REBUILD BY DESIGN

# THE SHALLOWS

## BAY LANDSCAPES AS ECOLOGICAL INFRASTRUCTURE


**SCAPE / LANDSCAPE ARCHITECTURE PLLC**

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LOT-EK
MTWTF
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**The SCAPE team has developed a science-driven methodology that pairs layered eco-infrastructural systems sited for risk-reduction with social and educational networks, rebuilding water based infrastructures in tandem with surrounding communities.**

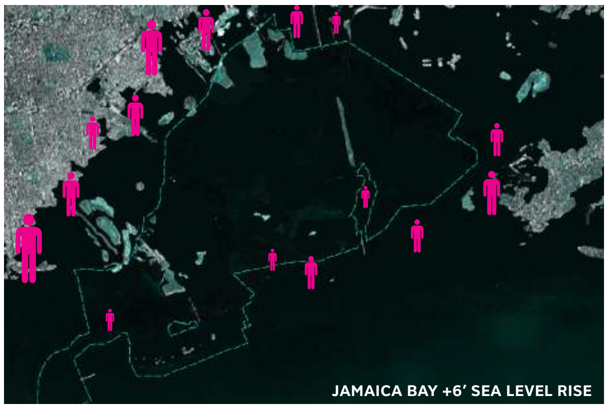
**SOCIAL RESILIENCY + PHYSICAL RESILIENCY**

# DEFINING THE SHALLOWS

The Shallows explores the potential for ecological infrastructure based on hard and soft, land and water, human-made and "natural" habitat within the Northeast regional network of coastal edges, shallow waters and bay systems. The project overlays coastal resiliency infrastructure with habitat enhancement techniques and environmental stewardship models, deploying a range of layered strategies that link in-water protective forms to onshore interventions. Our team has mapped potential enhancements to endangered bay land-scapes and communities, and through the process has evolved a range of design ideas that not only protect us from extreme storm events but also improve the quality of our everyday lives.

Climate change is bringing new challenges to the eastern seaboard of the United States. Its pre-dicted effects include a rise in mean temperature and precipitation, accelerated sea level rise, and more frequent, extreme flooding and storm events like Hurricane Sandy. These phenomena, coupled with the excess nitrogen levels in our waters from treated wastewater and fertilizers, put our critical estuaries and bays at risk of disappearing within decades, if not years. With their shallow bathyme-try and delicate balance of vulnerable marine life, a loss of these endangered waters would threaten not only the places we live, work, and play in but also our cultural connection to the water. We know that in addition to being beloved fishing and recre-ational grounds, bay landscapes are crucial absorp-tive ecological infrastructure that help reduce risk for communities located along the water's edge.

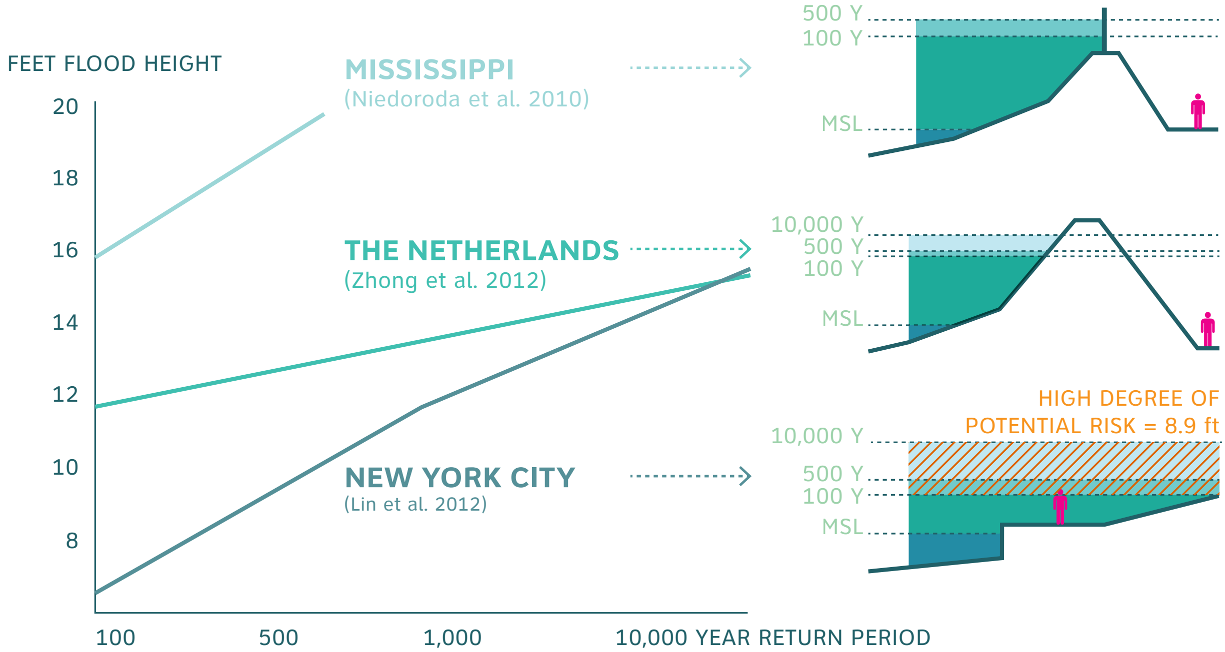




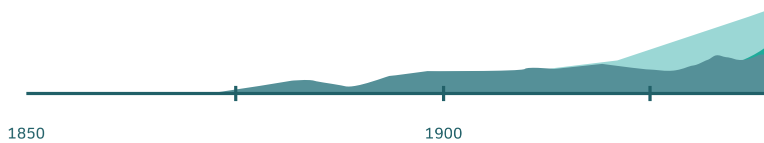

ECOSYSTEM FRAGILITY Bay landscapes face risks from urbanization, water contamination, sediment starvation, and sea level rise inundation. Jamaica Bay's wetlands are predicted to be completely lost by 2024 without intervention.

HISTORIC OYSTER BED LOCATIONS IN THE NEW YORK HARBOR

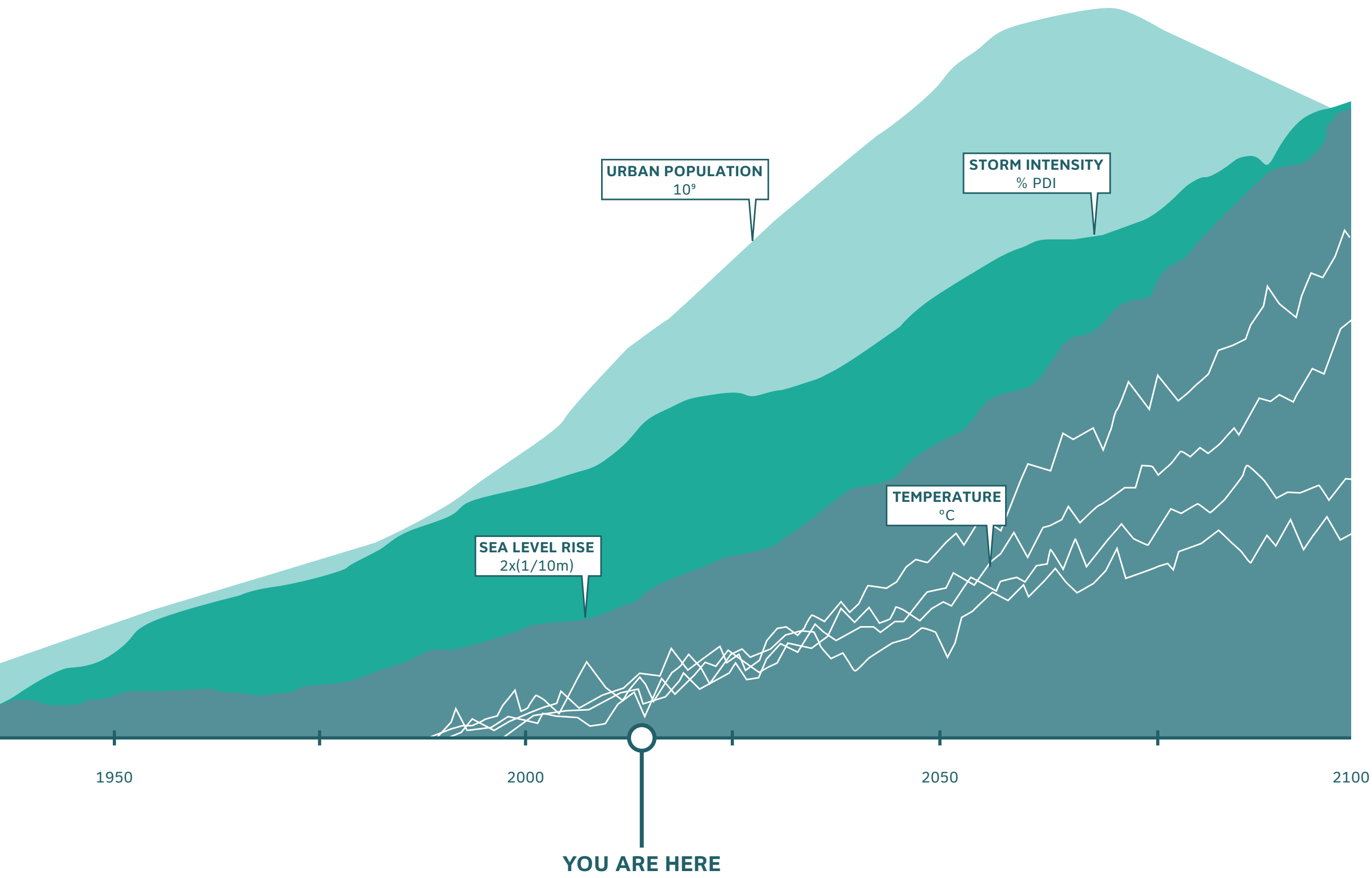
# DESIGN TO PERCEIVE RISK AND REDUCE FRAGILITY




THE HAZARD CURVE Much of the eastern seaboard of the U.S. faces high degrees of uncertainty when planning for risk, mostly due to the variable nature of hurricanes. Preparing for the 100-year flood can leave NYC vulnerable in the face of a substantially higher 1000-year flood event.



Risk is embedded in all strategies that are outlined in the following pages. Our approach aims to step down risk with each investment, redefine scales of harm, and move beyond the impossible scenario of enclosing “dry” from “wet” to addressing larger issues of ecosystem collapse, cycles of regional decline, and managed, calmer, and non-disastrous inundation events. We build up resiliency by strengthening networks, incrementally decreasing the overall risk embedded in the system. Our strategies mitigate the impacts of flooding without eliminating it altogether and re-focus the region on ecologically driven improvements that make flooding slower, cleaner, and safer, and less prone to catastrophic failure. We aim to make risk legible and part of everyday life, while building ecological and social resiliency through new stewardship programs on the waterfront.

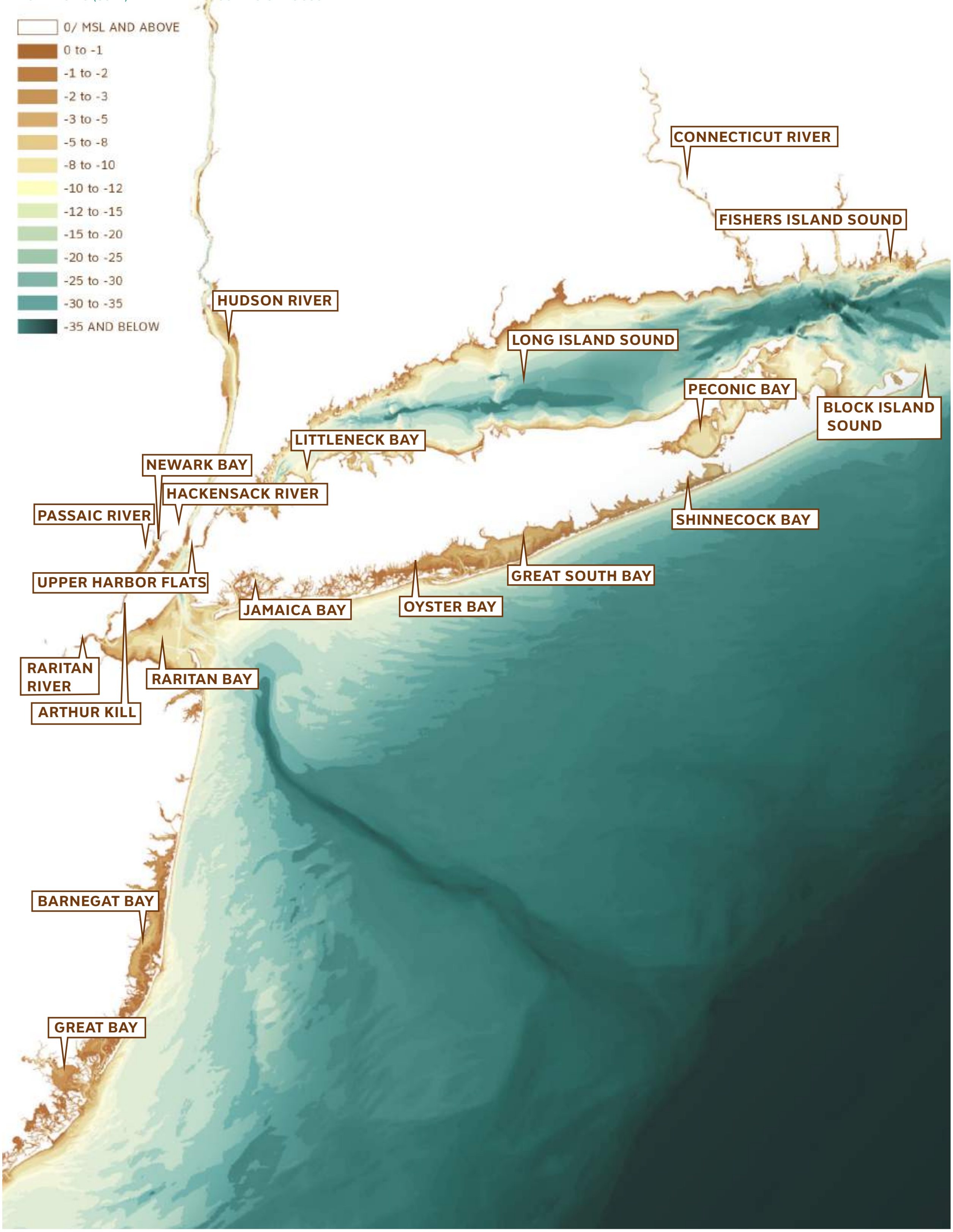


# HUMAN AND ECOLOGICAL HABITAT AT RISK

In an effort to identify the high-risk areas along the coastline, the team began by overlaying existing land-use maps with extents of the FEMA demarcated floodplains, as well as those of Sandy's impacts. Amongst pockets of impacted urbanized areas that emerged in this process, several ecologically sensitive landscapes attracted our attention. Taking from the Hazard Curve developed by Dr. Philip Orton of the Stevens Institute, New York City has a very high level of potential risk, compared to places like The Netherlands and the Mississippi Delta. Utilizing sources such as Surging Seas, the potential impacts of sea level rise are evident with the basic condition of certain landscapes set to completely change with higher waters.

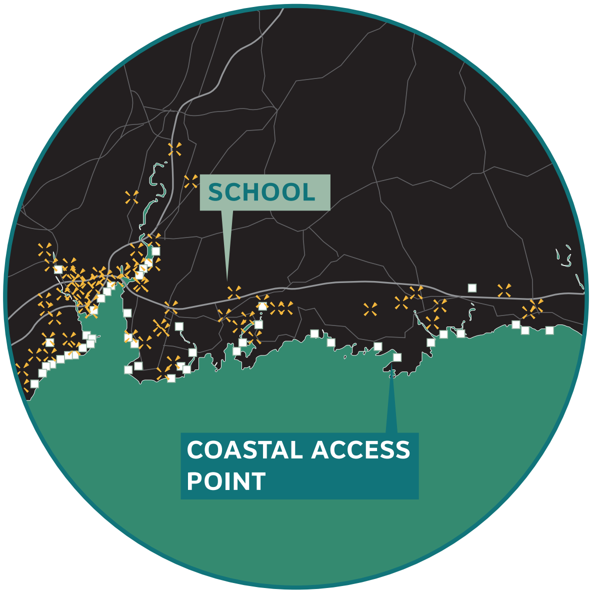
NOAA bathymetry maps were used to identify shallow waters ranging in depth up to 30 feet. Juxtaposing these shallow areas with the high risk areas determined by the initial mapping process brought to light areas that needed further study. Based on these shallow areas, the predominant landscapes of the bay emerged as focus areas of immense coastal protection potential as well as great habitats for marine life regeneration.

THE SHALLOWS (30 M) AND BAY LANDSCAPES OF FOCUS



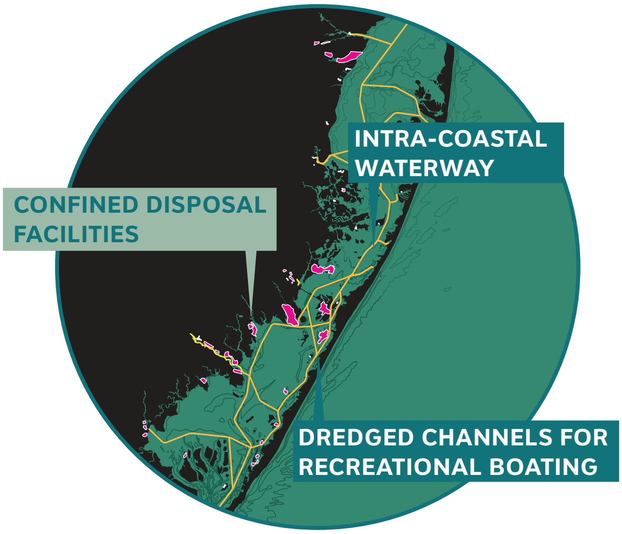
# SHALLOW WATER CYCLES

Shallow bay landscapes are complex and critical areas of topography, maritime economic activity, recreation, sources for dredge material, waste streams of glass and shell, as well as hosts to historical ecosystems which have now disappeared. In addition these landscapes bear the immense potential for educational engagement and community participation in their safekeeping. Interconnected systems by their very nature are more resilient—they are not dependent upon one element to succeed or fail but rather offer networked opportunities for change and continual recalibration. To us, this is the definition of resiliency.



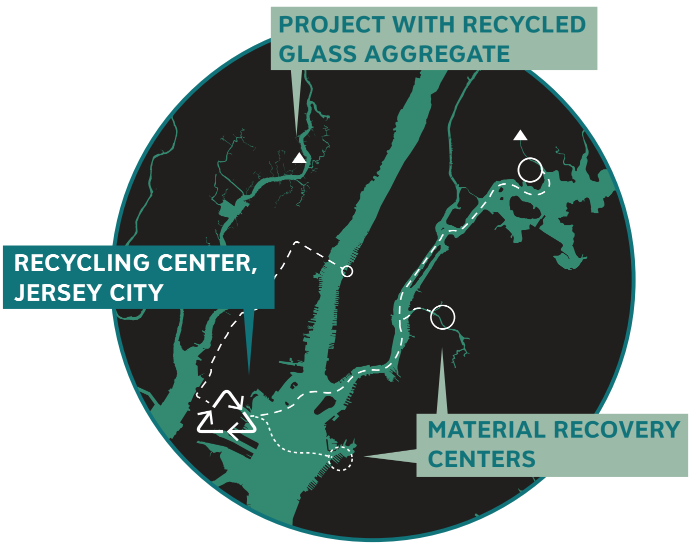

CONNECTING SCHOOLS TO WATER New applied science-based middle and high school curricula have established innovative frameworks for learning and engaging the joint built-natural environment, centered on critical water bodies as learning units. Harbor restoration, maritime skills, and aquaculture among many other skill sets overlay with the urgent task at hand to rebuild social as well as infrastructural resiliency.

BIOGENIC BUILDUP Eastern oysters and blue and ribbed mussels among many others in our regional ecosystem form an "ecological glue" that builds structural strength within coastal protective measures. These bivalves create 3D mosaic structures in the landscape that have beneficial hydrodynamic "roughness" factors, while simultaneously helping to filter out excess nitrogen in the water. Increased biological productivity directly improves long term ecological stability and resilience, generating systems that can grow with and adapt to climate change over time. New sources of oyster and mussel larvae in the tidal system leads to an exponential increase in harbor-wide benefits—"gluing" together disparate substrates and incrementally stepping up friction factors throughout the water column.




RETHINKING DREDGE NETWORKS Realignment of select systems ensure coastal access as well as increased protective benefit. Scales of dredge can be localized to nourish local wetlands or increase bathymetric levels to keep pace with anticipated sea level rise.

ECONOMIC SUSTENANCE Economic models related to the once prosperous fishing and shellfish industry show that it has been decimated in many zones along the East Coast. We are importing food from distant lands, in an unsustainable scenario. Long-term, we may be able to reclaim this landscape not only as a recreational resource but as a means of potential income and sustenance.

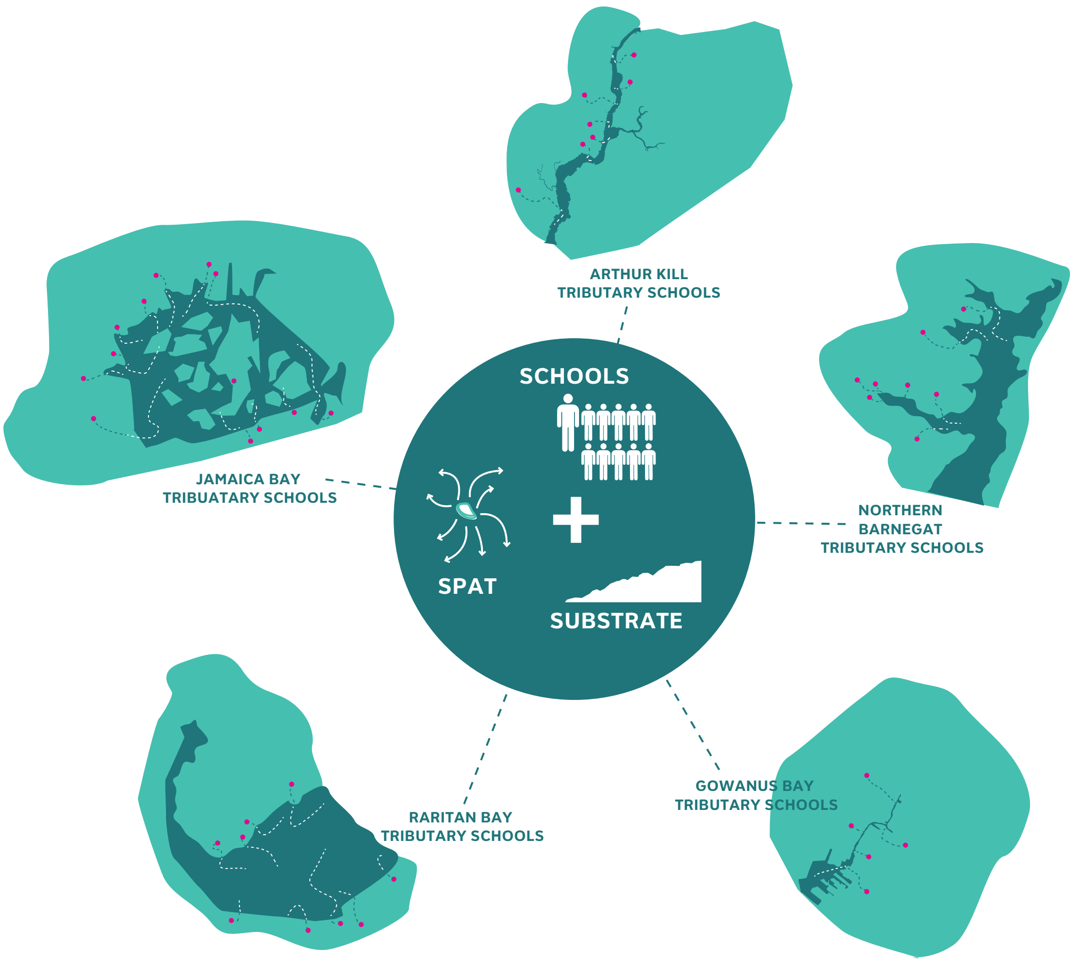



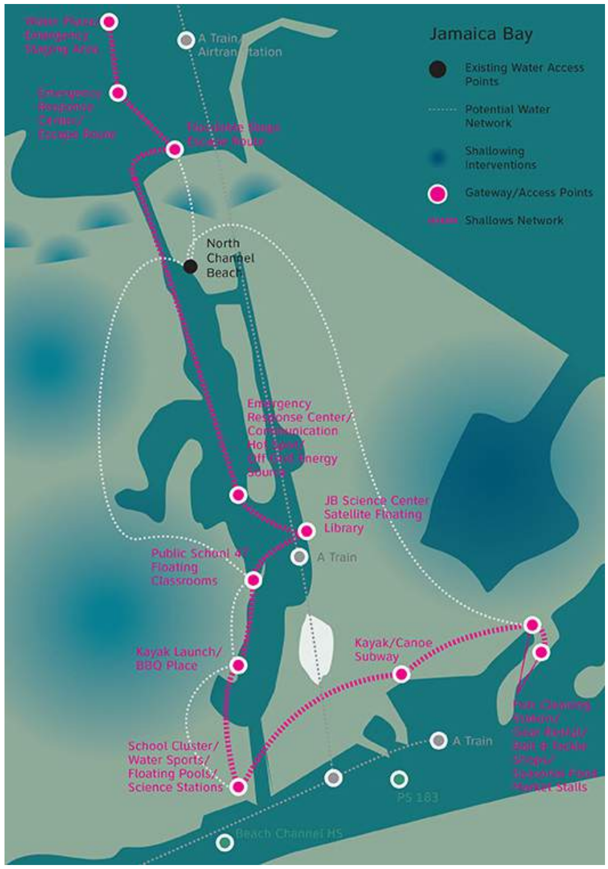

TAPPING INTO WASTE CYCLES Our project reclaims glass out of the waste cycle and—since this material is highly stable and has high biological recruitment value in a marine context—re-purposes this material as an aggregate for constructed breakwaters and reef systems. We also aim to remove precious oyster and clam shells from garbage dumps with the aim to treat and return them to the marine environment as substrate or aggregate additives to jump start the shallowing and breakwater building process.

# BUILDING COMMUNITY AROUND WATER

The strategies outlined here are not meant to be used alone and in isolation, but rather in concert with local communities and new and existing management models. Together, they thicken the coastal "edge"—calming waters and creating habitats while expanding the potential for human interaction with water. The Sandy impacted region is highly urbanized and in many cases lacks strong relationships to water—many people impacted by flooding did perceive the risk that their families or properties faced.

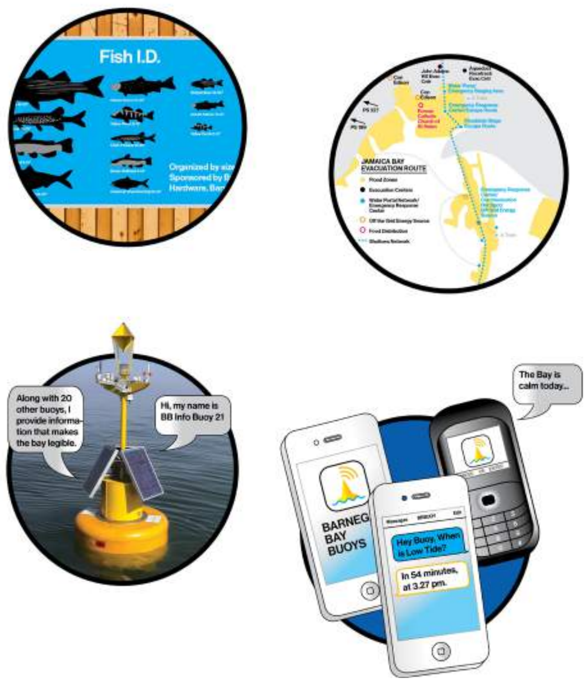
Fostering a water-based culture is at the heart of this project, and each strategy and site looks for low cost, simple techniques for linking people and neighborhoods to their waterfronts. Whether as small as a fish cleaning station or as large as a city-scale rental boat network, we propose that risk-reducing ecological infrastructures be coupled with new water activity hubs, weaving the realities of the waterfront into the fabric of everyday life.

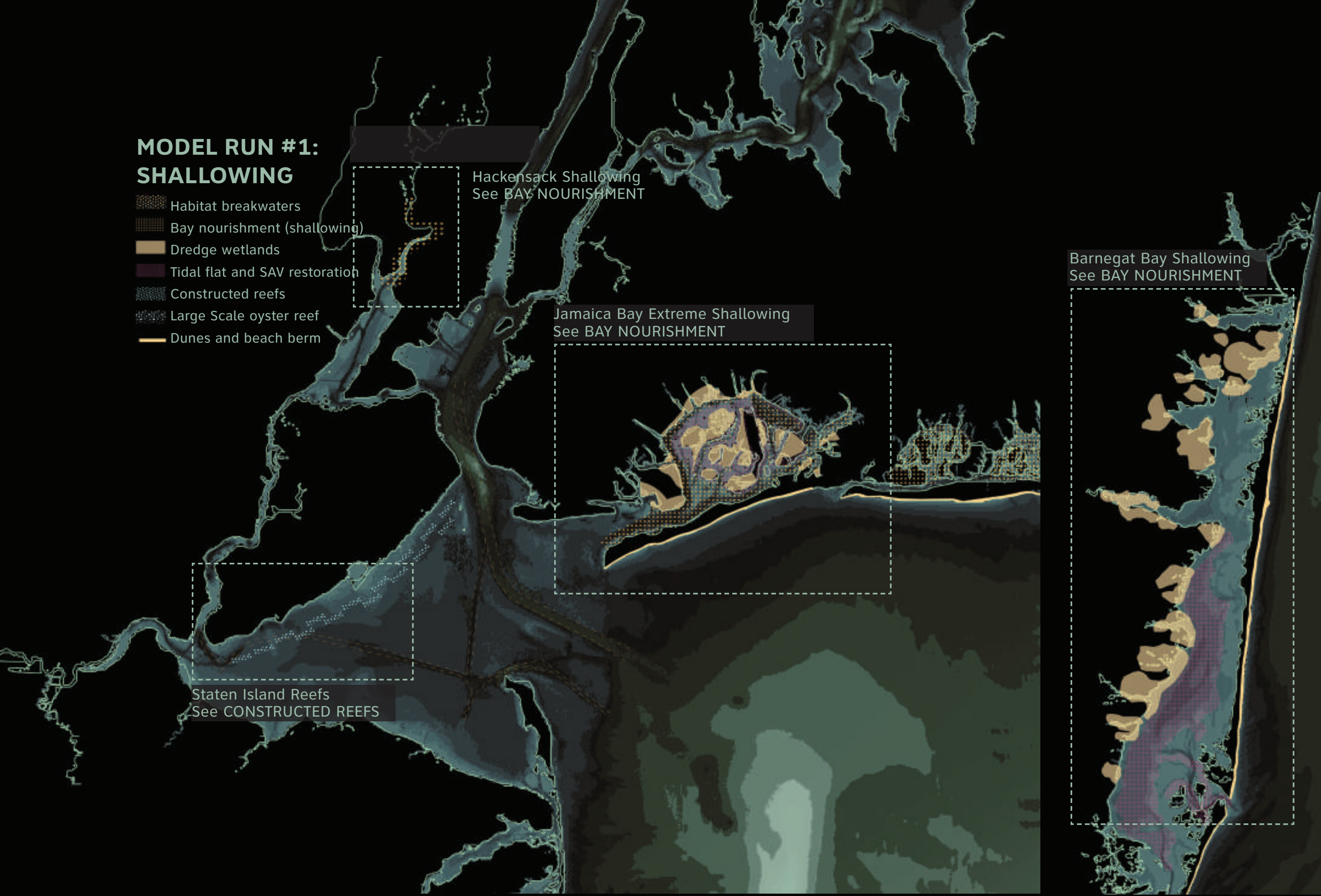


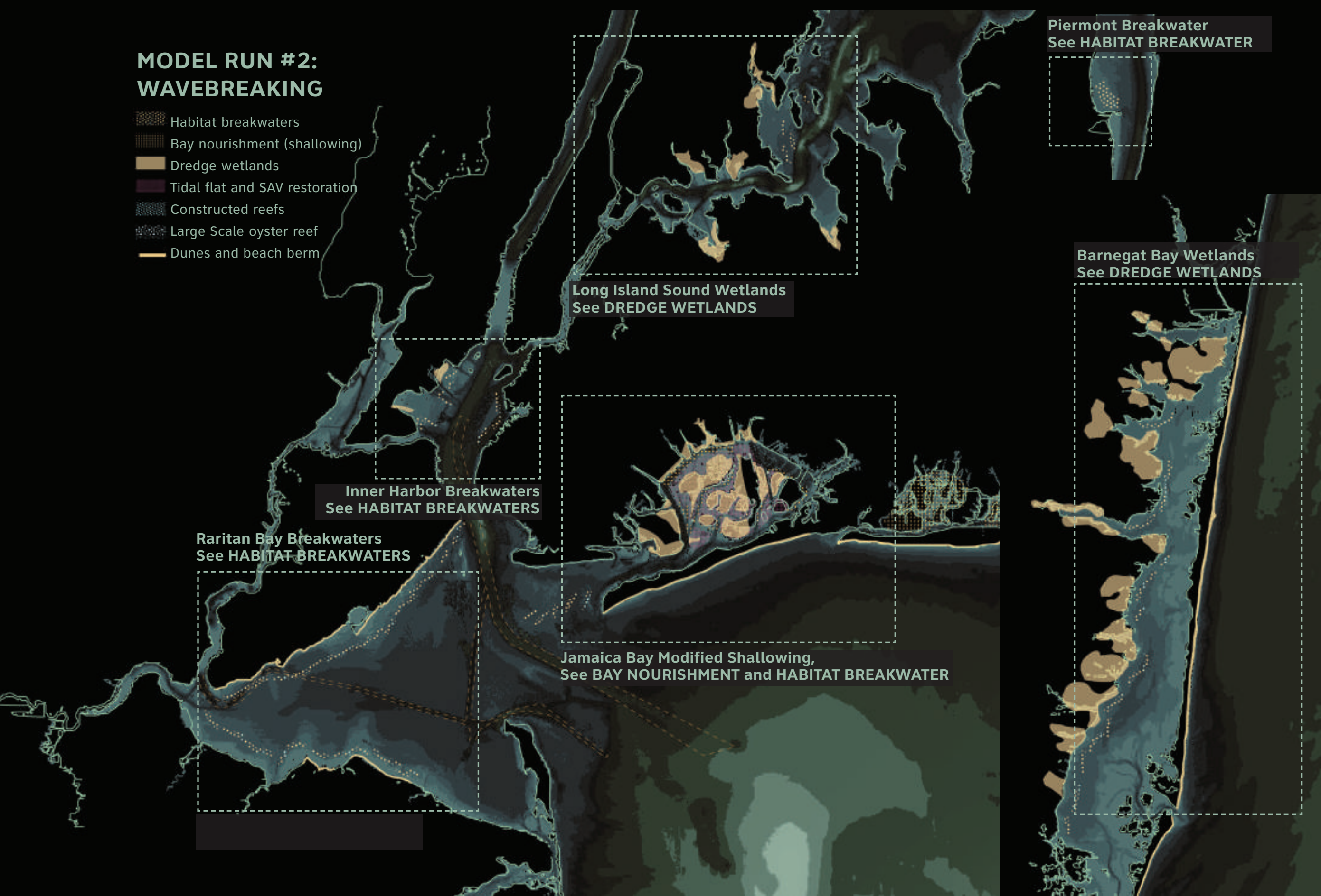

Schools offer additional opportunities for cultivating long term estuary stewardship. Our partner, The New York Harbor School, have advanced models for engaging middle and high school students in the active restoration and management of the New York Harbor, from biological inventory to maritime job training. All strategies offer opportunities to engage local schools in building resiliency within a community. We will work with the Harbor School to integrate scalable activities into the local curriculum—from oyster gardening to reef building, that build maritime knowledge and preparedness at the neighborhood scale.

Students learning about topics like aquaculture through programs included in academic curricula and physically interacting with these environments in outdoor classrooms at nearby shorelines through oyster cultivation for natural reefs instill a sense of ownership for those spaces, and are seen as key towards building more water-aware communities in the future.





MODEL RUN #1:
SHALLOWING
Habitat breakwaters
Bay nourishment (shallowing)
Dredge wetlands
Tidal flat and SAV restoration
Constructed reefs
Large Scale oyster reef
Dunes and beach berm
Hackensack Shallowing
See BAY NOURISHMENT
Jamaica Bay Extreme Shallowing
See BAY NOURISHMENT
Barnegat Bay Shallowing
See BAY NOURISHMENT
Staten Island Reefs
See CONSTRUCTED REEFS

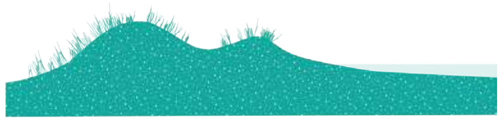



MODEL RUN #2:
WAVEBREAKING
Habitat breakwaters
Bay nourishment (shallowing)
Dredge wetlands
Tidal flat and SAV restoration
Constructed reefs
Large Scale oyster reef
Dunes and beach berm
Piermont Breakwater
See HABITAT BREAKWATER
Long Island Sound Wetlands
See DREDGE WETLANDS
Barnegat Bay Wetlands
See DREDGE WETLANDS
Inner Harbor Breakwaters
See HABITAT BREAKWATERS
Raritan Bay Breakwaters
See HABITAT BREAKWATERS
Jamaica Bay Modified Shallowing,
See BAY NOURISHMENT and HABITAT BREAKWATER

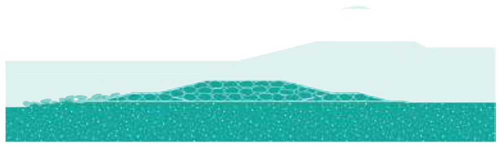
# TESTING THE ECOLOGICAL APPROACH

Communities that were flooded by Sandy face complex decisions about the future, and a quantification of risk-reduction impacts is a useful tool to understand the benefits of ecological infrastructure. Having developed a suite of strategies that could be applicable for coastal protection against storm surges, it was imperative that the team tested their performance within the regional scale. With Dr. Philip Orton of the Stevens Institute, we have run preliminary tests to evaluate the proposed strategies using the ADCIRC hydrodynamic model and SWAN wave model. Seen at left are the two sets of modeling runs that were developed—shallowing strategies and wave-breaking strategies. Results for each intervention can be seen in the appendix. In some instances these were dramatic, in others, minimal. Modeling results are one element of many within our regional research, as shallow water ecosystems have risk reduction capacities that move beyond questions of wet versus dry.

Category-2 Hurricane Donna struck Long Island in 1960 and caused the second highest water elevations in New York Harbor in the 90-year period of continuous tide gauge records at The Battery, at 7.4 ft above today's mean sea level.  Hurricane Sandy has been called an "idiosyncratic" storm and a "1000-year event" due to the uniqueness of much of its behavior, so we focused on a more common type of storm in our first modeling assessment. Prior to landfall, Donna's winds over the coastal zone and inland areas were from the East, whereas Sandy's winds were mostly from the NE, so there were differences in which bay shorelines were most heavily impacted by waves.  In both cases, the storm center offshore caused large swell to propagate similarly from the SE toward the region's open ocean shorelines. All results are preliminary, as each strategy requires further refinement and study with multiple storm and tide scenarios. This research was supported, in part, under National Science Foundation Grants CNS-0958379 and CNS-0855217 and the City University of New York High Performance Computing Center at the College of Staten Island.



DUNES AND BERMS



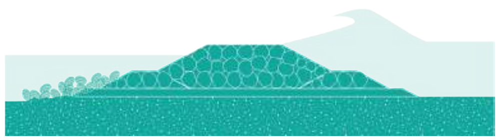
CONSTRUCTED REEFS

TIDAL FLATS

DREDGE WETLANDS

FRICTION FORESTS

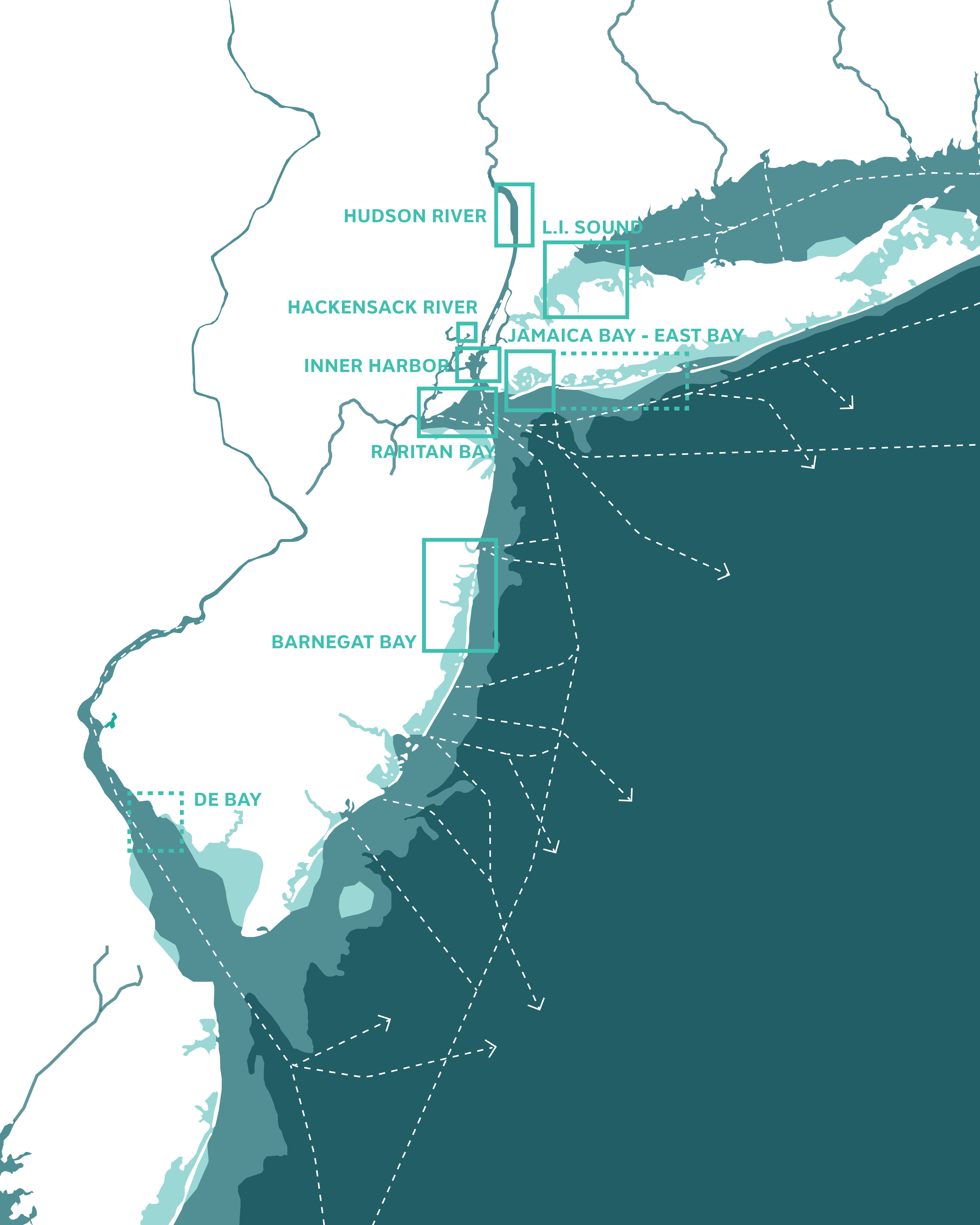
ABSORPTIVE EDGES

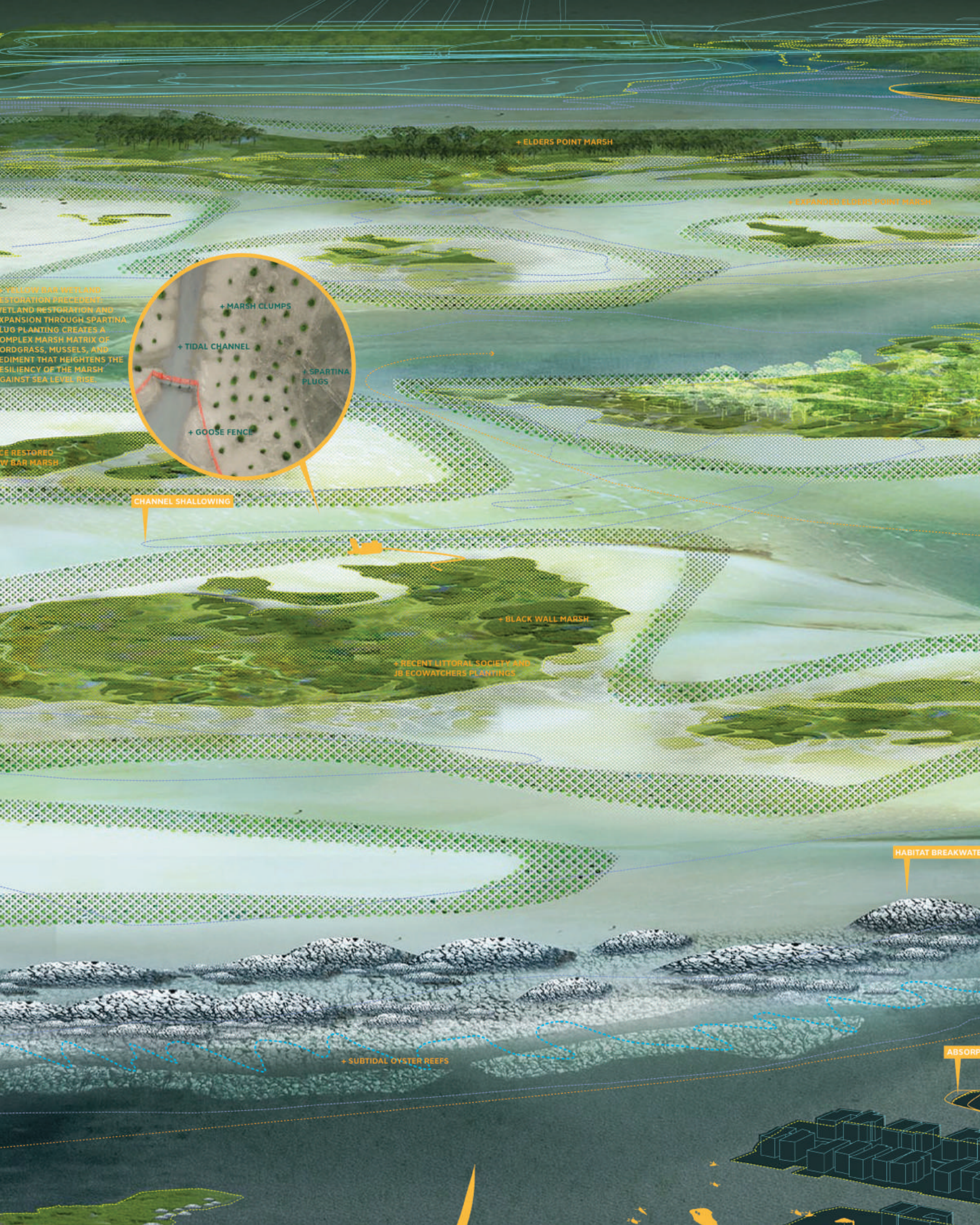


HABITAT BREAKWATERS

# REGIONAL DESIGN OPPORTUNITIES

The Northeastern seaboard presents several shallow areas that emerge as endangered landscapes and therefore potential test sites for our team's concepts—Barnegat Bay, Raritan Bay, the Inner Harbor, Jamaica Bay, the Great South Bay, and several areas along the Upper Hudson that were directly affected by the storm. Our team has developed a research process that links ecology with proven coastal protection to increase biodiversity, stewardship, and education models thereby reducing overall system-wide risk while enhancing recreational and economic opportunities for all.

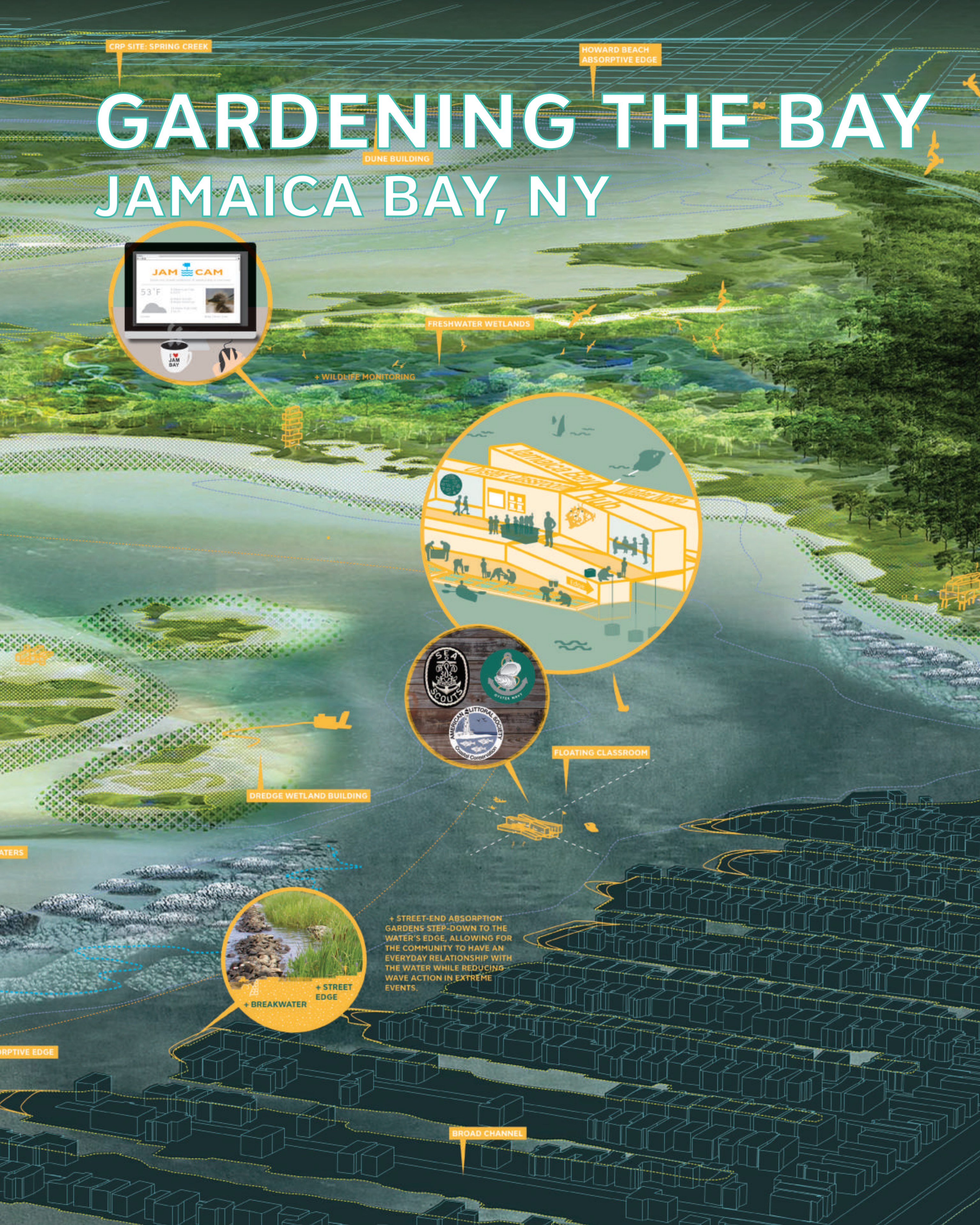

HUDSON RIVER
L.I. SOUND
HACKENSACK RIVER
JAMAICA BAY - EAST BAY
INNER HARBOR
RARITAN BAY
BARNEGAT BAY
DE BAY



+ ELDERS POINT MARSH
+ EXPANDED ELDERS POINT MARSH
+ YELLOW BAR WETLAND
ESTORATION PRECEDENT:
VETLAND RESTORATION AND
XPANSION THROUGH SPARTINA
LUG PLANTING CREATES A
OMPLEX MARSH MATRIX OF
ORDGRASS, MUSSELS, AND
EDIMENT THAT HEIGHTENS THE
ESILIENCY OF THE MARSH
GAINST SEA LEVEL RISE.
+ MARSH CLUMPS
+ TIDAL CHANNEL
+ SPARTINA PLUGS
+ GOOSE FENCE
CE RESTORED
W BAR MARSH
CHANNEL SHALLOWING
+ BLACK WALL MARSH
+ RECENT LITTORAL SOCIETY AND
JB ECOWATCHERS PLANTINGS
HABITAT BREAKWATE
+ SUBTIDAL OYSTER REEFS
ABSORP

# GARDENING THE BAY

## JAMAICA BAY, NY



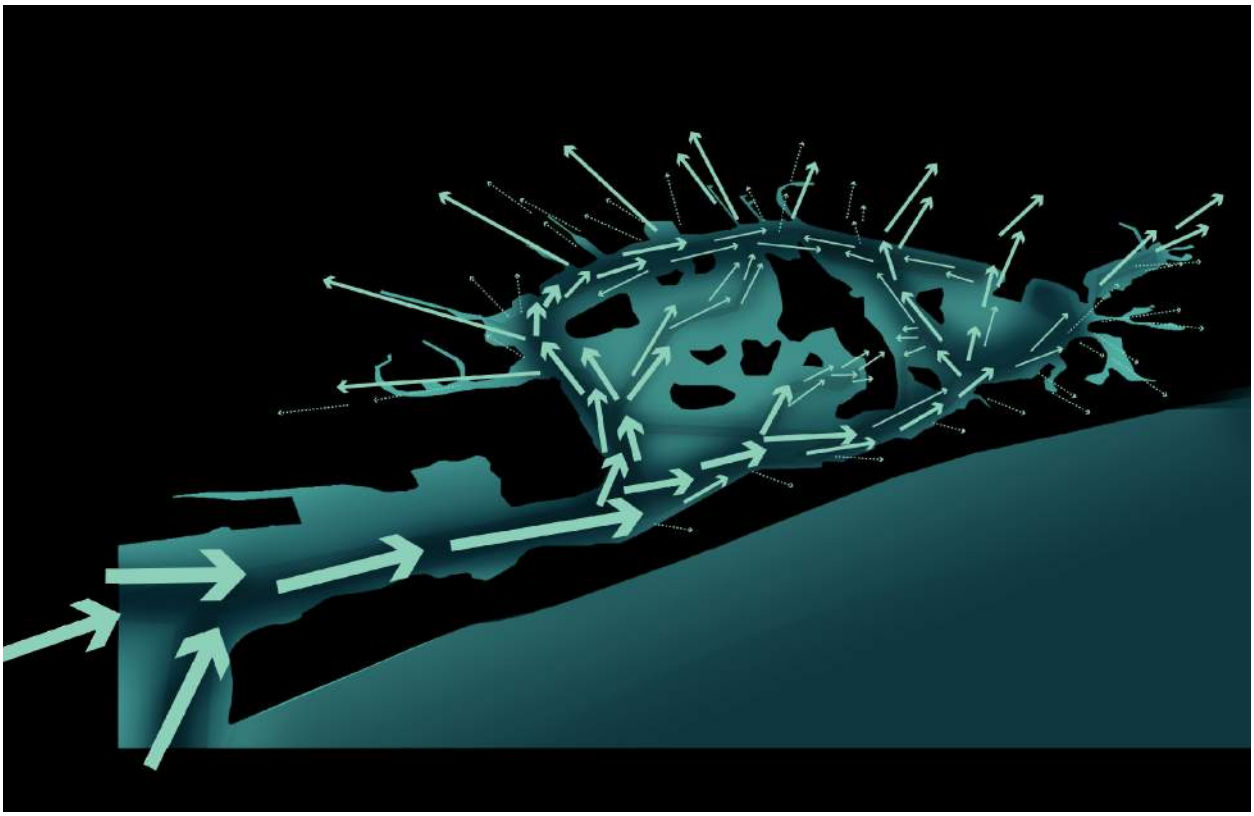
# STRATEGY
# BAY NOURISHMENT

Beach and bay ecosystems are intricately linked in coastal environments where water and sediment dynamics interact in an ever-changing interplay. In urban environments, shifting shorelines become fixed through the insertion of static infrastructure, requiring the artificial replenishment and nourishment of coastal beach berms and dune systems. These systems are actively designed to prevent breaching, leading to a loss of sediment replenishment on the bay side, leaving estuarine ecosystems starved of sediment, the basic substrate for growth.

Continued sea level rise combined with the hydrological and physical impacts of bay-side urbanization, dredge channel creation, maritime traffic, and water pollution mean that the salt marshes and tidal ecosystems of many east coast bays are at risk of disappearing.

Shallow estuarine systems have significant protective functions beyond wave energy dissipation. In bay and riparian systems with narrow inlets and shallow waters, hurricane force storm surges are partially deflected by the shallow water zones, allowing only some of the water in. Channel dredging over time has formed vectors for fast-moving water, directing it into bays and bay-shore neighborhoods developed within the floodplain. However the economic and

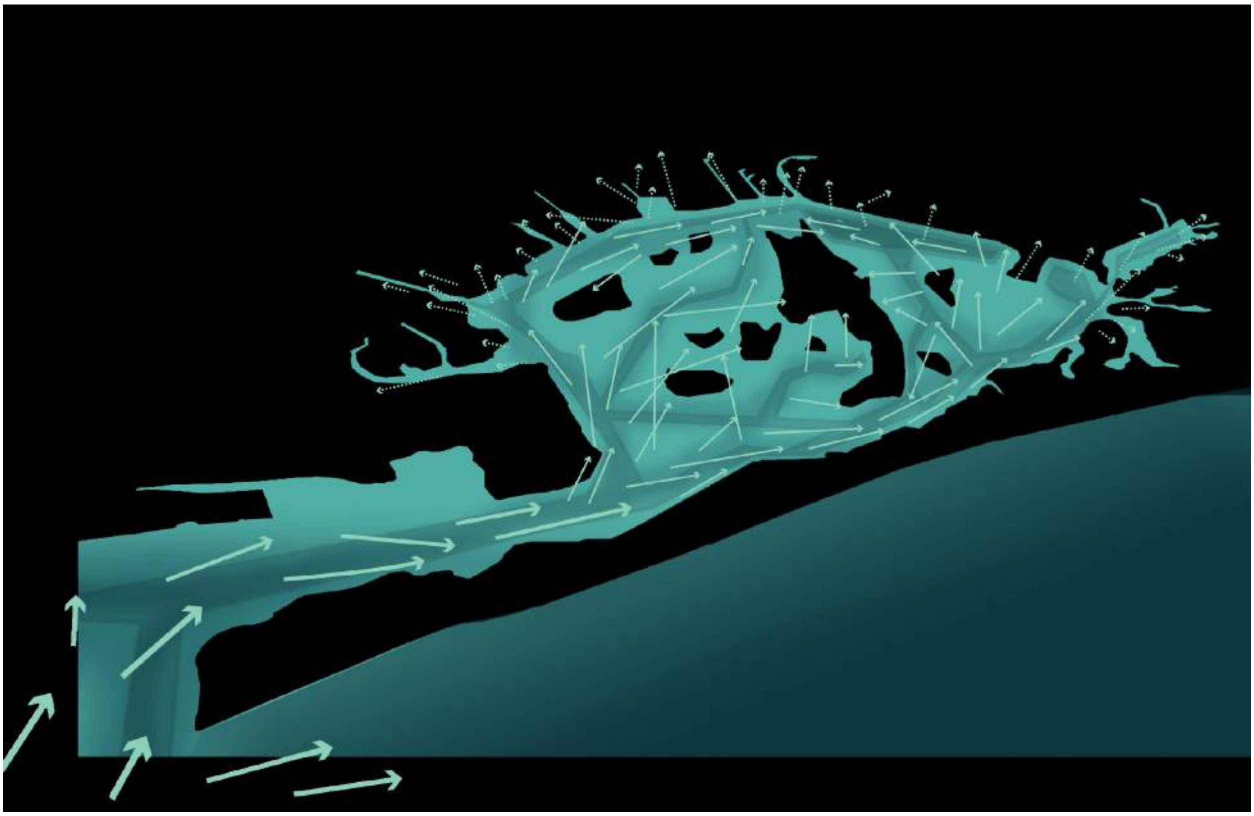
CURRENT CONDITIONS IN JAMAICA BAY EXACERBATE INLAND FLOODING



recreational impacts of the shipping channels are not to be ignored—in many cases these are the primary access points for bay use and activation and multiple alternatives need to be investigated.

As Atlantic beaches are nourished, a concurrent strategy for interior bay nourishment should be considered at the regional scale, to support and replenish shallow water ecological communities and reduce flooding in neighborhoods. Dredge wetland restoration, tidal flat expansion, reef building, dredge channel decommissioning and realignments are strategies that could combine to create the revitalized bays and estuaries of the future.

PROPOSED SHALLOWING REDUCES INFLOW TO BAY SUBSTANTIALLY

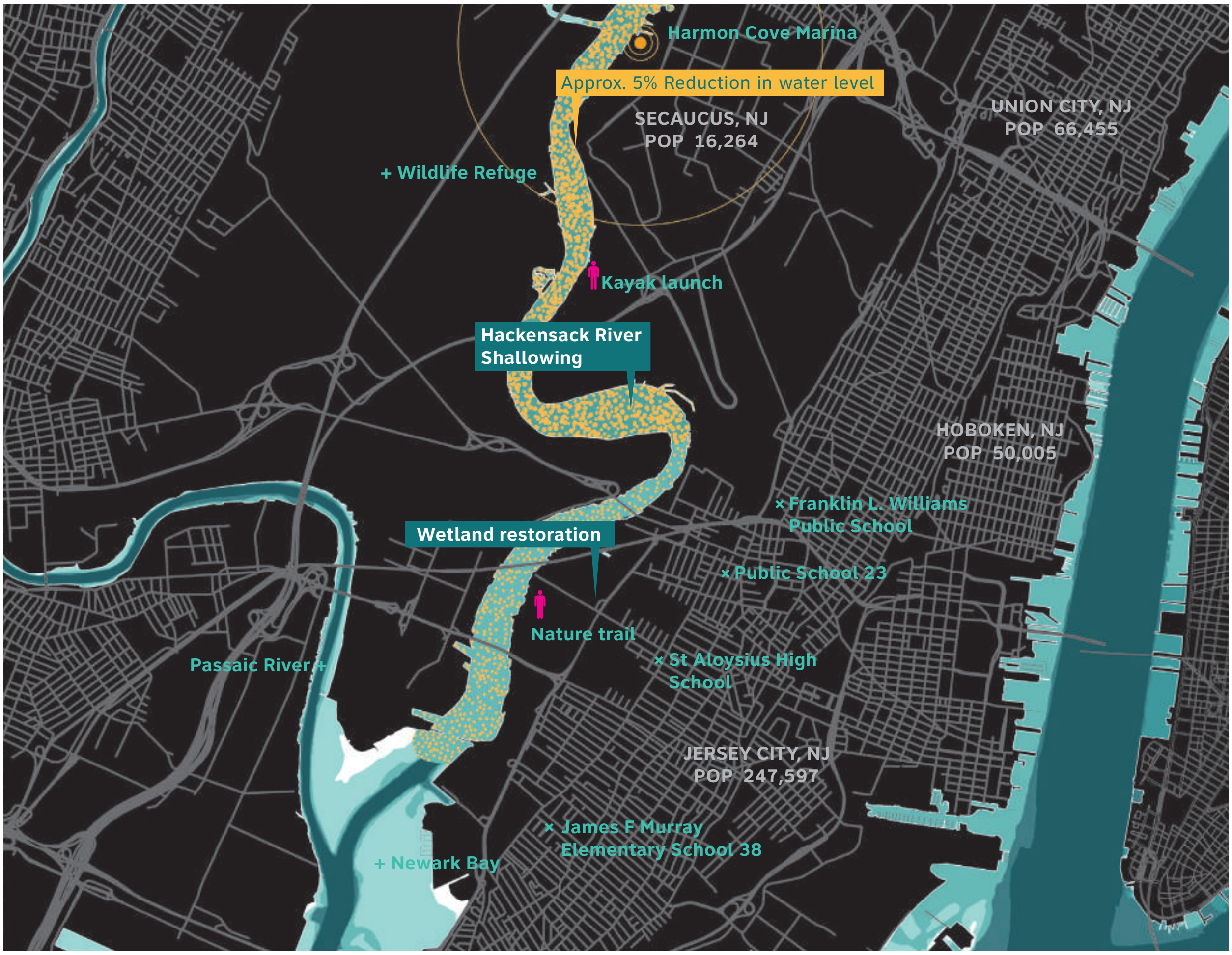


# REPLICABILITY
# HACKENSACK RIVER

**More wet meadows, less lands**
The Hackensack/Meadowlands landscape has historically been a dumping ground, a thoroughfare for critical infrastructure, and a zone of heavy industry. We propose to consider multiple long-term societal and ecological futures for this region and explore the gradual shallowing of under-utilized ship channels as part of a larger river restoration effort. Large-scale shipping channels increase the volume of the Hackensack River itself, amplifying the water mass and destructive force that occurs during a storm event. Shallowed systems closer to their historic water depths typically have less severe inundation and flooding—initial results for the Hackensack surprisingly suggest that flood water height reductions are definite and could potentially extend as far south as the densely populated Newark Bay as well as to Moonachie and Little Ferry in the north, two communities hard hit by Hurricane Sandy. In combination with wetland restoration, the conversion of abandoned upland parking lots, and freshwater wetland flood absorption features, the strategic conversion of land use within this watershed could provide reduction of flooding in residential areas.

**Industrial and Ecological Corridors**
The wetlands complex within the Meadowlands and Hackensack watershed has been severely degraded over the past century, not only from a contamination perspective but also in an ecological role within the water absorption cycle. A series of ditches, berms, and tidal gates were put in place by the Bergen County Mosquito Commission, but these were overwhelmed during Superstorm Sandy, keeping the water in rather than out. Moreover, on an everyday basis they stifle the porous functionality of the wetlands themselves. With potential collaboration with the Meadowlands Environmental Research Institute (MERI), an organization that is already monitoring sediment and water movement in the watershed, and the United States Army Corps of Engineers, whom has conducted flood control models in Little Ferry and Moonachie, these areas hold the power to transform the decaying industrial corridor that they occupy into a vibrant, protective landscape.

**Building Communities around Water** On a regional scale, the Hackensack and Newark Bay—with its high population density—provides a key node for community stewardship initiatives in the harbor region. Through partnering with NY/NJ Baykeeper, an already strong presence in the Hackensack and Meadowlands, new applied science-based middle and high school curriculum have established innovative frameworks for learning and engaging the joint built-natural environment, centered on critical water bodies as learning units. Wetland restoration, maritime skills, and aquaculture among many other skill sets overlay with the urgent task at hand to rebuild social as well as infrastructural resiliency. Though the salinity and oxygen levels in the Hackensack are suitable for oyster growing, contaminant levels are currently too high for their propagation. However, with the help of leaders in the community, as well as a regional coalition of environmental partners, we can begin to change this and bring back the historic maritime ecosystems of New York and New Jersey.



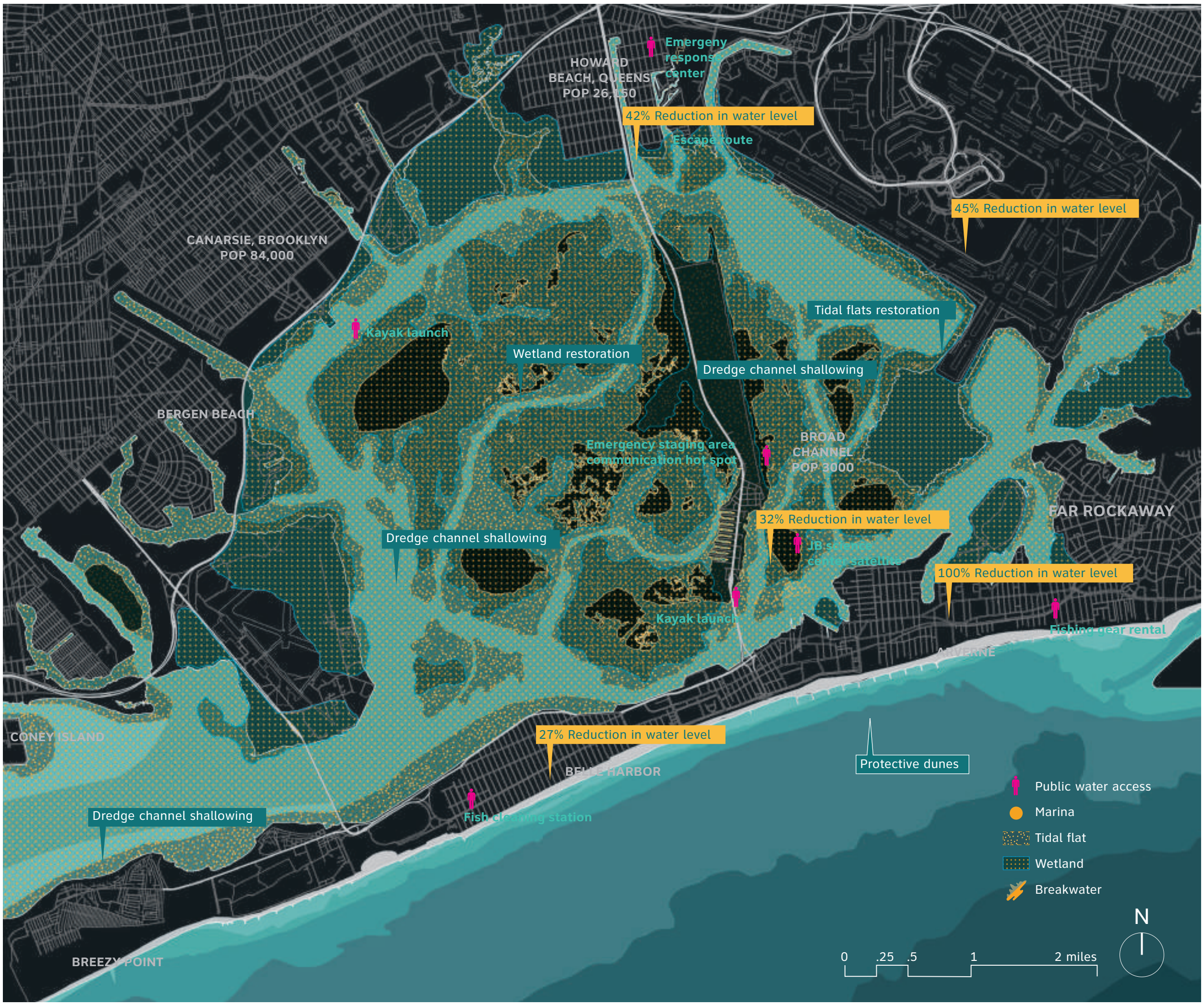

COMPLIMENTARY ONGOING INITIATIVES
US Army Corps flood studies
Hackensack Riverkeeper restoration sites

POTENTIAL COLLABORATORS AND ADVISORS
Port Authority of NY NJ
Hackensack Riverkeeper
Meadowlands Environmental Research Institute
Communities of Secaucus, Jersey City, Little Ferry,
Moonachie

# DESIGN OPPORTUNITY
# JAMAICA BAY COMPREHENSIVE SHALLOWING

Jamaica Bay is one of the nation's most urbanized tidal estuaries, hosting a high, vulnerable population density of over 500,000 people within a low lying watershed. Many Jamaica Bay communities including Breezy Point, the Rockaways, Broad Channel, New/Old Howard Beach, and Gerritsen Beach/Sheepshead Bay all suffered significantly from flooding, and some from wave action damage, during Hurricane Sandy. According to an assessment conducted by NYC Department of Buildings, 37% of the buildings destroyed during Sandy were located in this region. At the same time, the Bay serves as critical wildlife habitat and breeding grounds for hundreds of species of fish and birds, as well as protective infrastructure for surrounding communities. Its formerly shallow marine bathymetry, water quality, and flow has been drastically altered by dredging, urbanization at its edges, and excessive nitrogen pollution from four waste water treatment plants. This has threatened its value as precious intertidal marine habitat, and moreover has caused residents as well as transport infrastructure to be more directly exposed to wave action and flooding, both of which will exacerbate the steady threat of a rising sea. **We propose to consider multiple long-term societal and ecological futures in Jamaica Bay and to explore a layered approach of bay nourishment alternatives** combined with dredge wetland restoration, absorptive edge retrofits, constructed reefs, habitat breakwaters, and maritime friction forests. More than any other site across the region, Jamaica Bay signifies how we can shift our approach to resiliency, and offers potential to test a range of different strategies depicted here within the bay's disappearing marshes and shoals.

The many shallow lagoon systems along New Jersey, Long Island, and many other coastlines nationwide have significant structural protective functions for back-bay communities, including barrier islands along their shores, and narrow or shallow inlets where hurricane storm surges are partially deflected, providing a bottleneck to water flow that limits flooding inside the bay. Deep, dredged channels into and around the perimeter of Jamaica Bay now quickly deliver storm surge flood waters straight to populated areas, with very little attenuation. Restoring at least some of these channels to their shallower water depths would help reduce flood risks for waterfront neighborhoods, yet also presents challenges, limiting water access for critical vessels, potential changes to water dynamics and water temperature, which are also inevitable changes predicted from a course of "no action" and sea level rise. We have tested and modified bay-nourishment approaches with the Stevens Institute hydrodynamic ADCIRC model, trying to accrue similar protective benefits through a limited restoration of bay floor, tidal flat communities, and marshland communities where possible. The range of results is incredibly promising (1ft-1.5ft reductions in flood water heights in neighborhoods) and worthy of exploration in future phases of work.




COMPLIMENTARY ONGOING INITIATIVES:

Comprehensive Restoration Plan coastal resiliency assessment with US Army Corps of Engineers and the City of New York, including sites at Howard Beach/ Spring Creek and Sunset Cove

Jamaica Bay Resiliency Institute, Gateway Regional Management Plan

American Littoral Society and Jamaica Bay Ecowatchers

NY/NJ Baykeepers and New York Harbor School oyster restoration efforts

POTENTIAL COLLABORATORS AND ADVISORS

The City of New York

Jamaica Bay Resiliency Institute

American Littoral Society

US Army Corps of Engineers

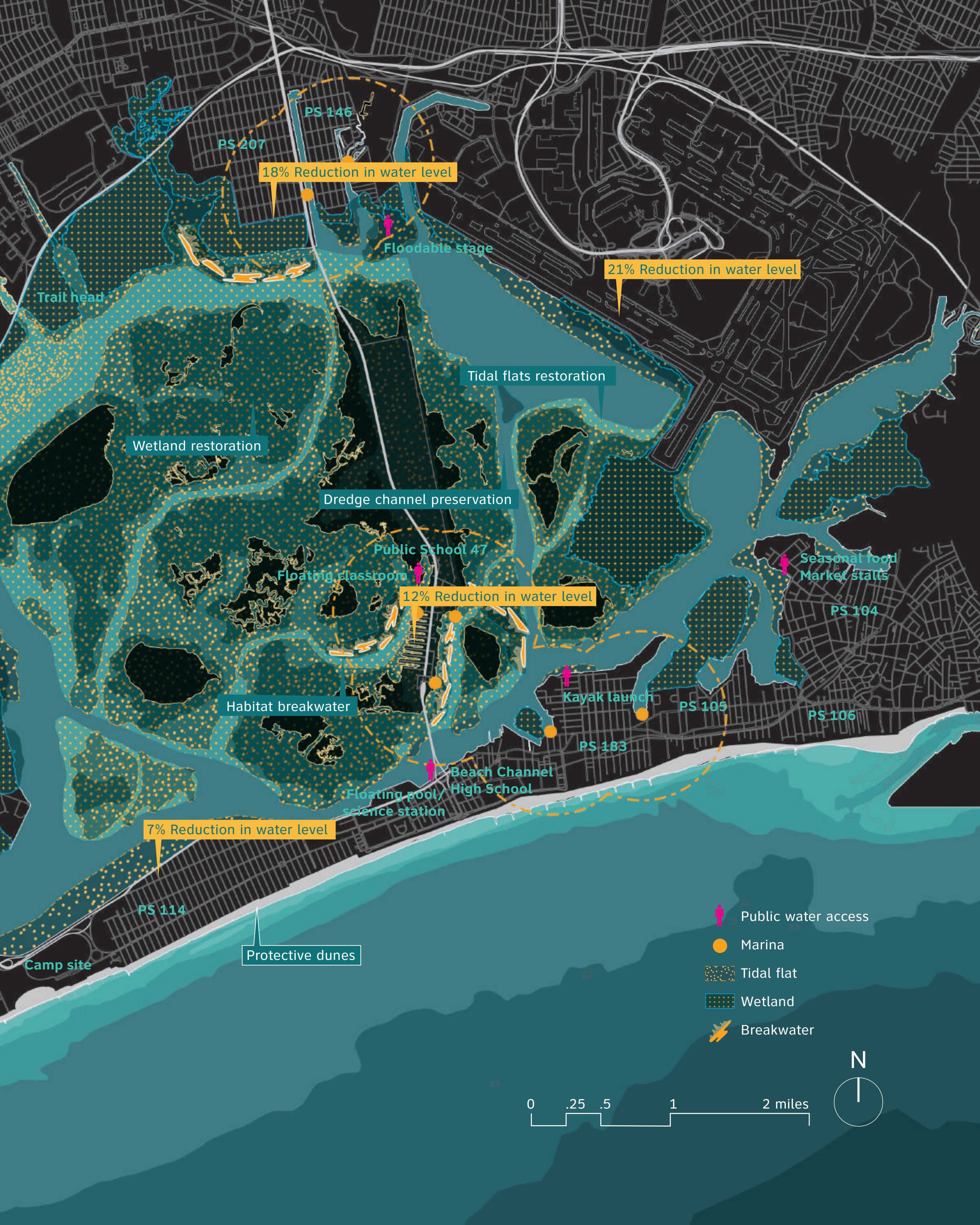
Jamaica Bay Ecowatchers

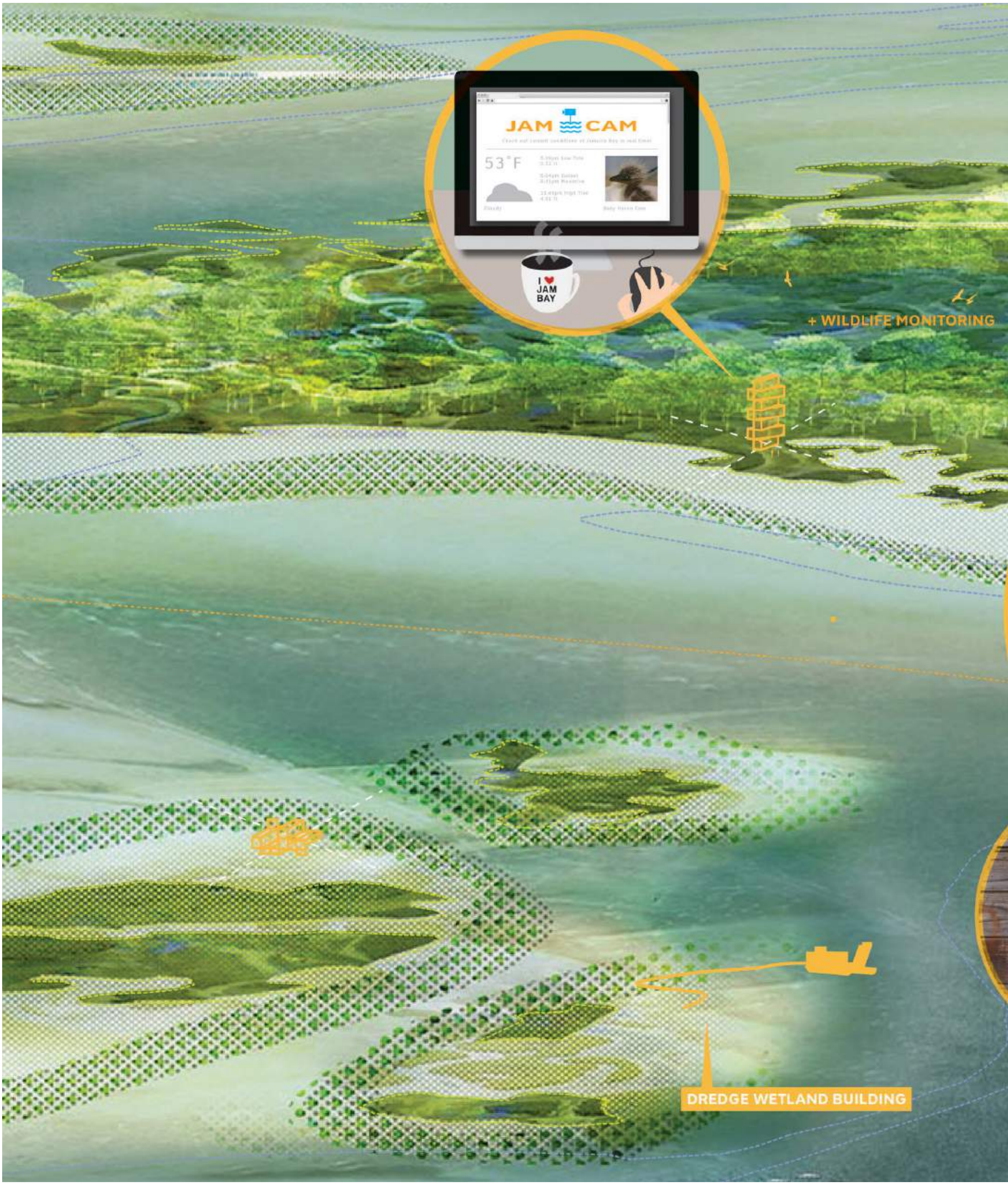
Communities of Rockaways, Broad Channel, Howard Beach, Canarsie

The NY/NJ Port Authority

# DESIGN OPPORTUNITY
# JAMAICA BAY MODIFIED SHALLOWING

**The Layered Approach** We propose to study ongoing restoration and research efforts through the lens of coastal resiliency and risk-reduction, directly linking these efforts with the future threats of sea level rise and storm surge. There are many actors and stakeholders in the Bay from federal, to state, to local and non-profit groups, and our team could help to coordinate this work by developing a framework that begins to synthesize these many initiatives and suggest multiple pilot sites and points of beginning. For example, complimentary ongoing projects and initiatives including absorptive edge buffers at Howard Beach and Spring Creek, breakwaters at Broad Channel and the peninsula tip, bay side access and flood reduction along the Rockaway peninsula, and bay-scale marsh and tidal flat restoration. Community and educational engagement within the Bay is critical to our strategy. We propose to link schools and neighborhoods to the water with a network of highly programmed water hubs—places to view the bay from above, share lessons on coastal risk and preparedness, and engage with the environmental systems of the bay firsthand.


PS 146
PS 207
18% Reduction in water level
Floodable stage
21% Reduction in water level
Trail head
Tidal flats restoration
Wetland restoration
Dredge channel preservation
Public School 47
Floating classroom
12% Reduction in water level
Seasonal food
Market stalls
PS 104
Kayak launch
PS 105
PS 106
Habitat breakwater
PS 183
Beach Channel
High School
Floating pool/
science station
7% Reduction in water level
PS 114
Camp site
Protective dunes
Public water access
Marina
Tidal flat
Wetland
Breakwater
N
0
.25
.5
1
2 miles


JAM CAM
53°F
I ♥ JAM BAY
+ WILDLIFE MONITORING
DREDGE WETLAND BUILDING


# GARDENING THE BAY

LAYERED STRATEGIES: Bay Nourishment, Dredge Wetlands, Absorptive Edges, Constructed Reefs, Habitat Breakwaters, Water hubs, Tidal Flat restoration, Friction Forests

BUILD ON EXISTING INITIATIVES: USACE study and pilot wetlands; CRP work with DPR; SIRR report recommendations; NY Rising community reconstruction program; Jamaica Bay Resiliency Institute and Gateway Regional Management Plan; Community Marsh Planting at Rulers Bar.

Jamaica Bay is one of the nation's most urbanized estuaries —a low coastal elevation zone with a high, vulnerable population density. It is largely part of the National Park system and serves as critical wildlife habitat and breeding grounds for hundreds of species of fish and birds. Its formerly shallow marine bathymetry has been drastically altered by deep dredging and the ongoing effects of nitrification from waste water treatment plants. This has threatened its value as precious intertidal marine habitat, and has made residents and transport infrastructure in its environs more exposed to wave action and flooding, both of which will exacerbate the steady threat of a rising sea. More than any other zone, Jamaica Bay signifies how we can shift our approach to resiliency, and offers a site with rich potential to test a range of different strategies depicted here both onshore and within the bay's disappearing marshes and shoals. Jamaica Bay will be home to a signature new Resiliency Institute, where we can contribute to ongoing research efforts and green/blue infrastructure upgrades— aligning habitat regeneration goals and coastal protection co-benefits.


MARITIME FRICTION FOREST
TOTTENVILLE
DUNE CONSTRUCTION
ND STORAGE
Forest
Reef
View
OYSTER REEF
SPECIES GUIDE
PREDATORS
ASSOCIATES
+ HANGING BASKETS
+ SPAT
+ SPAT MIGRATION
OYSTER REEF
CLEAN WATER
EASTERN
OYSTER
EXCESS
NUTRIENTS
+ ONE EASTERN OYSTER
(CRASSOSTREA VIRGINICA)
FILTERS 50 GALLONS OF WATER A
DAY. OYSTER REEFS ACCRETE
INTO GROWING, ADAPTIVE
COASTAL STRUCTURES THAT CAN
BE HARNESSED FOR RESILIENCY
AND GROW TO ADAPT TO SEA
LEVEL RISE.
+ CONSTRUCTED TIDEPO
PROVIDE SHELTERED SPA
SMALLER INVERTEBRATES
IMMATURE FISH TO THRIV
PLACED IN THE INTERTIDA
WATER IS FLUSHED THRO
BOTTOM OF THE STRUCTU
+ FISH SPAWNING HABITAT
+ OYSTERCATCHERS

# REGIONAL REEF NETWORK

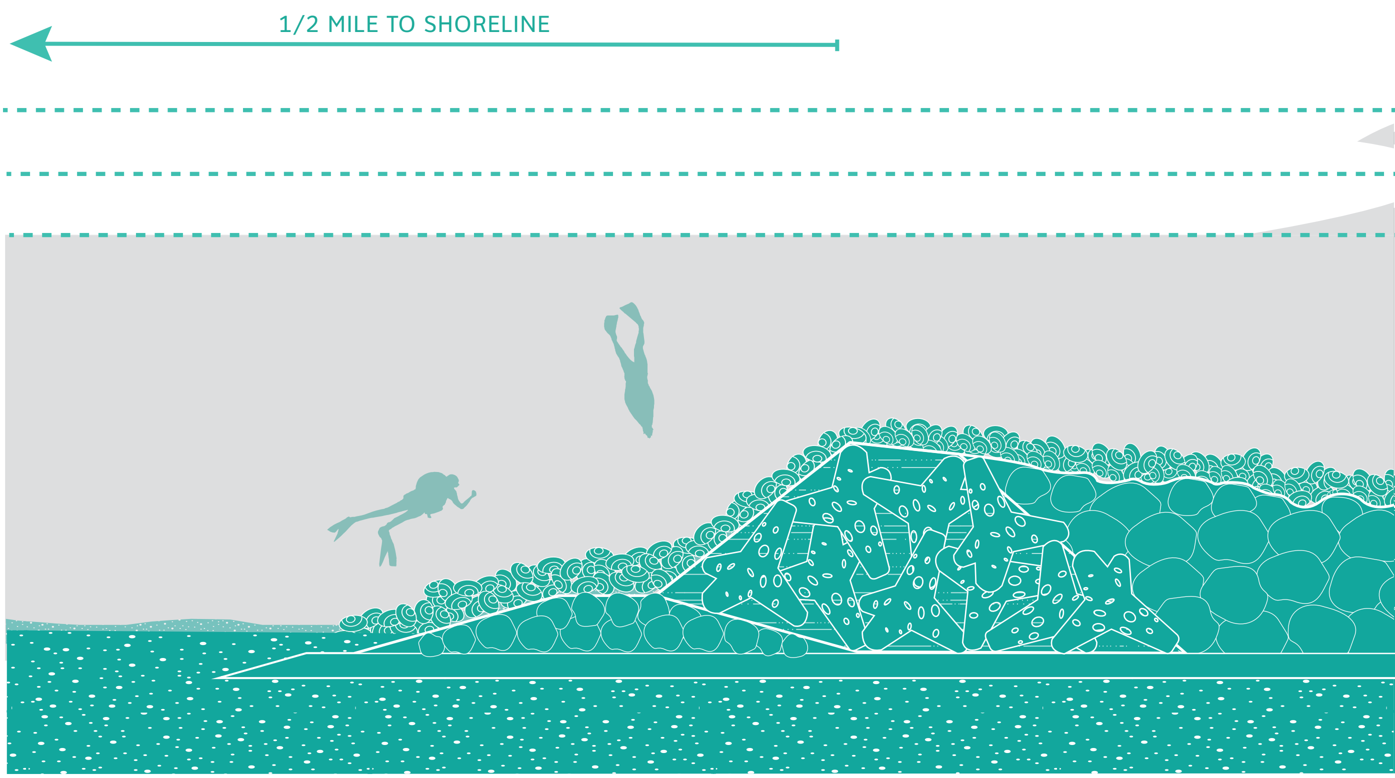
## STATEN ISLAND + INNER HARBOR , NY

## STRATEGY

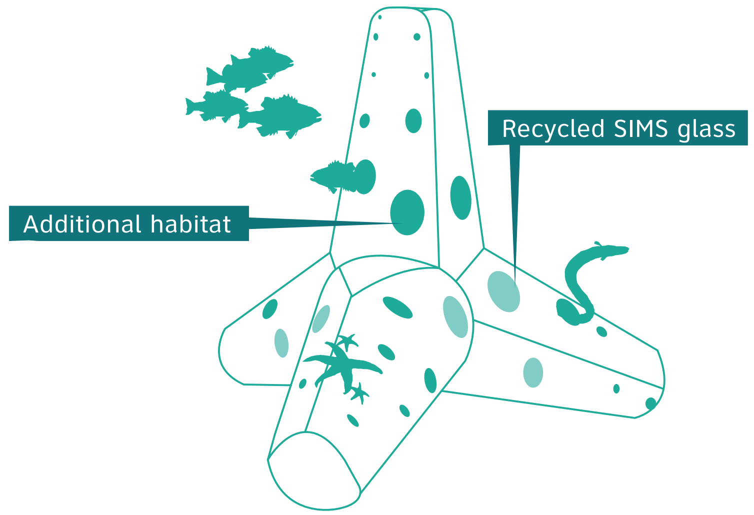
# SUBTIDAL HABITATS FOR WAVE ATTENUATION

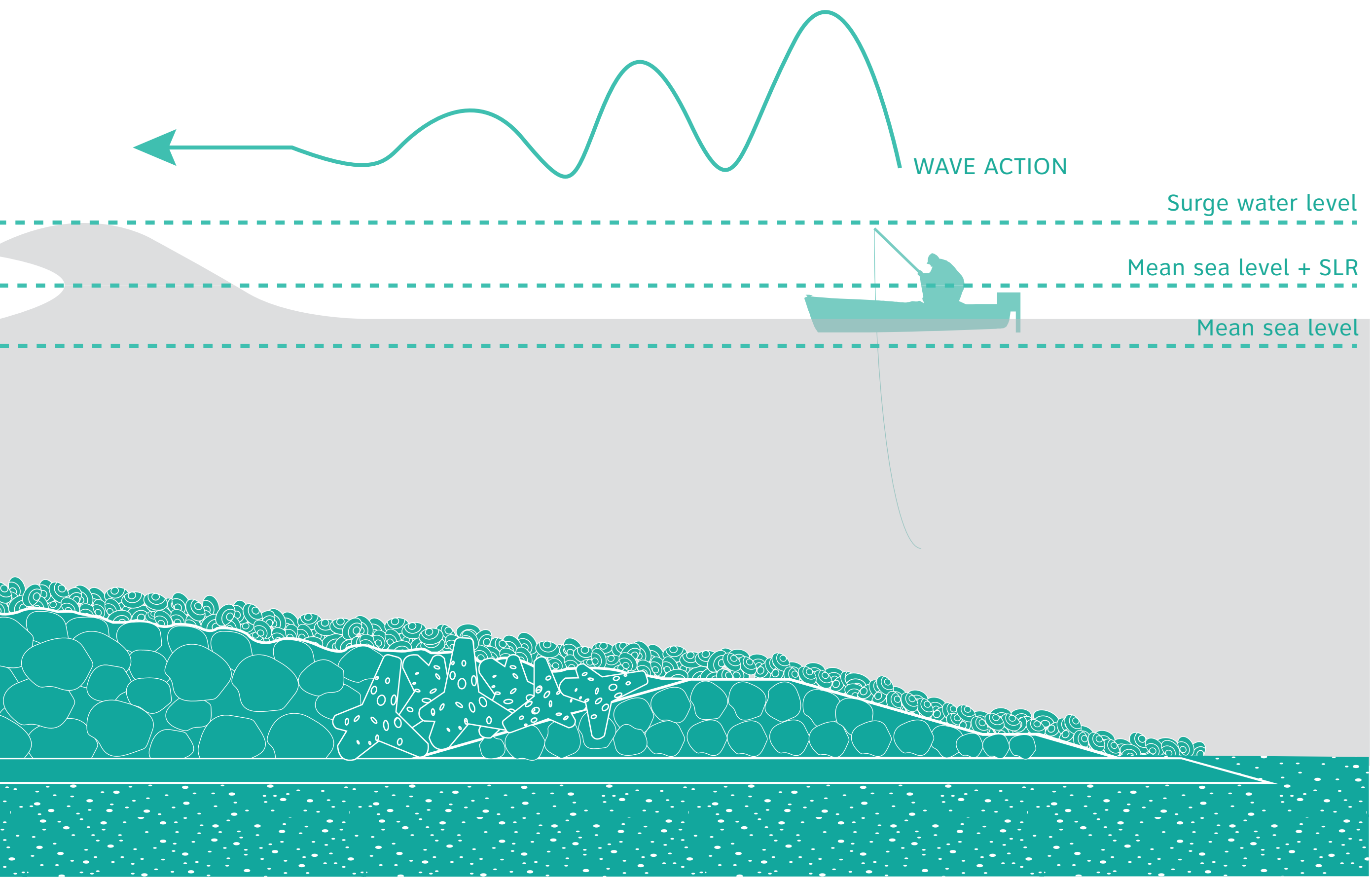
Constructed reefs break waves at the sea-floor, reducing wave velocity and heights on-shore. Completely subtidal, constructed reefs reduce a smaller proportion of a wave than breakwaters but more closely mimic historic ecosystems characteristic of the New York Harbor. Constructed reefs are often composed of interlocking rock, a structural matrix that is able to withstand the impacts of hurricane force waves. Voids within the rock structure become ideal feeding and resting places for small and large fish. Precast ecological concrete breakwater units and tide pools—made from a low pH mix designed for marine recruitment—can also act as a protective matrix and substrate for biological life.

Over time, the structural integrity of the reef improves, as oysters and mussels biogenically build strength through the accretion of calcium carbonate. Schools and communities can be reef stewards at a variety of scales—from a middle school classroom monitoring a spat (juvenile oyster) producing oyster garden to a neighborhood association seeding a constructed reef with "spat on shell." Reefs improve water quality and create shoreline destinations for fishermen and crabbers by encouraging upwelling, bringing nutrients and plankton to the water's surface, attracting fish and other larger maritime species.

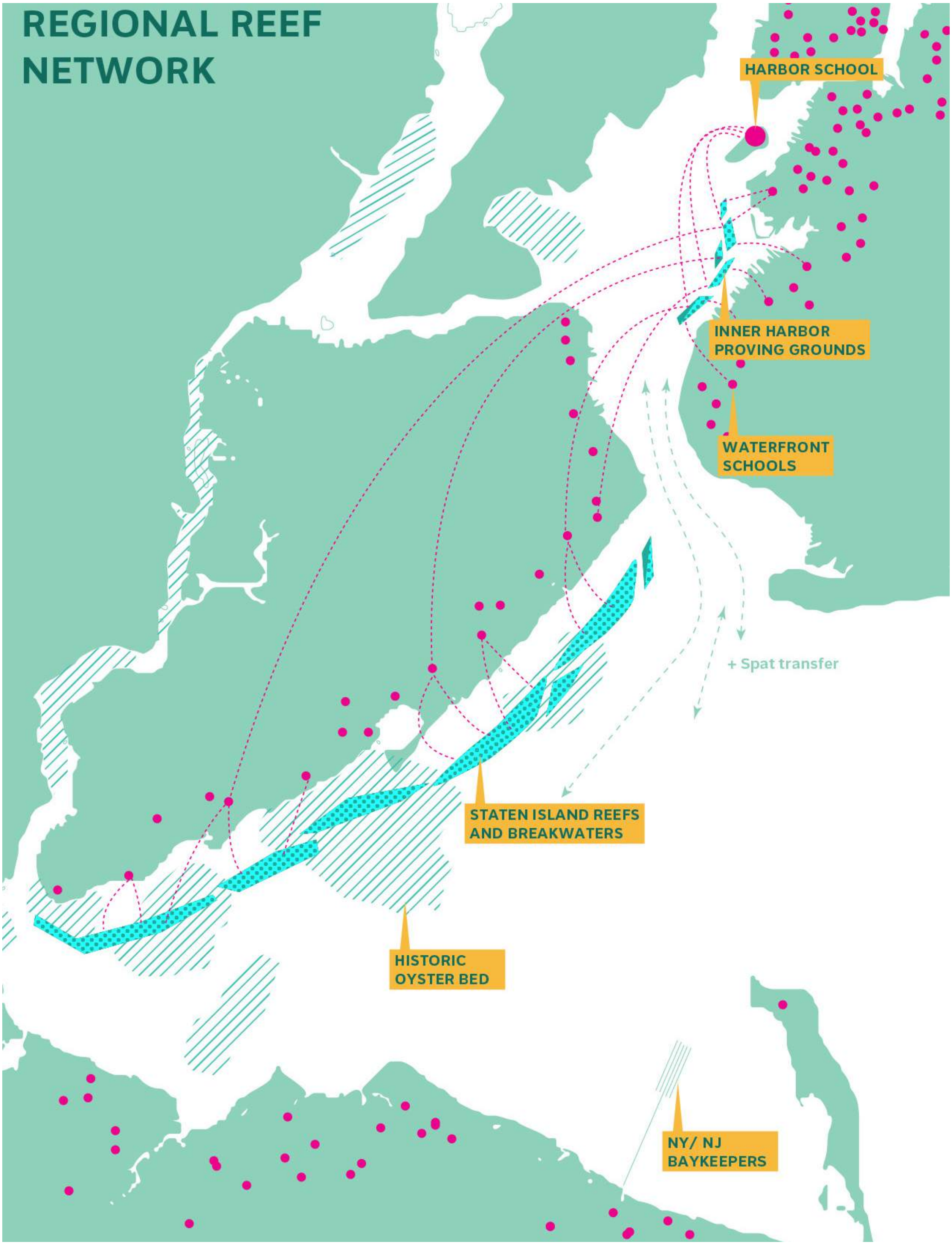


ECONCRETE UNITS



# REGIONAL REEF NETWORK



**Living, Growing Breakwaters** Staten Island and the New York/New Jersey Inner Harbor were hard hit by Sandy. Once protected by a wide shelf and series of oyster reefs along the coast, much of the shore of Staten Island remains exposed to wave action and erosion. The more protected Inner Harbor faces less risk from waves, but remains vulnerable due to significant industrial maritime uses dependent upon water access and navigation. It offers many potential breeding oyster colony sites, from Pier 5 to Bushwick Inlet that can continuously nourish this regional reef restoration network with oyster spat (juveniles), extending the impacts of the infrastructure beyond its constructed borders. **We propose to link risk-reducing reefs and breakwaters at the Inner Harbor and Staten Island shorelines as part of an educational and oyster recruitment effort at the larger harbor scale**. The shape and depth of the harbor, water quality conditions, tidal current flow, successful oyster restoration efforts, and risk-reduction potentials all point to this thread of shallow bathymetry as the right site within the Hudson-Raritan Estuary system to cultivate a network of large scale habitat breakwaters and reefs.

**Habitat breakwaters and constructed reefs** reduce risk in shoreline communities by absorbing wave energy and catalyzing the growth of protective ecosystems. Traditional breakwaters are modified to include a wave-breaking face made of interlocking rock and ecological concrete units that extend above the water's surface and support the emergence of an ecological culture in its lee. A protected face slopes below the tidal range, creating an undulating edge of shallow and deeper water that forms a diversity of niche habitats, such as salt marshes, water cleansing oyster-beds, mud flats, and colonial bird nesting sites. Constructed reefs remain completely subtidal, reducing wave breaking capacities but providing more potential habitat with less costly construction techniques. Used alone or in combination with other coastal protection techniques, breakwaters and reefs can reduce heights of on-shore structural solutions such as revetments, seawalls, and reinforced dunes—reconnecting us with our waterfront. Hydrodynamic modeling with the Stevens Institute ADCIRC model suggest that these techniques may reduce wave heights by 0.25ft–4ft dependent on strategy and location. We aim to refine these forms and locations in our modeling process in the next phase of work.

Water stewardship and education Working with locally impacted communities, a range of alternative futures can be developed that are effective, resilient, and complimentary to the ongoing shoreline work of the region. Typically located less than half a mile from the shoreline, habit breakwaters and constructed reefs create calm, slow water zones that allow safer interaction with the water during typical days as well as disasters. Learning from our partners at the New York Harbor School, a water-based curriculum for nearby middle and high schools will be developed that fosters the development of maritime skills, new engagement and stewardship of risk-reducing maritime ecosystems. Constructed waterfront access hubs become places to learn about the shoreline, cultivate reef ecosystems, and recreate within a cleaner, safer, and more accessible landscape enabled by this hybrid eco-infrastructure.

ECOncrete designed to promote biological assemblages using recycled materials from the SIMS glass facility. Developed by SeARC Consulting in conjunction with SCAPE/LANDSCAPE ARCHITECTURE PLLC.

# DESIGN OPPORTUNITY STATEN ISLAND REEF

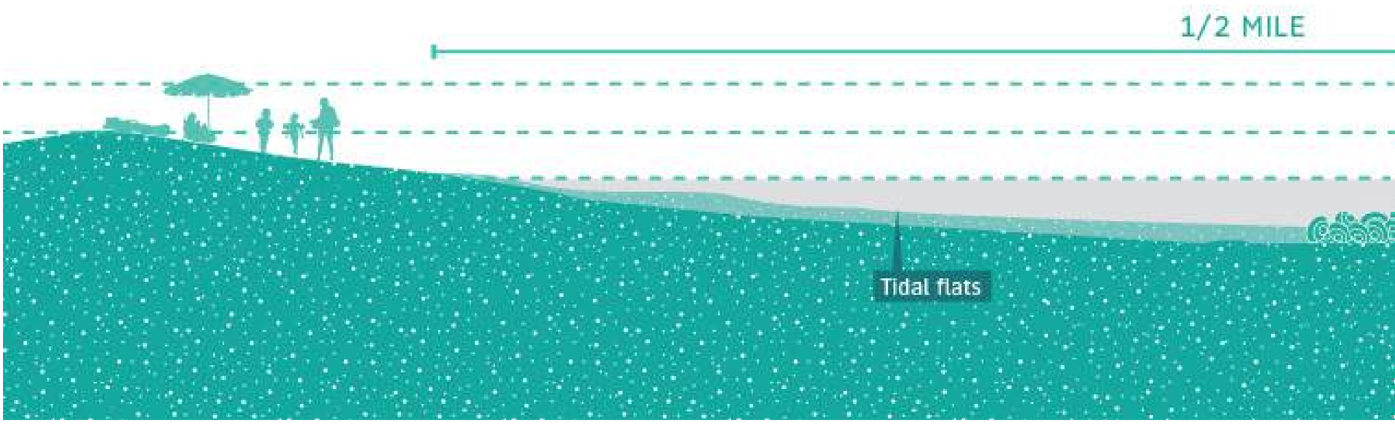
Constructed reefs along the seaward edge of Staten Island break waves below the water's surface, reducing velocities and wave heights at the shoreline. Unlike the habitat breakwaters scenario, constructed reefs would remain completely below the waterline and would not be visible from the shore. While their wave reduction impacts are reduced, they more closely mimic the historic oyster reefs once present at this location and are compatible with the coastal protection measures under planning by the US Army Corps of Engineers.

ADCIRC modeling with Hurricane Donna shows that the Staten Island constructed reefs modeled at 1m height from the sea bed had a small to moderate effect (0.25ft-1.5 ft , or 5-27%) on wave heights. A small increase (1" increase) in flood elevation was shown in the western Raritan Bay and requires further study.

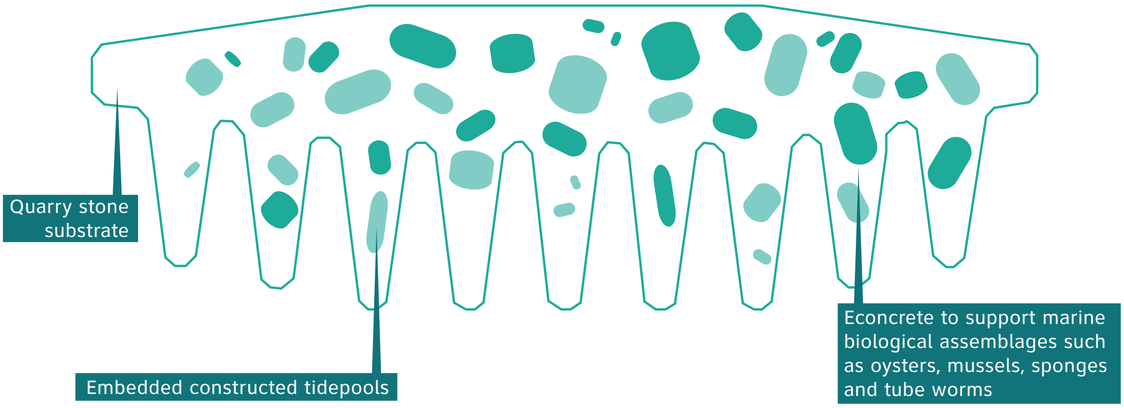
4% wave reduction
On-shore friction forests
Trail head
Reduced wave setup
7% wave reduction
Reef rumble strip
+ Raritan Bay

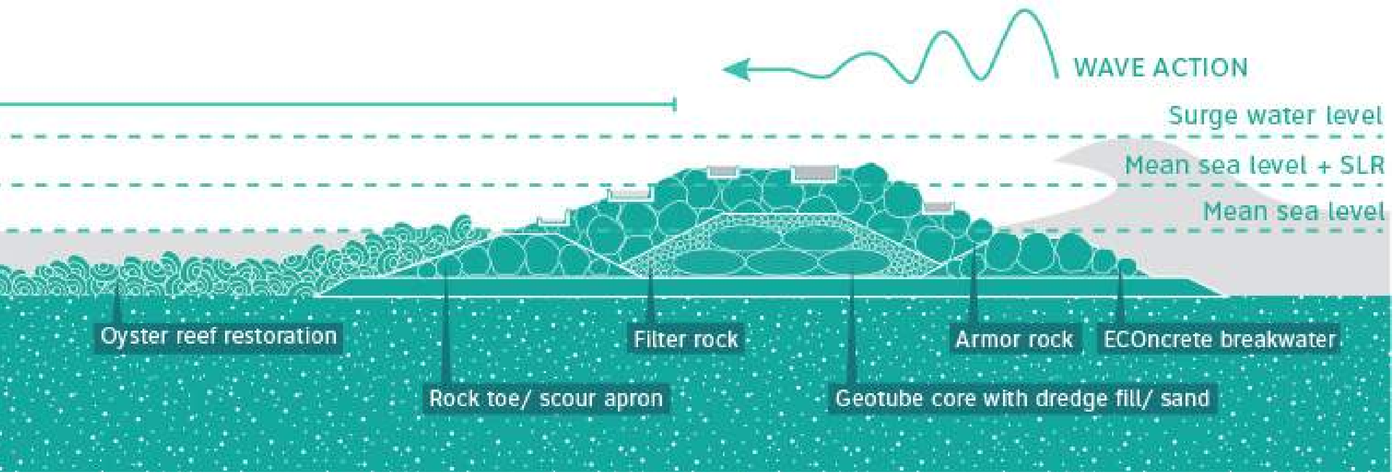
# STRATEGY
# HABITAT BREAKWATERS

Habitat breakwaters reduce risk in shoreline communities by absorbing wave energy and catalyzing the growth of protective ecosystems. A wave-breaking face composed of interlocking rock and ecological concrete units extends above the water's surface and supports the emergence of a protected ecological culture in its lee. This protected face slopes below the tidal range, creating an undulating edge of shallow and deeper water  that forms a diversity of niche habitats, such as saltwater marshes, water cleansing oyster-beds, mud flats, and colonial bird nesting sites. Typically located less than half a mile from the shoreline, habit breakwaters create calm, slow water zones that allow safer interaction with the water during typical days as well as disasters. The typical coastal breakwater cross-section is re-designed to host biological growth and restoration, reduce the velocity and erosive force of waves, and protect fragile shorelines and critical natural systems. Used alone or in combination with other coastal protection techniques, breakwaters can layer up with beach nourishment and dune building strategies, which together can reduce heights of on-shore structural solutions such as revetments and seawalls—reconnecting us with our waterfront. New waterfront access portals become places to view, garden, and enjoy the cleaner, safer, more richly textured and more accessible landscapes enabled by this hybrid eco-infrastructure.



BREAKWATERS WITH ENHANCED EDGES

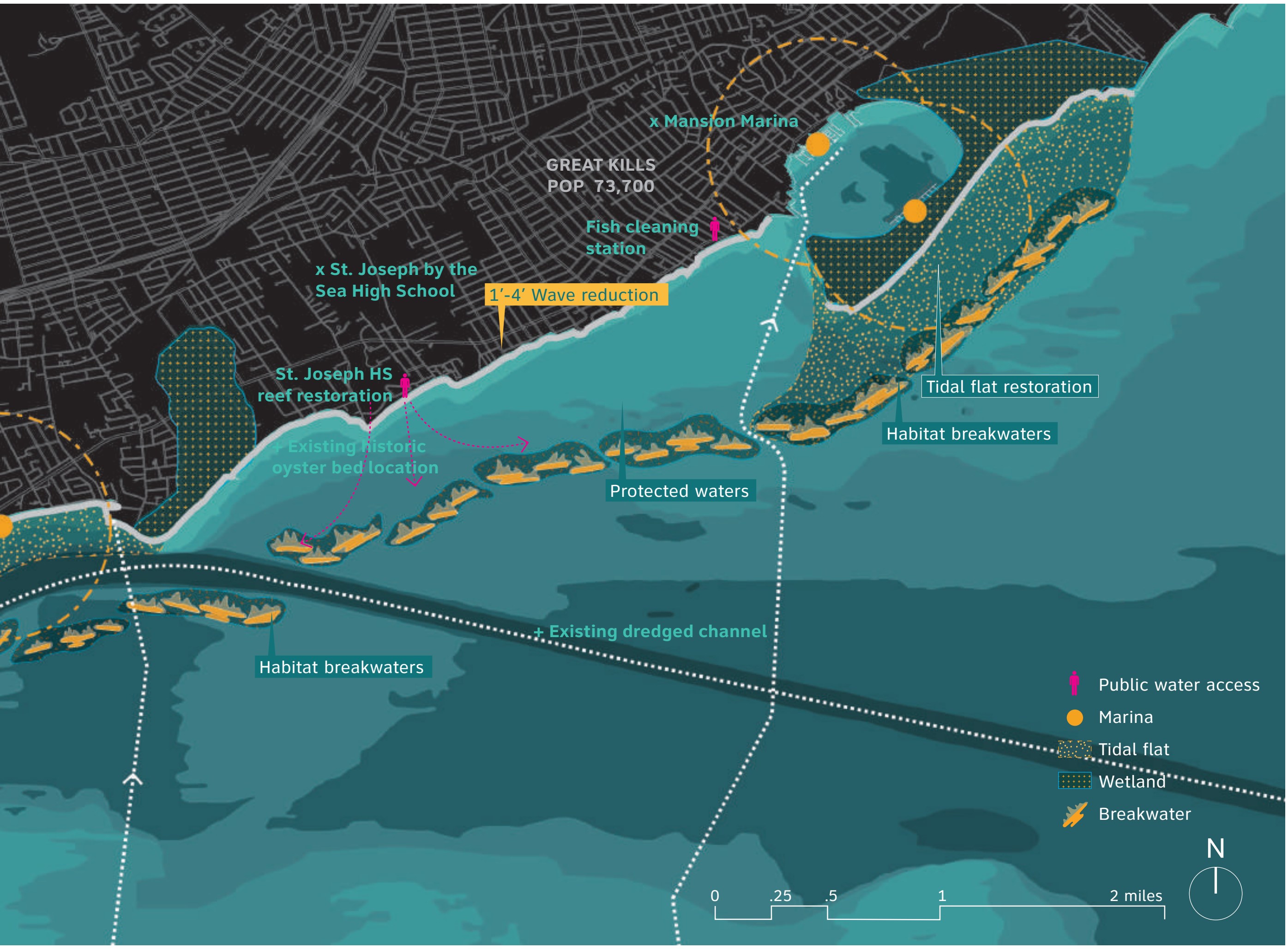


# DESIGN OPPORTUNITY
# STATEN ISLAND BREAKWATERS

The plan to the right shows an expanded network of habitat breakwaters along the coast of Staten Island, one of New York City's most exposed and vulnerable communities. Combined with inland freshwater wetland water capture, coastal maritime forest planting, dune building, and tidal flat restoration, this necklace of ecological infrastructure can reduce damaging wave action along the shoreline while working with ongoing resiliency efforts currently being planned by the US Army Corps of Engineers.

ADCIRC modeling with Hurricane Donna shows a very strong reduction in waves (1-4 ft) along the Staten Island shoreline. In select zones, an increase in flooding (0.3ft) inshore of the breakwaters occurred, which requires further design refinement and study.


x Mansion Marina
GREAT KILLS
POP. 73,700
Fish cleaning station
x St. Joseph by the Sea High School
1'-4' Wave reduction
St. Joseph HS reef restoration
+ Existing historic oyster bed location
Tidal flat restoration
Habitat breakwaters
Protected waters
+ Existing dredged channel
Habitat breakwaters
Public water access
Marina
Tidal flat
Wetland
Breakwater
N
0
.25
.5
1
2 miles

# REPLICABILITY
# UPPER HUDSON/ PIERMONT, NY

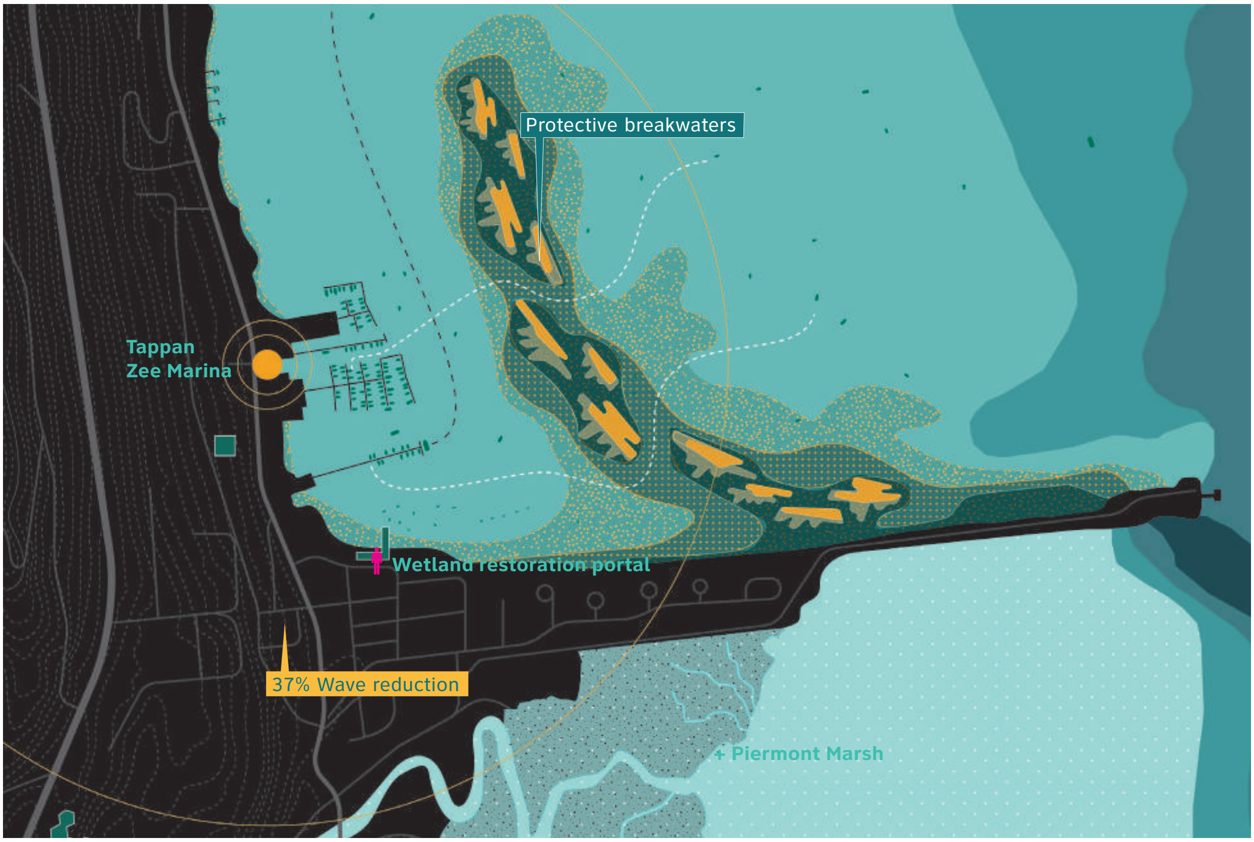
**Hudson Habitat** Impacts of Hurricane Sandy were felt throughout the Hudson River watershed, devastating communities and villages along the Hudson Valley, as far north as Albany. Piermont, a community based on river tourism and recreation on the expanded west bank of the river, sustained varying degrees of damage in part due to the lack or presence of natural systems. North of Piermont Pier, homes and water-based restaurants and marina enterprises were badly damaged after the storm—partially from wave action that builds up over the three-mile wide fetch across the Hudson River at that location. South of the pier, a thick one-mile wide Phragmites marsh broke waves, attenuated surge, and protected shoreline residents to a greater degree. Restoration plans to remove invasive plants in the marshlands have the potential to increase coastal fragility in the short term, while the remainder of the recreational waterfront remains at-risk. **We propose to look at the modification and restoration of historic ecosystems, including tidal marshlands and oyster reefs, as a new risk-reducing ecological infrastructure along the shoreline**—over half of which is currently hardened along the length of the lower Hudson River.

**The Layered Approach** Habitat breakwaters step-down risk in shoreline communities by absorbing wave energy and catalyzing the growth of protective ecosystems. The protected face slopes below the tidal range, creating an undulating edge of shallow and deeper water that forms a diversity of niche habitats, such as salt marshes, water cleansing oyster-beds, mud flats, and colonial bird nesting sites. We are proposing a re-designed breakwater cross-section to host biological growth and restoration, reduce the velocity and erosive force of waves, and protect fragile shorelines and critical natural systems. These systems are particularly apt in Piermont because of the degree of wave damage that occurred during Hurricane Sandy, with waves up to three feet coming into the community north of the Piermont Pier.

**Collaborative Models** By teaming up with key players such as Scenic Hudson and Hudson Riverkeeper on projects that could be replicable in other communities along the Hudson River waterfront, these ecologically productive buffer systems could not only benefit the community but also the environment. With multiple projects already underway centering on water quality and public spaces, Piermont and other similar villages are primed to re-imagine and mobilize around a new, productive, and resilient vision for the Hudson River waterfront.

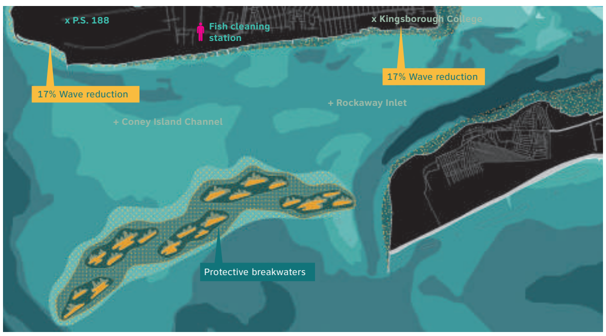
COMPLIMENTARY ONGOING INITIATIVES
Hudson River Improvement Fund
NY/NJ Harbor Estuary Program
Oyster Restoration Research Project

POTENTIAL COLLABORATORS AND ADVISORS
Scenic Hudson
Villages of Piermont, Nyack, Haverstraw, Kingston
Hudson Riverkeeper
Hudson River Foundation




PIERMONT, HUDSON RIVER, NY


INNER HARBOR, NY




ROCKAWAY PENINSULA, NY


LONG ISLAND SOUND, NY


OYSTER REEF
CLEAN WATER
EASTERN OYSTER
EXCESS NUTRIENTS
+ ONE EASTERN OYSTER (CRASSOSTREA VIRGINICA) FILTERS 50 GALLONS OF WATER A DAY. OYSTER REEFS ACCRETE INTO GROWING, ADAPTIVE COASTAL STRUCTURES THAT CAN BE HARNESSED FOR RESILIENCY AND GROW TO ADAPT TO SEA LEVEL RISE.
+ OYSTERCATCHERS


# LIVING, GROWING BREAKWATERS

LAYERED STRATEGIES: Constructed Reefs, Habitat Breakwaters, Water hubs, Friction Forests, Dunes

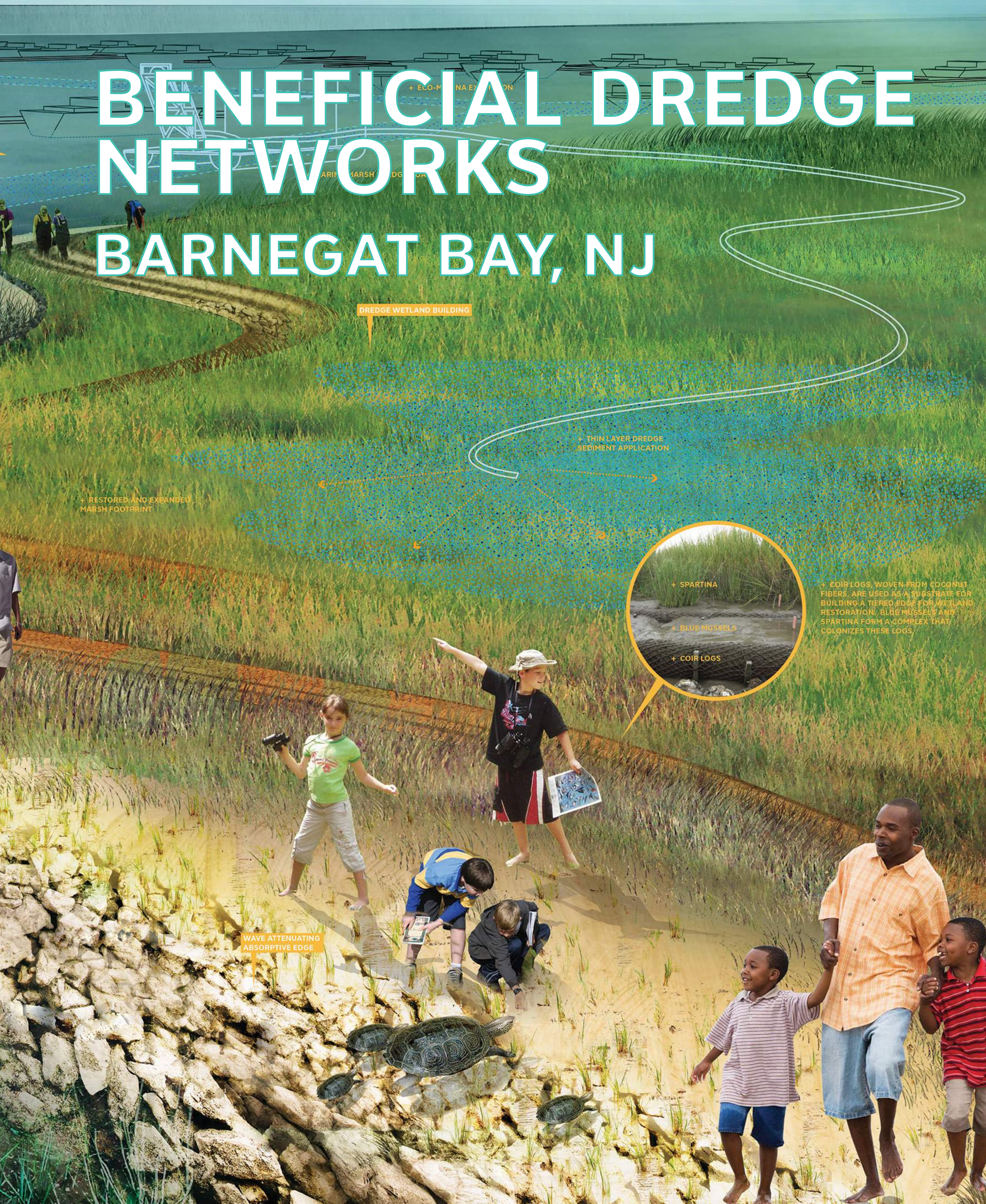
BUILD ON EXISTING INITIATIVES: USACE Upper Reach Proposals; NYC SIRR recommendations; Comprehensive Restoration Plan sites for coastal protection assessment; Tottenville Conference House Park site.

Staten Island & the Inner NY Harbor were hard hit by Sandy. Once protected by a wide shelf and series of oyster reefs, the south shore of Staten Island in particular remains exposed to wave action and coastal erosion. Our layered strategy introduces protective breakwaters and interior tidal flats that can dissipate wave energy and slow the water, while rebuilding sustainable oyster populations within the Harbor. Working with locally impacted communities such as Tottenville, a range of alternative futures can be developed that are effective, resilient, and complimentary to ongoing shoreline work in the area. We propose to link the oyster restoration breakwaters at the Inner Harbor and Staten Island shorelines as part of a larger educational and oyster recruitment effort at the harbor scale.


FISH CLEANING HUB
Fish I.D.
GOOD LUCK POINT MARINA
+ DREDGE CHANNEL
CONSTRUCTED TIDEPOOLS
ABSORPTIVE EDGE
+ DOUBLE-CRESTED CORMORANT
ALONG WITH 20 OTHER BUOYS, I PROVIDE INFORMATION THAT MAKES THE BAY LEGIBLE.
HI, MY NAME IS BB INFO BUOY 21!
+ INFORMATIONAL SCIENCE BUOYS
+ RESTORED WIDGEONGRASS BEDS

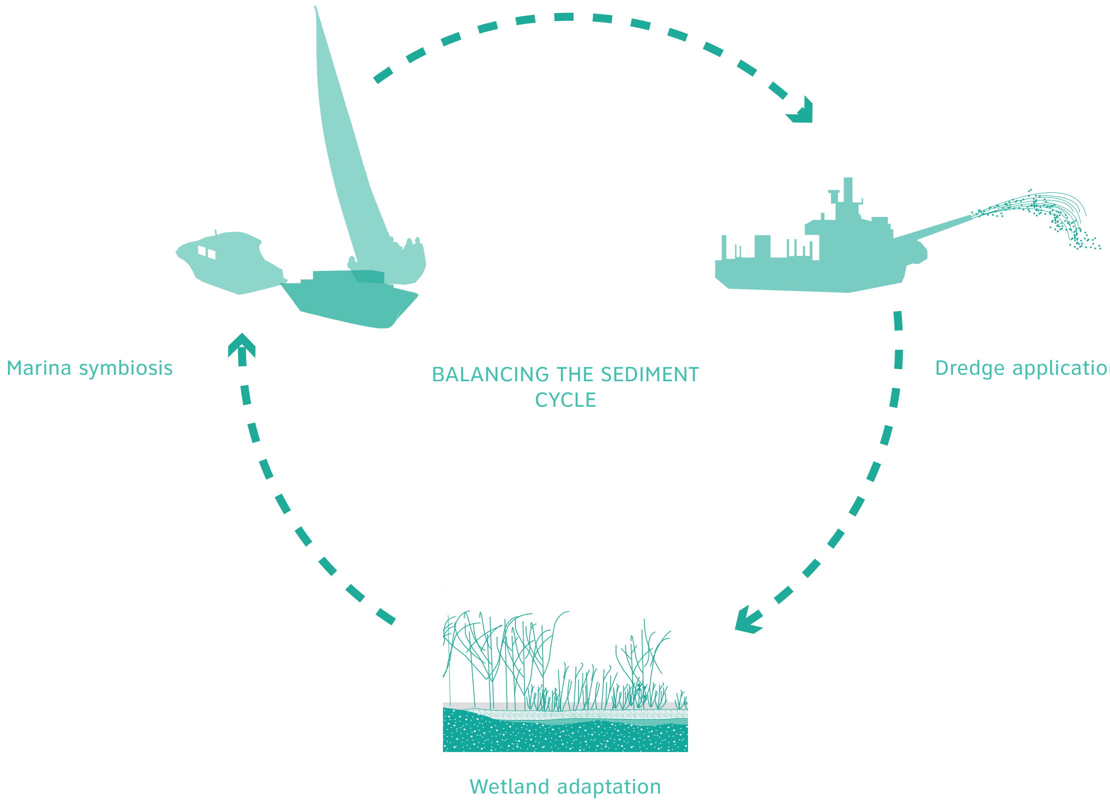
# BENEFICIAL DREDGE NETWORKS

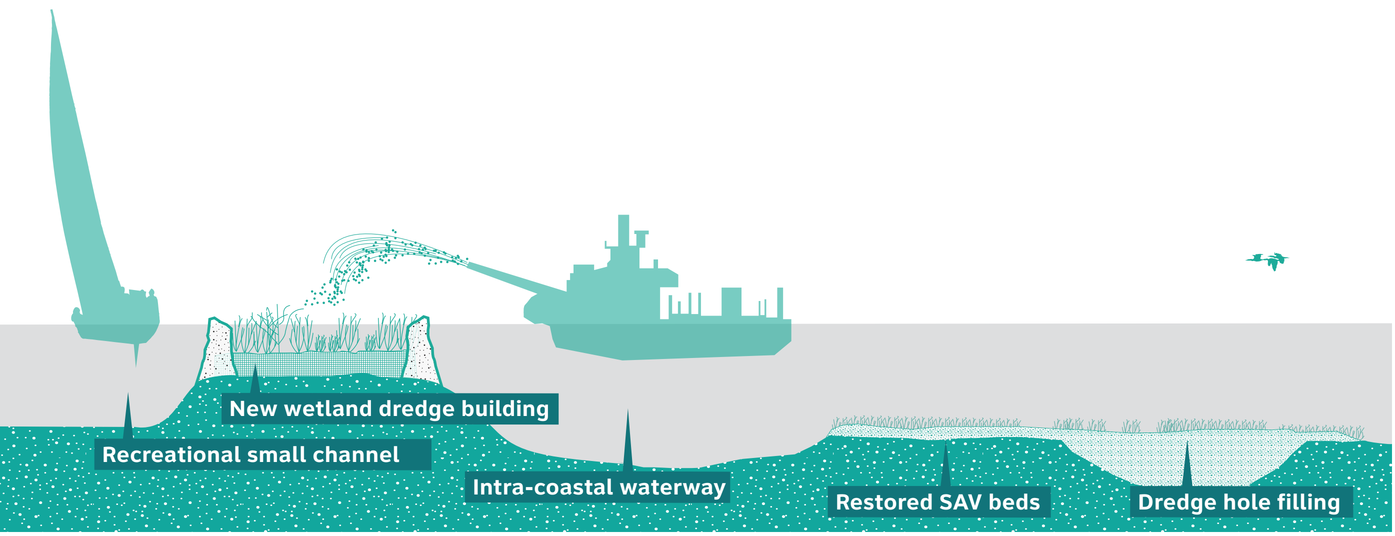
## BARNEGAT BAY, NJ



# STRATEGY
# DREDGE WETLANDS

Coastal wetlands can absorb surge waters and reduce wave impacts within coastal communities. Severely reduced from their historic footprint, these bay-side ecologies are threatened by development, erosion, and sea level rise inundation. Innovative strategies for sediment replacement and nourishment are needed to maintain and expand their protective footprints as time progresses. Bay side dredging provides one potential source of sediment for marsh restoration. Federally maintained recreational channels, such as the Intra-coastal Waterway, provide sources for clean dredge material that can be used for intermittent, larger-scale wetland restoration. At the local scale, regulatory structures can be streamlined to allow family-owned marinas to nourish wetlands adjacent to their facilities, recycling sediment within the sediment shed and further protecting their own waterfront facilities from damaging wave action. In New Jersey, combined disposal facilities created in the 1970's offer additional sources of clean sand and sediment for wetland rehabilitation close to the restoration sites, helping balance off-kilter sediment budgets. Successful local pilot sites for dredge wetland building exist within New York's Jamaica Bay and the Baltimore Harbor. Re-thinking sediment cycles at the bay-scale could have a dramatic impact on our region's protective wetland network, while easing the economic burden of dredge management for local small business owners.


Marina symbiosis
BALANCING THE SEDIMENT CYCLE
Dredge application
Wetland adaptation


New wetland dredge building
Recreational small channel
Intra-coastal waterway
Restored SAV beds
Dredge hole filling

# DESIGN OPPORTUNITY BARNEGAT BAY WETLANDS

Like Jamaica Bay, Barnegat Bay is a beloved recreational ground with hundreds of thousands of people living directly on its constructed edges. Dredging, filling, and pollution have endangered its shallow productive topography and sea level rise threatens to turn what was a rich marine mosaic of land and water into exposed open and flat environs devoid of the lifestyle qualities that drew many there in the first place and that have served as de facto absorptive infrastructure. Much of the post-Sandy reconstruction effort has focused on beach side towns, and less on the impacted shorelines of the Bay. **We propose 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.

**Dredge Wetlands** Coastal wetlands can absorb surge waters and reduce wave impacts within coastal communities. Severely reduced from their historic footprint, these bay-side ecologies are threatened by development, erosion, and sea level rise inundation. Innovative strategies for sediment replacement and nourishment are needed to maintain and expand their protective footprints as time progresses. Bay-side dredging provides one potential source of sediment for marsh restoration. Federally maintained recreational channels, such as the Intra-coastal Waterway, provide sources for clean dredge material that can be used for intermittent, larger-scale wetland restoration. At the local scale, regulatory structures can be streamlined to allow family-owned marinas to nourish wetlands adjacent to their facilities, recycling sediment within the sediment shed, reducing costs for struggling small business owners, and further protecting recreational waterfront infrastructure from damaging wave action. In New Jersey, combined disposal facilities created in the 1970's offer additional sources of clean sand and sediment for wetland rehabilitation close to the restoration sites, helping balance off-kilter sediment budgets.

**Testing and Refining** 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.

COMPLIMENTARY ONGOING INITIATIVES

Barnegat Bay Partnership living shoreline proposals
Combined Dredge Disposal facility revaluation plan
Marina and US Army Corps dredging programs
New Jersey Future Initiatives

POTENTIAL COLLABORATORS AND ADVISORS

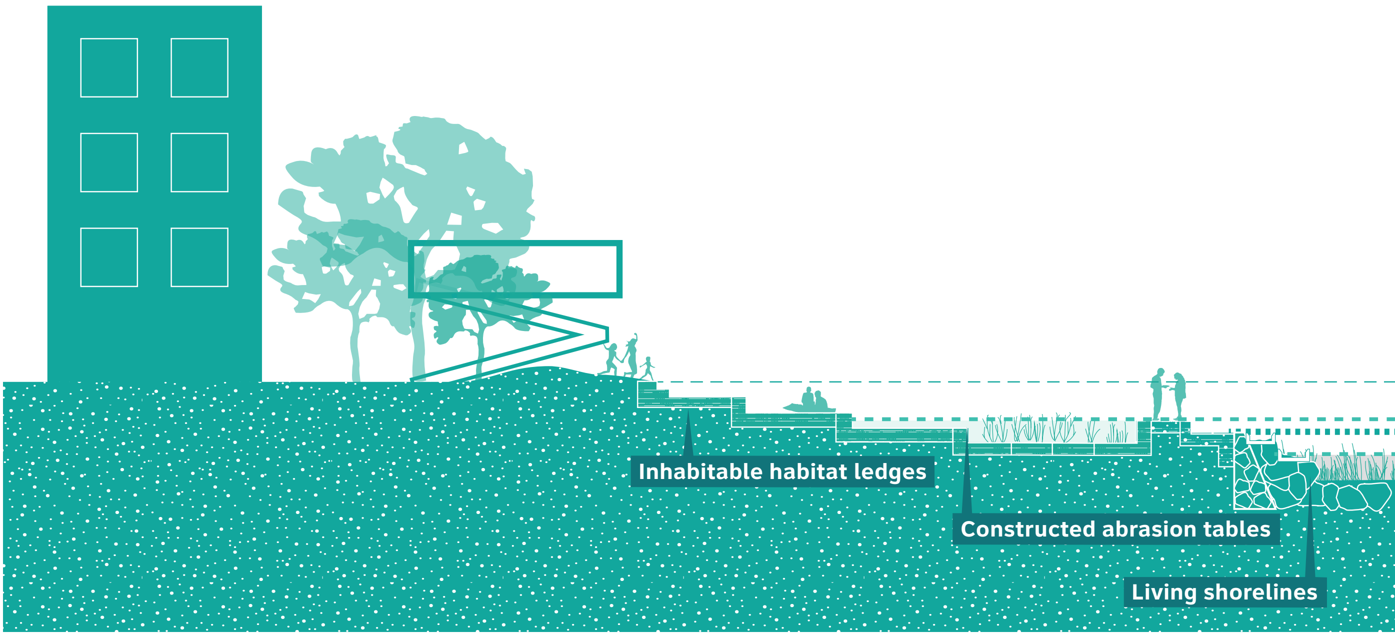
Barnegat Bay Partnership
Township of Tom's River
US Army Corps of Engineers
ReClaim the Bay

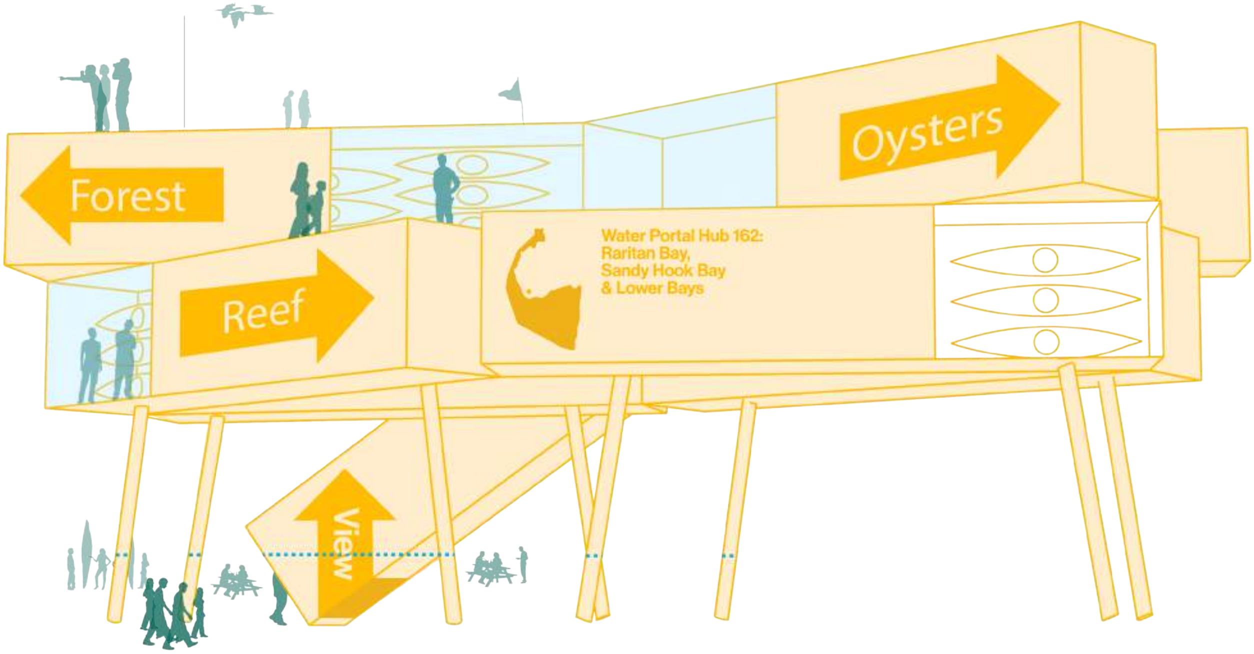
Tom's River High School East
20 % Reduction in water level
Berkeley Harbor Marina
Fishing hub
OCEAN GATE POP 2,023
Good Luck Point Marina
Protective dunes
Berkeley Township Elementary School
Wetland restoration learning center
BAYVILLE POP 9,193
Breakwaters
Claire B Worth Elementary School
Wetland restoration
Barnegat Bay Sailing School
12 % Reduction in water level
Lanoka Harbor Elementary School
Ocean Beach Marina
FORKED RIVER POP 5,244
Forked River Elementary School
Micro-dredge monitoring station
Tidal flat restoration
Micro-dredge from CDFs
10 min walk
Sand Beach Harbor
Friction areas along bay
0 .5 1 2 4 miles
N
Public water access
Marina
Confined Disposal Facility (CDF)
Tidal flat
Wetland
Breakwater

# STRATEGY
# ABSORPTIVE EDGES

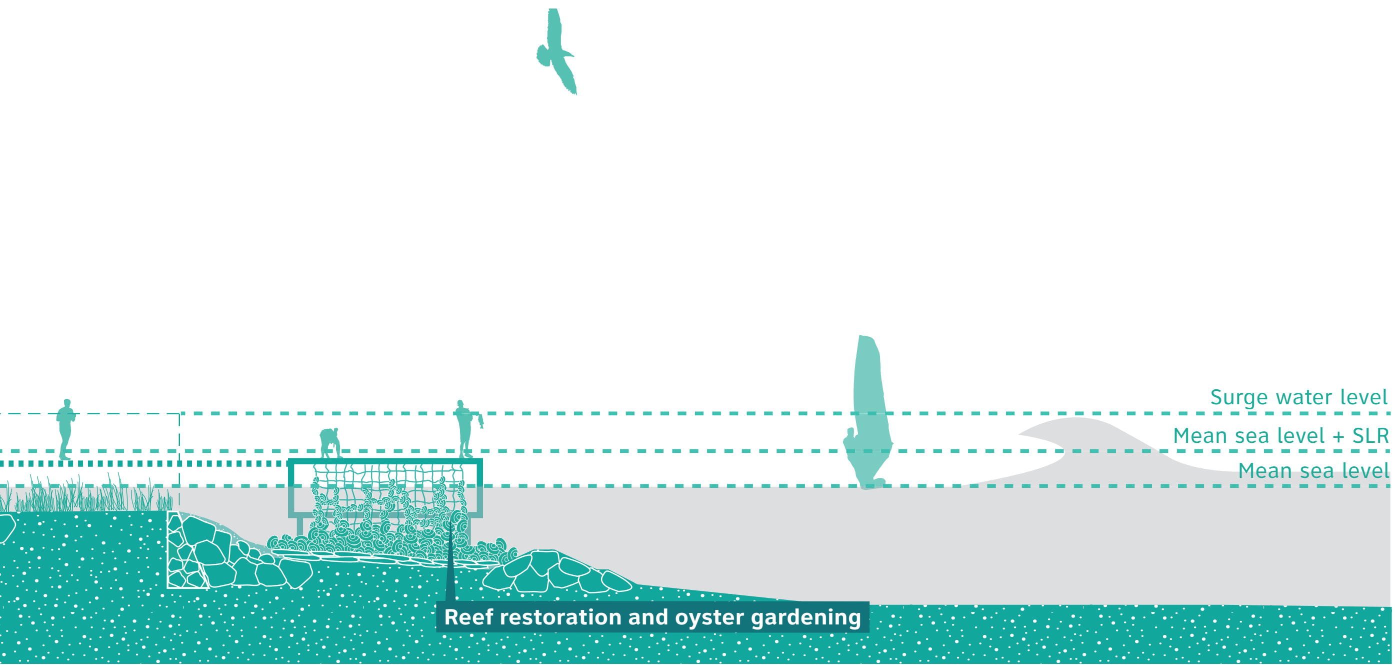
Much of the region's seawall and bulkhead infrastructures are ecologically damaging, limit access and experience to the water, and were destroyed or structurally impaired during Hurricane Sandy. Absorptive edges work to introduce shallow slopes into previously bulkheaded and abrupt transitions with the water. Extending the footprint of the protective infrastructure upland, the absorptive edge expands the interface between land and water, creating more surface area for friction plantings and wave dissipation, mimicking the function of the beach berm and dune in barrier island ecosystems. Edges in high velocity wave environments are highly erodible, so absorptive edges are ecologically engineered with a range of materials including reinforced ecological concrete, stone, gabions, and geotextiles. The absorptive edge is designed to mimic coastal ecosystems, including barrier islands, dunes, spartina marshlands, abrasion tables, or subtidal reefs.

In the urban context even small expansions of the typical vertical bulkhead wall can provide opportunities to diversity and increase maritime life: micro textures at the scale of centimeters cast into ecological concrete panels create a variety of conditions for the recruitment of marine organisms such as oysters, mussels, and sponges, which in turn attract a more diverse array of aquatic life. At the larger scale, constructed abrasion tables and tide pools capture water to form niche maritime habitats, while biologically growing structural strength over time. Heights of absorptive edges can be set through a community design process, and can be designed to either keep the water out (with all associated risks) or to attenuate waves and prevent erosion of the shoreline. Combined with water access get-downs, tidal steps, and overlooks, absorptive edges can provide an ecologically rich connection to the water for shoreline communities.



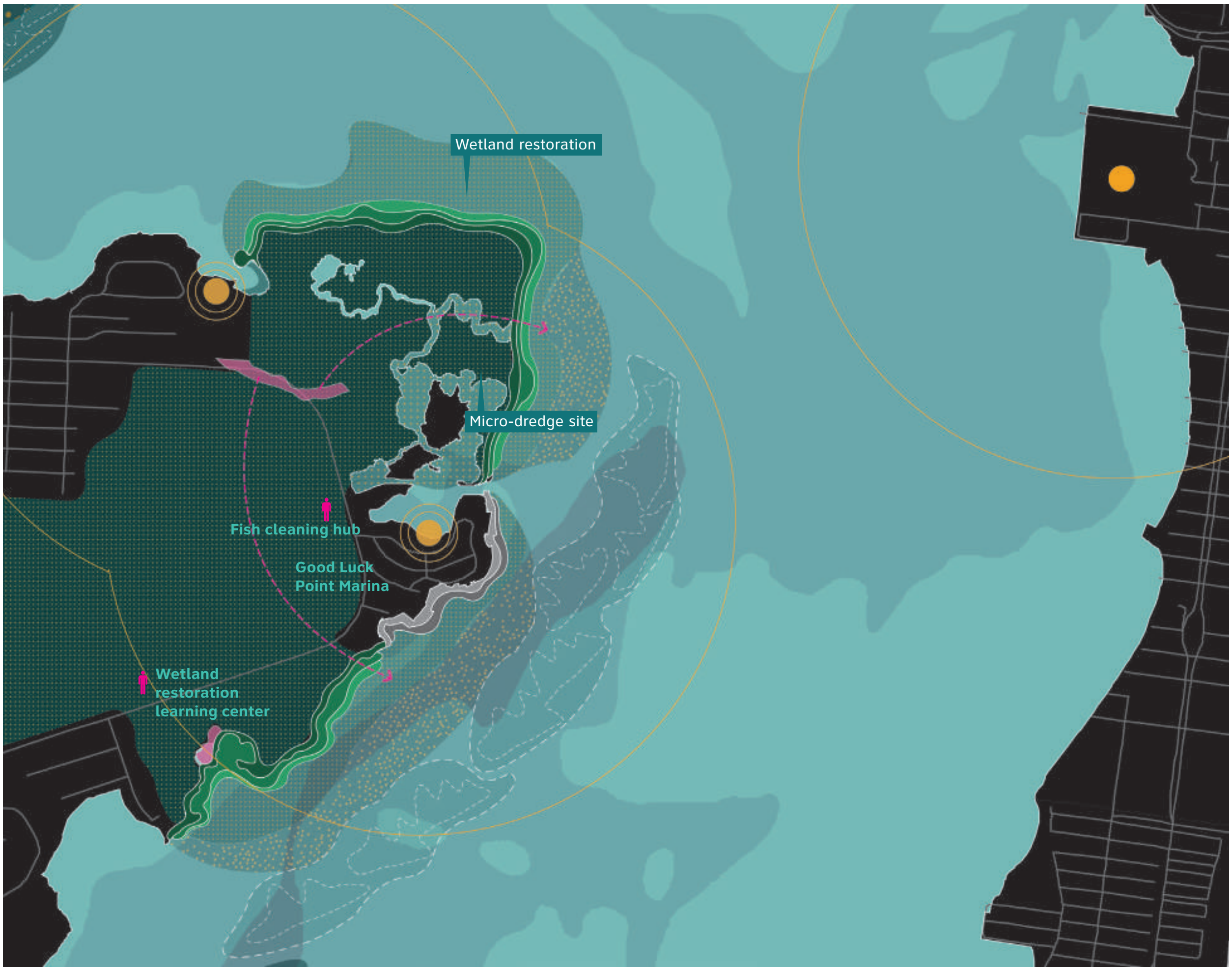



COMMUNITY KAYAK HUB

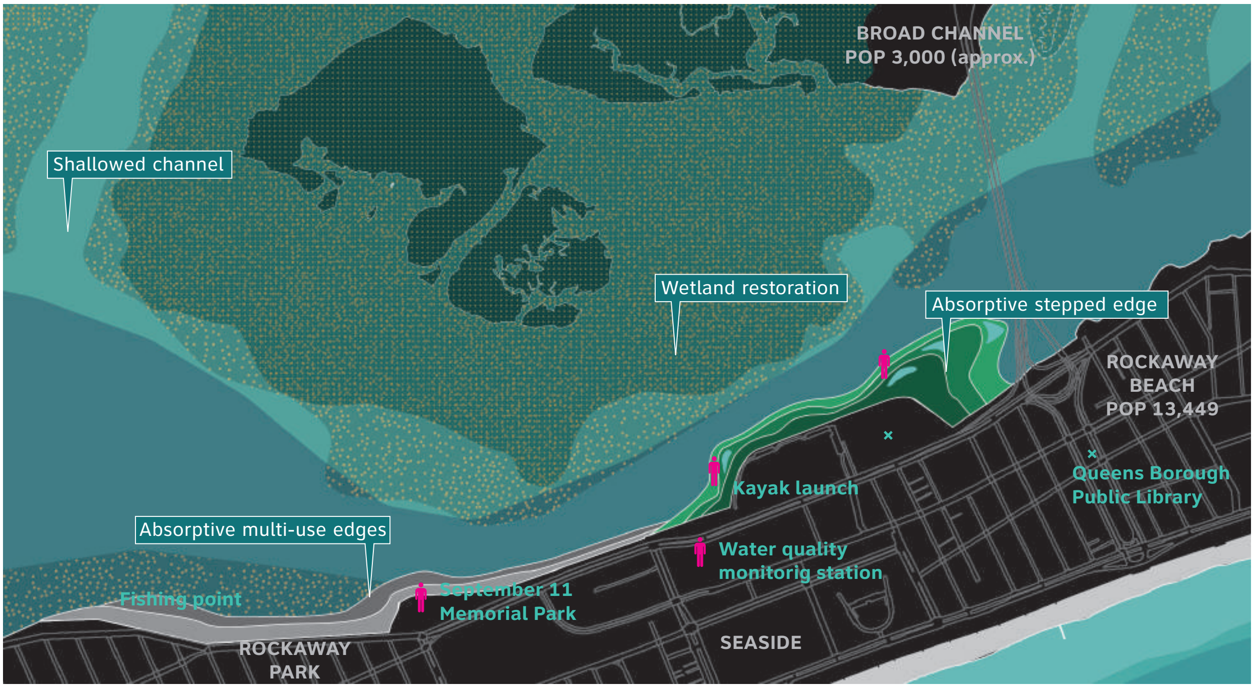


# REPLICABILITY
# BARNEGAT BAY WETLANDS

The wetlands of Barnegat Bay are eroding due to recreational boat traffic, changing hydrological systems, and increased storm intensity. Living, absorptive edges can help mitigate this loss over time, and help define extents for wetland restoration using reclaimed dredge material.

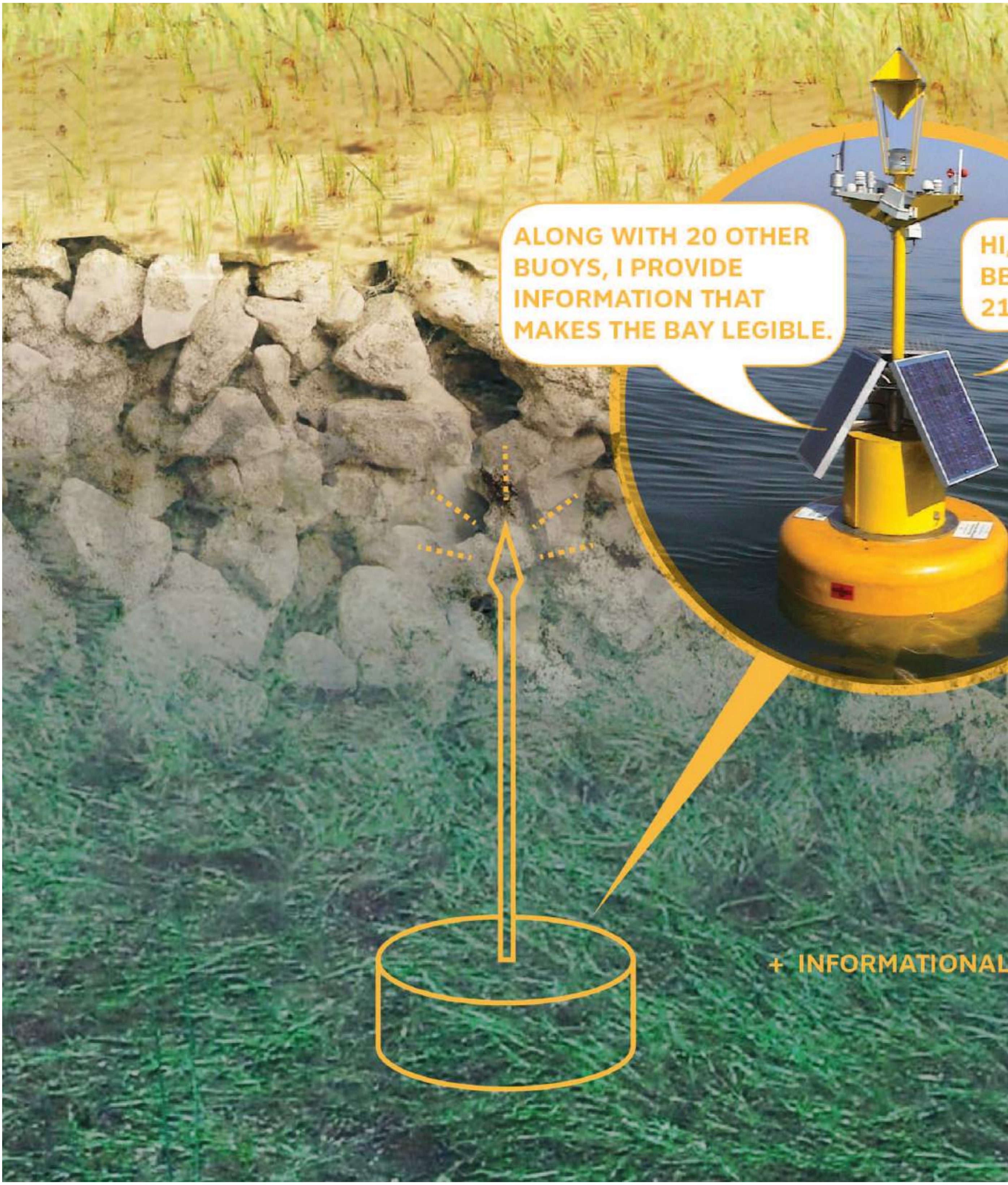



GOOD LUCK POINT, BARNEGAT BAY, NJ




ROCKAWAYS BACK BAY EDGE, QUEENS, NY


HOWARD BEACH, QUEENS, NY


ALONG WITH 20 OTHER BUOYS, I PROVIDE INFORMATION THAT MAKES THE BAY LEGIBLE.


# BARNEGAT BAY REMADE

LAYERED STRATEGIES: Dredge Wetlands, Constructed Reefs, Habitat Breakwaters, Water Hubs, Friction Forests, Tidal Flat Restoration, Bay Nourishment

BUILD ON EXISTING INITIATIVES: Combined Dredge Disposal facility revaluation plan by State of NJ; Barnegat Bay Partnership living shoreline proposals; NJ Futures Initiatives; Recreational channel dredging

Like Jamaica Bay, Barnegat Bay is a beloved recreational ground with hundreds of thousands of people living directly on its constructed edges. Dredging, filling, and pollution have endangered its shallow productive topography and sea level rise threatens to turn what was a rich marine mosaic of land and water into an exposed open and flat environs devoid of the lifestyle qualities that drew many there in the first place and that have served as de facto absorptive infrastructure. A combination of green/blue strategies in the form of tiered, absorptive edges embedded with tidepools and bird/fish habitat structures, will help regenerate lost ecological systems, recalibrate sediment cycles, and step down risk for waterfront communities. Man-made sediment cycles will be linked with natural cycles, helping ensure a productive and resilient bay landscape for future generations.

# APPENDIX

## The demonstrated modeling runs are a means to analyze conceptual design strategies. All modeling results require further development and study with multiple storm scenarios and design revisions.

HUD REBUILD MODELING  Communities that were flooded by Sandy face complex decisions about the future, and a quantification of risk-reduction impacts is a useful tool to understand the benefits of ecological infrastructure. With Dr. Philip Orton of the Stevens Institute, we have run preliminary tests to evaluate the proposed strategies using the ADCIRC hydrodynamic model and SWAN wave model through two sets of modeling runs—shallowing strategies and wave-breaking strategies. Results for each intervention can be seen on the following boards. In some instances these were dramatic, in others, minimal. Modeling results are one element of many within our regional research, as shallow water ecosystems have risk reduction capacities that move beyond questions of wet versus dry.

Our strategies are one key input of the model, the other is the storm. Category-2 Hurricane Donna struck Long Island in 1960 and caused the second highest water elevations in New York Harbor in the 90-year period of continuous tide gauge records at The Battery, at 7.4 ft above today's mean sea level. Trailing well behind Sandy's 11.5 ft, the inundation was still significant. Severe flooding occurred in many low-lying areas, such as The Rockaways, Hoboken, parts of Staten Island, and the edges of Lower Manhattan. Donna was a smaller, faster storm surge than Sandy.

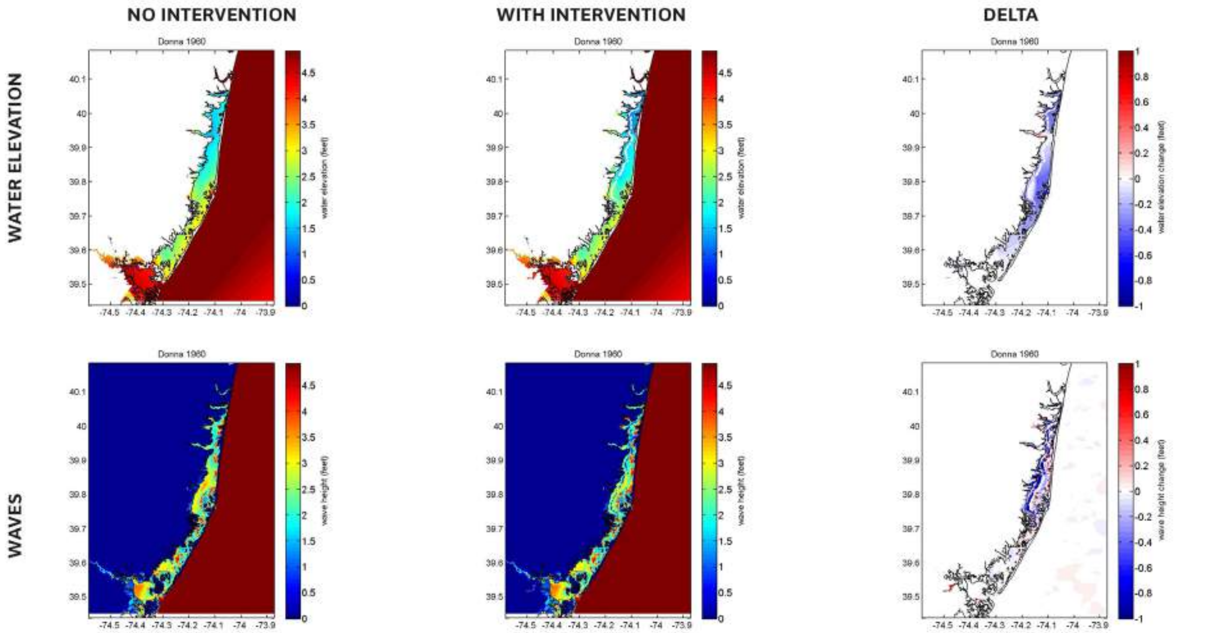
Hurricane Sandy has been called an "idiosyncratic" storm and a "1000-year event" due to the uniqueness of much of its behavior, so we are focusing on a more common type of storm in our first modeling assessment. Prior to landfall, Donna's winds over the coastal zone and inland areas were from the East, whereas Sandy's winds were mostly from the NE, so there were differences in which bay shorelines were most heavily impacted by waves.  In both cases, the storm center offshore caused large swell to propagate similarly from the SE toward the region's open ocean shorelines. All results are preliminary, as each strategy requires further refinement and study with multiple storm and tide scenarios. This research was supported, in part, under National Science Foundation Grants CNS-0958379 and CNS-0855217 and the City University of New York High Performance Computing Center at the College of Staten Island.

EXPANDED HUD MODELING PROCESS (DONNA ADCIRC + SWAN)  The potential surge and wave reduction from the strategies proposed were evaluated using the Advanced Circulation (ADCIRC) hydrodynamic model.  ADCIRC is the standard coastal storm-surge model used by the U.S. Army Corps of Engineers (USACE), the NOAA, and numerous other organizations for storm-tide analysis. Combining the geometry and friction of the proposed intervention with a storm scenario, the model is able help us understand the resulting impacts of our strategies on surge and wave heights.

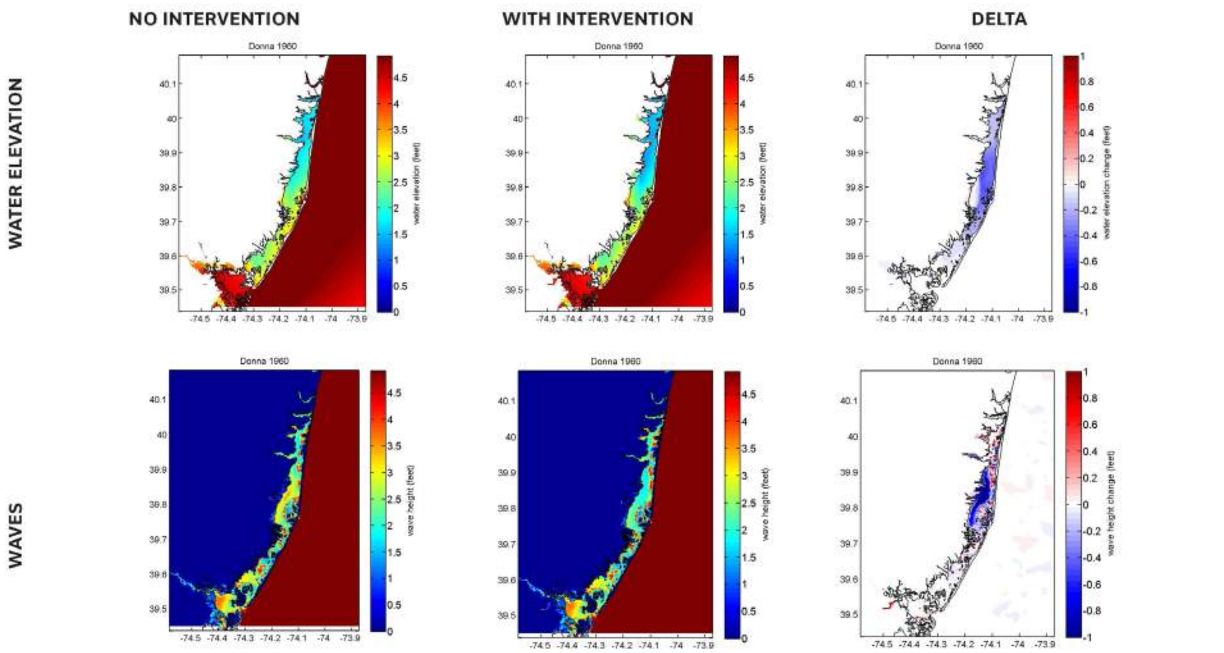
While our strategies are one key input of the model, the other is the storm. Different storms "behave" differently depending on a variety of factors including wind speed, direction, timing and duration among others. Storms can be "slow" or "fast", "big" or "small" , heavier on rain or heavier on surge. Hurricane Sandy was a huge storm, nearly 1,000 miles across which arrived at high tide for much of New York City and New Jersey and whose last minute change in direction drove floodwaters into many New York City communities. In examining the potential of the these strategies over a short time frame, the team sought out a model to approximate a slightly more frequent future storm.

PAST WORK WITH SIRR The team also examined the results of relevant interventions modeled as a part of the analysis done by New York City in preparation of the Mayors Report “A Stronger, more Resilient New York.” These models were of two types. One came from a set of individual interventions modeled with a storm meant to approximate the conditions of Sandy with sea level rise of 29”. The others were the result of models run on a draft version of the city’s combined full build and pilot interventions being developed in creating the city’s comprehensive coastal protection plan. These collections of interventions were modeled with a set of three storm conditions chosen from the suite of synthetic storms developed by FEMA and designed to match 100-year and 500 year statistical surge levels. The storm simulations also included estimated future sea-level rise values (10 inches for 2020 and 29 inches for 2050) for the New York City region. Some scenarios included below also have written (no visual) results from the SIRR modeling process.

Note: Hurricane Donna wind and pressure fields are from a model-based and observation-based meteorological reanalysis conducted by Oceanweather Inc.

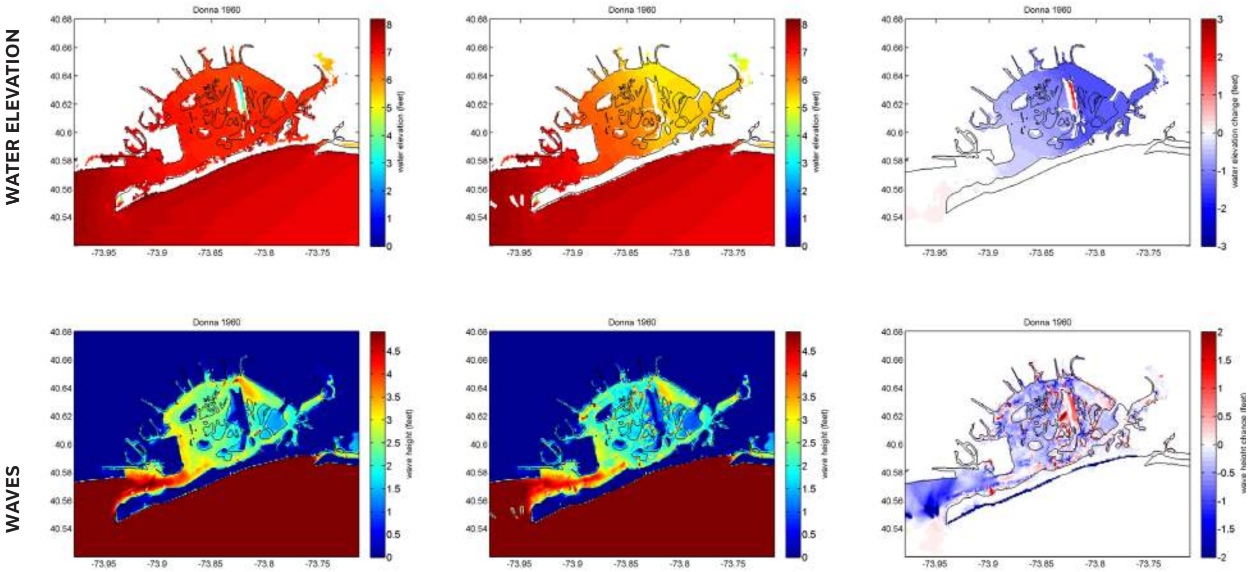



**BREAKWATERS, WETLANDS, AND DUNES IN BARNEGAT BAY ADCIRC MODELING WITH HURRICANE DONNA 1960:** ADCIRC modeling shows that the combination of shallowing and dune building reduced flooding in many areas by 0.4 ft (20%) with no apparent increases in other zones. Wave heights were reduced by 0.5 ft - 1 ft and eliminated completely in portions of the bay.




**SHALLOWS AND DUNES AROUND BARNEGAT BAY ADCIRC MODELING WITH HURRICANE DONNA 1960:** ADCIRC modeling shows that the combination of shallowing and dune building reduced flooding in many areas by 0.4 ft (20%) with no apparent increases in other zones. Wave heights were reduced by 0.5 ft - 1 ft and eliminated completely in portions of the bay.

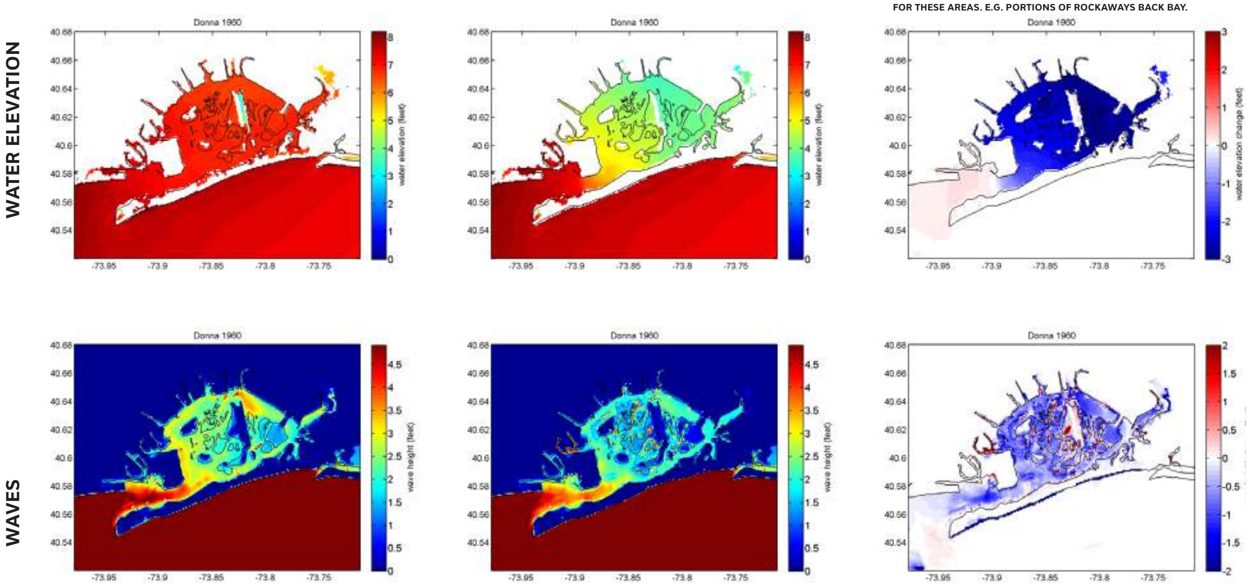
NO INTERVENTION | WITH INTERVENTION | **DELTA-** *DOES NOT SHOW AREAS WHERE FLOODING IS ELIMINATED COMPLETELY. LOOK BETWEEN "NO INTERVENTION" AND "WITH INTERVENTI FOR THESE AREAS. E.G. PORTIONS OF ROCKAWAYS BACK BAY.




**MODIFIED SHALLOWING, BREAKWATERS, AND ROCKAWAY DUNES AROUND JAMAICA BAY ADCIRC MODELING WITH HURRICANE DONNA 1960:** ADCIRC modeling shows that the combination of modified shallowing, minimal breakwaters, and dune construction at the Rockaways yielded significant reduction in flood heights within the north and south sides of the Rockaway peninsula, as well as flood heights on the west side (0.8 ft) and east side (1.5 ft) of the bay. Waves were reduced by 0.5ft-1ft but were increased in some zones. Flood heights were slightly increased ( inches) at the Cross Bay Parkway. Further study is required.

*Modeling for SIRR Report (not pictured here): Using three different 100 year storm scenarios and an assumption of 29" of sea level rise in 2050, large-scale wetland restoratic in Jamaica Bay (wetland restoration of all the bay but the navigation channels) showed limited reduction in storm surge (0.5-1.0 feet), though wave heights are reduced at the shore of Jamaica Bay by 0.5 to 3 feet in many areas with the majority of the shoreline seeing a 0.5 – 1 foot reduction. A combination of wetland restoration and breakwaters i surrounding Howard Beach yielded reductions in wave heights between 1.5 and 4 feet at Howard Beach, but little to no reduction in surge heights (100 year storm with 2050 s level rise).*

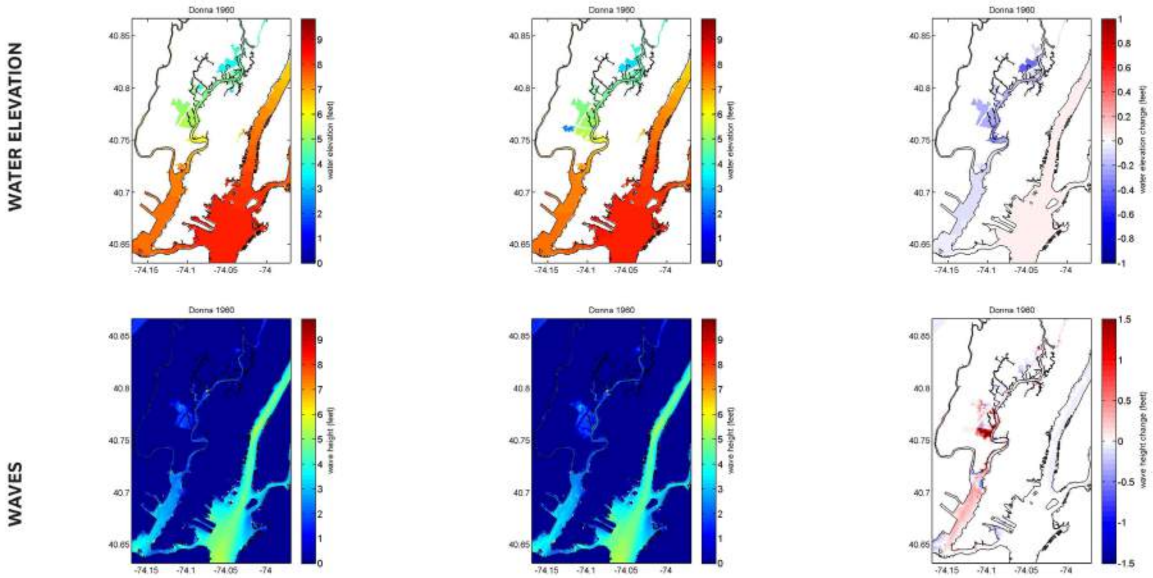
NO INTERVENTION | WITH INTERVENTION | **DELTA-** *DOES NOT SHOW AREAS WHERE FLOODING IS ELIMINATED COMPLETELY. LOOK BETWEEN "NO INTERVENTION" AND "WITH INTERVENT FOR THESE AREAS. E.G. PORTIONS OF ROCKAWAYS BACK BAY.




**EXTREME SHALLOWING, TIDAL FLATS, WETLANDS, AND ROCKAWAY DUNES AROUND JAMAICA BAY ADCIRC MODELING WITH HURRICANE DONNA 1960:** ADCIRC modeli shows that the shallowing, tidal flat and wetland restoration, maritime forest restoration, and dune construction at the Rockaways led to significant reduction in flood heights within the north and south sides of the Rockaway peninsula, as well as flood heights on the west side (2 ft) and east side (3 ft) of the bay. Waves were reduced by 0.5ft-1ft or eliminated completely. Flood heights were slightly increased ( inches) in other areas, including offhshore zones in NY Harbor, Raritan Bay, and Coney Island. Further study is required.

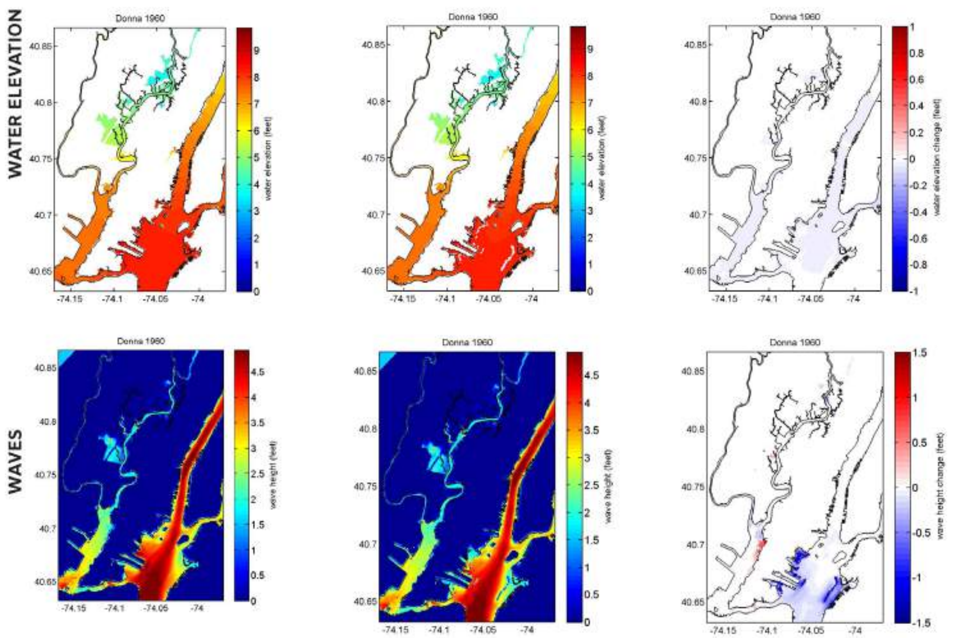
*Modeling for SIRR Report (not pictured here): Modeled with a Sandy –like storm and a 2050 sea level rise estimate of 29", a combination of bay wide shallowing (to 6.6 foot water depth), wetland restoration in the bay, and dune construction on the Rockaways, yielded significant reductions in both surge (2.5 – 4 feet) and waves (6" to 3') througho the Bay. However, this was only studied in one storm and would require large scale interventions across the entire bay that may have negative implications for water quality; further analysis would be needed to determine feasibility.*

**NO INTERVENTION** **WITH INTERVENTION** **DELTA**



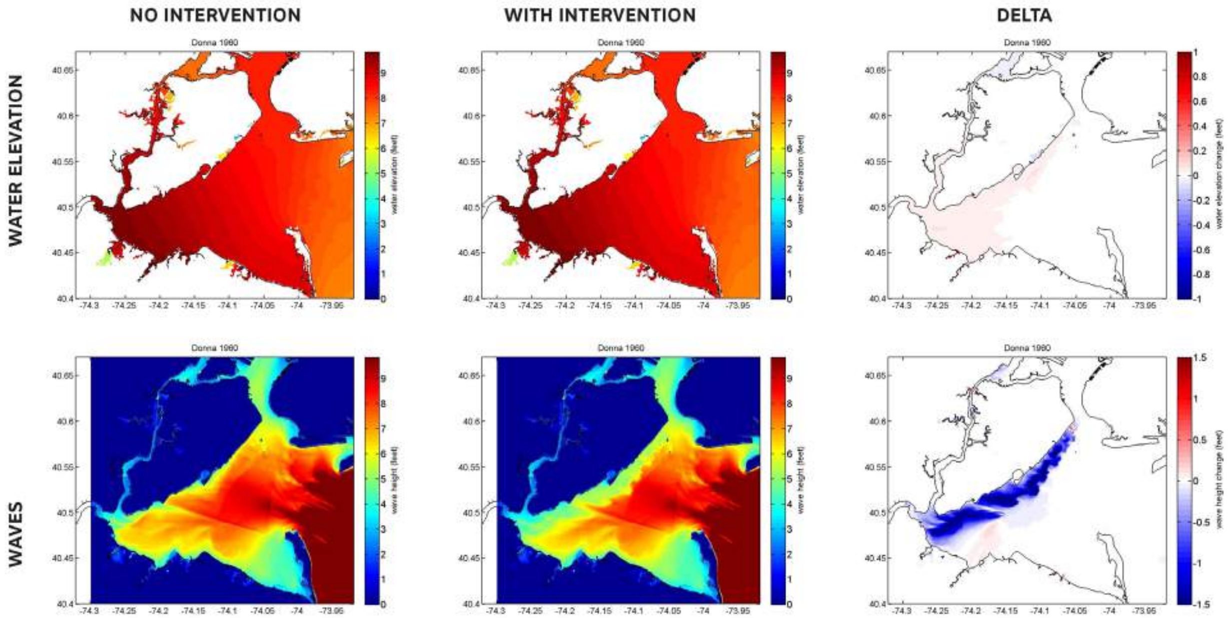

**OFF AND ON SHALLOWING IN THE LOWER REACH OF THE HACKENSACK RIVER ADCIRC MODELING WITH HURRICANE DONNA 1960:** ADCIRC modeling shows that shallowing in the lower reach reduced flooding 0.2 ft-0.5 ft (10%) in most areas. Flood heights were reduced 0.2 ft (3%) in the heavily populated Newark Bay. A small area received new flooding and wave action due to water overtopping the channel, further study and modification is required.

**NO INTERVENTION** **WITH INTERVENTION** **DELTA**

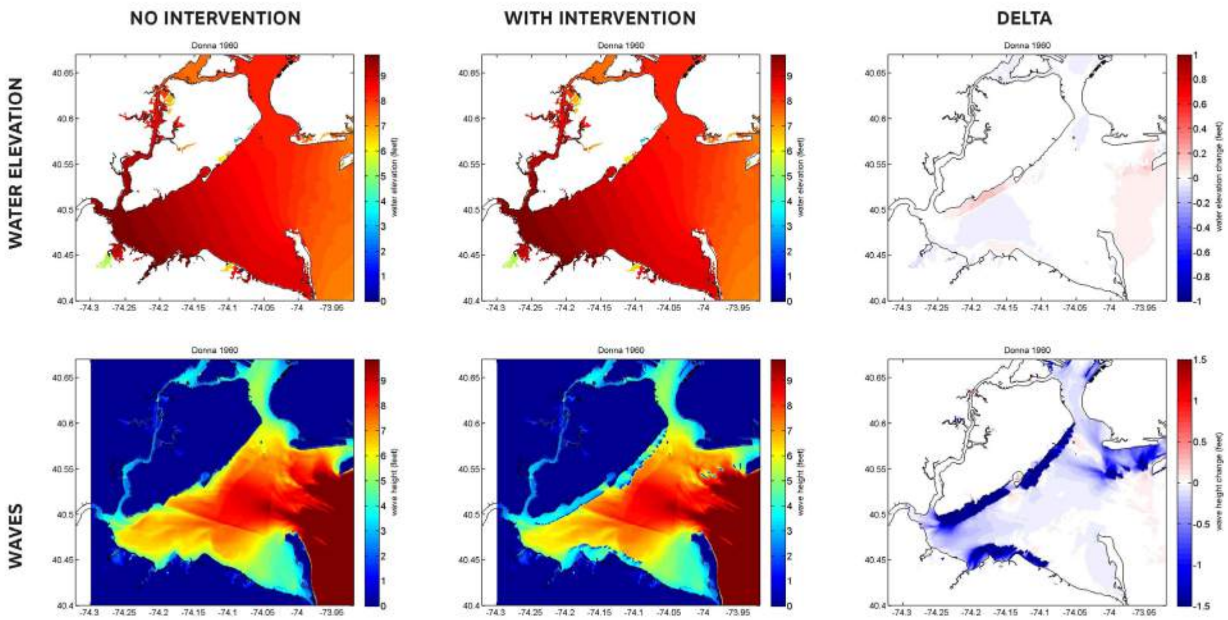



**BREAKWATERS IN THE INNER HARBOR ADCIRC MODELING WITH HURRICANE DONNA 1960:** ADCIRC modeling shows that the breakwaters reduced waves at the Inner Harbor shoreline by 0.5-1.5ft (15-45%). In some areas flooding was reduced by 1"-2".

*Modeling for SIRR Report (not pictured here): Using three different 100 year storm scenarios and an assumption of 29" of sea level rise in 2050, it was observed that wave heights are reduced by multiple feet (generally 1-2 feet) in many areas along the Brooklyn waterfront at and south of Red Hook due to placement of breakwater islands (elevation MSL +12').*

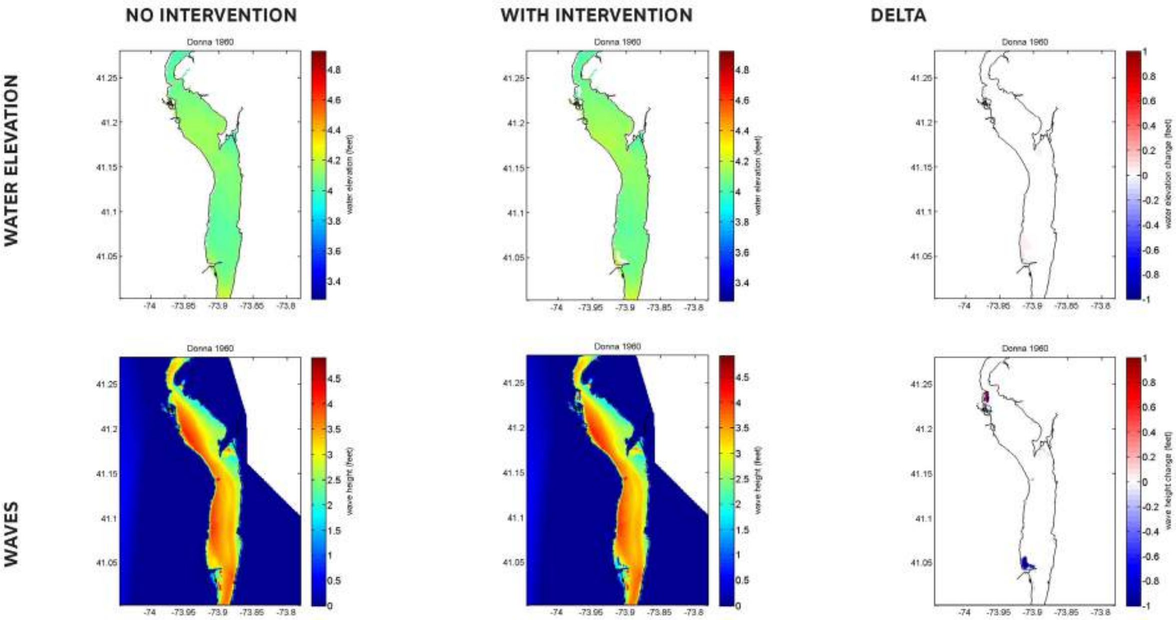



**RUMBLE STRIP REEFS IN RARITAN BAY ADCIRc MODELING WITH HURRICANE DONNA 1960:** ADCIRC modeling shows that the Staten Island constructed reefs had a small to moderate effect (0.25 ft-1.5 ft , or 5-27%) on wave heights. A small increase (1" increase) in flood elevation was shown in the western Raritan Bay and requires further study.




**STATEN ISLAND BREAKWATERS ADCIRC MODELING WITH HURRICANE DONNA 1960:** ADCIRC modeling shows a very strong reduction in waves (1-4 ft) along the Staten Island shoreline. In some areas, an increase in flooding (0.3ft) inshore of the breakwaters was shown which may be mitigated by realignment and further study.

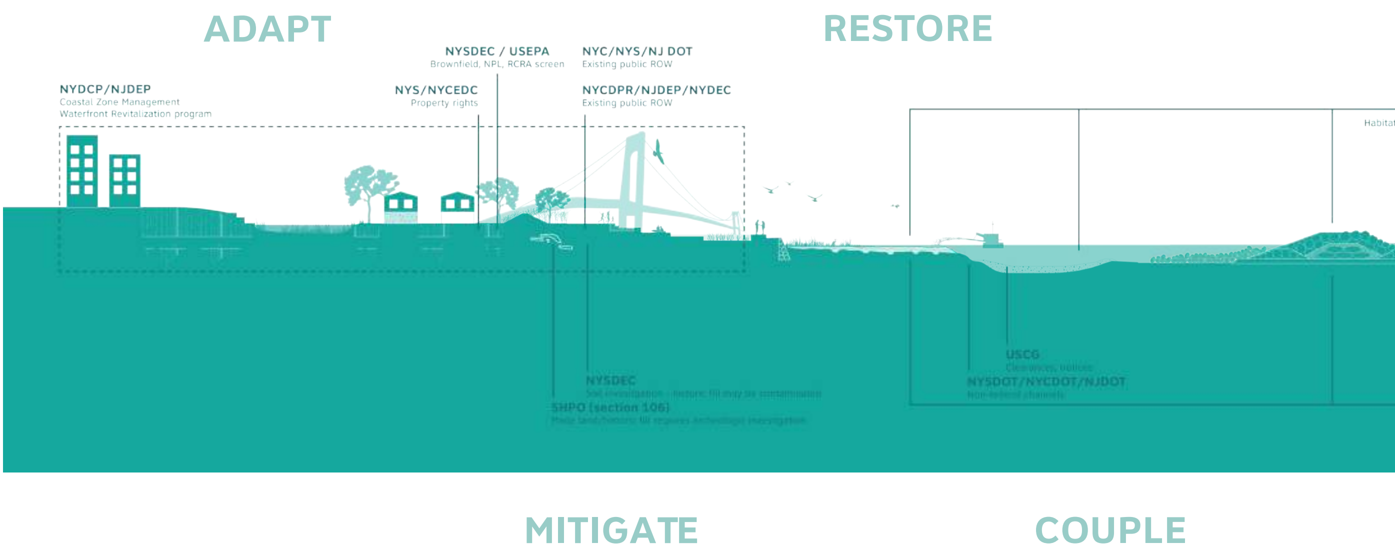
*Modeling for SIRR Report (not pictured here): Using three different 100 year storm scenarios and an assumption of 29" of sea level rise in 2050, it was observed that linear breakwaters (elevation MSL +12') located approximately ¼ mile offshore reduced wave heights at the shoreline along the southern end of Staten Island by 2-4 feet.*




**BREAKWATERS AROUND PIERMONT ADCIRC MODELING WITH HURRICANE DONNA 1960:** ADCIRC modeling shows that the Piermont breakwaters reduced wave heights by 1.25 ft (37%) along the shoreline.

# APPENDIX
## REGULATORY ENVIRONMENT IDENTIFYING POTENTIAL PARTNERSHIPS

Recognizing that the proposed strategies may seem new, unusual, or even contradictory to many current practices, they will inevitably face regulatory hurdles in implementation. Thus, the design strategies must be coupled with approaches to local, state, and federal regulations and permitting requirements that can leverage existing regulatory frameworks, capitalize on ongoing programs and shepherd these projects through permitting and review processes.



RESTORE historic habitats. Prioritize restoration/ enhancement to degraded habitat and protection of high quality/critical habitat. From a regulatory perspective it is much easier to "restore" than to "create."

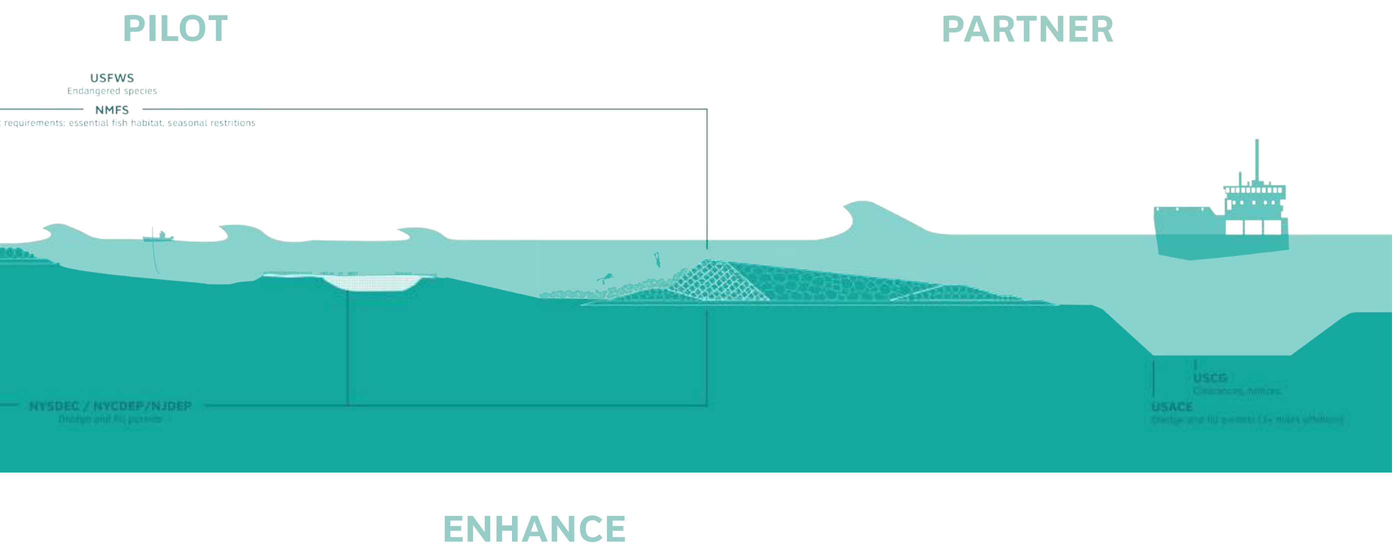
MITIGATE for other projects. Capitalize on and integrate with compensatory mitigation for other recovery efforts and ongoing or planned infrastructure projects. Large infrastructure projects often require environmental mitigation for potentially detrimental effects, which these strategies could provide.

ENHANCE ecosystem performance. Maximize habitat heterogeneity to demonstrate habitat and water quality benefits. Illustrating measurable improvements in environmental quality and ecosystem performance according to existing metrics can be used to justify the benefits of and thus investment in these strategies.

PARTNER with agencies, organizations and their existing projects. Build capacity of existing ongoing restoration and coastal protection efforts by groups already on the ground. Enhancements of existing projects can be easier to achieve than starting from scratch and inter-agency partnerships can facilitate faster and less complicated regulatory review.

COUPLE needed inputs with outputs of existing projects. Supply materials needed with outputs from other ongoing projects. Beneficially reusing dredge material from USACE Operation and Maintenance Program is a prime opportunity, but reuse / recycling of materials for reef construction is as well.

PILOT projects for protective habitat creation. Use pilot projects to identify and test opportunities. The urgent need for effective, implementable and affordable coastal protection measures has opened up new opportunities for accessing and leveraging expertise and funding for innovative coastal projects, particularly those with co-benefits.



| Site | Design Element | Design Approach | Potential/Likely Regulatory Hurdles | Review/Approval Agencies | Ongoing projects | Potential Partners |
|---|---|---|---|---|---|---|
| All Sites | All Elements | All Approaches | • Public perception conflicts with existing initiatives/programs<br>• Early outreach and partnering critical to success | See lists by strategy & site | See lists by site | HUD<br>USACE<br>NPS |

Overall Permitting Strategies

Establish Inter-Agency Work Group to facilitate regulatory review and approval

Partner with involved agencies and stakeholder organizations to facilitate regulatory review and approval by identifying/addressing concerns prior to regulatory agencies public comment periods.

Promote Cooperating Agency Status during NEPA review

Beneficially reuse dredge material from USACE Operation and Maintenance Program

Integrate compensatory mitigation for other recovery efforts

Prioritize restoration/enhancement to degraded habitat and protection of high quality/critical habitat

Integrate water quality improvements that reduce nitrates and sedimentation

Focus on building capacity of existing ongoing restoration efforts

Maximize habitat heterogeneity to demonstrate habitat and water quality benefits

AGENCY KEY:

NPS-National Park Service

USACE- US Army Corps of Engineers

USCG-US Coast Guard

USN-US Navy

NMFS-National Marine Fisheries Service

USFWS-US Fish and Wildlife Service

USEPA-US Environmental Protection Agency

FAA-Federal Aviation Authority

NJDEP-NJ Department of Environmental Protection

NYSDEC-NY State Department of Environmental Conservation

NYCDEP-NYC Department of Environmental Protection

NYCEDC-NYC Economic Development Corporation

NYCP&R-NYC Department of Parks and Recreation

DOT-Department of Transportation

SEQR-State Environmental Quality Review (NYS)

CEQR-City Environmental Quality Review (NYC)

SHPO-State Historic Preservation Office

NYCDCP = New York City Dpt of City Planning

NYCCPC = New York City City Planning Commission

| Site | Design Element | Design Approach | Potential/Likely Regulatory Hurdles | Review/Approval Agencies | Ongoing projects | Potential Partners |
|---|---|---|---|---|---|---|
| Jamaica Bay | Absorptive Edges | Restoration/ Enhancement<br><br>Incorporate bioengineering techniques to soften previously developed shoreline and naturalize | • made land/historic fill requires archeological investigation<br>• historic fill may be contaminated<br>• coastal zone management<br>• consistency determination with Waterfront Revitalization Program<br>• conflicts with: property rights, infrastructure/utilities, navigation channels, economic development<br>• pre-existing public Right of Way | **SHPO** (Section 106)<br>**NYSDEC/USEPA** (Brownfield, NPL, RCRA screen),<br>**NYSDEC** (soil invest.),<br>**NYCDCP** (coastal zone management **compliance),**<br>**NYC City Planning Commission,**<br>**NYS/NYCEDC** (eminent domain),<br>Utility agencies (coordination),<br>**NYCDOT, NYCDP&R,** | Hudson Raritain Estuary Comprehensive Restoration Plan (restoration), USACE<br><br>TBTA Bridge Feasibility Study (mitigation opportunity)<br><br>USACE navigation projects<br><br>NYC Projects<br><br>USFWS Management Activities<br><br>National Park Service Projects including Gateway General Management Plan Update<br><br>JFK International Airport hazard reduction activities<br><br>PANYNJ | Resiliency Institute in Jamaica Bay<br><br>USACE<br><br>NYCDPR<br><br>NYCDEP<br><br>USFWS<br><br>American Littoral Society<br><br>PANYNJ<br><br>Universities (CUNY, Stevens Institute, SUNY, Long Island University, College of Staten Island, Columbia,)<br><br>Community groups |
| | Dredge Wetlands | Restoration / Creation<br><br>Build on and expand existing efforts to restore previously degraded salt marsh | • generally all hurdles above except perhaps made land/historic fill issues<br>• conflicts with endangered species and essential fish habitat protection during construction<br>• water quality concerns<br>• conflict of habitat improvements with JFK International Airport bird strikes | **NYC DCP / City Planning Commission,**<br>**NYS/NYC EDC,**<br>**Utility agencies** (per above),<br>**USFWS** (endangered species),<br>**NMFS** (habitat requirements, seasonal restrictions)<br>**NYSDEC/NYCDEP/USACE** (dredge and fill permits)<br>**USDA/FAA/PANYNJ** (habitat/bird strikes) | | |
| | Bay Nourishment (Shallowing) | Beneficial reuse of dredge material to create Sub-tidal shallows and restore Submerged Aquatic Vegetation | • generally all hurdles in above box<br>• interference with navigation channels<br>• public waterfront access | All listed for "dredge wetlands"<br>**USCG** (clearance, notices),<br>**NYSDOT/NYCDOT** (non-federal channels),<br>**Federal Agencies** (public access to water mandatory for funding),<br>**NYS/NYC** (public trust doctrine) | | |
| | Habitat Breakwaters | Protect wetlands, absorptive edges from wave energy while improving habitat | • generally all hurdles in above Dredge Wetlands, Bay Nourishment / /Channel Shallowing boxes<br>• only justified to protect absorptive edges and dredge habitat wetlands | All in Above Dredge Wetlands, Underwater Shallowing/Channel Shallowing Boxes | | |
| | Constructed Reefs | Protect beaches, bluffs, wetlands, absorptive edges from wave energy | • interference with navigation channels<br>• conflicts with endangered species and essential fish habitat protection<br>• water quality concerns<br>• interference with littoral drift and beach nourishment | **USCG** (clearance, notices);<br>**NYSDOT/NYCDOT** (non-federal channels)<br>**USFWS** (endangered species); NMFS (habitat requirements, seasonal restrictions)<br>**NYSDEC/NYCDEP/USACE** (dredge and fill permits, state only within 3 miles of coast)<br>**NJDEP/NYDEC/USEPA** Major modeling of structures' effects on currents, sand deposition, navigation, economics, etc. with full **Environmental Impact Statement** | | |
| | Channel Shallowing/ Consolidation | Beneficial reuse of dredge material to enhance Essential Fish Habitat | • all hurdles in above box<br>• conflicts with deep pit locations | All listed for "Bay Nourishment"<br>**NYSDEC/NYCDEP/ USACE** (specific fill permits) | | |
| | Friction Forest | Preservation/Enhancement | • Preservation/Enhancement<br>• Incorporate reforestation and shoreline stabilization of existing and proposed CDFs | All listed above for "Absorptive Edges" | | |

| Site | Design Element | Design Approach | Potential/Likely Regulatory Hurdles | Review/Approval Agencies | Ongoing projects | Potential Partners |
|---|---|---|---|---|---|---|
| South Staten Island / Raritan bay lower harbor | Absorptive Edges | Restoration/ Enhancement<br><br>Incorporate bioengineering techniques to soften previously developed shoreline and naturalize | • made land/historic fill requires archeological investigation<br>• historic fill may be contaminated<br>• coordination with coastal zone management required<br>• consistency determination with Waterfront Revitalization Program<br>• conflicts with: property rights, infrastructure/utilities, navigation channels, economic development<br>• pre-existing public Right of Way | **SHPO** (Section 106)<br>**NYSDEC/USEPA/NJDEP** (Brownfield, NPL, RCRA screen), **NYSDEC** (soil invest.),<br>**NYCDCP/NJDEP** (coastal zone management compliance)<br>**NYCDCP/CPC**<br>**NYS/NYCEDC/NJ** (eminent domain);<br>**Utility agencies** (coordination)<br>**NYCDOT, NYCDP&R, NJ Municipalities** | Hudson Estuary Program<br><br>USACE navigation projects<br><br>NYC Projects<br><br>USFWS Management Activities<br><br>National Park Service Projects (Sandy Hook) | USACE<br><br>NYCDPR<br><br>NYCDEP<br><br>NYCDEP<br><br>NJDEP<br><br>USFWS<br><br>American Littoral Society<br><br>PANYNJ<br><br>Universities (CUNY, Stevens Institute, SUNY, Long Island University, College of Staten Island, Rutgers, Columbia)<br><br>Community groups |
| | Dredge Wetlands | Restoration / Creation<br><br>Build on and expand existing efforts to restore previously degraded salt marsh | • generally all hurdles above except perhaps made land/historic fill issues<br>• conflicts with endangered species and essential fish habitat protection during construction<br>• -water quality concerns | **NYCDCP/CPC** City Planning Commission,<br>**NYS/NYCEDC**<br>**Utility agencies** (per above)<br>**USFWS** (endangered species); NMFS (habitat requirements, seasonal restrictions)<br>**NYSDEC/NYCDEP/NJDEP/USACE** (dredge and fill permits | | |
| | Bay Nourishment (Shallowing) | Beneficial reuse of dredge material to create Sub-tidal shallows and restore Submerged Aquatic Vegetation | • generally all hurdles in above box<br>• -interference with navigation channels<br>• public waterfront access | All in Above Box<br>**USCG** (clearance, notices);<br>**NYSDOT/NYCDOT/NJDOT** (non-federal channels)<br>**Federal Agencies** (public access to water mandatory for funding);<br>**NYS/NYC /NJ** (public trust doctrine) | | |
| | Habitat Breakwaters (inshore breakwaters & reefs) | Protect wetlands, absorptive edges from wave energy while improving habitat | • generally all hurdles in Dredge Wetlands, Bay Nourishment/Channel Shallowing boxes<br>• -prohibitions on shellfish restoration in "no harvest" areas<br>• maintenance, operational, and navigation impacts on Naval Weapons Station Earle<br>• only justified to protect absorptive edges and dredge habitat wetlands | All in Above Dredge Wetlands, Underwater Shallowing/Channel Shallowing Boxes<br>**NJDEP** (dredge and fill permits, habitat impacts)<br>**US Navy** (navigation) | | |
| | Constructed Reefs | Protect beaches, bluffs, wetlands, absorptive edges from wave energy | • interference with navigation channels<br>• conflicts with endangered species and essential fish habitat protection<br>• water quality concerns<br>• interference with littoral drift and beach nourishment | **USCG** (clearance, notices);<br>**NYSDOT/NYCDOT/NJDOT** (non-federal channels)<br>**USFWS** (endangered species); NMFS (habitat requirements, seasonal restrictions)<br>**NYSDEC/NYCDEP/USACE** (dredge and fill permits, state only within 3 miles of coast)<br>**NJDEP/NYDEC/USEPA** Major modeling of structures' effects on currents, sand deposition, navigation, etc. with full **Environmental Impact Statement** | | |
| | Channel Shallowing / Consolidation | Beneficial reuse of dredge material to enhance Essential Fish Habitat | • all listed in "Bay Nourishment"<br>• conflicts with deep pit locations | All listed in "Bay Nourishment"<br>NYSDEC/NYCDEP/NJDEP/USACE (specific fill permits) | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Friction Forest | Preservation/Enhancement | • -Preservation/Enhancement<br>• -Incorporate reforestation and shoreline stabilization of existing and proposed CDFs | All in Above Living Shoreline/Absorptive Edges Box | | |

| Site | Design Element | Design Approach | Potential/Likely Regulatory Hurdles | Review/Approval Agencies | Ongoing projects | Potential Partners |
|---|---|---|---|---|---|---|
| Barnegat Bay Intertidal Shallows Enhancement | Absorptive Edges | Restoration/ Enhancement<br><br>Incorporate bioengineering techniques to soften previously developed shoreline and naturalize | • made land/historic fill requires archeological investigation<br>• - historic fill may be contaminated<br>• coastal zone management<br>• -conflicts with: property rights, infrastructure/utilities, navigation channels, economic development<br>• -pre-existing public Right of Way | **SHPO** (Section 106)<br>**USEPA/NJDEP** (Brownfield, NPL, RCRA screen),<br>**NJDEP** (soil invest.),<br>**NJDEP** (coastal zone management compliance)<br>**NJ** (eminent domain);<br>**Utility agencies** (coordination)<br>**NJDEP**,<br>**NJ Municipalities** | USACE navigation projects<br><br>NJDEP Projects<br><br>USFWS Management Activities,<br><br>William Forsythe Wildlife Reserve<br><br>NJ Island Beach State Park<br><br>USEPA Barnegat Bay Estuary Program | USACE<br><br>NJDEP<br><br>NJDOT<br><br>USFWS<br><br>American Littoral Society<br><br>Community groups<br><br>USEPA Barnegat Bay Estuary Program<br><br>Universities:<br><br>Jacque Cousteau National Estuarine Research Reserve / Rutgers Institute of Marine and Coastal Sciences<br><br>Richard Stockton College Coastal Research Center |
| | Dredge Wetlands | Restoration / Creation<br><br>Build on and expand existing efforts to restore previously degraded salt marsh | • generally all hurdles above except perhaps made land/historic fill issues<br>• conflicts with endangered species and essential fish habitat protection during construction<br>• water quality concerns | **NJDEP** (coastal zone management compliance);<br>**NJ** (eminent domain);<br>**Utility agencies** (coordination);<br>**NJDEP**<br>**NJ Municipalities** (per above)<br>**USFWS** (endangered species); NMFS (habitat requirements, seasonal restrictions)<br>**NJDEP/USACE** (dredge and fill permits) | | |
| | Bay Nourishment | Beneficial reuse of dredge material to create Sub-tidal shallows and restore Submerged Aquatic Vegetation | • generally all hurdles in above box<br>• interference with navigation channels<br>• public waterfront access | All in Above Box<br>**USCG** (clearance, notices);<br>**NJDOT** (non-federal channels)<br>**Federal Agencies** (public access to water mandatory for funding);<br>**NJ** (public trust doctrine) | | |
| | Habitat Breakwaters | Protect wetlands, absorptive edges from wave energy while improving habitat | • This approach is not suitable for the shallow water habitat of Barnegat Bay | | | |
| | Constructed Reefs | Protect beaches, bluffs, wetlands, absorptive edges from wave energy | • This approach is not applicable to Barnegat Bay | | | |
| | Channel Shallowing/Consolidation | Beneficial reuse of dredge material to enhance Essential Fish Habitat | • All listed in "Bay Nourishment"<br>• -conflicts with deep pit locations | All listed in "Bay Nourishment"<br>**NJDEP/USACE** (specific fill permits) | | |
| | Friction Forest | Preservation/Enhancement | • -Preservation/Enhancement<br>•<br>• -Incorporate reforestation and shoreline stabilization of existing and proposed CDFs | All listed in Absorptive Edges Box | | |