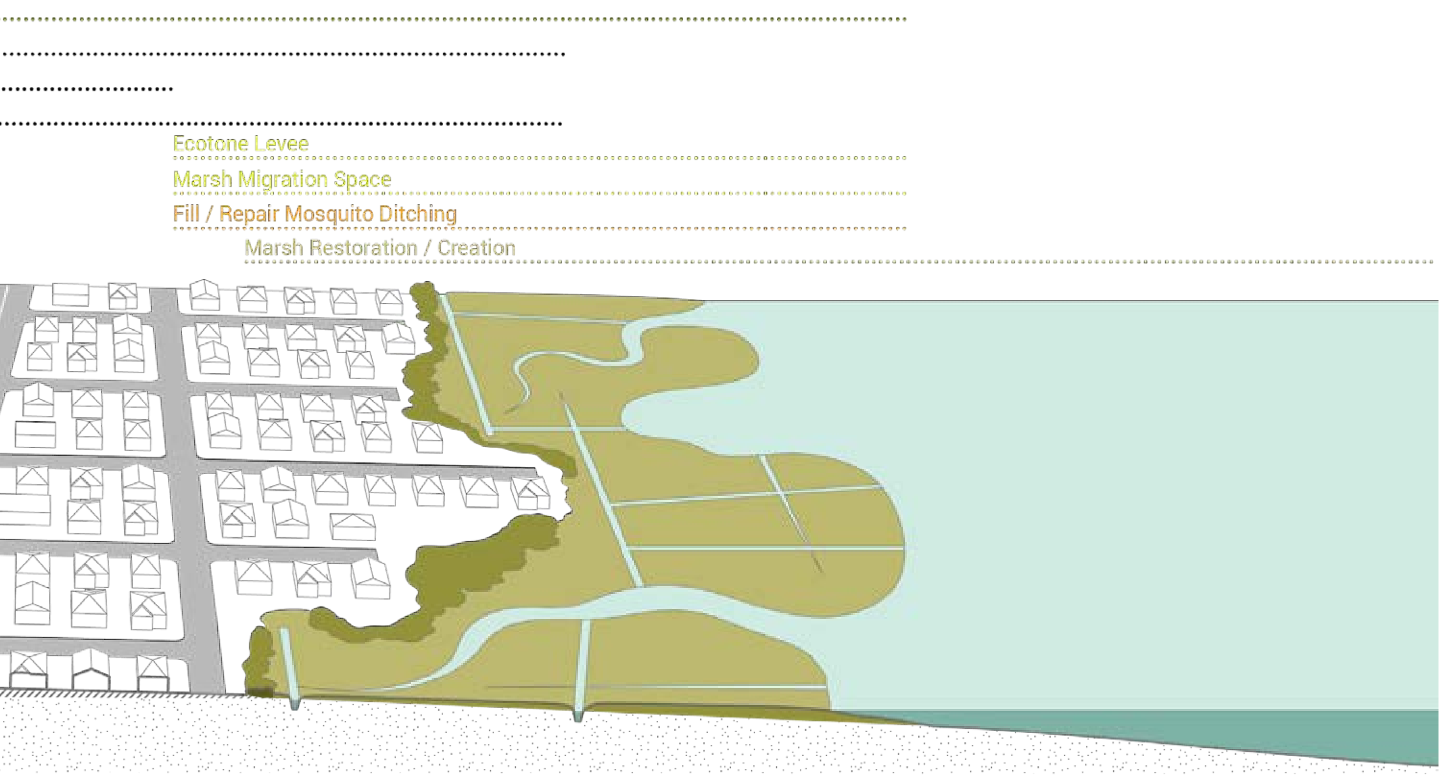
When acquisition or relocation is possible, marsh can be created with space for future upland migration. Further protections and marsh migration space can be created with an ecotone levee.



Diagrammatic Section perspective of a hypothetical bay community




ELEVATION +
MOSQUITO DITCH
REPAIR
ELEVATION +
ISLAND CREATION
ELEVATION +
MARSH CREATION
ELEVATION +
SAV CREATION +
LIVING BREAKWATERS


Ecotone Levee
Marsh Migration Space
Fill / Repair Mosquito Ditching
Marsh Restoration / Creation

Reflections and Further Considerations

Nonstructural measures and NNBF are mutually supportive. Nonstructural measures may create opportunities for the application of NNBF in the form of managed coastal retreat and strategic land use changes, while the application of NNBF has the potential to support investments in building retrofits. In addition to their physically cooperative alignments, nonstructural measures together with NNBF offer opportunities to address social and environmental concerns – establishing socially and ecologically resilient communities in order to manage risk to both human communities and ecological systems. However, the pairing of NNBF and nonstructural measures also have the potential to increase risk and/or vulnerability, which may be inequitably distributed within a broader region like the Back Bays. As a result, careful design, modeling, and planning is necessary for the successful combined application of NNBF and nonstructural measures, both physical and nonphysical.

With NNBF such as living breakwaters or ecotone levees, the positive benefits of a NNBF applied in one area might create vulnerabilities in another. (See Part III of this report, "NNBF Performance and Suitability", for discussion of some examples of how NNBF's CSRM effects may be positive in some areas and negative in others. It should also be noted that structural measures have a similar potential for divergent effects.) Modeling of the broader effects of new features is necessary to understand their implications and relationships to adjacent areas. Extensive and multi-scalar modelling would be helpful to plan for both SLR and changing ecological and hydrological dynamics in the bays. In the long run, redundancy and mutually supportive NNBF can help mitigate the impacts of SLR and catalyze desirable ecological shifts such as upland marsh migration.

Nonphysical measures such as changes to zoning, land use, and policy that support NNBF can disproportionately affect vulnerable communities and residents that occupy or depend on the current state and use of those lands. The acquisition and relocation of property and buildings has proven in many regions to be especially complex, with a high risk that impacts will be inequitably distributed. Managed coastal retreat (as planned adaptation) and unmanaged coastal retreat (in the wake of storm events) can perpetuate and deepen inequalities and vulnerabilities for both individuals and coastal communities as wholes.

Many examples of managed retreat have missed opportunities to address the important physical and social interconnections that communities and residents rely on for social, economic, and ecological resilience. Holistic planning across communities should be undertaken to avoid disproportionate burdens on vulnerable residents while increasing the potential for risk reduction. Efforts by researchers and practitioners in design and planning have begun to address these tendencies and consider more comprehensive approaches.

For instance, in Louisiana, the state's Coastal Protection and Restoration Authority has been developing nonstructural measures as part of their Coastal Master Plan since 2012. They have acknowledged the importance of measures that not only include building retrofits but also seek to support and grow socially resilient communities. Louisiana's Strategic Adaptations for Future Environments (LA SAFE 2019) is a multidisciplinary effort that has approached managed coastal retreat through extensive community engagement in coordination with risk reduction and restoration strategies. Also in Louisiana, efforts to relocate the Isle de Jean Charles community from their existing lands, which are imperiled by RSLR, to a newly-designed community further inland have exposed both challenges and pathways for communities to participate in the planning and design of their coastal retreat. These experiences, and others in locations like Puerto Rico and south Florida, suggest the importance of developing pathways for co-design and co-creation for displaced and relocated communities (Lizzie Yarina, Miho Mazereeuw, Larisa Ovalles 2019; Masoud 2017).

The potential for CSRM benefits through the combination of nonstructural measures and NNBF to reduce risk and strengthen the ecological resilience of the broader coastal landscape is high. These applications, facilitated by managed coastal retreat in particular, should be approached with thoughtful and careful coordination to protect and create equitable and resilient coastal communities and landscapes.

Part V

INITIAL QUALITATIVE COST INVESTIGATIONS

Considering Specific NNBF Ideas

As described in other sections of this report, the collaborative team initially identified numerous NNBF ideas through a series of workshops and communications. The collection of EWN ideas for each region can be found in Part I. As noted previously, seven concepts emerged as priorities to advance with additional analysis, drawings and renderings, current progress on which is documented in Part II. Those example projects include: Ocean City horizontal levee, created NNBF islands for lagoon communities, integration of surge filters in strategic locations, and terracing of coastal lakes. These prioritized examples exist as transferable concepts. For example, there are numerous locations where horizontal levees could be developed in addition to the Ocean City location. Similarly, placement of NNBF island(s) in close proximity to lagoon communities could occur at several locations within the NJBB. With these initial investigations, the EWN-LA team identified multiple communities where constructed islands could offer CSRM benefits (see pages 20-23).

Aside from the proposed terracing in the Coastal Lakes Region, constructing the remaining NNBF priorities will likely require large volumes of dredged sediment. Takeoffs that follow on pages 88-91 highlight the estimated cubic yards of material that would be required for the Tuckerton Peninsula options, Beach Haven Surge Filter, and Ocean City levee/wall, respectively, assuming the projects would be approached using the indicated dimensions. Acreage of vegetation (and proposed type relative to elevation) for each of the NNBF ideas is also offered in the same takeoffs. These material volumes and acreages should be understood as order of magnitude estimates.

These projects could be scaled up or down depending on availability of sediment, project funding, and/or the magnitude of storm risk reduction required from the project. Larger, more complex NNBFs at different locations in the NJBB are currently being modeled to determine flood risk and storm risk reduction benefits. The model area extents for these NNBF can be seen on page 39.

Cost Estimates and Associated Challenges

The team investigating NNBF ideas for possible inclusion in the NJBB CSRM study also conducted an initial characterization of data that would support the development of "high-level", qualitative cost estimates for preferred strategies and structures. As more information became available to the team, however, it was apparent that a large number of variables, coupled with a very broad range of uncertainty, will have great influence on adequately reporting anticipated cost, particularly at this stage of project development. The NACCS parametric cost data was reviewed as part of this analysis. Of the available data, the Excel Workbook titled, "2013 Parametric Cost Estimate" offered some insight with respect to cost estimates for traditional NNBF habitats including, but not limited to: wetlands, reefs, and submerged aquatic vegetation (Appendix 1).

Additional information was also made available to the team. Table 1 highlights that information and example cost for various NNBF-type efforts that have been reported in the NJBB and for a recent 2019 island restoration project in the Chesapeake Bay.

Table 1. Costs associated with recent NNBF-type efforts in Chesapeake Bay and New Jersey Back Bays.

Chesapeake Bay		
2019 Swan Island Restoration	Mob/Demob	~ $1,400,000
	Dredging Cost (Range)	$8-$15/cyd
	Ajax (31 meters)	$42,000
	Planting (200,000 plants for ~14 acres)	$480,000
	Turbidity curtain (500 lf), hay bayles (170 lf), coir fiber logs (2600 lf), and turbidity curtain (500 lf)	$155,000
New Jersey Back Bays		
NJ DOT	Dredging Cost	$247/cyd
Ring Island	Dredging Cost (Range)	$30-$45/cyd
Avalon	Dredging Cost w/ containment	~ $45/cyd
Mordecai Island	Dredging Cost w containment	$28-$30/cyd
Other Applicable Information		
(Based on Activities in NJBB)	Oyster Castles	$300/lf (estimate)
	Rock Sills	$600/lf (estimate)
	Breakwaters	$1100 - $1200/lf (estimate)
	Remove Sediment from Existing CDFs*	$50/cyd (estimate)
	*community may require additional tipping fees	

While the 2013 Parametric Cost Estimates (Appendix 1) and information in Table 1 offer considerable information about the materials, cost per unit, estimated O&M, anticipated project life, etc., there are inherent pitfalls in extrapolating these values (and approaches) in order to estimate the cost of prioritized NNBF ideas for the NJBB. Those pitfalls exist because there are currently many intangible factors that are specific to the diverse geographical settings in the NJBB. To date, those intangible factors have not been considered on a system scale or in a way that would inform the development of qualitative cost estimates. Those factors include, but are not limited to:

- **Maximizing the use of natural processes in the NJBB system to support construction and maintenance of the proposed NNBF.** A considerable amount of hydrodynamic data, models, etc. exists for the NJBB. Leveraging this information to identify areas where water circulation patterns, tides, currents, etc. can be harnessed to transport and deposit sediment in order "feed" (i.e., expand and/or maintain) NNBF is critical to optimizing placement features that are likely to be more self-sustaining. In turn, overall construction and O&M cost would likely be reduced as the result of optimizing siting and performance of the NNBF.

- **Identifying and strategically expanding existing natural features within the NJBB.** Existing natural features are ubiquitous within the NJBB. Where applicable, those existing features could be expanded to increase the engineering and ecosystem service benefits that are achieved. Leveraging these existing features would greatly reduce the overall amount of dredged sediment required for construction of NNBF.

- **Increasing use of sediment derived from maintenance dredging of navigation channels to construct NNBF.** Philadelphia District is responsible for maintaining approximately 500 miles of Federal navigation channels, which includes the Delaware River. Of that, approximately 200 miles are coastal or bay (the New Jersey Intracoastal Waterway composes 117 miles within the coastal/bay complex). However, only a small fraction of that material is used beneficially. Strategically constructing NNBF in locations that support the navigation mission and creates storm risk reduction opportunities would leverage funds already dedicated to the navigation business line.

- **Simplifying the overall project design and construction approach to NNBF.** In many situations, NNBF are over designed and/or constructed with an exorbitant number of stabilization and/or sediment containment measures. Likewise, planting of vegetation is often integrated into a project, and in most circumstances, that action could be scaled back. In some areas, planting may not be necessary at all with the availability of sufficient seed stock. Allowing additional time for maturity of the site(s), which would also allow for the "shaping/sculpting" by natural processes, could also result in greater cost savings.

- **Locating and characterizing sediment sources.** Sediment characteristics (e.g., sand vs. silt/clay) and pumping distance can greatly influence overall cost to the project. Knowing what type of material is available, where it is located, and proximity to a proposed NNBF site(s) are important parameters to consider. Strategically approaching NNBF siting and advanced characterization of available sediment sources would likely reduce overall project cost.

- **Developing contracts with dredging vendors that allow for more latitude in NNBF construction.** The disparity in reported cost between the NJDOT project (~ $247/cyd) and other NJBB projects (~ $28 - $45/cyd) highlights the variability of dredging cost when a contractor must accept all of the risk associated with construction of a project that includes contracting language with meticulous specifications (See Table 1). NNBF are very dynamic and some variation in overall approach to construction (and resulting footprint) will likely not reduce the overall benefits derived from the project. Allowing contractors more latitude in approach to project construction, enhancing onsite integration/communication between USACE and contractor staff, and adopting a "learn and refine" approach to contracts and project construction would likely reduce overall project cost.

When looking back across all of these factors, dredged sediment appears as a common denominator, and it is also an essential component of most NNBF that were identified through this study. The unknowns and/or unrealized opportunities that currently exist, coupled with the large NNBF size (and resulting volumes of dredged sediment, which would need to meet qualitative guidelines for NNBF construction), make it imprudent to offer estimated costs at this time. If pursued at this stage, the calculations would likely be very inaccurate and reflect very prohibitive values that would ultimately predispose such innovative EWN strategies from further consideration.

In closing, the previously described factors have not been investigated to any appreciable degree in order to identify and possibly create efficiencies. Once evaluated, however, the results could be integrated into an overall strategy that informs a logical approach for NNBF construction and O&M, thereby reducing project cost. Adaptive management will also provide opportunities to learn, refine, and improve practices over time. Finally, increase in long-term demand for NNBF projects will lead to more competition within the marine construction sector, including development of more efficient equipment and practices. If pursued correctly, innovative approaches are likely to emerge and revolutionize resource management in the NJBB, while also contributing considerable savings when integrating NNBF projects into an overall approach to CSRM.

Takeoffs for Individual Design Concepts

Ocean City Levee / Wall M-S:

Fill Material

910,000 cu. yd. within design area

Sea Wall

6400 Lineal Feet within design area

Plantings

7 acres High Marsh

43 acres of Tall Shrubland

Calculation Assumptions

The approximate length of the levee / wall to be modified per the proposed design would be 6,400 lf. Of this, approximately 1300 lf would be expanded to accommodate access and recreational areas and would consist of +/- 251,850 cu yd of material. The remaining 5100 lf would be standard horizontal levee at 1:30 and consist of +/- 655,500 cu yd of material. A standard flood wall will exist at the core of the levee and the first 2 elevational feet of the levee from the existing marsh will be planted with High Marsh plants, the remainder of the levee will be planted with Tall Shrubland plants and trees.

Tuckerton Peninsula L

Option 1: Horizontal Levee

Levee Construction Material:

Roadway: 23,000 linear feet

Bridges: 5 bridges totaling approximately 2700 linear feet

Plantings

Mowed salt meadow: 27.5 acres (1.2 million sq ft)

Tall shrubland: 243 acres (10.6 million sq ft)

Salt shrub: 108 acres (4.7 million sq ft)

High marsh: 36.7 acres (1.6 million sq ft)

Calculation Assumptions

The approximate length of the horizontal levee feature would be 20,000 lf. Based on the assumed slope of 1:30 on both sides of the levee and allowing for the presence of the existing roadbed, an approximate sectional area of 7,650 sq ft for the horizontal levee has been obtained. Multiplying these two measurements produces the estimate of 5.7 million CY. The habitat areas are based on the distributions of plant communities shown in the plan and section for this option.

Option 2: Living Breakwaters

35 individual breakwaters totaling 21,600 linear feet

Option 3: Marsh Enhancement

Fill for constructing hammocks: 680,000 CY

Dredged material for thin-layer placement: 530,000 CY

Material for marsh island construction: 1.32 MCY

Plantings

Salt shrub hammocks: 234 acres (10.2 million sf)

Marsh enhancement via thin-layer placement: 654 acres (28.5 million sf)

New marsh islands and existing marsh island expansion: 546 acres (23.8 million sf)

Calculation Assumptions

The hammocks are assumed to be raised to an average elevation of +3' NAVD88, from an average existing grade of +1.2' NAVD88. Thin-layer placement is assumed to involve placement of material to an average depth of 6". (Depending on level of subsidence, additional 'lifts' of material may be needed to achieve marsh plane elevation.) Marsh island construction is assumed to require an average placement of 1.5' of material, based on approximate average depths in the island construction locations.

Surge Filter XL

Fill Material

The proposed thickening of the sedge islands to form a surge filter, per the design in this report would require approximately 7 million cubic yards of fill.

Planting Areas

If the new islands are constructed with slopes similar to the surrounding islands (most well under 10%), a large percentage of each island would fall within the possible spartina alterniflora planting zone. An estimate of 60% is likely conservative, thus requiring 450 acres of low marsh planting.

Calculation Assumptions

The average depth in the areas where islands are to be created is approximately -2' MLLW (-3.83' NAVD88). The height of the islands would vary based on size, but would not exceed +4' NAVD88. For calculation purposes this report assumes an average elevation of all islands at +2' NAVD88. Thus the elevation of material added for the island areas would be +/- 5.83'. The proposed configuration of contains approximately 750 acres of newly created islands.

Barnegat Bay XXL:

As the current description of this strategy is general, rather than location-specific, it is not presently possible to make a precise estimate of sediment volumes required or habitat area that might be produced. However, as a rough indicator of the feasibility of a 'shallows' strategy, it is worth noting that the area of Barnegat Bay is roughly 167 sq km. If that 15% of that area were 'shallowed' by 1 m, this would require 25,000,000 cubic meters or 32,600,000 cubic yards of material. (A 'shallows' strategy would likely be more targeted than this, and thus likely require less material.)

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*Stewart Farrell and the Stockton University Coastal Research Center shared GIS information associated with these projects. The locations shown in the maps in this report correspond to detailed datasets that should be referenced in future planning and design initiatives of NNBF and ecological restoration in this region.

Appendix 1:
NACCS 2013 Parametric Cost Data

Beach Restoration - Parametric Cost Estimate

Table 1. First Construction Quantities & Costs

Item	**Quantity**		**Parametric Estimate**	
	Number	**Unit**	**Unit Cost**	**Total Cost**
Mob/demob	1	LS	$3,000,000	$3,000,000
Design Beach Fill Volume	1,279,056	cu.yd.	$12	$15,348,672
Advance Fill Volume	401,989	cu.yd.	$12	$4,823,868
Subtotal				**$23,172,540**
Contingency	25%			$5,793,135
Total Construction				$28,965,675
E&D	10%			$2,896,568
S&A	12%			$3,475,881
Total Estimated First Construction Cost				**$35,338,124**
Total Estimated First Construction Cost per Foot				**$3,533.81**

Beach Fill Length	10,000	ft

Table 2. Renourishment Quantities & Costs

Item	**Quantity**		**Parametric Estimate**	
	Number	**Unit**	**Unit Cost**	**Total Cost**
Mob/demob	1	LS	$3,000,000	$3,000,000
Renourishment Fill Volume	401,989	cu.yd.	$12	$4,823,868
Subtotal				**$7,823,868**
Contingency	25%			$1,955,967
Total Construction				**$9,779,835**
E&D	10%			$977,984
S&A	12%			$1,173,580
Total Estimated Renourishment Cost				**$11,931,399**
Total Estimated Renourishment Cost per Foot				**$1,193.14**

Table 2. Annualized Costs per Foot - Parametric Estimate

Annualized First Costs		$157.52
Annualized Renourishment Costs		$277.94
Fill Maintenance		$23.10
O&M	1%	$35.34
Total Estimated Annual Average Cost		**$493.89**

Project Life	50	Years
Renourishment Interval	4	Years
Discount Rate	3.75%	
CRF (First Construction)	0.045	
PVF (Renourishments)	5.226	

Revetment Parametric Cost Estimate

Table 1. First Construction Quantities & Costs

Item	**Quantity**		**Parametric Estimate**	
	Number	**Unit**	**Unit Cost**	**Total Cost**
Mob/demob	1	LS	$200,000	$200,000
Armor Stone	62,745	ton	$150	$9,411,750
Underlayer	26,335	ton	$150	$3,950,250
Toe Armor	11,085	ton	$150	$1,662,750
Geotextile	37,865	sq.yd.	$15	$567,975
Subtotal				**$15,792,725**
Contingency	25%			$415,688
Total Construction				**$16,208,413**
E&D	12%			$1,945,010
S&A	10%			$1,620,841
Total Estimated First Construction Cost				**$19,774,263**
Total Estimated First Construction Cost per Foot				**$3,954.85**

Revetment Length	5,000	ft

Table 2. Annualized Costs per Foot - Parametric Estimate

Annualized First Costs		$176.28
O&M	1%	$39.55
Total Estimated Annual Average Cost		**$215.83**

Project Life	50	Years
Discount Rate	3.75%	
Capital Recovery Factor	0.045	

Overwash Fan - Parametric Cost Estimate

Table 1. First Construction Quantities & Costs

Item	**Quantity**		**Parametric Estimate**	
	Number	**Unit**	**Unit Cost**	**Total Cost**
Mob/demob	1	LS	$3,000,000	$3,000,000
Overwash Fill Volume	200,000	cu.yd.	$12	$2,400,000
Subtotal				**$5,400,000**
Contingency	25%			$1,350,000
Total Construction				$6,750,000
E&D	12%			$810,000
S&A	10%			$675,000
Total Estimated First Construction Cost				**$8,235,000**
Total Estimated First Construction Cost per Foot				**$4,117.50**

Overwash Length	2,000	ft

Table 2. Annualized Costs per Foot - Parametric Estimate

Annualized First Costs		$183.53
O&M	0%	$0.00
Total Estimated Annual Average Cost		**$183.53**

Project Life	50	Years
Renourishment Interval	4	Years
Discount Rate	3.75%	
CRF (First Construction)	0.045	

Storm Surge Barriers - Parametric Cost Estimates

			First Construction Costs		Average Annual Costs	
			Total Cost		**Total Average Annual Cost**	**Average Annual Cost**
Barrier Location	**State**	**Length(ft)**	**($MILL)**	**Avg. ($/ft)**	**($MILL)**	**($/ft)**
Boston Harbor	MA	2,000	2,795	1,397,550	211	105,656
Beverly	MA	900	750	832,840	57	62,963
Pt. Judith Harbor	RI	300	141	470,270	11	35,553
Bridgeport	CT	3,000	3,259	1,086,192	246	82,117
Milford	CT	180	96	532,205	7	40,235
Verrazano Narrows	NY	4,190	5,612	3,536,762	409	97,549
Arthur Kill	NY	2,700	2,627	973,026	199	73,561
Newtown Creek	NY	400	287	718,203	22	54,297
Rockaway Inlet	NY	2,800	2,093	747,667	158	56,524
East Rockaway Inlet	NY	1,400	949	677,691	72	51,234
Jones Inlet	NY	2,250	1,617	718,825	122	54,344
Fire Island Inlet	NY	2,700	1,981	733,645	150	55,464
Moriches Inlet	NY	900	612	679,679	46	51,384
Shinnecock	NY	900	592	657,665	45	49,720
Cedar Beach	NY	600	526	875,999	40	66,226
Port Jefferson	NY	1,150	1,016	883,371	77	66,783
Huntington Bay	NY	2,700	2,479	918,093	187	69,408
Oyster Bay	NY	2,400	2,226	927,361	168	70,109
South River	NJ					
Flat Creek	NJ					
Pews Creek	NJ					
East Creek	NJ					
Sandy Hook-Breezy Point	NY/NJ	28,500	34,351	1,205,300	2,597	91,122
Cheesequake	NJ	270	148	547,788	11	41,413
Shewsbury River	NJ	1,650	1,022	619,603	77	46,842
Shark River	NJ	100	50	499,607	4	37,771
Manasquan Inlet	NJ	420	206	489,824	16	37,031
Indian River Inlet	DE	800	1,165	1,456,342	88	110,100
Christiana River	DE	1,250	1,318	1,054,603	100	79,729
Darby Creek PA	PA	420	172	410,109	13	31,005
Schuykill, PA	PA	720	643	893,303	49	67,534
Baltimore Patapsco	MD	2,250	1,560	1,520,388	152	67,348

Baltimore Bear Creek	MD	3,600	1,590	441,586	120	33,384
Solomons Island	MD	750	380	506,342	29	38,280
Ocean City	MD	2,000	1,488	743,783	112	56,230
Chincoteague Inlet	MD	6,500	3,557	547,215	269	41,370
Rudee Inlet	VA	100	53	531,091	4	40,151
Lynnhven Inlet	VA	1,000	502	501,698	38	37,929
Little Creek	VA	950	569	598,634	43	45,257
Elizabeth River	VA	2,640	2,009	761,042	152	57,535

Groins + Beach Restoration - Parametric Cost Estimate

Table 1. First Construction Quantities & Costs

Item	**Quantity**		**Parametric Estimate**	
	Number	**Unit**	**Unit Cost**	**Total Cost**
Mob/demob	1	LS	$4,000,000	$4,000,000
Design Beach Fill Volume	1,279,056	cu.yd.	$12	$15,348,672
Advance Fill Volume	463,833	cu.yd.	$12	$5,565,996
Armor Stone	79,676	ton	$150	$11,951,400
Underlayer / Core Stone	31,092	ton	$150	$4,663,800
Blanket Stone	36,875	ton	$150	$5,531,250
Geotextile	38,219	sq.yd.	$15	$573,285
Excavation	75,621	cu.yd.	$13	$983,073
Subtotal				**$48,617,476**
Contingency	25%			$12,154,369.00
Total Construction				$60,771,845
E&D	12%			$7,292,621
S&A	10%			$6,077,185
Total Estimated First Construction Cost				**$74,141,651**
Total Estimated First Construction Cost per Foot				**$7,414.17**

Beach Fill Length 10,000 ft

Table 2. Renourishment Quantities & Costs

Item	**Quantity**		**Parametric Estimate**	
	Number	**Unit**	**Unit Cost**	**Total Cost**
Mob/demob	1	LS	$3,000,000	$3,000,000
Renourishment Fill Volume	463,833	cu.yd.	$12	$5,565,996
Subtotal				**$8,565,996**
Contingency	25%			$2,141,499
Total Construction				**$10,707,495**
E&D	10%			$1,070,750
S&A	12%			$1,284,899
Total Estimated Renourishment Cost				**$13,063,144**
Total Estimated Renourishment Cost per Foot				**$1,306.31**

Table 2. Annualized Costs per Foot - Parametric Estimate

Annualized First Costs		$330.48
Annualized Renourishment Costs		$140.97
Fill Maintenance		$0.00
O&M	1%	$74.14
Total Estimated Annual Average Cost		**$545.59**

Project Life	50	Years
Renourishment Interval	8	Years
Discount Rate	3.75%	
CRF (First Construction)	0.045	
PVF (Renourishments)	2.421	

Breakwaters + Beach Restoration - Parametric Cost Estimate

Table 1. First Construction Quantities & Costs

Item	**Quantity**		**Parametric Estimate**	
	Number	**Unit**	**Unit Cost**	**Total Cost**
Mob/demob	1	LS	$4,000,000	$4,000,000
Design Beach Fill Volume	660,611	cu.yd.	$12	$7,927,332
Advance Fill Volume	401,989	cu.yd.	$12	$4,823,868
Armor Stone	223,328	ton	$150	$33,499,200
Underlayer	58,165	ton	$150	$8,724,750
Core/Bedding Stone	8,025	ton	$150	$1,203,750
Subtotal				**$60,178,900**
Contingency	25%			$8,374,800
Total Construction				$68,553,700
E&D	12%			$8,226,444
S&A	10%			$6,855,370
Total Estimated First Construction Cost				**$83,635,514**
Total Estimated First Construction Cost per Foot				**$8,363.55**

Beach Fill Length 10,000 ft

Table 2. Renourishment Quantities & Costs

Item	**Quantity**		**Parametric Estimate**	
	Number	**Unit**	**Unit Cost**	**Total Cost**
Mob/demob	1	LS	$3,000,000	$3,000,000
Renourishment Fill Volume	401,989	cu.yd.	$12	$4,823,868
Subtotal				**$7,823,868**
Contingency	25%			$1,955,967
Total Construction				**$9,779,835**
E&D	10%			$977,984
S&A	12%			$1,173,580
Total Estimated Renourishment Cost				**$11,931,399**
Total Estimated Renourishment Cost per Foot				**$1,193.14**

Table 2. Annualized Costs per Foot - Parametric Estimate

Annualized First Costs		$372.80
Annualized Renourishment Costs		$128.76
Fill Maintenance		$0.00
O&M	1%	$83.64
Total Estimated Annual Average Cost		**$585.19**

Project Life	50	Years
Renourishment Interval	8	Years
Discount Rate	3.75%	
CRF (First Construction)	0.045	
PVF (Renourishments)	2.421	

Living Shoreline Parametric Cost Estimate

Table 1. First Construction Quantities & Costs

Item	**Quantity**		**Parametric Estimate**	
	Number	**Unit**	**Unit Cost**	**Total Cost**
Mob/demob	1	LS	$500,000	$500,000
Armor Stone	33,500	ton	$150	$5,025,000
Geotextile	20,000	sq.yd.	$15	$300,000
Sand Fill	28,000	cu.yd.	$20	$560,000
Grass Plantings	170,000	each	$2	$340,000
Subtotal				**$6,725,000**
Contingency	25%			$1,681,250
Total Construction				**$8,406,250**
E&D	12%			$1,008,750
S&A	10%			$840,625
Total Estimated First Construction Cost				**$10,255,625**
Total Estimated First Construction Cost per Foot				**$2,051.13**

Living Shoreline Length	5,000	ft

Table 2. Annualized Costs per Foot - Parametric Estimate

Annualized First Costs		$91.43
O&M	0.5%	$10.26
Total Estimated Annual Average Cost		**$101.68**

Project Life	50	Years
Discount Rate	3.75%	
Capital Recovery Factor	0.045	

Wetland - Parametric Cost Estimate

Table 1. First Construction Quantities & Costs

Item	**Quantity**		**Parametric Estimate**	
	Number	**Unit**	**Unit Cost**	**Total Cost**
Mob/demob	1	LS	$500,000	$500,000
Sand Fill	225,000	cu.yd.	$20	$4,500,000
Grass Plantings	1,000,000	each	$2	$2,000,000
Subtotal				**$7,000,000**
Contingency	25%			$1,750,000
Total Construction				**$8,750,000**
E&D	12%			$1,050,000
S&A	10%			$875,000
Total Estimated First Construction Cost				**$10,675,000**
Total Estimated First Construction Cost per Foot				**$2,135.00**

Wetland Length	5,000	ft

Table 2. Annualized Costs per Foot - Parametric Estimate

Annualized First Costs		$95.17
O&M	0.5%	$10.68
Total Estimated Annual Average Cost		**$105.84**

Project Life	50	Years
Discount Rate	3.75%	
Capital Recovery Factor	0.045	

Oyster Reef - Parametric Cost Estimate

Table 1. First Construction Quantities & Costs

Item	**Quantity**		**Parametric Estimate**	
	Number	**Unit**	**Unit Cost**	**Total Cost**
Mob/demob	1	LS	$250,000	$250,000
Base Stone	82,500	ton	$150	$12,375,000
Oyster Reef Material	55,000	cu.yd	$200	$11,000,000
Subtotal				**$23,625,000**
Contingency	25%			$5,906,250
Total Construction				**$29,531,250**
E&D	12%			$3,543,750
S&A	10%			$2,953,125
Total Estimated First Construction Cost				**$36,028,125**
Total Estimated First Construction Cost per Foot				**$7,205.63**

Reef Length	5,000	ft

Table 2. Annualized Costs per Foot - Parametric Estimate

Annualized First Costs		$321.19
O&M	0.0%	$0.00
Total Estimated Annual Average Cost		**$321.19**

Project Life	50	Years
Discount Rate	3.75%	
Capital Recovery Factor	0.045	

Submerged Aquatic Vegetation (SAV) - Parametric Cost Estimate

Table 1. First Construction Quantities & Costs

Item	**Quantity**		**Parametric Estimate**	
	Number	**Unit**	**Unit Cost**	**Total Cost**
Mob/demob	1	LS	$500,000	$500,000
Sand Fill	220,000	ton	$20	$4,400,000
SAV Plantings	750,000	each	$4	$3,000,000
Subtotal Construction				**$7,900,000**
Contingency	25%			$1,975,000
Total Construction				**$9,875,000**
E&D	12%			$1,185,000
S&A	10%			$987,500
Total Estimated First Construction Cost				**$12,047,500**
Total Estimated First Construction Cost per Foot				**$2,409.50**

SAV Bed Length	5,000	ft

Table 2. Annualized Costs per Foot - Parametric Estimate

Annualized First Costs		$107.40
O&M	0.0%	$0.00
Total Estimated Annual Average Cost		**$107.40**

Project Life	50	Years
Discount Rate	3.75%	
Capital Recovery Factor	0.045	

Levee Parametric Cost Estimate

Design Elevation Based on BFE 4 ft above grade plus 3 ft. Added 3 ft of Freeboard per FEMA Standard.

Typical costs based on weighted average of costs estimated for good and poor foundation conditions.

Table 1. First Construction Quantities & Costs

	Quantity		**Parametric Estimate**	
Item	**Number**	**Unit**	**Unit Cost**	**Total Cost**
Mob/demob	1	LS	$200,000	$200,000
Levee Construction	1	Mile	$4,966,932	$4,966,932
Drainage Outlets	13	ea	$35,000	$455,000
Subtotal				$5,621,932
Contingency	25%			$1,405,483
Total Construction				**$7,027,415**
E&D	12%			$843,290
S&A	10%			$702,741
Total Estimated First Construction Cost				**$8,573,446**
Total Estimated First Construction Cost per Foot				**$1,623.76**

Levee Length	5,280	ft

Table 2. Annualized Costs per Foot - Parametric Estimate

Annualized First Costs		$72.38
O&M	$2/LF + $10,000 per drain	$9.40
Total Estimated Annual Average Cost		**$81.78**

Project Life	50	Years
Discount Rate	3.75%	
Capital Recovery Factor	0.045	

Floodwall Parametric Cost Estimate

Design Elevation Based on BFE 4 ft above grade plus 3 ft. Added 3 ft of Freeboard per FEMA Standard.
Typical costs based on weighted average of costs estimated for good and poor foundation conditions.

Table 1. First Construction Quantities & Costs

	Quantity		Parametric Estimate	
Item	**Number**	**Unit**	**Unit Cost**	**Total Cost**
Mob/demob	1	LS	$200,000	$200,000
Floodwall Construction	1	Mile	$17,284,524	$17,284,524
Drainage Outlets	13	ea	$100,000	$1,300,000
Subtotal Construction				$18,784,524
Contingency	25%			$4,696,131
Total Construction				**$23,480,655**
E&D	12%			$2,817,679
S&A	10%			$2,348,065
Total Estimated First Construction Cost				**$28,646,399**
Total Estimated First Construction Cost per Foot				**$5,425.45**

Levee Length	5,280	ft

Table 2. Annualized Costs per Foot - Parametric Estimate

Annualized First Costs		$241.84
O&M	$2/LF + $10,000 per drainag	$9.40
Total Estimated Annual Average Cost		**$251.24**

Project Life	50	Years
Discount Rate	3.75%	
Capital Recovery Factor	0.045	

Deployable Floodwall Parametric Cost Estimate

Design Elevation Based on BFE 3 ft above grade plus 3 ft.

Line of Protection 50% Permanent Floodwall, 50% Deployable Floodwall.

Typical floodwall costs based on weighted average of costs estimated for good and poor foundation conditions.

Table 1. First Construction Quantities & Costs

	Quantity		**Parametric Estimate**	
Item	**Number**	**Unit**	**Unit Cost**	**Total Cost**
Mob/demob	1	LS	$200,000	$200,000
Deployable Floodwall	1	0.5 Mile	$10,780,000	$10,780,000
Floodwall Construction	1	0.5 Mile	$6,565,662	$6,565,662
Stoplog Storage	1	ea	$445,000	$445,000
Drainage Outlets	13	ea	$100,000	$1,300,000
Subtotal Construction				**$19,290,662**
Contingency	25%			$4,822,665
Total Construction				**$24,113,327**
E&D	12%			$2,893,599
S&A	10%			$2,411,333
Total Estimated First Construction Cost				**$29,418,259**
Total Estimated First Construction Cost per Foot				**$5,571.64**

Levee Length	5,280	ft

Table 2. Annualized Costs per Foot - Parametric Estimate

Annualized First Costs		$248.35
O&M	$2/LF + $10,000 per drainage stru	$9.40
O&M	Install/Dismantle Deployable Wal	$5.11
Total Estimated Annual Average Cost		**$262.86**

Project Life	50	Years
Discount Rate	3.75%	
Capital Recovery Factor	0.045	

E&D	10%
S&A	12%
Contingency	25%
Project Life	50
Discount Rate	3.75%

Unit Costs

Stone	150	$/ton
Beach Fill	12	$/cu.yd.
Geotextile	15	$/sq.yd.
Fill Maintenance	15	$/ft
Storm Surge Barrier	878	$/cu.ft.
Sand Fill	20	$/cu.yd.
Grass Plantings	2	$/each
SAV Plantings	4	$/each
Oyster Reef Material	200	$/cu.yd.
Excavation	13	$/cu.yd.

Appendix 2: NNBF Case Studies

This appendix contains examples of NNBF similar to the NNBF explored in this report. The majority of these NNBF are built and/or under construction, though a few planning studies are also included. A significant percentage of these examples are located within the NJBB themselves. Collectively, they demonstrate the feasibility of NNBF techniques such as wetland creation, thin-layer placement, and living breakwaters. They have been organized by these types of techniques.

Unfortunately, though, because the majority of this work is recent, data demonstrating the precise CSRM benefits of individual case studies is generally not available yet. Monitoring and study is on-going at many of these sites, but it will take time for those benefits to be fully quantified and understood. In the interim, the primary means of demonstrating the CSRM benefits of NNBF is via reference to studies that have been conducted on the CSRM benefits of natural features such as coastal wetlands and dunes. Such studies are noted in Part II and cited in this document's references.

The text that describes each case study has been drawn from official project descriptions. These sources are noted on each individual case study.

Avalon thin-layer placement

Location
Avalon, New Jersey

Description
45,000 cubic yards of dredged sediment was used to elevate 14 hectares of nearby marsh to height deemed suitable by project partners. The project was understood as a pilot experiment to study the various effects of thin-layer placement on marshes and monitor their physical and biologic development over time. The placement of material occurred between 2015 and 2016.

Project Partners
U.S. Army Corps of Engineers
The Nature Conservancy
GreenVest
The Wetlands Institute
New Jersey DEP

Contact
Monica Chasten
United States Army Corps of Engineers
Philadelphia District

Source: https://doer.el.erdc.dren.mil/infographics/Bailey_et_al.pdf

BENEFICIAL USE:

Mordecai Island
island restoration providing CSRM benefits

Location
Beach Haven, New Jersey

Description
A 45-acre uninhabited coastal salt marsh island that supports a variety of breeding and migratory bird species, including the American Oystercatcher and the Black Skimmer. The island has significantly eroded, particularly on its northern side as a large cut developed. The island is adjacent to a section of the New Jersey Intracoastal Waterway that required dredging due to shoaling. Approximately 30,000 cubic yards of material was dredged from the New Jersey Intercoastal Waterway (NJIWW) between channel markers 107 and 108. The material was placed in the breached northern area of the island to the same elevation as the adjacent existing salt marsh vegetation.

Project Partners
U.S. Army Corps of Engineers
NJDEP Office of Dredging and Sediment Technology
NOAA
Land Trust

Contact
Monica Chasten
United States Army Corps of Engineers
Philadelphia District

Source: https://www.nap.usace.army.mil/Portals/39/docs/Civil/Coastal/Mordecai-Island-Factsheet-December-2019.pdf?ver=2019-12-13-120440-430; https://www.nj.gov/dep/oclup/case-studies-projects/nj-ecol-solution-projects.html

Ring Island thin-layer placement

Location
Stone Harbor, New Jersey

Description
Ring Island is a wetland complex located within the back bay system behind Seven Mile Island in New Jersey. It was originally constructed in 2014 as nesting habitat for the black skimmer and least tern. Material was again added to the site in 2018 to expand/enhance the habitat. Bird surveys have confirmed nesting on the site by the black skimmer, the least and common tern, and the American oystercatcher. The larger Ring Island area is also planned for future beneficial re-use projects.

Project Partners
U.S. Army Corps of Engineers
The Wetlands Institute

Contact
Monica Chasten
United States Army Corps of Engineers
Philadelphia District

Source: https://www.nap.usace.army.mil/Portals/39/docs/Civil/Public%20Notice/Draft-NJIWW-Ring-Island-2018-EA.pdf?ver=2018-10-02-135410-530

BENEFICIAL USE

Battery Island

Location
Havre de Grace, Maryland

Description
The primary objective of the Battery Island restoration project was to beneficially use dredged material to restore an eroded waterfowl nesting site and historic lighthouse in the Susquehanna National Wildlife Refuge.The island was restored to approximately 11 acres (above water) to support American black duck (Anas rubripes) and Caspian tern (Hydroprogne caspia) habitat, and to prevent the flooding of the historic Fishing Battery Lighthouse. Habitats restored were tidal marsh, intertidal marsh, high marsh, upland and submerged aquatic vegetation (SAV) that could support a variety of species About 60,000 native plants were planted by USACE contractors to encourage establishment of native vegetation and to minimize establishment of invasive species (e.g.,Phragmities spp.).

Project Partners
The USFWS
National Park Service
MDNR
Maryland Department of the Environment (MDE)
City of Havre de Grace
Hartford County, MD

Contact
Burton C. Sudel
USACE Engineer and Research and Development Center
Vicksburg, Mississippi

Source: https://www.researchgate.net/publication/332330455_Realizing_Multiple_Benefits_in_US_Army_Corps_of_Engineers_USACE_Baltimore_District_Dredging_Projects_through_Application_of_Engineering_With_NatureR_Principles

Poplar Island

Location
Chesapeake Bay: Talbot County, Maryland

Description
The Paul S. Sarbanes Ecosystem Restoration Project at Poplar Island (Poplar Island) is located in Talbot County, Maryland in the Chesapeake Bay. Poplar Island is approximately 30 miles south of Baltimore and is comprised of the existing island, 1140 acres, which is currently under construction. The Poplar Island project is the collaborative effort of many state and Federal agencies to provide habitat for fish and wildlife species. This remote island habitat is providing critical and unique habitat that is and will be used for nesting, foraging, resting, and reproduction in addition to providing a valuable placement location for the highly used Chesapeake Bay shipping channels. Habitats were specifically designed for attracting nesting terns and other priority species such as snowy egret, American black duck, and diamondback terrapin. Through 2019, 373 acres of tidal wetland have been created, 110 acres of open water embayments, and over 34 MCY of dredged material beneficially reused.

Project Partners
Maryland DNR
US Department of Fish and Wildlife
Port of Baltimore
Maryland Port Administration
Maryland Department of Transportation

Contact
United States Army Corps of Engineers
Baltimore District
2 Hopkins Plaza
Baltimore, MD. 21201

Source: https://www.nab.usace.army.mil/Portals/63/docs/Environmental/PoplarIsland/Lrr%20Report%202013/Final%20LRR%20Report%202013.pdf?ver=2018-11-20-133209-727; https://cdm16021.contentdm.oclc.org/digital/collection/p16021coll11/id/4295

Margate City

Location
Absecon Island Area, Margate City, Atlantic County, New Jersey

Description
Margate City in coordination with various partners are working to address, design and permit at least three sites for marsh restoration in the Absecon Island Area which may include raising the elevations of existing wetlands or creating new wetlands through the beneficial reuse of dredged material. The three marsh sites will be selected based on having aspects that fall under the restoration criteria. Once chosen the site will need a variety of further investigations including surveying, water quality data, and vegetation/habitat data. Additional sites may be identified, provided that they offer an ecological uplift through habitat restoration, natural hazard mitigation solutions and are able to receive the dredged material.

Project Partners
New Jersey Department of Environmental Protection (NJDEP)
U.S. Army Corps of Engineers
Stockton University Coastal Research Center
Margate City

Contact
Margate City
9001 Winchester Ave.
Margate, NJ 08402
(609) 822-2605

Source: NJDEP, https://www.nj.gov/dep/oclup/case-studies-projects/nj-ecol-solution-projects.html

Cedar Bonnet Island, Stafford Twp.

Location
Cedar Bonnet Island, Stafford Township, Ocean County, New Jersey

Description
A Coastal General Permit #29, NJDEP File #1530-14-0006.1, has been approved for this project. The project consists of a habitat restoration and enhancement on Cedar Bonnet Island, which will include the excavation of existing dredge spoils, the creation of intertidal/subtidal shallows, the enhancement of riparian zones and wetlands, the construction of tidal channels into the interior of the island, and the enhancement of the vegetative community on the island by removing invasive species and planting tidal wetland and maritime forest plant species. Also, a stone trail around the island and two 20' by 20' public access pavilions will be constructed.

Project Partners
New Jersey Department of Transportation (NJDOT)

Contact
NJDOT
1035 Parkway Ave.
Trenton, NJ 08625

Source: NJDEP, https://www.nj.gov/dep/oclup/case-studies-projects/nj-ecol-solution-projects.html

SHALLOWS

The Shallows

Location
Hurriane Sandy affected areas including: Staten Island, Jamaica Bay, Hackensack, Long Island (NY), Raritan Bay, and Barnegat Bay

Description
For the Rebuild by Design competition, the SCAPE team proposed the shallowing of a number of coastal areas that were affected by Hurricane Sandy. The Barnegat Bay shallowing strategy focused on beneficial dredge networks. The team proposes to forge new links within sediment cycles of the bay, layering strategies of absorptive edge creation, dredge wetland building, and habitat breakwater and reef building to step down risk for waterfront communities. Man-made and natural cycles will be considered in tandem, helping ensure a productive and resilient bay landscape for future generations. Hydrodynamic modeling with the Stevens Institute ADCIRC model suggest that these techniques may reduce flood water heights by 15-20% and reduce or eliminate wave damage within bay-side neighborhoods, all to be developed with further study. These techniques are not new—local and regional precedents exist for dredge wetland building within New York's Jamaica Bay and the Baltimore Harbor. A re-thinking of sediment cycles at the bay-scale, combined with absorptive edge creation and habitat breakwaters and reefs could have a dramatic impact on the Bay's protective ecological network, revitalizing an ecosystem and economy at risk of decline.

Project Partners
SCAPE / LANDSCAPE ARCHITECTURE
Parsons Brinckerhoff
Stevens Institute Of Technology
Ocean And Coastal Consultants
Searc Consulting
The New York Harbor School
Lot-Ek
Mtwtf
Paul Greenberg

Contact
SCAPE/LANDSCAPE ARCHITECTURE
277 Broadway, Ninth Floor
New York, NY 10007
212.462.2628
office@scapestudio.com

Source: The Shallows: Bay Landscapes as Ecological Infrastructure Report for the Rebuild by Design Competition. https://www.hud.gov/sites/documents/THE_SHALLOWS.PDF

Dredge Hole 25, SAV Restoration

Location
Barnegat Bay off West Coast of Lavallette, Ocean County, New Jersey (39°58'15.0"N 74°04'37.0"W)

Description
A Coastal General Permit #24, NJDEP File #1506-16-0056.1, has been approved for this project. The New Jersey Department of Transportation (NJDOT) Office of Maritime Resources has proposed the restoration of an ecologically impaired subaqueous borrow pit (dredged hole) and the restoration of Submerged Aquatic Vegetation (SAV) within the area of the dredged hole.

Project Partners
New Jersey Department of Transportation
New Jersey Department of Environmental Protection

Contact
NJDOT Office of Maritime Resources
1035 Parkway Ave.
Trenton, NJ 08625

Source: NJDEP, https://www.nj.gov/dep/oclup/case-studies-projects/nj-ecol-solution-projects.html

DREDGE HOLE RESTORATION

Dredge Hole 18, SAV Restoration

Location
Long Island Cove off West Coast of Brick Beach, Ocean County, New Jersey (40°00'35.0"N 74°03'42.0"W)

Description
A Coastal General Permit #24, NJDEP File #1506-16-0055.1, has been approved for this project. The New Jersey Department of Transportation (NJDOT) Office of Maritime Resources has proposed the restoration of an ecologically impaired subaqueous borrow pit (dredged hole) and the restoration of Submerged Aquatic Vegetation (SAV) within the area of the dredged hole.

Project Partners
New Jersey Department of Transportation
New Jersey Department of Environmental Protection

Contact
NJDOT Office of Maritime Resources
1035 Parkway Ave.
Trenton, NJ 08625

Source: NJDEP, https://www.nj.gov/dep/oclup/case-studies-projects/nj-ecol-solution-projects.html

Living Breakwaters

Location
Tottenville, Staten Island, NYC

Description
Living Breakwaters originated as one of the winning teams in the Rebuild by Design competition led by SCAPE. The project is currently being implemented by the Governor's Office of Storm Recovery (GOSR) with $60 million of CDBG-DR funding. Planned for the neighborhood of Tottenville, Staten Island, the project links in-water infrastructure with on-shore education and outreach, to help increase awareness of risk, enhance ecologies, and bring local school curriculum to the waterfront. SCAPE was commissioned by the GOSR to lead the schematic design process with a strong coalition of ecological and engineering partners, iteratively testing and designing scenarios for breakwater height, width, and location along the Tottenville shoreline. The team has worked closely with members of the community to create a design that benefits the community while positively affecting regional ecosystems and resiliency efforts. The schematic design process incorporates hydrodynamic and wave modeling, ecological data collection, active community feedback, agency coordination, and constructability assessment.

Project Partners
SCAPE/LANDSCAPE ARCHITECTURE
Parsons Brinckerhoff
ARCADIS
Ocean and Coastal Consultants
SeArc Ecological Marine Consulting
The New York Harbor Foundation
LOT-EK Architecture
MFS Consulting Engineers
Prudent Engineering

Contact
SCAPE/LANDSCAPE ARCHITECTURE
277 Broadway, Ninth Floor
New York, NY 10007
212.462.2628
office@scapestudio.com

Source: https://www.scapestudio.com/projects/living-breakwaters-design-implementation/

HORIZONTAL LEVEE

Oro Loma Horizontal Levee

Location
Long Island Cove off West Coast of Brick Beach, Ocean County, New Jersey (40°00'35.0"N 74°03'42.0"W)

Description
The Oro Loma Horizontal Levee Project is a multi-agency and multi-jurisdictional project combining the expertise of numerous project partners to address multiple functions for the Oro Loma wastewater treatment facility. The $9.1 million Horizontal Levee Project took approximately two years to complete, and will be monitored post-construction to evaluate its success. The project converted a ten-acre field along the Bay's edge into an eight-million gallon holding basin connected to an adjacent horizontal levee. Water entering the treatment facility will first go through a conventional treatment process and then pumped into a wet weather treatment basin. The water will then seep into the adjacent horizontal levee for additional treatment. The horizontal levee tests multiple functions including adaptive strategies for climate change and sea level rise, filtration of wastewater, as well as provide native habitat along the ecotone slope. Unlike a traditional levee with a 1:1 slope, the horizontal levee designed by ESA is a 30:1 slope. The levee slope comprises 12 different "experimental beds" referred to as "cells", containing several mixtures of substrates and vegetation/habitat types.

Project Partners
Oro Loma and Castro Valley Sanitary Districts
ESA Associates
Peter Baye
Whitley Burchett and Associates
ReNU-Wit
The Bay Institute
David Sedlak and Alex Horne, UC Berkeley
The Bay Institute
Save The Bay

Contact
Oro Loma Sanitary Distrcit
2655 Grant Ave
San Lorenzo, CA 94580
(510) 276-4700
info@OroLoma.org

Source: https://oroloma.org/horizontal-levee-project/; http://www.oroloma.org/wp-content/uploads/horizontallevee-overview

Little Egg Harbor

Location
Great Bay Boulevard Wildlife Management Area, Little Egg Harbor Township, Ocean County, New Jersey

Description
Little Egg Harbor Township proposes the construction of 100,000 square feet of new living shoreline along 2,500 linear feet of severely damage coastline, addressing erosion and water quality issues in the tidally influenced areas of the Barnegat Bay and Great Bay Watershed Management Areas. The two locations for the living shorelines include the Mystic Island Preserve along Iowa Court at Mystic Island (Project A) and the Great Bay Boulevard Wildlife Management Area at Big Thorofare inlet (Project B).

Project Partners
National Fish and Wildlife Foundation (NFWF)
New Jersey Future
The New Jersey Corporate Wetlands Restoration Partnership
The Barnegat Bay Partnership (BBP)

Contact
Garrett Loesch, Administrator and Finance Officer
Administrative Justice Complex
665 Radio Rd.
Little Egg Harbor, NJ 08087
(609) 296-7241, Ext. 220
loesch@leht.com

Source: NJDEP, https://www.nj.gov/dep/oclup/case-studies-projects/nj-ecol-solution-projects.html

West Wildwood Living Shoreline

Location

West 26th Avenue Peninsula, West Wildwood, Cape May County, New Jersey

Description

The project proposes the construction of a living shoreline and marsh restoration to seek the stabilization of the coastline, increase terrestrial and marine habitat, and improve the overall resiliency of the area and the 40 homes affected by recurring nuisance flooding. The Nature Conservancy also hopes to apply NJDEP's emerging Citizen Science framework to engage the community in the caretaking of the project beyond the life of the NOAA grant. The design and permitting of the project is ongoing from what started in 2017, building off the project's conceptual design. The first year of the project will be dedicated to baseline monitoring, social science data collection, and engagement of the local community to facilitate their participation in several aspects of the project. The second year will be focus on construction, and post-construction monitoring. The final year of the project will be focused on additional monitoring and adaptive maintenance, as well as implementing citizen science engagement and handoff of the project to community caretakers/stakeholders.

Project Partners

The Nature Conservancy
New Jersey Department of Environmental Protection (NJDEP)
National Oceanic and Atmospheric Administration (NOAA) Coastal Resilience Grants Program

Contact

Patricia Doerr, Director of Coastal and Marine Program, The Nature Conservancy
2350 Route 47
Elmont, NJ 08314
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Christopher Ridings, Business Administrator / Office of Emergency Management, Borough of West Wildwood
701 W. Glenwood Ave.
West Wildwood, NJ
(609) 522-4845, Ext. 308
cridings@westwildwood.org

Source: NJDEP, https://www.nj.gov/dep/oclup/case-studies-projects/nj-ecol-solution-projects.html

Little Egg Harbor

Location

Great Bay Boulevard Wildlife Management Area, Little Egg Harbor Township, Ocean County, New Jersey

Description

Little Egg Harbor Township proposes the construction of 100,000 square feet of new living shoreline along 2,500 linear feet of severely damage coastline, addressing erosion and water quality issues in the tidally influenced areas of the Barnegat Bay and Great Bay Watershed Management Areas. The two locations for the living shorelines include the Mystic Island Preserve along Iowa Court at Mystic Island (Project A) and the Great Bay Boulevard Wildlife Management Area at Big Thorofare inlet (Project B).

Project Partners

National Fish and Wildlife Foundation (NFWF)
New Jersey Future
The New Jersey Corporate Wetlands Restoration Partnership
The Barnegat Bay Partnership (BBP)

Contact

Garrett Loesch, Administrator and Finance Officer
Administrative Justice Complex
665 Radio Rd.
Little Egg Harbor, NJ 08087
(609) 296-7241, Ext. 220
loesch@leht.com

Source: NJDEP, https://www.nj.gov/dep/oclup/case-studies-projects/nj-ecol-solution-projects.html

This report covers findings from 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 FY2020.

This report has been prepared by the investigators at **Auburn University**, the **University of Toronto**, and the **University of Pennsylvania**; it also incorporates text and insights from ERDC's **Engineering With Nature®** project team.

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

US Army Corps of Engineers® EWN® AUBURN UNIVERSITY UNIVERSITY OF TORONTO Weitzman SCHOOL OF DESIGN University of Pennsylvania Dredge Research Collaborative

Final Version issued 10 June 2020

Enhanced Modeling in Support of Recommended EWN/NNBF Measures and Efficacy in Providing Flood/Storm Risk Reduction

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U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180

June 2020

Prepared for USACE Philadelphia District
100 E Penn Square East
Philadelphia, PA 19107

Table of Contents

Executive summary

Evidence suggests NNBF such as coastal wetlands and islands can reduce maximum water levels during storms through a combination of both wave and surge attenuation. However, the efficacy of these measures is a function of the configuration of the coastline, characteristics of the NNBF, and the characteristics of the storm itself such as the intensity, forward speed, size, and landfall location. Consequently, the effect of any proposed NNBF and/or structural measure should be examined under a suite of storms that represent a range of likely water level responses. To examine the effect of proposed large-scale NNBF in coastal New Jersey, we developed three implementations of very large scale NNBF measures to determine whether the NNBF concept could reduce water levels in the back bay areas adjacent to inlets when applied in conjunction with surge barriers (and instead of surge barriers at Little Egg and Brigantine Inlets): the Holgate region landward of Little Egg Inlet; the Brigantine region, influenced by both Little Egg Inlet to the north and the smaller Brigantine Inlet; and the Great Egg region landward of Great Egg Harbor Inlet. The NNBF configuration, topography, and roughness were developed in ArcMap 10.7 and used to modify the existing ADCIRC and STWAVE model domains for the region developed as part of the North Atlantic Coastal Comprehensive Study. A suite of 10 synthetic tropical storms were applied to the existing and modified model domains to determine how the proposed NNBF affected water levels in the back bay areas around the proposed NNBF.

The results indicated storm characteristics, particularly wind direction, strongly influenced water level response to the implementation of the proposed NNBF. Water level change attributable to NNBF for most NJBB domain was relatively modest (on the order of 10-30 with some areas up to 50 cm), for most storms regardless of the magnitude of base water level response; however, the duration of reductions in water levels was many hours and could potentially reduce flooding due to the prolonged reductions in peak water levels. 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. The results from this initial modeling study show NNBF could potentially provide some benefit to reducing coastal storm risk in the New Jersey back bays in some areas. While no configuration showed that the addition of NNBF measures were able to reduce water levels enough to reduce flooding during the largest storms without the implementation of additional perimeter NNBF and structural measures, the results do indicate that NNBF paired with the structural measures simulated in this study may show promise in reducing operation frequency of surge barriers or reducing the required height of cross-bay closures and perimeter flood walls and levees, which may not only reduced costs for those measures but may also be desirable to preserve the view shed for the residents of back bay communities.

Final decisions on the utility of the NNBF measures implemented in this report should be informed by economic models to determine if the maximum water level reduction and duration of reduction in these regions may translate to economic benefits either directly through reduction in damages or indirectly through reduction in height of perimeter structural measures or reduced operations of surge barriers. The authors of this report acknowledge that the NNBFs as modeled and described in this report would require very large volumes of sediment that would likely

render such features cost prohibitive. However, the modeling conducted in this study was not designed to determine if "medium" and "large" NNBFs, which utilize smaller footprints and/or lower elevations (i.e., less overall sediment volume), could sufficiently reduce water levels in critical parts of the back bays. Additional NNBF configurations and associated modeling would be required to ascertain how much initially estimated sediment quantities required to construct the "extra-large" scale NNBFs described in this study would be reduced. Additionally, the feasibility of utilizing sediment from routine maintenance dredging should be examined to determine if the required volume of "borrow source" sediment can be reduced. Further analysis with the PDT should provide additional information on the potential CSRM benefits. Moreover, quantification of additional benefits aside from National Economic Development (NED) benefits should be considered as NNBFs are designed to provide additional environmental, social, and economic benefits apart from benefits associated solely with CSRM.

1 Introduction

This report details the modeling and analysis efforts that were conducted as part of a larger report entitled "Assessment of Engineering With Nature® (EWN®) Strategies and Natural and Nature Based Features (NNBF) as Coastal Storm Risk Management Attributes for the Tentatively Selected Plan (TSP)" in support of the New Jersey Back Bays Coastal Storm Risk Management Feasibility Study led by the USACE Philadelphia District (NAP). The goal of the study was to identify and prioritize NNBF options and/or other EWN strategies on a systems level to support the comprehensive CSRM approach for the NJBB Feasibility Study. In order to achieve those goals and provide NAP with relevant evidence of the efficacy of proposed NNBF options to manage coastal storm risk, advanced modeling of a subset of NNBF options was required to better quantify the degree to which NNBF could reduce water levels in the back bay environment.

The New Jersey Back Bays Coastal Storm Risk Management Interim Feasibility Study and Environmental Scoping Document was released for public comment in March 2019 and stakeholder feedback indicated a desire for the NJBB Product Delivery Team (PDT) to evaluate options that fully integrate NNBF measures into the tentatively selected plan and Draft Feasibility Report (anticipated April 2020). In July 2019, the NAP PDT (including representatives from the New Jersey Department of Environmental Protection, ERDC, and members of the Dredge Research Collaborative (DRC) assembled in Philadelphia to brainstorm NNBF options in the back bays. Several areas were identified as likely candidates for implementation of large-scale NNBF. However, the degree to which these options could potentially affect water levels in the back bay alone or in combination with structural measures was not known, necessitating this modeling study.

Evidence suggests NNBFs such as coastal wetlands and islands can reduce maximum water levels during storms through a combination of both wave and surge attenuation (van Berchum et al., 2019; Leonardi et al., 2018; Narayan et al., 2017; Lopez, 2009). However, the efficacy of these measures is a function of the configuration of the coastline, characteristics of the NNBFs, and the characteristics of the storm itself such as the intensity, forward speed, size, and landfall location. Consequently, the effect of any proposed NNBF and/or structural measure should be examined under a suite of storms that represent the full range of likely conditions. The large-scale NNBF concepts developed during the July 2019 workshop likely would affect both storm surge and waves, requiring both to be evaluated by adapting existing models developed for the North Atlantic Coast Comprehensive Study (Cialone et al., 2015). The ERDC modeling team developed a modeling proof-of-concept approach to determine if what is referred to as extra large-scale NNBFs (on the order of >50% of the back bay cross-section area occupied by NNBF) produced changes in water levels significant enough to potentially produce CSRM benefits. These extra large-scale features were also rendered into drawings developed by the DRC to illustrate what NNBF at these scales would look like. Some of these renderings are presented within this report but for more details, please refer to the report entitled "Engineering With Nature® and Landscape Architecture: New Jersey Back Bays".

2 Methods

2.1 Configuration description

Three areas were targeted to add extra large-scale NNBF measures to determine whether the NNBF concept could reduce water levels in the back bay areas adjacent to inlets in addition to the reduction from surge barriers. The Holgate region landward of the Little Egg Inlet is the northernmost proposed NNBF area. Within this region two types of NNBF features were proposed: a horizontal levee along Great Bay Boulevard along the Tuckerton Peninsula and expansion of the island complex landward of Beach Haven (Figure 1) utilizing the "surge filter" concept described in the Engineering With Nature® and Landscape Architecture: New Jersey Back Bays report (Figure 2). The horizontal levee concept was developed in the San Francisco Bay region and consists of a traditional levee material core with a shallow ecotone slope atop the side slopes designed to provide more habitat zones transitioning from intertidal areas to upland areas (Leo et al., 2019). The added benefit of a longer and more gradual slope is enhanced wave attenuation along the ecotone slope, which may reduce wave overtopping under some conditions.

The goal of the NNBF measures in this region is to slow or block surge and waves that would propagate from Little Egg Inlet northward into Barnegat Bay.

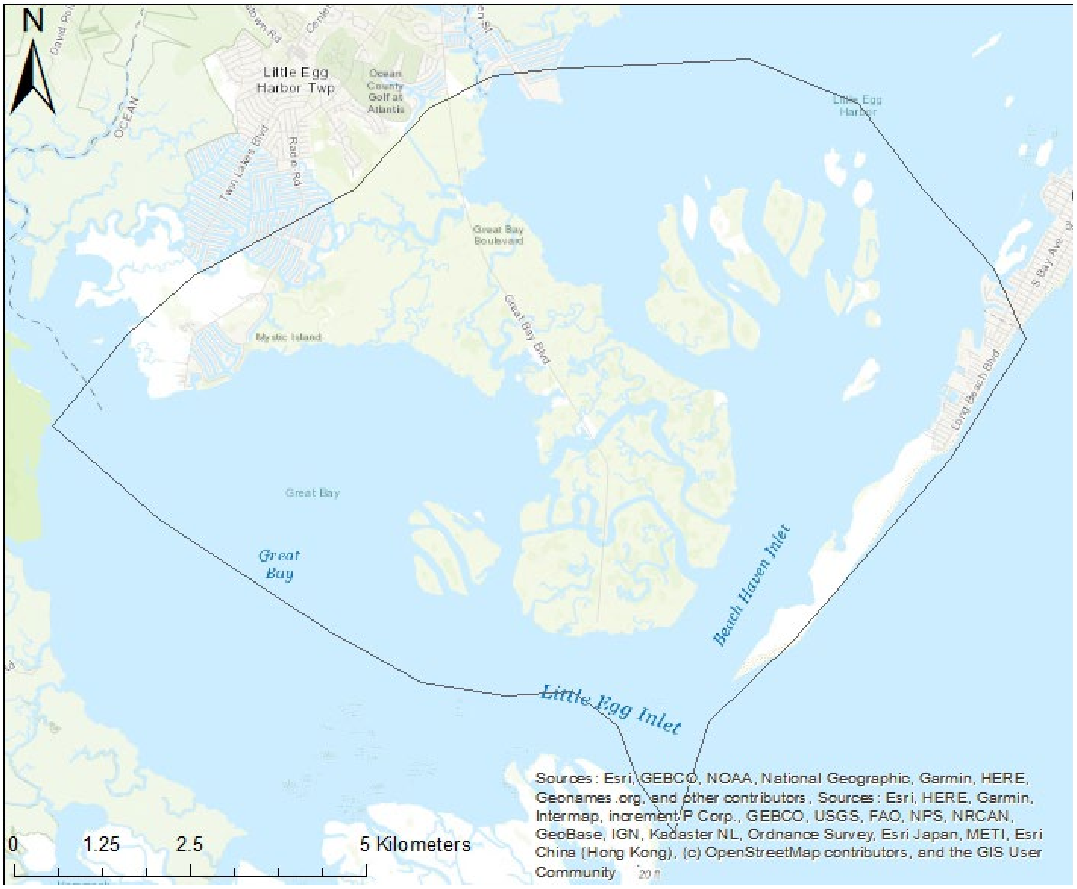

Figure 1 Map of Holgate NNBF area

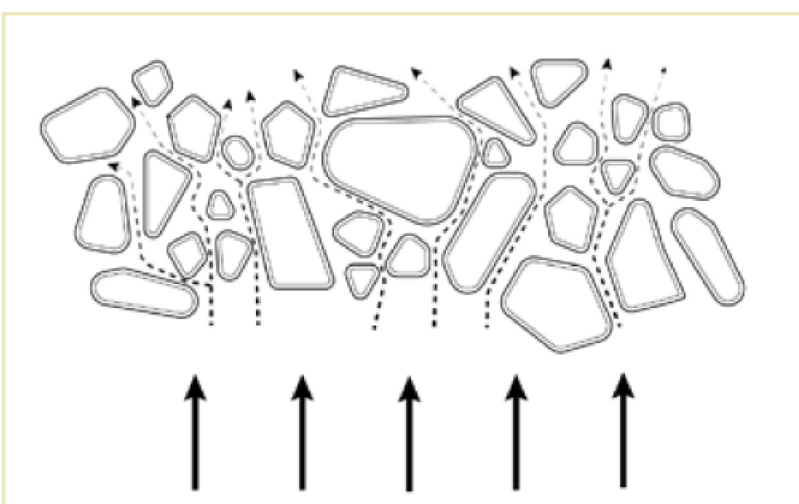

Figure 2 Surge filter concept diagram from Engineering With Nature® and Landscape Architecture: New Jersey Bay Bays report

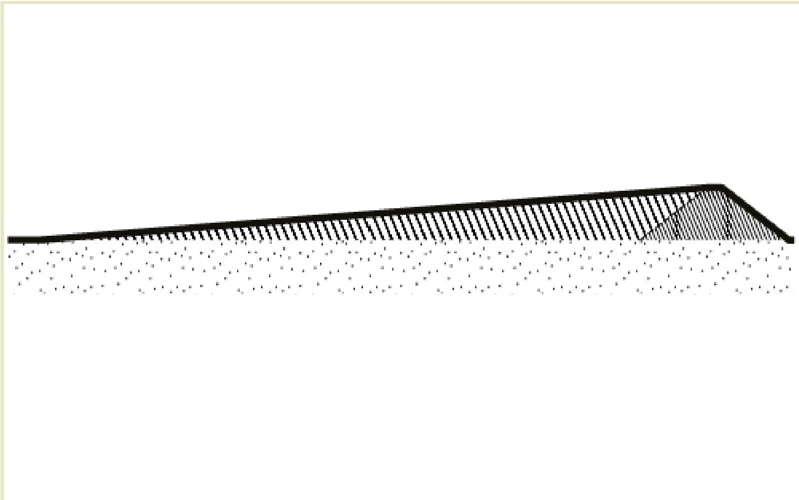

Figure 3 Horizontal levee concept diagram from Engineering With Nature® and Landscape Architecture: New Jersey Back Bays report

The Brigantine region is influenced by both Little Egg Inlet to the north and the smaller and more southern Brigantine Inlet (also referred to as Little Egg/Brigantine), both of which are not stabilized and Absecon Inlet, which is stabilized with jetties (Figure 4). The region is dissected by a number of navigational channels, some of which cut through existing marsh, and the existing marsh islands are mostly low-lying and fragmented by mosquito ditching, potentially impacting the capability to attenuate surge and wave propagation. The NNBF measures proposed in this area also utilize the "surge filter" concept and include expansion and elevation of existing marsh islands with a focus on creating more sinuosity in open water areas of the back bay.

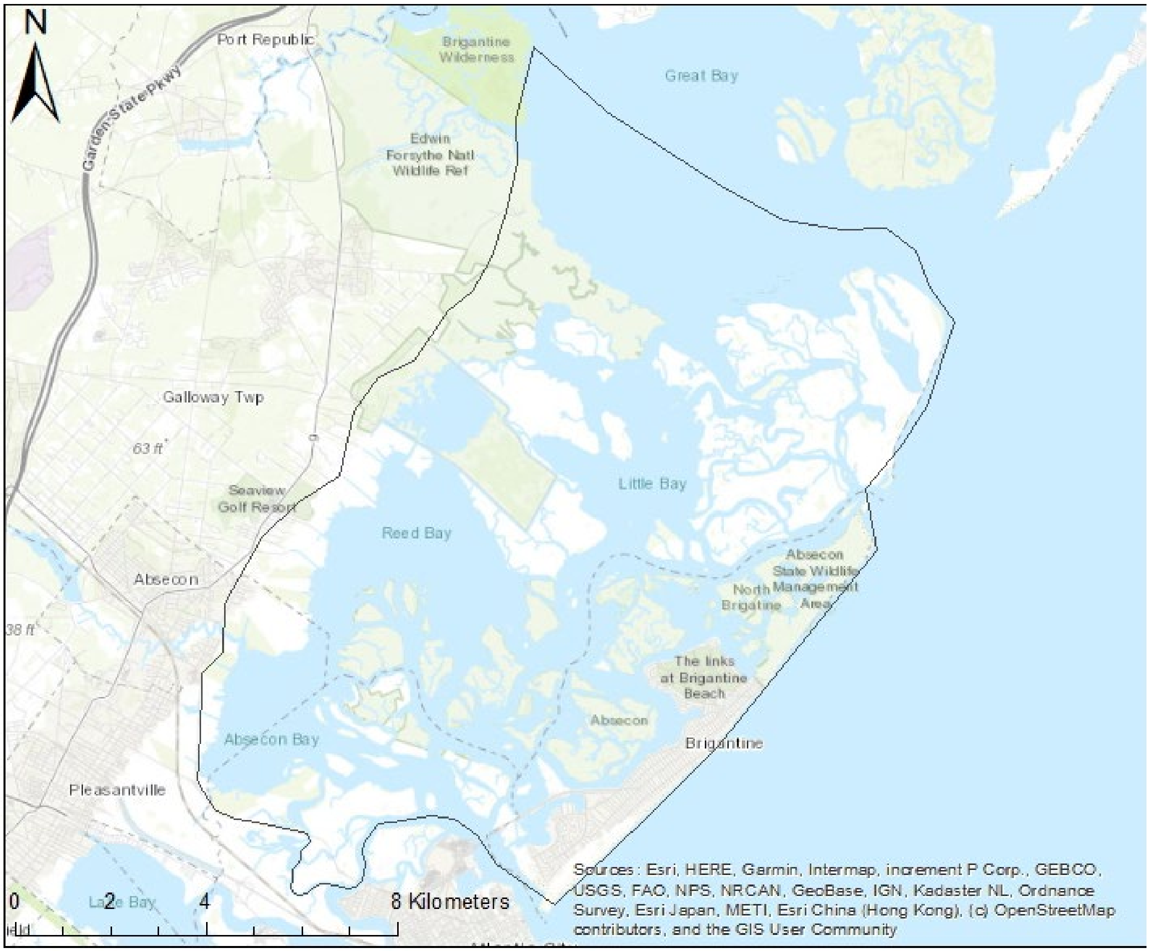

Figure 4 Map of Brigantine NNBF area

The Great Egg region is the most southern NNBF evaluation area and is focused on preventing surge and waves from propagating into the back bay through Great Egg Harbor Inlet (Figure 5). The NNBF measures proposed also utilize the "surge filter" concept and are similar to those in Brigantine: expand and elevate existing marsh islands and construct new islands to further reduce flow into the back bay. The northern portion of this area is characterized by a large number of wetland islands in the back bay as opposed to the southern portion, which has relatively fewer wetland islands and a larger proportion of open water areas.

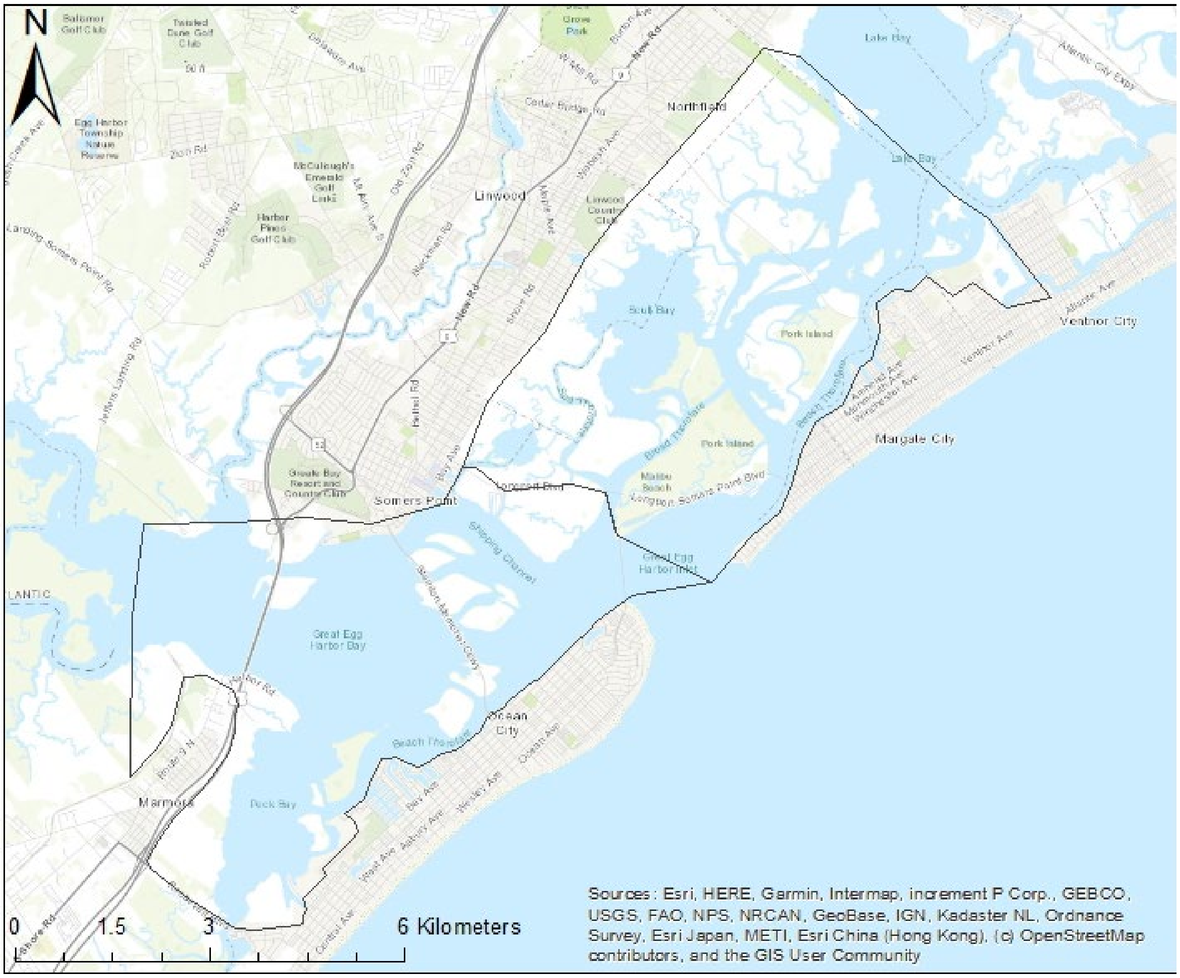

Figure 5 Map of Great Egg Harbor Inlet NNBF area

The effects of extra large-scale NNBF were assessed in two model configurations: Configuration 8, which included storm-surge barriers at Manasquan Inlet and Barnegat Inlets, expansion of the island complex west of Beach Haven in the Holgate region of the E.B. Forsythe National Wildlife Refuge, a horizontal levee along Great Bay Boulevard, and expansion of the wetland island complex landward of and to the north and south of Great Egg Inlet (Figure 6) and configuration 5, which included storm-surge barriers at Great Egg and Absecon Inlets and wetland island expansion in the back bay region west of Brigantine (Figure 7). Note that NNBF measures in the Holgate and Great Egg regions were combined into one configuration because the proposed interventions were spaced far enough apart that their effects were independent of each other as determined from the earlier hydrodynamic evaluation of surge barrier combination (Slusarczyk et al. 2020) so only two model configurations were required to assess the efficacy of NNBF in three areas of the NJBB domain. These NNBF with surge barrier configurations were compared with two surge-barrier-only configurations, Configuration 3 and North, that only included the structural measures described above; Configuration 3 was compared with Configuration 5 and North was compared with Configuration 8. The purpose of this comparison was to determine how the proposed NNBF affected water levels (surge only in the case of North and Configuration 8 and surge and waves for Configurations 3 and 5) in the three areas.

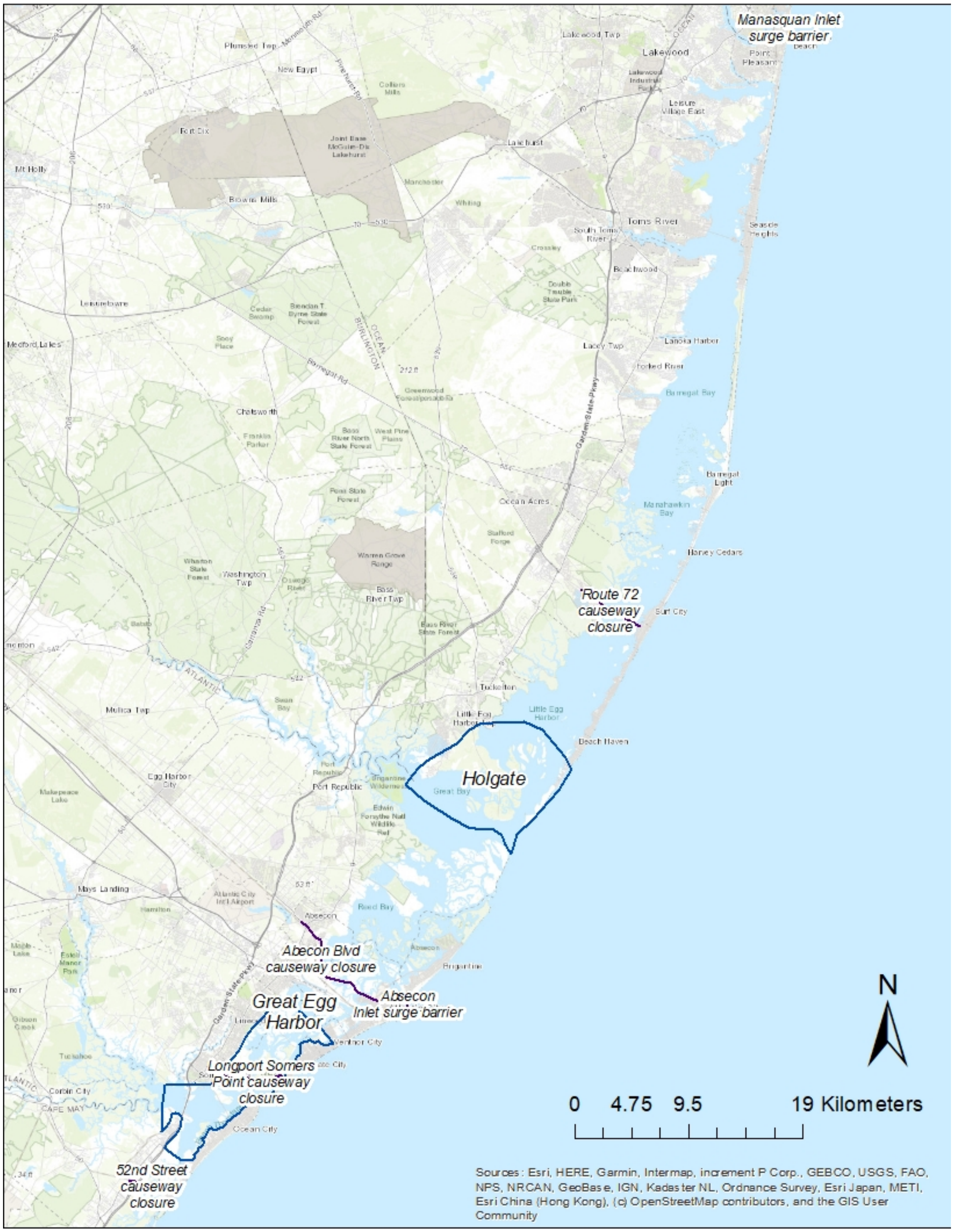

Figure 6 Configuration 8 included NNBF measures in the Holgate and Great Egg Harbor areas as well as surge barriers at Manasquan and Absecon Inlets

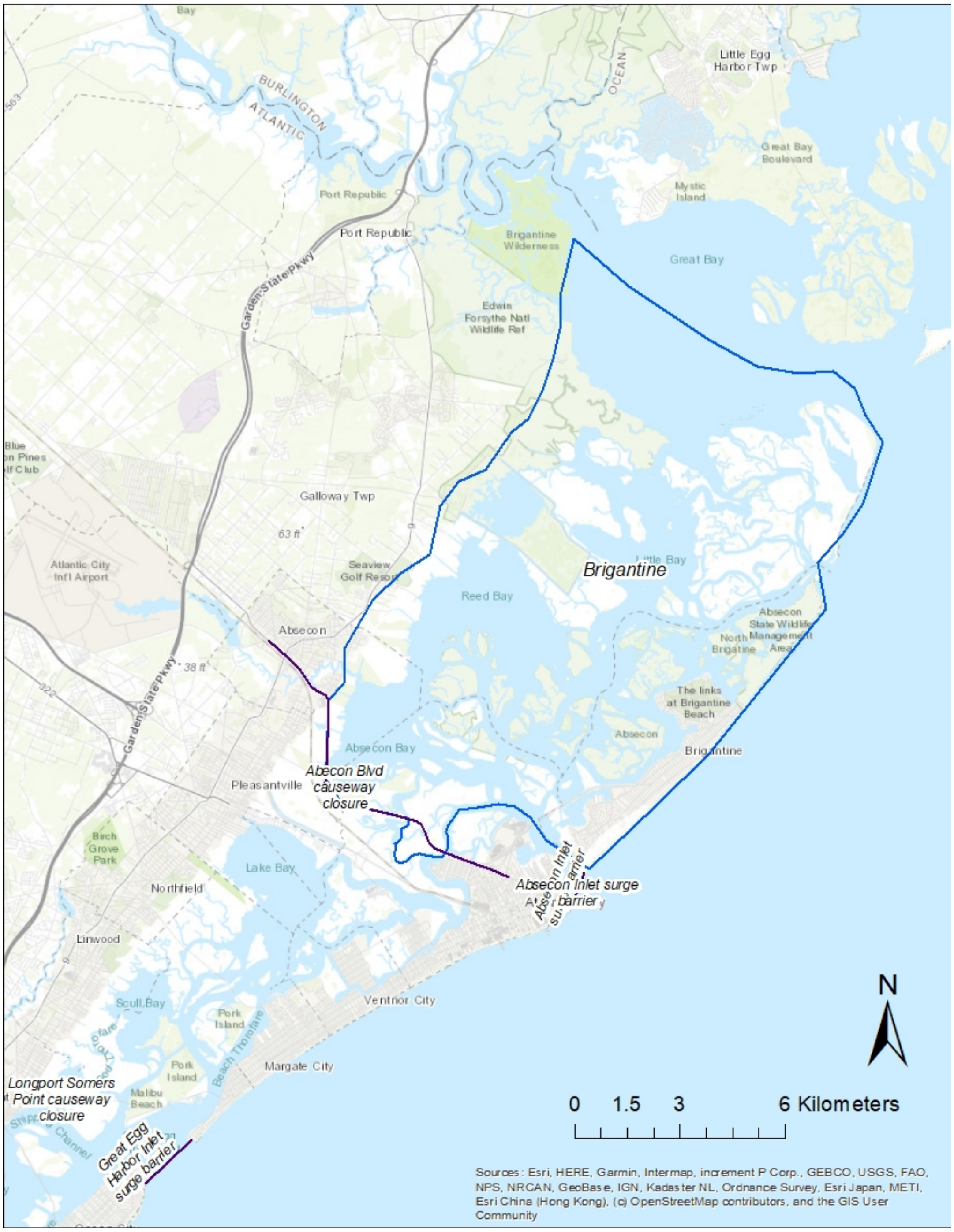

Figure 7 Configuration 5 included NNBF within the Brigantine NNBF area as well as a surge barrier at Absecon Inlet

2.2 Development of NNBF characteristics

The NNBF feature configurations were developed in ArcMap 10.7 using the Continually Updated Shoreline Product available from NOAA (2018) to define the present land-water interface. Existing elevation data were used to define the existing topography and bathymetry from USGS Coastal National Elevation Database (2015). The existing island boundaries were manipulated using ArcMap 10.7 Editor through a combination of scaling existing islands, merging adjacent smaller islands into larger islands, and creating new islands. Edge elevation was assigned as the mean elevation of existing shorelines in the NNBF area. The elevation of the islands was determined by assigning a constant slope to the feature, typically 0.5%, increased to 1% for small islands. For large features, once the elevation exceeded 3 m, the slope was further reduced to 0.25%.

The vegetation type and corresponding roughness value of the vegetation was inferred from the elevation using the rules adapted from Correll et al. (2018) for vegetation communities in coastal New Jersey. Four vegetation communities were assumed to occupy the proposed NNBF: low marsh, characterized by elevations ranging from mean sea level to mean higher high water and occupied by *Spartina alterniflora*; high marsh, characterized by elevations ranging from mean higher high water to the extent of the highest astronomical tide and occupied by *Spartina patens Distichlis spicata, Juncus gerardii,* and short form *Spartina alterniflora*; transitional marsh characterized by typical elevations from highest astronomical tide to maximum flood and characterized by *Typha angustifolia, Iva frutescens, Baccharis halimifolia, Solidago sempervirens, Scirpus robustus, and Spartina pectinata*; and coastal shrub-scrub, characterized by elevations greater than the maximum flooding extent and occupied by *Juniperus virginiana* and other woody species stunted by proximity to the coast. Local mean sea level and mean higher high water for each region were estimated using NOAA's Vdatum version 4.01 software (NOAA, 2019) and the highest astronomical tide and maximum flood level recorded at the Atlantic City, NJ NOAA water level gage were used for all areas. The vegetation communities were selected to correspond with the existing inventory of Manning's n roughness coefficients compiled in Bunya et al. (2010) and represented the majority of natural land areas in the back bay region excluding urban and developed areas.

The horizontal levee geometry was developed using the Feature Stamping tool in SMS version 13.0. The centerline of the levee followed the existing centerline of Great Bay Boulevard. The levee height was +3.1 m (10 ft) NAVD88 with a top width of approximately 30 m corresponding to the ADCIRC mesh resolution. The side slopes ranged from 2 to 3.3% depending on the available area. Major creeks were not blocked by the horizontal levee and instead were designed to be closed off only during storm conditions using gates.

2.3 Storm suite selection

In Phase 1 of the NJBB study (Slusarczyk et al., 2020), CHL selected an initial subset (10) of the 1050 synthetic tropical cyclones that were designed and simulated in the North Atlantic Coastal Comprehensive Study (NACCS) using Gaussian process metamodeling (GPM) and a design of experiments (DoE) approach. This 10-storm subset (Storms 99, 349, 350, 357, 433, 434, 469, 524, 636, and 646) was used to simulate the response of the proposed NNBF to varying storm conditions such as intensity, direction, and translational speed. The storm characteristics of the ten storms are listed in Table 1 and the storm tracks are shown in Figure 8.

Table 1 Storm characteristics of the ten storm suite used to model response in the study domain

TROPICAL CYCLONE ID	NACCS SUBREGION	MASTER TRACK ID	Θ (DEG)	ΔP (HPA)	RMAX (KM)	VF (KM/H)
99	3	31	-40	88	65	16
349	2	9	-60	78	125	65
350	2	9	-60	68	52	26
357	2	10	-60	58	88	28
433	2	55	-20	88	55	62
434	2	55	-20	78	82	27
469	2	76	0	78	74	38
524	2	98	20	78	73	38
636	2	120	40	78	47	14
646	2	121	40	83	67	59

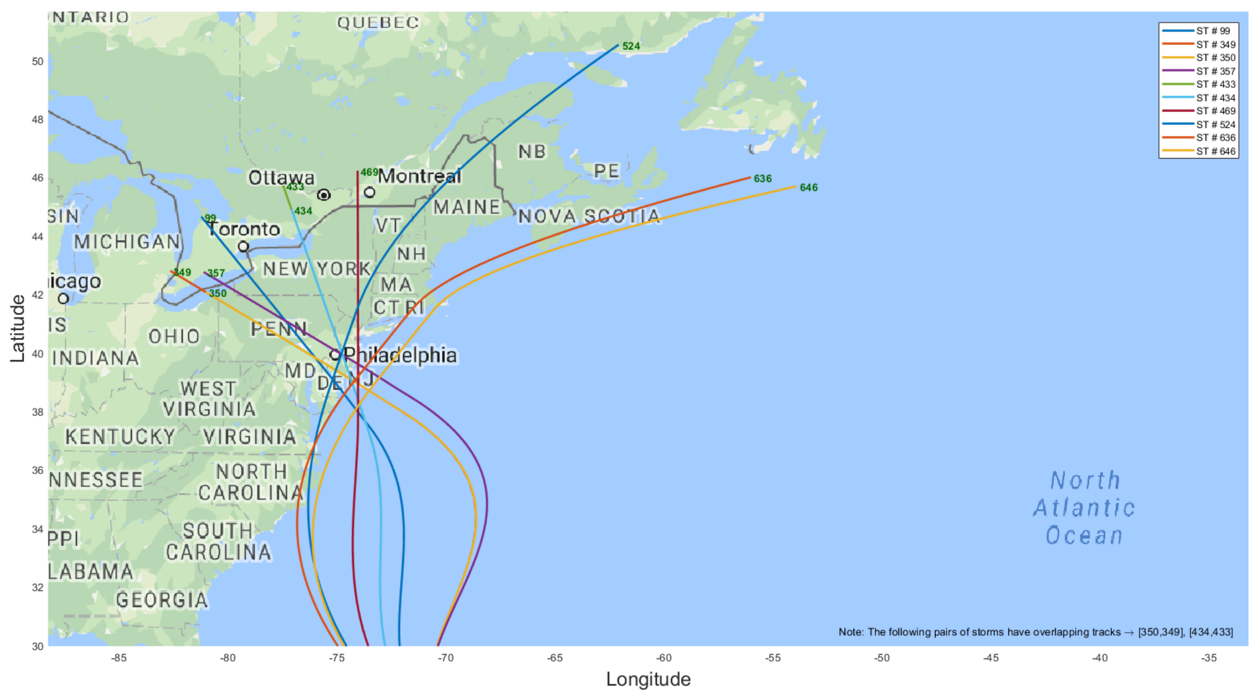

Figure 8 Synthetic storm tracks for the ten storms simulated

Table 2 shows a full summary of the water level responses (surge and waves) and associated annual exceedance probabilities (AEPs) for selected save points in the NNBF interest areas as interpolated from the AEP water level response curves reported in the Coastal Hazards System (Melby and Green, 2015). These AEPs represent the water level responses due to the ten synthetic tropical storms if no CSRM measures (structural or NNBF) were in place based on modeling that occurred after Hurricane Sandy and are intended to help the reader get a sense for the relative likelihood of the water level responses induced by these ten storms.

For most save points, storms 99 and 433 produced the greatest water level response at all save points, and storms 357 and 646 produced the smallest responses. The save point locations are shown in Figure 19, Figure 22, and Figure 24 in the Results section. Note that these water levels and associated AEPs were from previous modeling efforts associated with the North Atlantic Coastal Comprehensive Study and published to the Coastal Hazards System (Melby and Green, 2015). For New Jersey Back Bays study, the model geometry was updated to include changes in bathymetry and restoration of barrier islands, which will alter the water level and AEP values reported in Table 2. The peak water level response data for the modeling scenarios included in this study are found in Tables 6 and 7 in Section 3.2.

Table 2 Summary of the water level responses (surge+waves) and associated annual exceedance probabilities within the NNBF areas without any structural or NNBF measures implemented (from Coastal Hazards System; Melby and Green, 2015)

AREA			HOLGATE			BRIGANTINE		GREAT EGG HARBOR		
SAVE POINT ID (THIS STUDY)			61	73	33	59	50	49	117	111
CHS SAVE POINT ID			11399	11459	13580	11369	11316	11315	13513	13496
STORM ID	99	WL elev. MSL (m)	2.34	3.09	3.00	3.00	3.94	3.79	3.39	3.36
		AEP	4.0E-03	1.9E-03	3.7E-03	3.9E-03	1.6E-03	1.7E-03	4.1E-03	2.6E-03
	349	WL elev. MSL (m)	2.23	2.43	2.77	2.54	2.68	2.64	2.61	2.32
		AEP	4.8E-03	7.8E-03	5.5E-03	9.0E-03	1.3E-02	1.1E-02	1.8E-02	2.5E-02
	350	WL elev. MSL (m)	2.29	3.04	2.83	2.76	3.31	2.79	2.37	2.48
		AEP	4.3E-03	2.2E-03	4.8E-03	6.0E-03	4.5E-03	8.8E-03	3.1E-02	1.6E-02
	357	WL elev. MSL (m)	1.57	1.67	1.73	1.83	1.72	1.43	1.44	1.63
		AEP	1.5E-01	1.5E-01	1.7E-01	1.3E-01	2.5E-01	3.7E-01	4.0E-01	3.0E-01
	433	WL elev. MSL (m)	2.78	3.01	3.78	3.63	3.40	3.33	3.78	3.20
		AEP	1.2E-03	2.4E-03	7.8E-04	9.8E-04	4.0E-03	3.7E-03	1.9E-03	3.6E-03
	434	WL elev. MSL (m)	2.54	2.95	2.85	2.92	3.38	3.09	2.88	2.89
		AEP	2.3E-03	2.8E-03	4.7E-03	4.4E-03	4.1E-03	5.0E-03	1.1E-02	6.6E-03
	469	WL elev. MSL (m)	2.10	2.37	2.49	2.70	3.04	2.70	2.71	2.67
		AEP	1.0E-02	8.8E-03	9.4E-03	6.9E-03	7.1E-03	9.9E-03	1.5E-02	1.0E-02
	524	WL elev. MSL (m)	1.11	1.67	2.09	1.84	2.21	2.46	2.36	2.17
		AEP	5.4E-01	1.5E-01	4.6E-02	1.3E-01	4.7E-02	1.5E-02	3.1E-02	4.2E-02
	636	WL elev. MSL (m)	1.83	2.19	1.94	2.09	2.79	2.11	2.16	2.37
		AEP	4.9E-02	1.6E-02	8.6E-02	4.6E-02	1.0E-02	3.8E-02	4.4E-02	2.0E-02

	646	WL elev. MSL (m)	1.33	1.45	1.66	1.93	2.07	1.71	2.22	2.20
		AEP	3.2E-01	2.9E-01	2.1E-01	8.9E-02	8.6E-02	1.6E-01	4.0E-02	3.8E-02

2.4 Implementation in ADCIRC

The ADvanced CIRCulation (ADCIRC) model was used to simulate the surge and circulation response to storms. Two ADCIRC meshes (North and Central 1) developed in the NJBB Phase 2 study (Slusarczyk et al., 2020) as part of the NJBB Feasibility Study were modified to accommodate the proposed NNBF by increasing the resolution where the NNBFs were to be placed. In these areas, the bathymetry and the Manning's n values were also modified to match the elevation and Manning's n values assigned in ArcMap 10.7 (ESRI, 2018). The minimum node spacing after the grid refinement in the area of interest is approximately 30 m, which is approximately double compared to the original grid resolution. An example of changes to the mesh for the Brigantine region to accommodate the proposed NNBF is shown in Figure 9. Mesh changes in the Holgate and Great Egg Harbor region are found in Appendix A.

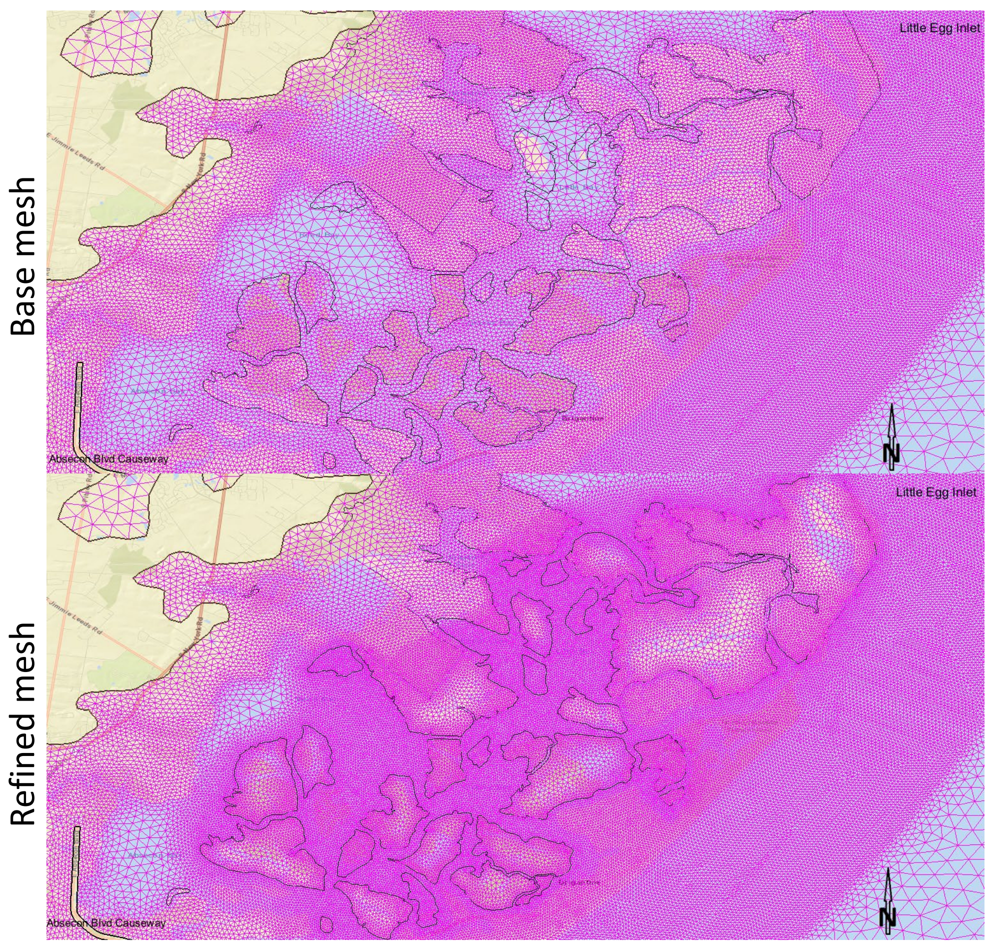

Figure 9 Change in mesh resolution in the Brigantine area to accommodate the NNBF

2.5 Implementation in STWAVE

2.5.1 STWAVE

STWAVE is a steady-state spectral wave model for nearshore wave generation, propagation, transformation, and dissipation (Smith et al. 2001, Smith 2007, Massey et al. 2011). STWAVE numerically solves the steady-state conservation of spectral wave action along backward-traced wave rays:

$$(C_g)_i \frac{\partial}{\partial x_i} \frac{CC_g \cos \alpha E(\sigma,\theta)}{\sigma} = \sum \frac{S}{\sigma} \quad (1)$$

where i is tensor notation for x- and y- components, Cg is group celerity, θ is wave direction, C is wave celerity, σ is wave angular frequency, E is wave energy density, and S is energy source and sink terms. Source and sink mechanisms included surf-zone wave breaking, wind input, wave-wave interaction, whitecapping, and bottom friction.

2.5.2 Coordinate System

STWAVE is formulated on a Cartesian grid, with the x-axis oriented in the cross shore direction (I) and the y-axis oriented alongshore (J), parallel with the shoreline. Angles are measured counterclockwise from the grid x-axis.

2.5.3 Grid Development

For simulation, two STWAVE domains (parent and nested) were developed to simulate wave growth, propagation, and transformation around the added NNBF features. The parent grid uses a 200-m resolution comprised of 452 cells in the cross-shore direction (I) and 1017 cells in the alongshore direction (J). However, finer resolution is needed in the areas of interest to resolve the NNBF features. Dictated by the geometry of the added features, the finer resolution was set at 50-m comprising of 672 cells in the cross-shore direction (I) and 1441 cells in the alongshore direction (J). The nesting approach will use the parent grid as the offshore domain using the boundary forcing already developed during the NACCS effort. This offshore domain will then be used to transform offshore waves to the boundary of a nearshore, high-resolution domain. The advantage of grid nesting is it minimizes computation requirements and increases accuracy due to a more accurate description of the bathymetry and topography

The developed parent grid extended offshore from the 80 m contour to the -70 m contour onshore and extends Northward to Fort Hancock and Southward to Cape May point. The developed child grid extended offshore from the 30 m contour to the -15 m contour onshore and extends to the North to Stafford Township and to the South to Sea Isle City, to capture the fetch around the NNBF features. The projection of the grid was UTM 18 with a vertical datum relative to NAD83. The properties of both STWAVE domains are provided in Table 3 and shown in Figure 10.

Table 3 STWAVE grid properties

GRID	PROJECTION	GRID ORIGIN (X,Y) [M]	AZIMUTH [DEG]	ΔX/ΔY [FT]	NUMBER OF CELLS	
					I	J
PARENT	UTM 18, NAD83 meters	(659306.740683, 4449647.677174)	154.23	200	452	1017
CHILD	UTM 18, NAD83 meters	(588858.409910, 4374090.260479)	140.14	50	672	1441

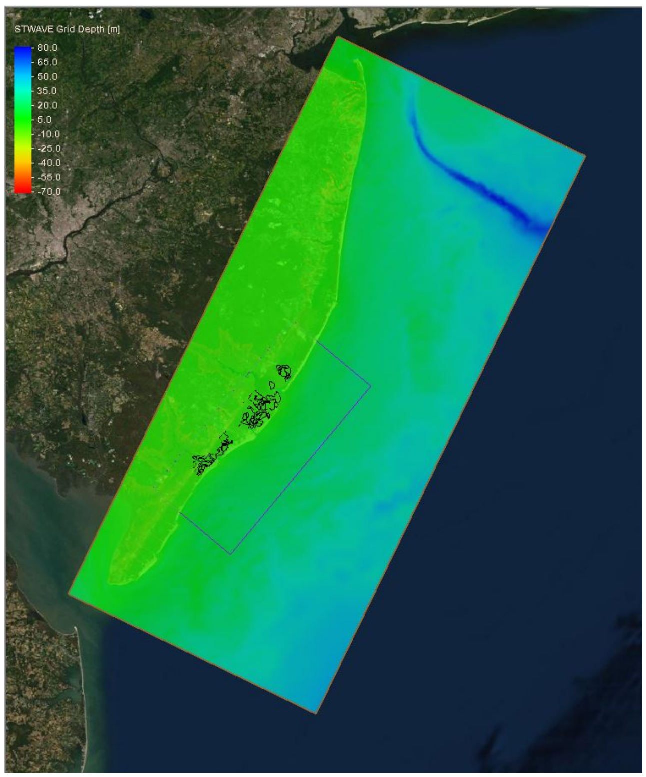

Figure 10 Parent Child STWAVE domains

The bathymetry, topography, and bottom friction Manning’s n values were interpolated from the ADCIRC mesh. The nested Child STWAVE domain is shown in Figure 11.

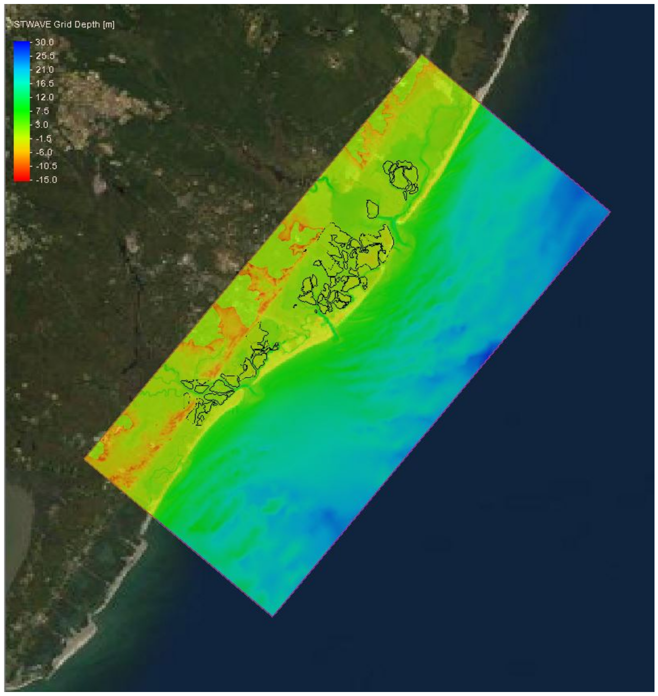

Figure 11 Child STWAVE Domain Extents

Two cases were modeled with the use of STWAVE, referred to as Configuration 3 and Configuration 5. The implemented design features of Configuration 3 were the storm surge barrier at Great Egg Inlet and the storm surge barrier at Absecon Inlet. The implemented design features of Configuration 5 were in addition to the storm surge barrier of Configuration 3, maximal island restoration in the Absecon/Brigantine wetlands. Given that the features included in the Configuration 3 design are also included in Configuration 5, Configuration 3 will be treated as the baseline condition and Configuration 5 as the test condition for analysis. The NNBF features included in the child domain are shown in Figure 12 below, and are depicted as a difference between the bathymetry of Configuration 3 (no NNBF) and Configuration 5 (with NNBF).

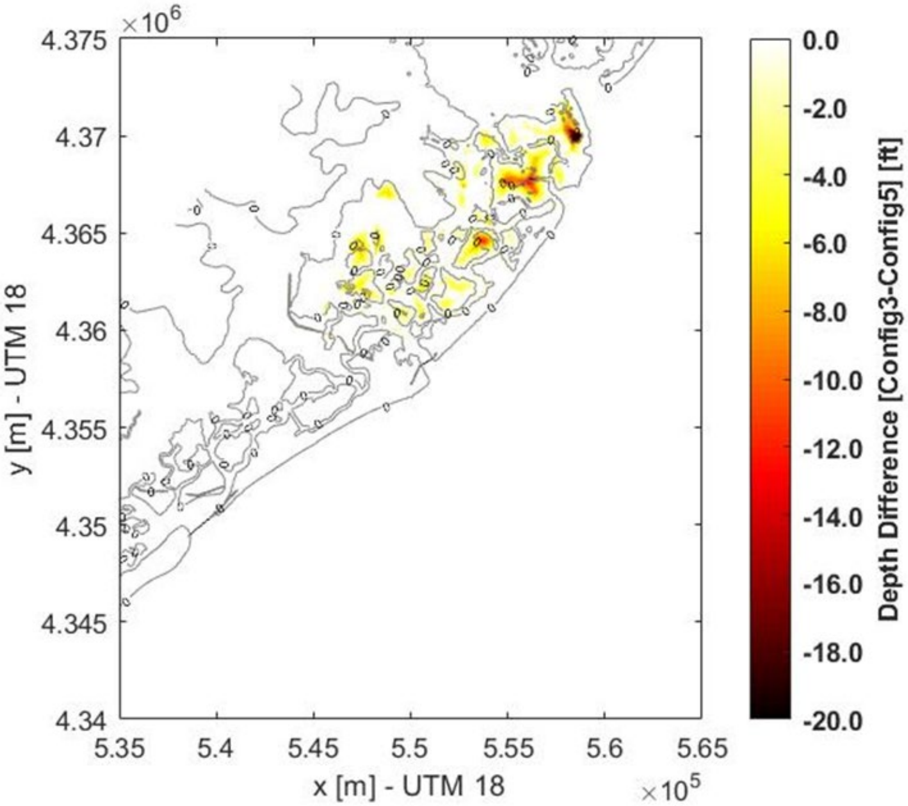

Figure 12 Implemented NNBF features and storm surge barrier included in the STWAVE child domains for Configuration 5. The NNBF are depicted as a difference between the bathymetry of Configuration 3 (no NNBF) and Configuration 5 (with NNBF.)

2.5.4 Boundary Spectra

Ten storms were identified for simulation in STWAVE. The parent grid was run with the NACCS resolved spectra, represented by 28 frequency bands, ranging from 0.031 Hz (32.2 sec) to 0.309 Hz (3.24 sec), and 72 angle bands, from an angle of 0 degrees to 355 degrees with respect to the x-axis (154.23). Each TMA spectrum within a simulation is an IDD. For simulation, the IDD type was selected as 'year/date' format with regularly spaced intervals of 15 min, the same as the NACCS modeling effort. The child grid was run with spectra generated at specified points from the Parent grid. These points were generated along the 65 ft (20 m) contour within the parent grid. The locations of these nested points are shown in Figure 13. The generated nesting spectra had identical time spacing and IDD formatting as the parent grid. Additional STWAVE inputs, such as winds and water elevations were included during coupling with ADCIRC.

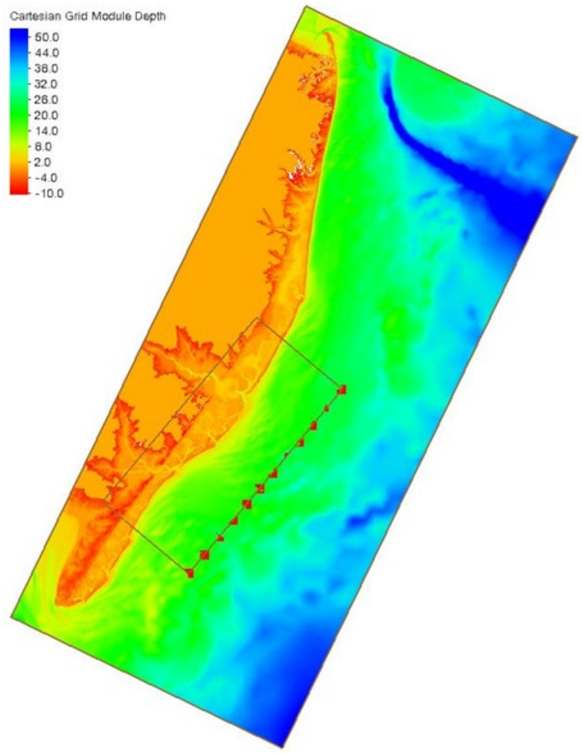

Figure 13 Nesting Locations inside the Parent grid Identified by the red dots along the child grid offshore boundary

2.5.5 Model Execution

Each STWAVE simulation conducted used the full-plane mode of STWAVE to allow for wave generation and transformation in a 360-degree plane. The full-plane version of STWAVE uses an iterative solution process that requires user-defined convergence criteria to signal a suitable solution. Boundary spectra information is propagated from the boundary throughout the domain during the initial iterations. Once this stage converges, winds and surges are added to the forcing, and this final stage iteratively executes until it also reaches a convergent state. The convergence criteria for both stages include the maximum number of iterations to perform per time-step, the relative difference in significant wave height between iterations, and the minimum percent of cells that must satisfy the convergence criteria (i.e., have values less than the relative difference.) Convergence parameters were selected based on a previous study by Massey et al. (2011) in which the sensitivity of the solution to the final convergence criteria was examined. The relative difference and minimum percent of cells were set as (0.1, 100.0) and (0.05, 99.8) for the initial and final iterations, respectively. STWAVE was set up with parallel in-space execution whereby each computational grid was divided into different partitions (in both the x- and y-direction), with each partition executing on a different computer processor. For the parent grid, the number of partitions in the x direction was 8, while the number of partitions in the y direction was 17. For the child grid, the number of partitions in the x direction was 12, while the number of partitions in the y direction was 25. The maximum number of initial and final iterations was set to a value of 25 and 32 respectively for the parent grid and a value of 45 for both the initial and final iterations for the child grid. For both the parent and child grid, this value is higher than the largest partition size.

Additionally 186 station locations from the ADCIRC station list were identified within the STWAVE domain for the parent grid, and 107 station locations were identified within the child grid. During the simulations, these stations recorded the significant wave height, mean wave period, mean wave direction, peak wave period, wind magnitude, wind direction, and water elevation for each time step. Station numbers 49, 50, 59,111, and 117 were chosen to produce time plot comparisons.

3 Results

3.1 NNBF configurations

The proposed NNBF were designed to attenuate surge and waves by increasing both elevation and roughness, which will lead to a change in the proportion of open water area and the habitat types of the areas. Table 4 summarizes the changes in the proportion of open water, the elevation of emergent land, and changes in open water, low marsh, high marsh, and shrub-scrub communities in each area. Note that the habitat changes are for the NNBF as modeled and were designed to be extra large-scale in both horizontal extent and elevation and do not reflect actual proposed changes in habitat types. As wetland elevation depends on mineral and biological accretion processes, any future predictions of wetland area in the future would require additional modeling to predict future accretion. However, habitat changes will be inevitable in the vicinity of any proposed CSRM measures. As sea levels rise, we expect coastal shrub-scrub area to convert to high marsh and high marsh to convert to low marsh and low marsh to convert to open water.

Table 4 Changes in habitat properties associated with implementation of proposed NNBF measures

PROPERTY	SCENARIO	HOLGATE ISLANDS	HORIZONTAL LEVEE*	BRIGANTINE	GREAT EGG
PROPORTION OPEN WATER	Base	66.9%	n/a	50.5%	50.1%
	NNBF	54.4%	n/a	42.5%	38.7%
MEAN ELEVATION (STANDARD DEVIATION) (M)	Base	0.55 (±0.95)	0.50 (±0.35)	0.27 (±0.61)	0.06 (±1.19)
	NNBF	1.06 (±1.02)	1.86 (±0.74)	1.21 (±0.82)	1.20 (±1.18)
OPEN WATER AREA (HA)	Base	1134.6 (73.6%)	26.9 (16.5%)	2199.2 (40.0%)	1382.0 (42.8%)
	NNBF	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
LOW MARSH AREA (HA)	Base	31.5 (2.0%)	11.4 (7.0%)	451.5 (8.2%)	277.0 (8.6%)
	NNBF	330.6 (21.4%)	1.7 (1.1%)	509.8 (9.3%)	1398.3 (43.3%)
HIGH MARSH AREA (HA)	Base	360.3 (23.4%)	110.7 (68.0%)	2608.7 (47.4%)	1316.2 (40.7%)
	NNBF	543.8 (35.3%)	19.5 (12.3%)	2672.4 (48.6%)	450.7 (13.9%)
TRANSITIONAL MARSH (HA)	Base	9.9 (0.6%)	11.6 (7.1%)	154.8 (2.8%)	146.6 (4.5%)
	NNBF	119.0 (7.7%)	36.6 (23.1%)	503.3 (9.1%)	325.9 (10.1%)
SHRUB-SCRUB AREA (HA)	Base	6.2 (0.4%)	2.1 (1.3%)	87.6 (1.6%)	109.3 (3.4%)
	NNBF	549.1 (35.6%)	100.8 (63.6%)	1816.3 (33.0%)	1056.2 (32.7%)

* Total area of habitat for the horizontal levee NNBF and base scenarios is slightly different due to rounding errors; shrub-scrub habitat area also includes road surface area

All proposed NNBF will require large volumes of sediment as proposed. Assuming a constant unit cost for sediment, sediment requirements can be used a proxy measurement for cost associated with construction of the NNBF. All NNBF configurations as proposed are assumed to be extra large-scale and are designed as proof-of-concept demonstrations of NNBF in the area. Based on the model results presented, the scale of any recommended NNBF will likely be reduced to minimize not only the volume of sediment required but also the changes in habitat and possible changes in estuarine circulation. As simulated, the Holgate region requires the least amount of sediment (123M yd^3 including both island expansion and the horizontal levee) while both the Brigantine and Great Egg Harbor regions are similarly sized.

Table 5 Summary of required volume of sediment required to construct extra large-scale NNBF measures

SITE	VOLUME OF SEDIMENT REQUIRED
HOLGATE	~114M yd^3 (87M m^3)
HORIZONTAL LEVEE	~9M yd^3 (7M m^3)
BRIGANTINE	~252M yd^3 (192M m^3)
GREAT EGG	~242M yd^3 (185M m^3)

3.1.1 Holgate-Beach Haven area

In the Holgate-Beach Haven area, an existing island complex and peninsula of wetland (Tuckerton Peninsula) already occupied a large proportion of back bay area to the north of Little Egg Inlet. To implement the proposed NNBF, the island complex was expanded (Figure 14). Existing islands were increased in size and elevation and new islands were created. The resulting modifications changed the percent open water from 66.9% to 54.4%, which is more open water than other regions.

Figure 14 Holgate area NNBF includes a horizontal levee along Great Bay Boulevard and island expansion and creation

The existing wetland peninsula on which the horizontal levee is located is dissected by a number of tidal creeks, which are designed to be closed by a gate during storm conditions, allowing free exchange of water during typical conditions. The horizontal levee along Great Bay Boulevard ranged in width from 137to 265 m (449 to 869 ft.), had side slopes ranging from 1:50 to 1:30, and increased the elevation from 0.50 m near the levee edges to 3.1 m at the levee crest (1.6 and 10 ft., respectively). The Engineering With Nature® and Landscape Architecture: New Jersey Back Bays report illustrates a typical cross-section for a potential horizontal levee design.

3.1.2 Brigantine

The Brigantine area was already characterized by extensive wetland islands; however, many had been dissected by navigation channels that provide conduits for easy transmission of surge into the back bay. Similar to the approach at Holgate, wetland islands were expanded, merged together, and created to reduce the total open water area and connectivity of the back bay (Figure 15). Island expansion was focused on areas of the back bay that had previously been wetland as far back as the 1930s. Other islands were created in areas of more extensive open water to prevent further wave generation where possible. The NNBF configuration (Configuration 5) included a storm surge barrier at Absecon Inlet and a cross-bay barrier along Absecon Boulevard.

Figure 15 Brigantine area NNBF included expansion and elevation of existing wetland islands

3.1.3 Great Egg Harbor Inlet

The area landward and to the north and south of Great Egg Harbor Inlet was characterized by a few wetland islands (Figure 16). The area south of the inlet had a higher proportion of open water, necessitating more island creation than the area to the north of the inlet or even the Brigantine and Holgate regions. The role of NNBF in these areas was to slow down surge entering the inlet and prevent it from propagating through the back bay and into Great Egg.

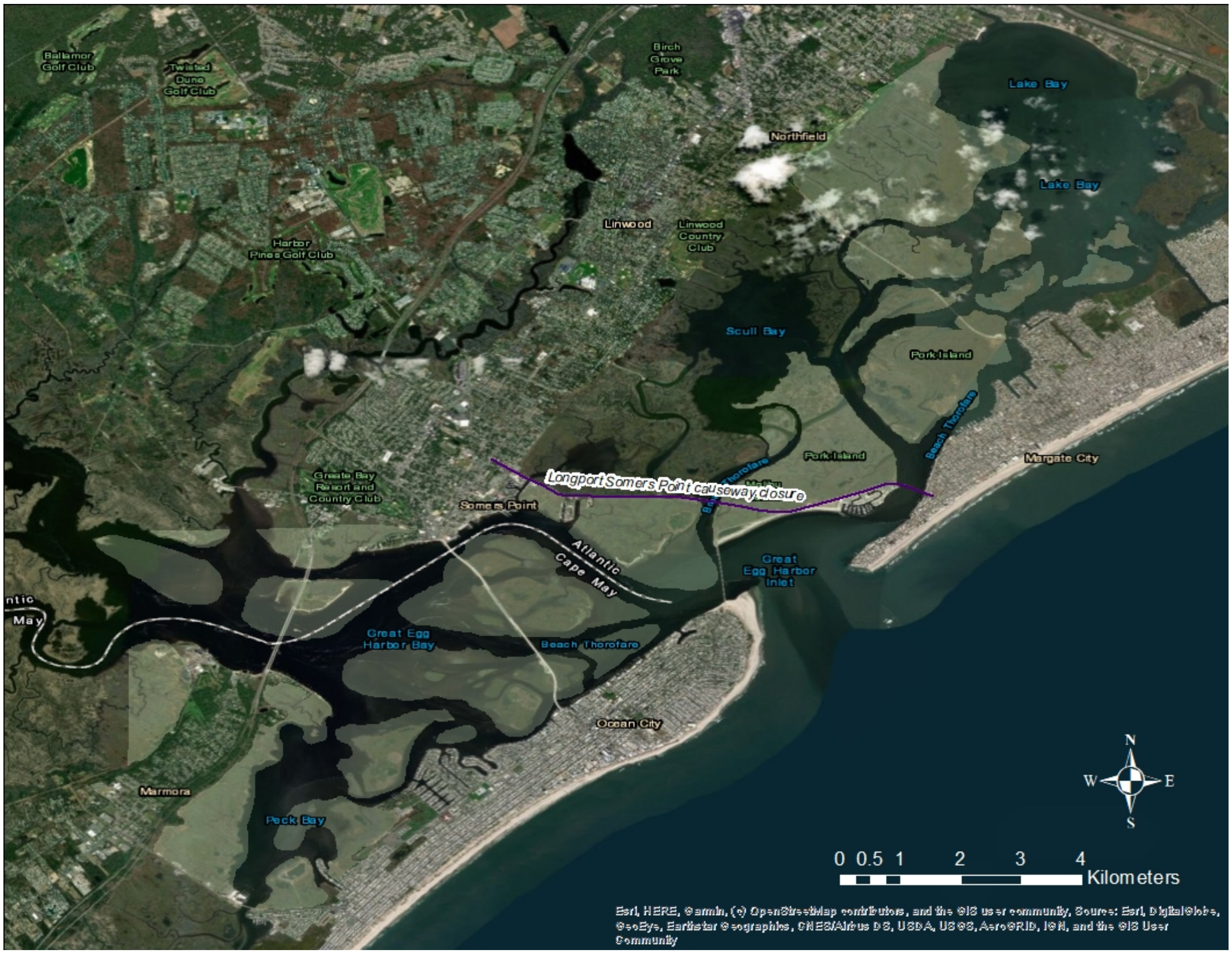

Figure 16 Great Egg Harbor Inlet area NNBF included mostly island expansion and creation south of the inlet

3.2 ADCIRC results

For both model configurations 5 (which includes the Brigantine NNBF) and 8 (which includes both the Holgate and Great Egg Harbor inlet NNBF), water level changes associated with implementation of the NNBF measures relative to the without NNBF (structural protection only) extended well beyond the area immediately adjacent to the proposed NNBF (Figure 17). Storms 350 and 636 showed two typical patterns of water level response to storms for most of the NNBF and surrounding areas. Notice that for both storm types and both configurations, there are areas of water level reductions (shown in cool blue colors) and areas of water level increases (shown in warm yellow and red colors). The water level responses in all three NNBF areas without any CSRM measures in place was greater for Storm 350 than Storm 636 (see Table 2). Storm 350 produced greater water level responses in the Holgate and Brigantine areas than the Great Egg Harbor area while Storm 636 produced the greater water level response in the Great Egg Harbor and Brigantine NNBF areas.

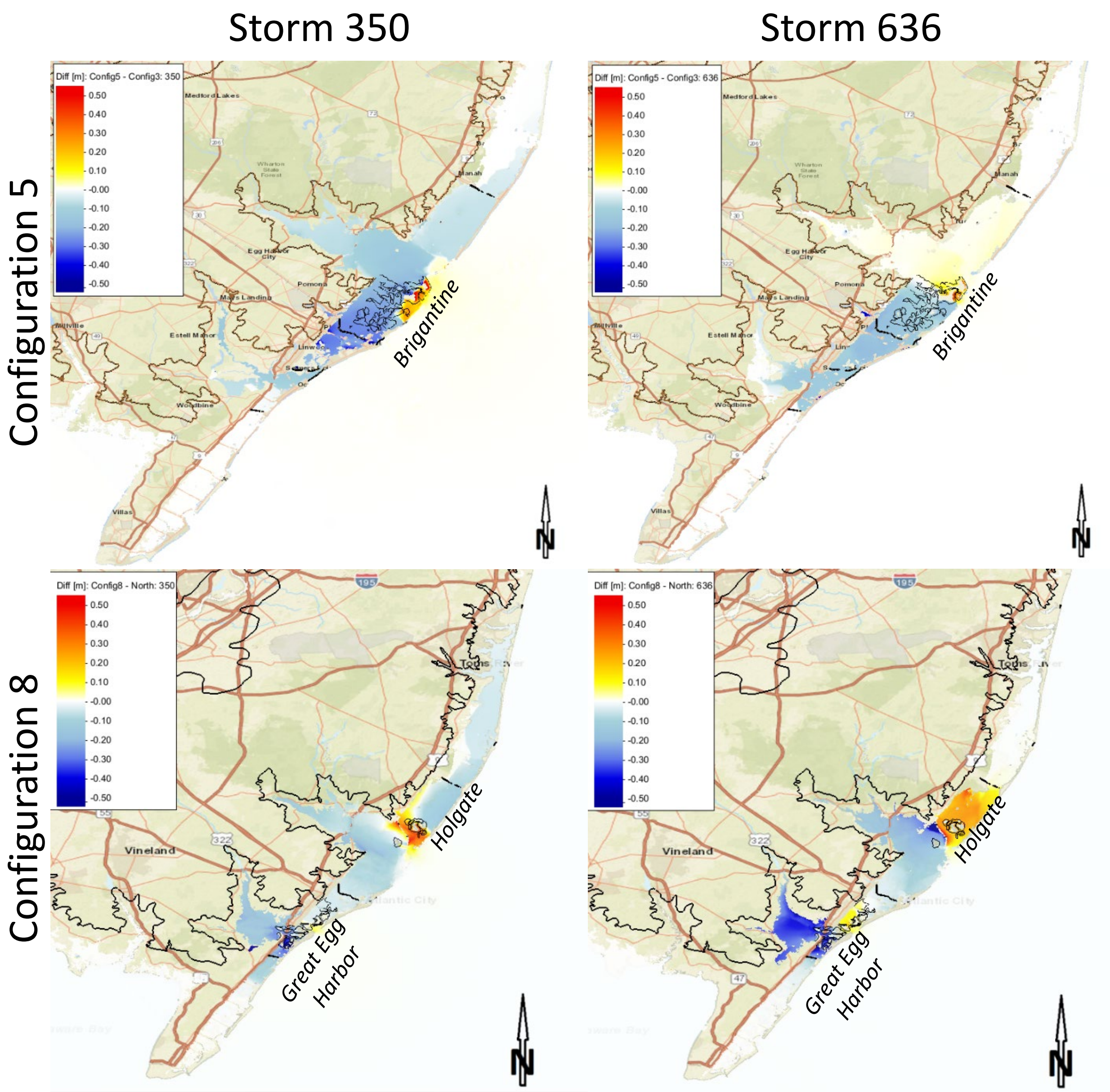

Figure 17 Difference in maximum water level elevation for storms 350 and 636 under modeling configuration 5 (Brigantine NNBF) and configuration 8 (Holgate and Great Egg Harbor NNBF) compared to the non-NNBF (structural protection only) configurations

In this report, the effects of the NNBF on back-bay water levels during storm events were compared to the water levels with only structural measures in place, to see if the NNBF could be used in combination with structural measures to improve outcomes (i.e., reduce back bay water levels and wave heights). Table 6 and Table 7 shows the peak water levels for selected save points for structural only configurations (indicated as ST) and structural and NNBF configurations (indicated as ST+NNBF). While the data in Table 2 are not directly comparable to the data is Tables 6 and 7 due to changes in the existing conditions modeled in CHS (Melby and Green, 2015) as well as the exclusion of wave influence in Table 6, the results indicate the majority of simulated water level reduction is attributable to the structural measures. The addition of NNBFs to the structural measures provides some further reductions or increases, depending on the pattern of water level response but those changes are lesser in magnitude than those induced by the structural measures. However, even in cases where NNBF may increase water levels relative to the structural-measure-only configuration, there is generally an improvement over the "do nothing" condition.

Table 6 Peak water level elevations due to surge for selected save points with structural measures only (ST, "North") and structural and NNBF (ST+NNBF, "Configuration 8") meshes.

AREA			HOLGATE						GREAT EGG HARBOR					
SAVE POINT ID			61		73		33		49		117		111	
CONFIG			ST	ST+ NNBF	ST	ST+ NNBF	ST	ST+ NNBF	ST	ST+ NNBF	ST	ST+ NNBF	ST	ST+ NNBF
STORM ID	99	WL elev. MSL (m)	1.85	1.69	2.48	2.40	2.34	2.32	3.11	3.15	2.73	2.85	2.72	2.32
	349		1.51	1.31	1.71	1.47	2.20	2.27	1.96	1.93	2.12	2.18	1.75	1.56
	350		1.51	1.39	1.97	2.03	2.30	2.34	2.23	2.19	1.93	2.02	2.16	1.72
	357		1.13	1.11	1.11	1.08	1.40	1.40	1.15	1.15	1.11	1.11	1.29	1.11
	433		1.75	1.76	1.99	1.79	3.69	3.89	2.21	2.21	3.12	3.48	2.41	2.03
	434		1.59	1.60	1.77	1.93	2.17	2.17	2.15	2.16	2.09	2.19	2.22	1.87
	469		1.35	1.45	1.48	1.67	2.02	2.06	1.67	1.68	2.03	2.14	2.12	1.75
	524		1.02	0.83	1.37	1.30	1.39	1.40	1.88	1.88	1.77	1.82	1.46	1.53
	636		1.05	1.26	1.49	1.73	1.63	1.60	1.43	1.43	1.70	1.78	2.04	1.68
	646		0.99	1.08	0.94	1.04	1.41	1.43	1.12	1.07	1.61	1.69	1.82	1.43

Table 7 Peak water level elevations due to surge and waves for selected save points with structural measures only (ST, "Configuration 3") and structural and NNBF (ST+NNBF, "Configuration 5") meshes.

AREA			BRIGANTINE			
SAVE POINT ID			59		50	
CONFIG			ST	ST+ NNBF	ST	ST+ NNBF
STORM ID	99	WL elev. MSL (m)	2.72	2.75	3.70	3.50
	349		2.23	2.59	2.13	1.89
	350		2.38	2.49	2.89	2.62
	357		1.70	1.62	1.67	1.54
	433		3.46	4.11	2.23	1.81
	434		2.66	2.54	3.08	2.84
	469		2.15	2.20	2.23	2.01
	524		0.94	1.02	1.28	1.14
	636		2.38	2.22	2.66	2.48
	646		1.72	1.72	1.51	1.36

Configuration 8 did not include the effects of the NNBF on waves. However, based on the STWAVE results from Configuration 5, the reduction or amplification of wave heights associated with the NNBF may significantly affect water level response and should be accounted for to capture the full effect of the NNBF.

3.2.1 Holgate

At the Holgate restored marsh location, storms, such as 99, 350, and 433 showed peak water level reductions north and south of the horizontal levees and islands and increased water levels in the vicinity of the island complex (Figure 18, top panel). However, storms 636, 646, 434, and 469 exhibited strong north to south winds; the horizontal levee and created islands blocked flow from exiting Little Egg Harbor resulting in an extensive area of increased maximum water levels north of the restored marsh (Figure 18, bottom panel). This pattern persisted for storms with north to south winds regardless of the magnitude of the water level responses.

For all storms including storm 636, the gates across the tidal creeks along the horizontal levee remained closed. However, the increases in water levels associated with the north to south wind direction may be moderated by leaving the horizontal levee gates open. The extent to which the gates can be used to affect water levels north of the Holgate NNBF is not clear. Further analysis would be required to balance water level response reductions in one area with increases in others. For instance storm 350 produced widespread reductions in water levels south of the levee in Great Bay and in parts of Little Egg Harbor and Manahawkin Bay north of Beach Haven while increasing water levels along Tuckerton Beach, the fringing wetlands along the landward shoreline of Little Egg Harbor and Manahawkin Bay, and in areas around Mystic Island. Additionally, several of the islands remain emergent at high water levels indicating that island elevations could potentially be lowered while still reducing storm water levels for storms that produced lower water level responses under storm conditions similar to storm 350, potentially moderating some of the adverse effects on water level response under some storm conditions.

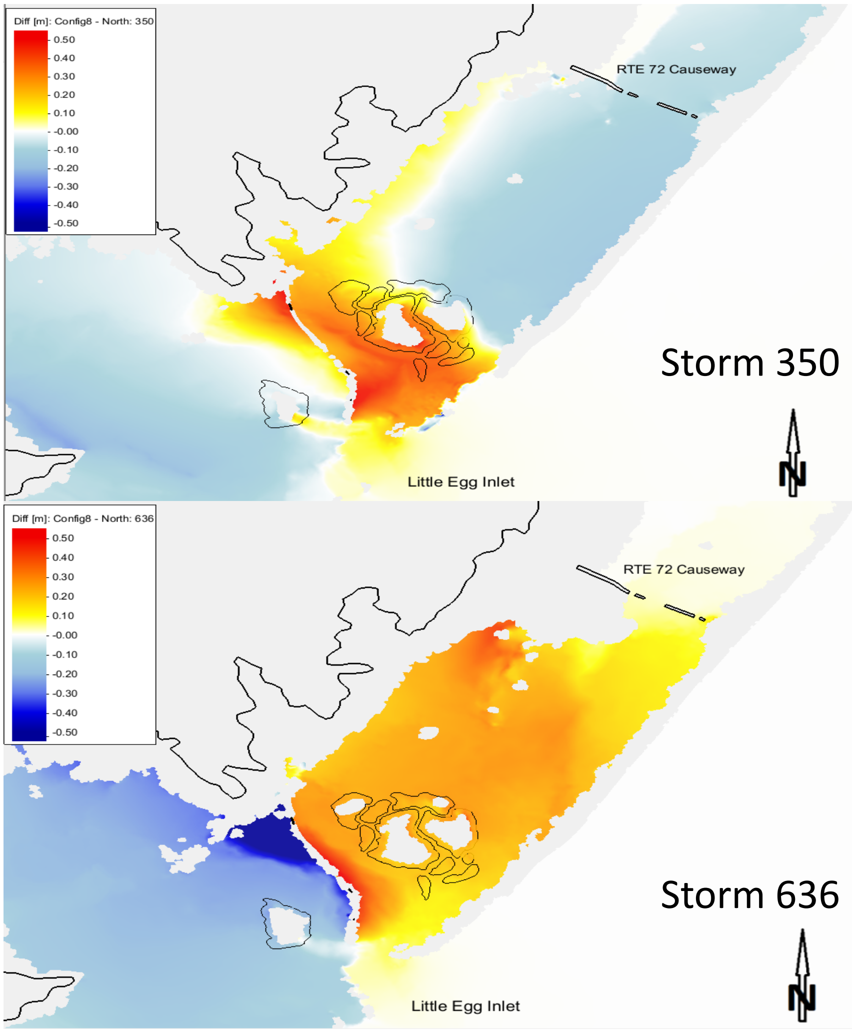

Figure 18 Peak water level differences due to Holgate Island and horizontal levee NNBF for storms 350 and 636

Like peak water levels, the effects of the NNBF on individual storm hydrographs was variable. Figure 19 shows the location of the three save points used in the Holgate region to show the effect of NNBFs on storm hydrograph characteristics such as duration and peak timing. Save point 33 was “in front of” the NNBF while points 61 and 73 were “behind” the NNBF, assuming Little Egg Inlet was the primary conduit for surge into Little Egg Harbor and Manahawkin Bay. For reference, the base condition peak water levels reported at points 61 and 73 in the Coastal Hazards System for these save points were 2.29 and 3.04 m, respectively, which indicates that the surge barriers further north at Manasquan and Barnegat Inlets already reduce water levels at these locations to 1.50 and 1.98 m, respectively. For this storm, the NNBF has a negligible effect on the water level hydrograph at point 33, there is a slight increase in water level and phase lead (more rapid increase in water level) at point 73 to 2.04 m, and decreased water level to 1.35 m that leads in phase at point 61.

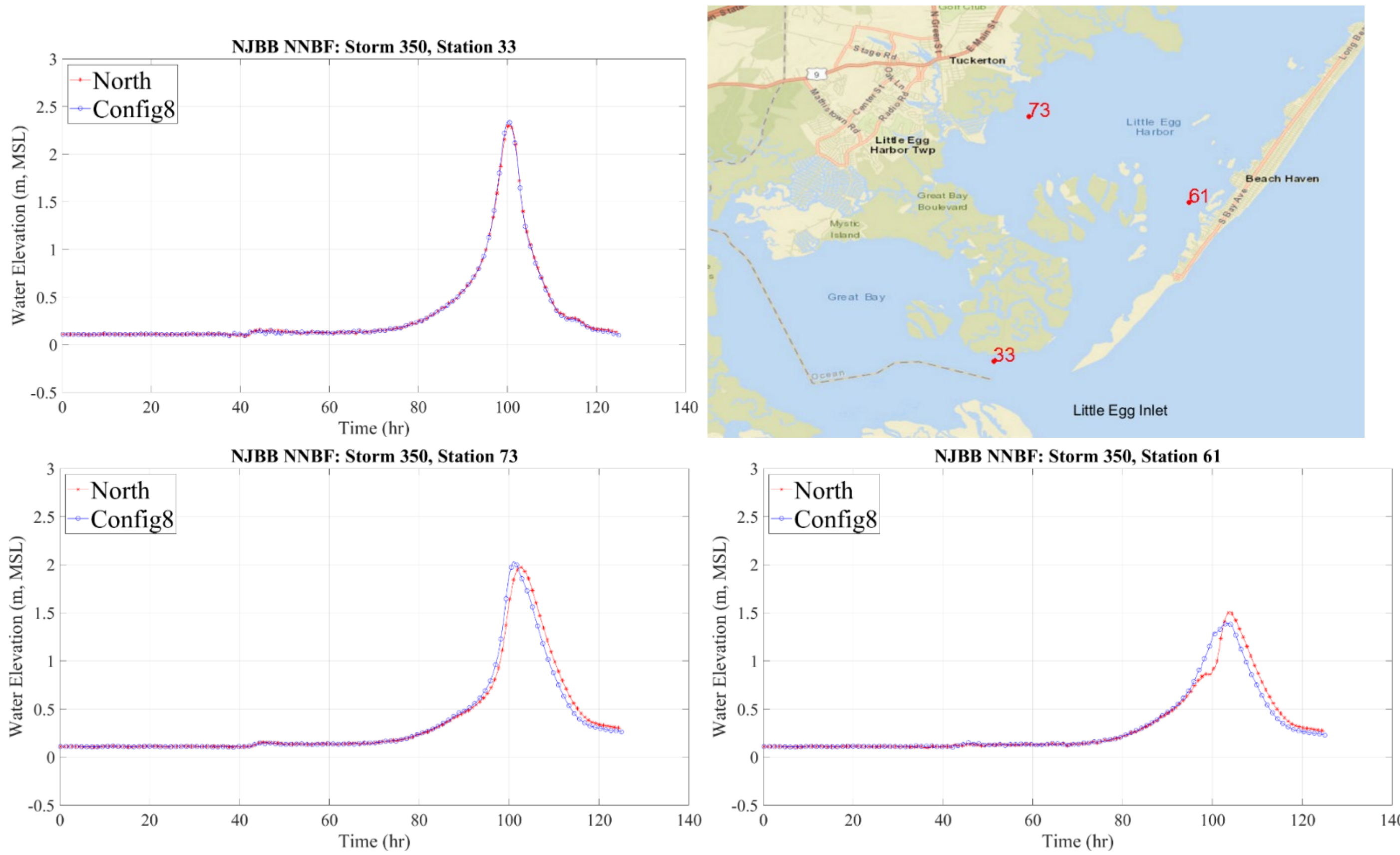

Figure 19 Holgate save points and examples of storm hydrograph effects for storm 350. The blue hydrograph represents the configuration with NNBF and structural measures and the red hydrograph represents the configuration with structural measures only

For storms 357 and 524, which of all simulated storms produced the lowest water level responses in this area with no CSRM measures in place, the effect of the NNBF on the hydrograph shape was inconsistent. In the case of storm 357, water levels increased more rapidly and initially fell more quickly with only a few centimeters reduction in peak water level elevation at station 73. However, for storm 524, water levels increased at about the same rate but water levels fell more quickly with the NNBF in place, decreasing the duration of potential flooding.

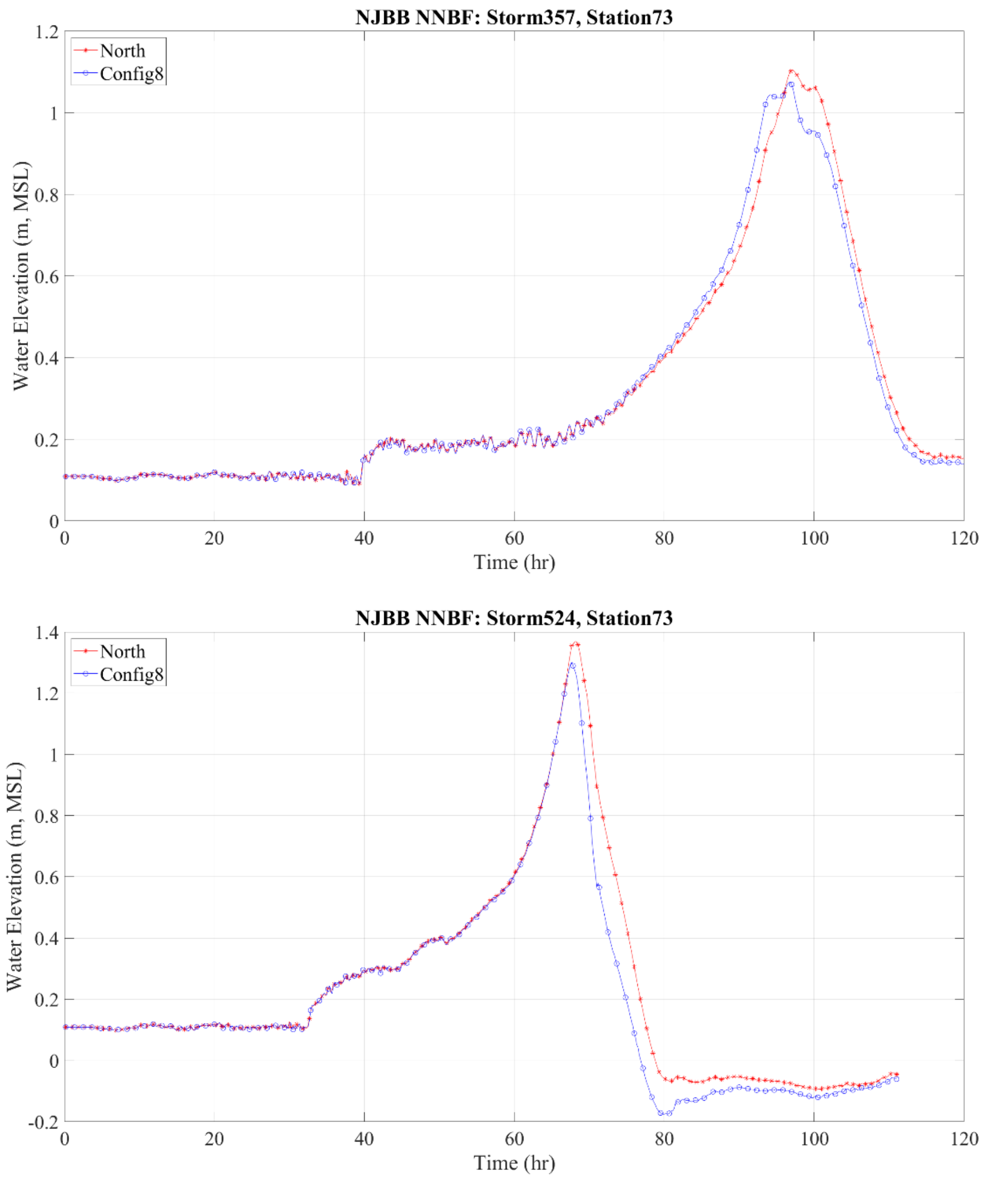

Figure 20 Holgate NNBF effects on hydrographs at save point 73 for two high annual exceedance probability storms. The blue hydrograph represents the configuration with NNBF and structural measures and the red hydrograph represents the configuration with structural measures only

3.2.2 Brigantine

The maximum water level envelope comparisons show that the Absecon Bay marshes provide an added reduction in water level due to surge and waves in Absecon Bay and Reed Bay on the order of 10 to 30 cm, depending on the characteristics of the simulated storm (Figure 15, Figure 21). The NNBFs serve to suppress flow into these bays with a corresponding slight increase in water level in Great Bay for storms with stronger winds from the north and fairly significant increased water levels (10-40 cm) near the low barrier island section/ocean fronting edge of the marsh when winds are from the east. The spatial extent of the reduced water levels extends beyond the marsh restoration area for a surprising great distance. Maximum water levels are reduced with the marshes restored as far north as Little Egg Harbor and southward into Lake Bay, Scull Bay, Great Egg Harbor Bay, and Peck Bay.

Of the ten storms that were simulated, six show partial to complete bay reductions of 10-30 cm in the southern bays, showing that the NNBF serve to suppress flow from the north and thus mitigates surge from entering the southern bays through the navigation channel opening at the Absecon Blvd causeway. Storm 350 shows a typical response of reduction in maximum water level in Absecon and Reed Bay extending northward into Great Bay and Little Egg Harbor and southward into Lake Bay, Scull Bay, Great Egg Harbor Bay, and Peck Bay and increased maximum water levels near the ocean fronting edge of the restored marsh region.

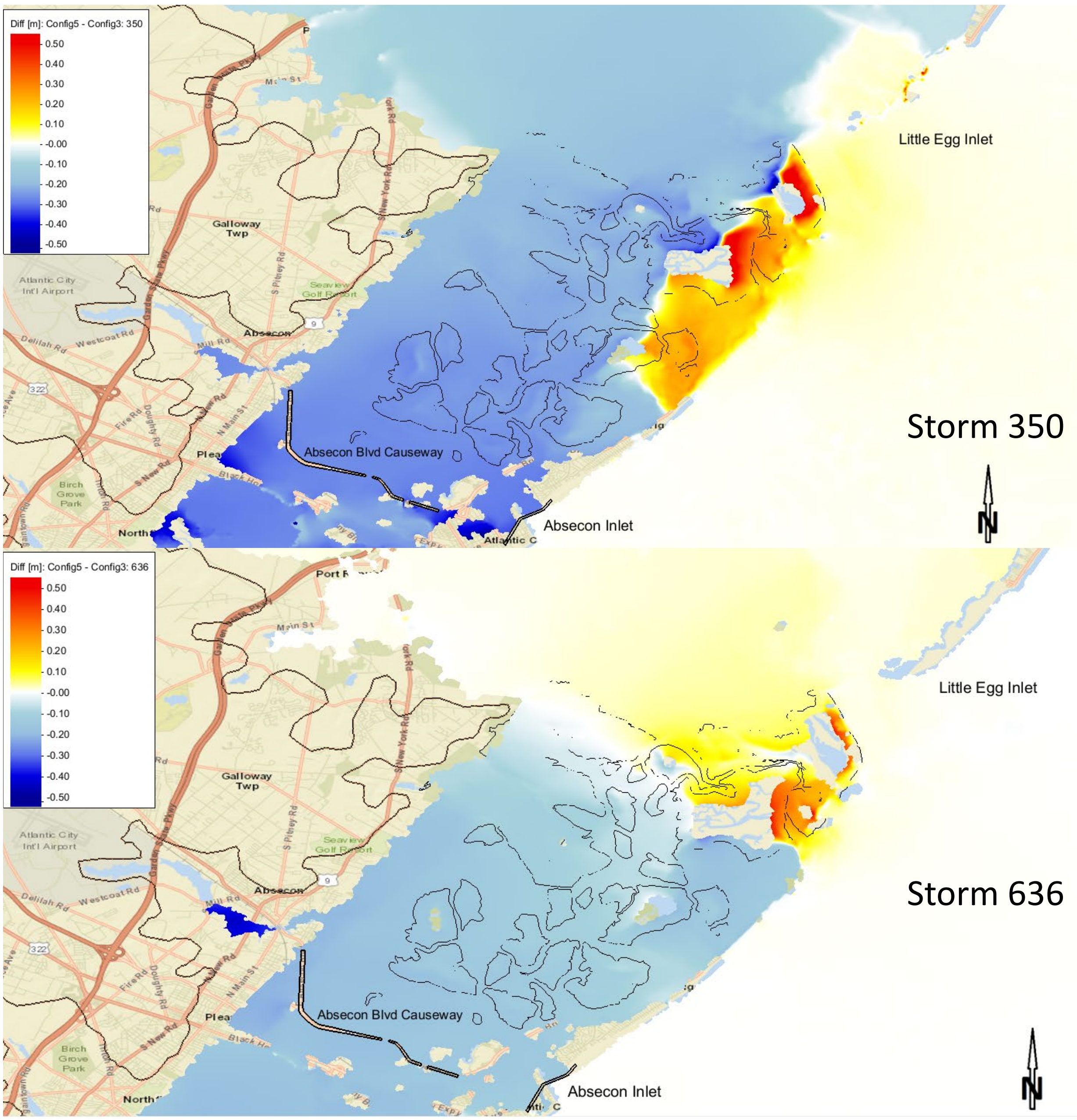

Figure 21 Peak water level differences due to Brigantine area NNBF for storms 350 and 636

The second typical response is demonstrated by the response to Storm 636 forcing, which results in increased water levels north of the restored marsh region and reductions extending from Reed Bay southward to Peck Bay, due to the predominant north to south wind direction and the suppression of flow to the south afforded by the restored marshes.

The NNBF typically reduced the duration of elevated water levels in Absecon Bay at save point 50 (Figure 22). The duration of water level above 2.6 m was reduced on the order of 10 hours for storm 350, which could reduce potential flooding in some surrounding areas, especially in cases where elevated water levels cause overtopping of existing or proposed floodwalls or levees.

The addition of the NNBFs reduced water levels in Absecon Bay at save point 50 during all storm conditions when compared with structural measures alone. The area of water level reduction for Storms 350 and 636 also extended south into Lake Bay to save point 49 on the other side of Absecon Boulevard causeway.

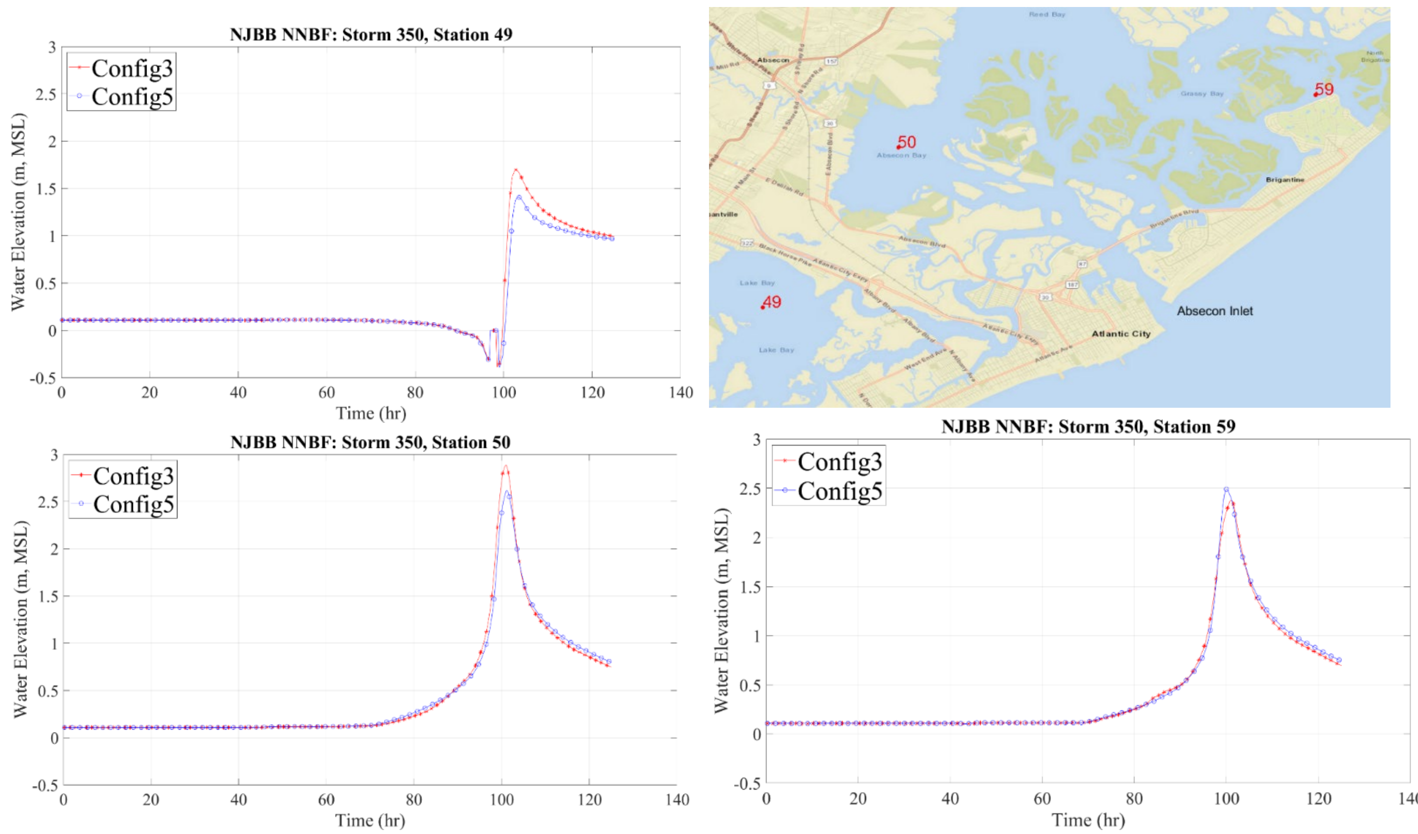

Figure 22 Brigantine save points and examples of storm hydrograph effects for storm 350. The blue hydrograph represents the configuration with NNBF and structural measures and the red hydrograph represents the configuration with structural measures only

3.2.3 Great Egg Harbor Inlet

The Great Egg Harbor Inlet response was significantly different in the areas north and south of the inlet (Figure 23). Generally the magnitude of water level reduction was the greatest for the areas south of the inlet and more modest for areas to the north. However, this was expected as the extent of existing wetland in the back bay limited the degree to which additional NNBFs could be expanded and the Longport-Somers Point causeway already serves to reduce storm surge propagating northward from Great Egg Harbor Inlet into the back bay.

With Great Egg Harbor Inlet open to surge propagation and the addition of fairly extensive (relative to the size of the bay) NNBFs in close proximity to the inlet entrance, maximum water levels actually increase in the Great Egg Harbor Inlet/restored marsh region and maximum water levels are in most cases reduced in Great Egg Harbor Bay "behind" the NNBF regions. This response is similar to closing Great Egg Harbor Inlet with a surge barrier, except that with the inlet open and NNBFs in place, maximum water levels increase in the portion of the bay closest to the inlet opening and adjacent to the barrier islands. Storms 99, 433, 434, 469, and 636 show this typical response in the Great Egg Harbor region.

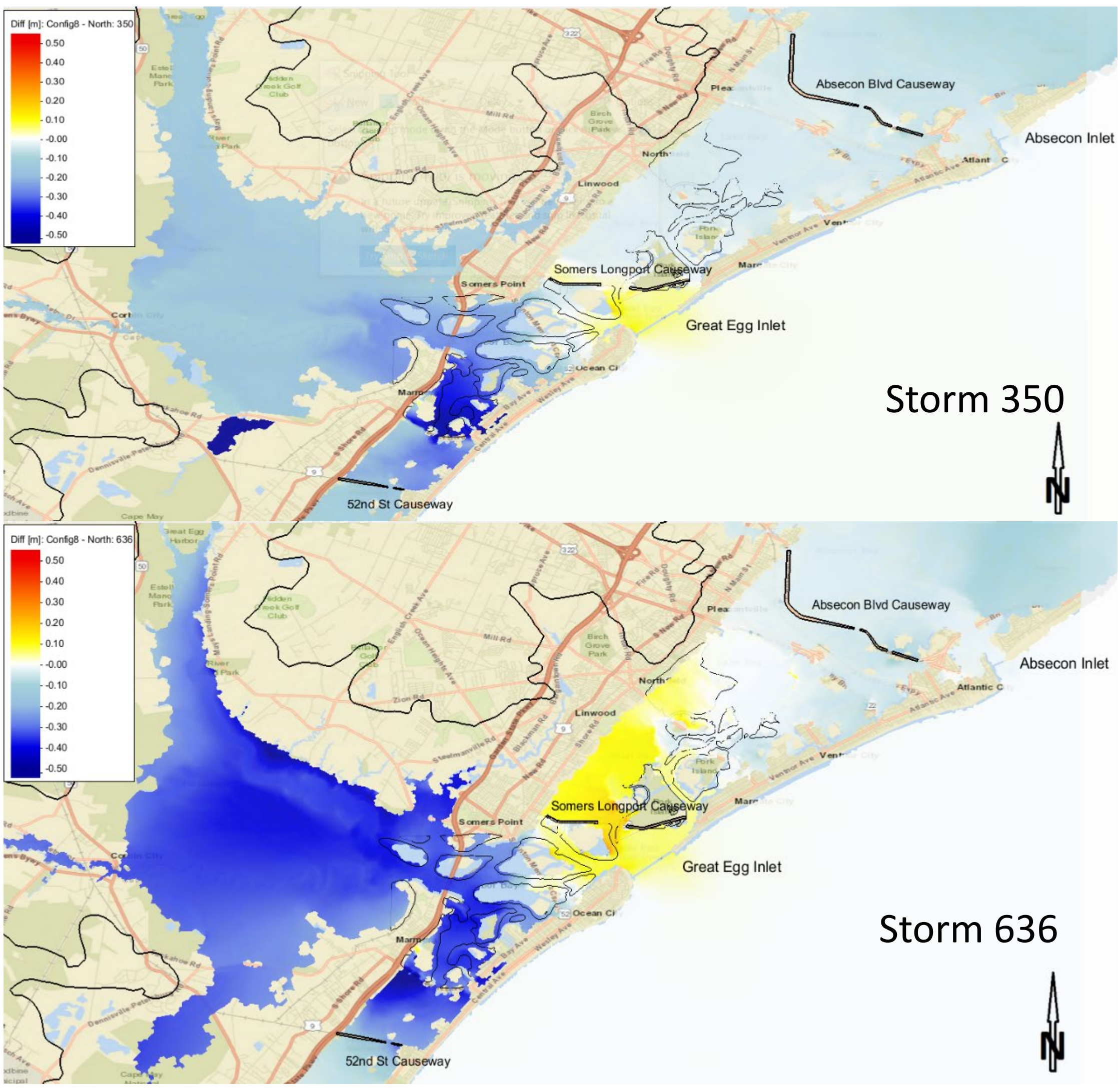

Figure 23 Peak water level differences due to Great Egg Harbor area NNBF for storms 350 and 636

Storm 636 also shows increases in water levels north of the inlet due to the blocking effect of the islands adjacent to the inlet, similar to the island blocking effect observed at Holgate. However, Figure 21 indicates the Brigantine area NNBF can also reduce water levels in Lake Bay and

Scull Bay during storm 636. Since Configuration 8 was run independently of Configuration 5, it is unclear what the combined effect of the proposed NNBF in the Brigantine and Great Egg Harbor areas would be and if the Brigantine NNBF could potentially reduce the adverse effects on water levels in the back bay areas north of Great Egg Harbor Inlet.

In the Great Egg Harbor area, storm hydrograph responses were fairly consistent for most storms regardless of the overall water level. Negligible differences in the water level hydrographs were observed at save point 49 with and without the NNBFs. Elevated water levels were consistently observed at save point 117 near the inlet with more significant water level increases occurring during storms with greater forward speed. The greatest water level decreases occurred to the south of the inlet at save point 111. Generally, peak water levels were reduced but the trailing end of the hydrograph was slightly prolonged since the islands decreased the rate at which water could leave the back bay.

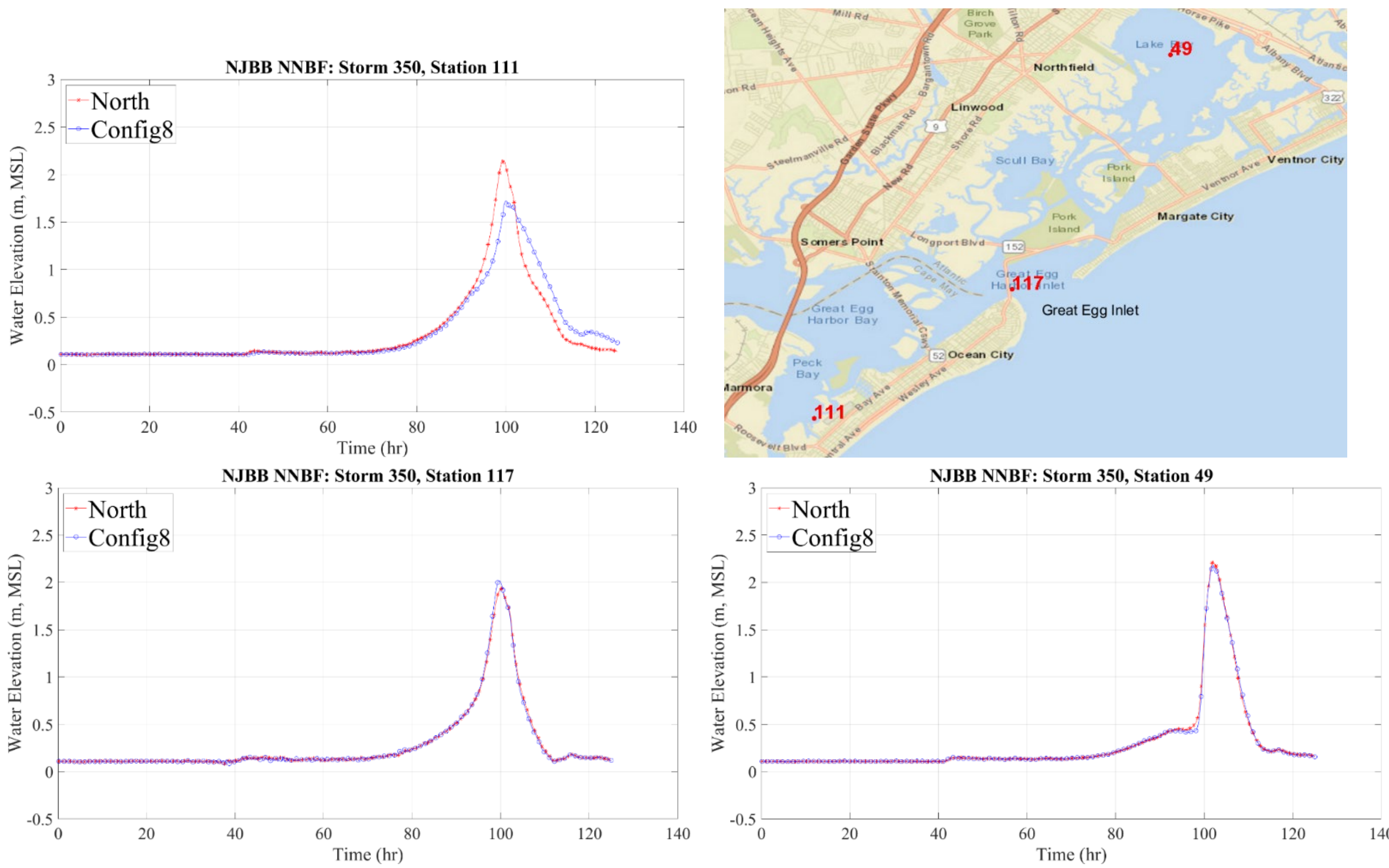

Figure 24 Great Egg Harbor save points and examples of storm hydrograph effects for storm 350. The blue hydrograph represents the configuration with NNBF and structural measures and the red hydrograph represents the configuration with structural measures only

NNBF options in the Great Egg Harbor area may have some dependency on the NNBF proposed in the Brigantine area and the effects should be investigated together. Additional modeling should consider the potential effects of the NNBF in the southern portion of the Great Egg

Harbor area on flows from Great Egg Harbor River to ensure that the NNBFs do not exacerbate potential riverine flooding upstream.

3.3 STWAVE results

From the results of the child domain, plots of the maximum significant wave height for each simulation, as well as, time series plots from the 5 identified stations are provided in Appendix B. For discussion, the plots and results from Storms 350 and 636 will be included here.

Figure 25 and Figure 26 show a "zoomed-in" depiction of the wave heights around the project designs. Shown in Figure 25 are the maximum significant wave heights for storm 350 for Configurations 3 and 5. The maximum observed significant wave height values were greater than 20 ft., with most of the wave energy breaking along the open coastline, indicating the waves generated around the NNBF islands, which are sheltered behind the barrier islands, is due to local wind growth. Storm 636, shown in Figure 26, the maximum significant wave height values were also greater than 20 ft., and similar to what was observed in storm 350, the wave energy appears to break along the coastline, indicating local generation in the areas of the NNBF.

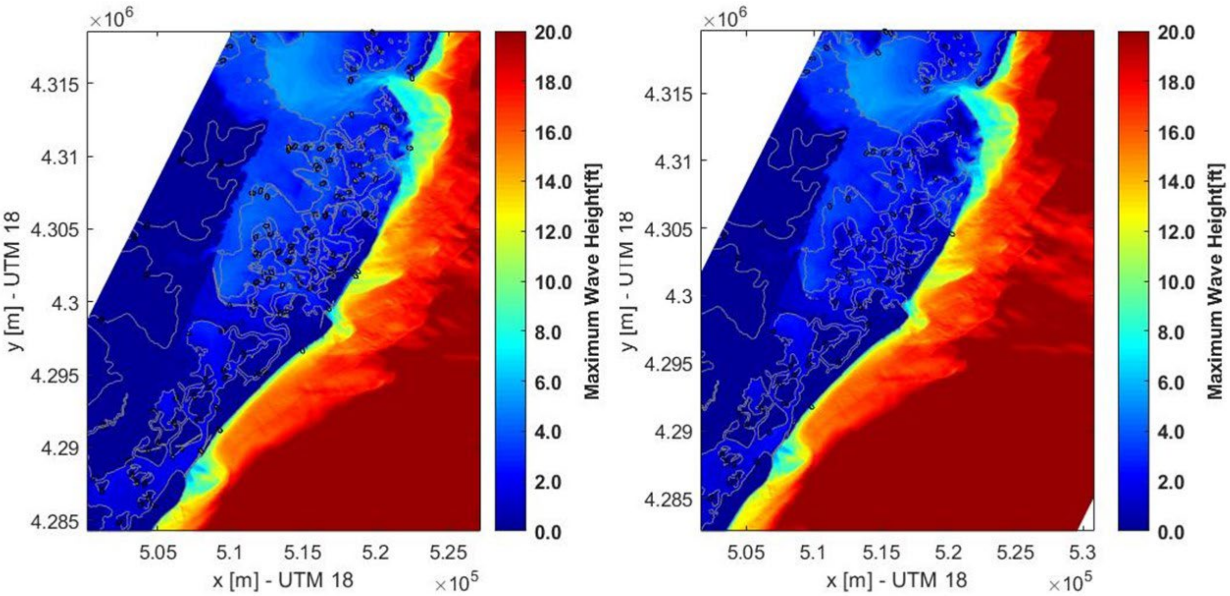

Figure 25 Max Wave Height (ft) of Storm 350 for Configuration 3 (left) and Configuration 5 (right).

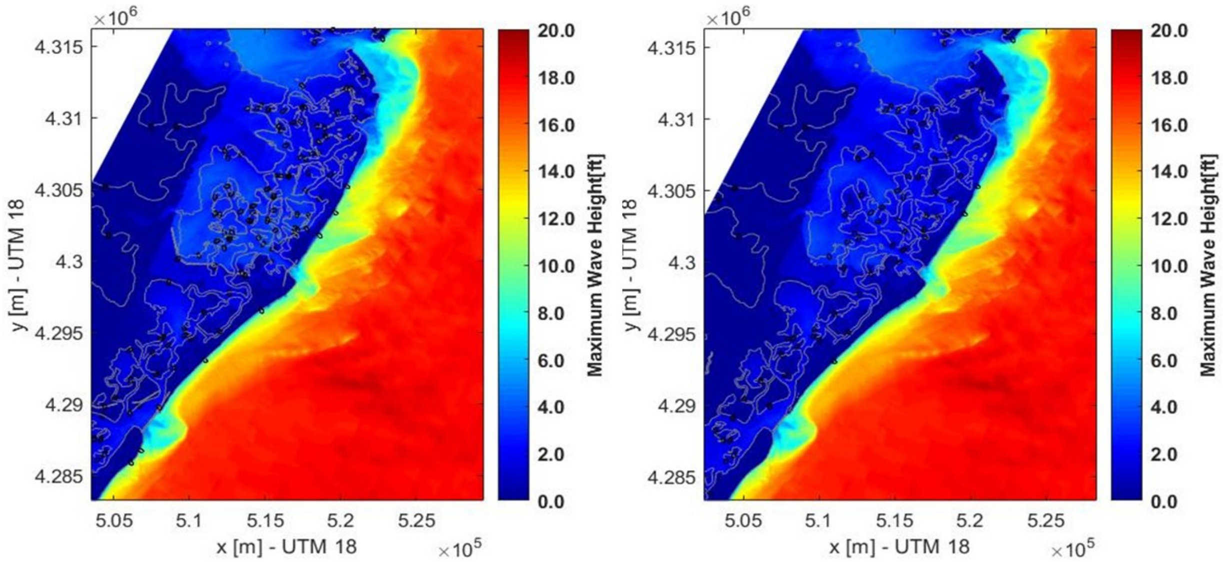

Figure 26 Max Wave Height (ft) of Storm 636 for Configuration 3 (left) and Configuration 5 (right).

Differences are observed in the maximum wave heights between Configuration 3 and 5. For storm 350, shown in Figure 27, a reduction of 3.5 ft. is shown due to the presence of the NNBF. Slight increases of ~1 ft. are observed behind the storm surge barrier at Little Egg and Brigantine Inlets, and along the perimeter of a few of the NNBF islands. For storm 636, shown in Figure 28, reductions of 2-3 feet are shown in the areas where the implemented NNBF islands are present. Some slight, 1 ft. or fewer, increases are observed around the perimeter of a few of the NNBF

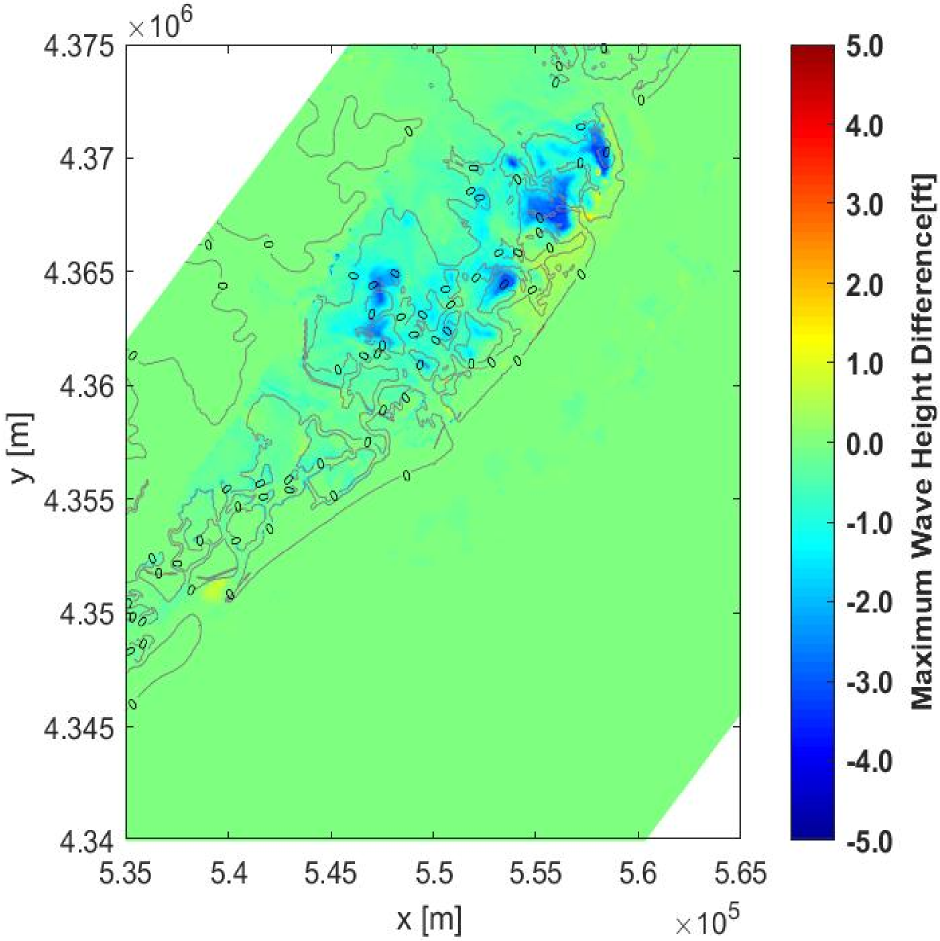

Figure 27 Maximum wave height difference for storm 350 between Configuration 3 and Configuration 5. Cool tones indicate reductions in wave height due to NNBFs and warmer tones indicate wave height increases due to NNBFs.

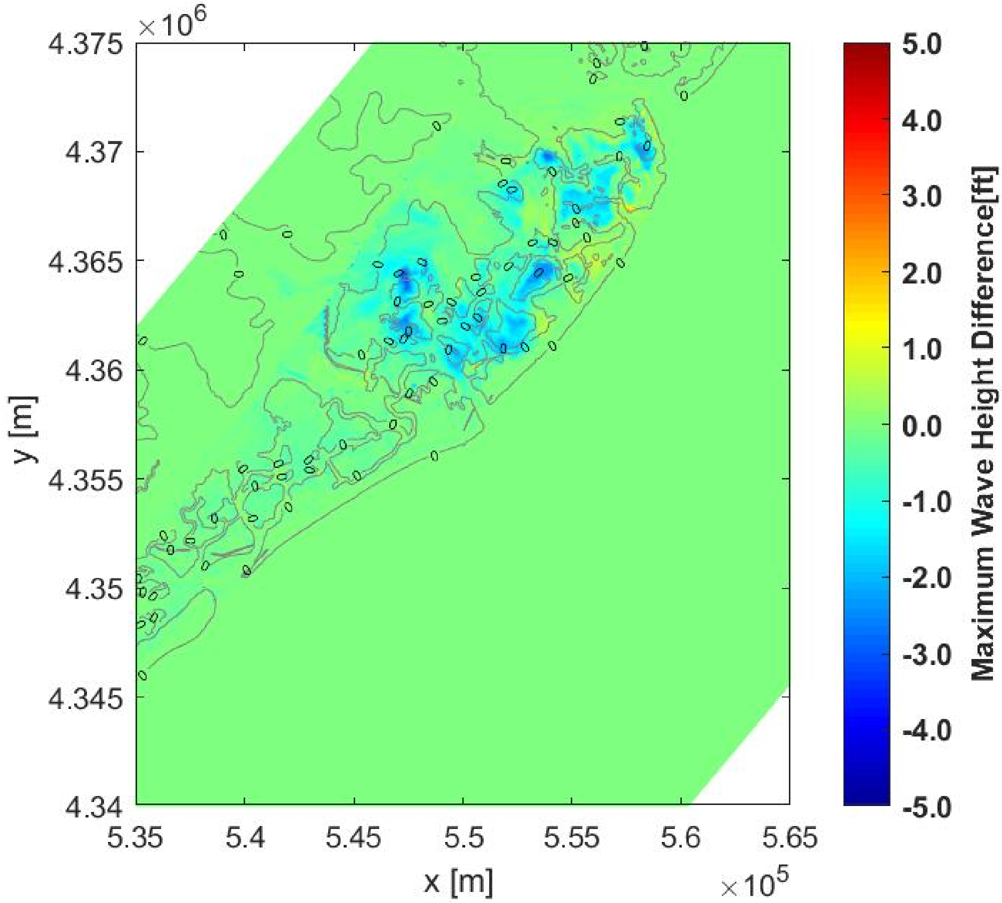

Figure 28 Maximum wave height difference for storm 636 between Configuration 3 and Configuration 5. Cool tones indicate reductions in wave height due to NNBFs and warmer tones indicate wave height increases due to NNBFs.

The time series plots show the growth and decay of wave heights through the simulated storm event, at each of the selected locations (Figure 29 and Figure 30). For storm 350, stations 49, 111, and 117 show very little difference in significant wave height between the two configurations. However, station 50 shows decreases in the significant wave height for configuration 5 of approximately 0.3m during the peak of the storm and station 59 shows a consistent decrease in significant wave height throughout the entire storm of roughly 0.05m. For storm 636, stations 49, 50 and 111 show very slight decreases in wave height during the peak of the storm between the two configurations, and station 59 shows decreases in wave height of approximately 0.3m during the peak and decay of the storm. While, station 117 shows a slight increase (~0.1m) in the wave height during the growth and peak of the storm for configuration 5.

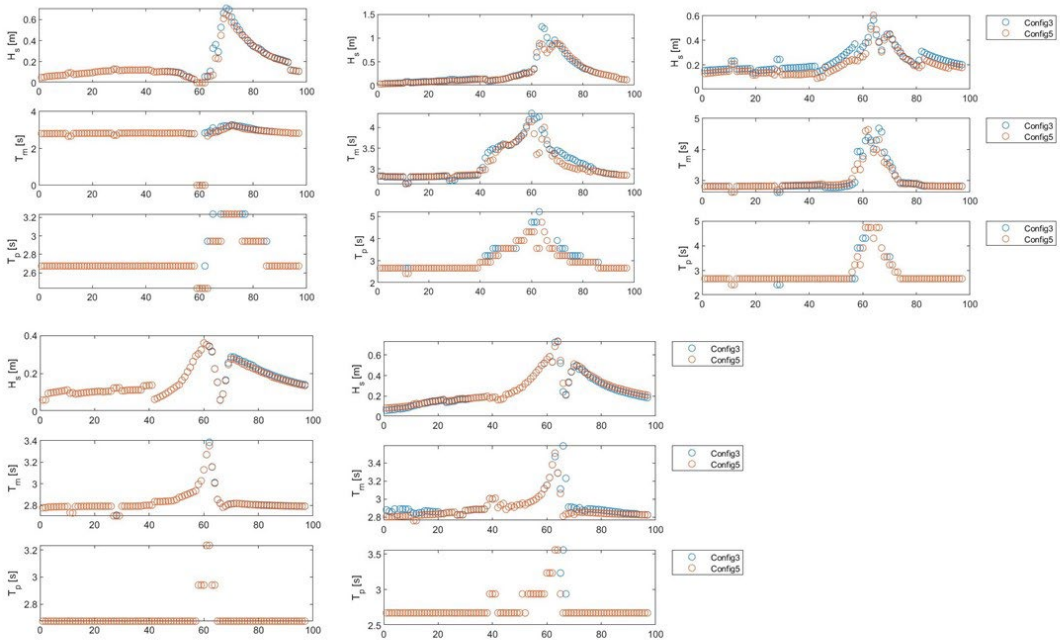

Figure 29 Time series of significant wave height, peak period, and mean period for Storm 350. Top row, from left to right is station 49, 50, 59. Bottom row, from left to right is station 111, 117. Configuration 3 is shown in blue, Configuration 5 in orange.

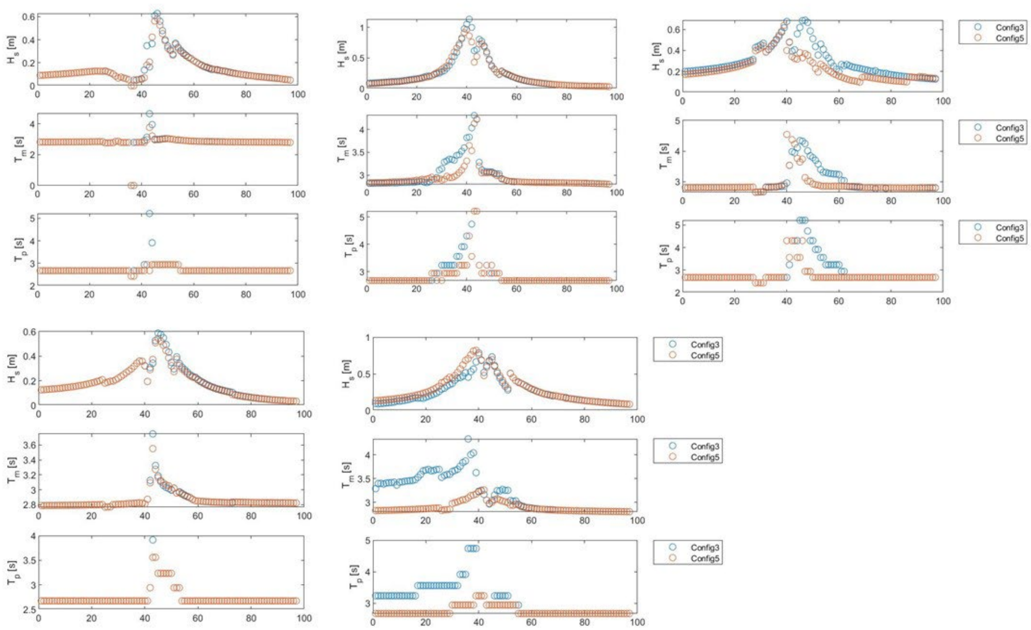

Figure 30 Time series of significant wave height, peak period, and mean period for Storm 636. Top row, from left to right is station 49, 50, 59. Bottom row, from left to right is station 111, 117. Configuration 3 is shown in blue, Configuration 5 in orange.

4 Discussion

Storm characteristics, particularly wind direction and overall storm intensity, strongly influenced how water levels responded to the implementation of the proposed NNBF. In some cases, the addition of NNBFs increased water levels relative to the configurations that included only structural measures, especially in situations that created strong north to south winds. For the storms that exhibited the greatest water level response in the NJBB area (particularly storms 0099 and 0434 with water level elevations greater than 3 m MSL without CSRM measures in place for almost all save points considered), most of the proposed NNBFs did little to affect water levels in most areas. However, even under relatively high water levels (around 3 m MSL), wave heights were reduced by approximately 0.3 m near storm peaks in the Brigantine area. The impact of the NNBF on wave heights was not assessed in the Holgate and Great Egg Harbor area since STWAVE was not run for Configuration 8 but if potential wave attenuation is factored in, the NNBFs in those areas may result in more pronounced reductions in water levels for some parts of the model domain.

For storms with less extreme water level responses, the proposed NNBFs reduced water levels from the base configurations that only included simulated structural measures in many locations. Depending on operation rules for proposed surge barriers, the proposed NNBFs could possibly provide enough reduction in water levels during higher storm response events to permit surge barriers to be left open during some less intense storms, reducing operations costs and minimizing any potential adverse environmental impacts associated with barrier closure. Additional analysis would be required to determine the storm conditions that would permit proposed barriers to be left open.

As mentioned previously, there are some areas adjacent to NNBF that could experience increases in water levels, especially during storms with north to south wind direction; these increases are relatively localized along the leading edge of the features in some areas such as Brigantine and widespread in others such as during storm 0636 where elevated water levels in Little Egg Harbor Bay and the southern portion of Manahawkin Bay are on the order of ~30 cm. Careful design can minimize these effects in some cases. For instance, the NNBF can be designed so unavoidable local regions of water level increase to fall in unpopulated and undeveloped or minimally developed areas such as wildlife refuges or golf courses. If NNBFs are designed to provide benefits for storm events with higher water levels, the elevation can be constrained to prevent extreme water level increases over large areas. For the Holgate area, the horizontal levee could be redesigned, removed, or the proposed gates blocking tidal creeks along the horizontal levee could be left open in the event of sustained north to south winds. Open gates would potentially reduce water levels north of the levee caused by flow blocking. However, the impact of any of these changes would need additional analysis to determine the magnitude of the effect during different storm conditions.

While water level change attributable to NNBF for most of the NJBB domain was relatively modest (on the order of 10-30 with some areas up to 50 cm), for many storms, the reductions in water levels occurred over a several-hour time span (~10 hours for storm 350 at save point 50 in Absecon Bay, for example). In areas protected by other structural measures such as levees or flood walls, the duration of the reduction of peak water levels can lead to reductions in flooding due to overtopping of structures as well as the load stress by shortening the duration of the highest water levels. The degree to which this water level reduction produces CSRM benefits will vary with the design of the comprehensive system of structural, NNBF, and nonstructural measures put into place. While NNBF alone may not provide the full scale of CSRM benefits, when combined with target structural and nonstructural measures, economic benefits may emerge such as reducing the required heights of structural measures such as flood walls and levees, reduced operation of surge barriers for lower magnitude storm events, improving the safety of residents not required to evacuate through reduced risk of overtopping as well as reduced risk of structural failure by reducing total loading on structural measures in the back bay environment. To quantify these potential benefits, the results provided here should be used to design additional perimeter structures and combined with economic models or simple stage-damage curves to determine how NNBF can be combined with additional structural measures to reduce economic damages and improve life safety.

5 Recommendations and next steps

The results from this initial modeling study show NNBF can provide some benefit by reducing coastal storm risk in the New Jersey back bays in some areas. The degree to which the simulated features can provide reductions in water level depends strongly on the location of concern relative to the NNBF location and the storm characteristics. While no configuration showed that the addition of the proposed NNBF measures were able to reduce water levels enough to eliminate the need for additional structural measures such as perimeter floodwalls or levees, the results do indicate that NNBF paired with some additional structural measures may show promise in reducing operation frequency of surge barriers or reducing the required height of cross-bay closures and perimeter flood walls and levees, which may be desirable from an aesthetic standpoint.

Wave modeling results in the Brigantine area show that the simulated NNBF measures were particularly effective at reducing wave heights well into the back bay region despite increasing wave heights along the fronting edge of the island features. The design of these features can be altered by changing the elevation and location of the features to minimize the wave amplification caused by these features or localize the region of amplification to undeveloped regions of the back bay.

Future work should consider reconfiguration of NNBF measures at Holgate and Great Egg Harbor to minimize adverse effects on water level during certain storm conditions. Performing coupled ADCIRC and STWAVE simulations for these areas may indicate additional benefits of the NNBFs in this region. At Holgate, the proposed horizontal levee uses gates where major tidal creeks cross Great Bay Boulevard. Additional modeling of storms such as storm 636 with strong north to south winds should be considered to determine if adverse effects on water levels north of the NNBF islands and the horizontal levee can be reduced by keeping the gates open or if the horizontal levee should be re-designed or eliminated to prevent flooding caused by the presence of the levee and islands. The widespread reductions in water levels throughout some parts of Little Egg Harbor and Manahawkin Bay during certain storm conditions show the NNBF islands and the horizontal levee are effective at reducing surge entering through Little Egg Inlet but the effect of the islands or the horizontal levee alone was not assessed. Likewise, it is unclear if the islands or the horizontal levee is the primary driver of the widespread increases in water levels associated with storm conditions that produce north to south winds. Further analysis is required to determine what types of NNBF could potentially produce CSRM benefits in that area.

At Great Egg Harbor, like Brigantine, the features as proposed cause some surge amplification near the inlet mouth. Reconfiguration and changes in the height of the features may allow this unavoidable amplification to be localized to well-protected or undeveloped areas whereas in the current configuration, the amplification occurs close to the well-developed inlet. Examination of the NNBF in association with structural measures in this region is especially critical given the density of development in the inlet area.

Final decisions on the utility of the NNBF measures implemented in this report should be informed by economic models to determine if the maximum water level reduction and duration of reduction in these regions may translate to economic benefits either directly through reduction in damages or indirectly through reduction in height of perimeter structural measures or reduced operations of surge barriers. While NNBF measures as modeled in this report are likely not cost-effective given the volume of sediment required, further work should examine the efficacy of the measures if the elevation and/or extent of the features are reduced. Given water level changes attributable to NNBFs were strongly controlled by storm characteristics rather than baseline water level alone, the effect of “medium” or “large” sized NNBFs should be examined to determine if sediment volumes required to construct the features could be reduced while still reducing water levels in critical areas under a subset of storm conditions. Since 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. Additionally, the feasibility of utilizing navigational dredged material to construct any NNBFs as part of routine maintenance should be examined as a cost-savings measure, utilizing the Seven Mile Island Innovation Lab as a testbed to determine how to cost-effectively utilize dredged material in this manner. Likewise, additional modeling should examine the benefits of existing wetland and back bay islands, especially under future conditions that factor in the effects of sea level rise, to determine the value of preserving and restoring the existing wetlands in the system similar to the analysis conducted by The Nature Conservancy (Narayan et al., 2017). The current modeling results alone are not sufficient to exclude any type of NNBF from consideration. Further analysis with the PDT should provide additional information on the potential CSRM benefits.

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Appendix A: ADCIRC auxiliary modeling results

Mesh changes implemented in ADCIRC

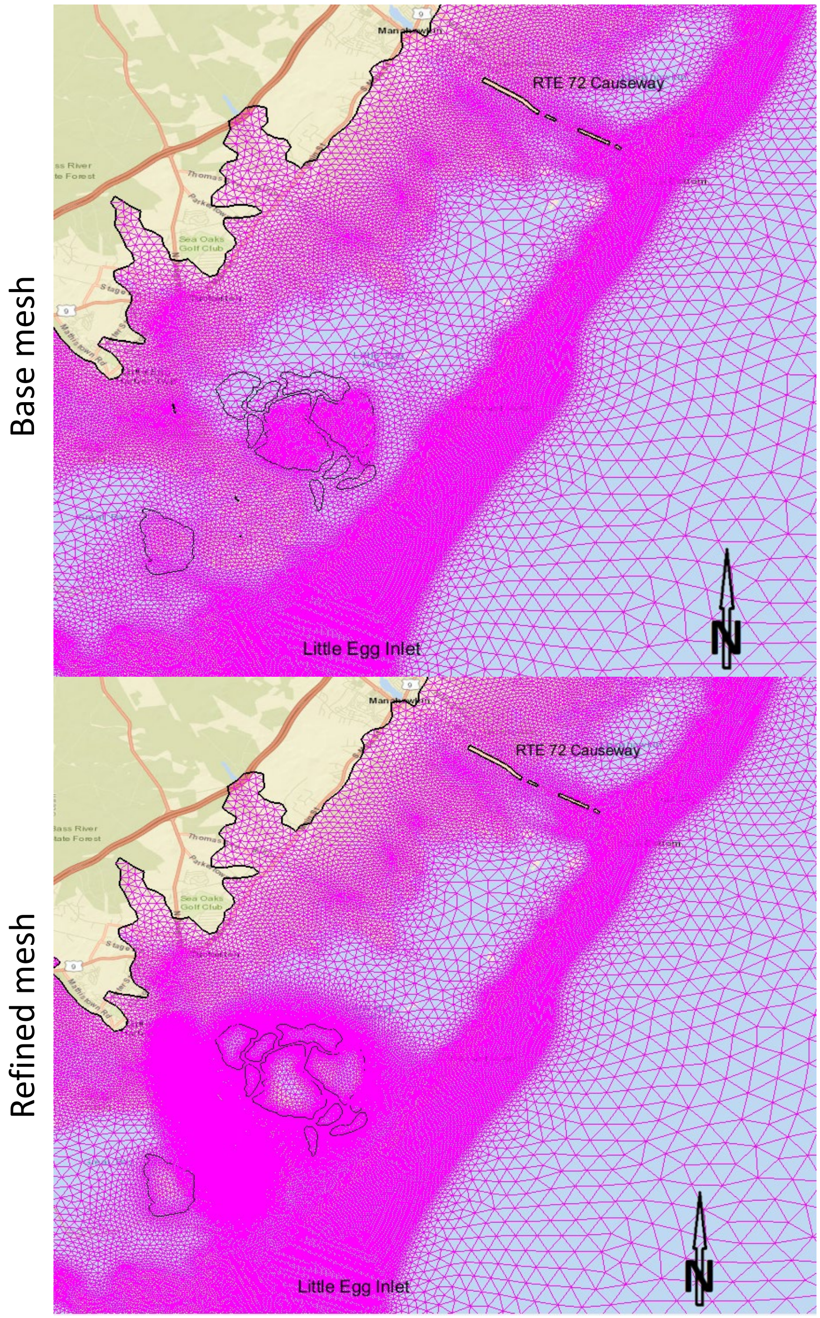

Figure 31 Change in mesh resolution in the Holgate area to accommodate the NNBF

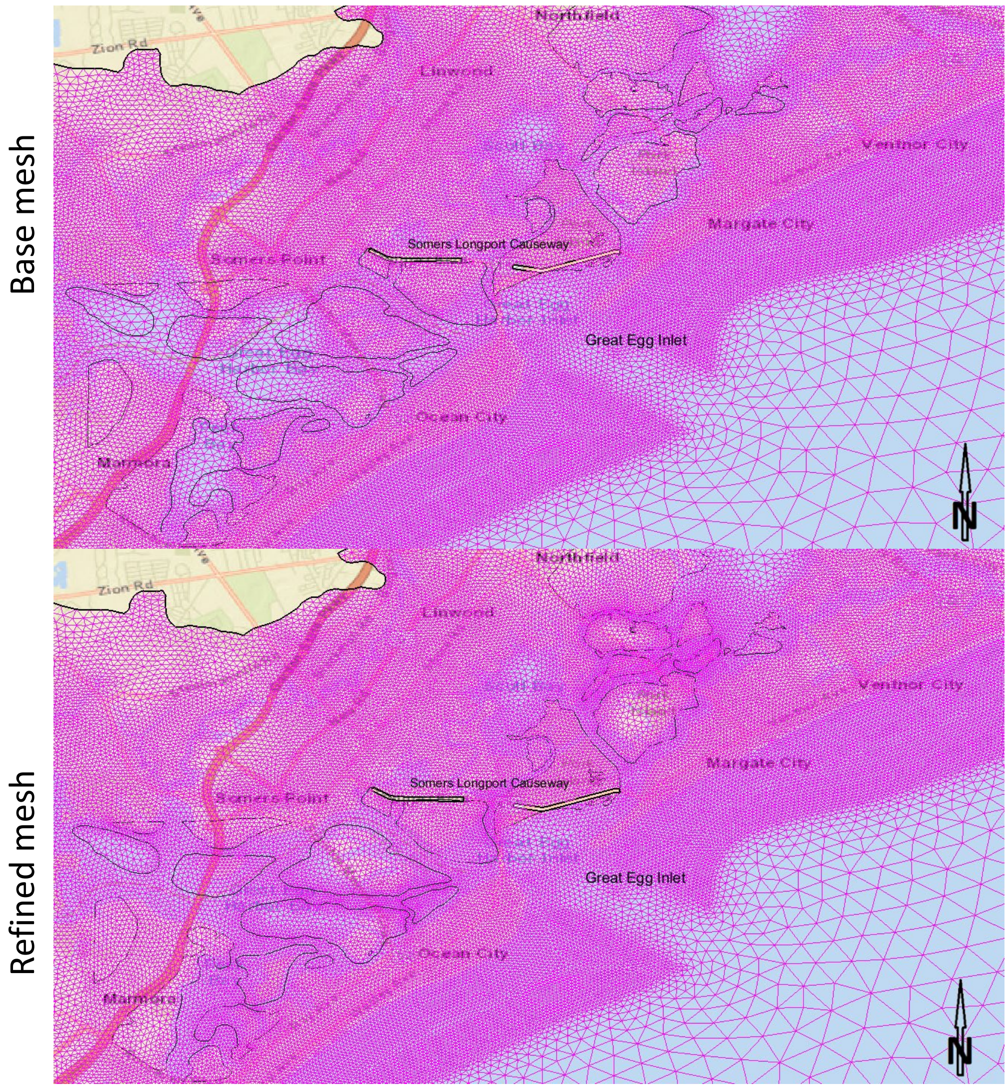

Figure 32 Change in mesh resolution in the Great Egg Harbor area to accommodate the NNBF

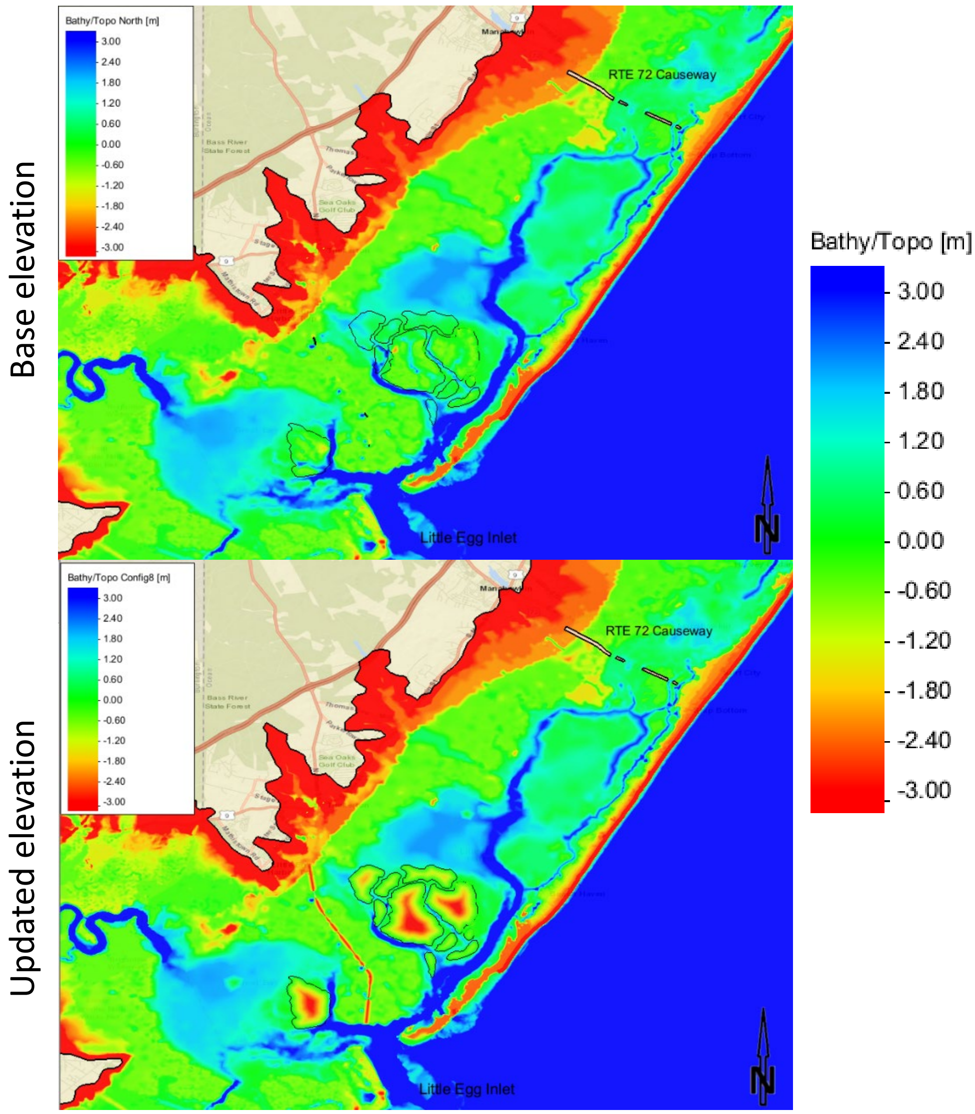

Figure 33 Updated ADCIRC elevation for Holgate area

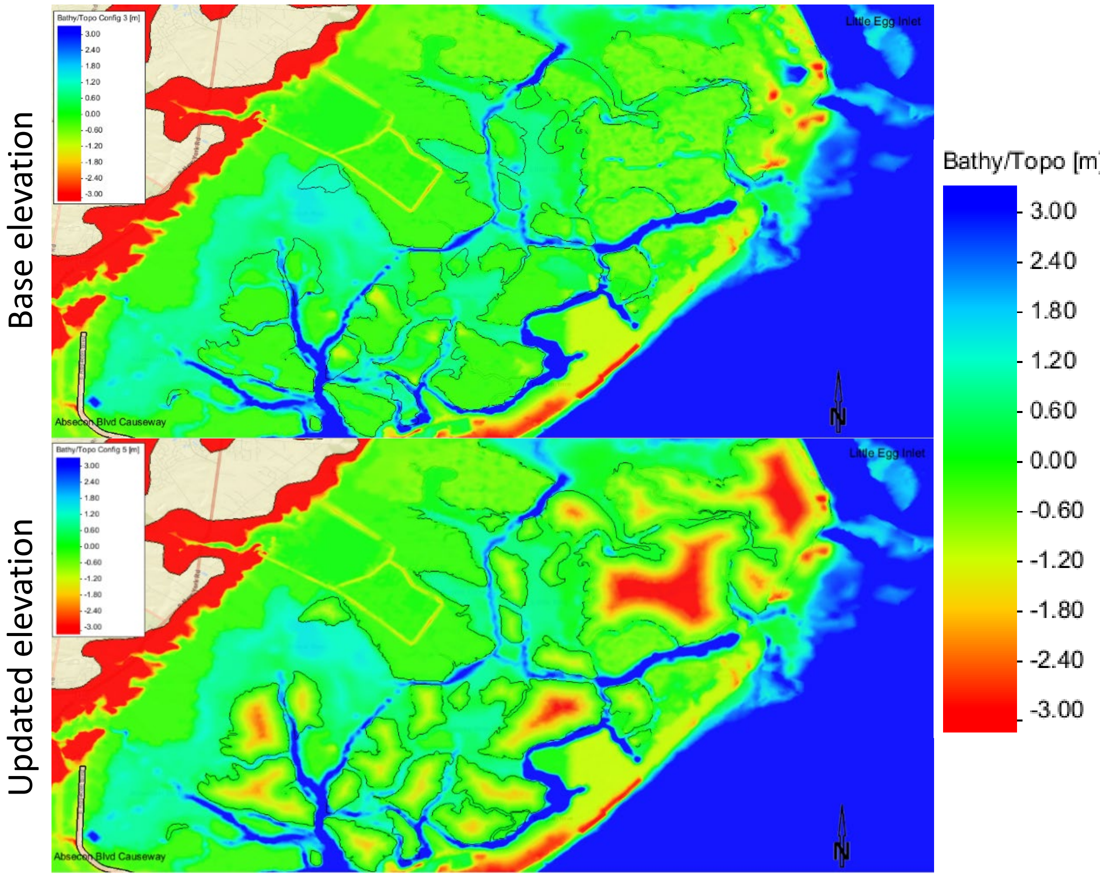

Figure 34 Updated ADCIRC elevation for Brigantine area

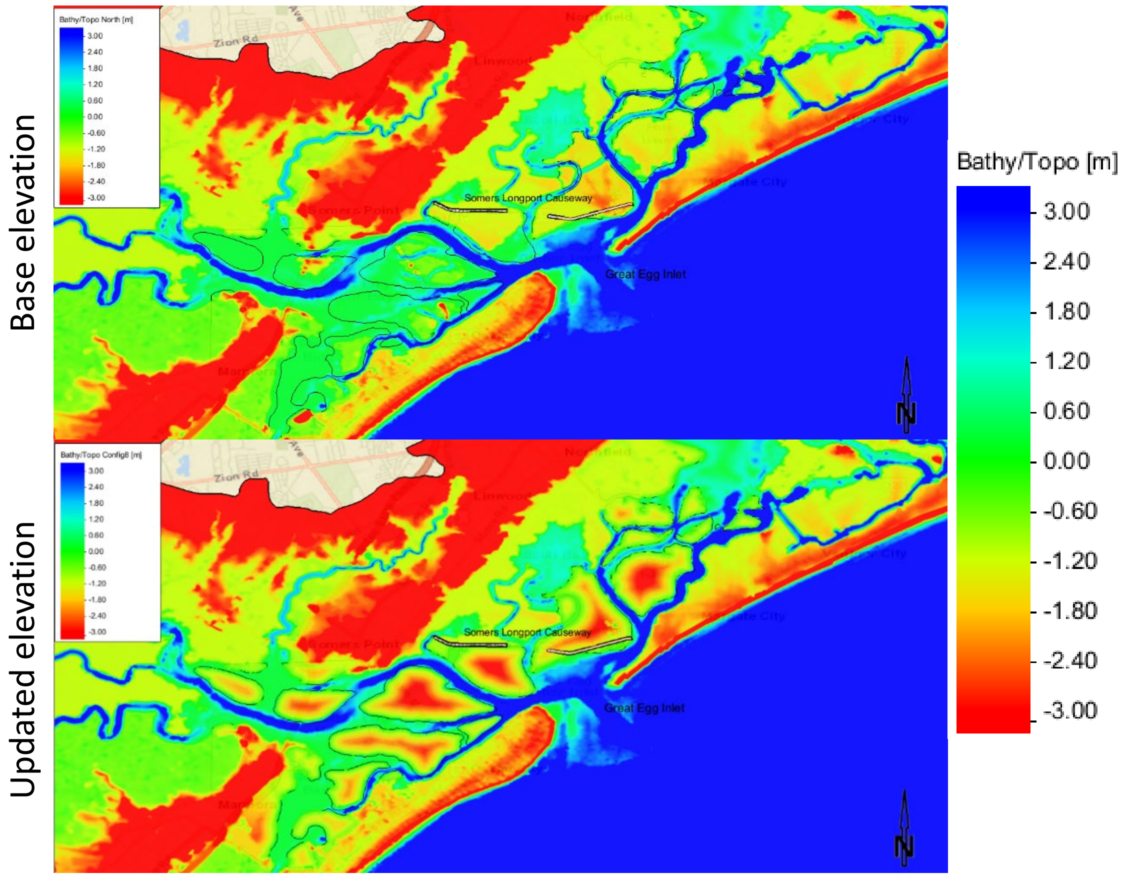

Figure 35 Updated ADCIRC elevation for Great Egg Harbor area

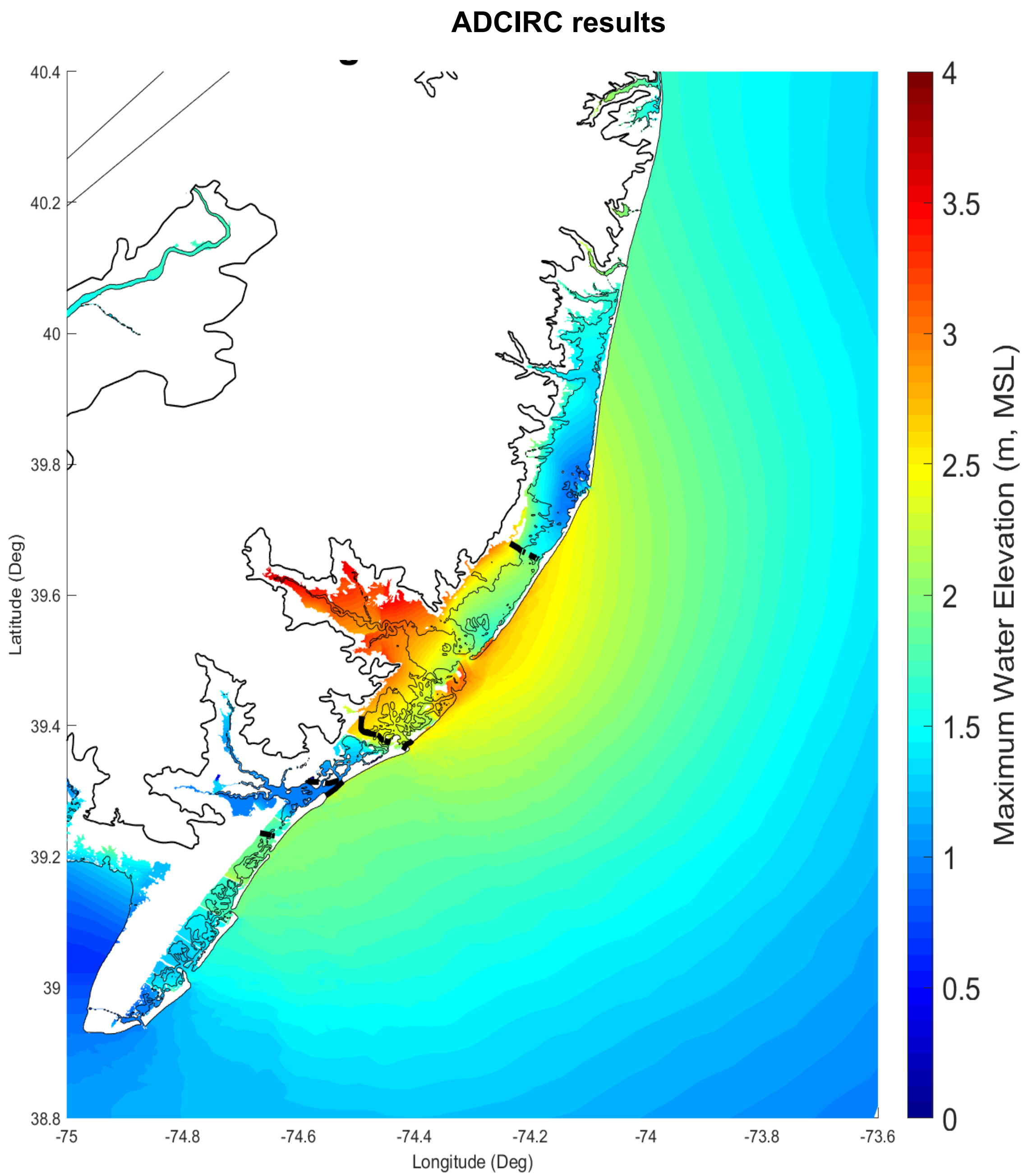

Figure 36 Maximum surge envelope for Storm 350 Configuration 5 (Brigantine area NNBF)

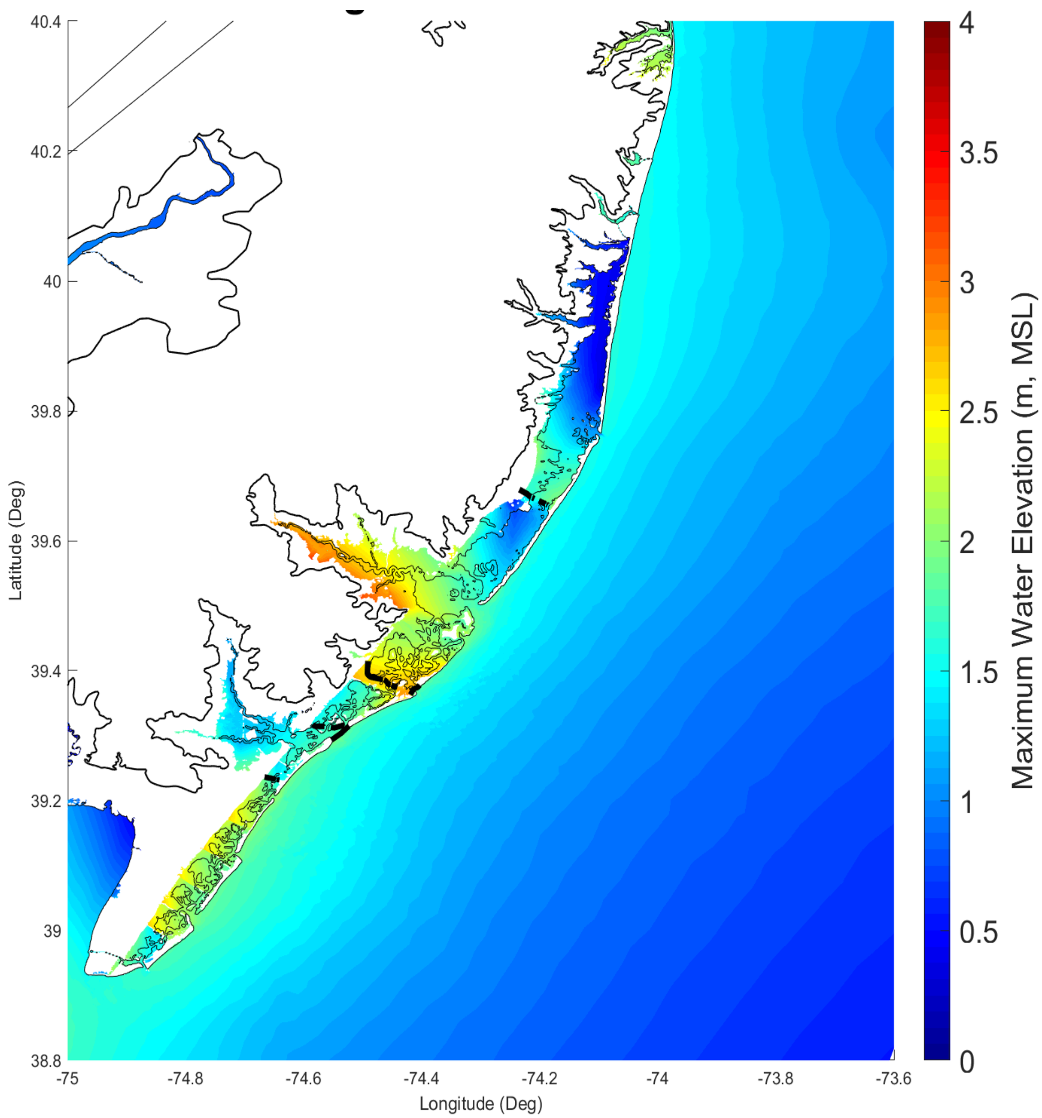

Figure 37 Maximum surge envelope for Storm 636 Configuration 5 (Brigantine area NNBF)

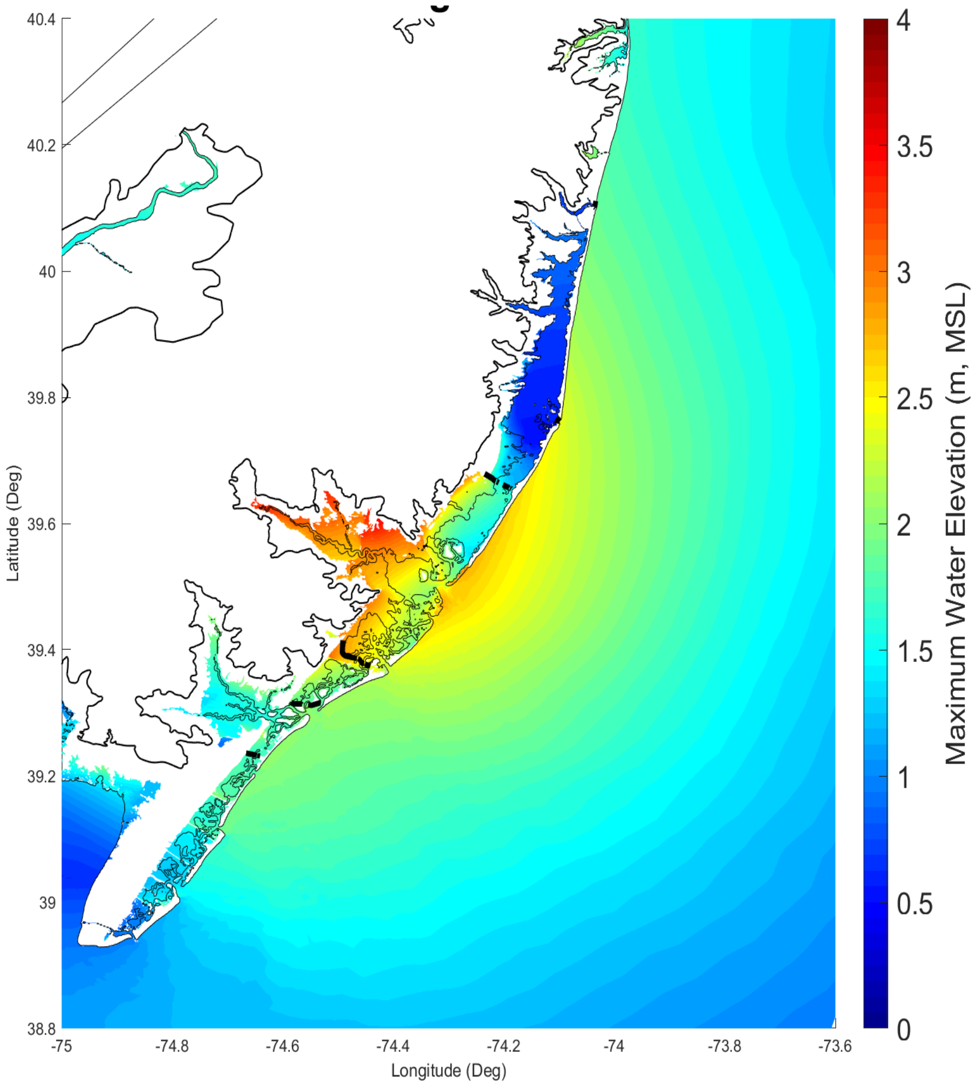

Figure 38 Maximum surge envelope for Storm 350 Configuration 8 (Holgate and Great Egg Harbor area NNBF)

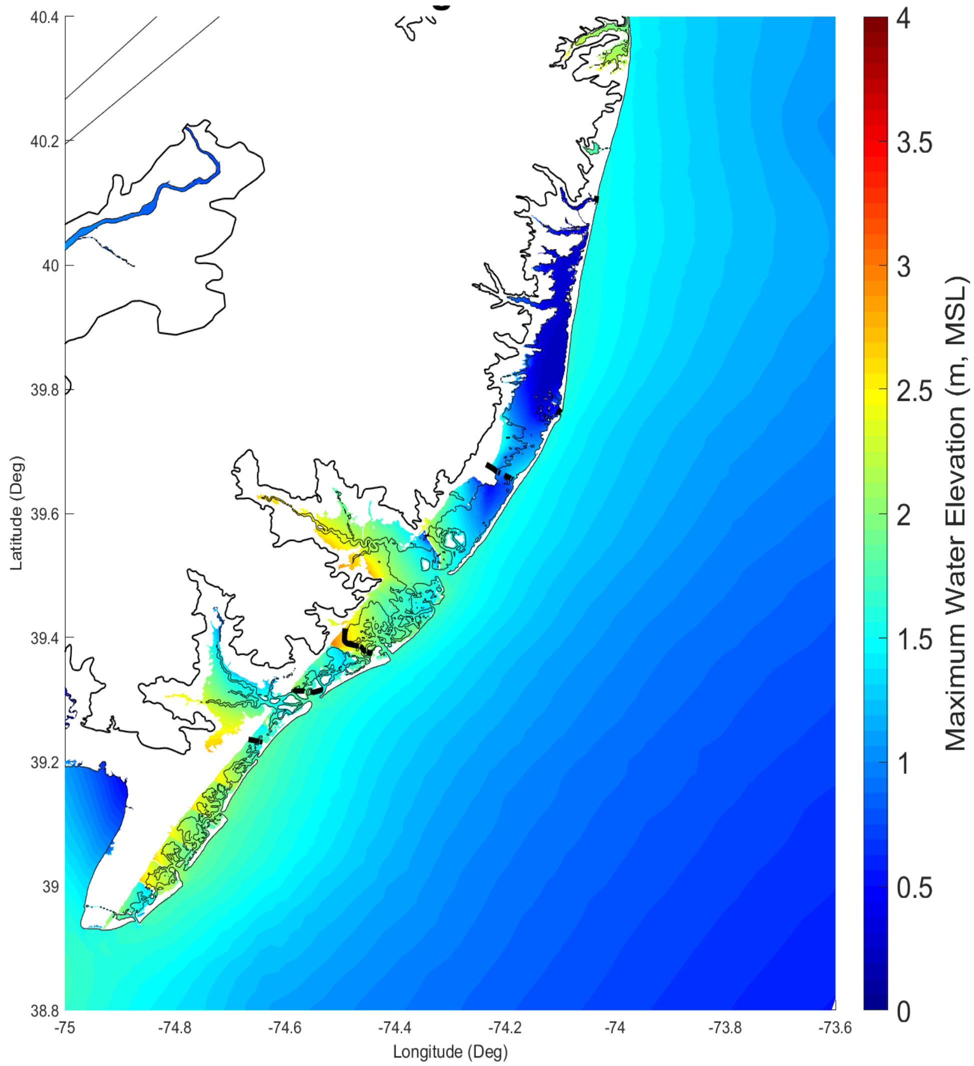

Figure 39 Maximum surge envelope for Storm 636 Configuration 8 (Holgate and Great Egg Harbor area NNBF)

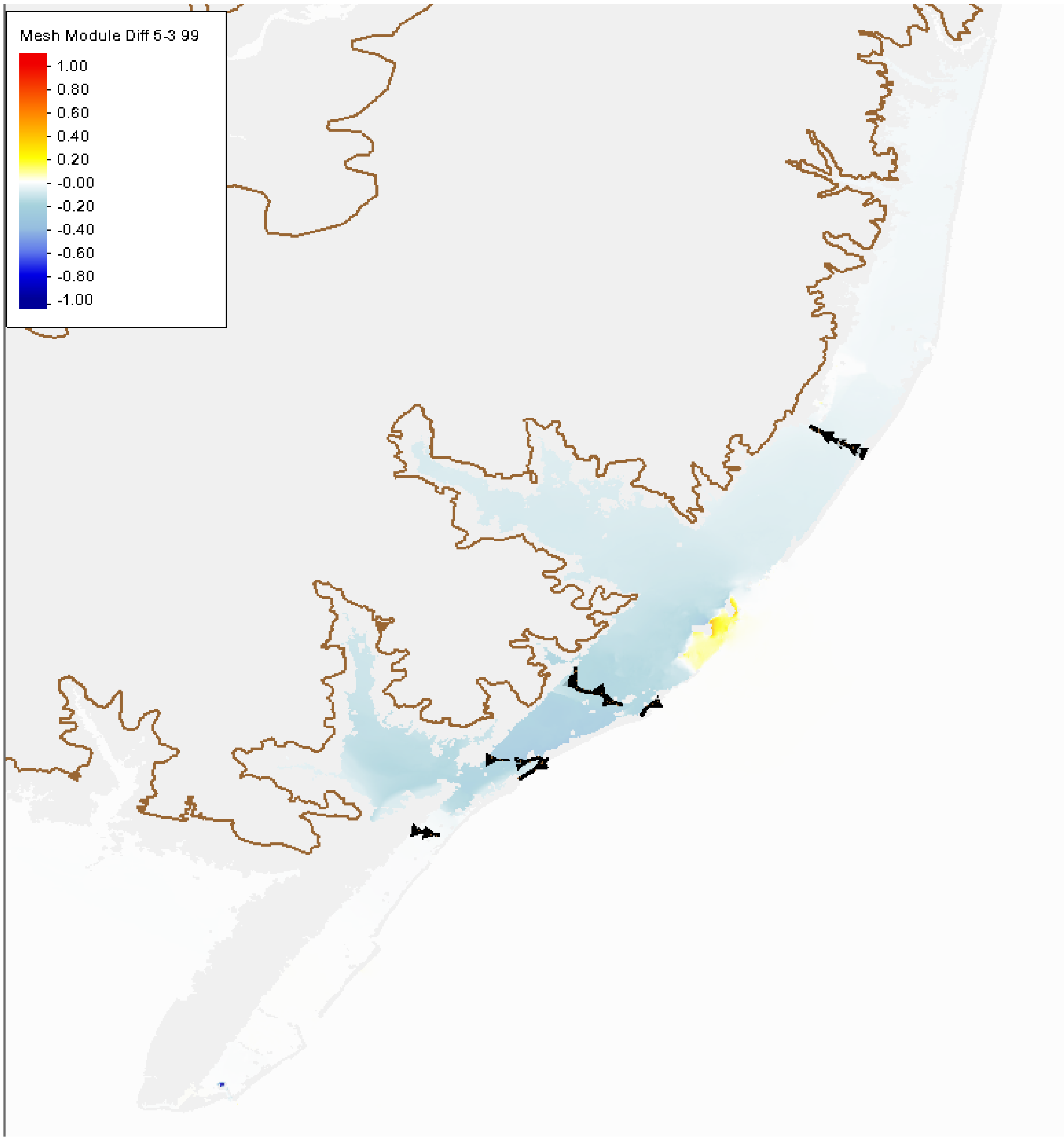

Figure 40 Peak water level differences between Configuration 5 (Brigantine area NNBF) and Configuration 3 (structural only) for storm 99

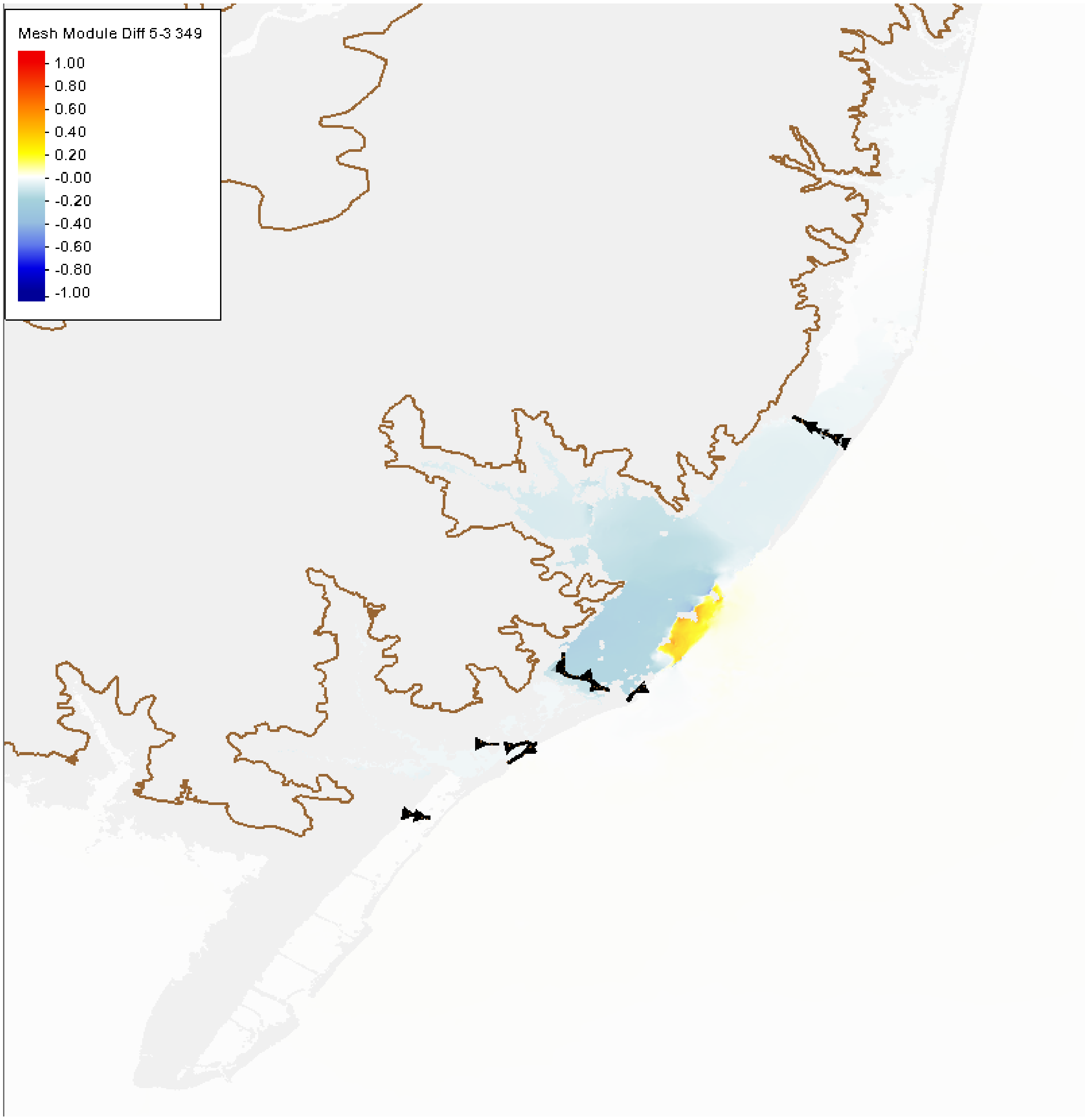

Figure 41 Peak water level differences between Configuration 5 (Brigantine area NNBF) and Configuration 3 (structural only) for storm 349

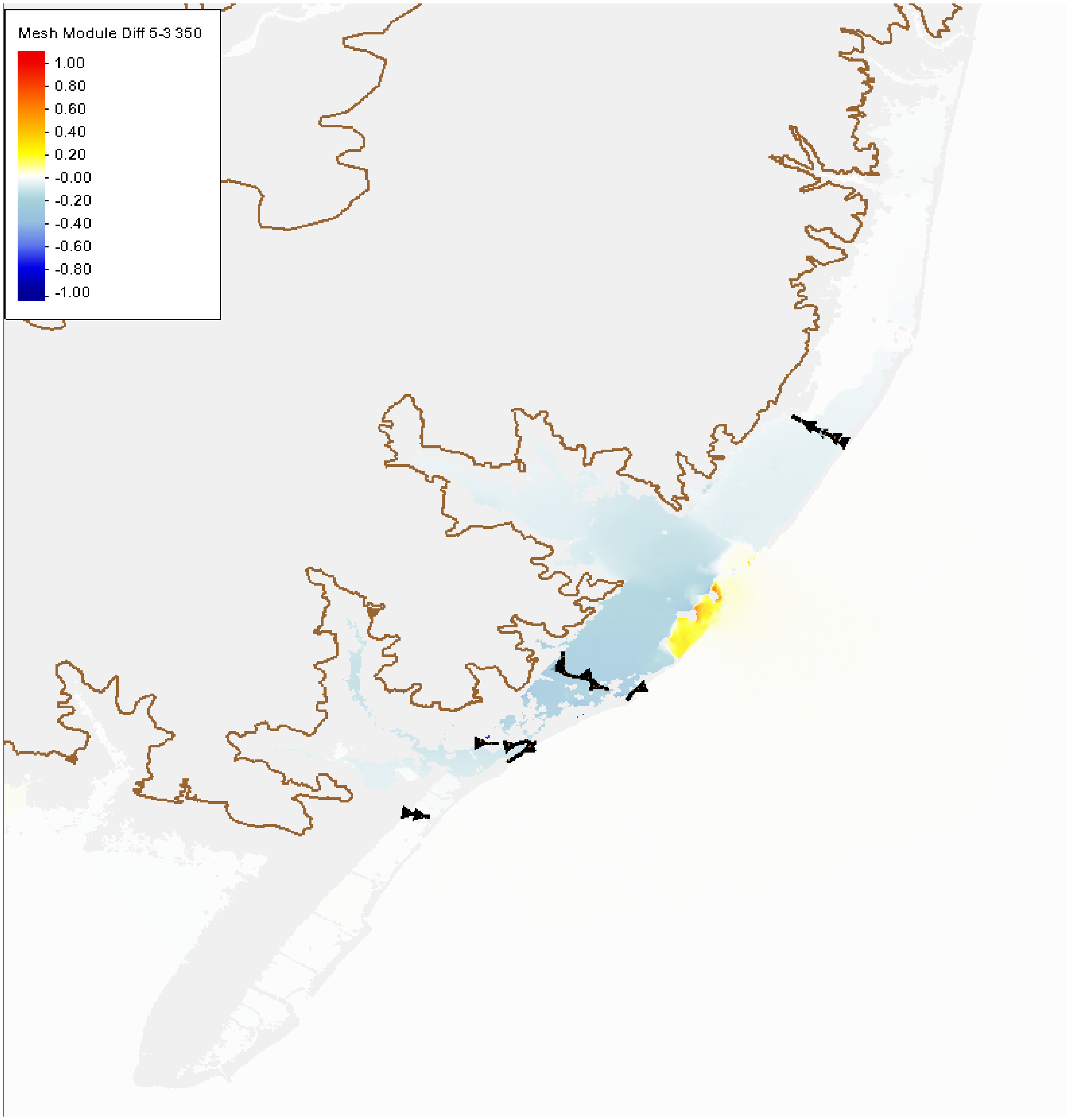

Figure 42 Peak water level differences between Configuration 5 (Brigantine area NNBF) and Configuration 3 (structural only) for storm 350

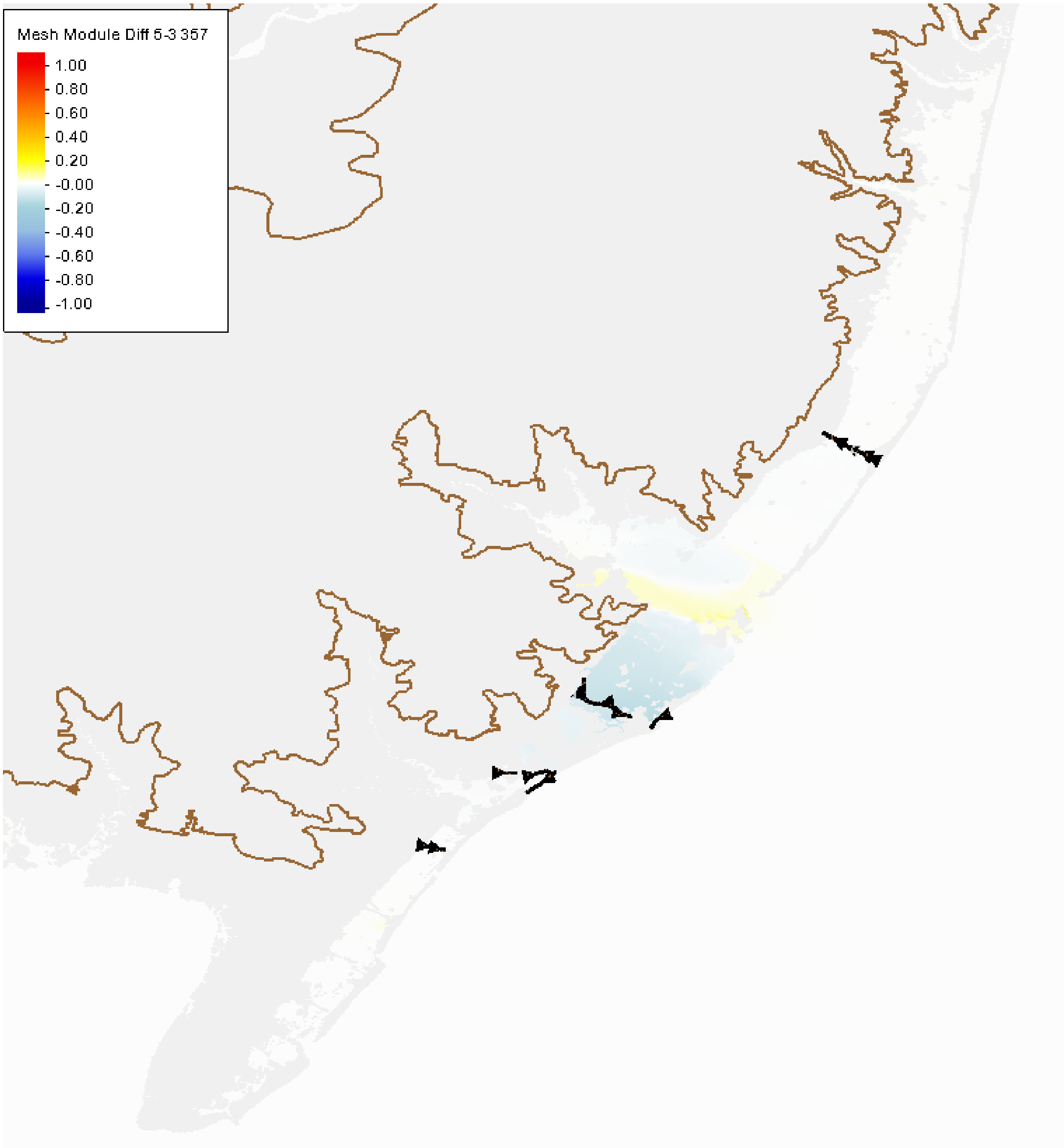

Figure 43 Peak water level differences between Configuration 5 (Brigantine area NNBF) and Configuration 3 (structural only) for storm 357

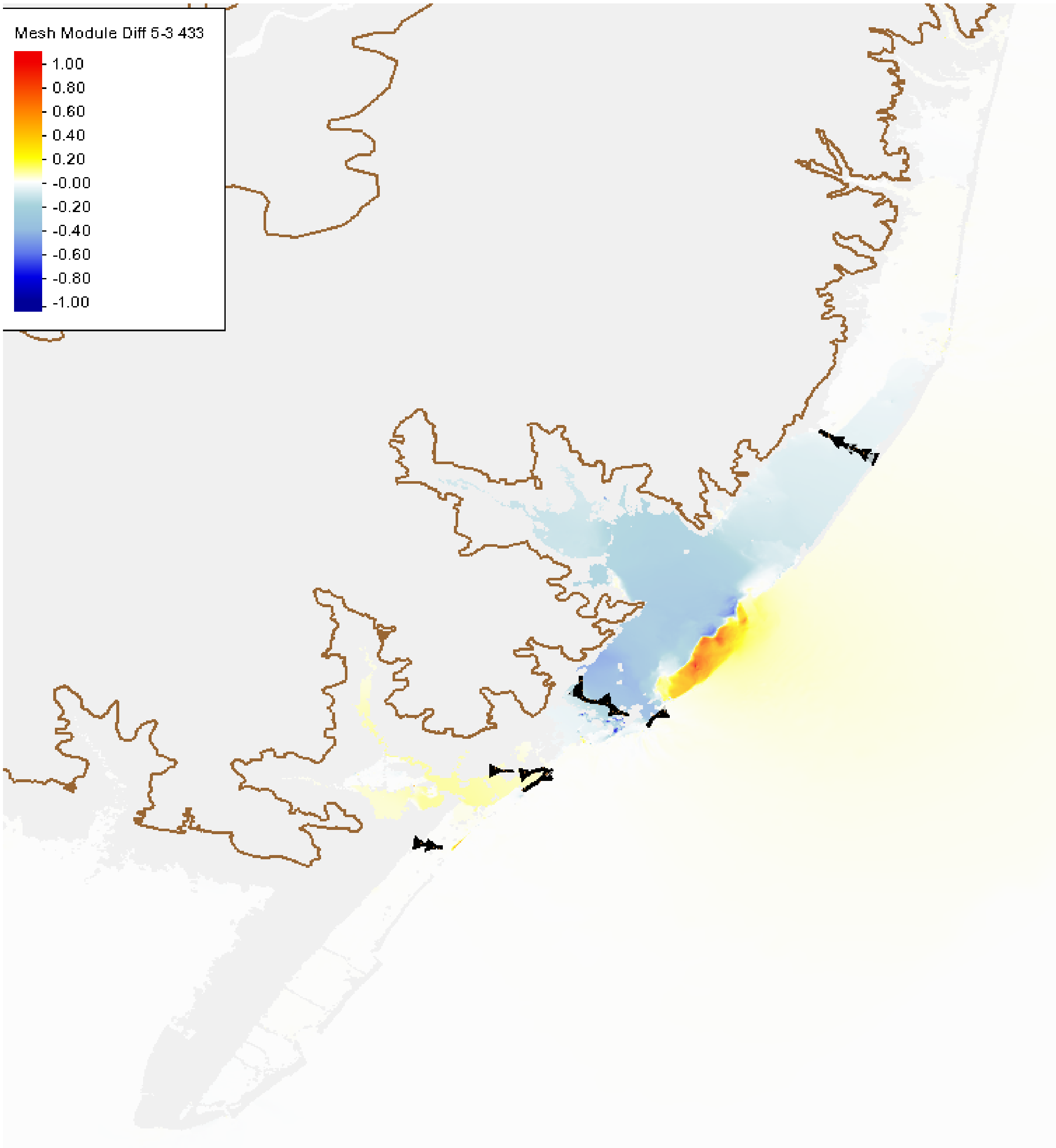

Figure 44 Peak water level differences between Configuration 5 (Brigantine area NNBF) and Configuration 3 (structural only) for storm 433

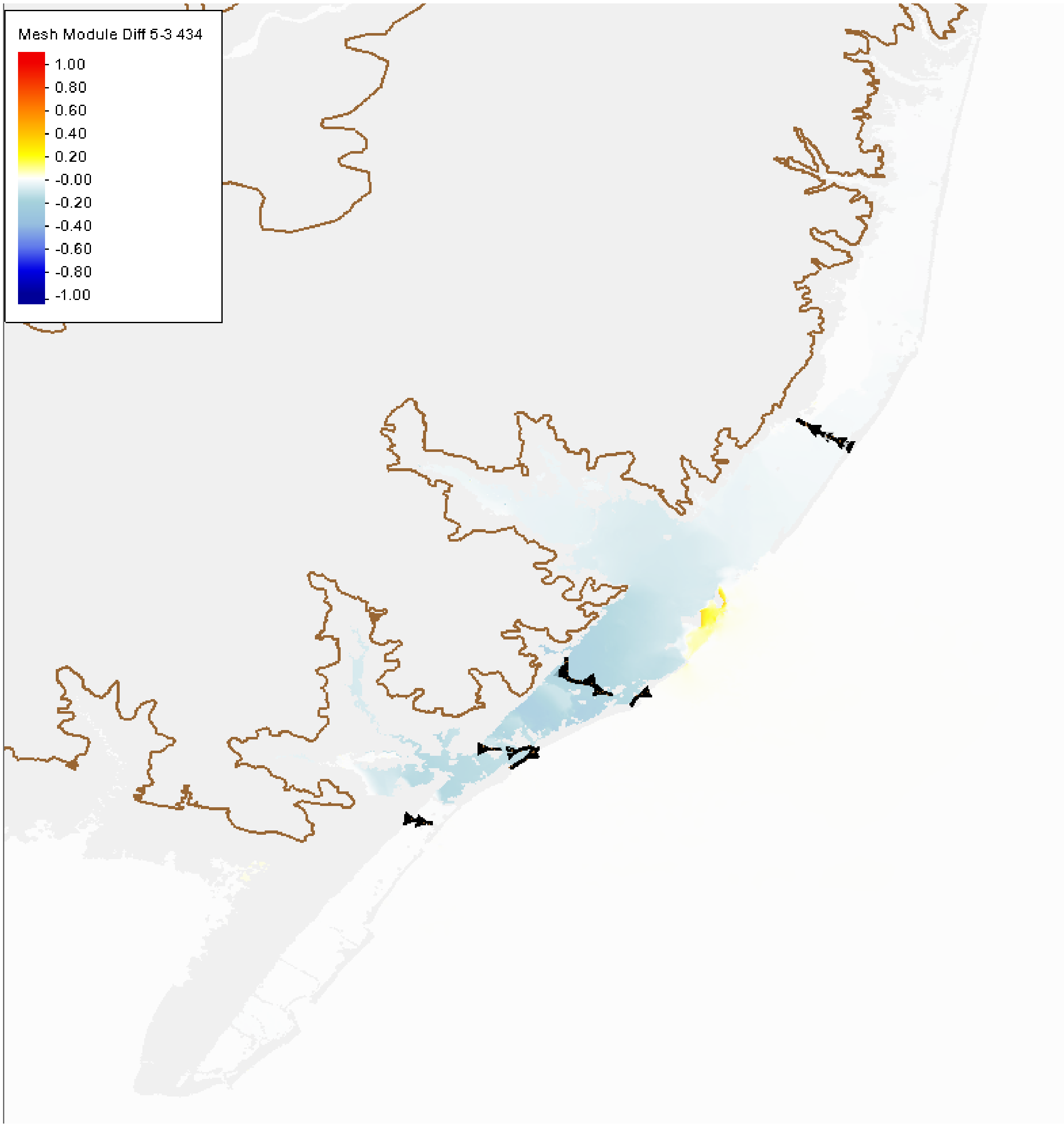

Figure 45 Peak water level differences between Configuration 5 (Brigantine area NNBF) and Configuration 3 (structural only) for storm 434

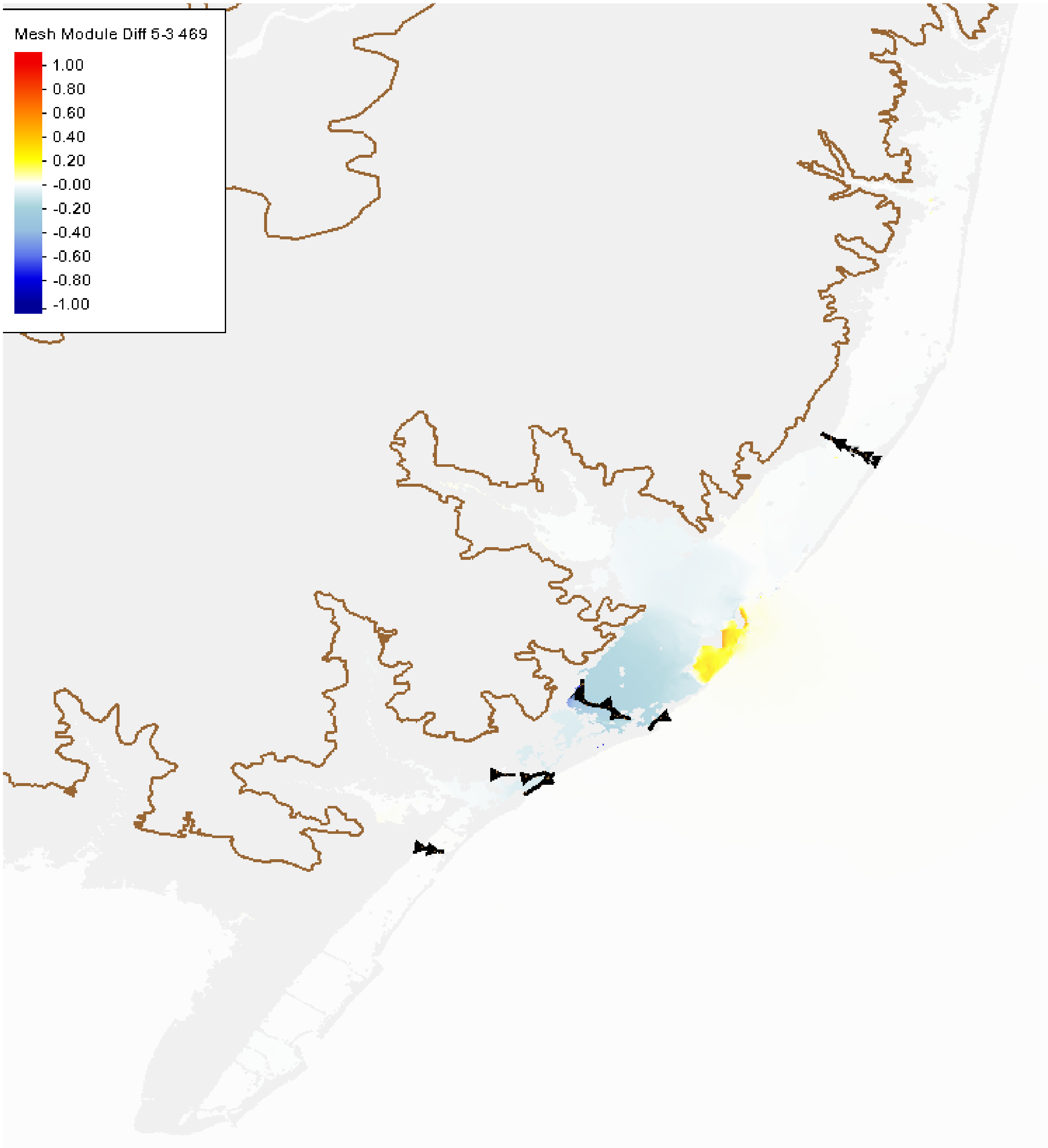

Figure 46 Peak water level differences between Configuration 5 (Brigantine area NNBF) and Configuration 3 (structural only) for storm 469

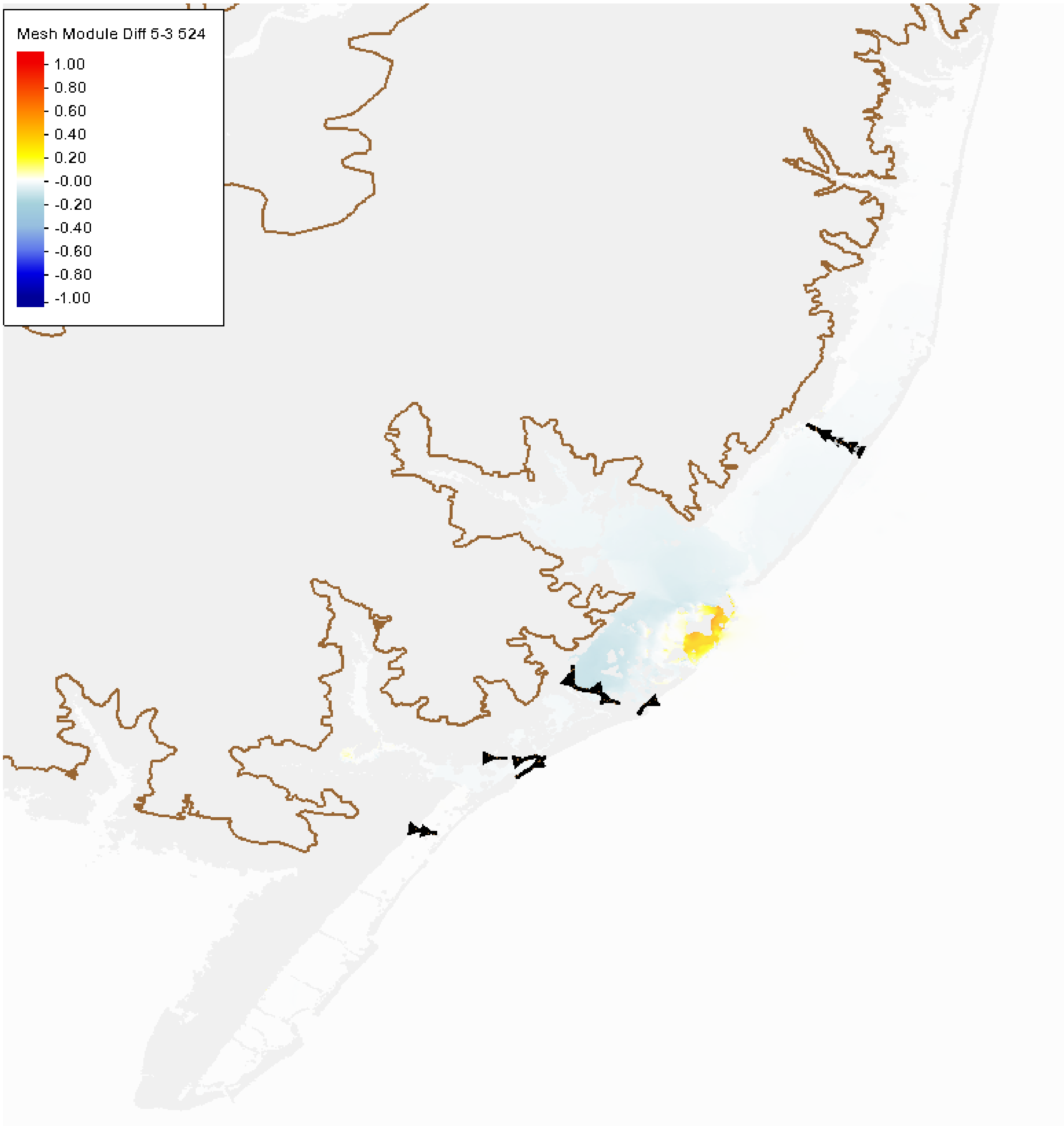

Figure 47 Peak water level differences between Configuration 5 (Brigantine area NNBF) and Configuration 3 (structural only) for storm 524

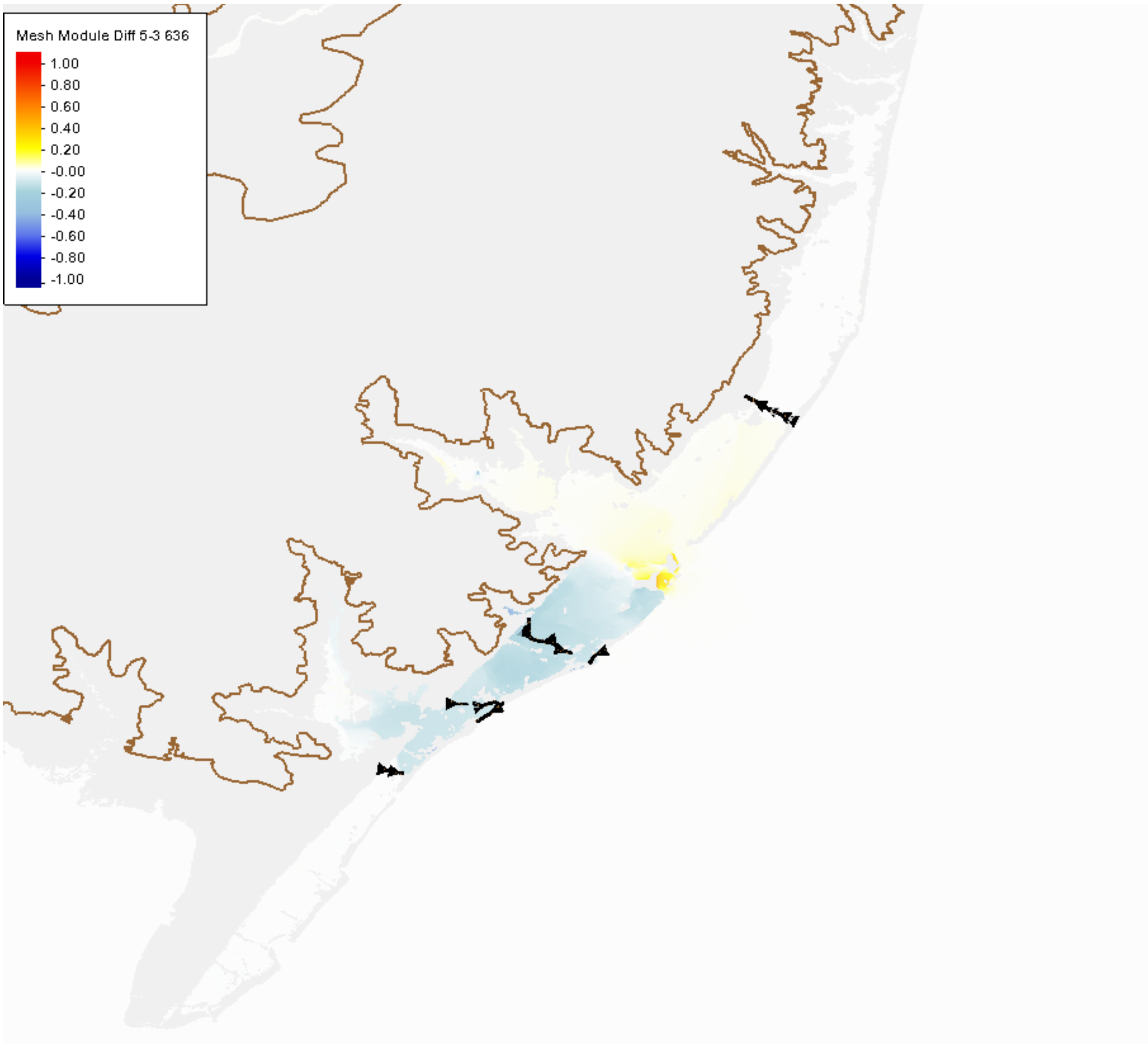

Figure 48 Peak water level differences between Configuration 5 (Brigantine area NNBF) and Configuration 3 (structural only) for storm 636

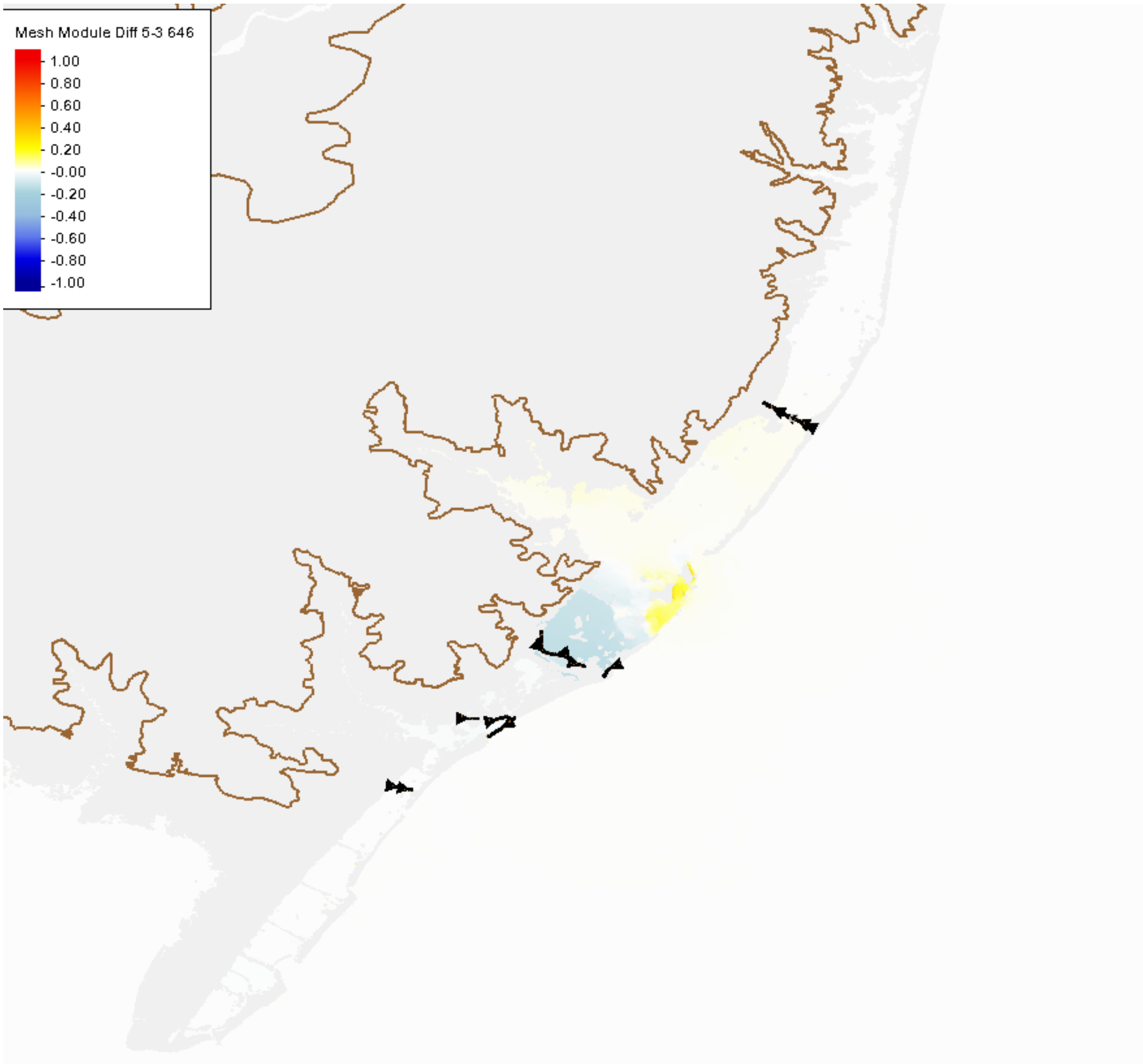

Figure 49 Peak water level differences between Configuration 5 (Brigantine area NNBF) and Configuration 3 (structural only) for storm 646

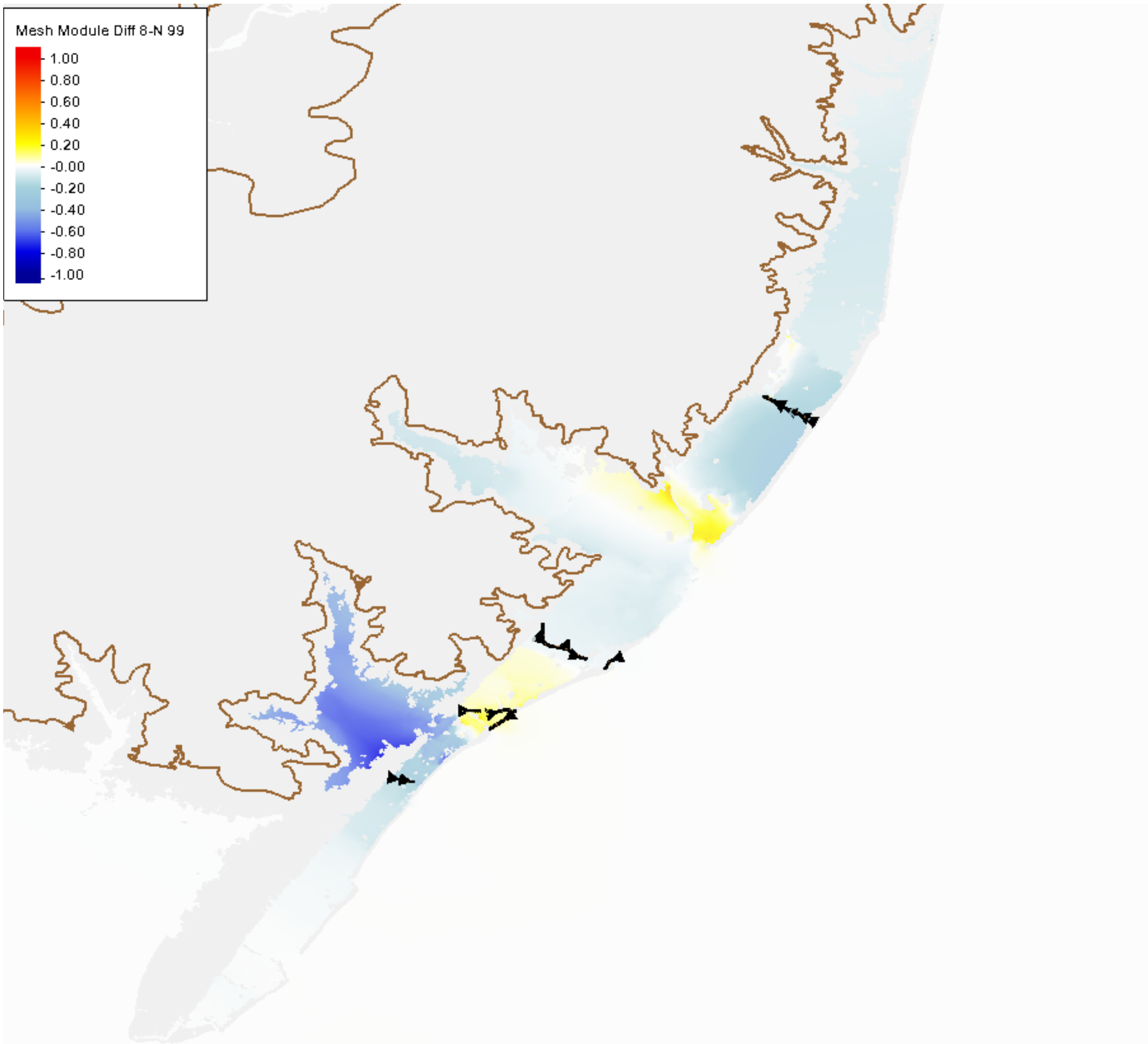

Figure 50 Peak water level differences between Configuration 8 (Holgate and Great Egg Harbor area NNBF) and North Configuration (structural only) for storm 99

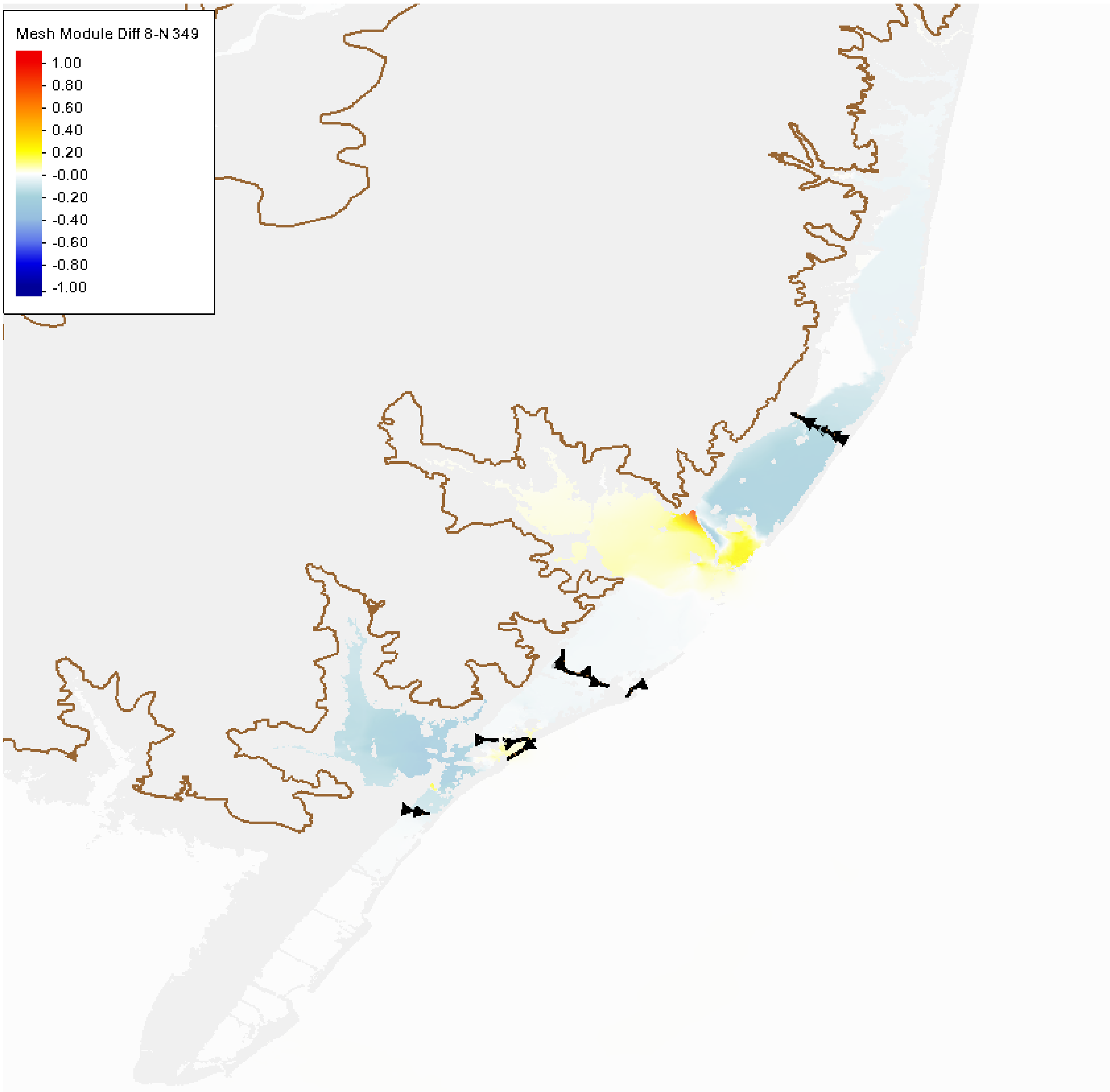

Figure 51 Peak water level differences between Configuration 8 (Holgate and Great Egg Harbor area NNBF) and North Configuration (structural only) for storm 349

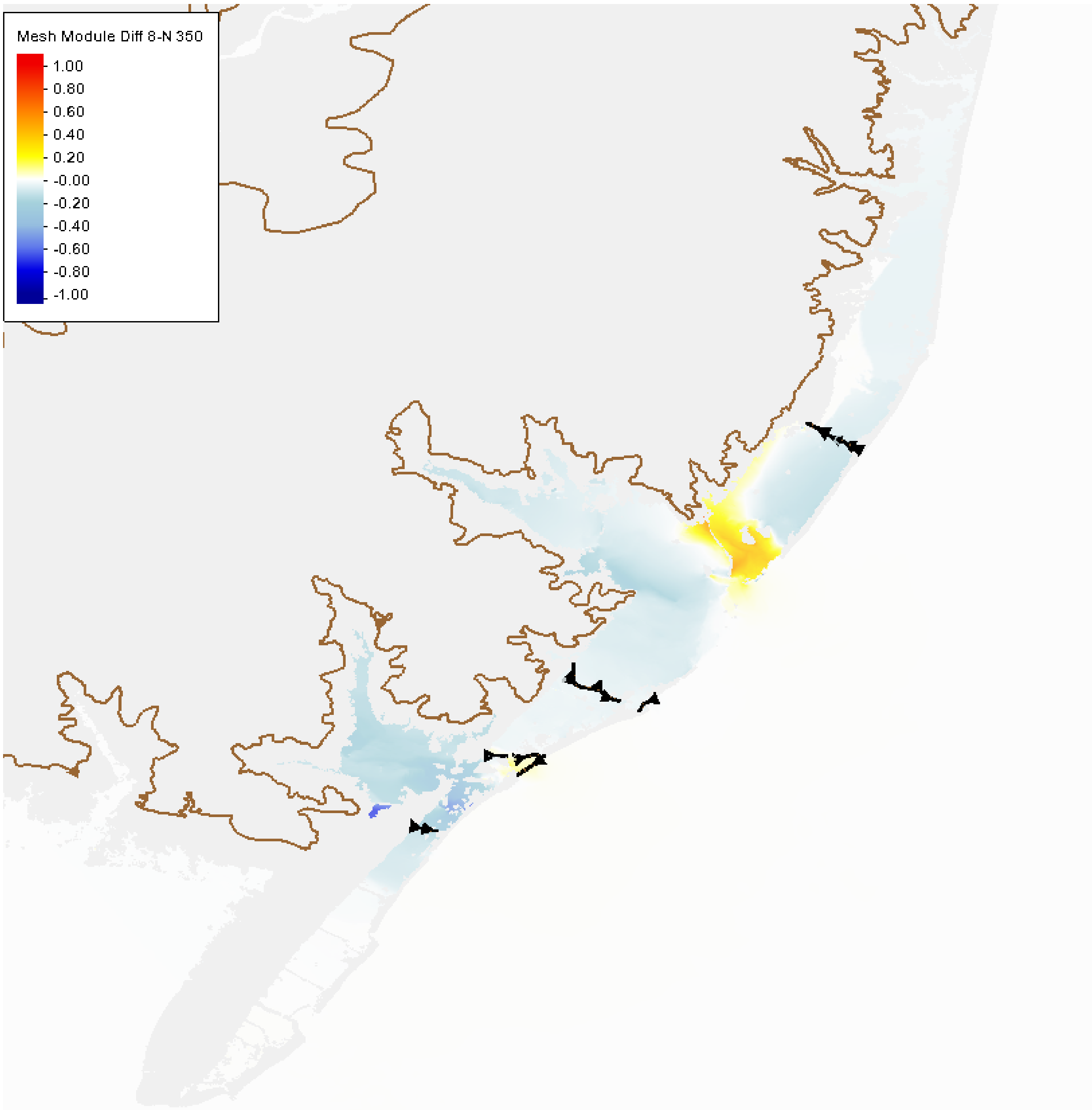

Figure 52 Peak water level differences between Configuration 8 (Holgate and Great Egg Harbor area NNBF) and North Configuration (structural only) for storm 350

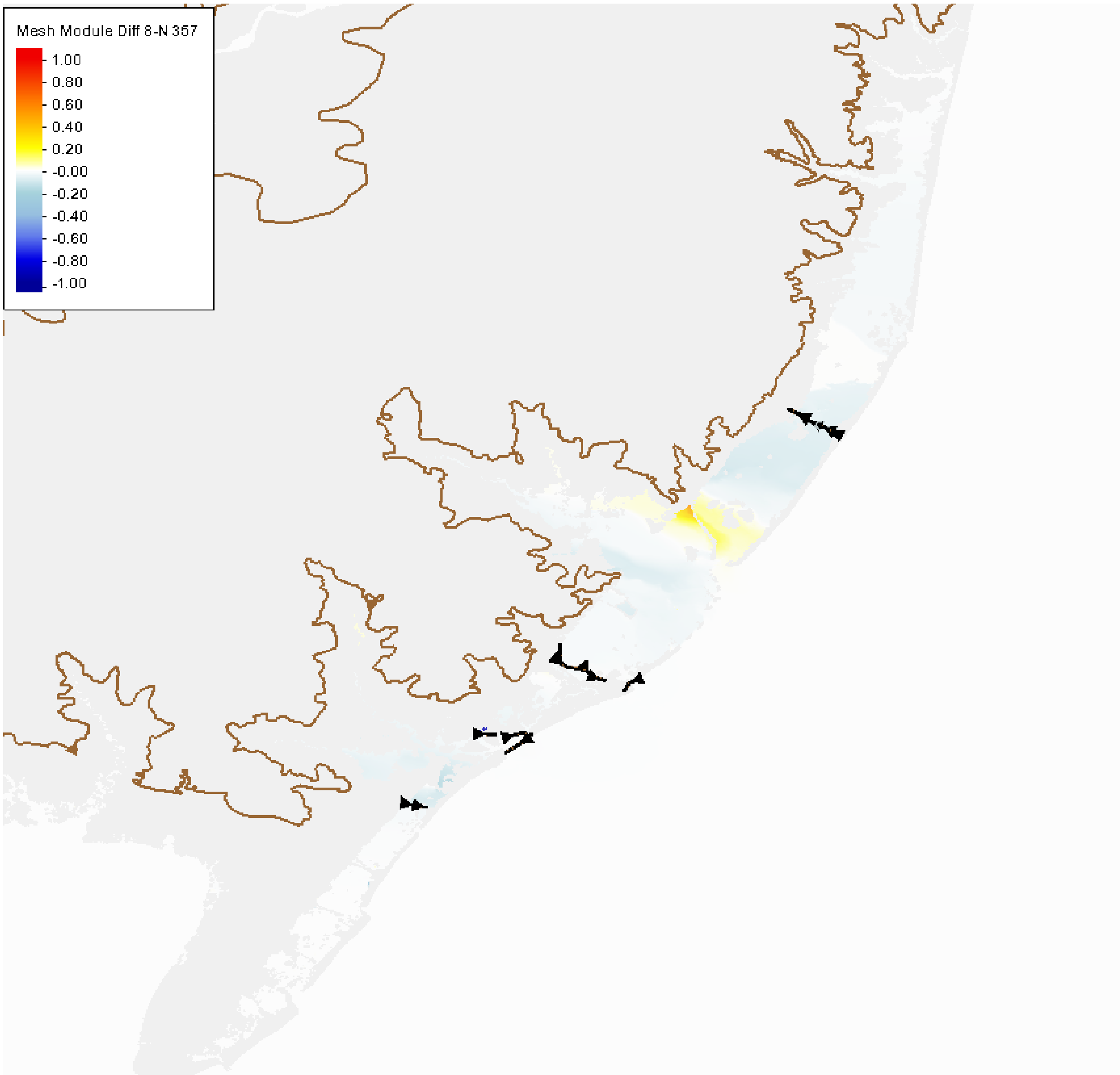

Figure 53 Peak water level differences between Configuration 8 (Holgate and Great Egg Harbor area NNBF) and North Configuration (structural only) for storm 357

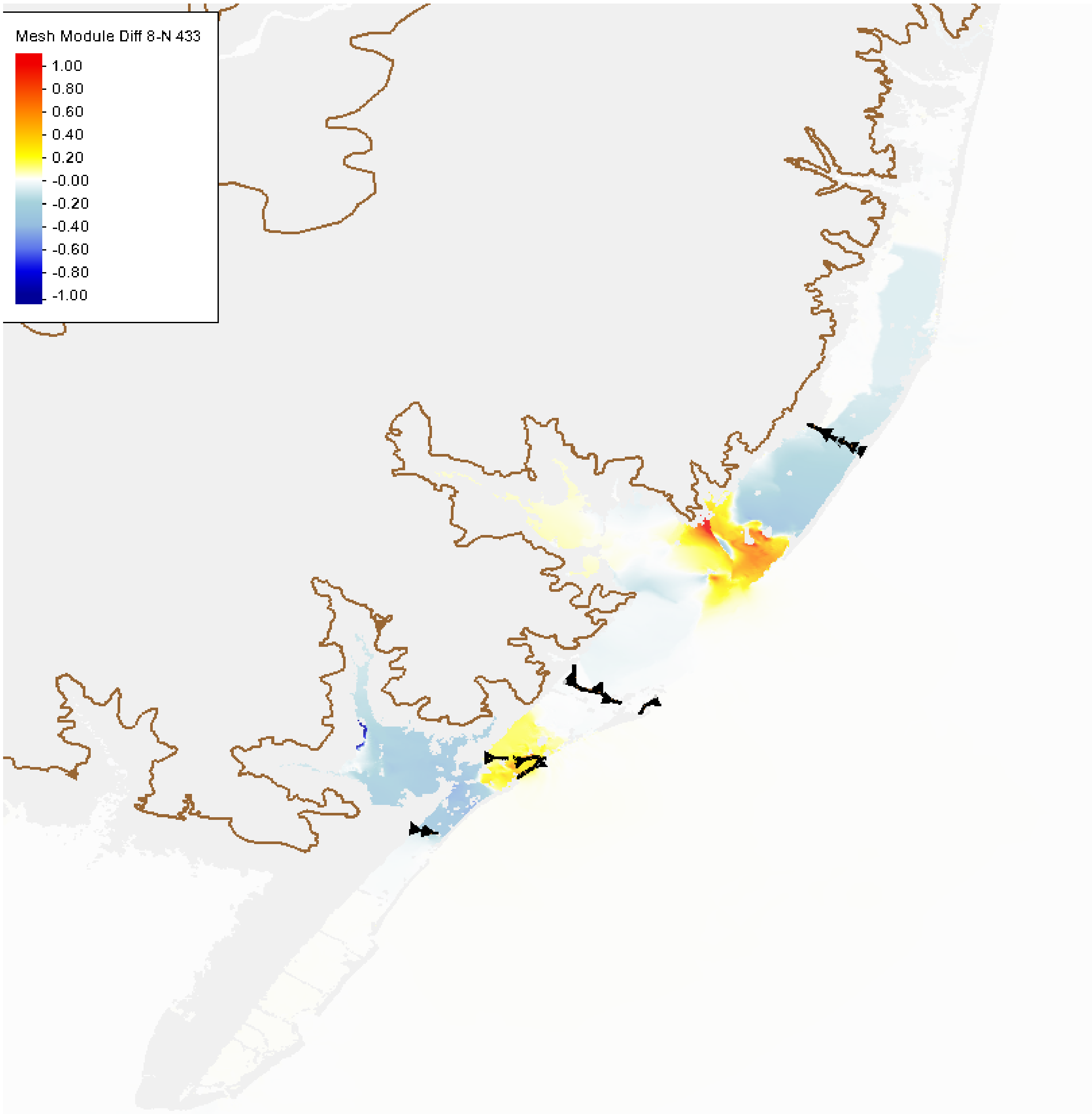

Figure 54 Peak water level differences between Configuration 8 (Holgate and Great Egg Harbor area NNBF) and North Configuration (structural only) for storm 433

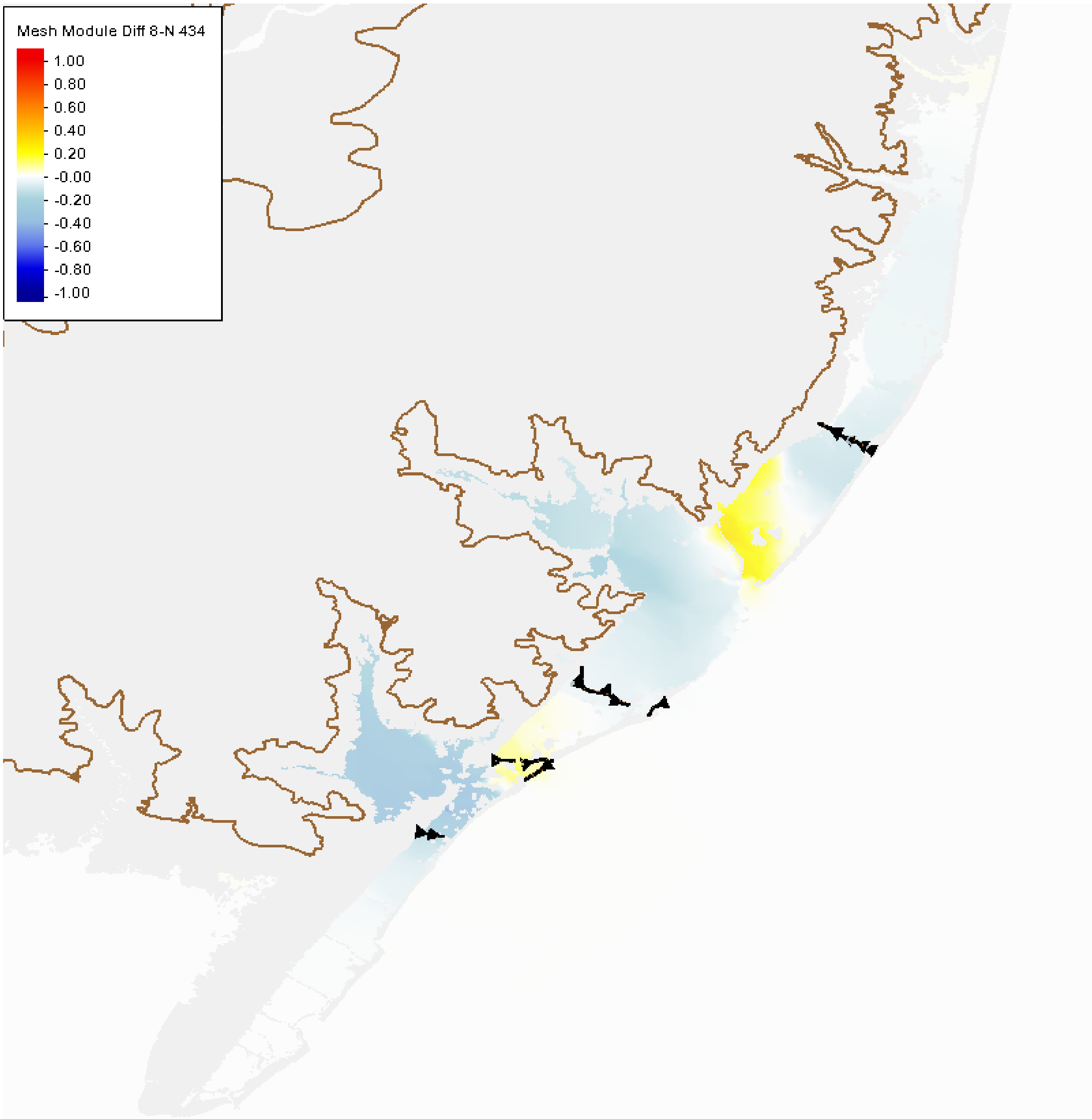

Figure 55 Peak water level differences between Configuration 8 (Holgate and Great Egg Harbor area NNBF) and North Configuration (structural only) for storm 434

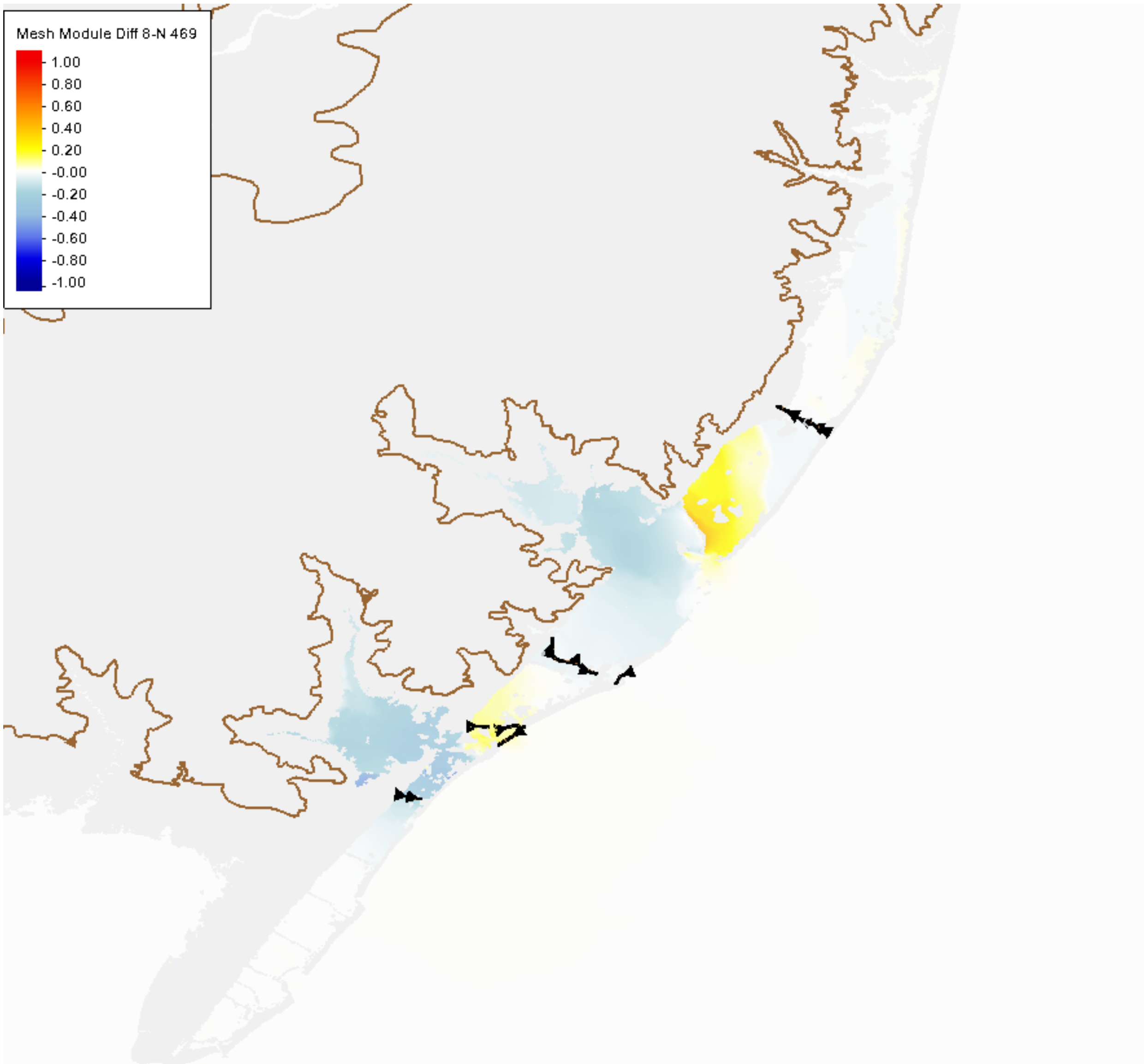

Figure 56 Peak water level differences between Configuration 8 (Holgate and Great Egg Harbor area NNBF) and North Configuration (structural only) for storm 469

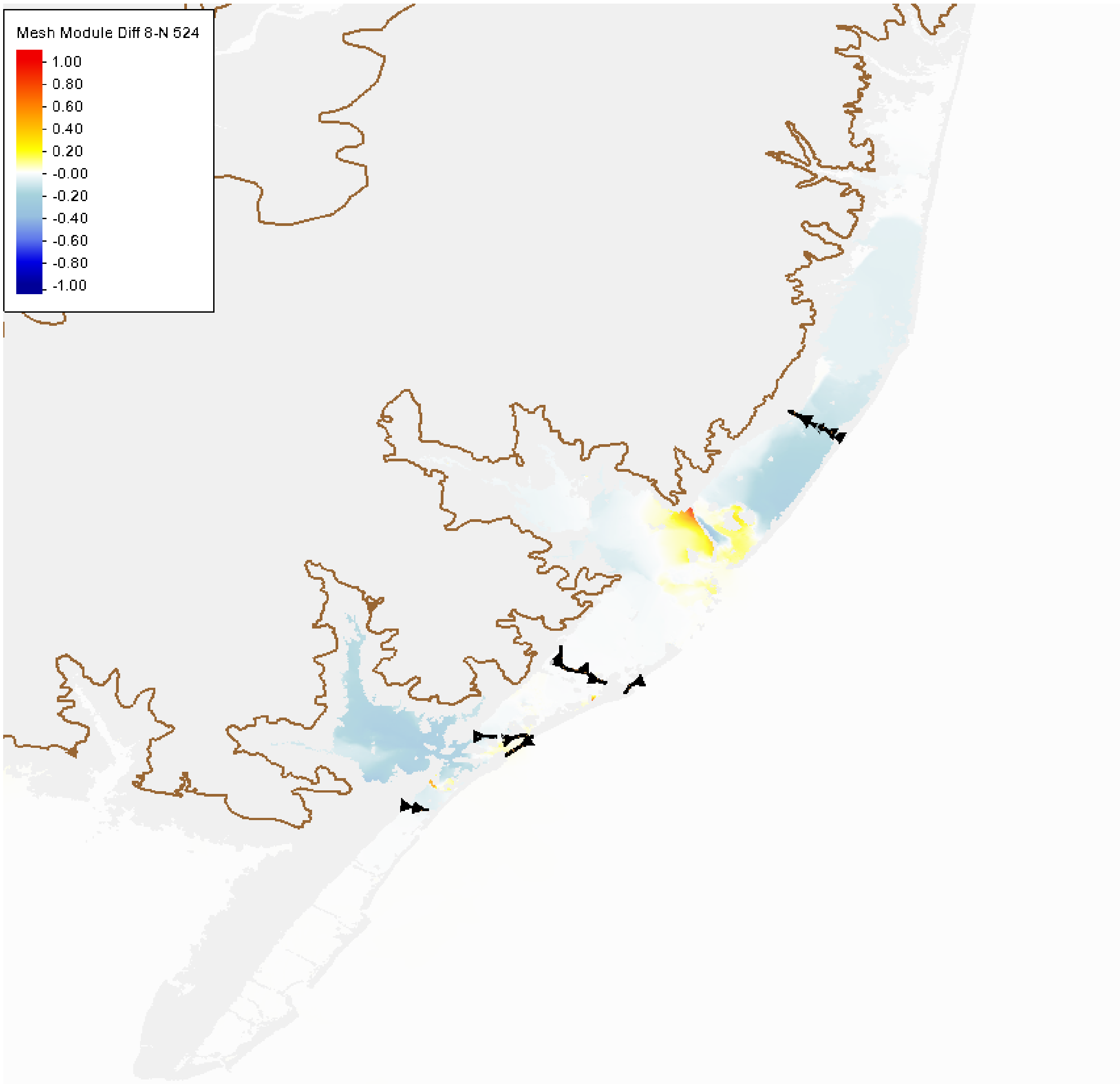

Figure 57 Peak water level differences between Configuration 8 (Holgate and Great Egg Harbor area NNBF) and North Configuration (structural only) for storm 524

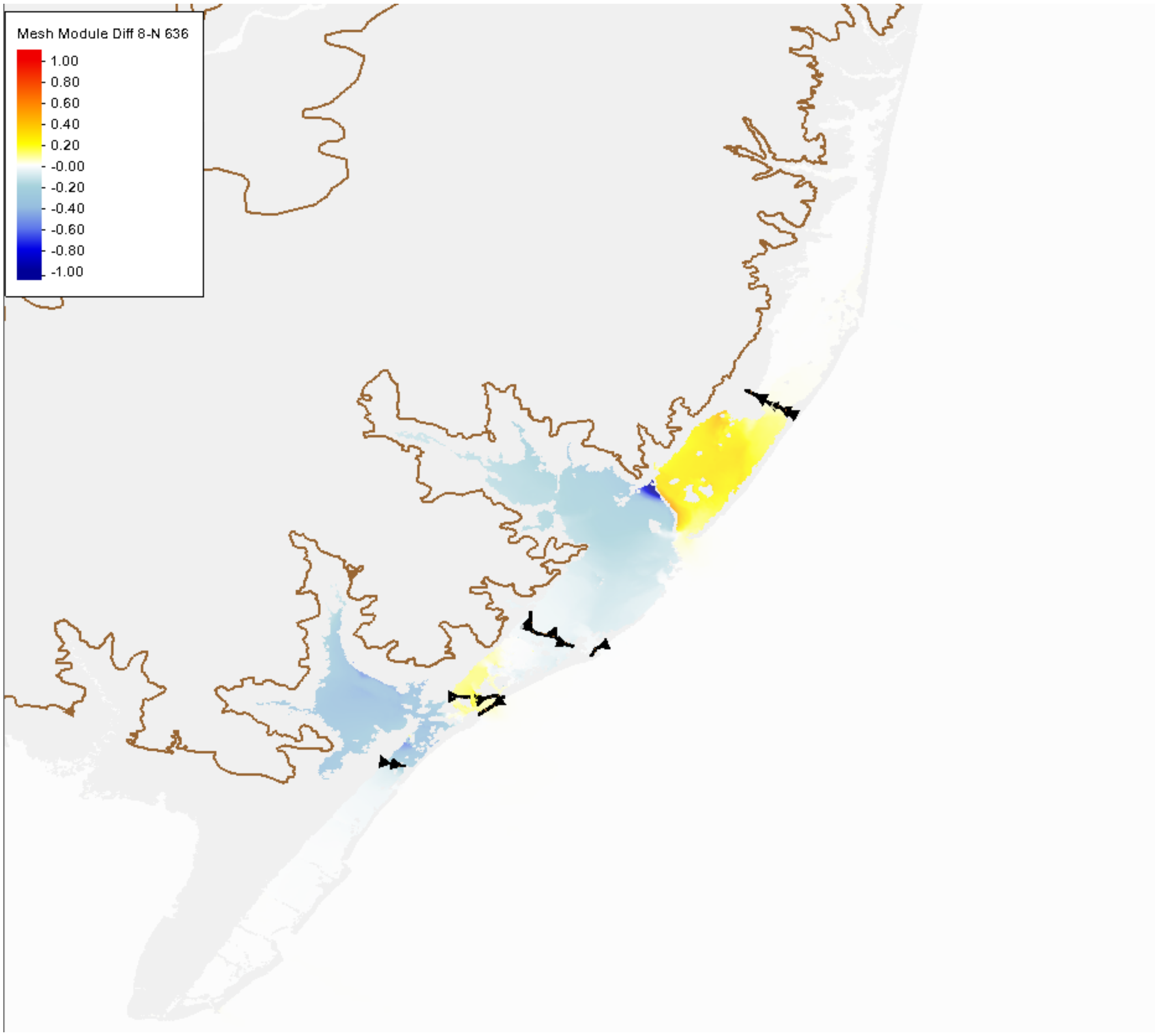

Figure 58 Peak water level differences between Configuration 8 (Holgate and Great Egg Harbor area NNBF) and North Configuration (structural only) for storm 636

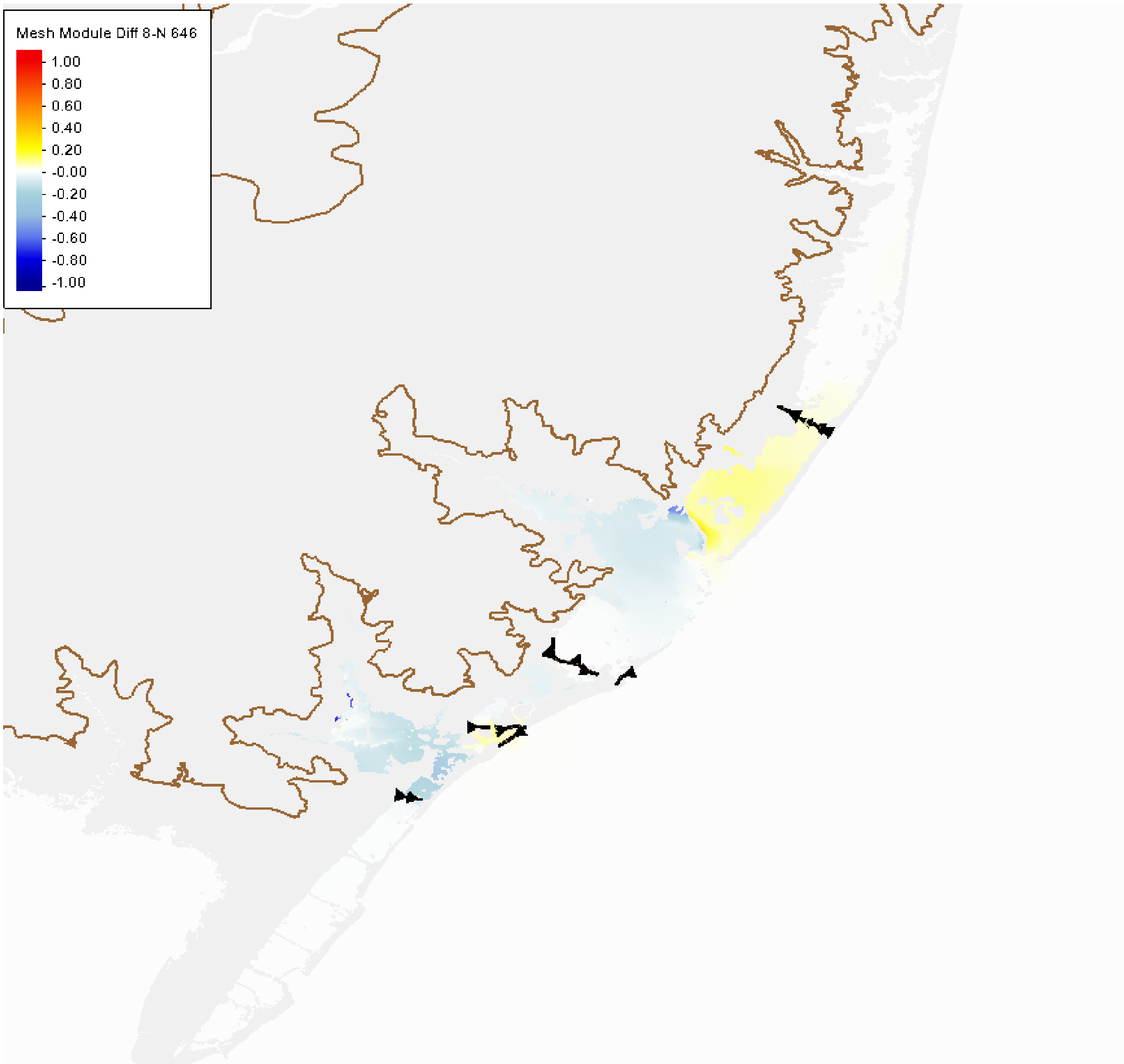

Figure 59 Peak water level differences between Configuration 8 (Holgate and Great Egg Harbor area NNBF) and North Configuration (structural only) for storm 646

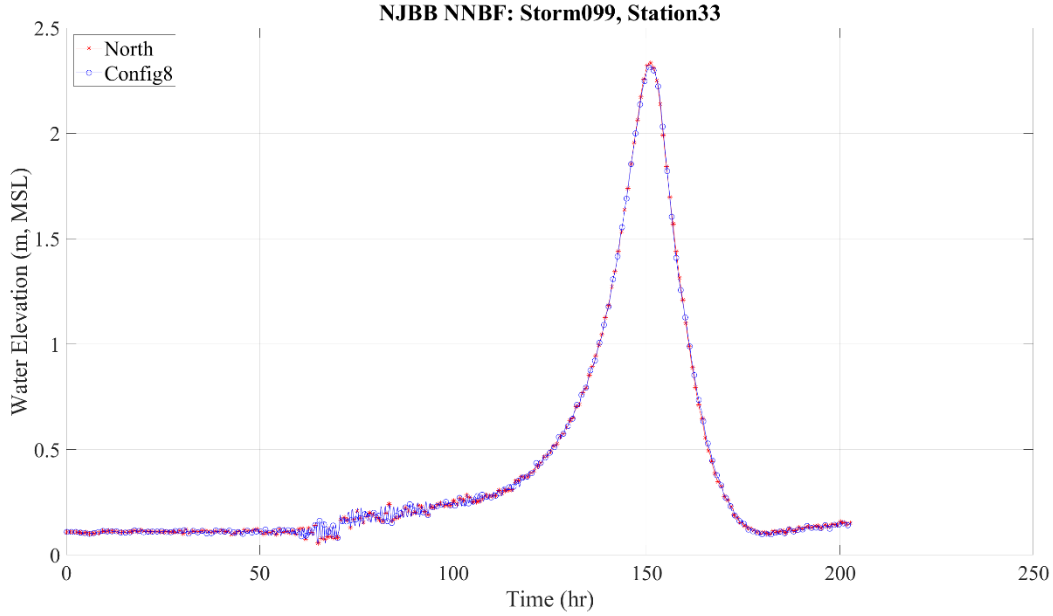

Figure 60 Storm 99 hydrograph for save point 33 "in front of" Holgate area with and without NNBF

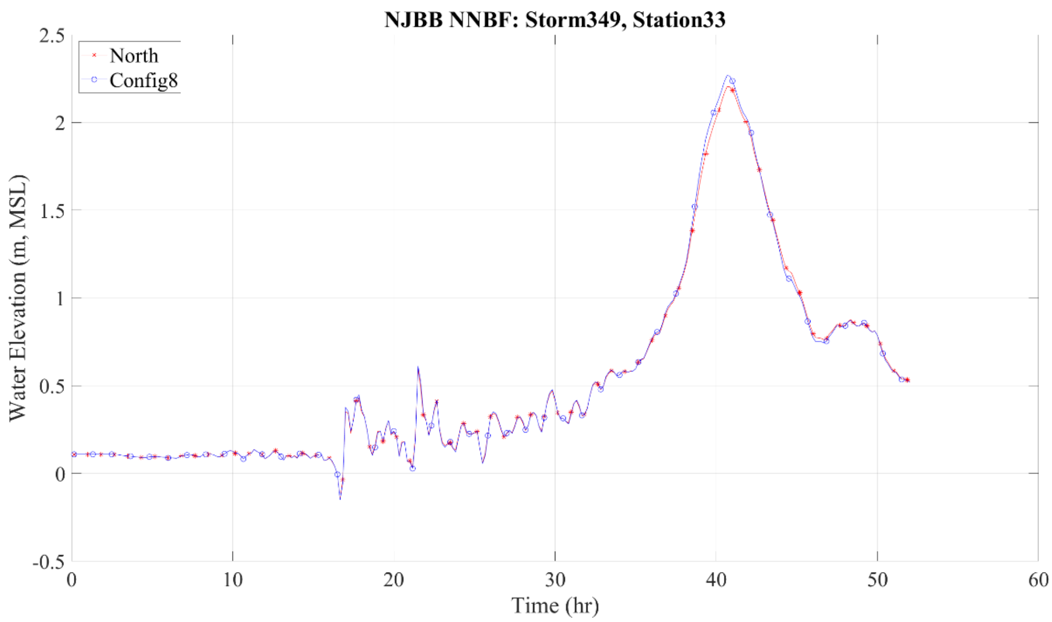

Figure 61 Storm 349 hydrograph for save point 33 "in front of" Holgate area with and without NNBF

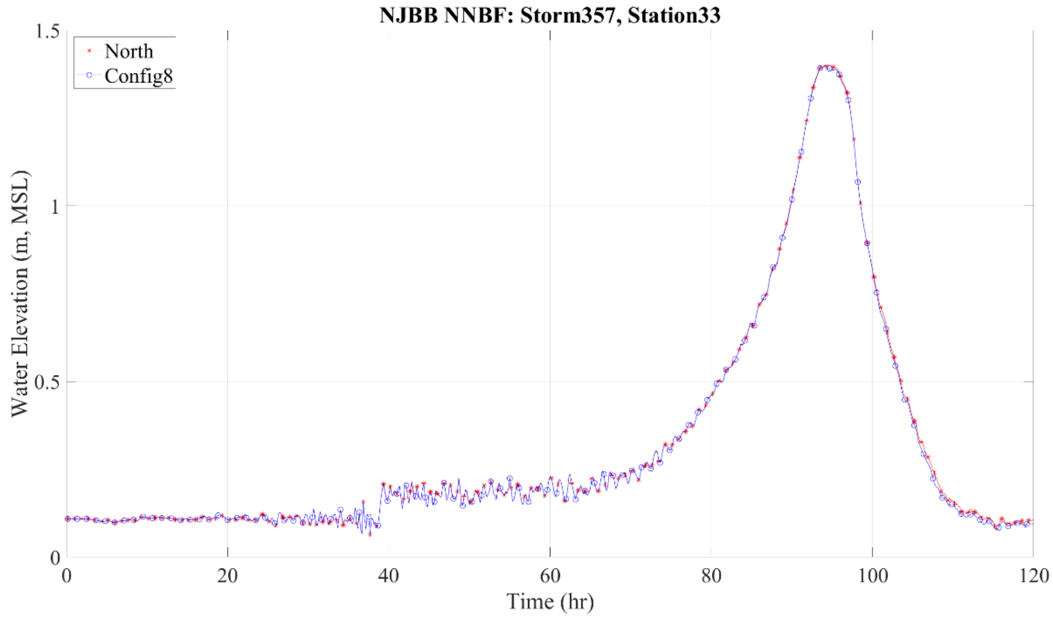

Figure 62 Storm 357 hydrograph for save point 33 "in front of" Holgate area with and without NNBF

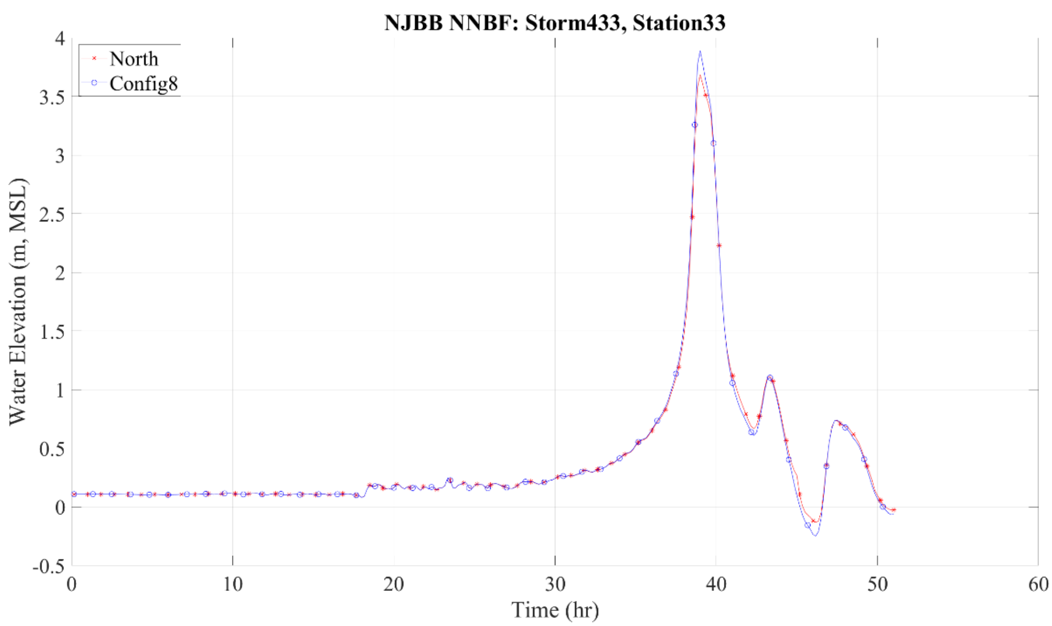

Figure 63 Storm 433 hydrograph for save point 33 "in front of" Holgate area with and without NNBF

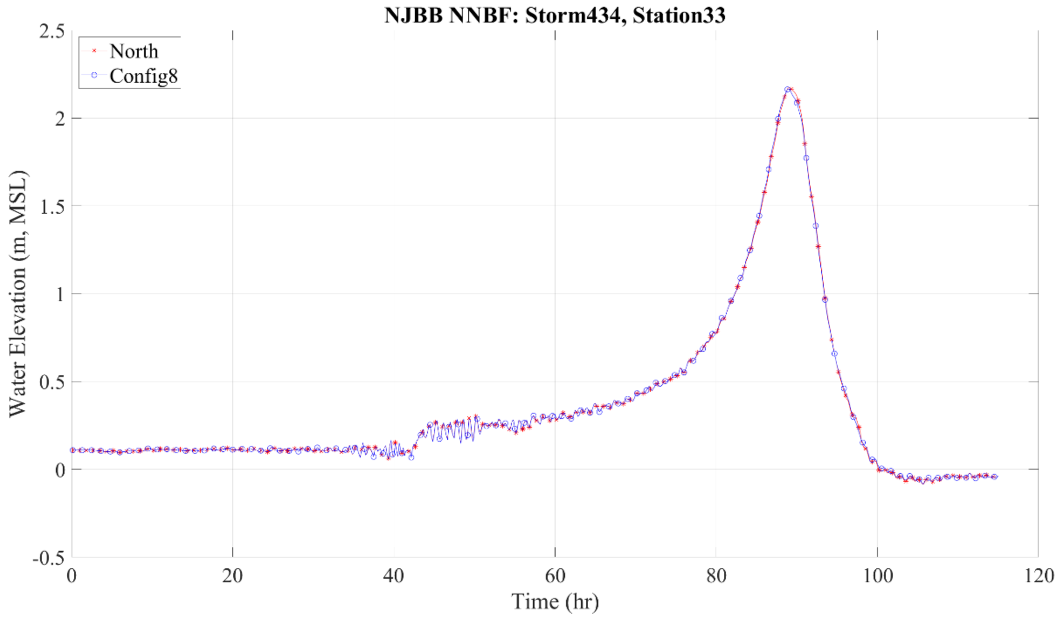

Figure 64 Storm 434 hydrograph for save point 33 "in front of" Holgate area with and without NNBF

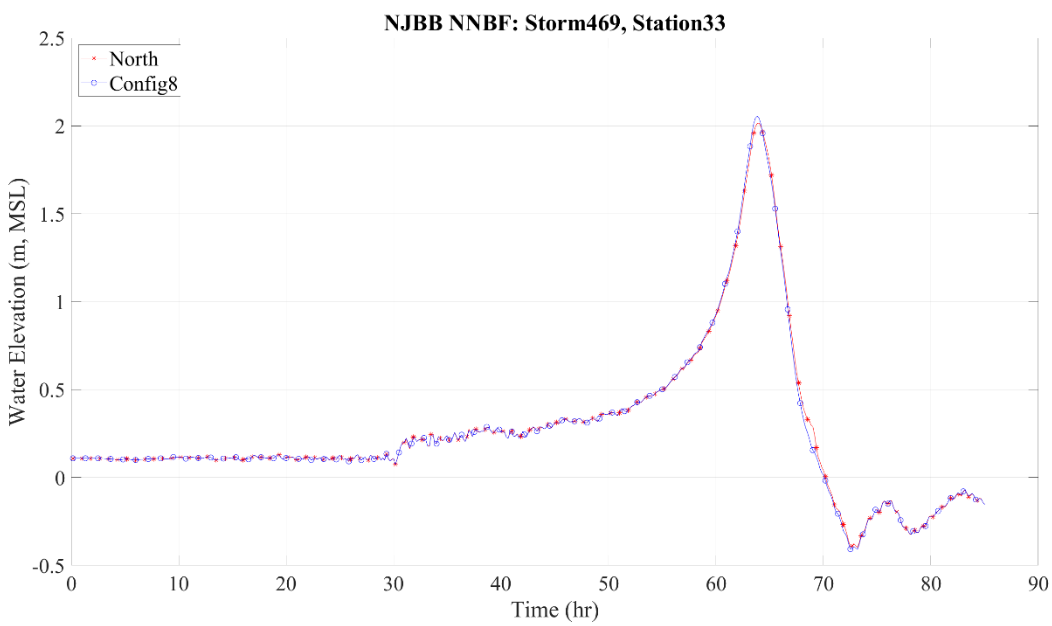

Figure 65 Storm 469 hydrograph for save point 33 "in front of" Holgate area with and without NNBF

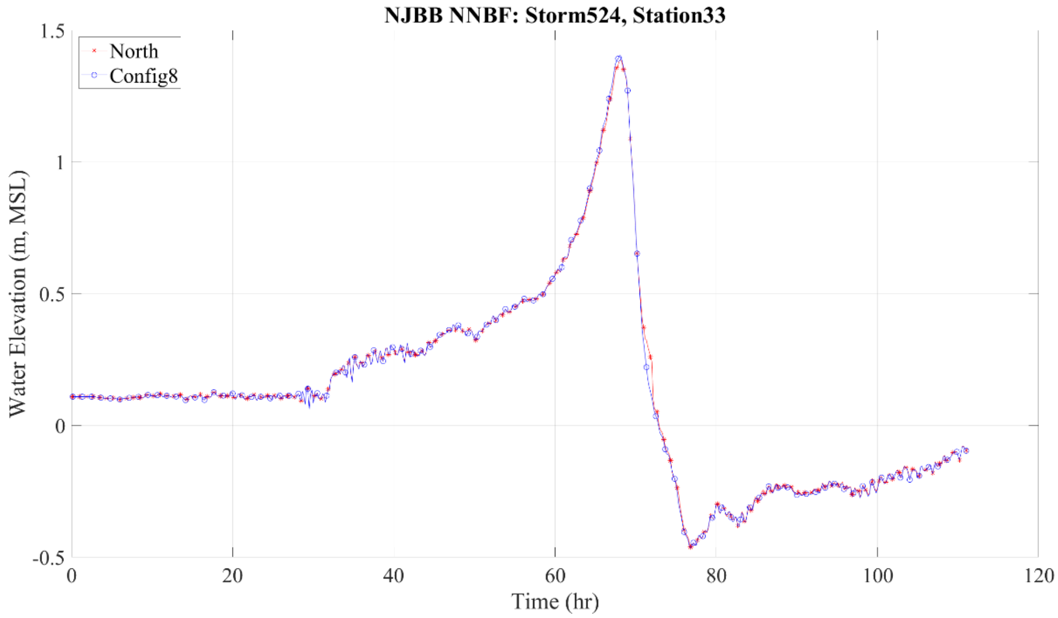

Figure 66 Storm 524 hydrograph for save point 33 "in front of" Holgate area with and without NNBF

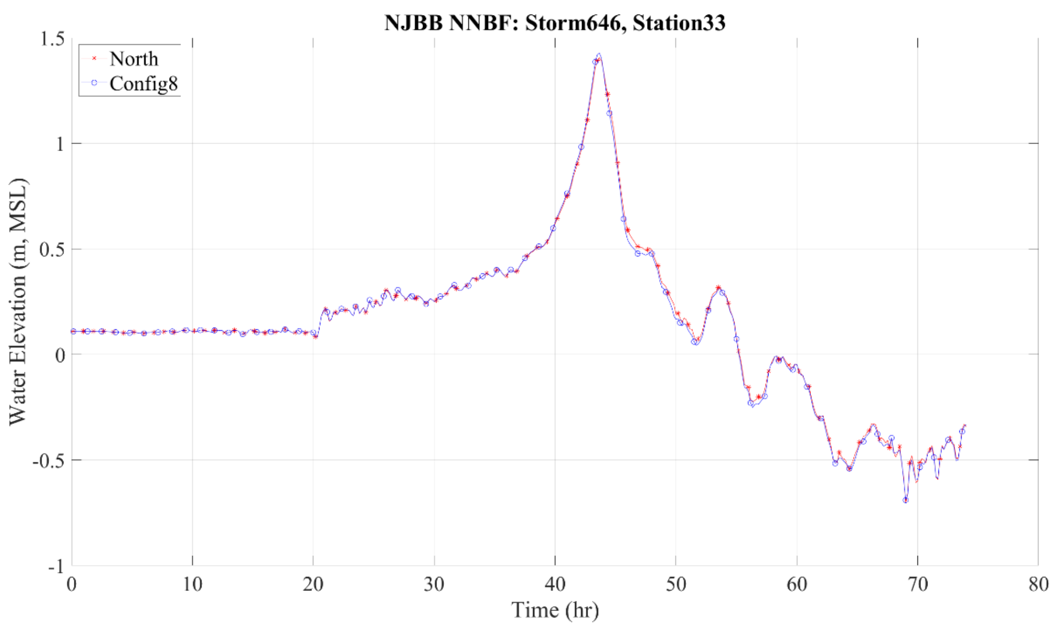

Figure 67 Storm 646 hydrograph for save point 33 "in front of" Holgate area with and without NNBF

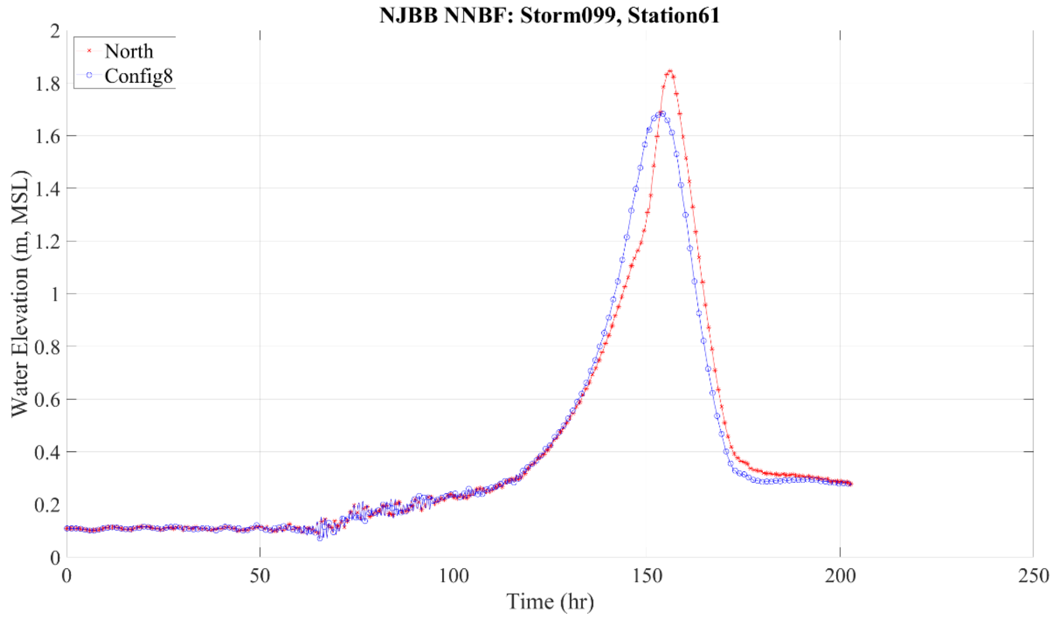

Figure 68 Storm 99 hydrograph for save point 61 "behind" Holgate area with and without NNBF

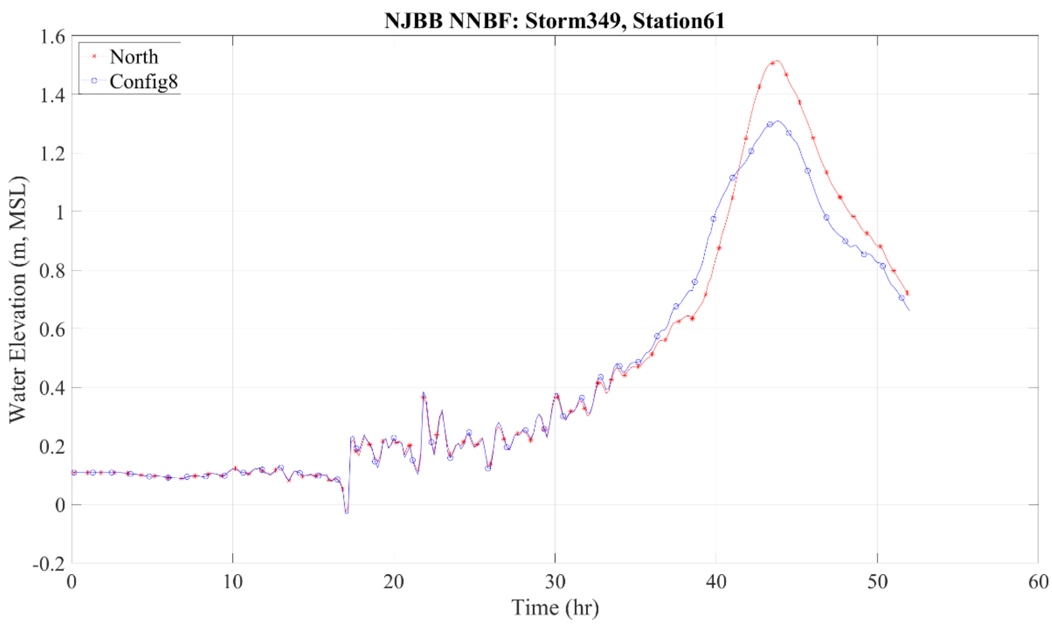

Figure 69 Storm 349 hydrograph for save point 61 "behind" Holgate area with and without NNBF

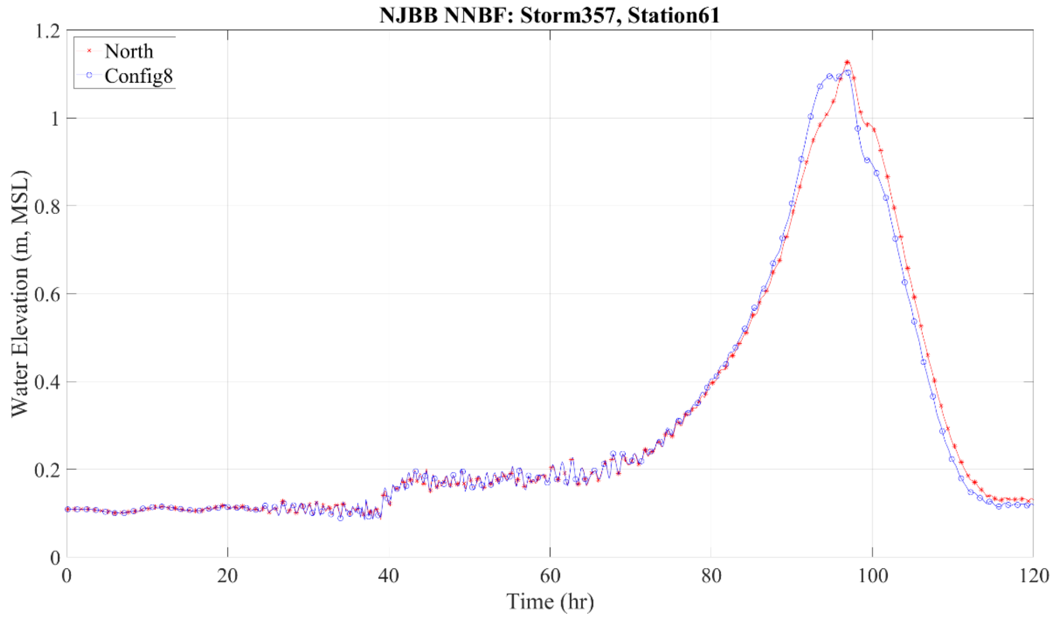

Figure 70 Storm 357 hydrograph for save point 61 "behind" Holgate area with and without NNBF

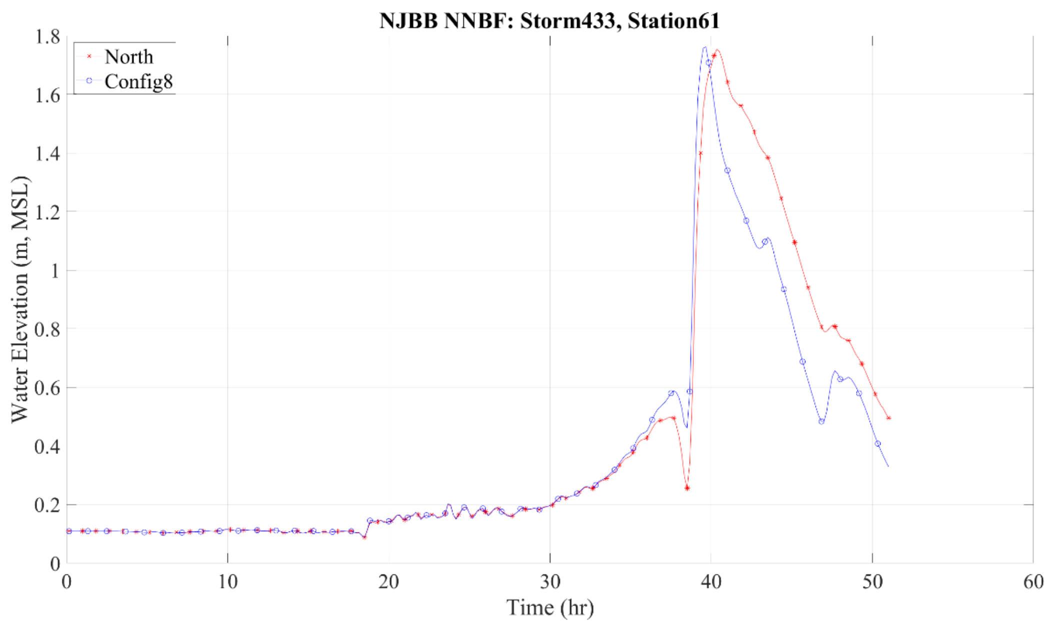

Figure 71 Storm 433 hydrograph for save point 61 "behind" Holgate area with and without NNBF

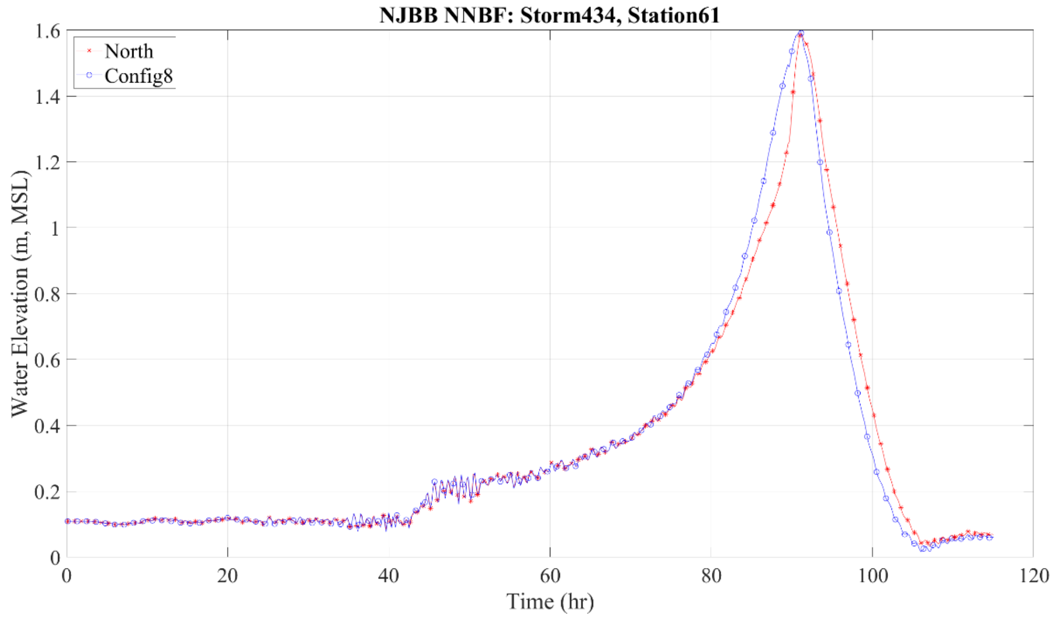

Figure 72 Storm 434 hydrograph for save point 61 "behind" Holgate area with and without NNBF

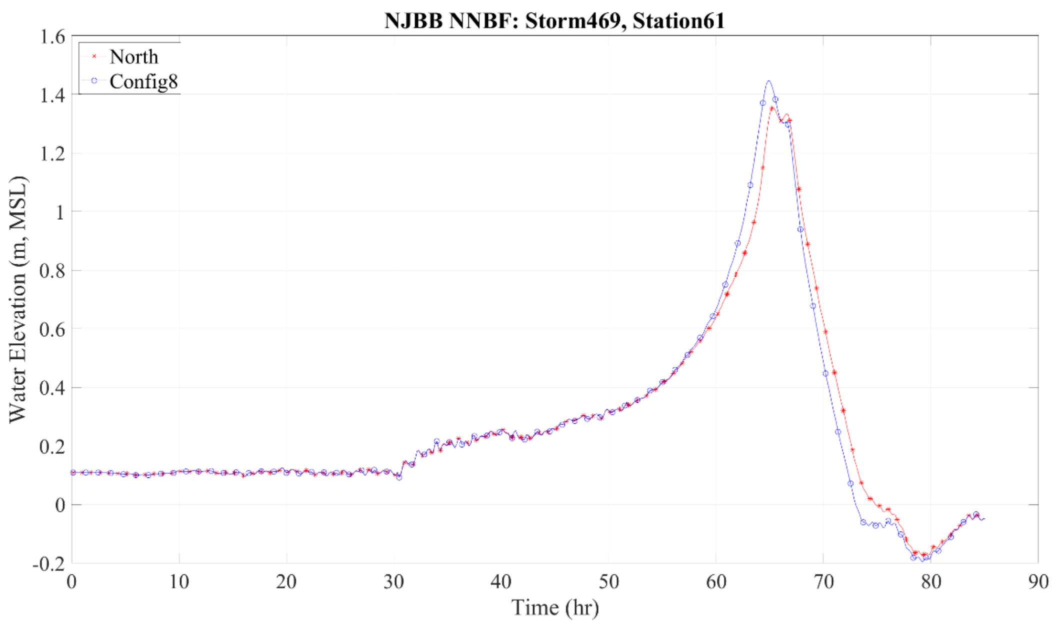

Figure 73 Storm 469 hydrograph for save point 61 "behind" Holgate area with and without NNBF

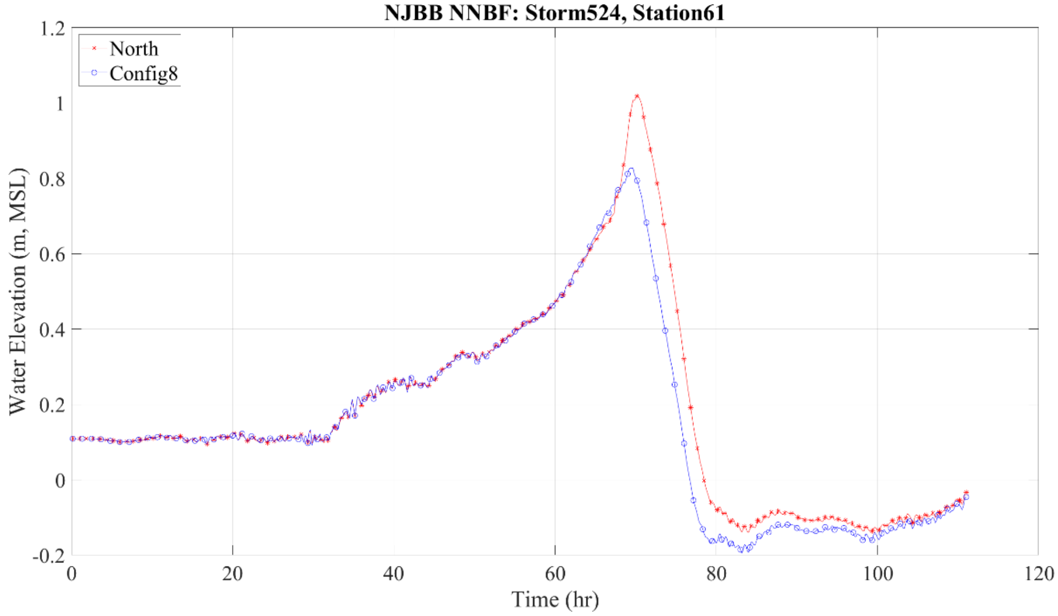

Figure 74 Storm 524 hydrograph for save point 61 "behind" Holgate area with and without NNBF

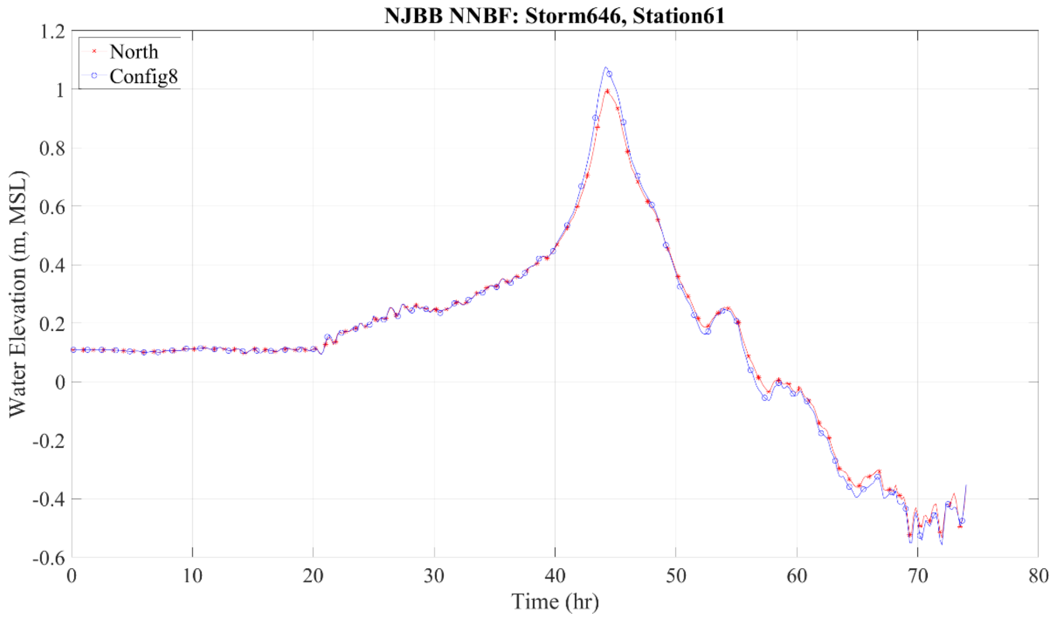

Figure 75 Storm 646 hydrograph for save point 61 "behind" Holgate area with and without NNBF

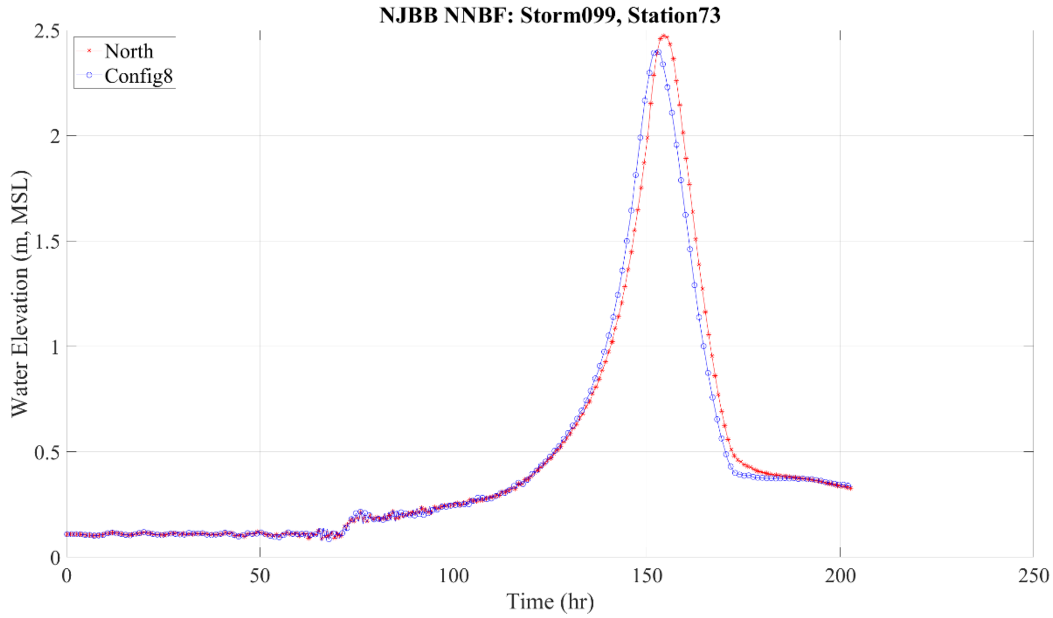

Figure 76 Storm 99 hydrograph for save point 73 "behind" Holgate area with and without NNBF

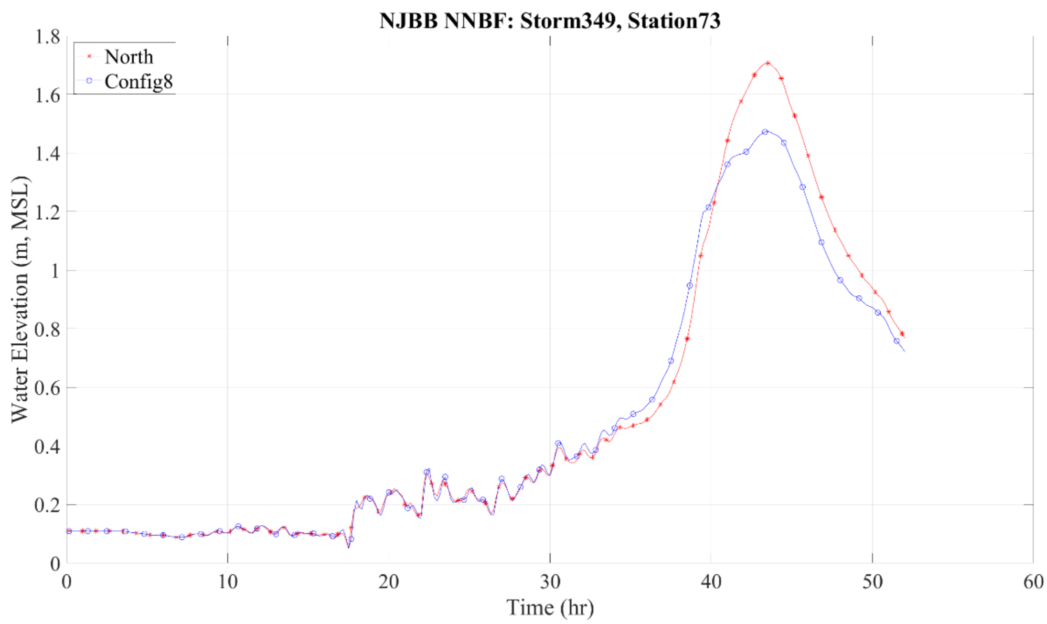

Figure 77 Storm 349 hydrograph for save point 73 "behind" Holgate area with and without NNBF

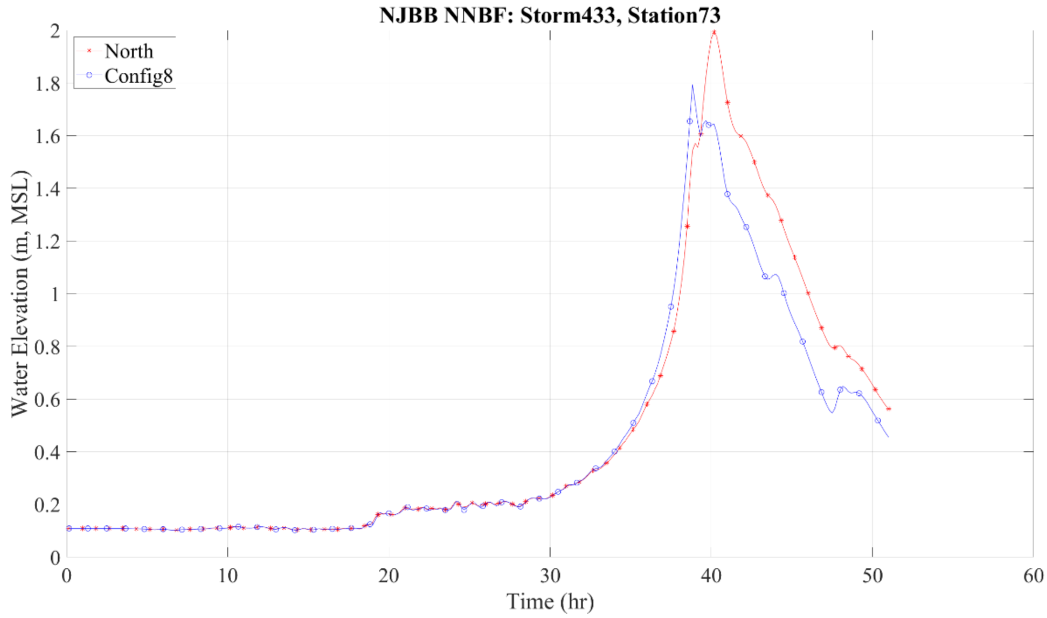

Figure 78 Storm 433 hydrograph for save point 73 "behind" Holgate area with and without NNBF

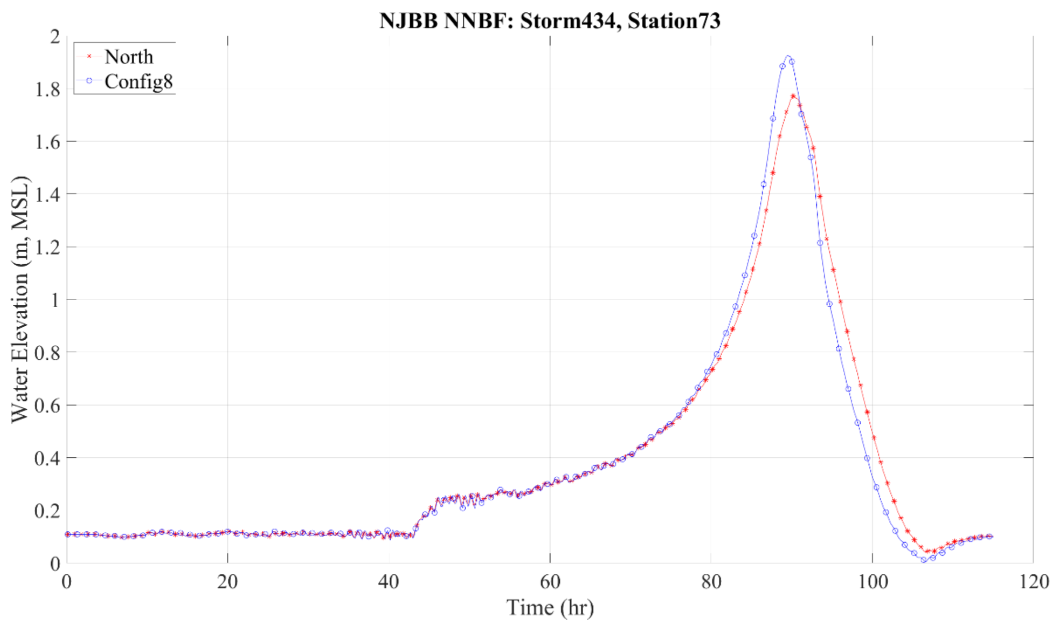

Figure 79 Storm 434 hydrograph for save point 73 "behind" Holgate area with and without NNBF

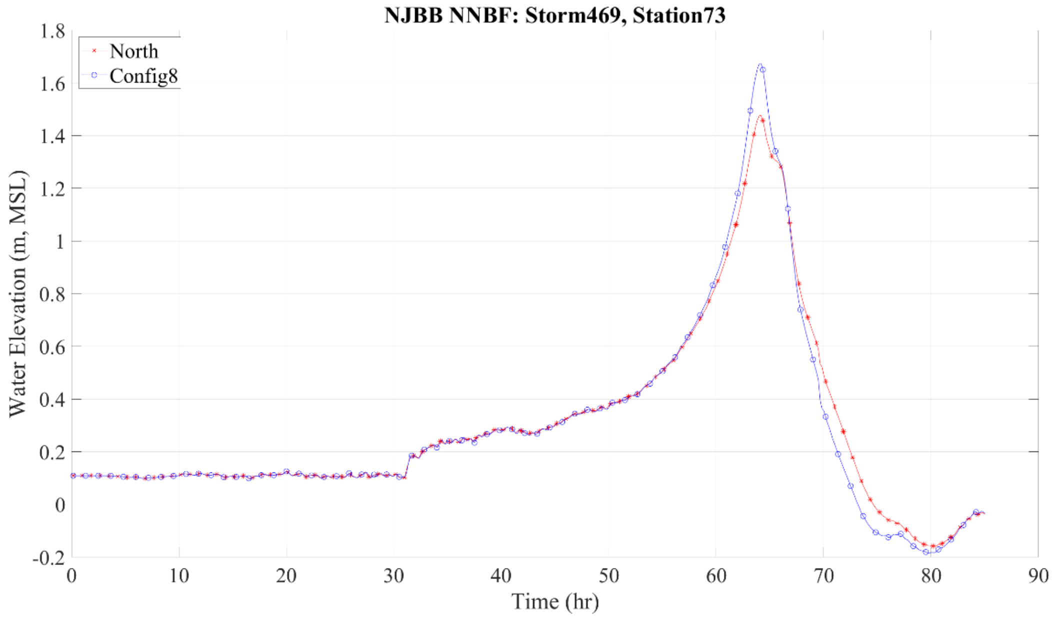

Figure 80 Storm 469 hydrograph for save point 73 "behind" Holgate area with and without NNBF

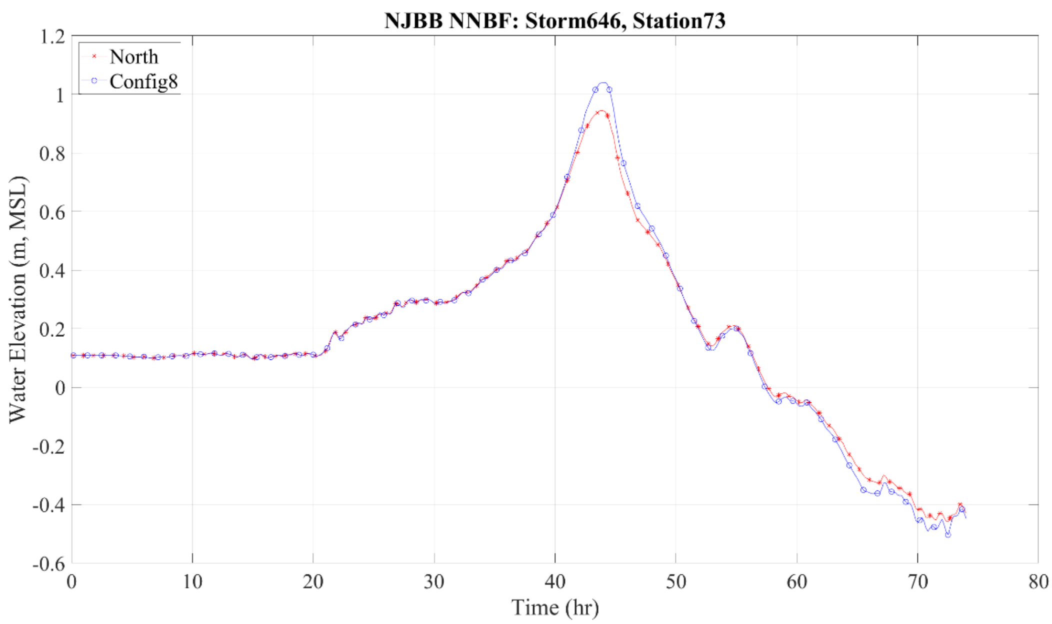

Figure 81 Storm 646 hydrograph for save point 73 "behind" Holgate area with and without NNBF

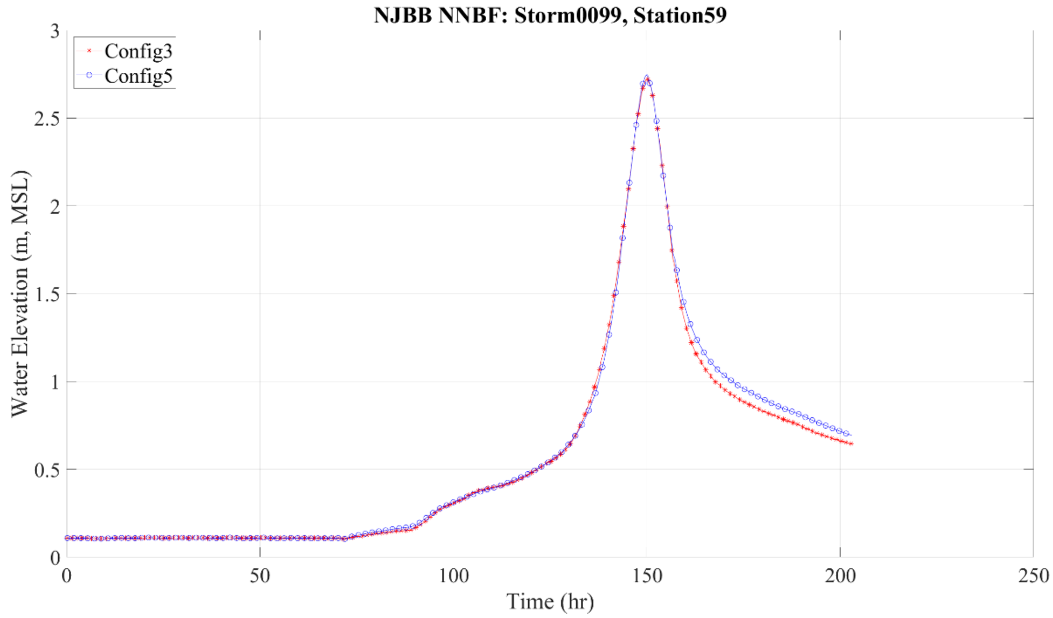

Figure 82 Storm 99 hydrograph for save point 59 "in front of" Brigantine area with and without NNBF

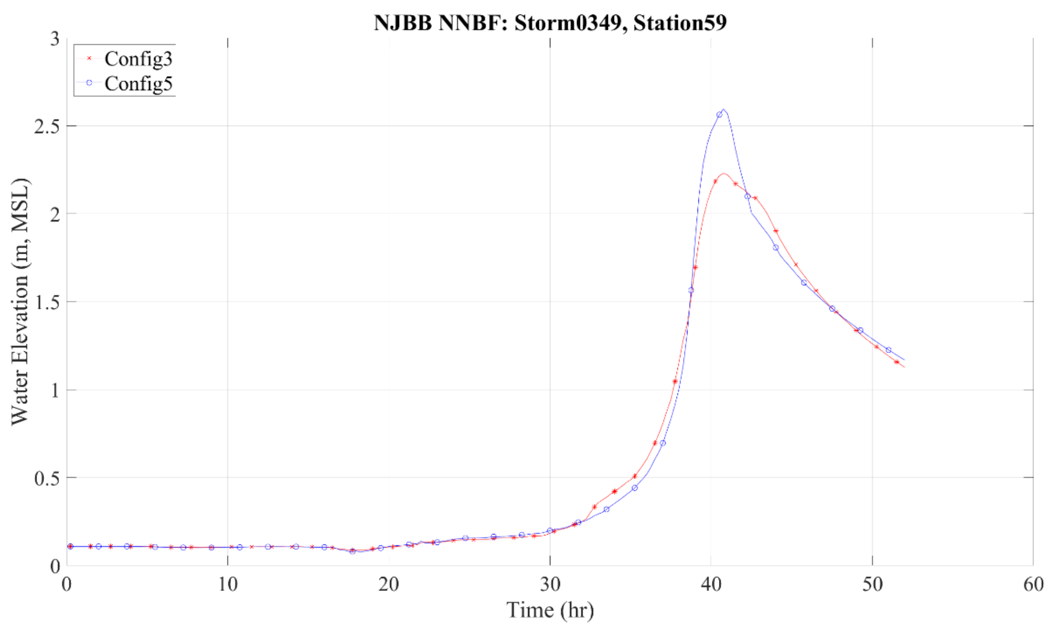

Figure 83 Storm 349 hydrograph for save point 59 "in front of" Brigantine area with and without NNBF

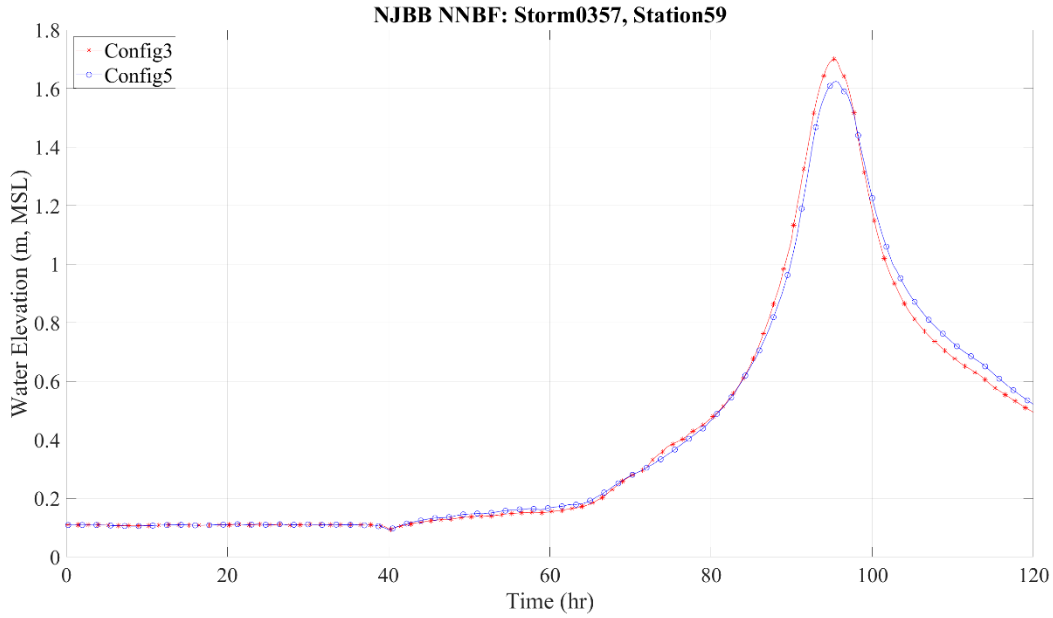

Figure 84 Storm 357 hydrograph for save point 59 "in front of" Brigantine area with and without NNBF

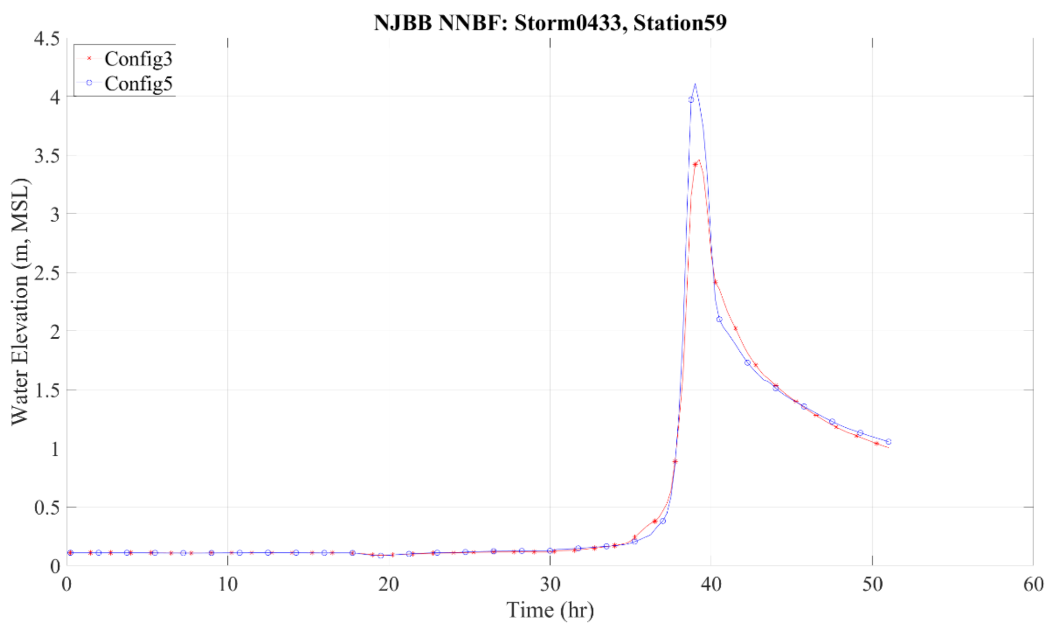

Figure 85 Storm 433 hydrograph for save point 59 "in front of" Brigantine area with and without NNBF

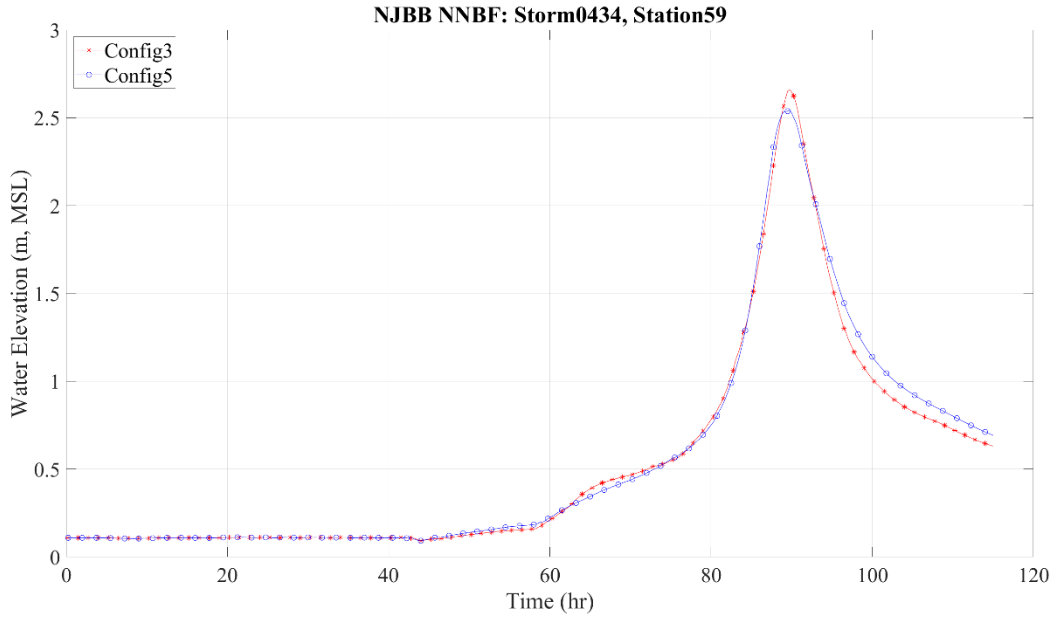

Figure 86 Storm 434 hydrograph for save point 59 "in front of" Brigantine area with and without NNBF

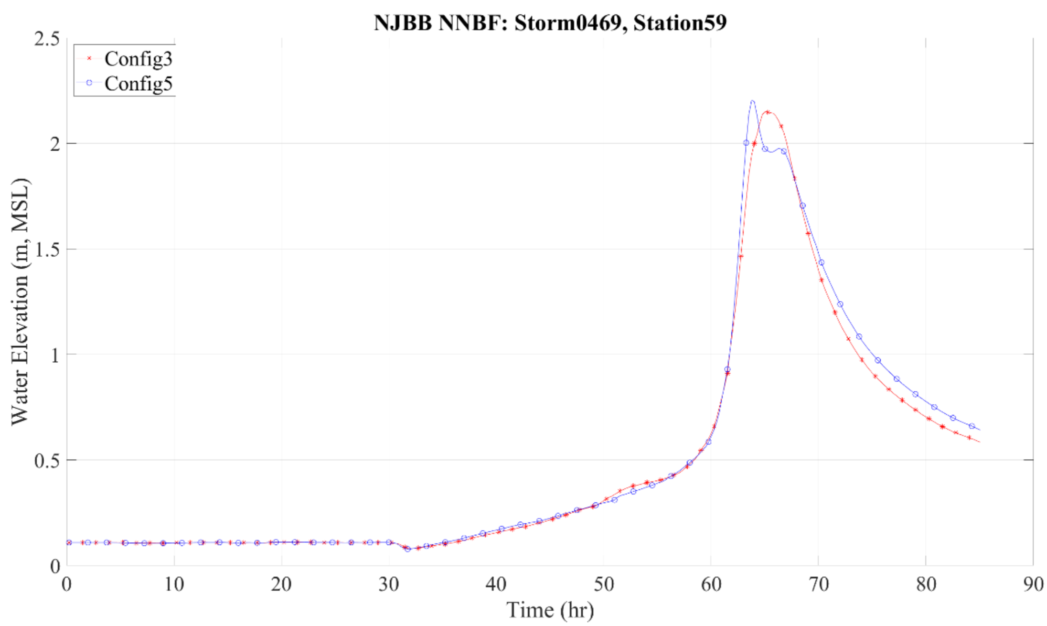

Figure 87 Storm 469 hydrograph for save point 59 "in front of" Brigantine area with and without NNBF

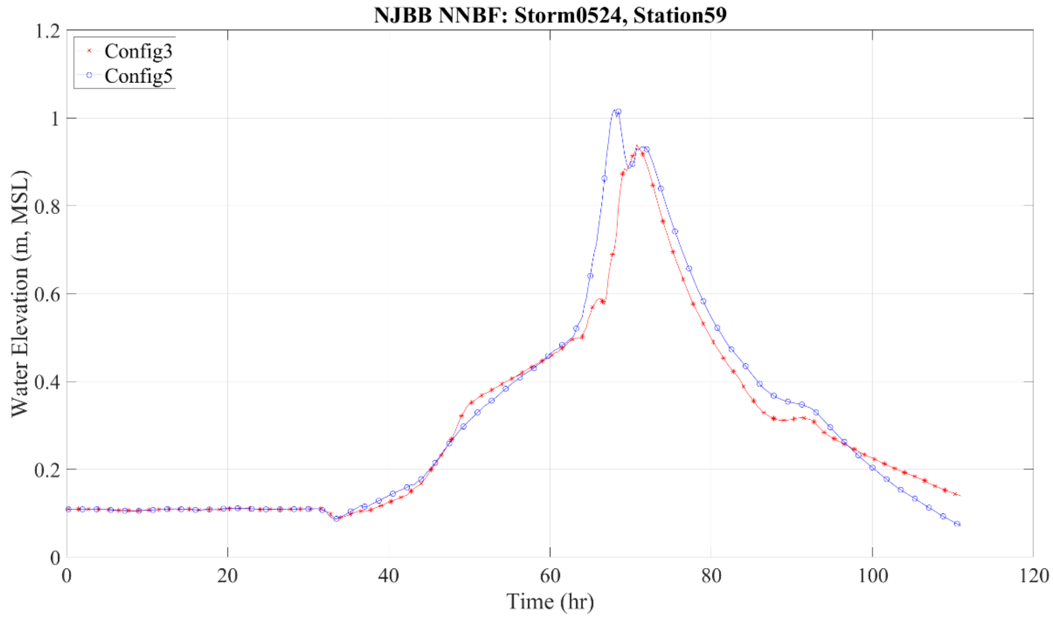

Figure 88 Storm 524 hydrograph for save point 59 "in front of" Brigantine area with and without NNBF

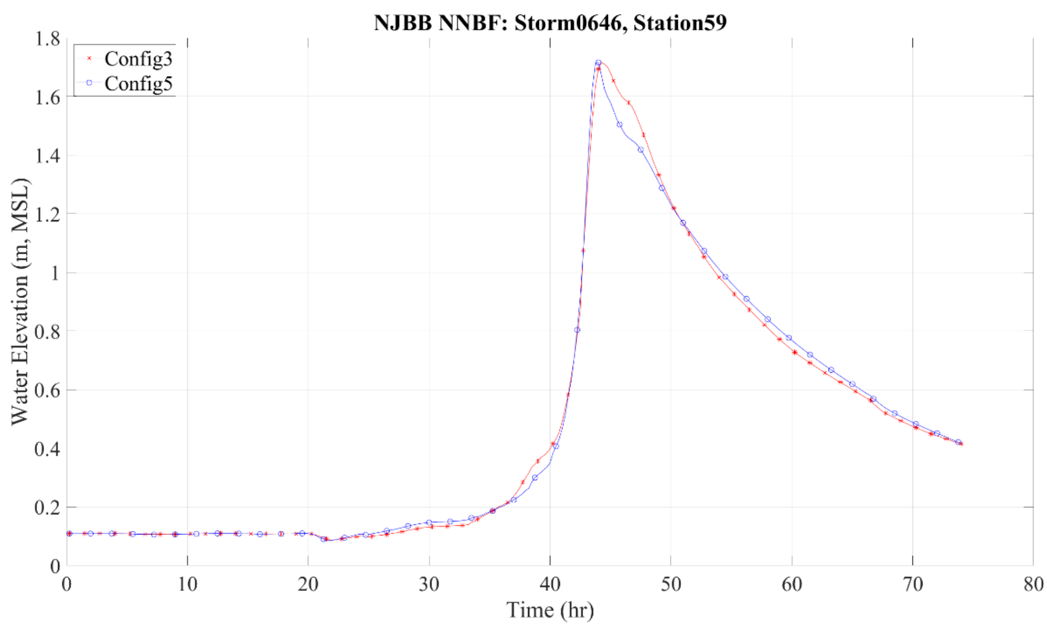

Figure 89 Storm 646 hydrograph for save point 59 "in front of" Brigantine area with and without NNBF

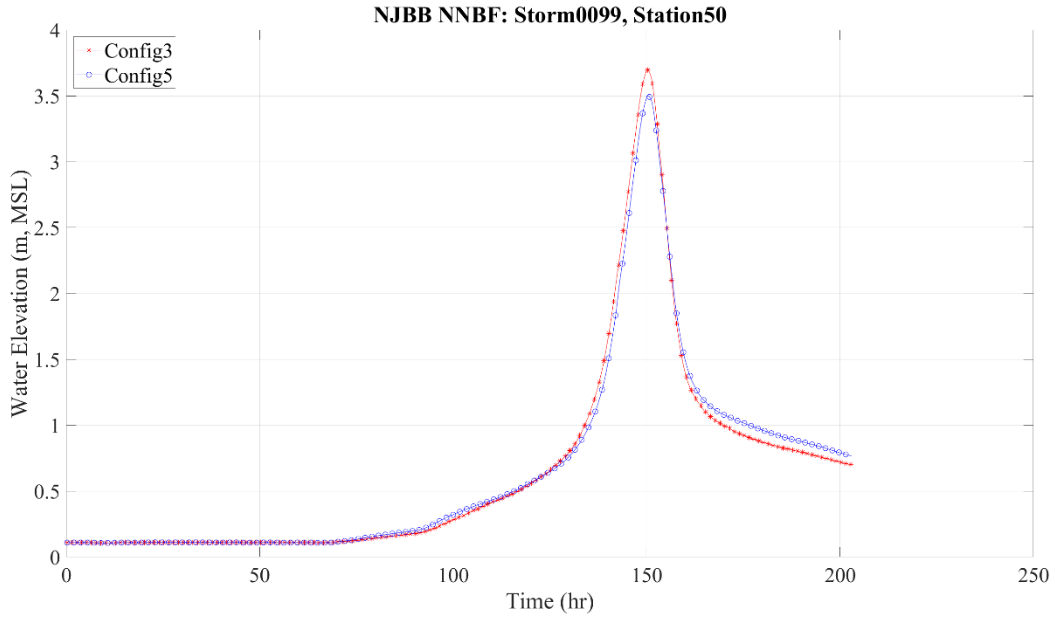

Figure 90 Storm 99 hydrograph for save point 50 "behind" Brigantine area with and without NNBF

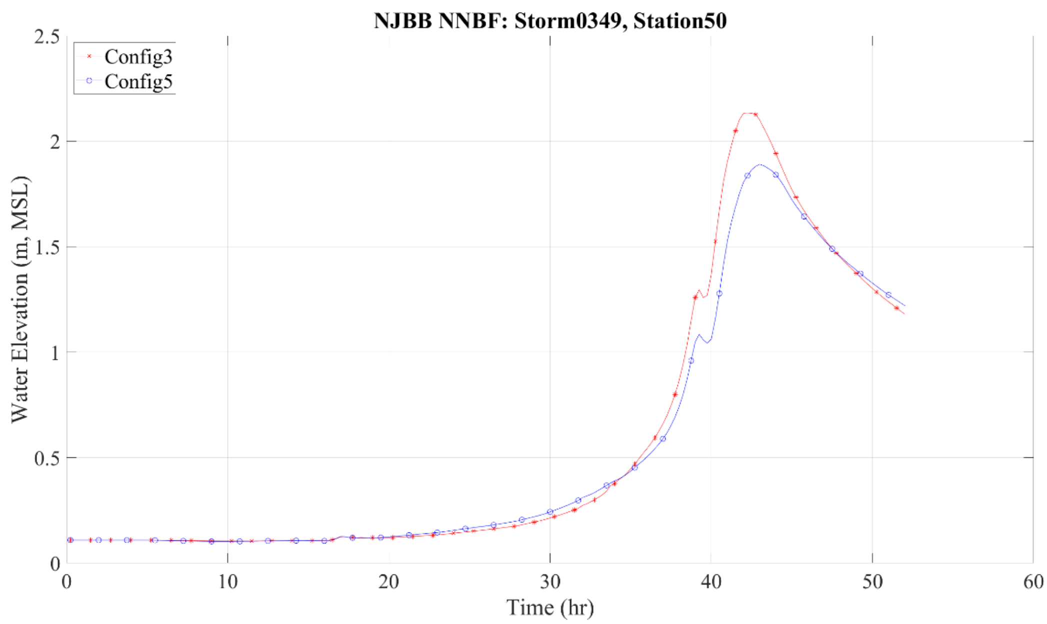

Figure 91 Storm 349 hydrograph for save point 50 "behind" Brigantine area with and without NNBF

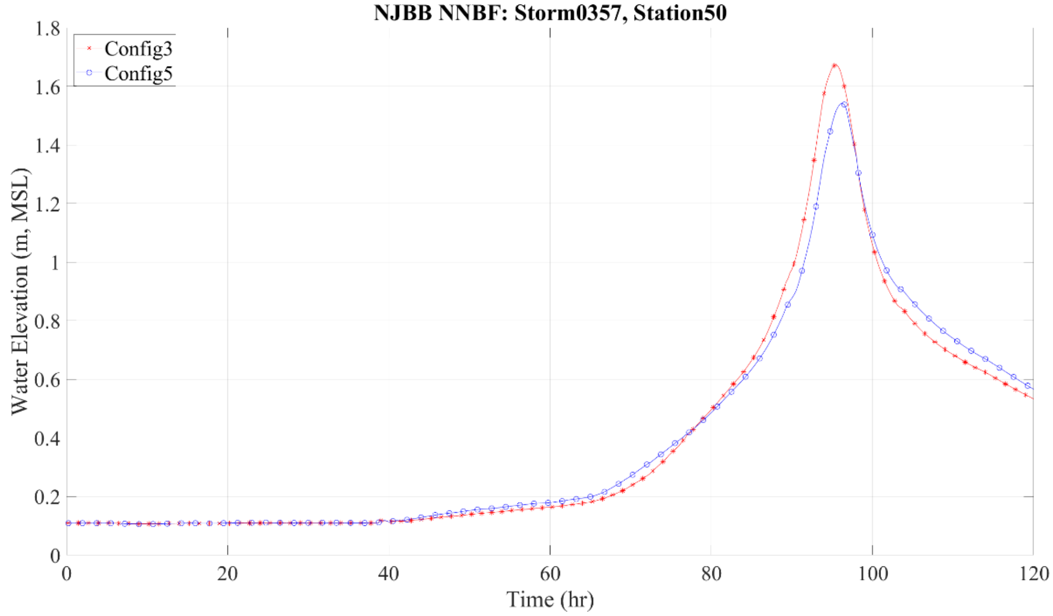

Figure 92 Storm 357 hydrograph for save point 50 "behind" Brigantine area with and without NNBF

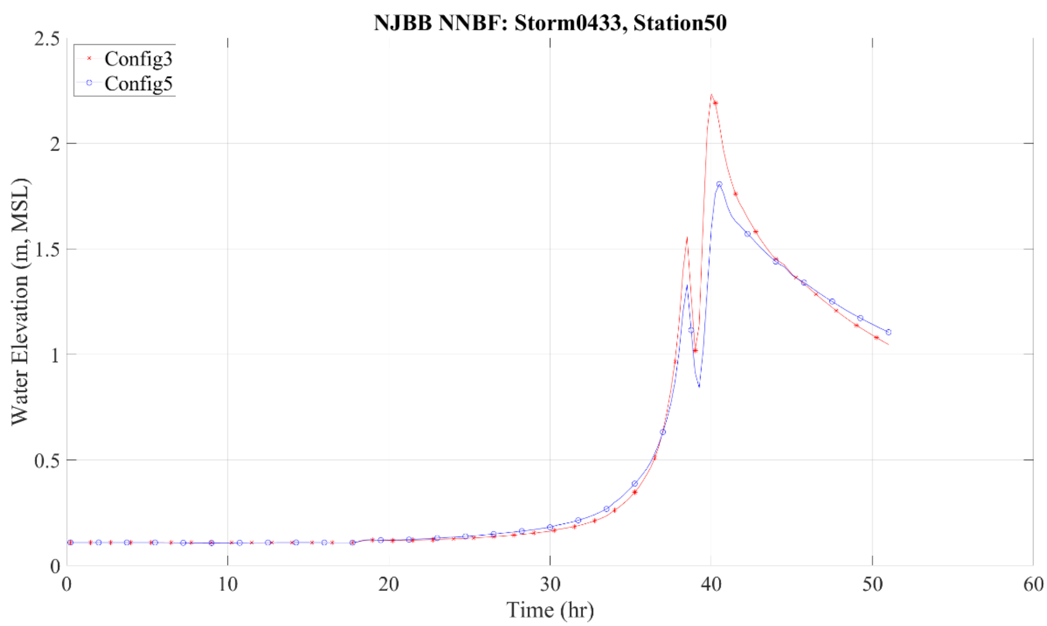

Figure 93 Storm 433 hydrograph for save point 50 "behind" Brigantine area with and without NNBF

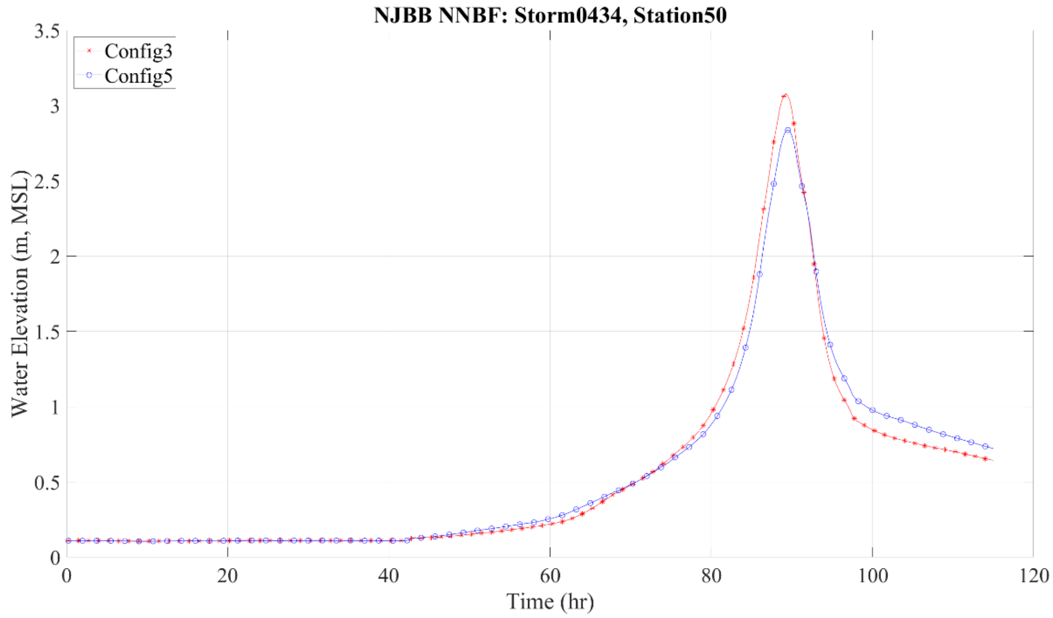

Figure 94 Storm 434 hydrograph for save point 50 "behind" Brigantine area with and without NNBF

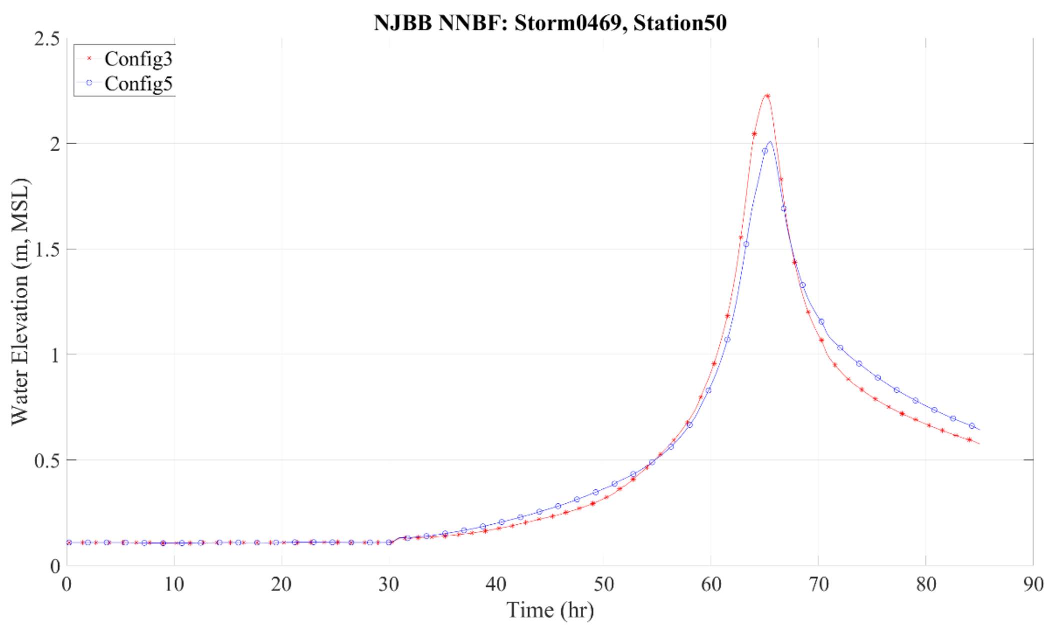

Figure 95 Storm 469 hydrograph for save point 50 "behind" Brigantine area with and without NNBF

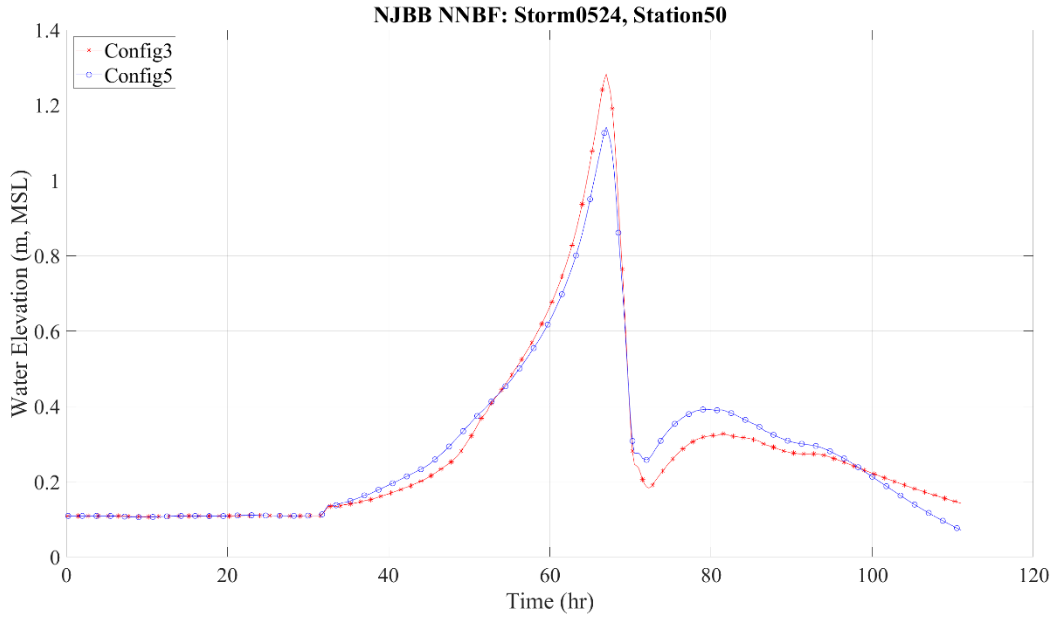

Figure 96 Storm 524 hydrograph for save point 50 "behind" Brigantine area with and without NNBF

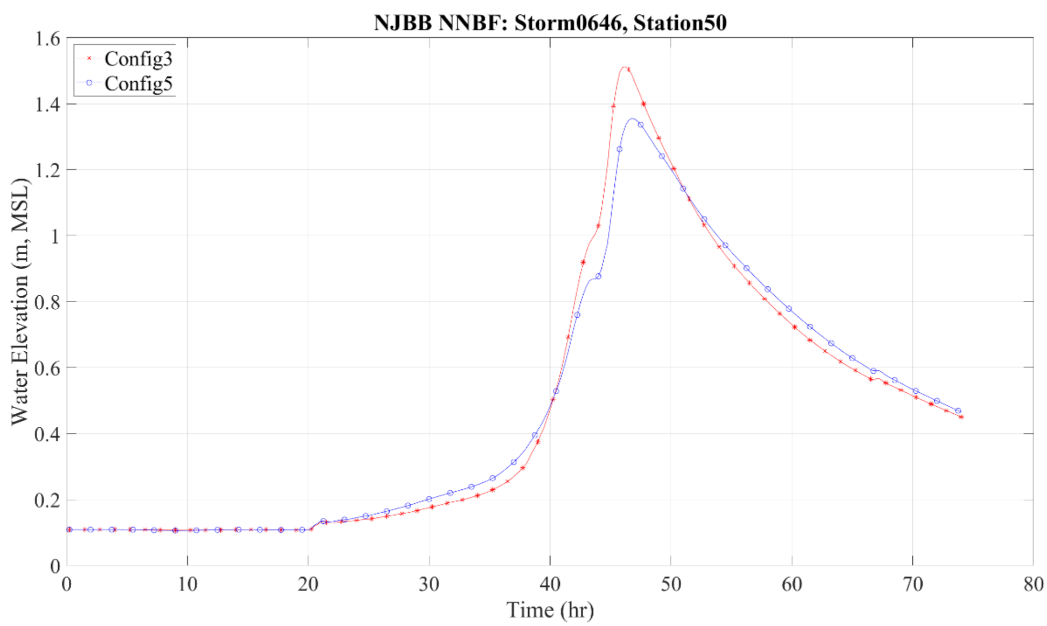

Figure 97 Storm 646 hydrograph for save point 50 "behind" Brigantine area with and without NNBF

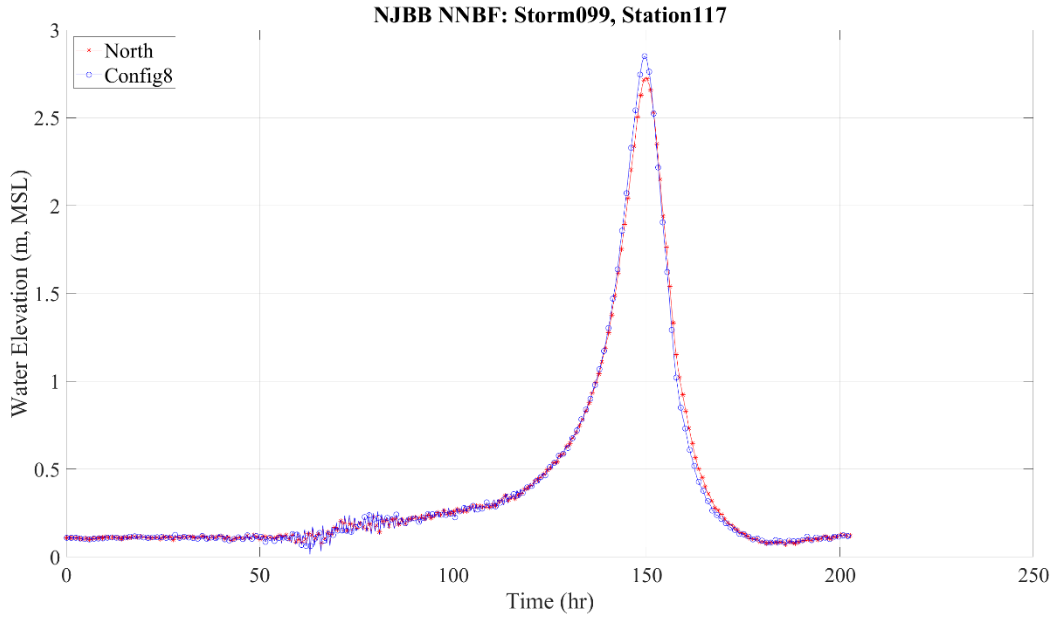

Figure 98 Storm 99 hydrograph for save point 117 "in front of" Great Egg Harbor area with and without NNBF

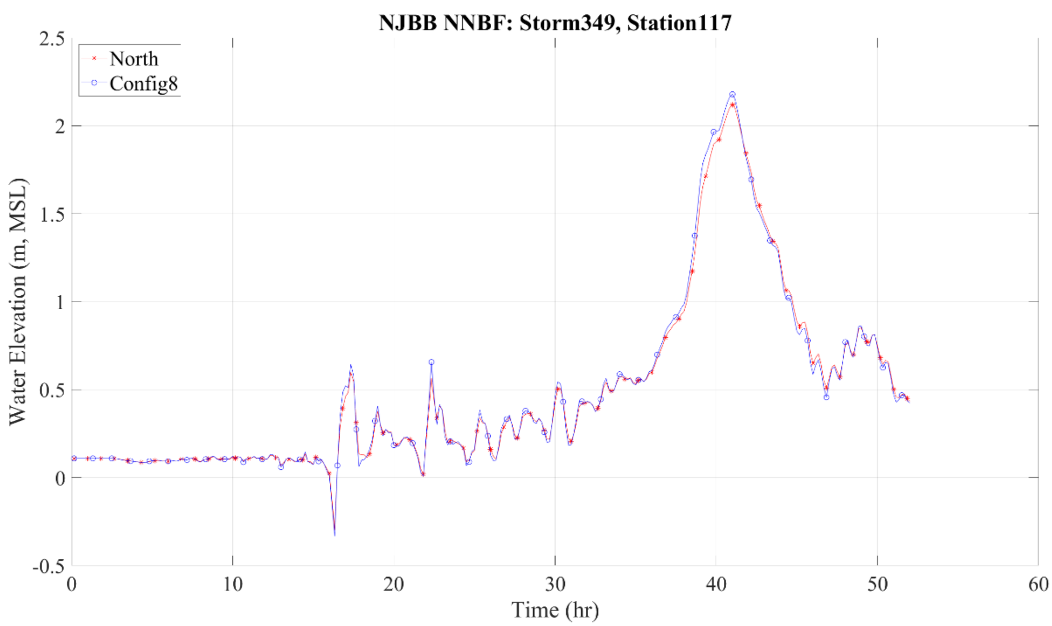

Figure 99 Storm 349 hydrograph for save point 117 "in front of" Great Egg Harbor area with and without NNBF

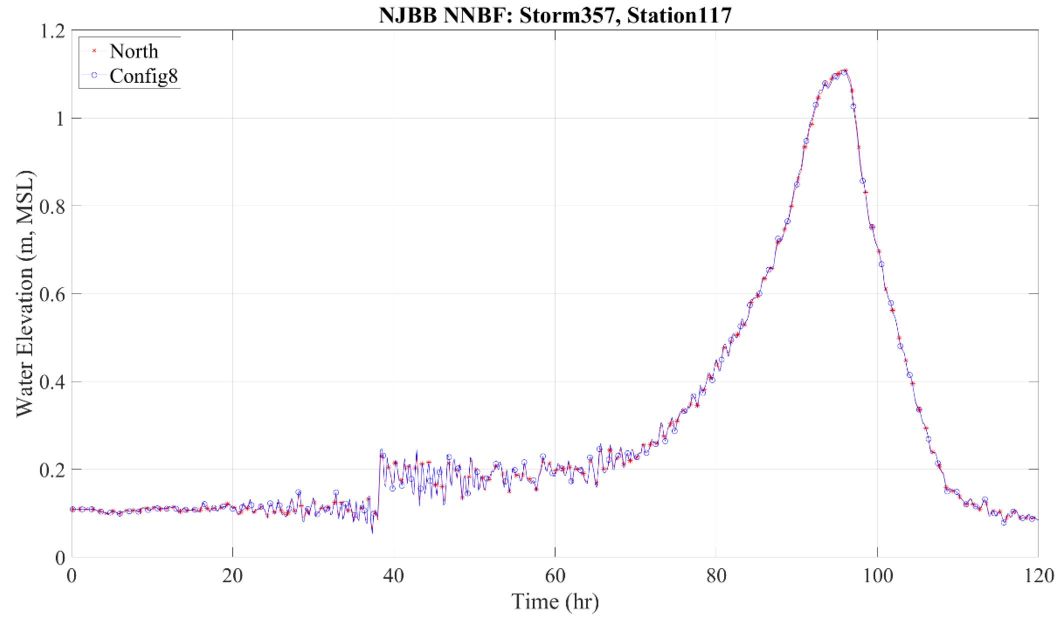

Figure 100 Storm 357 hydrograph for save point 117 "in front of" Great Egg Harbor area with and without NNBF

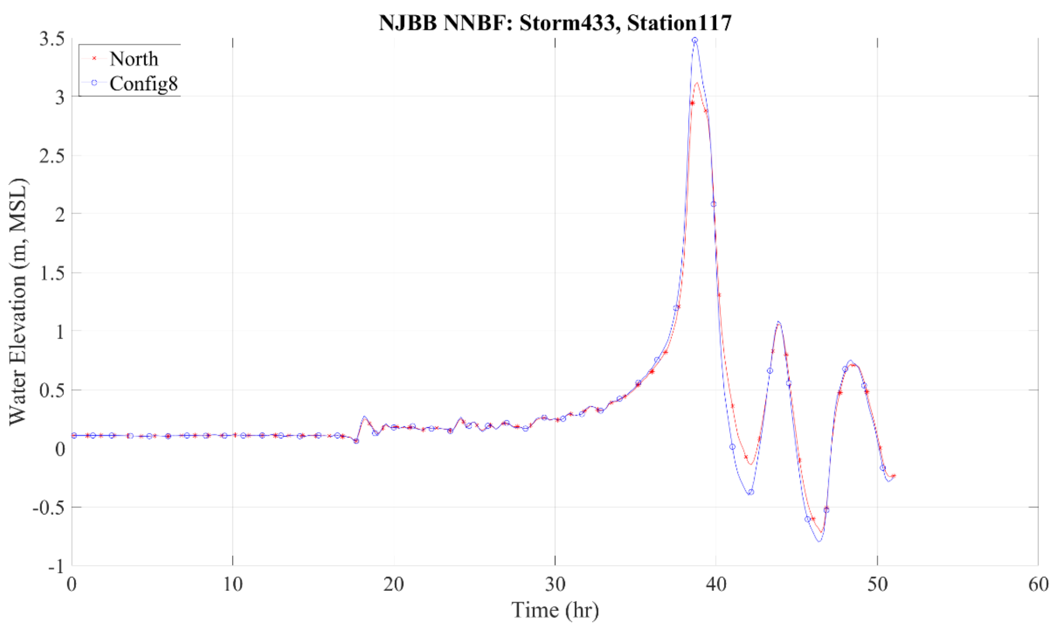

Figure 101 Storm 433 hydrograph for save point 117 "in front of" Great Egg Harbor area with and without NNBF

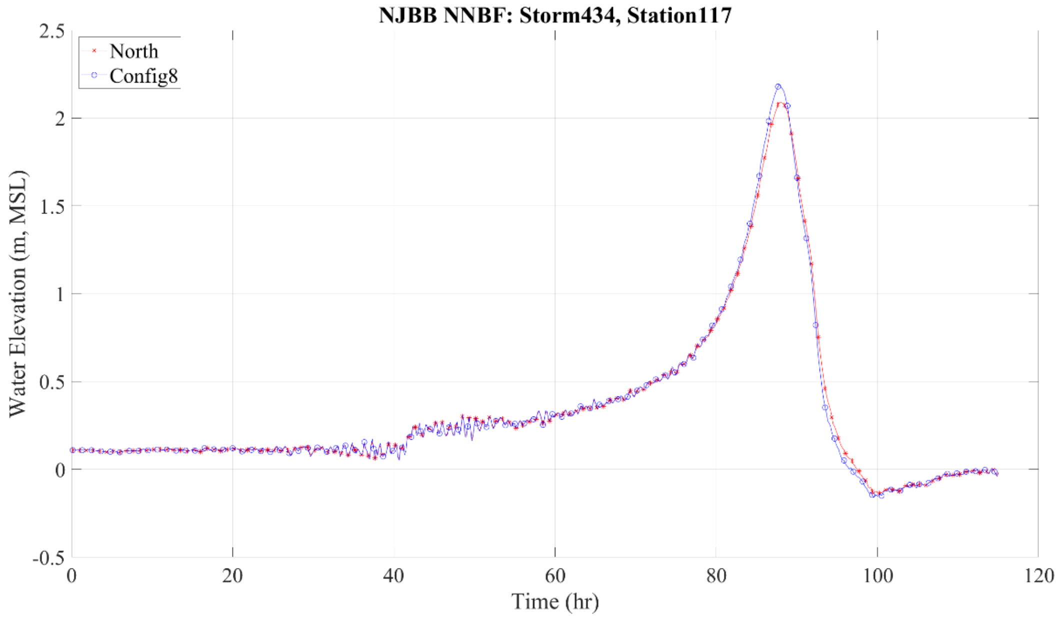

Figure 102 Storm 434 hydrograph for save point 117 "in front of" Great Egg Harbor area with and without NNBF

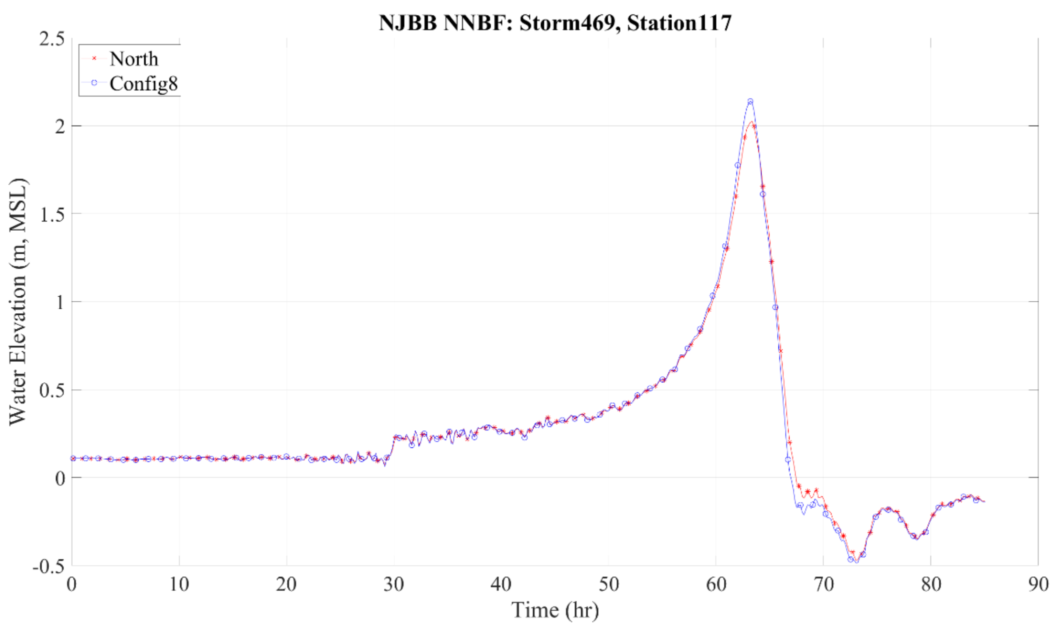

Figure 103 Storm 469 hydrograph for save point 117 "in front of" Great Egg Harbor area with and without NNBF

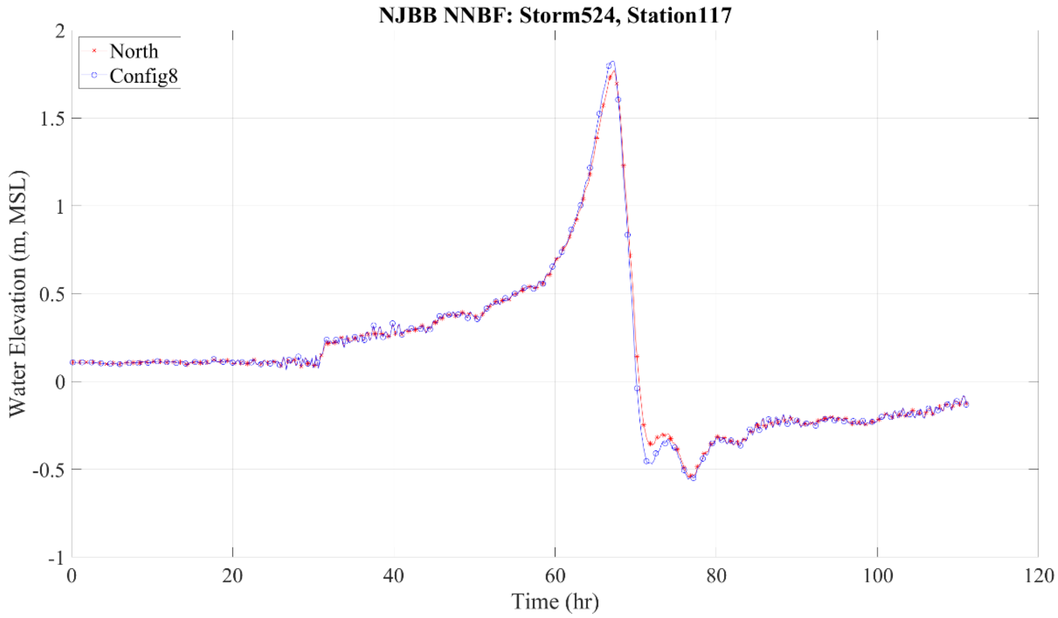

Figure 104 Storm 524 hydrograph for save point 117 "in front of" Great Egg Harbor area with and without NNBF

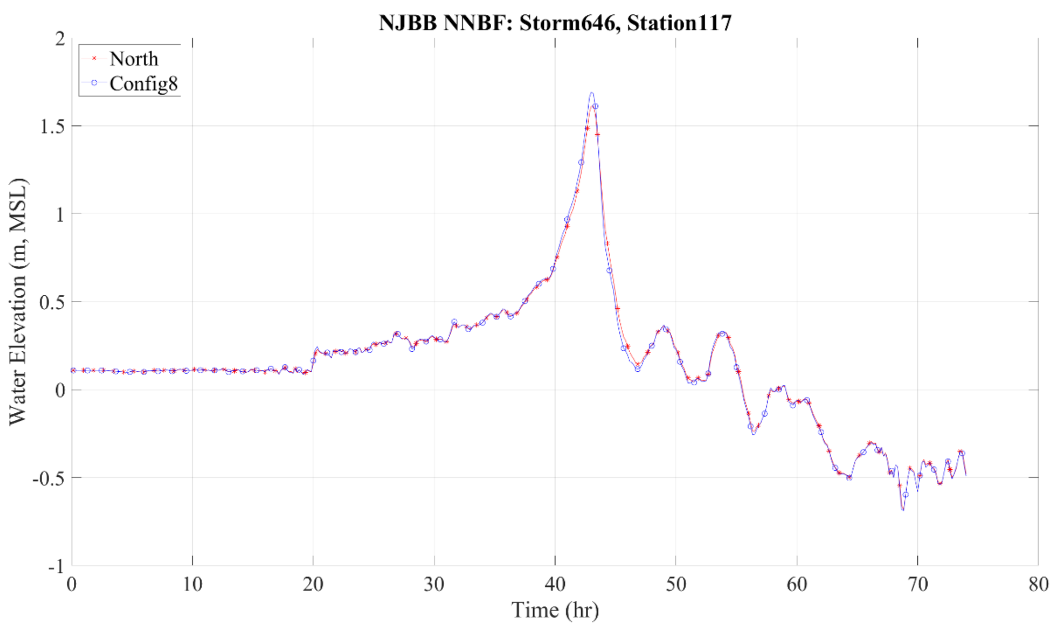

Figure 105 Storm 646 hydrograph for save point 117 "in front of" Great Egg Harbor area with and without NNBF

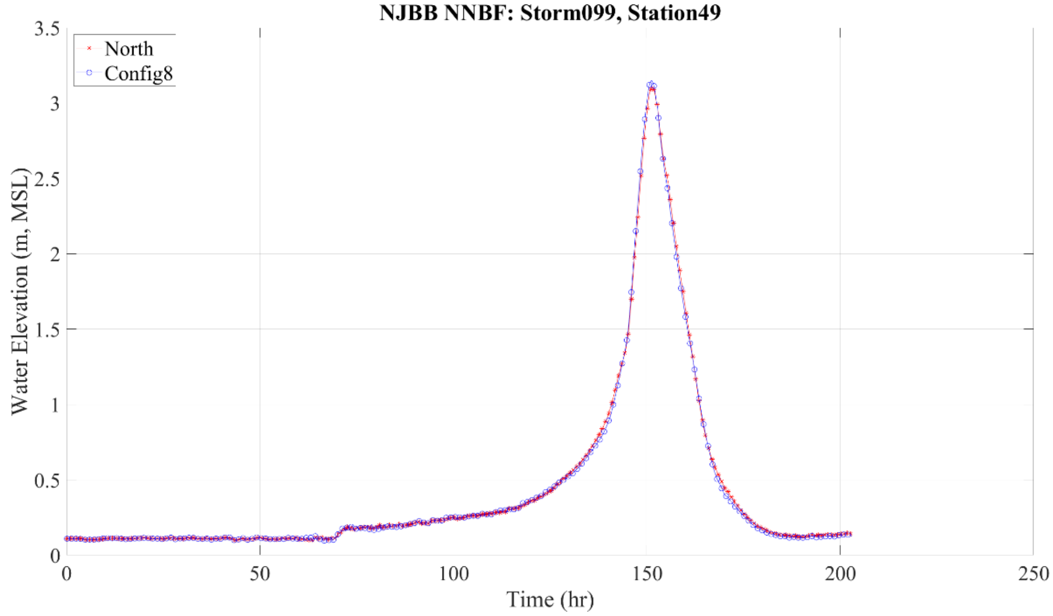

Figure 106 Storm 99 hydrograph for save point 49 "behind" Great Egg Harbor area with and without NNBF

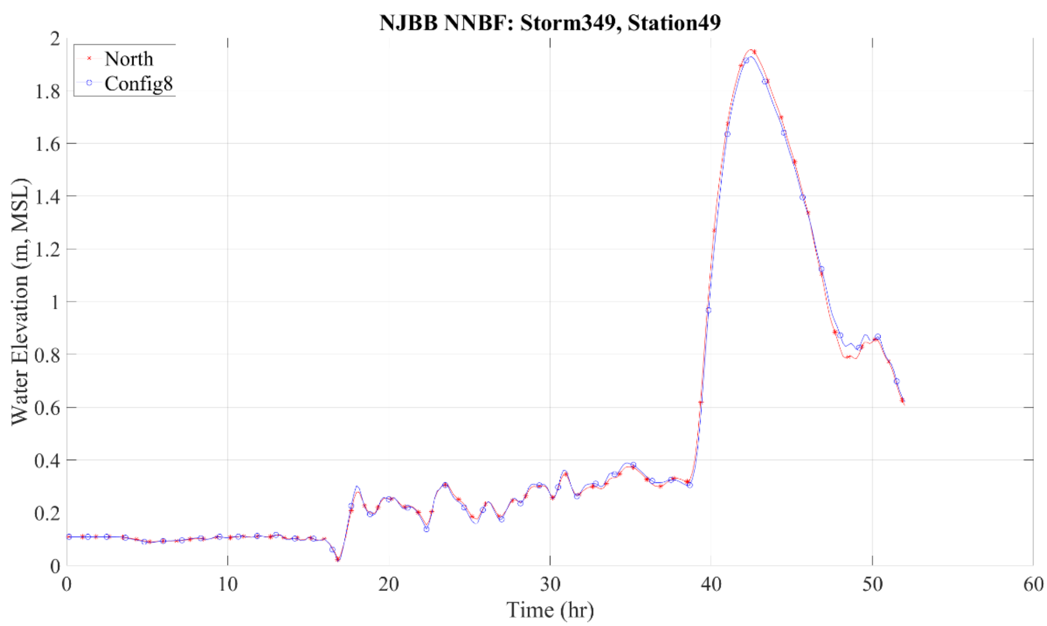

Figure 107 Storm 349 hydrograph for save point 49 "behind" Great Egg Harbor area with and without NNBF

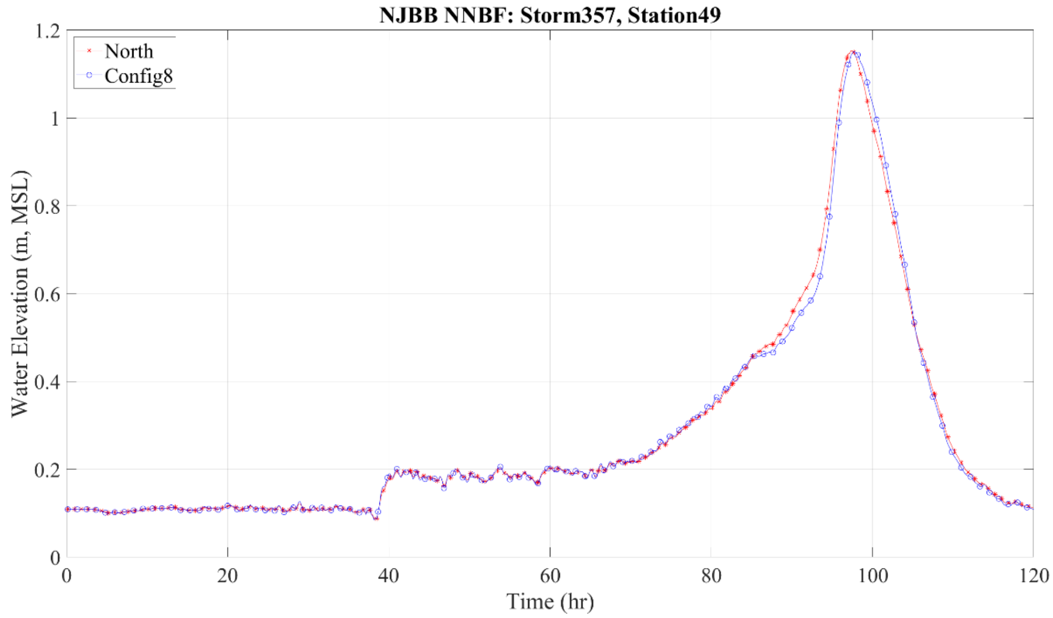

Figure 108 Storm 357 hydrograph for save point 49 "behind" Great Egg Harbor area with and without NNBF

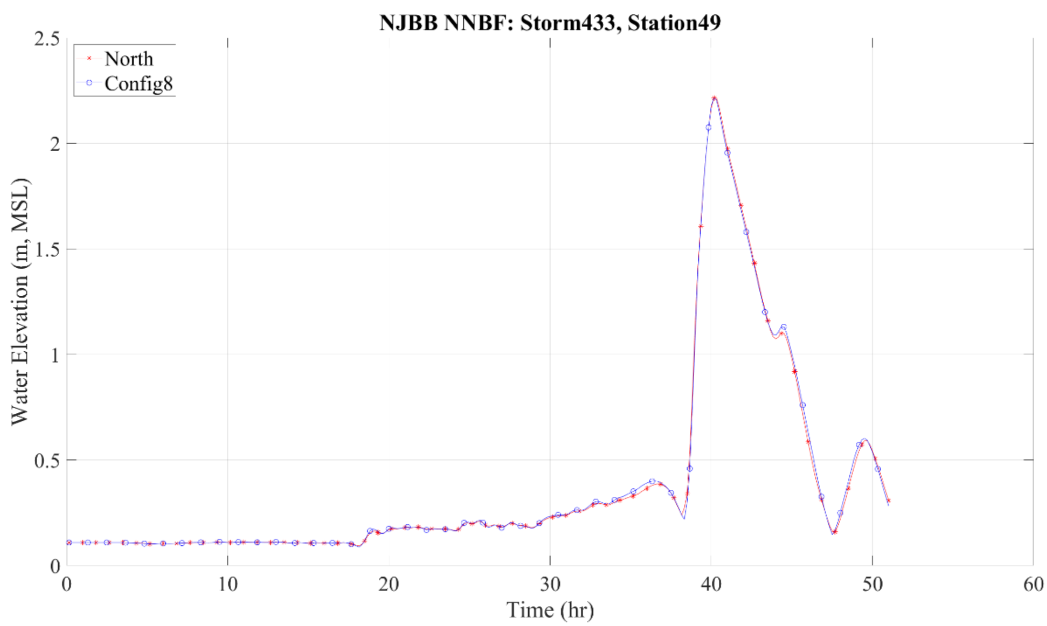

Figure 109 Storm 433 hydrograph for save point 49 "behind" Great Egg Harbor area with and without NNBF

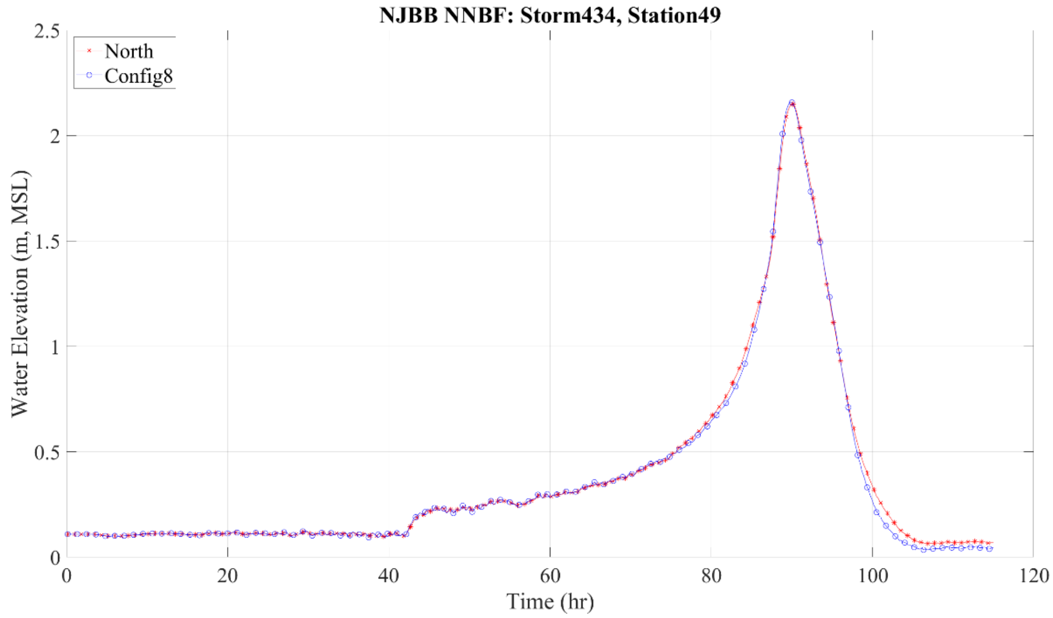

Figure 110 Storm 434 hydrograph for save point 49 "behind" Great Egg Harbor area with and without NNBF

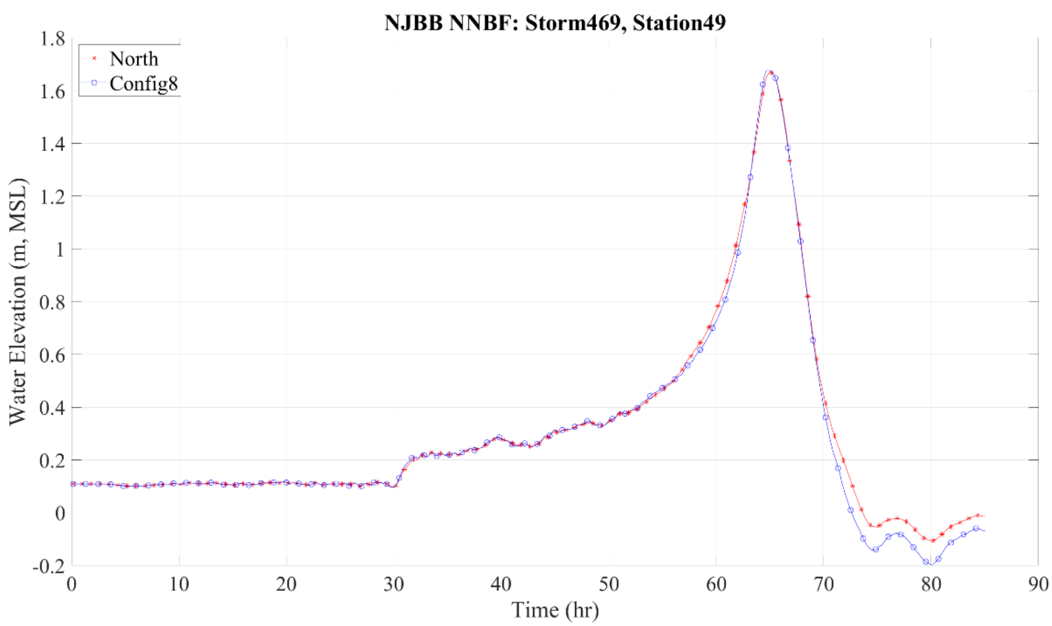

Figure 111 Storm 469 hydrograph for save point 49 "behind" Great Egg Harbor area with and without NNBF

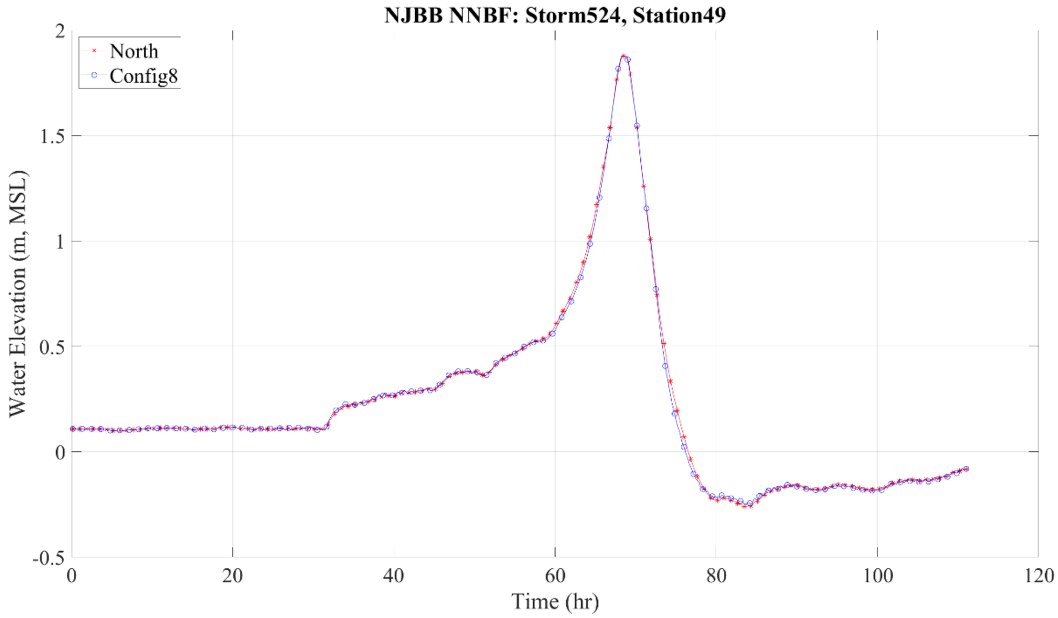

Figure 112 Storm 524 hydrograph for save point 49 "behind" Great Egg Harbor area with and without NNBF

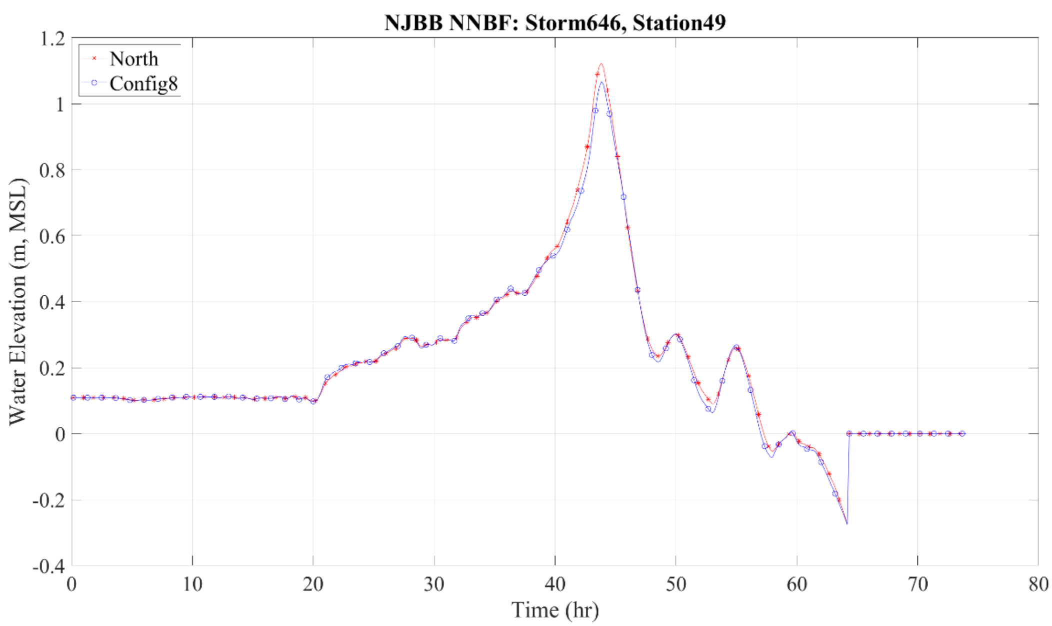

Figure 113 Storm 646 hydrograph for save point 49 "behind" Great Egg Harbor area with and without NNBF

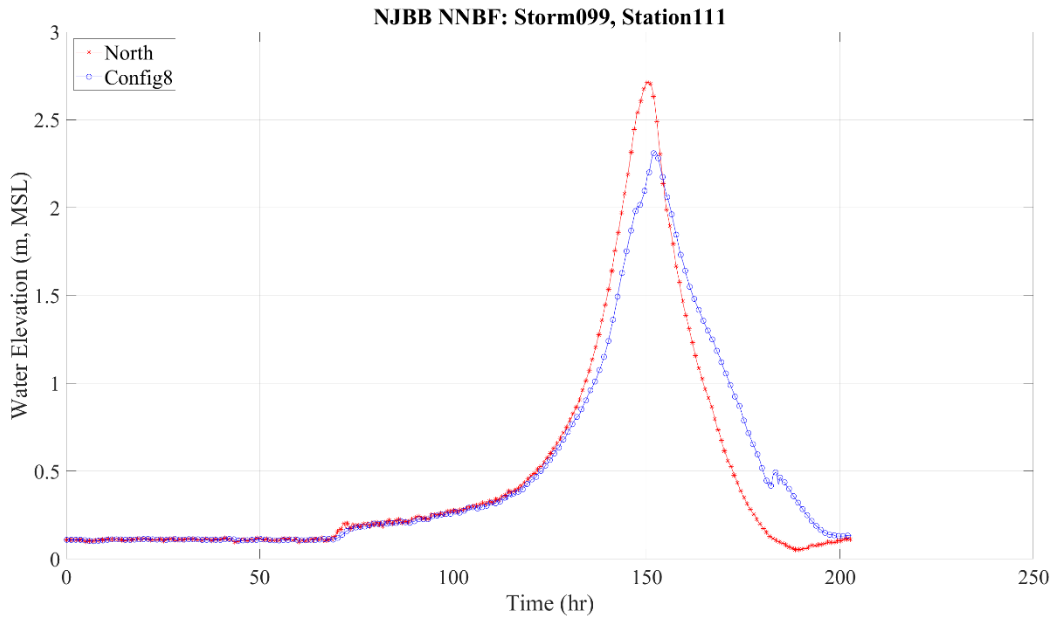

Figure 114 Storm 99 hydrograph for save point 111 "behind" Great Egg Harbor area with and without NNBF

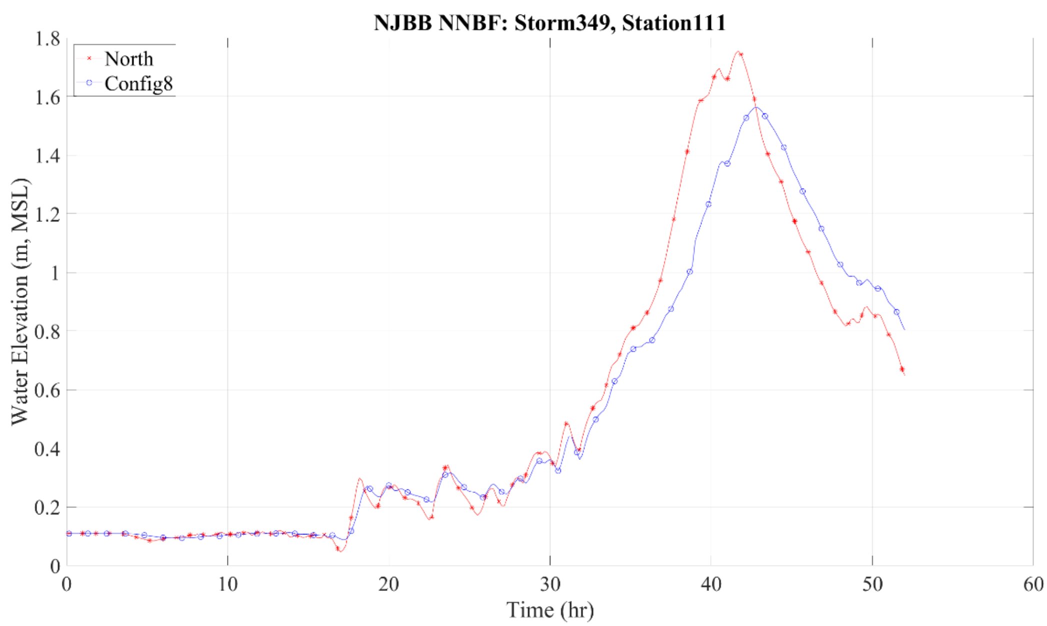

Figure 115 Storm 349 hydrograph for save point 111 "behind" Great Egg Harbor area with and without NNBF

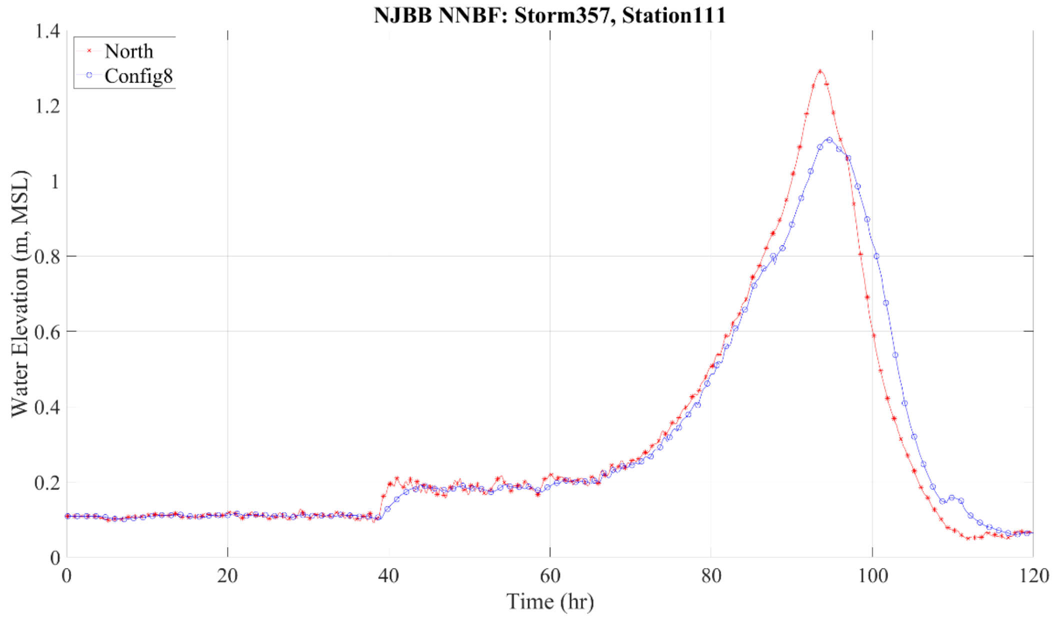

Figure 116 Storm 357 hydrograph for save point 111 "behind" Great Egg Harbor area with and without NNBF

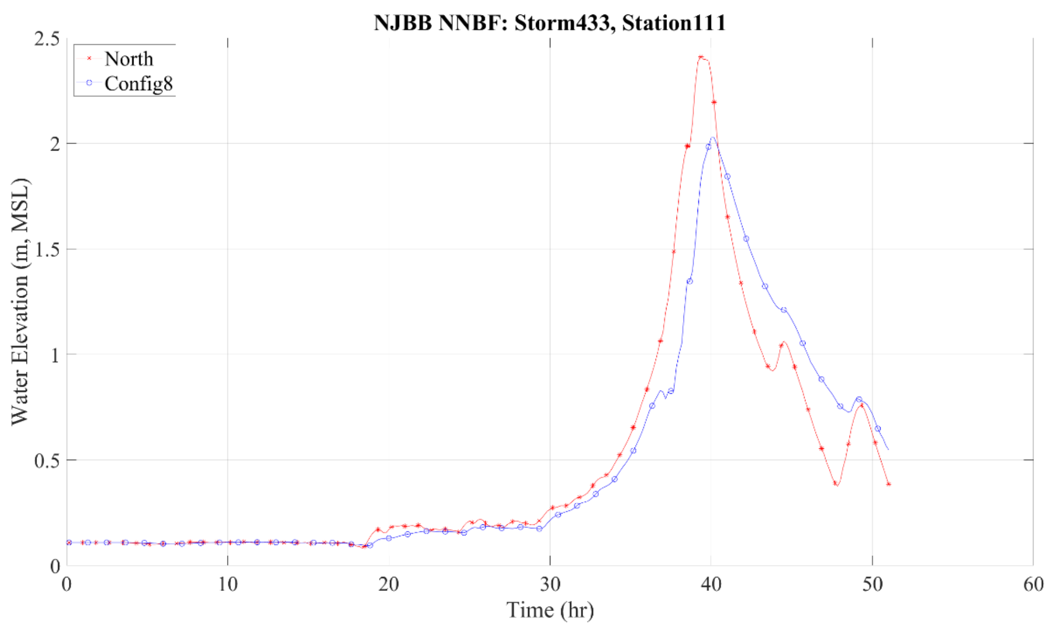

Figure 117 Storm 433 hydrograph for save point 111 "behind" Great Egg Harbor area with and without NNBF

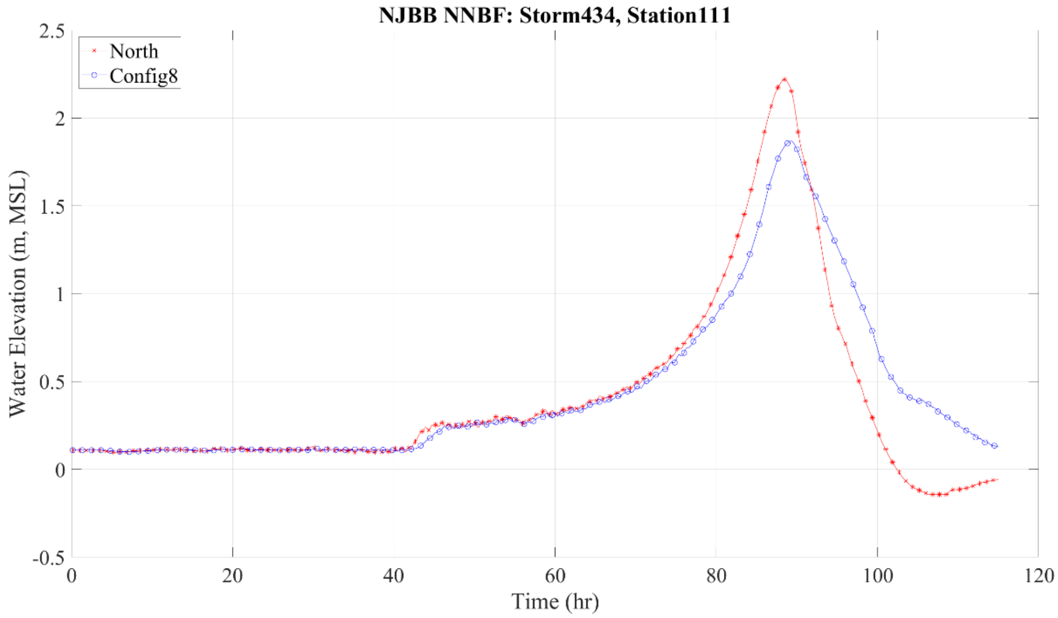

Figure 118 Storm 434 hydrograph for save point 111 "behind" Great Egg Harbor area with and without NNBF

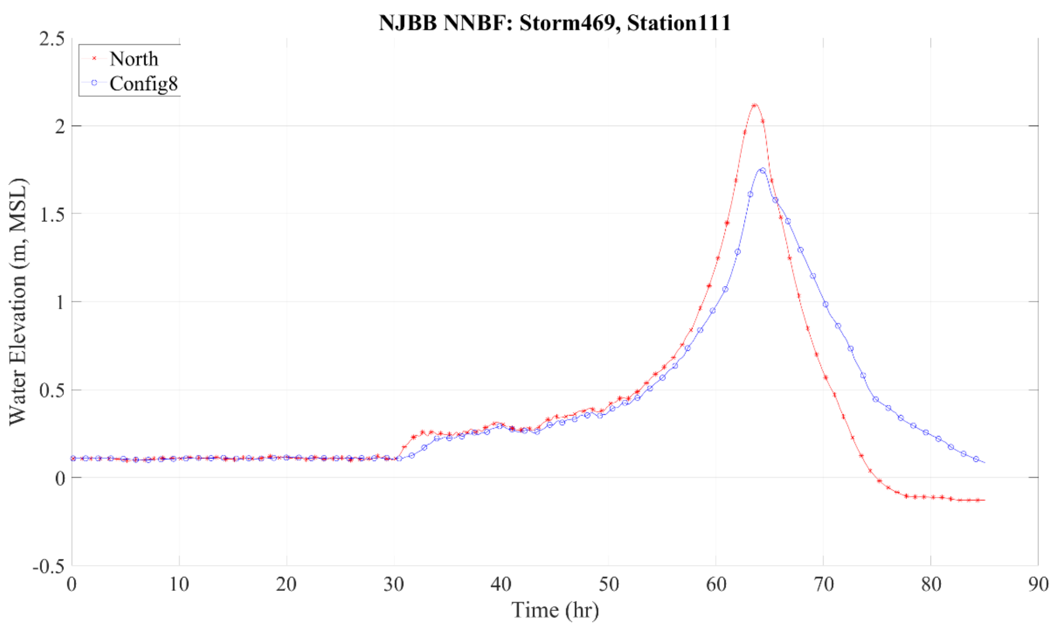

Figure 119 Storm 469 hydrograph for save point 111 "behind" Great Egg Harbor area with and without NNBF

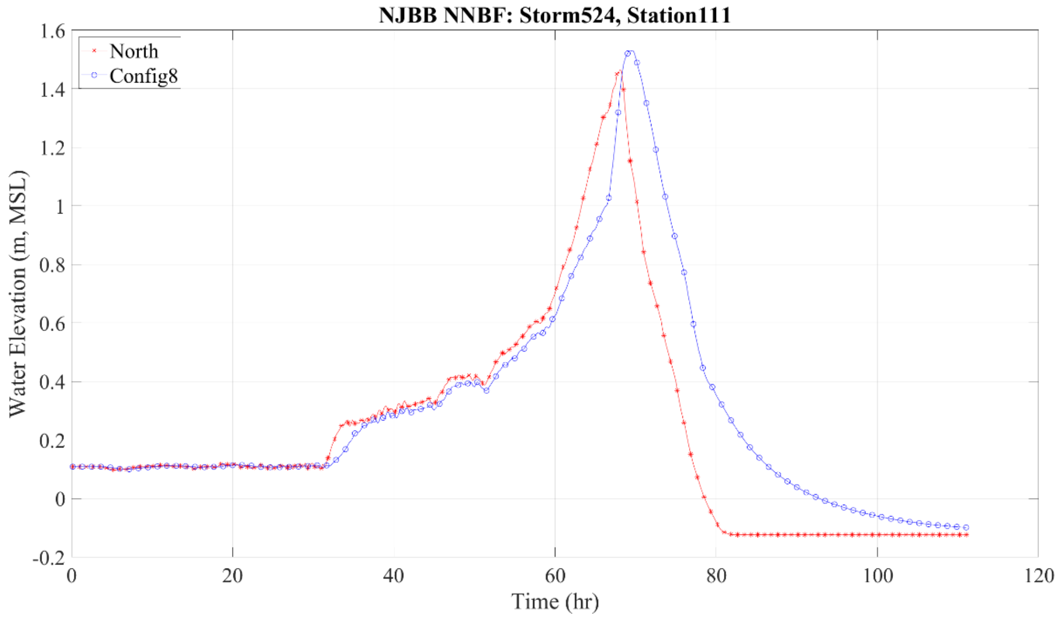

Figure 120 Storm 524 hydrograph for save point 111 "behind" Great Egg Harbor area with and without NNBF

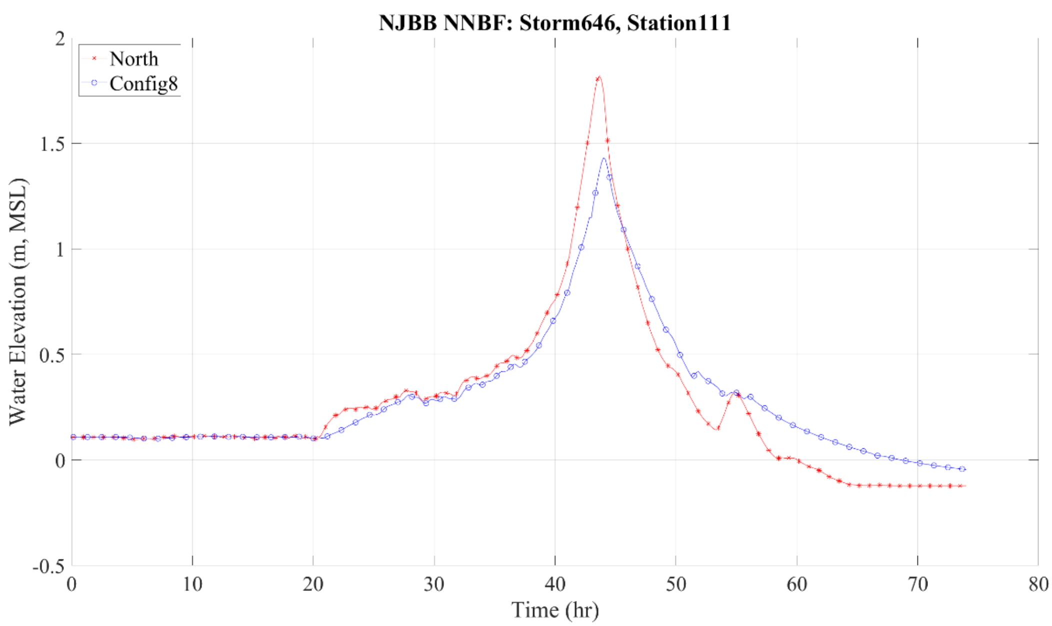

Figure 121 Storm 646 hydrograph for save point 111 "behind" Great Egg Harbor area with and without NNBF

Appendix B: STWAVE auxiliary modeling results

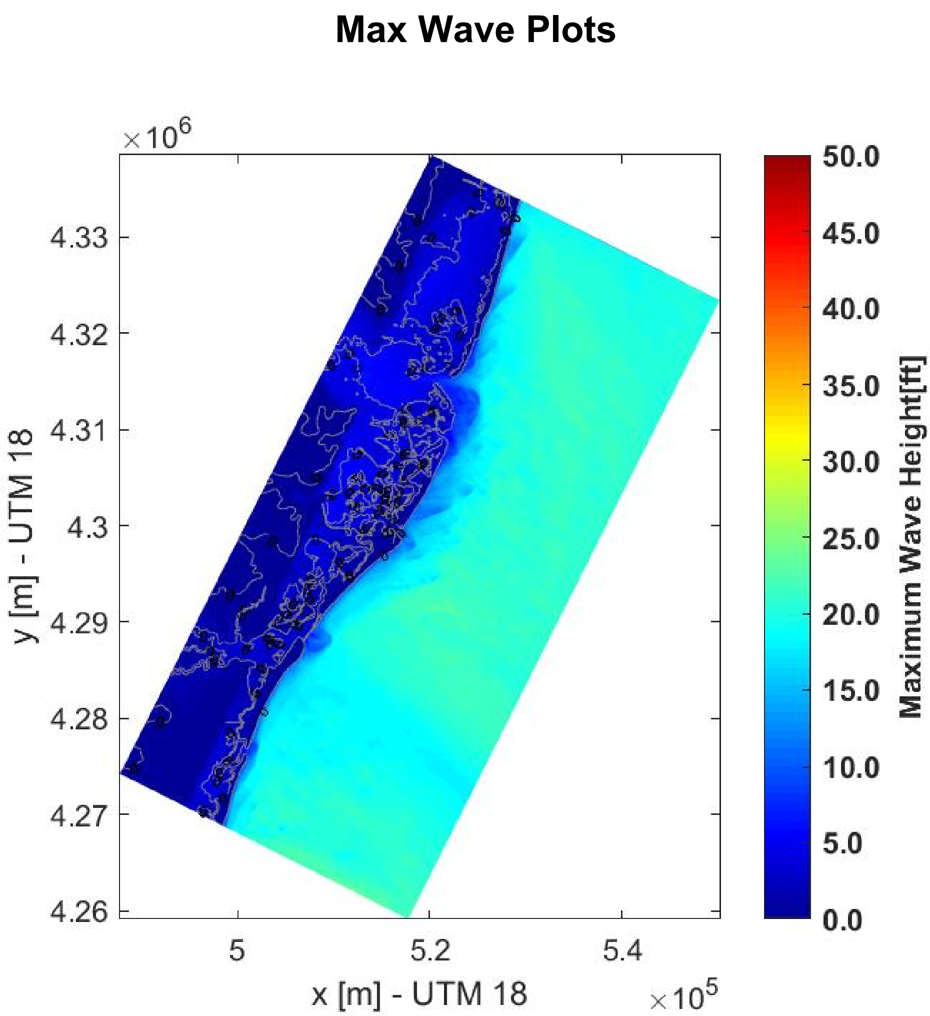

Figure *122*: ST0099 Configuration 3

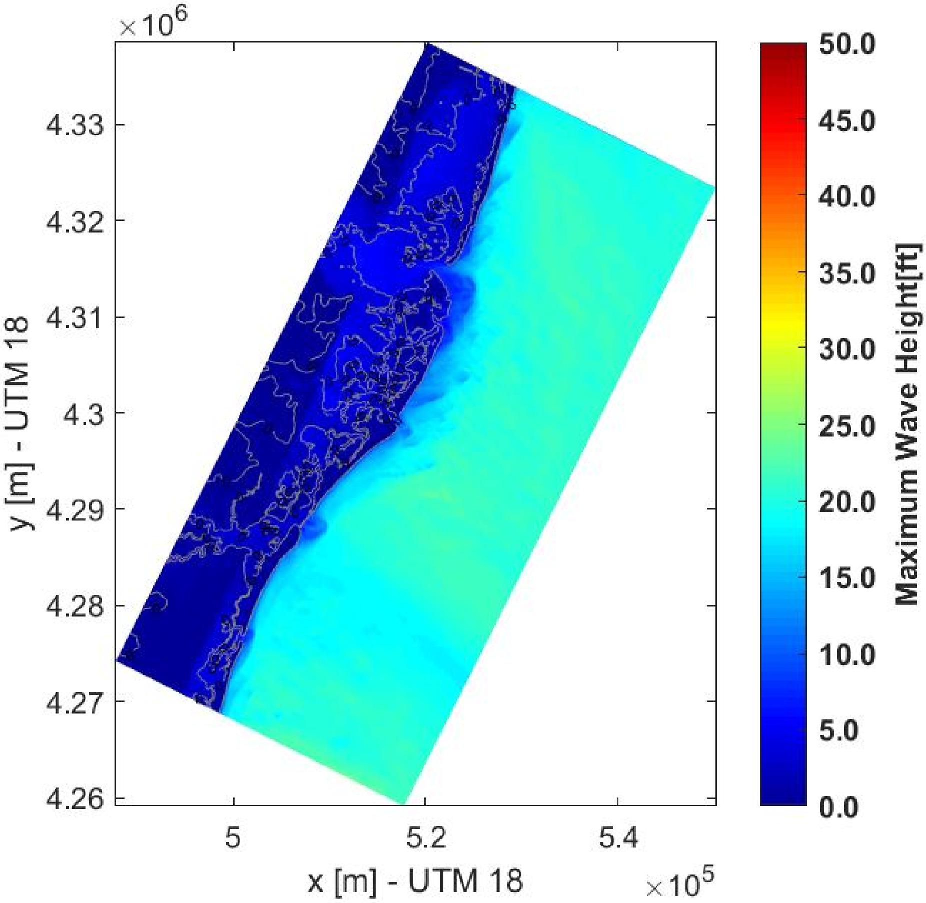

Figure *123*: ST0099 Configuration 5

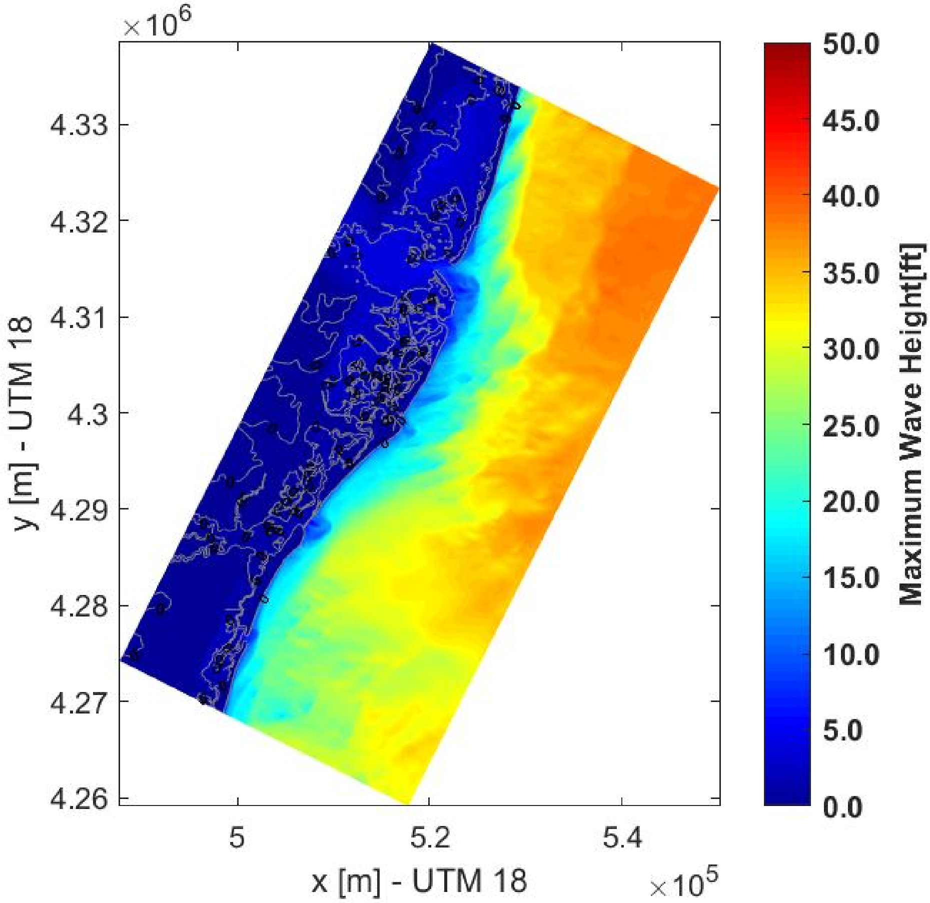

Figure *124*: ST0349 Configuration 3

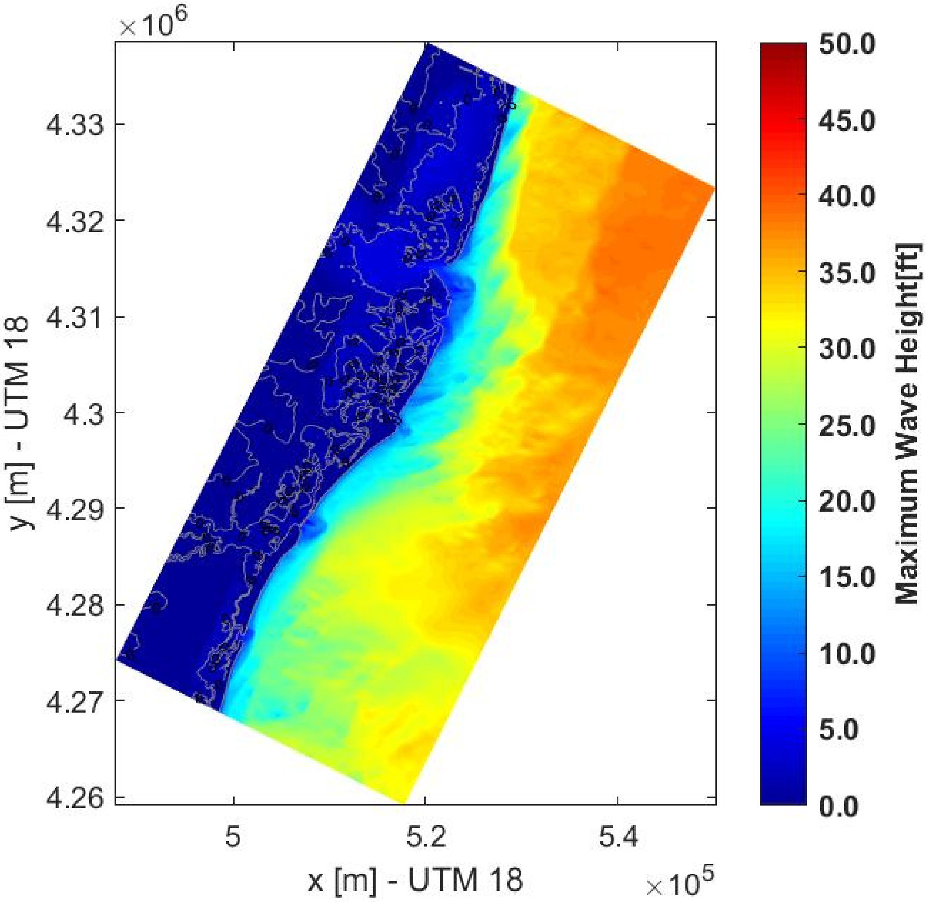

Figure *125*: ST0349 Configuration 5

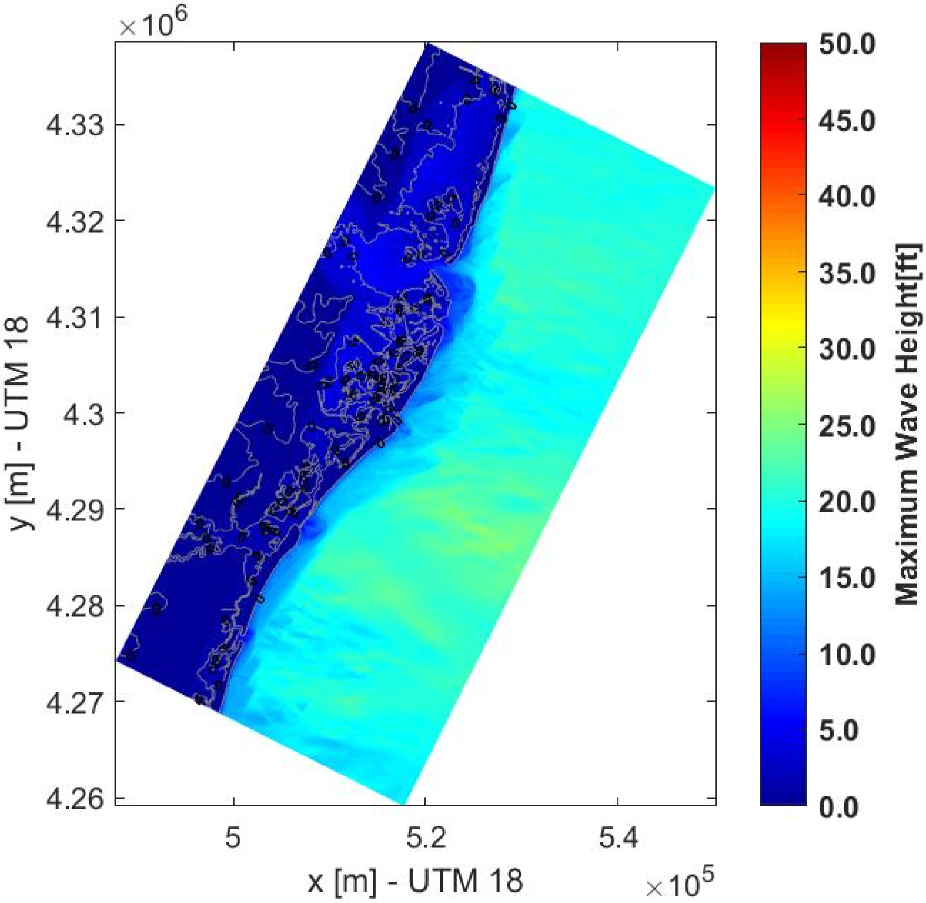

Figure *126*: ST0350 Configuration 3

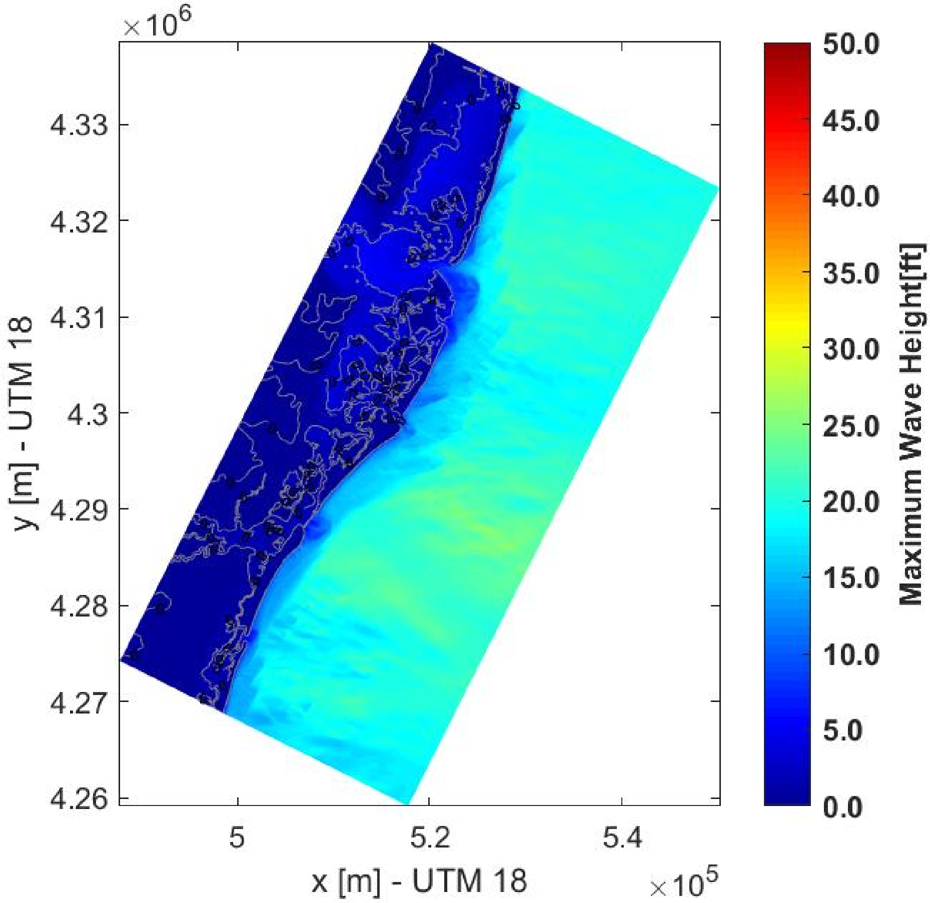

Figure *127*: ST0350 Configuration 5

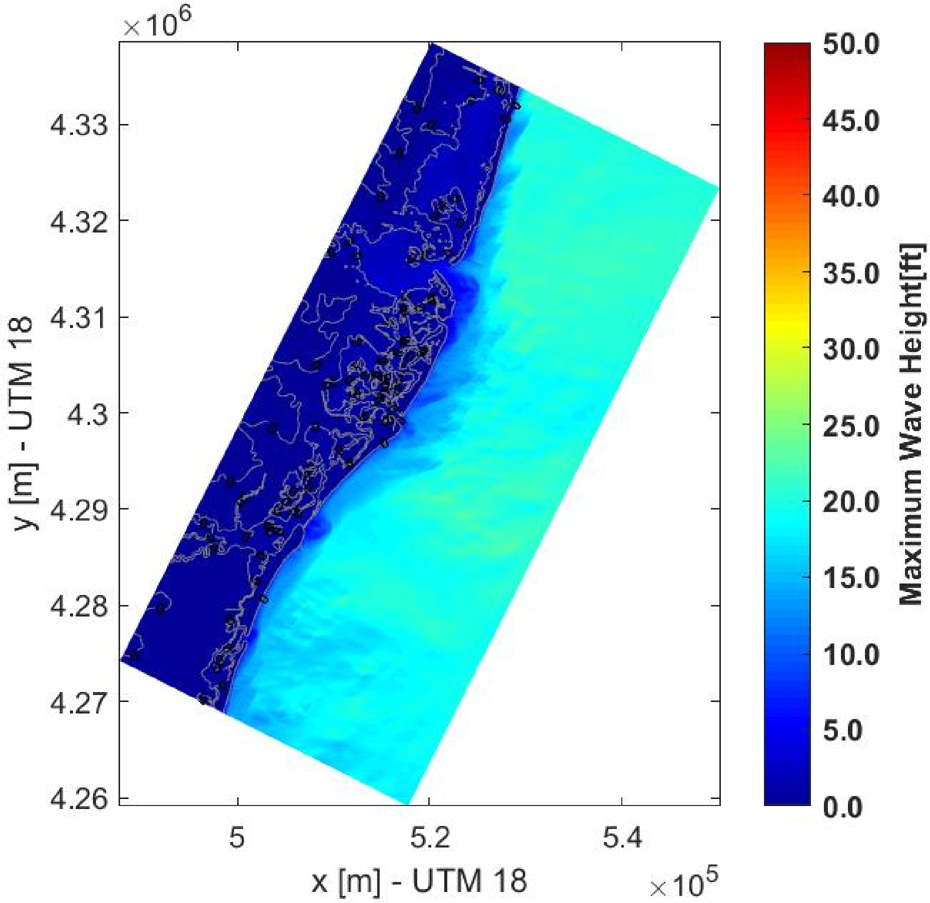

Figure *128*: ST0357 Configuration 3

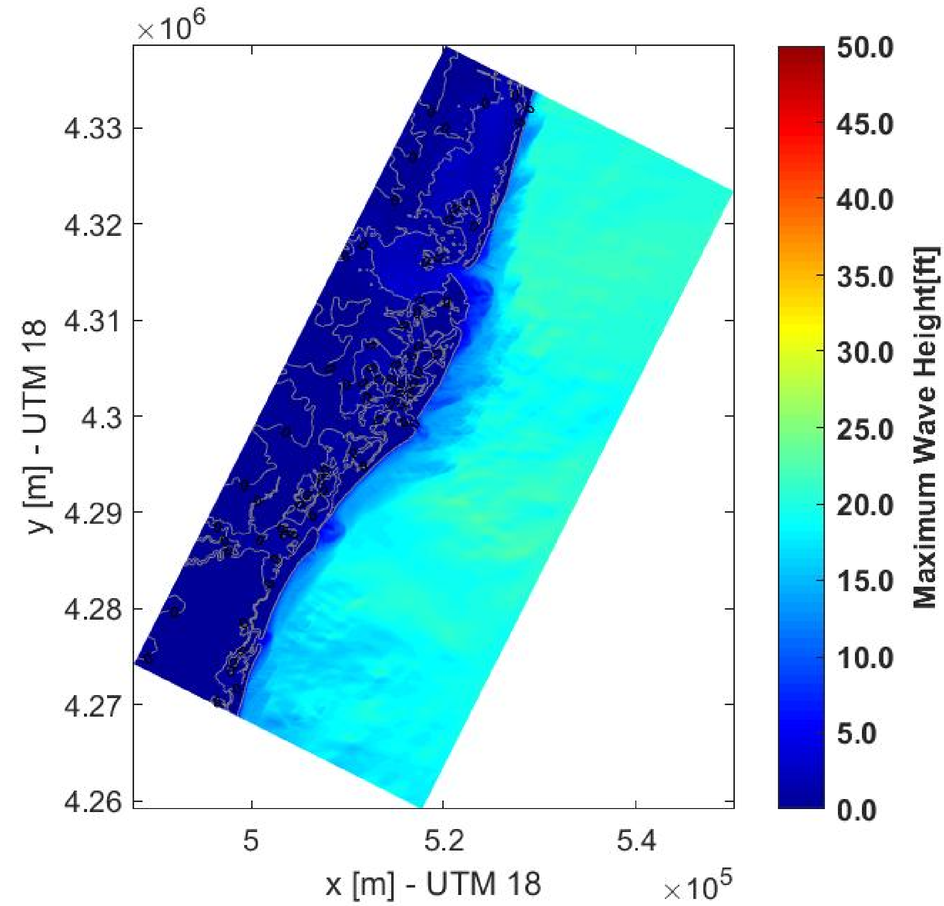

Figure *129*: ST0357 Configuration 5

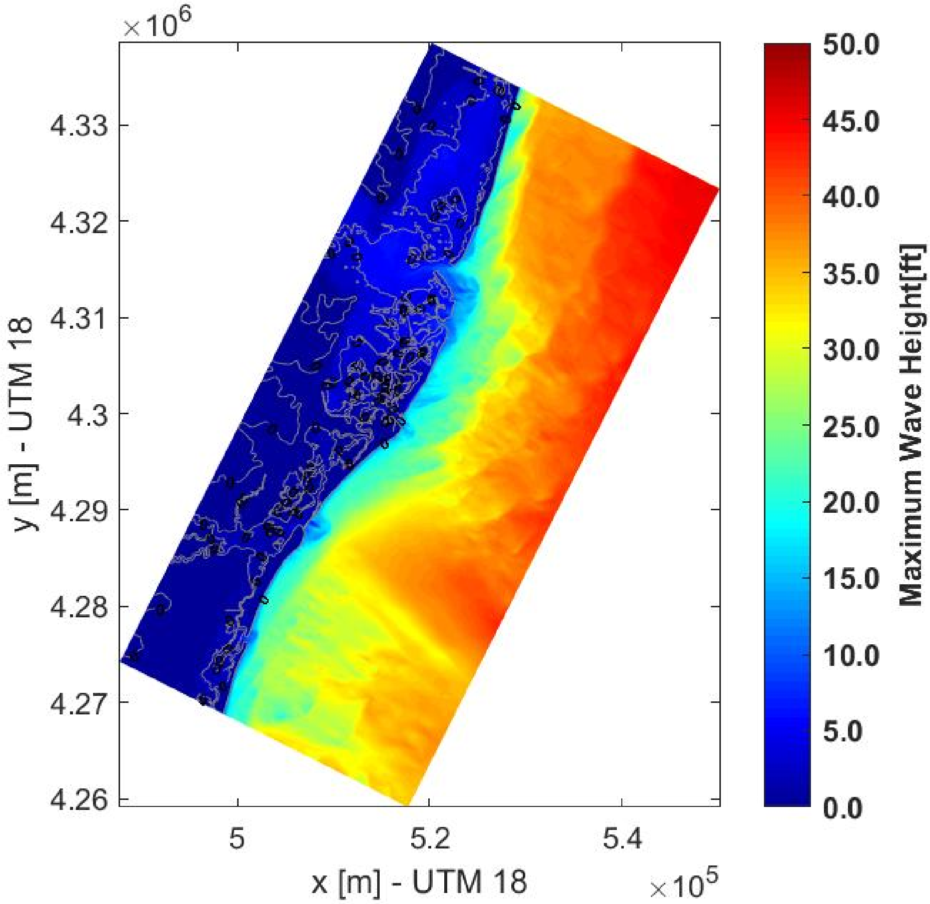

Figure *130*: ST0433 Configuration 3

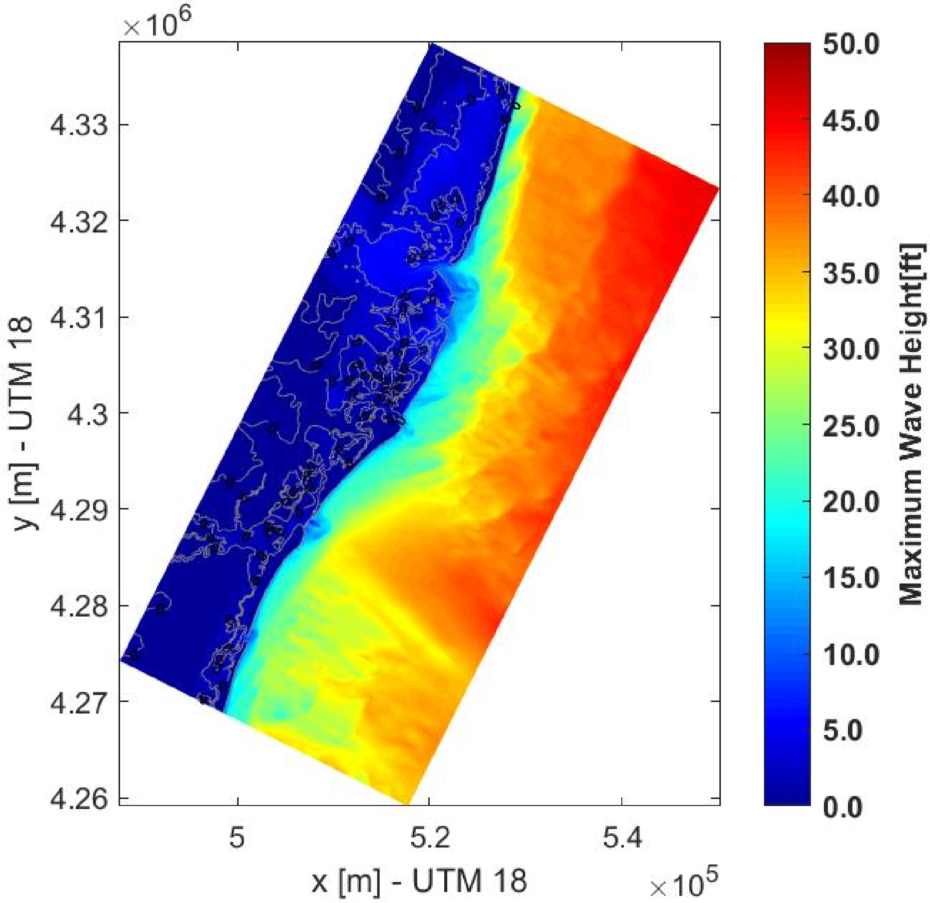

Figure *131*: ST0433 Configuration 5

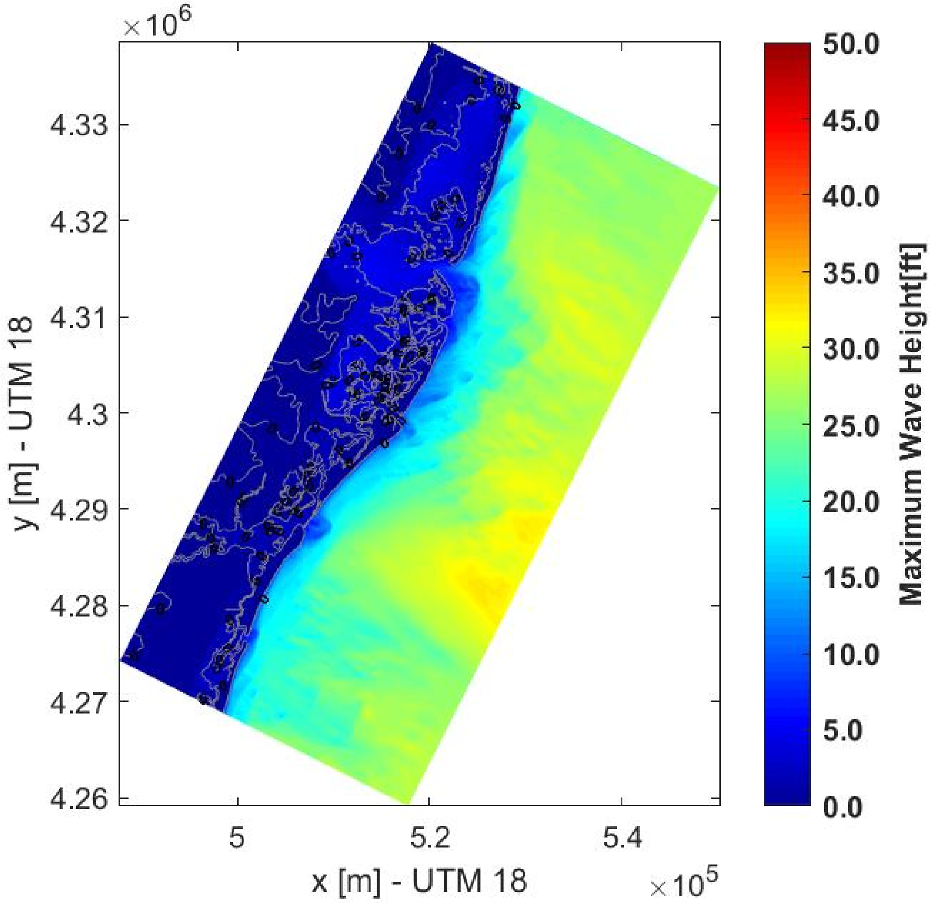

Figure *132*: ST0434 Configuration 3

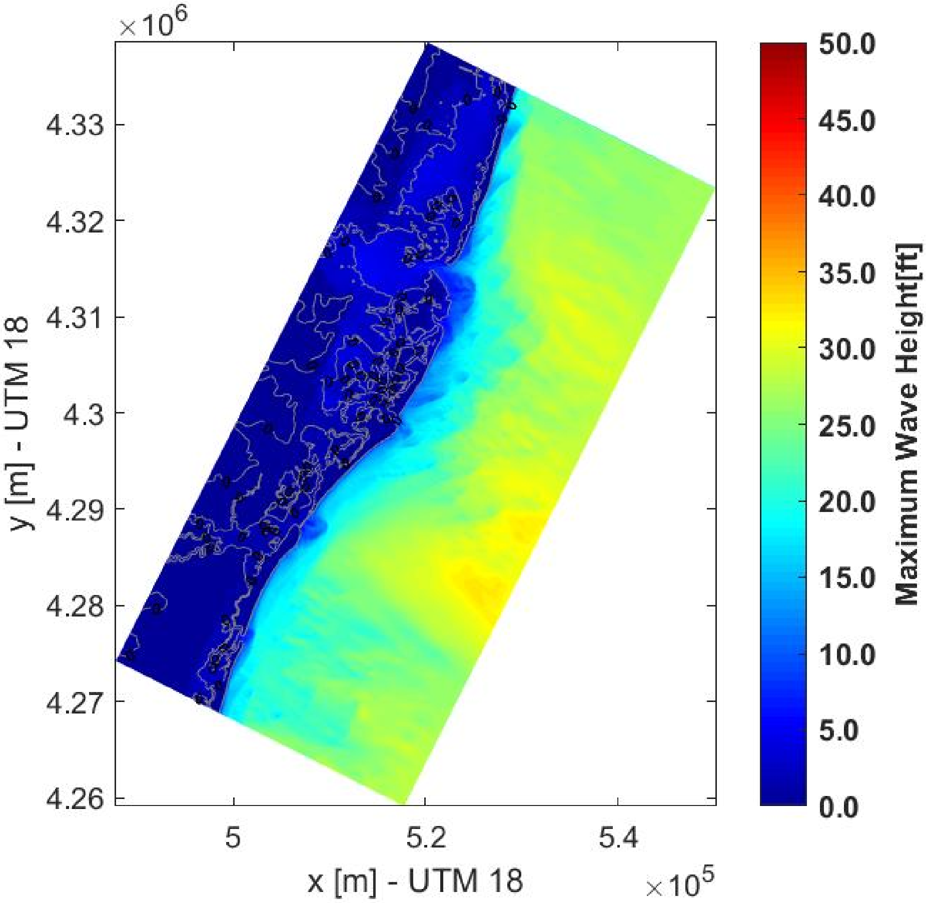

Figure *133*: ST0434 Configuration 5

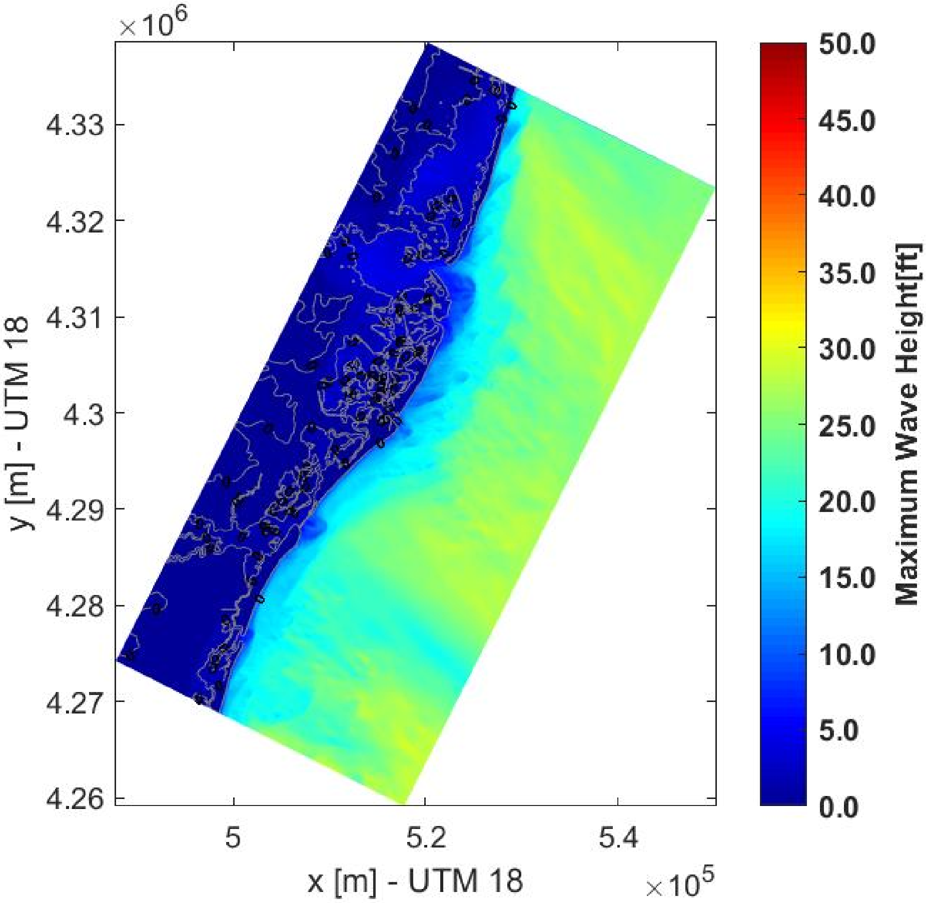

Figure *134*: ST0469 Configuration 3

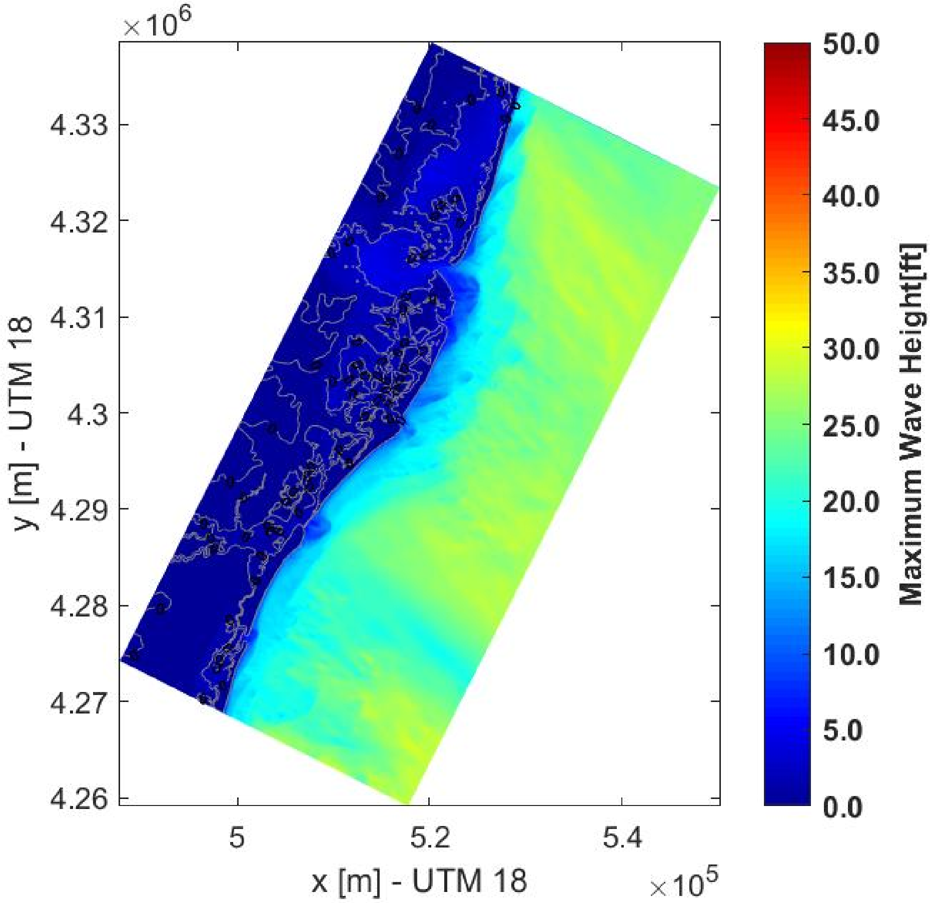

Figure *135*: ST0469 Configuration 5

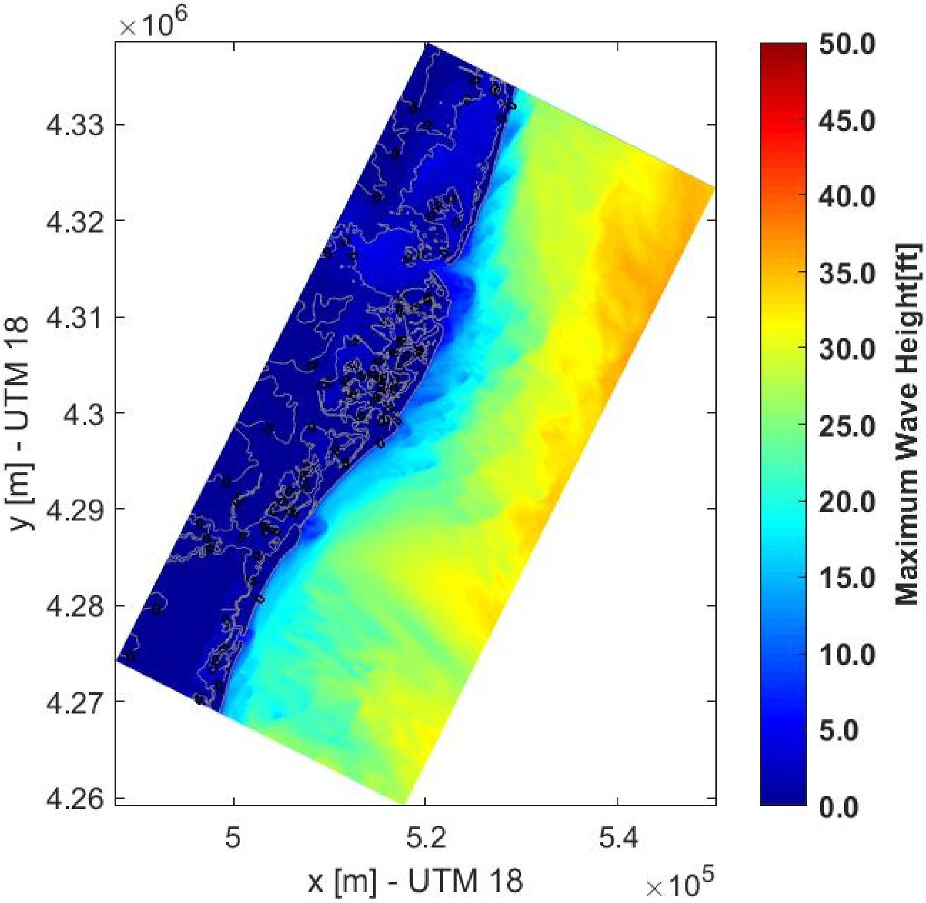

Figure *136*: ST0524 Configuration 3

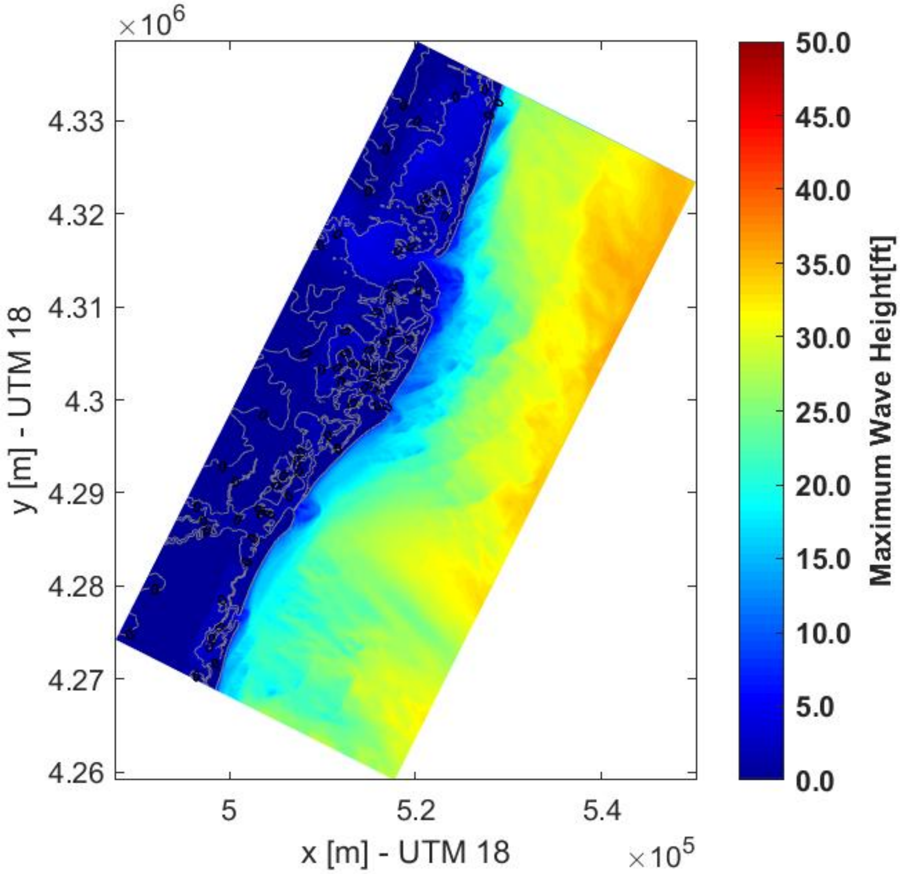

Figure 137: ST0524 Configuration 5

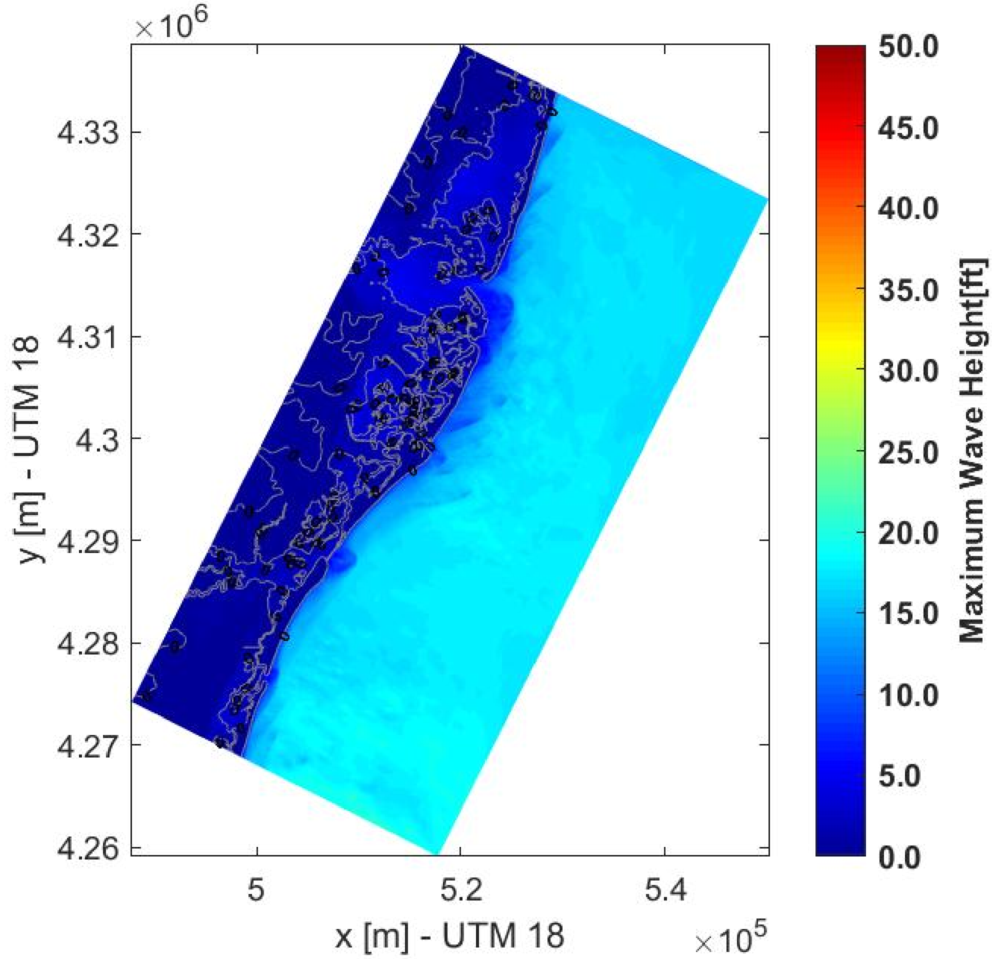

Figure 138: ST00636 Configuration 3

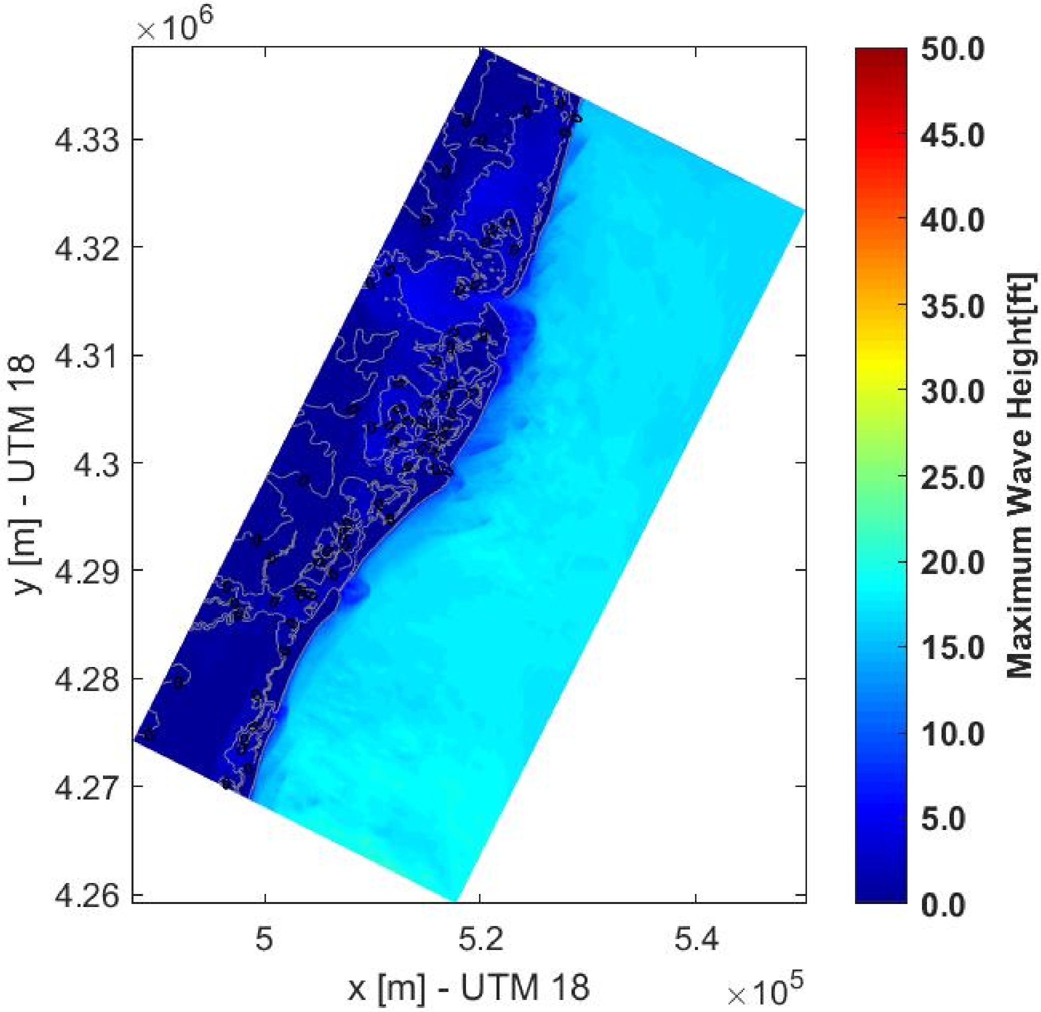

Figure 139: ST0636 Configuration 5

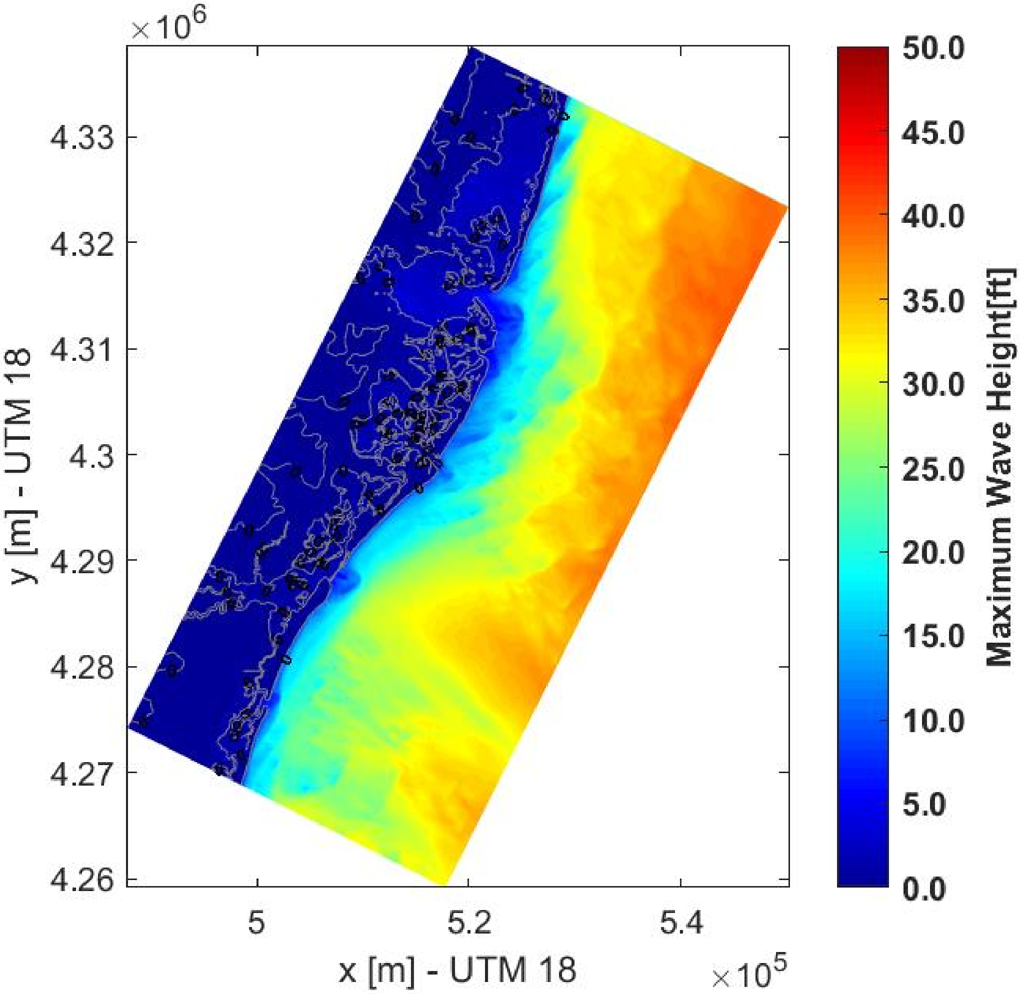

Figure 140: ST0646 Configuration 3

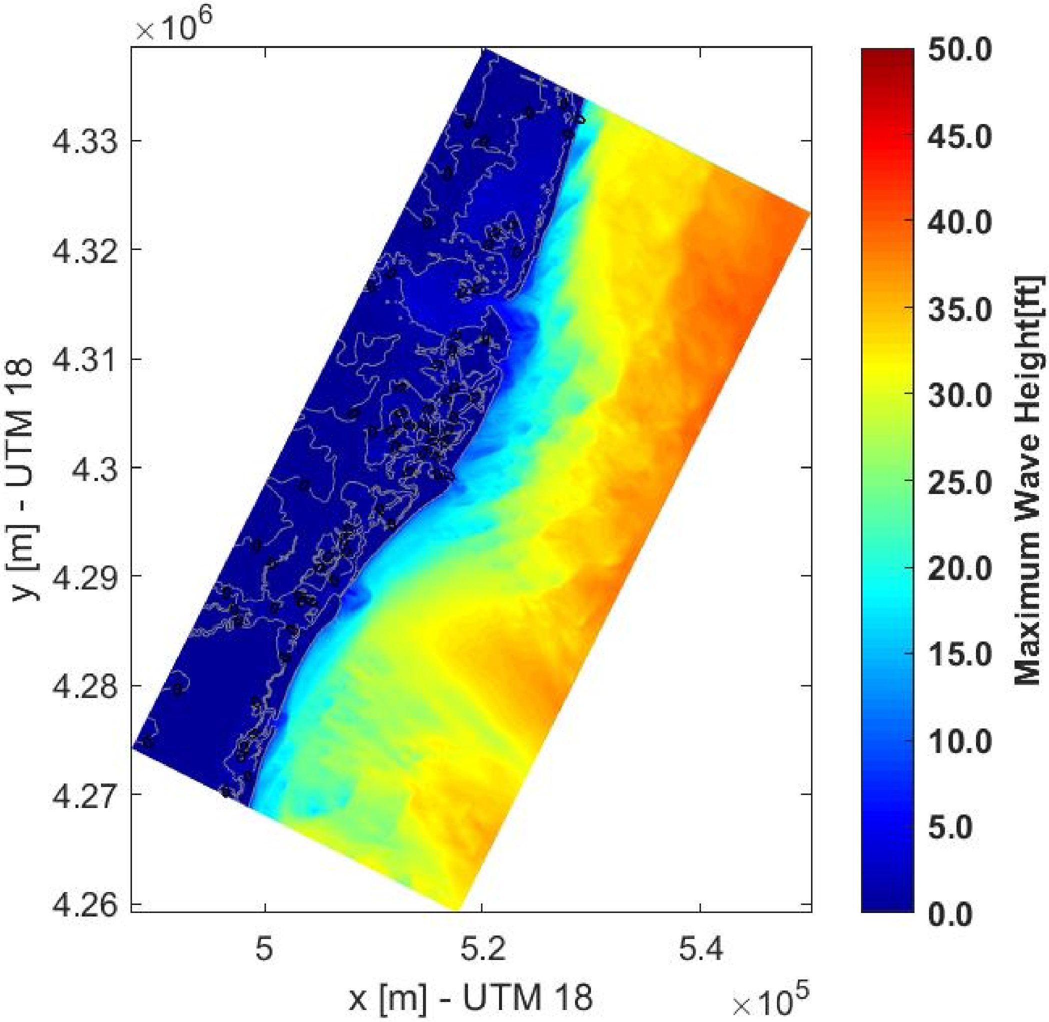

Figure 141: ST0646 Configuration 5

Time Series Plots

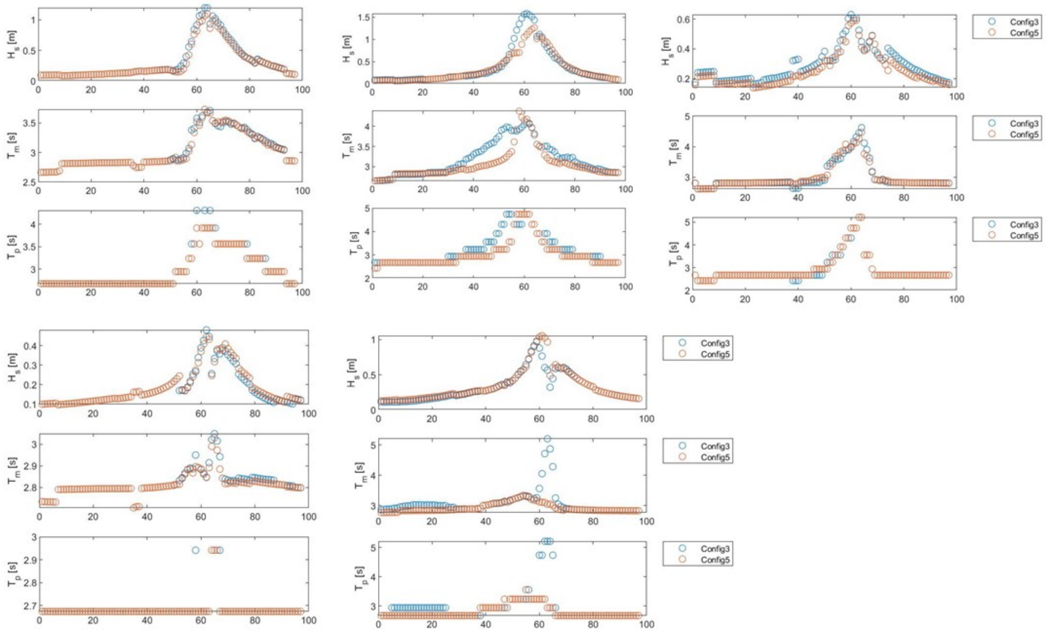

Figure *142*: Time series of significant wave height, peak period, and mean period for Storm 99. Top row, from left to right is station 49, 50, 59. Bottom row, from left to right is station 111, 117. Configuration 3 is shown in blue, Configuration 5 in orange.

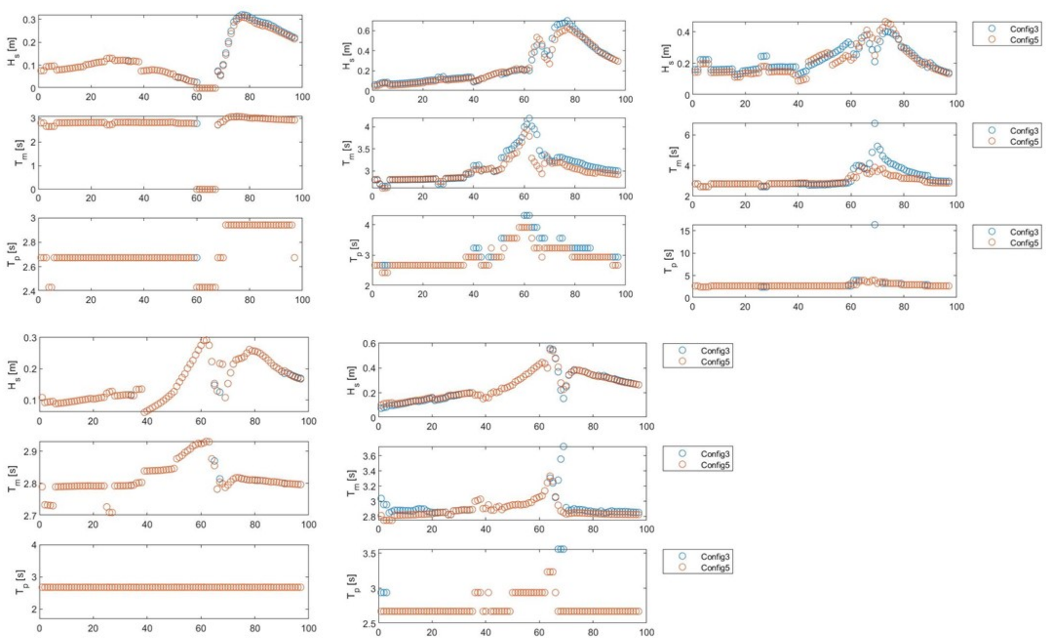

Figure *143*: Time series of significant wave height, peak period, and mean period for Storm 349. Top row, from left to right is station 49, 50, 59. Bottom row, from left to right is station 111, 117. Configuration 3 is shown in blue, Configuration 5 in orange.

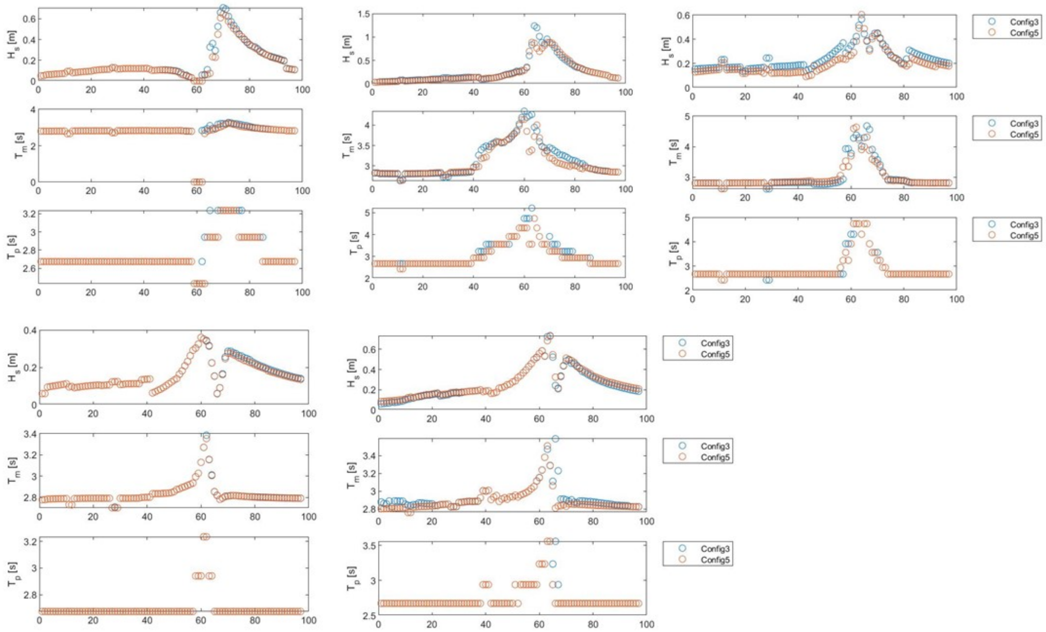

Figure *144*: Time series of significant wave height, peak period, and mean period for Storm 350. Top row, from left to right is station 49, 50, 59. Bottom row, from left to right is station 111, 117. Configuration 3 is shown in blue, Configuration 5 in orange.

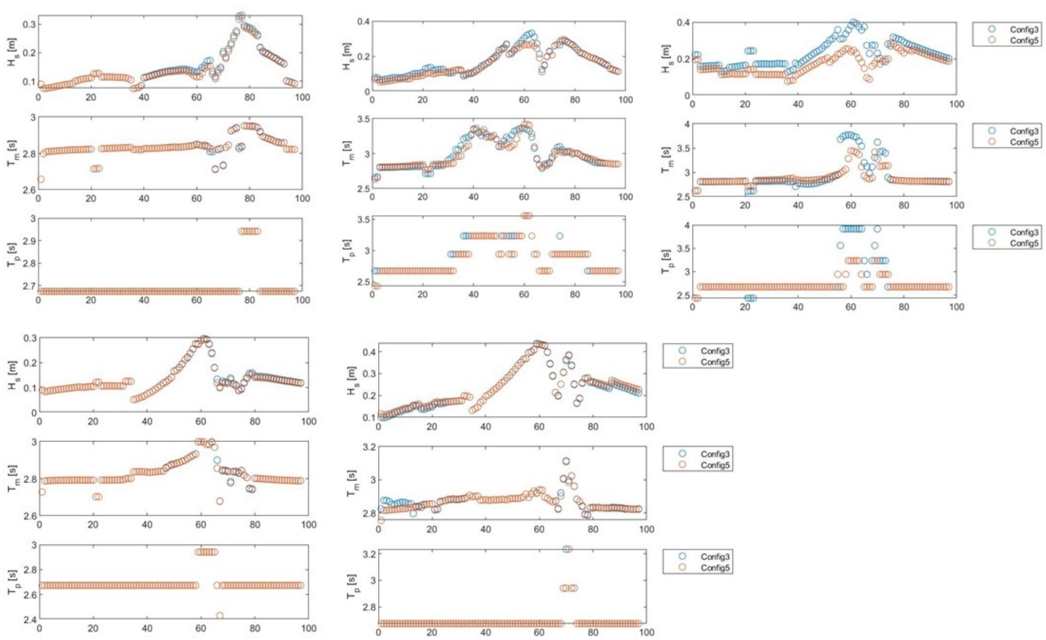

Figure *145*: Time series of significant wave height, peak period, and mean period for Storm 357. Top row, from left to right is station 49, 50, 59. Bottom row, from left to right is station 111, 117. Configuration 3 is shown in blue, Configuration 5 in orange.

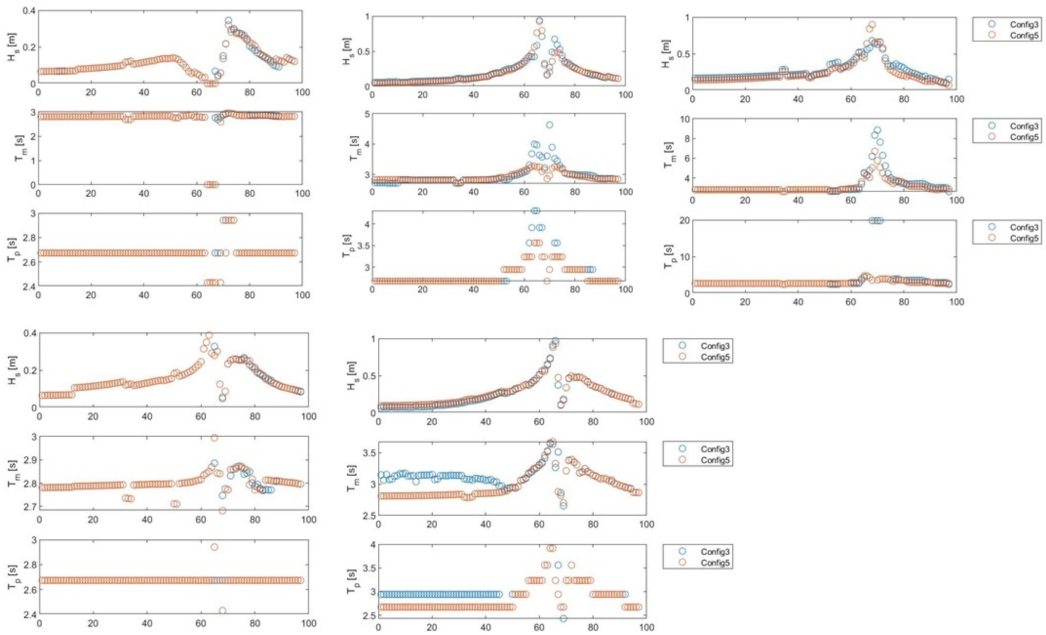

Figure *146*: Time series of significant wave height, peak period, and mean period for Storm 433. Top row, from left to right is station 49, 50, 59. Bottom row, from left to right is station 111, 117. Configuration 3 is shown in blue, Configuration 5 in orange.

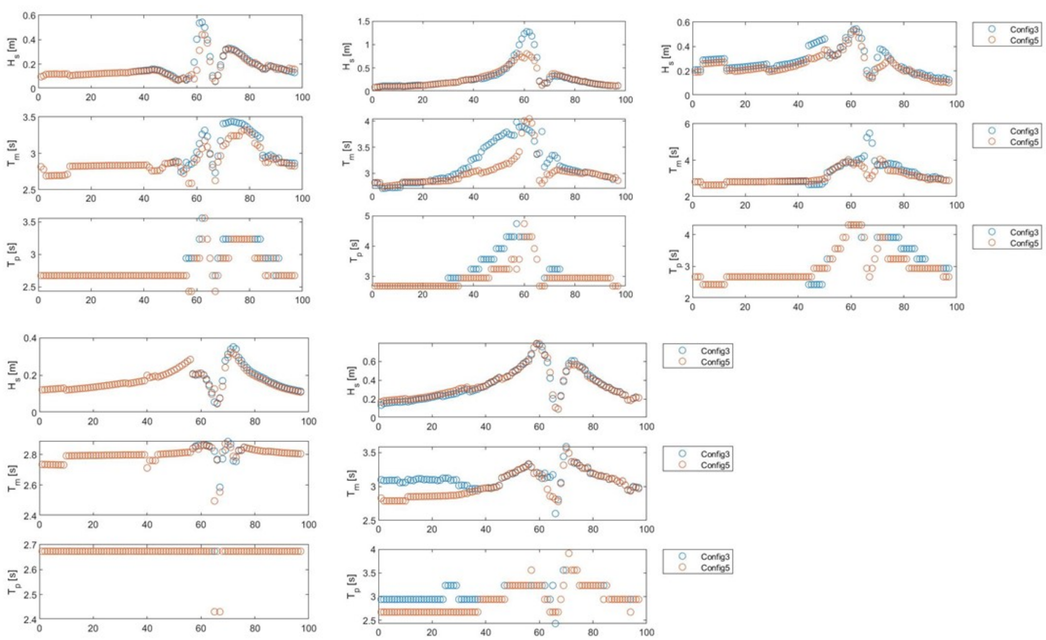

Figure *147*: Time series of significant wave height, peak period, and mean period for Storm 434. Top row, from left to right is station 49, 50, 59. Bottom row, from left to right is station 111, 117. Configuration 3 is shown in blue, Configuration 5 in orange.

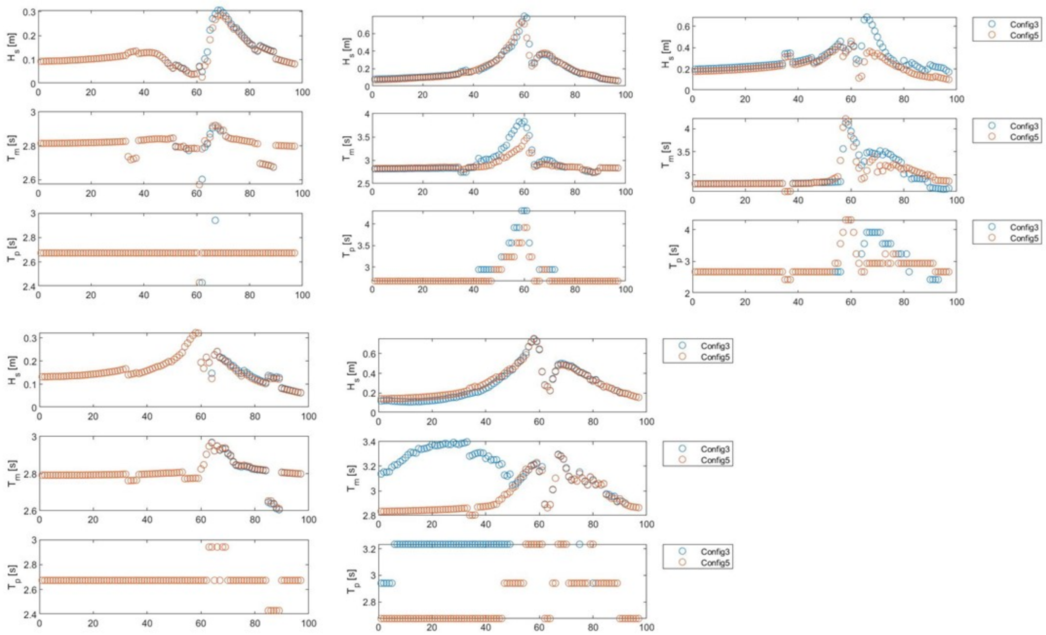

Figure *148*: Time series of significant wave height, peak period, and mean period for Storm 469. Top row, from left to right is station 49, 50, 59. Bottom row, from left to right is station 111, 117. Configuration 3 is shown in blue, Configuration 5 in orange.

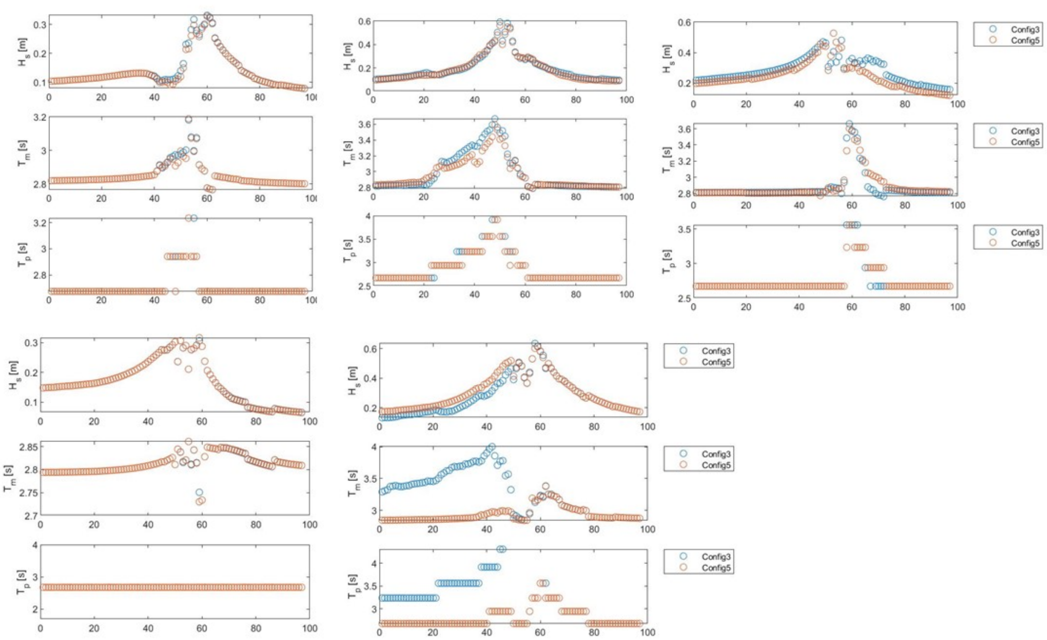

Figure *149*: Time series of significant wave height, peak period, and mean period for Storm 524. Top row, from left to right is station 49, 50, 59. Bottom row, from left to right is station 111, 117. Configuration 3 is shown in blue, Configuration 5 in orange.

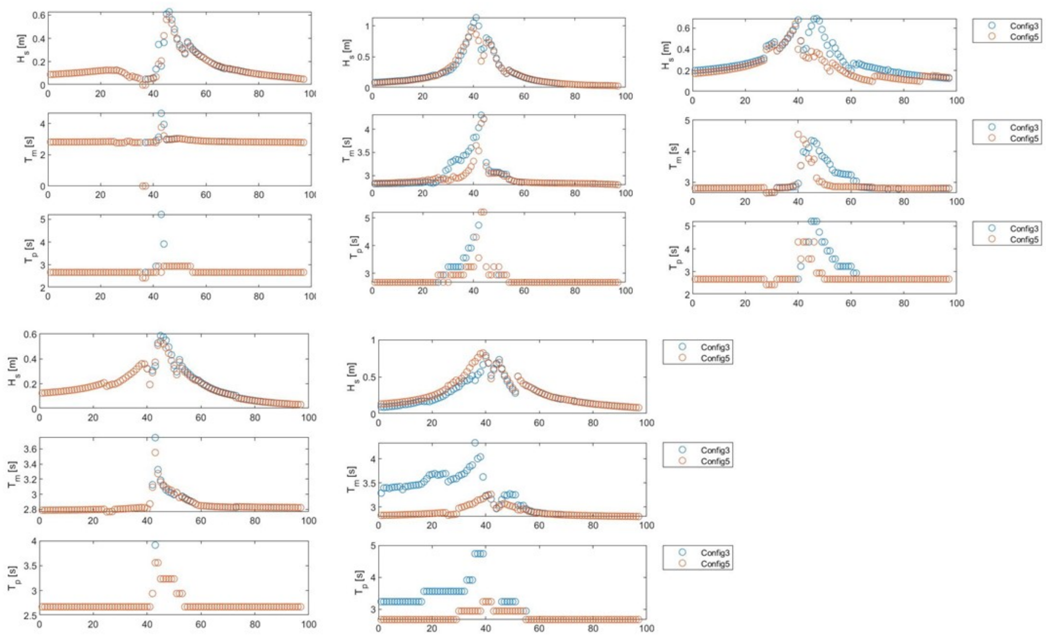

Figure *150*: Time series of significant wave height, peak period, and mean period for Storm 636. Top row, from left to right is station 49, 50, 59. Bottom row, from left to right is station 111, 117. Configuration 3 is shown in blue, Configuration 5 in orange.

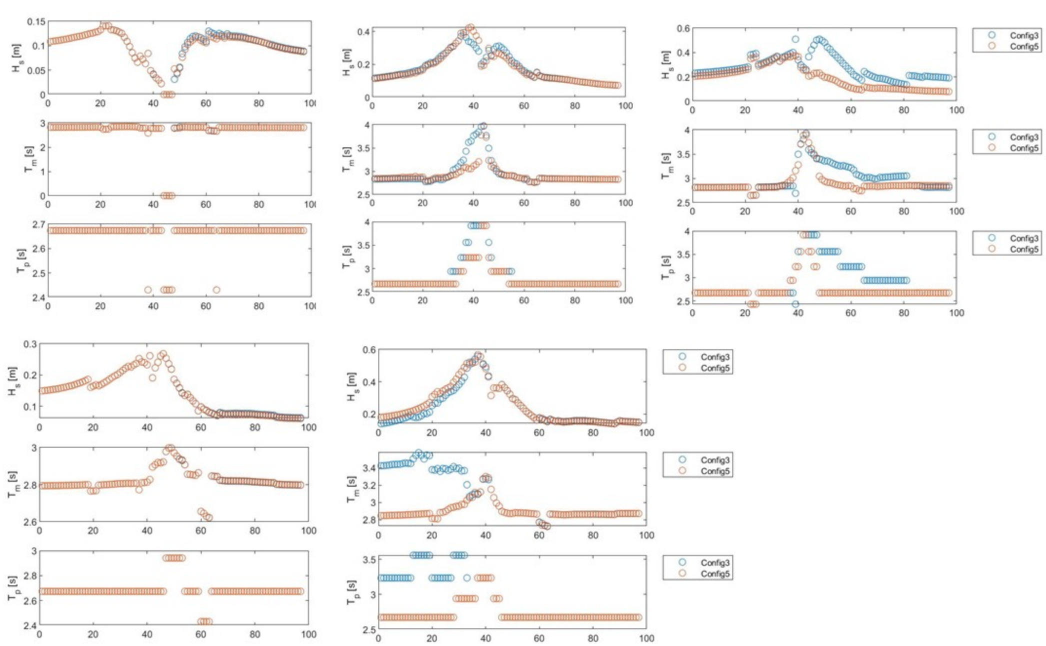

Figure *151*: Time series of significant wave height, peak period, and mean period for Storm 646. Top row, from left to right is station 49, 50, 59. Bottom row, from left to right is station 111, 117. Configuration 3 is shown in blue, Configuration 5 in orange.