Structures of Coastal Resilience

Phase 1
Context, Site, and Vulnerability Analysis

February 2014

SCR
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February 2014

Princeton University
School of Architecture

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Department of Civil and Environmental Engineering

Woodrow Wilson School of Public and International Affairs

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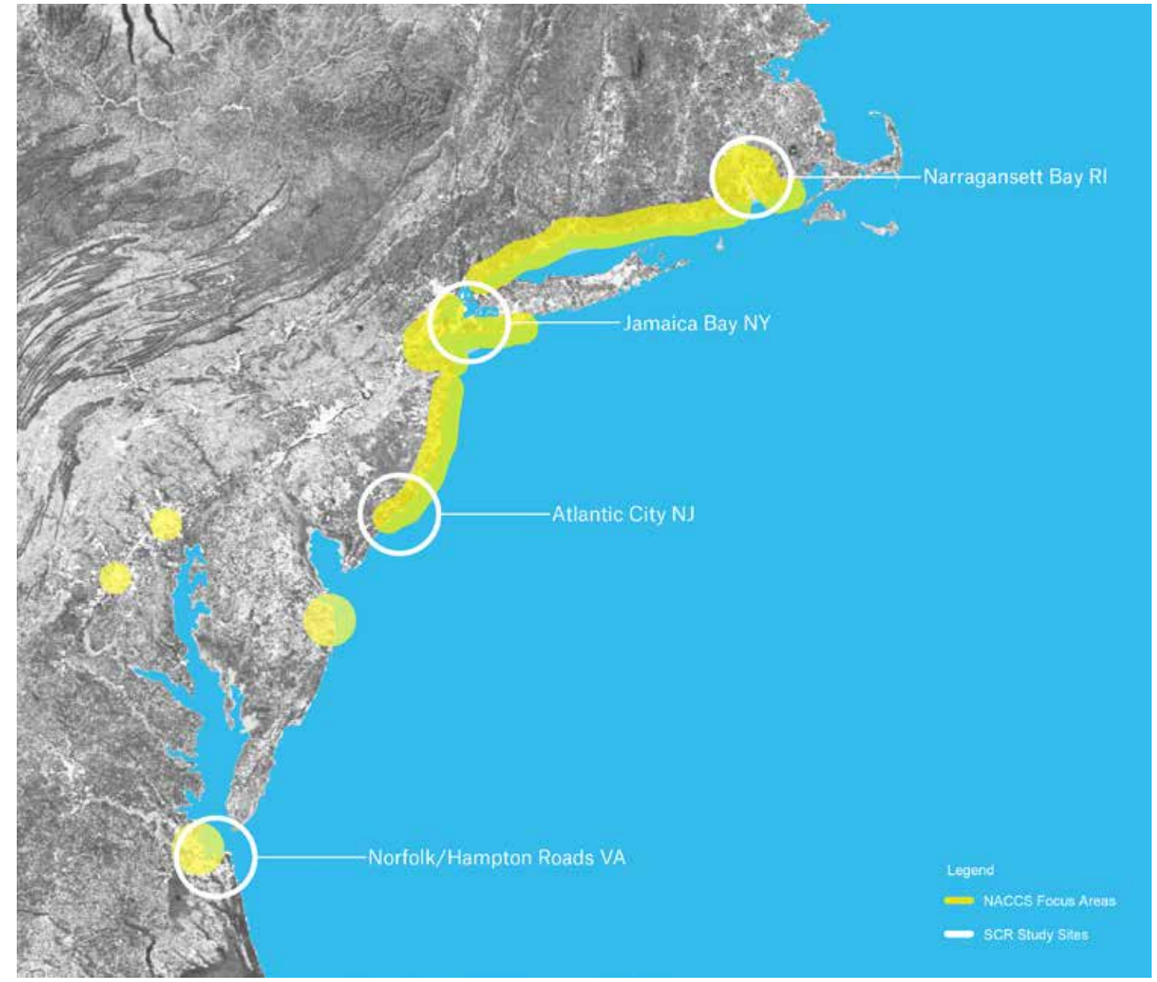

Executive Summary

Structures of Coastal Resilience (SCR), a Rockefeller Foundation-supported project, is dedicated to studying and proposing resilient designs for urban environments on the North Atlantic coast of the United States. SCR has prepared the following report detailing the work and research completed during Phase 1 of the project.

Phase 1 began in October 2013 and involves substantial contextual, site, and vulnerability analyses in four urban coastal areas: Narragansett Bay, Rhode Island; Jamaica Bay, New York; Atlantic City, New Jersey; and Norfolk and Hampton Roads, Virginia. These areas feature ongoing projects by the US Army Corps of Engineers, demonstrate socioeconomic vulnerability, and are highly prone to flooding.

01 Introduction To Structures of Coastal Resilience

The extensive damage caused by Hurricane Sandy in October 2012 has heightened public awareness of the vulnerability of urban coastal areas to catastrophic storms, and highlighted how climate change drives sea level rise and warming oceans. These factors will continue to affect the frequency and severity of storms. Therefore, coastal planning and design must be re-assessed so that inhabited coastal regions can adapt to both the gradual and extreme consequences of these changes in climate and natural hazards.

Re-evaluating Flood Risk Management and Mitigation
The National Flood Insurance Program (NFIP), a mechanism by which the US Federal Emergency and Management Agency (FEMA) promotes storm surge protection and provides financial resources for post-storm recovery, must also be re-evaluated in light of climate change and its resultant effects on storms. The NFIP is flawed for several reasons:

- It does not consider the effects of sea level rise and ocean warming due to climate change;
- The FEMA calculations used to determine its flood maps use available data relating to storm surge and wave effects in an inconsistent manner and do not take into account specific land and structural details because of a slowed map development process;
- NFIP promotes risky development by exempting communities behind existing flood control structures in 'residual risk areas' from insurance and building code requirements;
- Political pressures often produce reduced flood insurance levels, resulting in an inability to cover the cost of recovery and building.

Although coastal flood resistant design has improved, it has not kept up with developments in similar fields such as earthquake and wind hazard protection. Earthquake and wind-resistant building practices involve the identification of large hazardous zones that incorporate adjacent neighborhoods and structures. However, this is not the case with coastal flood resistant design and flood plain management, where standard practices still rely on a clear delineation between 'hazardous' and 'non-hazardous' zones, even in the presence of uncertainties.

Designing for Risk
There are some design practices that incorporate elements of uncertainty. For example, automotive design already employs features that absorb and dissipate the energy created by collisions. Buildings that are earthquake or blast-proof are also designed to absorb energies while allowing for irreparable damage in order to save lives. Wind-resistant building practices involve the creation of economically-efficient designs that can withstand damage.

Figure 1: Jamaica Bay view of JoCo Marsh, JFK Airport runway, Brooklyn terminal moraine, and Manhattan skyline

A similar approach can and should be applied to flood resistant design. This approach can be summarized using the principles of attenuation, protection, and planning: attenuating and dissipating the energy of waves to reduce the demands on coastal structures; protection through improved flood protection and building code requirements; and planning for controlled flooding through urban and flood plain management and design.

SCR has analyzed the selected urban coastal regions and is developing integrated coastal resilient designs. These desgins feature multiple layers of existing and planned natural and structural defenses, take into account the locations of ongoing or projected USACE works, and calculate the risk of coastal storm surge, flooding and other climate change impacts. The research emphasizes local demographic, historic, and economic context; the local ecology; and environmental and natural hazards. In short, the teams consider as broad a range of contexts, hazards, and circumstances as possible.

SCR Project Team Members
SCR brings together a distinguished group of engineers, scientists, architects, landscape architects, and scholars, matching an unparalleled depth of design experience with the latest science. The project is coordinated and managed by Guy Nordenson, professor at the Princeton University School of Architecture, and Enrique Ramirez, a postdoctoral research associate also at the Princeton University School of Architecture. The engineering team working on aspects of the coastal storm and climate change probabilistic hazards assessment is based at Princeton University and includes Michael Oppenheimer and Christopher Little at the Woodrow Wilson School of Public and International Affairs, and Ning Lin with Talea Mayo at the Department of Civil and Environmental Engineering. Michael Tantala, a consulting engineer and Geographic Information Systems (GIS) specialist, is working to help visualize the effects of climate change on storm surge and sea level rise—an aspect of the project that considers the role that uncertainty and risk play in coastal resiliency.

SCR

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The four university-based design teams include the Harvard University Graduate School of Design team led by landscape architects Michael Van Valkenburgh and Rosetta Elkin; the City College of New York Spitzer School of Architecture team led by Catherine Seavitt; the Princeton School of Architecture team led by Paul Lewis; and the University of Pennsylvania School of Design team led by Anuradha Mathur and Dilip da Cunha. Each team is focusing on a specific study area: the Harvard team is developing strategies for Narragansett Bay, Rhode Island that include a close analysis of botanical species as well as close engagement with local stakeholders. The CCNY Spitzer School of Architecture team is studying ways to address back bay flooding, sediment nourishment, and water quality at Jamaica Bay, New York. The Princeton University School of Architecture team is creating resiliency schemes for Atlantic City, New Jersey that consider the social and economic history of the region while assessing local USACE work that followed in the wake of Hurricane Sandy. The University of Pennsylvania School of Design team is examining Norfolk and Hampton Roads, Virginia, specifically the conflux of the James and Elizabeth Rivers, and the effects of storm surge and sea level rise in a region that has been subsiding at an alarming rate.

This interdisciplinary collaboration between architects, landscape architects, engineers, climate scientists, civil engineers, and hydrologists will produce integrated designs, analyses, and presentation deliverables that other conventional public and private initiatives have not.

Complementing and Improving Prior USACE Work
One of the most significant coastal planning initiatives is the North Atlantic Coast Comprehensive Study which was assigned to the USACE under authority of the Disaster Relief Appropriation Act of 2013. As part of a group of Federal initiatives enacted in the wake of Hurricane Sandy, the Comprehensive Study is to address the flood risks of vulnerable coastal populations in the areas that were affected by Hurricane Sandy within the boundaries of the North Atlantic Division of the Corps via the deployment of structural, nonstructural, natural, and nature-based solutions.

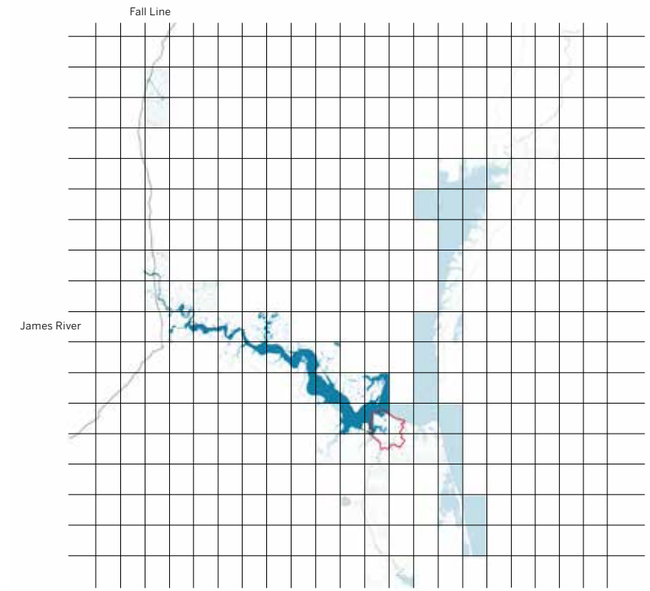


Figure 2: West Frontier: James River via the Fall Line
Figure 3: Eastern and Western Passage to Narragansett Bay

Despite this latest grant of authority, the USACE has historically been limited in its efforts to implement similar schemes. Slow authorization of Federal funding often results in delays extending completion dates for some projects. A reliance on conventional engineering practices also limits USACE's ability to embrace state-of-the-art approaches. In addition, the USACE has had difficulties using appropriate visual languages and presentation techniques to engage stakeholders.

The goal of SCR is to improve on these situations and augment their statutory prerogative by providing specific and actionable recommendations for hurricane protection that can result in USACE feasibility studies. The SCR principles of 'attenuation, protection, and planning' complement the USACE's approach of using structural, non structural, natural, and nature-based features for coastal resilient design. Whereas natural and nature-based features belong under the 'attenuation' category, non-structural are clearly under the 'plan' category. The structural features fall under both 'protection' and 'attenuation' in this framework.

A further contribution of the SCR project is a re-evaluation of storm modeling techniques. Using methods and studies pioneered by Ning Lin, her team, and collaborators, at Princeton University, SCR will eschew the current trend of using historical storms and instead model synthetic storms in order to make a probabilistic assessment of coastal storm surges that accounts for various uncertainties including the effects of global climate change on sea level rise. These assessments, based on Sea, Lake, and Overland Surges from Hurricanes (SLOSH) and Advanced Circulation Model (ADCIRC) modeling, will then be translated into probabilistic flood maps using Geographic Information Systems (GIS) software.

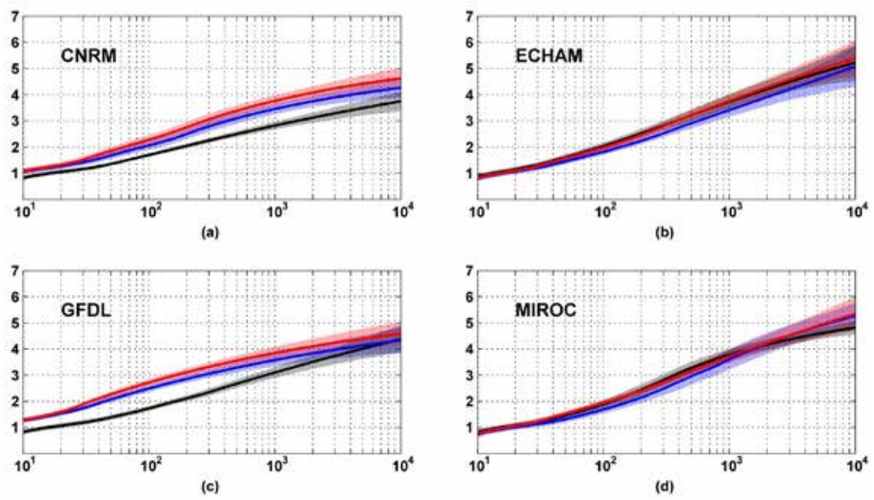


Figure 4: Estimated storm tide levels for the Battery, predicted with each of the four climate models using SLOSH and ADCIRC. Black represents the current climate, blue represents the IPCC A1B climate, and red represents the IPCC A1B climate with the outer radius and the radius of maximum winds increased by 10% and 21%, respectively.

02 Hurricane Storm Surge Assessment For Structures Of Coastal Resilience

Our assessment of hurricane storm surge considers the extent to which the SCR study areas are particularly vulnerable—and will continue to be vulnerable—to damage. In assessing the risk of storm surge at these locations, and with consideration of the changing climate, SCR will assess the risk for both current and future climate scenarios.

This research will rely on the methods developed by Ning Lin, her team, and collaborators, which use a statistical-deterministic hurricane model to generate synthetic storms. These storms use hydrodynamic and wind field data provided by the National Center for Environmental Protection (NCEP) and the National Center for Atmospheric Research (NCAR) to create a deterministic atmospheric-ocean-coupled model that will factor in data provided by four Global Climate Circulation models.

The wind and pressure data will be combined to make a hydrodynamic model that will calculate storm surge. The two hydrodynamic models currently being used for storm surge modeling—SLOSH and ADCIRC—differ in terms of resolution and computing time when used to calculate shallow water equations (SWEs). SLOSH offers a coarse-grain resolution but it generates models more quickly than ADCIRC which, while slower and more expensive to operate, has finer resolution and is less prone to numerical error.

With this in mind, SCR will use SLOSH models with modified wind fields to cut down on operational expenses and computational time. SLOSH modeling will be particularly useful in filtering those storms that can be modeled using ADCIRC during later phases of the project. This approach is not inconsistent with those used by the National Weather Service (NWS) or the National Oceanic and Atmospheric Administration (NOAA). In fact, as Figure 1 shows, the results obtained using the two models can be complementary. The SCR storm modeling is also unique in that it factors in sea level rise (SLR) data—the probability distribution of the surge flood height will include both the probability distribution of the surge height and the probability distribution of the SLR.

03 Geographic Information Systems (GIS) Modeling for Structures of Coastal Resilience

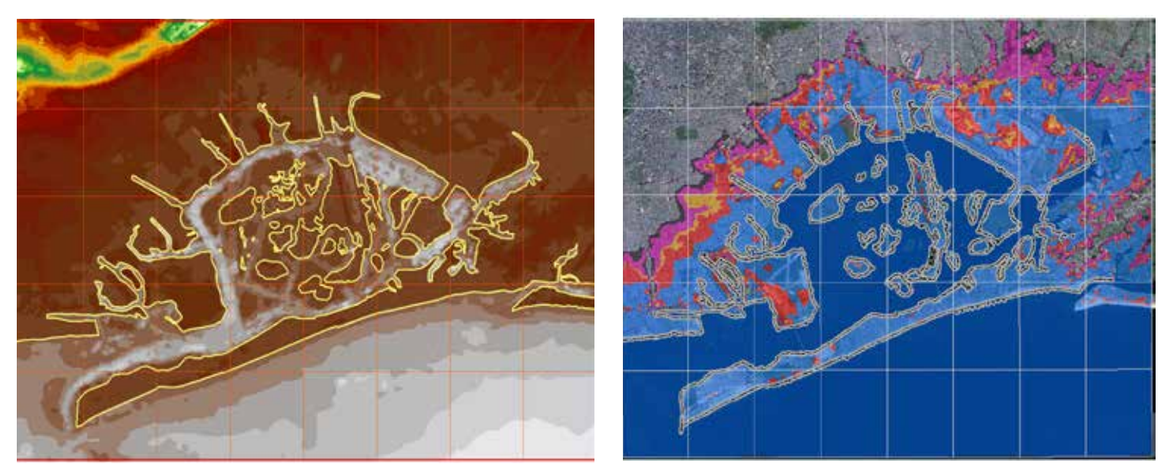
The SCR project uses geospatial models to evaluate the effects of flooding in the four study regions. Coastal elevation and bathymetric data were combined using Geographic Information Systems (GIS) software to create a topobathy model. Topobathy allows the study of continuous changes in elevation from the seafloor, a method that is especially useful in analyzing the effects of sea level rise and flooding on coastal structures.

The SCR geospatial maps and models were created using the projection system favored by the US Geological Survey (USGS), FEMA, the Department of Homeland Security (DHS), and other agencies. The quarter-quadrangle (QQ) and quarter-quarter quadrangle (QQQ) grid reference systems, which are related to the USGS 7½ minute quadrangle index maps, were then combined with coarse- and fine-grained computational basins from SLOSH and ADCIRC models to create a baseline geospatial framework for SCR.

SLOSH and ADCIRC already use topobathic data. When paired with the baseline geospatial framework, the topobathy models produced by SCR will be used as inputs into SLOSH, and will create an accurate database for modeling synthetic storm tracks (Figure 5). The topobathy models will also be used to create highly-detailed floodplain maps for use during latter stages of the project.

These inundation analyses will complement methods used by FEMA, such as the Flood Rate Insurance Maps (FIRMs) and Wave Height Analysis for Flood Insurance Studies (WHAFIS). However, the SCR models are an improvement because they will demonstrate the role that uncertainty can play in modeling storm surges. The SCR models and initial simulations are being mapped out and will be used in subsequent phases.

Figure 5: (Left) A Sample Topobathy Model for the Jamaica Bay (NY) Study Region (Right) ADCIRC inundation - 100, 500, 1000, 5000 year returns and worst case of all storms envelope



04 Future Sea Level Changes

SCR will generate fully probabilistic projections of sea level rise at four coastal tide gauge locations in Rhode Island, New York, New Jersey, and Virginia through the year 2100. These projections—which account for processes that result in sea level changes over annual to decadal timescales—will be combined with projections of short-term sea level variability (storm surge) to generate a risk assessment of coastal flooding for the four study locations. These projections will improve on previous work because they present uncertainty in a comprehensive manner at a local level.

Global mean sea level has been rising at 1.7+/- 0.2 mm/yr since 1900, and 3.2 +/- 0.4 mm/yr since 1993. Thermal expansion of ocean water and melting land ice are the major contributing phenomena to sea level rise. Local sea level rise (LSL), however, is the result of a combination of factors, including vertical land motion. In particular, the Eastern Coast of the United States has been experiencing a higher-than-global-mean rate of sea level rise. The rate of sea level rise at the Battery, in New York City, for example, has averaged approximately 3.0 mm/yr since 1900, about 50% higher than the global mean rate.

Our LSL modeling will include up-to-date, fully probabilistic estimates of all components of sea level change for each location.

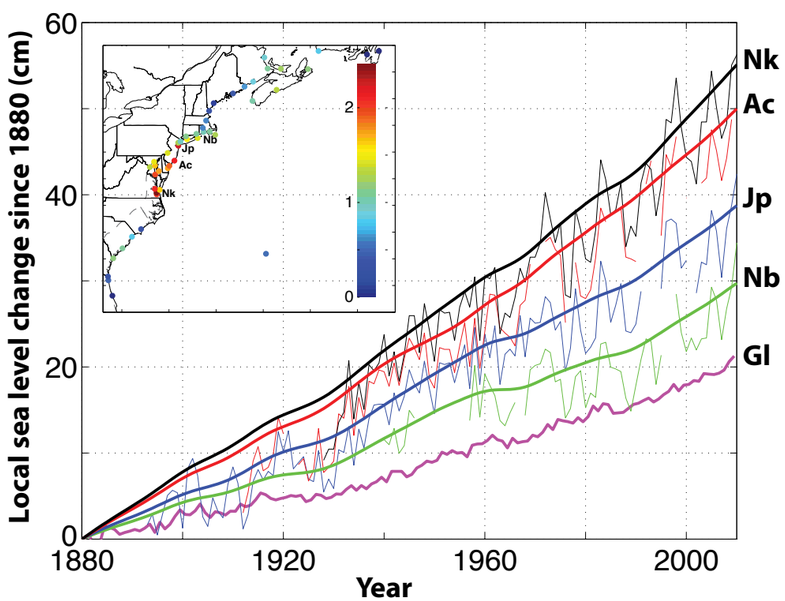


Figure 6: The historical local sea level record (thin lines) and long-term trends (thick lines, from Kopp 2013) at the closest tide gauges to the four design sites: Norfolk (Nk, black); Atlantic City (Ac, red); Jamaica Bay (Jp, blue); Narragansett Bay (Nb, green). Sea level at each location is shown relative to the value of the smoothed trend in 1880. The global mean trend (from Chuch and White, 2011) is shown in purple. The inset shows long-term linear trends in relative sea level (colors, in mm/yr), for the Eastern United States and Canada. Data and inset map courtesy of Bob Kopp and modified from Kopp (2013).

05 Designing Structures of Coastal Resilience

SCR's innovations should be considered within a larger consideration of 'resilience.' No matter the historical or technological context, 'resiliency' almost always refers to the ability to recover from change or adversity. The term is also relevant in design and planning as it suggests the ability of buildings and cities to withstand and respond to near-catastrophic change.

The USACE has used its technical expertise to address issues of coastal resilience and well as climate change since the mid-twentieth century. Special Boards, Institutes, and Centers all featured an evolving level of expertise to the analysis and modeling of beach and costal erosion. With this sophistication came an increasing reliance on technical manuals used to explain resilience as a technological endeavor, not as a design process.

Today, the USACE's terminology marks a change from its reliance on hard and tectonic structures as part of its approach to coastal resilience. This is evident in its classification of 'natural,' 'nature-based,' 'structural,' and 'nonstructural' features as part of its comprehensive approach to coastal risk reduction. These features have yet to be fully implemented into USACE schemes. They also have not been the subjects of prolonged study. In principle, these kind of features dovetail with the 'attenuate, protection, and planning' approach to create a multi-layered approach to coastal risk reduction. This would lead to the development of a performance-based system that addresses (1) the range of demands associated with moderate to extreme low-probability storms and (2) the depth of protection provided by wave-attenuating offshore features as well as static barriers.

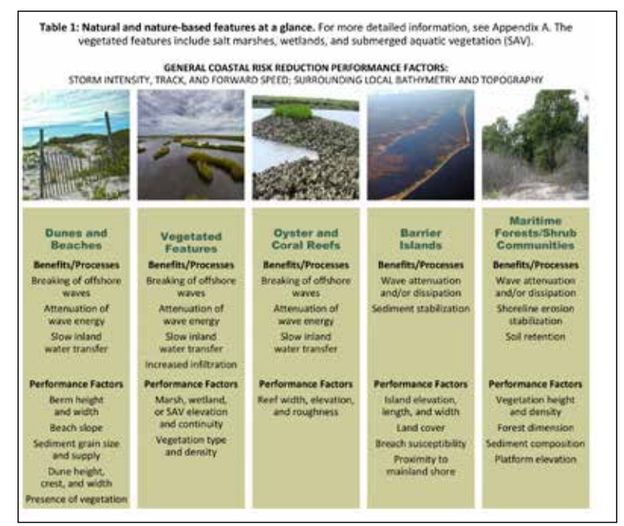


Table 1: Natural and nature-based features at a glance. For more detailed information, see Appendix A. The vegetated features include salt marshes, wetlands, and submerged aquatic vegetation (SAV).

GENERAL COASTAL RISK REDUCTION PERFORMANCE FACTORS:
STORM INTENSITY, TRACK, AND FORWARD SPEED; SURROUNDING LOCAL BATHYMETRY AND TOPOGRAPHY

Dunes and Beaches	Vegetated Features	Oyster and Coral Reefs	Barrier Islands	Maritime Forests/Shrub Communities
Benefits/Processes	**Benefits/Processes**	**Benefits/Processes**	**Benefits/Processes**	**Benefits/Processes**
Breaking of offshore waves	Breaking of offshore waves	Breaking of offshore waves	Wave attenuation and/or dissipation	Wave attenuation and/or dissipation
Attenuation of wave energy	Attenuation of wave energy	Attenuation of wave energy	Sediment stabilization	Shoreline erosion stabilization
Slow inland water transfer	Slow inland water transfer	Slow inland water transfer		Soil retention
	Increased infiltration			
Performance Factors	**Performance Factors**	**Performance Factors**	**Performance Factors**	**Performance Factors**
Berm height and width	Marsh, wetland, or SAV elevation and continuity	Reef width, elevation, and roughness	Island elevation, length, and width	Vegetation height and density
Beach slope	Vegetation type and density		Land cover	Forest dimension
Sediment grain size and supply			Breach susceptibility	Sediment composition
Dune height, crest, and width			Proximity to mainland shore	Platform elevation
Presence of vegetation				

Figure 7: USACE Natural and Nature-Based Features

06 Narragansett Bay, Rhode Island
Harvard University Graduate School of Design

Narragansett Bay is a mixed estuary that bisects Rhode Island from north to south, a region that includes Providence at its northern reaches and Newport on its southern periphery. The bay extends approximately 45 km along this north-south axis, reaches 18 km at its widest point, and covers an area of 342 sq km. Shoreline types include fringing and meadow salt marshes, bulkhead and other modified perimeters, which comprise 25% of Narragansett Bay's coastline. Its coastal areas feature a combination of drastically disturbed sites, preserved transitions or post-industrial fill. Coastal planting strategies offer few solutions within a variety of conditions, and tend to be overinvested in replacing iconic species or renewing marshlands, rather than creating a functional and necessarily transitional coastal space. Since Rhode Island lies at the northernmost extent of Sandy's devastation, it offers an exemplary site for developing structures of coastal resilience that are not based on typical responses and reactions, but rather on approaches rooted in systematic evaluation and adaption. The USACE has an opportunity to study this site: an area that has flirted with the potential of disaster and one that remains vulnerable to extreme weather events in the future.

The Harvard University Graduate School of Design (GSD) team strategizes resilience by taking two main perspectives into account: the storm and the species. Rather than defining sites through purely analytical methods, the team will move beyond traditional considerations of site and will propose new models of practice and cooperation that engage stakeholders.

The team recognizes two general storm tracks that have traversed Narragansett Bay and considers their shared characteristics in order to narrow site selection. The aim is not to find the 'hardest hit' areas, but rather to qualify the connections between sites and the surge patterns of the greater Rhode Island coastal zone. Physical attributes—benthic slope, bed form, and coastline material composition—must be analyzed alongside low income, high commercial activity, and/or potentially impactful ecological structure. Yet creating a portfolio of interventions located on the shore is not as critical as defining the powers and processes that combine to form an appropriate response. The GSD team's strategy relies on a method that combines the ephemeral (weather), the submerged (bathymetry), and the terrestrial (plants) in order to approach issues of such scale and complexity (Figure 9).

This method acknowledges resilience as a biological trait as opposed to an ecosystem value. By nature competitive, plants emerge and 'spring back' based on regimes of

Figure 8: Warren Base Map and Section Housing, The Hummocks – Island Park

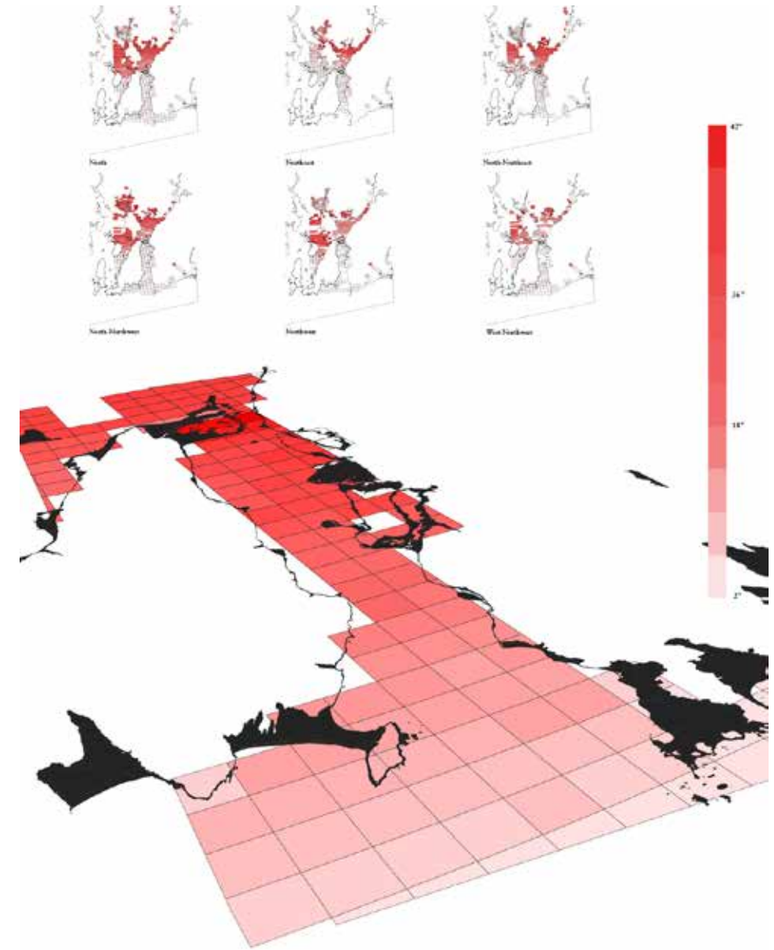
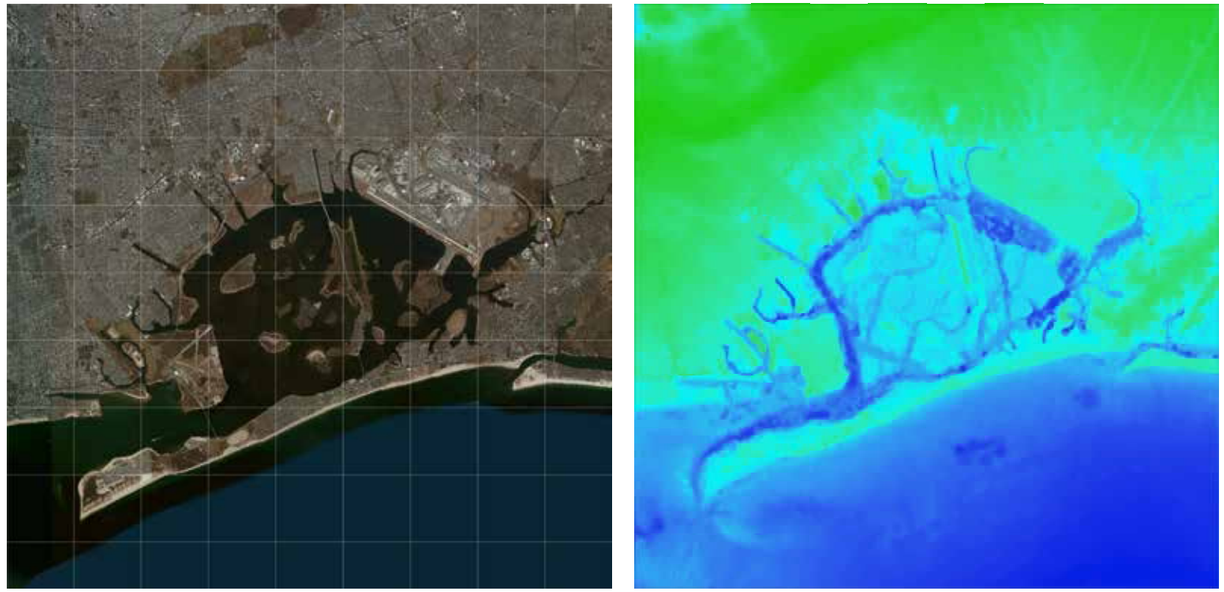


Figure 9: Surge Projections, Saline Gradient, and Species: Existing Data Evaluations for Inundation as a Contributing Method to Site Definition and Selection.

disturbance that ought to be acknowledged and exploited rather than eclipsed by the discourses of native or restorative environmentalism. The GSD team acknowledges that understanding plant behavior is crucial to the principles of design and fluctuations that are part of coastal ecology. The plant unit becomes a scalar device, one that creates relationships and provides the foundation for a portfolio of interventions that can be manipulated and controlled alongside typical construction materials. As designers, the GSD team considers this study as an opportunity to offer a vision of community-based resilience, with the aim of creating a public resource without resorting to the restrictive procedures associated with conservation.

This study aims to promote landscape architecture as a compliment to the USACE's expertise in planning nature and nature-based features. The GSD team imagines features that can be defined as a staged and tested set of design specifications and species palettes. Specifications and scalar typologies are critical to creating feasible propositions that operate both within a community and across organizations. By proposing designs that can be methodically installed and easily observed, the GSD team aims to put forward solutions that build on the expertise of the SCR multi-disciplinary team, and that work across scales, sites and disciplines. The main deliverable of the GSD team's proposal is therefore a series of design recommendations that are highly specific to particularly identifiable conditions, a format that offers a language that can be shared, reproduced, reformed and ameliorated by various stakeholders.



07 Jamaica Bay, New York
Bernard and Anne Spitzer School of Architecture, City College of New York

Jamaica Bay, located in the New York City boroughs of Brooklyn and Queens, is a 31-square mile water body (approximately 20,000 acres) and the westernmost embayment along the south shore of Long Island. The Rockaway Peninsula, a narrow barrier island, frames the bay's southern edge. The bay's waters connect to the Lower Bay of New York and the Atlantic Ocean via the Rockaway Inlet, at the western end of the peninsula. Jamaica Bay's historic watershed captured approximately 142 square miles from the terminal moraine ridge southward across the outwash plain, with numerous upland streams from the west, north, and east providing fresh water and sediment to the bay. Extensive low-lying salt marsh islands and intertidal flats dominate the center of the bay. A rich ecological resource for the greater region, this estuarine area provides a diverse habitat complex, including salt marsh, grasslands, maritime forest, and woodlands.

Today the Jamaica Bay watershed has been transformed into a constructed sewershed, including much of Brooklyn and Queens as well as part of Nassau County at the eastern end of the bay. Four sewage treatment plants, three recently capped sanitary landfills, and historic dumping sites ring the bay's perimeter, and combined sewage overflow (CSO) outfalls discharge directly into its waters, compromising water quality and ecological health. Increased levels of nitrogen in the bay as well as sea level rise have caused an enormous loss of salt marsh island acreage. Because of the extensive urban development and impervious land cover in the upland zones surrounding Jamaica Bay, most storm waters are channeled through storm sewers. This has increased the pollutants delivered to the bay and removed its fresh water and sediment tributary sources. This continues to affect the health of Jamaica Bay's marsh islands, water quality, and benthic environment.

Currently the US Army Corps of Engineers dredges only the western entrance channel to the bay, Rockaway Inlet, to a working depth of 18 feet. Other navigation channels within the bay are used by the New York City Department of Environmental Protection (NYCDEP) barges serving the sewage treatment plants, as well as by other commercial and non-commercial vessels, but at the moment these channels are not being dredged by the USACE.

Figure 10: (Left) Aerial imagery of Jamaica Bay, (Right) Merged Bathymetric / Topographic Digital Elevation Model, (DEM)

The City College of New York (CCNY) team approaches the bay as an interconnected hydrologic, ecologic, and highly managed urban system, with the capacity to enhance coastal storm risk reduction and to provide for adaptive transformation as sea levels rise. The team also supports the goals of identifying the vulnerable populations and ecosystems of Jamaica Bay, as well as enhancing social resiliency and environmental stewardship in these communities.

Many projects have been proposed, and some successfully implemented, to support both the environmental and social resiliency of the Jamaica Bay region. Prior to Hurricane Sandy, USACE worked closely with the local environmental groups and initiated restoration projects to counteract salt marsh loss at several islands within the bay. These projects included both beneficial placement of dredge materials and strategic hand-planting of sea grasses. Other initiatives are directed at improving the collaboration between the New York City Department of Parks and Recreation and the National Parks Service, whose Gateway National Recreational Area includes parcels throughout the Jamaica Bay region, including Floyd Bennett Field, the Jamaica Bay Wildlife Refuge, and Jacob Riis Park. The integration of improved opportunities for community and recreational uses for the adjacent dense and underserved neighborhoods of Brooklyn and Queens is another significant strategy for enhancing both environmental stewardship and social resiliency.

The impact of Hurricane Sandy on Jamaica Bay, the Rockaway Peninsula, and the surrounding communities was extensive. Urban development in the region has stressed and compromised the protective capacity of the marsh islands to reduce wave impact, surge velocity, wind forces, and the extent of flooding. Multiple layers of infrastructures, both "soft" and "hard," may be deployed to protect and transform the dense populations around the bay's perimeter, particularly vulnerable low-lying communities. As sea levels rise and the risk of storm surge and flooding from hurricanes and other storm events increases, the vast scale of Jamaica Bay allows this region of the city to be recast and re-structured as an impactful ecological, infrastructural, and community asset, reducing vulnerability and enhancing the region's resiliency.

The CCNY team has identified several opportunities and initiatives to explore through systematic research and analysis. The first of these is an evaluation of singular versus multiple approaches to storm protection that considers a singular large-scale protective initiative for the entire bay versus a suite of smaller, local scale initiatives for vulnerable communities within the bay and along its margins. Both of these strategic approaches (the singular and multiple) will be examined in light of both ecosystem services and protective capacity given implementation times, performance of nature-based features, sea level rise, new risk maps, and the possibility of future retreat scenarios. A combination of both approaches, as suggested by the SIRR report, is certainly a possibility. The recasting of USACE's current set of ecosystem restoration projects in Jamaica Bay as part of a suite of storm protection strategies will be studied

Next, the CCNY team will examine and propose a cycle of both bay and beach nourishment at the regional scale of Jamaica Bay. Dredge and drift cycles will be studied to develop a local dredge material management plan with a balanced cut / fill ratio. USACE has expressed interest in the use of local dredge materials, sourced from Rockaway Inlet and East Rockaway Inlet navigational maintenance dredging as well

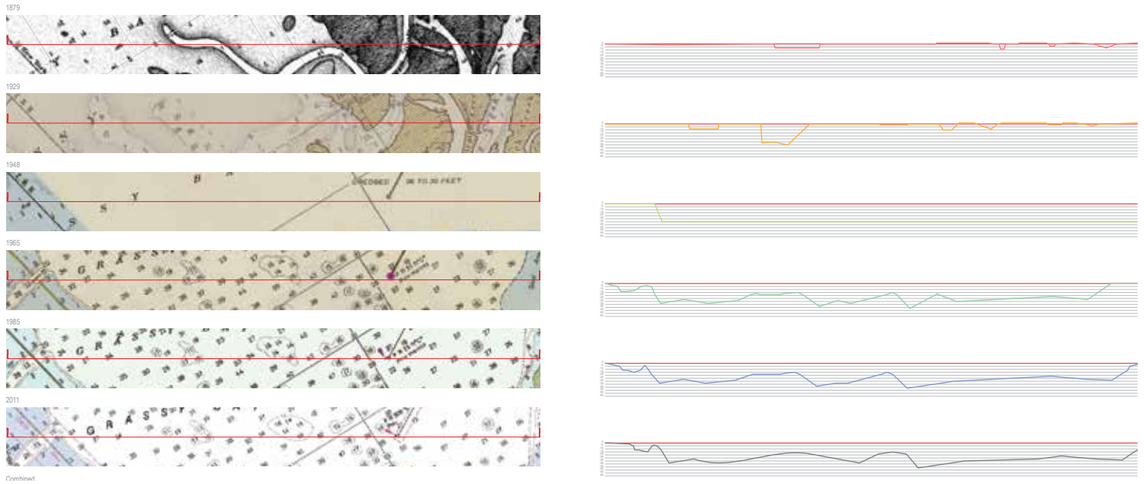


Figure 11: Sectional evolution of Grassy Bay borrow pits, 1879-2011

as offshore borrow areas A-West and A-East. This material may be used in a cyclical schedule to nourish coastal beaches, bay marsh islands, and living shorelines.

The CCNY team will also examine and test recommendations to improve the water quality and flushing of Jamaica Bay via land breaching. The residency time of water is significantly greater in the easternmost reaches of the bay; improved ecological health within the bay is dependent on the reduction of this residency time. In addition, it has been observed that the surge of water that entered the bay during Hurricane Sandy retreated slowly; additional outlets may accelerate the retreat of floodwaters. Three zones will be considered as possible locations for land breaches / channels: the peninsula of Floyd Bennett Field, the eastern end of the Rockaway Peninsula, and the Rockaway Spit. These passages may be developed as navigational channels, opportunistic locations for wetland development, or outfall points for high tides or floodwaters.

The team recognizes that the loss of wetland marsh islands within the heart of the bay has been rapidly accelerating over time. Supporting a healthy marsh ecology is necessary for the bay as both an ecological and coastal storm protection measure. The CCNY team will support initiatives to nourish and restore the marsh islands within the bay, and will also explore the recontouring of the deep channel passages between them. New restoration strategies, including establishing higher elevations and profiles independent of historical models, will be considered. Alternative planting methods (seed / plug / spontaneous growth) and armoring methods (foundation support / perimeter armoring / guided sedimentary drift) will be studied and evaluated.

The CCNY team's approach will support the USACE North Atlantic Coast Comprehensive Study's vulnerability analyses by providing a finer-grained analysis using metrics particularly relevant to Jamaica Bay. The social vulnerability index of New York City will be examined and the specifics of Jamaica Bay will be addressed. Communities most vulnerable to surge and sea level rise due to socio-economic status and other factors will be identified. Resilient community networks will be identified. Environmental vulnerability, including the loss of fragile ecosystems and habitat, and infrastructural vulnerability will also be considered.

This project grant provides the opportunity to holistically synthesize, evaluate, visualize, transform, and design multiple proposals for Jamaica Bay, New York, using sea level rise projections, hurricane risk and variable hazard data, and hydrodynamic models. Community strengthening, ecological restoration, environmental enhancement, and coastal flood protection are all aspects of this proposal's approach to resilient design.

08 Atlantic City, New Jersey
Princeton University School of Architecture

Atlantic City is economically and geographically vulnerable. As a low-lying barrier island, this city has been in the path of several historic storms and has sustained significant alterations to its coastal morphology. Additionally, Atlantic City is the only barrier island in New Jersey with densely developed urban fabric. With one quarter of its population living below the poverty line, and with a per capita income of $15,402, Atlantic City is also one of the state's poorest communities.

This legacy of social and economic vulnerability can be mapped onto Atlantic City's history of boom and bust, reinvention and decline. Beginning in the mid-19th century, the city grew as a resort destination. Though the beach provided the initial draw for visitors, Atlantic City entrepreneurs developed attractions along the coast to keep up with the demand from seasonal tourists. The post-war era saw an increasingly mobile generation of tourists seeking destinations farther afield. The decline continued through the 1970s and 1980s, despite the legalizing of gambling. New casinos in the underdeveloped marina district briefly garnered enthusiasm for wider economic growth, but revenues began falling immediately due to the legalization of gambling in nearby states and the 2008 recession. Between 2006 and 2010, profits fell by 30%. Additionally, government programs financed by those revenues were struggling, crippling the city further.

Storms have caused significant damage to Atlantic City's iconic boardwalk throughout its existence. Among the earliest recorded hurricanes, the 1889 storm destroyed the city's boardwalk and inundated most of the avenues approaching the beach. Later hurricanes beached and destroyed ships. In keeping with the city's spirit of amusement, entrepreneurs built docks out to scuttled and abandoned ships and charged admission. Most recently, the widely-seen images of the Absecon Inlet gave potential tourists the impression that the Atlantic City boardwalk had been destroyed during Hurricane Sandy. In truth, the section of the boardwalk shown on news outlets was already abandoned and in disrepair. Hurricane Sandy merely accelerated the destruction of the blighted boardwalk.

The State of New Jersey has tailored its economic policies to meet the challenges brought by catastrophic storm damage. Some of these initiatives gave the state a stronger role in the governance and promotion of Atlantic City. For example, the New Jersey Casino Redevelopment Authority (NJCRDA), an important and active agent in the city's plans for economic growth since 1984, released a flood mitigation plan shortly before Hurricane Sandy. The NJCRDA is just another instance demonstrating how the economic health of Atlantic City has always been dependent on coastal engagement. With increasing threats of catastrophic storms and sea level rise comes a reenergized concern for resiliency. The city must reconsider its natural features and vulnerabilities in order to survive as a destination and to grow as a community.

Since 2003, the United States Army Corps of Engineers (USACE) has undertaken a program of beach nourishment and dune systems along Absecon Island's Atlantic coast. The enhanced beach profiles (with an elevation of +14.75 and a beach width of

Figure 12: South Inlet and Chelsea Heights are typical inlet and back bay conditions additionally plagued by economic and social vulnerability. Source: United States Census.

200 feet) designed by the USACE effectively protected much of Atlantic City's seaside properties during Hurricane Sandy. However, significant storm surge entered through the inlets at both ends of Absecon Island, flooding much of the city's back bay. Flood and erosion protection features along the city's inlet and back bay edges are a collage of engineered bulkheads and revetments implemented by various federal, state, and municipal agencies, as well as private interests. A number of weak points or unprotected edges undermine the function of all other barriers around them. The USACE has approved plans to fill a number of the major gaps on the inlet side of the city, but has yet to begin construction.

The beach nourishment program in Atlantic City is indicative of the USACE's approach to the issue, centered on the use of a prototypical cross-section. A profile is first developed, following precedent and conventional practices, then extruded, creating a singular solution often miles long, regardless of the immediately adjacent urban forms. The USACE regards the city too closely as a measure of economic impact—does the value of property sufficiently justify a coastal intervention? Instead, the very logic of urban form could be integrated into the USACE's newly reformulated 'full array of measures' which combines natural, nature-based, structural, and nonstructural solutions in order to add economic and social value.

In the wake of recent storm events, the USACE is supporting a greater integration of natural or nature-based features, such as wetlands and dunes, with structural interventions and other engineered solutions, such as seawalls and breakwaters. Along with nonstructural solutions, the full array of measures hopes to layer these interventions to achieve an approach to risk reduction that can simultaneously improve natural, social, and economic conditions.

In preliminary information sessions for the NACCS, the USACE has offered 'combined profiles' that mobilize a number of natural and nature-based features in conjunction with structural interventions. However, this strategy may be repeating the shortcomings of conventional and singular profiles. Strategies are aggregated by adjacency; for example, a submerged breakwater, a seawall, and a meadow shrubland are placed in a linear sequence. The benefits of each remain isolated. In evaluating these combined scenarios, only individual effects of individual features can ever be measured, as there is no metric for a potentially multiplied or layered system.

Atlantic City provides an opportunity to combine existing USACE typologies with unique complexities of natural resiliency and urban organizational logics that can contribute to a more dynamic system. These typologies can be integrated with other existing infrastructure in order to create scenarios that enhance the quality of urban life.

Protective measures—seawalls, bulkheads, revetments—have the tendency to break the city's relationship with the coast. Though they often defend the city from wave action and storm surge, they cut off the urban from the natural, visually and physically. Because these measures are inhibitive, the Princeton team favors an approach that considers the vital relationship between city and ocean, one where the complexities and logic of each are fully hybridized to improve the quality of life.

A combination of natural, structural, and urban features yields a broad range of rich scenarios at the city's edge (Figure 13). Certain hybrids between structural interventions and natural features of course already exist: for example, a living shoreline is a hybrid wetland and revetment. These combinations may potentially reveal the internal logic of each ingredient more clearly. What value might a wetland block or a breakwater yard hold?

Atlantic City is newly mindful of the role coastal storms and rising sea levels may play in the immediate future. The sea is the city's signature amenity harkening back to its early days as a summer resort. Its low elevation means that the city will continue to be grievously vulnerable. Though the USACE has protected much of the seaside coast with beach nourishment, conditions along the inlet and back bay remain unaddressed. Moreover, these are typical conditions found throughout the Northeast Coast. Atlantic City is an ideal testing ground for the tactical implementation of the array of measures the USACE intends to develop. Could more radically combined measures, further enriched by urban fabric, yield scenarios in which water is more fully and beneficially lived with?

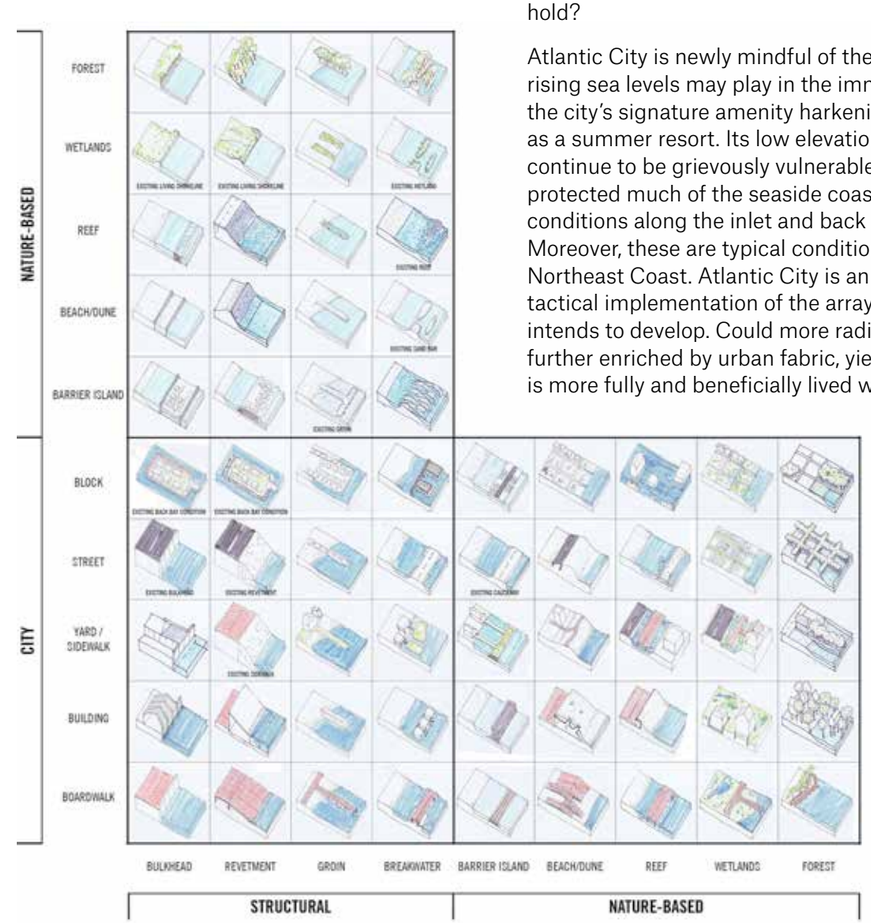


Figure 13: An initial suite of hybrids. While some are either existing or completely illogical, others open up interesting possibilities.

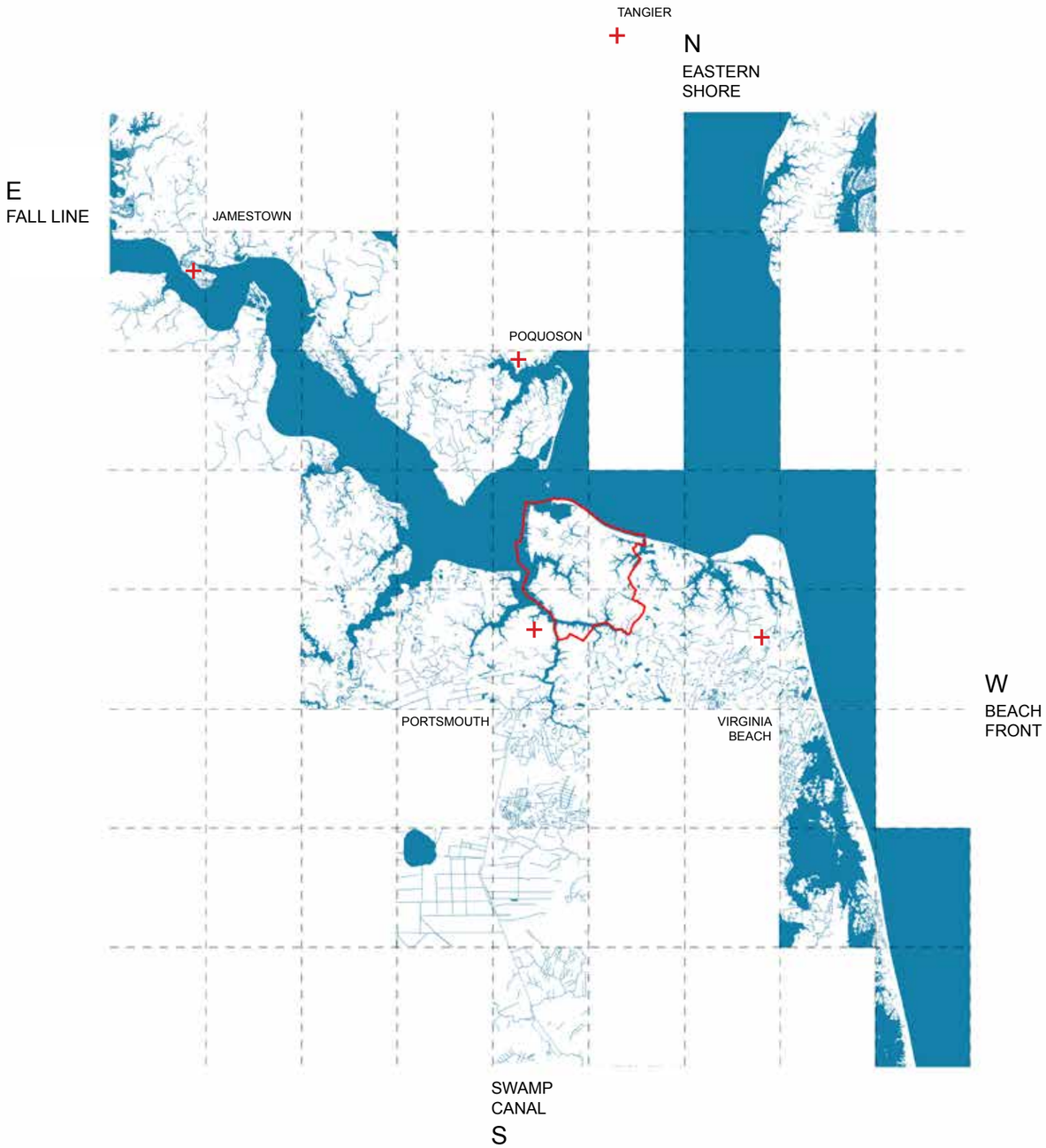


Figure 14: Mapping a strategy of "Off-Sites"

09 Norfolk and Hampton Roads, Virginia
University Of Pennsylvania School of Design

Sea level rise in Norfolk, perhaps more than most places on the east coast of the United States, is so real, close, and extensive, that it cannot be seen as a problem to solve; it needs to be seen as an opportunity to reimage, reimagine, and reconstitute settlement on the ground of water. It makes this part of Virginia, also referred to as 'Tidewater Country', an opportune place to investigate structures of coastal resilience. It is a place where the idea of the frontier and its associated notions of front, confront, and battlefront took root in a line drawn by European settlers between land and sea in the 1500s. This line moved west from here across tidewater country, the fall line, the Blue Ridge, the Mississippi River, the Rocky Mountains, all the way to the Pacific coast. Each threshold fulfilled prospects and opened new horizons, but each also reinforced and hardened that 'first' line that would become the east coast of the United States. With this first line consolidated on the ground, in maps, and in the mind, the immediate impulse in the face of a rising sea is to enforce and reinforce its act of separation. This, however, is a difficult task in an unequal fight between local land and global seas made even more difficult in Norfolk by land that is subsiding. The sea has risen 14-odd inches in 80 years in Norfolk, 5 inches more than New York, and is expected to rise as much in the next few decades. In low-lying tidewater country where the coast turns into numerous creeks, Norfolk does not call for barriers and protection; it calls for design intervention on the basis of a new visualization of the coast as a place where land meets sea, not across a line, but in a field of points.

The University of Pennsylvania team's project, then, is to turn the coast of Norfolk and its environs so that land does not meet the sea across a 'front', but rather through a number of discrete fingers of high grounds (Figure 8). Each finger is a unique gradient or a unique gathering of gradients between land and sea, working to structure a coast that is more fractured, cumulative and diverse than it is continuous, linear, and absolute. The Penn Team sees these fingers as pointing, extending, bending, reaching, folding, nudging and retracting. They probe and modify the sea on one side and land on the other. In the immediate they serve as islands of refuge in times of storm and surge; perhaps even upon occasion as protective barriers. In the long term, however, they become grounds of new settlement and resettlement that turn the frontier and allow new ecologically sensitive infrastructures and practices to infiltrate human habitation.

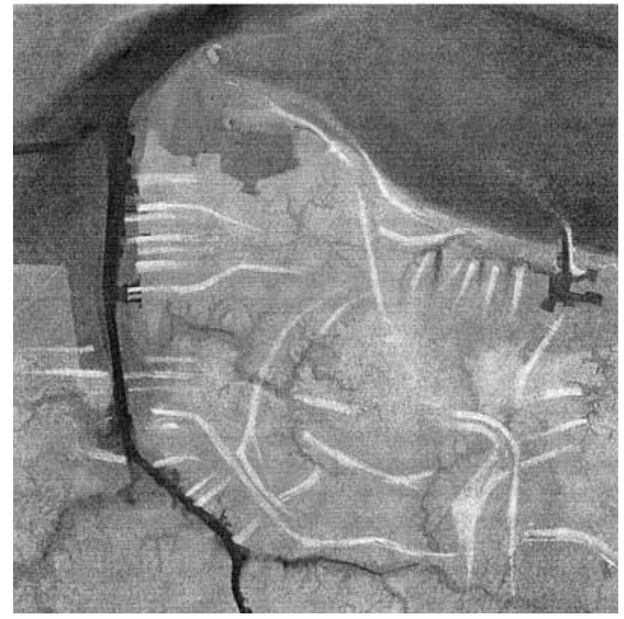
The inspiration for a coast that is cumulative rather than continuous comes from the tidewater country of Virginia itself. Here rivers meet the sea, creeks meet rivers, and rills meet creeks between fingers of high ground that are endlessly fractured by ever smaller runs of water and wetness. To those who seek a coastline, this complex estuary provides something of an obstacle. Here, the sea extends deep into the continent and retracts into an ever-transforming pattern of shoals, marshes, sand bars, and islands. To the team, this complexity is a defining characteristic of the Norfolk area: a coast with a dynamic and shifting reciprocity between land and sea, a field of gradients in space and time enjoyed by numerous animals and plants. The team sees in this complexity an intrinsic and powerful ability to not only withstand or recover from the shock of events such as hurricanes, but also to accept and take in stride what

are really natural events—even if they are made more frequent and severe by human interventions. To the Penn team, this is resilience as a proactive design sensibility rather than a reactive tendency of settlement, more aligned to 'natural' trajectories across land and sea than to defense mechanisms against a sea that has been made an 'unnatural' enemy.

Turning the coast as such requires much more than fingers of high ground; it requires turning the frontier that is deeply rooted in image and imagination, most of all in the coastline which figures in maps, histories, policies and plans, in school textbooks and everyday conversations. Turning this line will necessarily need to gather multiple publics on the ground of a new visualization of the coast and unique gradients of an estuary. This visualization will be the platform for presentations, publications and exhibitions that engage those in a position to affect people's lives as well as those affected: experts and children, activists and policy-makers, those in power and those in need of empowerment.

Norfolk is not at the 'bottom' of the Chesapeake Bay as it is shown in most maps of the area. It is rather a place where four fields of ecological, economic, historical and operational gradients converge along lines of four 'local' design-fields: the fall line to the west, the Swamp Canal to the south, the Beach Front to the east, and the Eastern Shore to the north. Each design-field provides programmatic possibilities and a design language for conceiving and initiating fingers of high ground in selected vulnerable off-sites in Poquoson, Jamestown, Portsmouth, Chesapeake, Virginia Beach and Tangiers Island. The challenges faced in these off-sites, not just from sea level rise but also from low income, pollution, subsidence, et cetera, allow us to broaden our conception and programming of fingers, their gradients, and their possibilities. They provide a practical and contextual knowledge with which to converge on Norfolk. It is important to the larger aspiration of coastal resilience that these fingers of high ground do much more than raise land above the sea; they must perform richly as the future DNA of settlement on the coast.

The four design-fields converge on in-sites in Norfolk with material and operational possibilities for designing fingers of high ground that engage, on the one side, a sea that is in the Bay to the north, the Elizabeth River to the west and south and in numerous creeks within, and, on the other side, a land that is low-lying and not



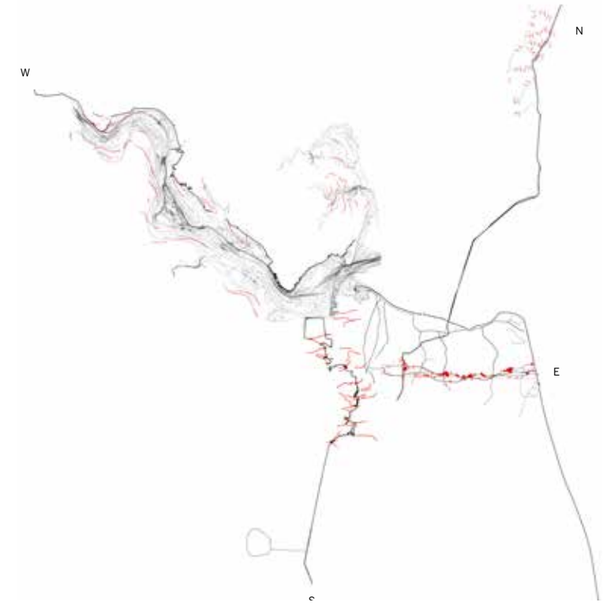


Figure 15 : Building Resilience with Fingers of High Ground

easy to drain. In fact, in a storm event, most of the 250,000 residents of Norfolk, the economically weak in particular, are caught between rising creeks and backed-up rain. The city is considering walls, gates and pumps in various areas. These may work in the short term; but in the long term will surely create an even more vulnerable situation.

Sites will therefore be chosen with a potential to mediate between rain and sea, not just land and sea.

The team will also choose sites with the potential of being infrastructural, ecological and economical sites that are currently interstitial, such as those between the naval station and the port, adjacent to freeways and rail lines, adjoining treatment plants, and so on.

It must be said that the case for constructing fingers of high ground in Norfolk is strengthened by the strategic importance of the city as home to the largest naval station in the world and one of the most important commercial ports on the eastern seaboard. Indeed, the port and naval station are two pillars of Norfolk's economy. The case for high ground is even further strengthened by Norfolk's place at the center of extensive dredging operations in the bay up to Baltimore, Hampton Roads, the Elizabeth River, and the James River. These are operations for which Craney Island, across the mouth of the Elizabeth River from Norfolk, was extended into a massive soil-processing field. It offers a unique opportunity for remediation and use.

The objective for the first stage of the project has been to hone in on complementary sites in Norfolk, sites to be carried into detailed design and programming in stage two. The objective has also been to open key players, organizations and communities in the region to the possibilities of a new visualization of the coast as a cumulative field of gradients rather than a continuous line.

10 Conclusions

SCR Phase 1 featured close collaboration between the engineering and design teams. The assessment of hurricane, storm surge, sea level rise, and mapping techniques completed by the engineering teams complemented the exhaustive context, site, and vulnerability analyses by the four design teams. During the course of Phase 1, all teams met on a monthly basis to go over their research, methods, and findings. This body of work has led to a number of important conclusions and is a platform for further investigations that will move SCR forward during the subsequent phases.

Work completed by the engineering teams has led to the following:

- Combined SLOSH and ADCIRC modeling will be used to generate a probabilistic assessment of storm surge hazard. This modeling will take into account the four GCMs as well as findings produced by the SLR team. This modeling will generate tens of thousands of synthetic storms that will be used to give an assessment of storm surge hazards that takes risk and uncertainty into account in ways that other modeling methods do not.
- The SCR geospatial models will combine the storm surge models created with SLOSH and ADCIRC with a baseline reference system and will lead to improved hazard assessments. A reliance on merged topobathy modeling will allow the engineering and design teams to properly visualize and analyze the effects of storm surge along a continuous surface that includes the sea floor and coastal structures.
- An improved assessment of the effects of climate change on sea level rise and hurricane storm surges will include a regional estimate of sea level rise. Local sea level rise will require a better understanding of the individual physical components that contribute to this process, and will feature the latest data and methods relating to glacial isostatics as well as the movement of land.

Figure 16: Atlantic City NJ, South Inlet during Hurricane Sandy (2012)

The choice of sites in Narragansett Bay RI, Jamaica Bay NY, Atlantic City NJ, and Norfolk VA allow for the consideration of both existing and possible USACE project sites and the consideration of new sites that warrant serious consideration. Each team deployed different methods that adhered to the USACE priority on using natural, nature-based, structural, and nonstructural features and that led to the following conclusions:

- A strong local devotion to issues of coastal resiliency in Rhode Island requires a constant and systematic engagement with local stakeholders and state authorities. This level of engagement is vital and requires that the GSD team consider sites within the Narragansett Bay region using multiple dynamics, such as weather, bathymetry, and plant species. The GSD team views the Narragansett Bay as a singular yet complex physical and social fabric. Its future work will rely on choosing sites where persistent and meaningful community engagement is possible.
- Jamaica Bay, NY is a complex field of stakeholder interaction, physical processes, and multiple jurisdictions. The CCNY team will consider a multilayered approach along the bay that improves the quality of water flushing and sediment transport, and creates a better understanding of the social, ecological, and infrastructural vulnerabilities in the area.
- Atlantic City, NJ is an area of squandered opportunities when it comes to social, economic, and coastal resiliency. The Princeton team reassessed the USACE's and State of New Jersey's structural, tectonic, and economic solutions to coastal protection in the area and identified various opportunities to develop the complex physical and urban features to their fullest advantage. Their approach will rely on a matrix combining natural, nature-based, structural, and nonstructural features in Atlantic City's urban and back bay areas to create a field of opportunities.
- Norfolk, VA is unique in that it is experiencing unprecedented effects of sea level rise. In considering this historically rich site, the University of Pennsylvania team will deploy a series of 'fingers of high ground.' As a category of landscape interventions, these 'fingers' show the University of Pennsylvania team reimagining and rethinking the social and economic dimensions of coastal flood plain management.

11 Next Steps

With the Phase 1 context, site, and vulnerability analyses and storm surge modeling assessments complete, SCR will move to the next phase. Phase 2 will focus on detailed design and will involve the following;

- Identification of specific sites within the 4 study areas;
- Frequent meetings between design teams and planning and engineering teams to evaluate the physical and climactic factors for each site;
- The creation of a Geographic Information Systems (GIS) working group whose goal will be the creation of a geospatial database of existing hazard assessments for each of the study areas;
- Monthly design team meetings where the planning and engineering team will evaluate and comment on design work;
- Meetings with USACE personnel to go over design work; and
- A Phase 2 workshop resulting in a report detailing the design work completed during this period.

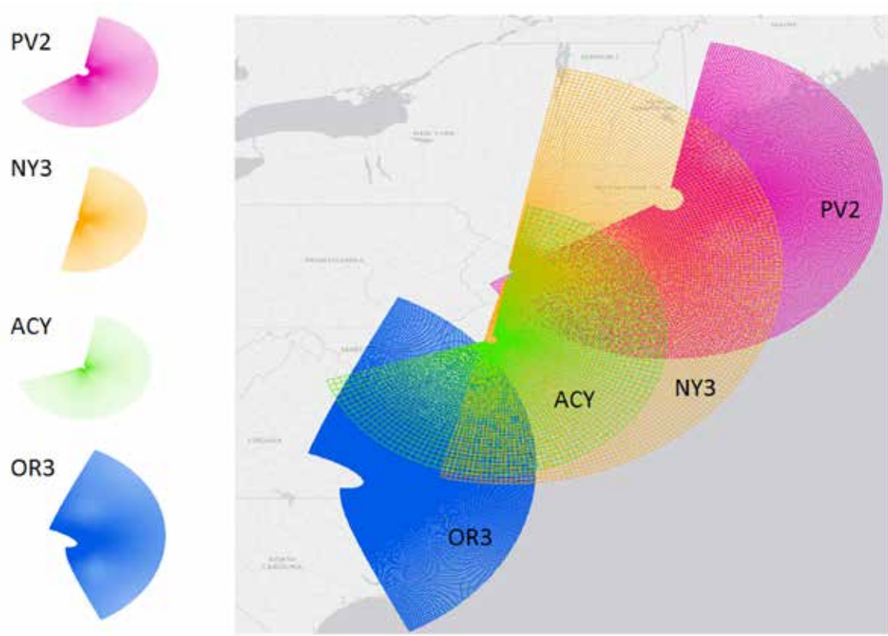


Figure 10: Study Region Slosh Computation Basins for the Jamaica Bay (NY), Providence (RI), Atlantic City (NJ) and Norfolk (VA) study regions

01

Introduction to Structures Of Coastal Resilience

Guy Nordenson
Professor

School of Architecture
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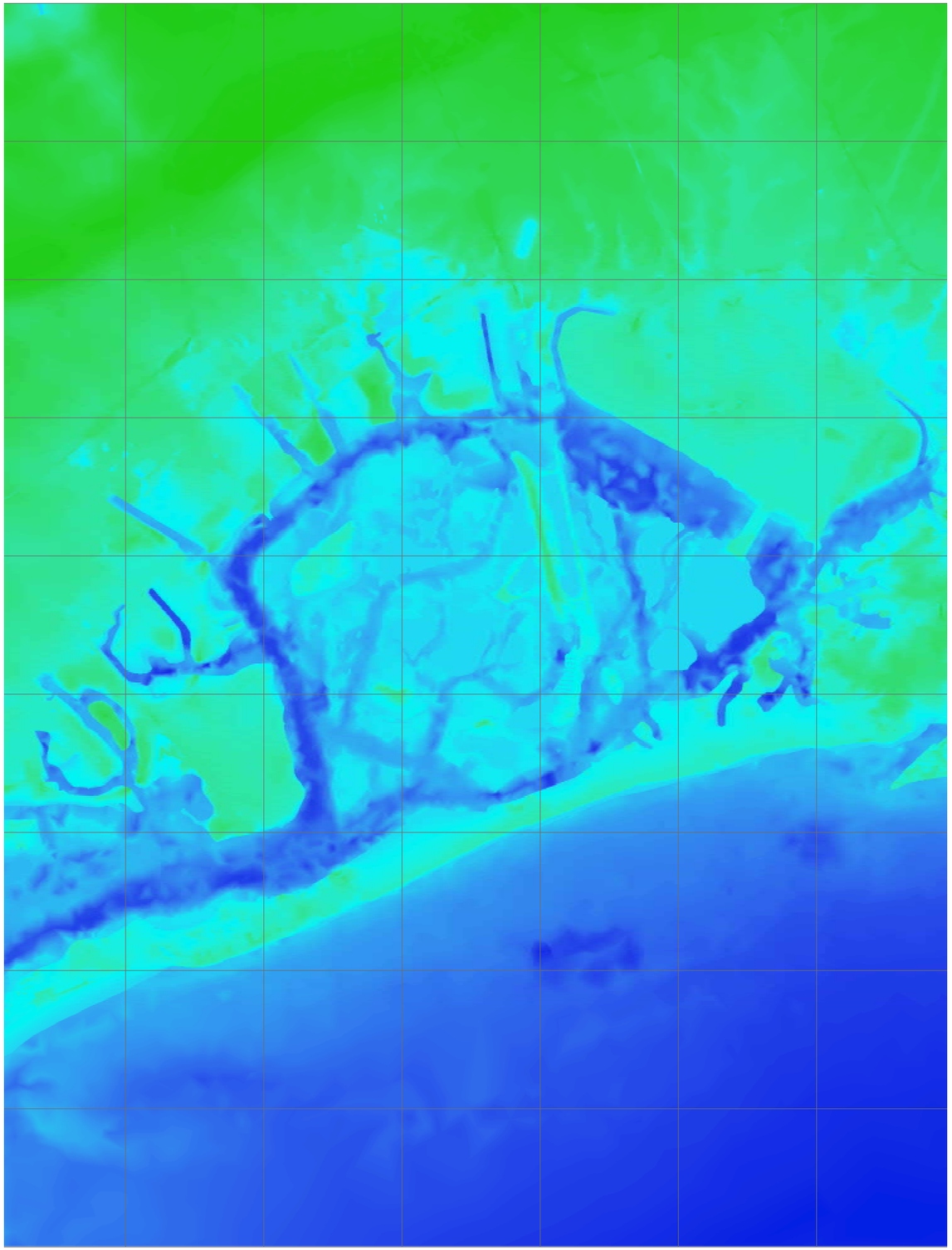

1.1 Background and Context

1.1.1 Limitations of Existing Coast Flood Protection Programs

Recent severe tropical cyclones and other storms in the United States (US), and along the North Atlantic coast in particular, have highlighted the vulnerability of coastal cities and caused unnecessary loss of life and property and major economic losses. Hurricane Sandy struck the North Atlantic coast in October 2012, initiating a growing public and political recognition that sea level rise and warming oceans caused by global climate change have been and will continue to affect the frequency and severity of storms. This calls for a re-assessment of coastal resilience planning and design to adapt to both the gradual and extreme consequences of these climate and natural hazard changes.

This re-assessment also includes a re-examination of the effectiveness of the National Flood Insurance Program (NFIP). The NFIP is a mechanism by which the US is able to both promote storm surge and flood hazards protection through building and planning regulations; through it, the US builds financial reserves to assist in post storm recovery and rebuilding, while on occasion discouraging development in hazard prone flood plains.

Several flaws in the NFIP are apparent, and include:

- The absence of any consideration of the effects of sea level rise and climate-change induced ocean warming in the development of the Federal Emergency Management Agency (FEMA) flood maps.
- The sensitivity of calculations underlying the FEMA flood maps to details of land and structural elevations, and to the computational methods used to model the tropical storms, storm surge, and wave effects themselves. This leads to numerous challenges and frequently unscientific and inconsistent outcomes or politically driven 'compromises' among localities. The high cost and slow speed of the map development process itself also means that FEMA cannot keep up with the morphological evolution of the coast.
- The fact that 'residual risk areas' behind new and old flood control structures are deemed safe and exempt from insurance and building code requirements, despite the uncertain reliability of those structures. As a result, the NFIP and related flood control measures have often promoted risky development in flood plains rather than discouraged it.
- The fact that flood insurance has been used to discourage development in flood hazard-prone locations is not effective because flood insurance rates are often reduced due to political pressures. As a result of this, in combination with other factors, the insurance moneys collected have not been sufficient to cover the cost of recovery and rebuilding.

The practice of coastal flood resistant design and coastal flood plain management has improved, but the basic mechanisms have remained static for many decades. This is not the case with the related practices of earthquake hazard and extreme wind hazard reduction. In these practices, the hazardous zones are more broadly defined, and earthquake and wind resistant building techniques are more widely applied where necessary. It is not possible to consider a neighborhood of Los Angeles or Miami to be exempt from seismic or wind resistant building practice while including adjacent vicinities—all are part of the same hazardous zone. On the other hand, The FEMA flood maps imply a clear delineation of hazardous and safe zones despite the fact that a clear presentation of the uncertainties would show otherwise.

1.1.2 Managing Coastal Storm Surge and Climate Change Uncertainties

With natural or other disasters or hazards, the scale and details are always unpredictable. Providing adequate protection requires means that are insensitive to the details of the hazard. Thus, the crash resistance of cars—as well as the seat belts and air bags that protect occupants—are not detailed for any specific event, but rather cover the full range of likely impacts and kinetic energy. Crash-resistant car design aims to save lives and even limits damage by absorbing some of the

energy created by the impact. This 'sacrificial' strategy has also been applied to earthquake or blast- resistant design where the redundancy and ductility—in other words, the energy-absorption capacity of building structures and bridges—protects lives while accepting sometimes irreparable damage.

In these cases, the extreme difference in the demands of a disaster or hazard as compared to more common loads and events requires the reliance on energy absorption and redundancy. For wind-resistant design, the practice is somewhat different because it is possible to design structures economically to survive the predicted extreme wind velocities without structural damage. However, it is still common to use vibration damping and energy dissipation techniques to reduce wind induced vibration of bridges and tall buildings.

"These principles of attenuation, protection, and planning (APP) are central to the design approach and methodology that define the Structures of Coastal Resilience project."

The implications for flood resistant design are clear and can be summarized in three principles:

- **attenuation and dissipation** of wave energy offshore to reduce the demands on barriers and levees or wetlands where they exist or to building and structures where they do not;
- **protection** with both flood protection structures and building code requirements knowing that some flooding will inevitably occur; and
- **planning** for controlled flooding through urban and landscape flood plain management and design.

These principles of attenuation, protection, and planning (APP) are central to the design approach and methodology that define the Structures of Coastal Resilience project.

1.2 The Structures Of Coastal Resilience (SCR) Project

1.2.1 SCR Project Objectives

This project objective is to develop four integrated coastal resilient designs and strategies sited within the following urban coastal regions: Norfolk and Hampton Roads, Virginia; Atlantic City, New Jersey; Jamaica Bay, New York; and the Narragansett Bay, Rhode Island.

All four regions include multiple layers of existing and planned natural and structural defenses and are locations of ongoing or projected US Army Corps of Engineers (USACE) works. All the sites are affected by coastal storm surge and flooding, sea level rise, as well as other climate change impacts, and vary from densely urban to urban parkland. The site selection within each region will consider the local demographic, historic and economic context, as well as the local ecology, and natural hazards so that the designs can address as varied a set of contexts, hazards and circumstances as possible.

The design strategies and projects proposed in this effort are specific to the selected locations along the North Atlantic coast and to the lessons learned from Hurricane Sandy. We will make use of the latest science to determine the storm and climate change hazards so these will be related to the specific weather and changing climate patterns of the North Atlantic as well as to the geomorphology of that coast. The degree to which these studies will be adaptable to other locations around the world will be limited by this specificity. Climate change and storm hazards are different in every coastal region.

The project is coordinated and managed by Guy Nordenson, professor at the Princeton University School of Architecture, and Enrique Ramirez, a postdoctoral research associate also at the Princeton University School of Architecture. The engineering team working on aspects of the coastal storm and climate change probabilistic hazards assessment is based at Princeton University and includes Michael Oppenheimer and Christopher Little at the Woodrow Wilson School of Public and International Affairs, and Ning Lin with Talea Mayo at the Department of Civil and Environmental Engineering. Michael Tantala, a consulting engineer and Geographic Information Systems (GIS) specialist, is working with both teams to help visualize the effects of climate change on storm surge and sea level rise—an aspect of the project that considers the role that uncertainty and risk play in coastal resiliency.

The four university-based design teams include the Harvard University Graduate School of Design team led by landscape architects Michael Van Valkenburgh and Rosetta Elkin; the City College of New York Spitzer School of Architecture team led by Catherine Seavitt; the Princeton School of Architecture team led by Paul Lewis; and the University of Pennsylvania School of Design team led by Anuradha Mathur and Dilip da Cunha.

The objective is to provide not only design solutions to known problems, but also innovative approaches to defining those very problems through an interdisciplinary collaboration. This interdisciplinary collaboration between architects, landscape architects, engineers, climate scientists, civil engineers, and hydrologists will produce integrated designs, analyses, and presentation deliverables that other conventional public and private initiatives have not.

1.2.2 Collaboration with the US Army Corps of Engineers (USACE)

The USACE has been charged to produce a North Atlantic Coast Comprehensive Study under the authority of the Disaster Relief Appropriation Act of 2013 signed into law by the President as Public Law 113-2 (P.L. 113-2). The Comprehensive Study is 'to address the flood risks of vulnerable coastal populations in the areas that were affected by Hurricane Sandy within the boundaries of the North Atlantic Division of the Corps.' As part of the Comprehensive Study the USACE is charged with identifying coastal strategies including structural and non-structural solutions that are in keeping with the National Oceanic and Atmospheric Administration's (NOAA) Coastal and Marine Spatial Planning framework[1] as well as the White House's Climate Change Adaptation Task Force [2] and Principles and Guidelines for Water and Land Related Resource Implementation Studies.[3]

The number and the complexity of both environmental and socio-political factors limit the design and implementation of coastal protection measures by the USACE. An example is the ongoing Fire Island to Montauk Point Reformulation Study (FIMP), in which the USACE will 'identify, evaluate, and recommend' solutions for hurricane protection and beach erosion control along the 83 miles of Long Island, New York, between the Fire Island Inlet and Montauk Point [4]. This project dates back to the Rivers and Harbors Act of 14 July 1960, and yet parts are only now being implemented as a result of the funds authorized by Congress after Hurricane Sandy.

The USACE has limited means at its disposal, from beach widening and dune raising to the construction of groins or other structural interventions. It is also constrained by the many municipal, state and federal agencies it must coordinate with, as well as the needs and opinions of the affected communities. More critically, the design of USACE projects must follow precedent and conventional engineering practices. Therefore, it is difficult for the USACE to experiment with new design strategies or interdisciplinary approaches. In terms of communication, the visual representations of USACE projects are sometimes insufficient or even confusing to affected stakeholders.

Our goal in this study is to be able to provide specific and actionable project recommendations for hurricane protection and climate adaptation that could result in USACE feasibility studies. Our proposal is intended to augment the USACE's statutory prerogative. These new directions in coastal resiliency design strategies are exemplary of a public/private approach. It is also a way to engage the general public through publicized design charrettes, exhibitions, and publications.

1.2.3 Probabilistic Coastal Storm Surge and Climate Change Assessment

One key contribution of this project is an original approach to the assessment of coastal storm surge and the influence of climate change. The SCR probabilistic assessment of storms—which is detailed in parts 2.0 and 4.0 of the report—uses the General Circulation Models (GCM)—which are also used for the Intergovernmental Panel on Climate Change (IPCC)[5] —to track up to 27,000 simulated hurricanes for each of the four

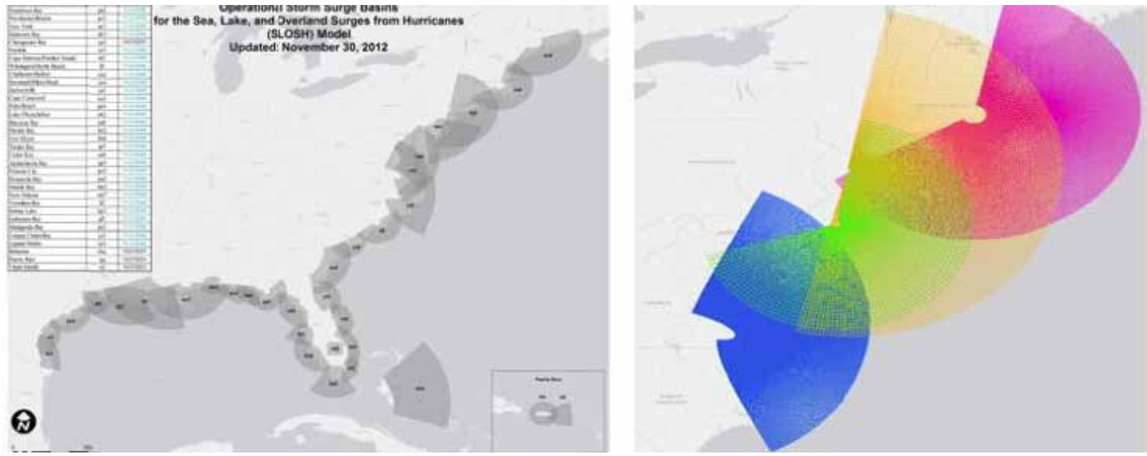

Figure 1.1: NOAA SLOSH Storm Surge Basins for Narragansett Bay (red 'pv2') New York (yellow 'ny3'), Atlantic City (green 'acy') and Norfolk VA (blue 'or3')

regions, and then generates a physics-based probability distribution of local coastal storm surges. These surges are calculated based on a combination of Sea, Lake, and Overland Surge from Hurricanes (SLOSH)[6] and Advanced Circulation (ADCIRC)[7] computational fluid dynamic models. The SLOSH models are the standard ones used for each of the regions under study by NOAA for hurricane forecasting. These models are used to identify the hurricanes and tracks that produce the dominant storm surge for each return period. The storm surge hazards curves are plotted continuously for the full range of return periods with the uncertainty bands shown, and include distributions for both the storm surge and the storm tides (including the probability of simultaneous surge and high tide as occurred with Hurricane Sandy). For a select number of return periods, the coastal storm surge elevations along the coast are translated onshore using Geographic Information Systems (GIS) software to create probabilistic storm surge flood maps. Note that these maps do not include the contribution of wave setup and run-up, and so correspond to the 'still water elevation' given by FEMA flood maps.

Because the hurricane modeling is based on GCMs it is possible to re-run the simulations for a future climate. Thus the flood maps that will be generated in this project will be done for both the 1980-2000 current and the 2080-2100 future climates separately. The selection of the emission scenarios and other factors affecting the future GCMs is described in parts 2.0 following.

A limitation of this approach is the absence of wave modeling. This is by necessity, given the project schedule and the computational and logistical challenges of such detailed modeling for the four distinct regions and sites. But, this necessity also affords a chance to outline an approach to coastal storm surge resistant design that is less dependent on detailed wave modeling and therefore, is potentially more robust. In addition many of the sites being considered—including Narragansett and Jamaica Bays, the back bay of Atlantic City and the Norfolk/Hampton inner harbor—are not directly exposed to ocean waves and are subject to a more complex range of possible wave trains due to local fetch and other contingent factors.

Given the philosophy of attenuation, protection, and planning (APP) the expectation is that the designs developed by each team will include offshore breakwaters or other wave-attenuating features so that the uncertainties regarding wave effects are by design localized.

Finally, the probabilistic storm surge hazard assessment (PSSHA) approach taken in this project, when compared to the FEMA probabilistic flood maps and NOAA deterministic SLOSH maps, highlights the uncertainties inherent in setting the boundaries of flood zones and the necessity of providing broader based means of "protection and planning."

1.2.4 Layered Structures of Coastal Resilience—Attenuation, Protection, and Planning

The September 2013 USACE publication *Coastal Risk Reduction and Resilience: Using the Full Array of Measures* (CWTS 2013-3)[8] provides an excellent and comprehensive account of the so-called 'natural' or 'nature-based' (eg wetlands and dunes), 'structural' (eg seawalls and breakwaters) and 'nonstructural' (eg building codes and emergency response such as early warning and evacuation plans). All of these features can be deployed in the context of the proposed 'attenuation, protection, planning' (APP) approach. Generally, the natural and nature based features described belong under the 'attenuation' category, while the non-structural are categorized under 'planning'. However, the structural features can be categorized as both 'protection' and 'attenuation' in this framework.

To Summarize the approach:

- attenuation, absorption and wave energy-dissipating features would include wetlands, forests and shrubs, oyster and coral reefs, dunes and beaches, and barrier islands, along with detached breakwaters and groins;
- protection would include levees and berms, storm surge barriers, seawalls, revetments, and any others that will hold back some amount of storm surge flooding;
- planning includes the use of flood plain management, relocation and updating of building codes, the raising or protection of utilities and critical facilities, as well as storm surge forecasting and adequate means of controlling flooding which overtops protective features including, retainage and drainage after the flood.

No one measure provides full protection. Given that the range of hazards is changing and uncertain both today and in the future, the central argument of this project is that we must address a range of hazards with a range of measures, to attenuate, protect, and plan across the full range probabilities both of the coastal storm surges and the resilience measures themselves.

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02

Hurricane Storm Surge Risk Assessment for Structures of Coastal Resilience

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2.1 Objectives

Storm surges are one of the most devastating aspects of land-falling hurricanes. They are the primary cause of death and a significant source of damage to ecological and structural systems. Areas along coastal regions are particularly vulnerable to these hazards. The Structures of Coastal Resilience (SCR) design teams have identified several susceptible sites along the North Atlantic Coast of the United States. Our objective is to assess the risk of storm surge at these locations. With consideration of the changing climate, we will assess the risk for both current and future climate scenarios.

2.2 Methodology

2.2.1 Storm Simulation

For this research, we will use the methodology of Lin et al [1]. We will simulate storm surges using hydrodynamic models forced with the wind and pressure fields of synthetic hurricanes, which are generated with a statistical-deterministic hurricane model.[2, 3, 4]

The hurricane model utilizes large-scale atmospheric and oceanic conditions as model inputs, which are often estimated from observations or climate model projections. To model hurricanes under the present climate conditions, the model will utilize data from the 1981-2000 statistics as estimated by the National Center for Environmental Protection (NCEP) and the National Center for Atmospheric Research (NCAR) reanalysis[5]. To model the effect of climate change, the hurricane model will be driven by four climate models, which are a subset of the seven models that comprise the fifth phase of the Coupled Model Intercomparison Project (CMIP5), and are chosen as they produce climate scenarios that span the spectrum of results of all seven. The four climate models include both the estimated 1981-2000 and projected 2081-2100 statistics from the RCP8.5 emission scenario of the Intergovernmental Panel on Climate Change (IPCC) fifth assessment report AR5.[6]

For a given climate, the statistical component of the hurricane model is used to synthesize hurricane tracks. The tracks are initialized through a random seeding technique. The track is then generated according to the large-scale wind field simulated according to the

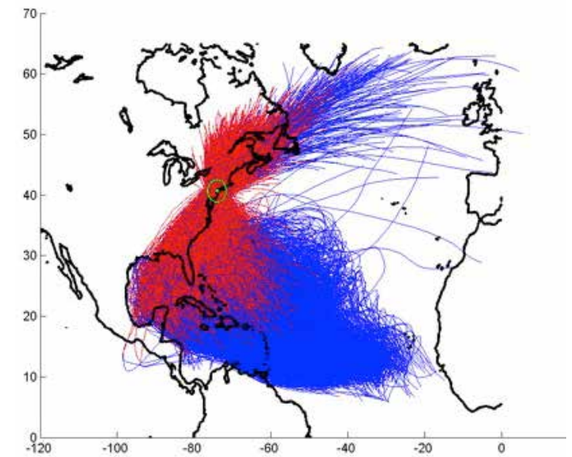

Figure 2.1: 5000 synthetic tracks that pass within 200 km of the Battery with maximum wind speeds > 20 m/s simulated by a statistical/deterministic hurricane model

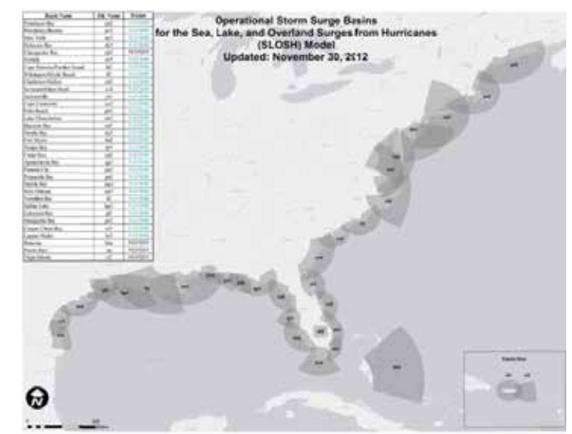

Figure 2.2: SLOSH Basins for the eastern United States coastal regions.

statistics of the atmospheric state. A deterministic atmospheric-ocean-coupled model is then used to simulate hurricane intensity. Together, the simulated track and intensity form a synthetic hurricane (Figure 2.1).

2.2.2 Storm Surge Modeling

Once the synthetic storms are generated, their wind and pressure fields will be generated and used to force a hydrodynamic model that simulates hurricane storm surge.

Hydrodynamic models numerically solve the shallow water equations (SWEs), which describe the motion of fluids for processes with large horizontal length scales relative to the vertical length scales, e.g. the coastal ocean. One well-known hydrodynamic model is the Sea, Lake, and Overland Surge from Hurricanes (SLOSH) model.[7] The SLOSH model is used by the National Weather Service, the National Hurricane Center, and the Federal Emergency Mangagement Agency for emergency planning (e.g. development of floodplain maps) and response (e.g. storm surge prediction and evacuation advisories). It evolved from earlier models of the late 1960s and early 1970s[8], and solves the SWEs using the finite difference numerical method on structured grids referred to as basins (Figure SLOSHbasin.png). Another widely used, more advanced model is the Advanced Circulation (ADCIRC) model.[9, 10] It is used by the United States Army Corps of Engineers, as well as many academic groups. This model solves the SWEs using the finite element method, allowing for much higher numerical resolutions (Figure 2.3).

Because of the numerical discretization of the SWEs, hydrodynamic models are always subject to numerical error. Performing high-resolution simulations can reduce this error. However, high resolution simulations are computationally intensive, so we will model the surge in such a way that the main computational effort is concentrated on those storms that impact the storm surge risk at the project sites. For the simulated storms (all have maximum wind speeds greater than 20 m/s and make landfall within 200 km of the project sites), we will use a low resolution model (~1 km) to select those storms that produce extreme surge events at the project sites, i.e. surges with return periods greater than 10 years in terms of maximum storm surge height at

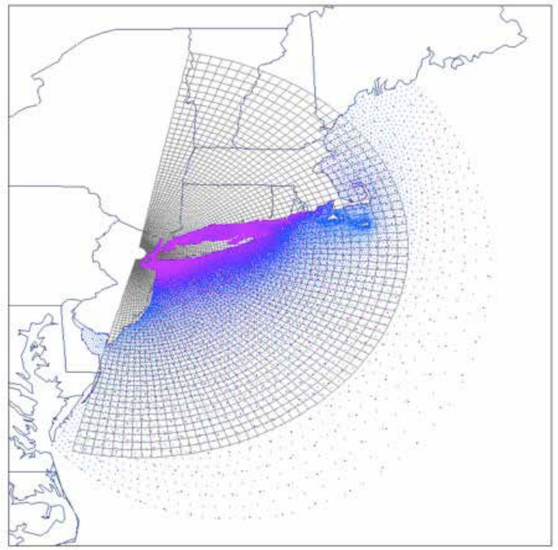

Figure 2.3: SLOSH and ADCIRC meshes for the New York area.

these locations. These extreme surge events will then be more accurately simulated using a higher resolution model (~100 m). We limit the resolution to 100 m as a result of previous studies, which have shown that higher resolutions (e.g. ~10 m) do not significantly improve model results (Figure 2.4). Thus, we will use the 100 m simulations to determine probability distributions of the storm surges at the project sites.

In previous research, both the SLOSH and ADCIRC models were utilized for the low- and high-resolution simulations, respectively [1]. The ADCIRC model, though highly accurate, is significantly more computationally expensive than the SLOSH model. Thus, we desire to reduce the computational cost of our risk assessment by using the SLOSH model. It has been shown that the wind component of the SLOSH model can introduce large errors [11], so a critical step in this approach will lie in modifying the wind field. Once this is completed, the SLOSH model will be used for all the simulations for risk analysis. In the later phase of the project, we will also apply ADCIRC modeling to one or more of the sites. The SLOSH results can first provide complete information for design and then filter the storms for further analysis with the ADCIRC model.

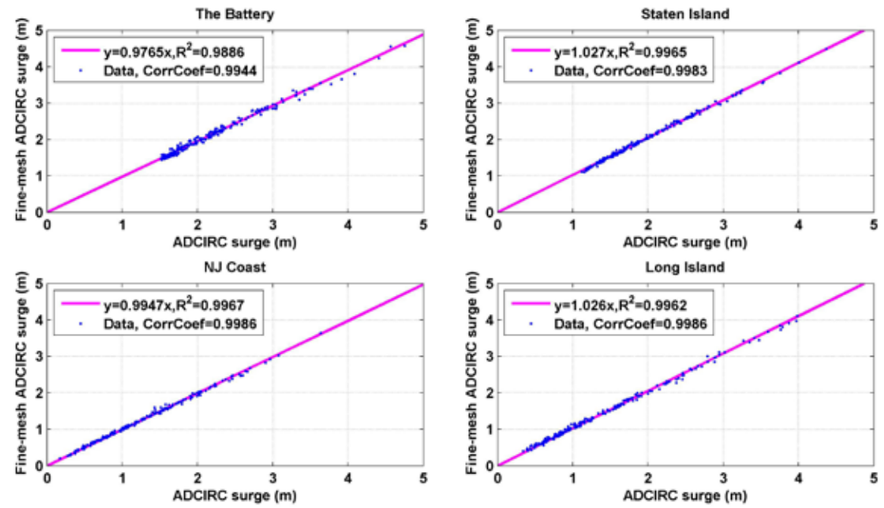

Figure 2.4: Comparison of the ADCIRC simulated storm surges using a ~100 m mesh and ~10 m mesh for four locations around the New York Harbor

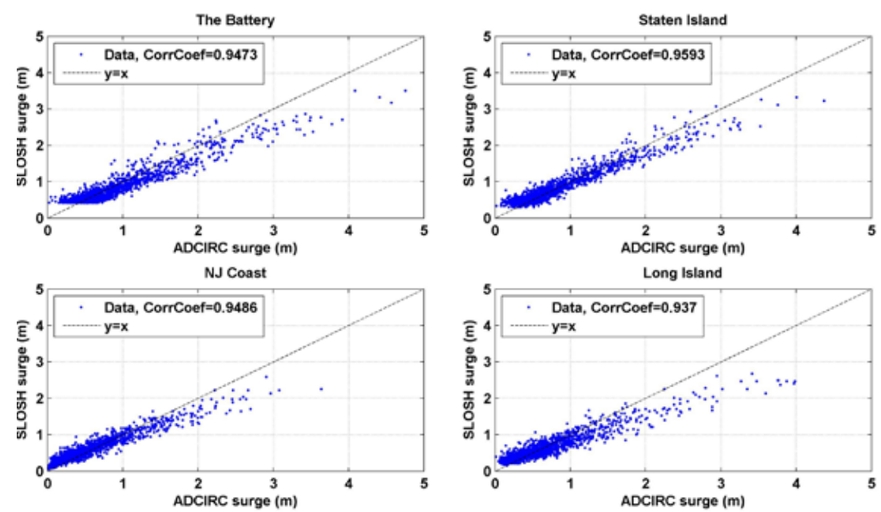

Figure 2.5: Comparison of the SLOSH and ADCIRC simulated storm surges for four locations around the New York Harbor

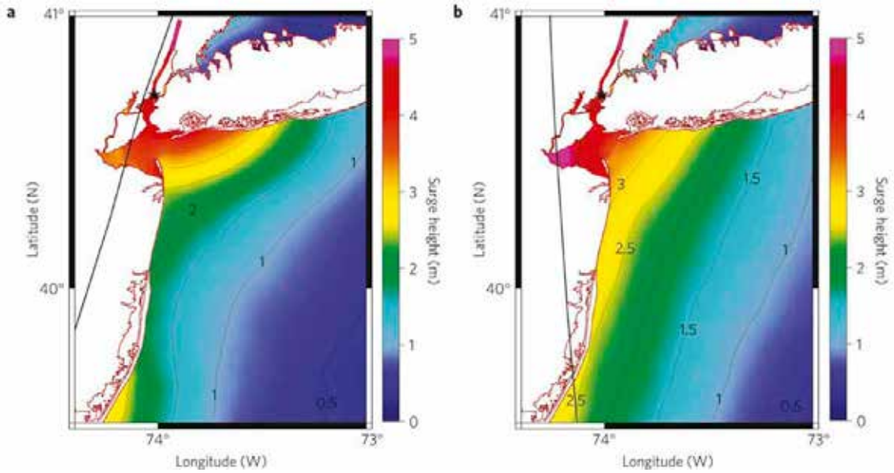

Figure 2.6: Two worst-case sure events for the Battery under the NCEP/NCAR 2081- 2100 climate.

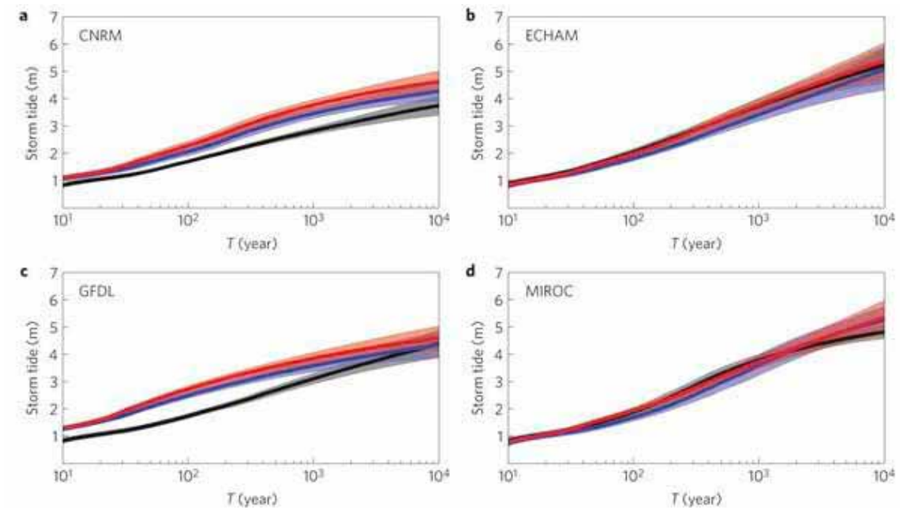

Figure 2.7: Estimated storm tide levels for the Battery, predicted with each of the four climate models. Black represents the current climate, blue represents the IPCC A1B climate, and red represents the IPCC A1B climate with the outer radius and the radius of maximum winds increased by 10% and 21%, respectively.

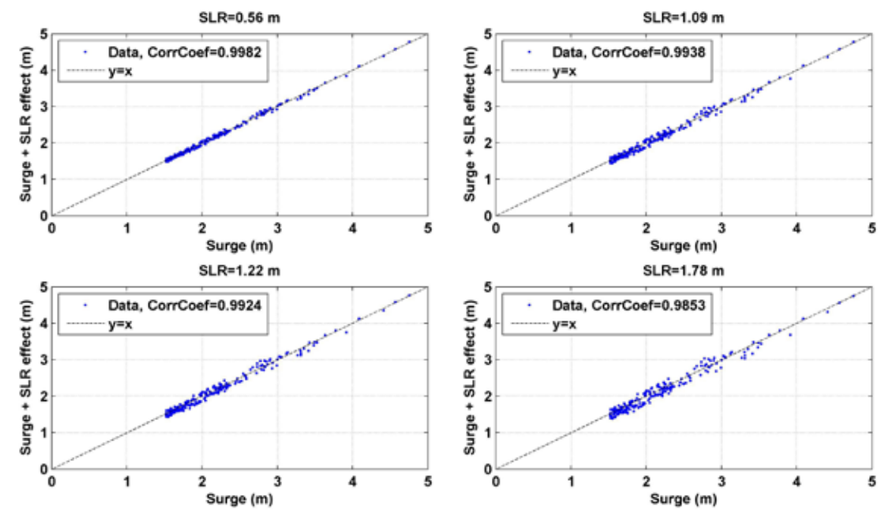

Figure 2.8: Comparison of the ADCIRC simulated surges without and with the effect of SLR at the battery for four SLR levels (0.56 m, 1.09 m, 1.22 m, 1.78 m)

SLOSH and ADCIRC results will be compared, and the ADCIRC results may be recommended to be used in the second phase of the design if they are shown to be more accurate. Results for surge in the New York area computed using the two models have been compared previously (Figure 2.5). Previous analyses for the same region computed using both models are shown in Figures 2.6 and 2.7.

In addition to current climate conditions, we will also account for future climate scenarios by using projected climate data to generate synthetic storms as described above. However, storm surge is modeled relative to the mean sea level; thus we will additionally account for climate change by including sea level rise (SLR) projected by the SLR research group of the SCR project. Previous research has shown that the effect of an increased sea level on storm surge simulations has a statistically insignificant nonlinear component along the New York coast (Figure 2.8).[1] Additionally, this nonlinear component has not been well studied. Thus, we recommend accounting for the SLR linearly, i.e. the probability distribution of the surge flood height will be a convolution of the probability distribution of the surge height and the probability distribution of the SLR.

2.3 References

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03

Geographic Information System (GIS) Modeling for Structures of Coastal Resilience

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3.1 Overview

For the Structures of Coastal Resilience (SCR) study, geospatial models were created to understand the consequences of flooding and its potential impact on our infrastructure, ecosystems, and coastal communities. These models incorporate information about water depth, land elevation and resiliency features and were created as a framework to support the individual SCR design teams. Elevation and coastal feature data were initially collected and combined with the use of Geographic Information Systems (GIS) to form topobathy models. A topobathy or digital elevation model (DEM) is a single surface combining the land elevation with the seafloor surface, which can be used to examine processes that occur across coastal and near shore areas.[1] These models were then analyzed with static and hydrodynamic models and GIS analyses to determine potential impacts and consequences from flooding events and simulations. Geospatial analysis provides a high level of detail for analyzing how natural and manmade threats such as sea level rise, drought, storm flooding, and development may interact with natural and nature-based coastal resiliency features.

3.2 Projections, Datums, Reference Systems

In surveying and geodesy, a datum is a reference point on the earth's surface against which position measurements are made and associated in a model of the earth for computing positions. SCR uses the North American Datum of 1983 (NAD 83) State Plane Projection in feet as its horizontal datum and the North American Vertical Datum of 1988 (NAVD 88) (Figure 3.1) in feet as its vertical datum. The topographic and hydrographic data are referenced to this datum of NAD 83 so that manipulation and analyses are consistent.

The SCR study regions are defined and referenced to quarter-quadrangle (QQ) and quarter-quarter quadrangle (QQQ) grid reference systems. These grid systems are related to the USGS 7½ minute quadrangle index maps divided into quarter quadrangles. Each quarter quadrangle is designated as NW, NE, SW, or SE. QQ and QQQ are common spatial references for the USGS, FEMA, the Department of Homeland Security (DHS), and many others (Figures 3.2, 3.3 and 3.6).

Quad	GCS scale	Scale	Approx - M	Approx - Ft
Q	7.5 min	1:24k	10k x 14k	35k x 45k
QQ	3.75 min	1:12k	5k x 7k	17k x 22k
QQQ	1.875 min	1.6k	2.5k x 3.5k	8.5k x 11k

Figure 3.1: Reference Scale and Geographic Coordinate System (GCS)

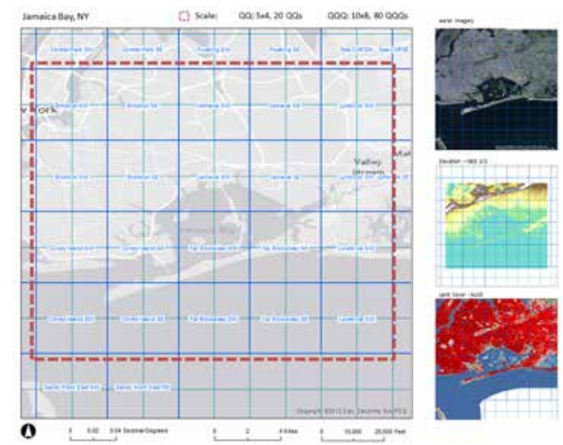


Figure 3.2: Sample QQ (light blue) and QQQ (heavy blue) indices for Jamaica Bay Study Region with Imagery, Elevation and National Land Cover Data (NLCD)

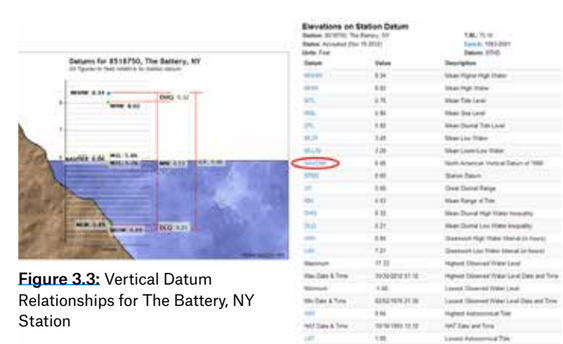


Figure 3.3: Vertical Datum Relationships for The Battery, NY Station

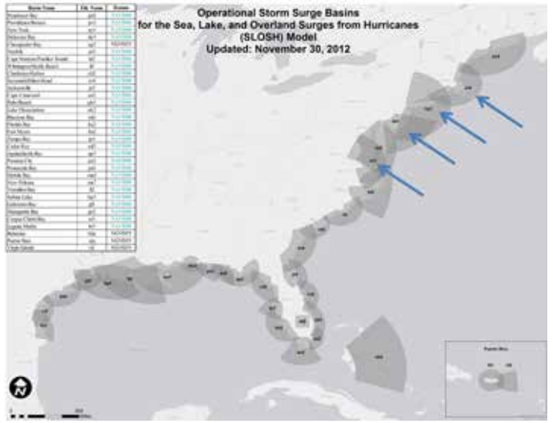


Figure 3.4: SLOSH Computation Basin Indices

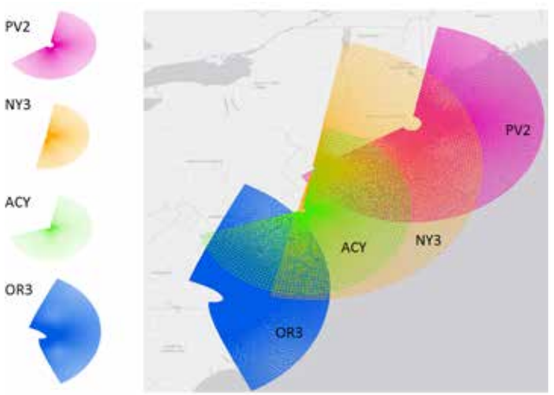


Figure 3.5: Study Region Slosh Computation Basins for the Jamaica Bay (NY), Providence (RI), Atlantic City (NJ) and Norfolk (VA) study regions

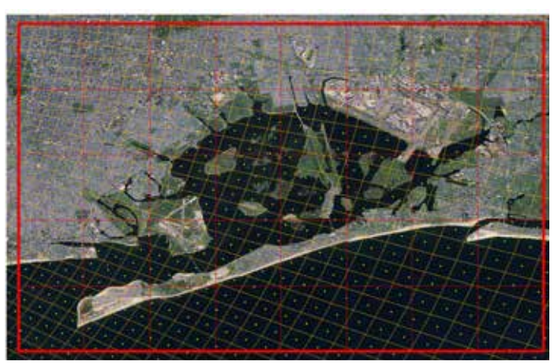


Figure 3.6: A Sample Relationship between SLOSH Computational Indices (Orange) and SCR QQ (Red) indices for Jamaica Bay

Additionally, pre-defined computational index basins were used for storm surge analyses. SLOSH (Sea, Lake, and Overland Surges from Hurricanes) model coverages are subdivided into 37 regions or basins; four of these were selected for the SCR regions. Figures 3.4 and 3.5 show computational SLOSH basin indices used for the Jamaica Bay (NY), Providence (RI), Atlantic City (NJ) and Norfolk (VA) study regions. These basins are centered upon particularly susceptible features: inlets, large coastal centers of population, low-lying topography, and ports.

3.3 Topobathy Models

The physical features of the earth's surface—whether offshore, underwater or on land—are important in determining the response of the coastal ocean to strong storm events.

Bathymetric and topographic features block waves and currents, dissipate energy, channel water movement, and generally affect the ability of a strong storm to move water. To understand the effects of a change in coastal water level or the impacts of inundation, a seamless surface that represents both the topography of the land and the bathymetry of the seafloor is necessary.[1] Such a seamless topobathy surface can require high-resolution data and is an important factor when modeling processes (such as storm surge) that occur across the land-water interface. It is therefore critical to create accurate databases of this information for use in modeling storm surge.

This study uses two hydrodynamic models: SLOSH (Sea, Lake, and Overland Surges from Hurricanes) and ADCIRC (the Advanced Circulation Model). More information about these two models is available in Section 2.0.

SLOSH is a computerized model run by the National Hurricane Center to estimate storm surge heights and winds resulting from historical, hypothetical, or predicted hurricanes.[3] With SLOSH analysis, the Maximum of the Maximum Envelope of High Water (MEOW), or MOM, provides a worst case snapshot for a particular storm category under "perfect" storm conditions.

Each MOM considers combinations of forward speed, trajectory, and initial tide level. These products are compiled when a SLOSH basin is developed or updated.

Commonly, the MOMs are also used to develop the nation's evacuation zones.

ADCIRC is a system of computer programs for solving time-dependent, free-surface circulation and transport problems in two and three dimensions. These programs utilize the finite element method in space, allowing the use of highly flexible, unstructured grids.[3] Typical ADCIRC applications have included modeling tides and wind-driven circulation, and analysis of hurricane storm surge and flooding. The ADCIRC code system is freely available but is typically run by universities and federal agencies.[3] Therefore, the output may be made available from a variety of sources.

SLOSH, ADCIRC, and other inundation prediction models use topobathy data as a basis for analysis. This allows the model to accurately predict how deep and how far inland water will surge during a major coastal storm. Numerous, simulated, possible coastal storm tracks are then input into the prediction models to map the extents of surge and inundation, and to evaluate proposed features for coastal resiliency (Figure 3.7).

3.4 Inundation Analysis

Maps that depict inundation are based on output from a hydrodynamic model, or a combination of hydrodynamic and wave models are developed to calculate a total water level surface. Some prevalent examples of this type of map include the FEMA Flood Insurance Rate Maps (FIRMs) and storm surge zone maps. The FIRMs depict the 1% annual chance flood zone based on studies that incorporate several different models, such as the ADCIRC model, Wave Height Analysis for Flood Insurance Studies (WHAFIS), and others. Storm surge zone maps in this study depict the potential extent of storm surge from hurricanes based on model output from SLOSH, ADCIRC, or other models (Figures 3.8, 3.9).

Detailed comparisons were also made between computational simulations (ADCIRC and SLOSH), field verifications from Hurricane Sandy and benchmark results from FEMA's Preliminary Work Maps (PWMs); these comparisons are made for different return periods (Figures 3.10-3.15).

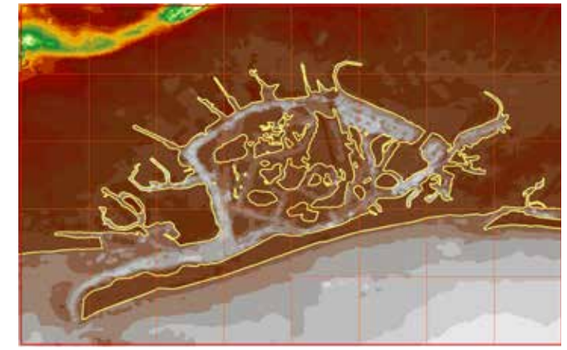


Figure 3.7: A Sample Topobathy Model for the Jamaica Bay (NY) Study Region

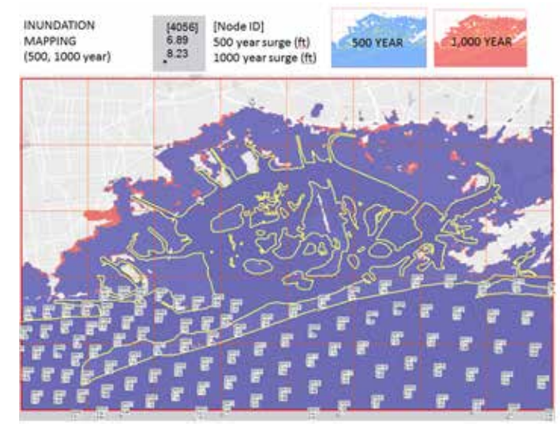


Figure 3.8: Sample Inundation Model Results Using ADCIRC model

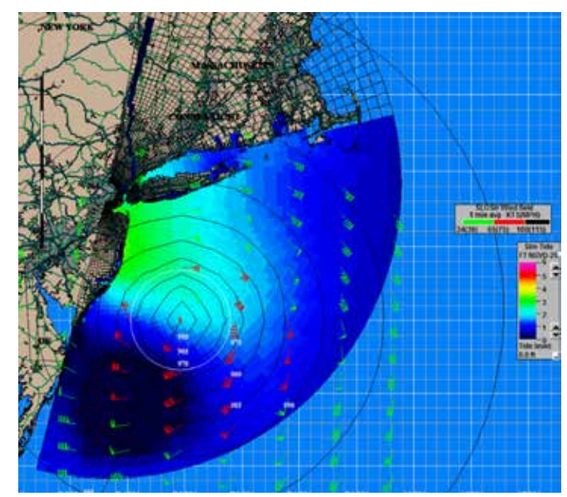


Figure 3.9: Sample Slosh Simulation Using the NY3 Basin Displaying Wind Field and Tidal Data

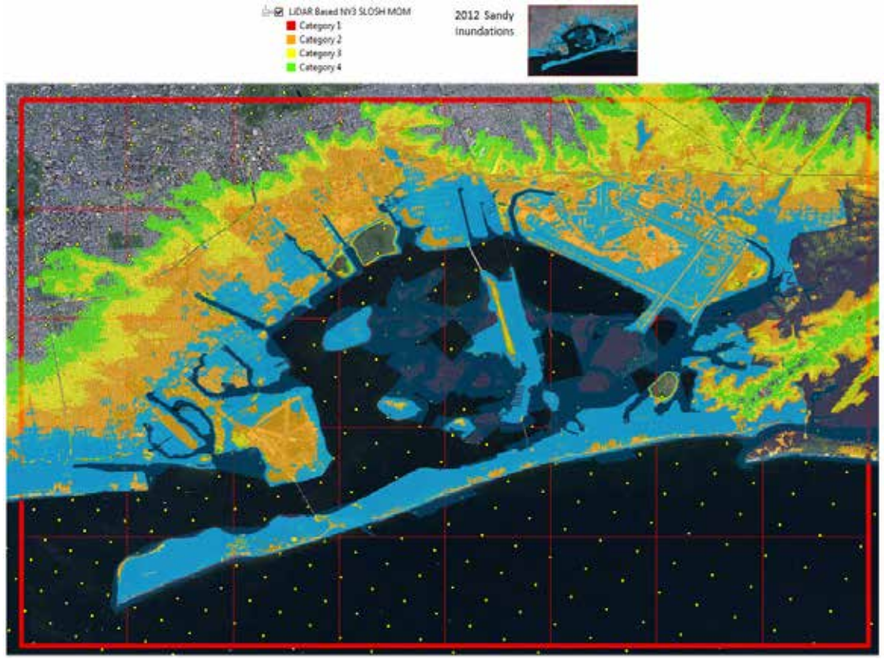
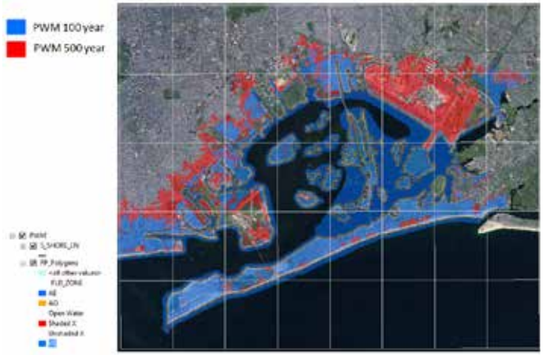


Figure 3.10: Comparison of SLOSH NY3 MOMs for Categories 1, 2, 3 and 4 and Field Verified Hurricane Sandy Surge Extents

Figure 3.11: PWM inundation – 100 year and 500 year returns

Figure 3.12: Comparison of ADCIRC and PWM inundation –100 year return



3.5 Conclusion

GIS and geospatial modeling are key frameworks for relating numerical models with natural and nature-based features and for understanding coastal resiliency in context. Elevation and coastal feature data were collected and combined with the use of GIS to form topobathy models.

These models were then analyzed using limited scenarios for two hydrodynamic models: SLOSH (Sea, Lake, and Overland Surges from Hurricanes) and ADCIRC (the Advanced Circulation Model). Preliminary output from these models and initial simulations are in the process of being mapped to depict inundation for use in the next phases of the SCR project and use by the design groups in their study regions.

Comparative analyses of computational, benchmark and field measures for inundation for different return periods highlight the variability and sensitivity of analysis methods. Similarly, comparison of these methods and measures can provide an envelope of scenarios for consideration in support of resilient design strategies.

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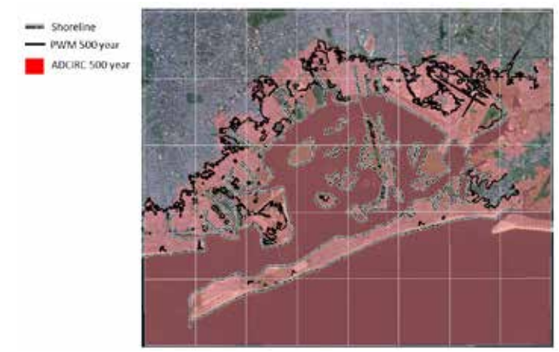
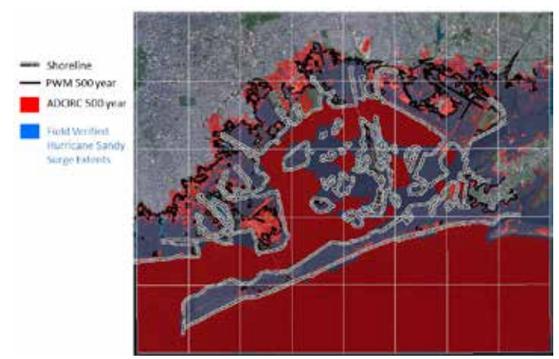
Figure 3.13: Comparison of ADCIRC and PWM inundation –500 year return

Figure 3.14: Comparison of ADCIRC and PWM inundation –500 year return and Field Verified Hurricane Sandy Surge Extents

Figure 3.15: ADCIRC inundation – 100, 500, 1000, 5000 year returns and worst case of all storms envelope





04

Future Mean Sea Level Changes

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4.1 Summary

Sea level variability occurs over a wide range of timescales and involves many distinct physical processes ("components"). Projections of century-timescale sea level change must address considerations of uncertainty and non-stationarity in these components in a comprehensive, self-consistent, manner. In this project, we use the methodology of Kopp et al (in preparation -> submitted) to generate fully probabilistic projections of sea level rise at coastal tide gauge locations in Rhode Island, New York, New Jersey, and Virginia through the year 2100. The tide gauges are as close as possible to the four design sites: for Norfolk, we have used the Sewell's point tide gauge; for Atlantic City, Atlantic City; for Jamaica Bay, the Battery; for Narragansett Bay, Providence. Our projections—which account for physical processes that result in sea level changes over annual to decadal timescales ("mean sea level")—will be combined with projections of short-term sea level variability (storm surge) to generate a risk assessment of coastal flooding for these four locations.

4.2 Background

On a globally averaged basis, sea level has been rising at 1.7+/- 0.2 mm/yr since 1900, and 3.2 +/- 0.4 mm/yr since 1993 (purple line in Figure 4.1). Mean global sea level (GSL) is controlled primarily by the thermal expansion of ocean water and the melting of land ice in glaciers, ice caps, and ice sheets (IPCC 2013, [Fifth Assessment Report, or AR5]). Local mean sea level (LSL) change can differ from GSL change (Milne 2009) due to:

1. non-uniform changes in ocean properties and dynamics;
2. changes in the Earth's gravitational field, rotation and lithospheric flexure (together known as static-equilibrium effects) associated with the redistribution of mass between the cryosphere and the ocean; and

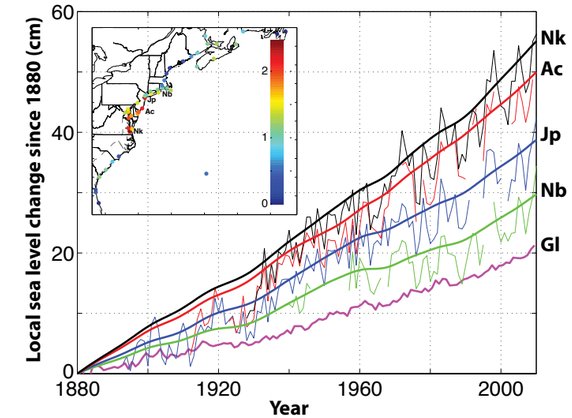

Figure 4.1: The historical local sea level record (thin lines) and long-term trends (thick lines, from Kopp 2013) at the closest tide gauges to the four design sites: Norfolk (Nk, black); Atlantic City (Ac, red); Jamaica Bay (Jp, blue); Narragansett Bay (Nb, green). Sea level at each location is shown relative to the value of the smoothed trend in 1880. The global mean trend (from Chuch and White, 2011) is shown in purple. The inset shows long-term linear trends in relative sea level (colors, in mm/yr), for the Eastern United States and Canada. Data and inset map courtesy of Bob Kopp and modified from Kopp (2013).

3. vertical land motion due to glacial isostatic adjustment (GIA), tectonics, local groundwater withdrawal, and natural sediment compaction and transport. Over the 20th century, the eastern coast of the United States has experienced a higher-than-global-mean rate of LSL rise due to vertical land motion and changing ocean circulation (Kopp 2013). The sites considered in this report have experienced long-term rates of LSL rise ranging from 2.5 to 4.3 mm/yr (approximately 50-150% higher than GSL rise) (Figure 4.1).

4.3 Method

LSL projections require the aggregation of the individual components of sea level change including changes in steric and dynamic ocean height, glacier mass balance, ice sheet mass balance, land water storage, and vertical land motion. In this project we utilize projections developed in Kopp et al. (submitted), based on climate changes forced by one or two Representative Concentration Pathways (RCPs) (Meinshausen et al 2013). The probability distributions for future LSL change due to each component are informed by climate models (AOGCM's), expert assessment, and tide gauge observations, and are combined using a Monte Carlo technique (Figure 4.2).

4.4 Preliminary Results

We present projections of GSL and LSL rise at four tide gauge locations in Figure 4.3. Though these projections are preliminary, and may change with subsequent versions of this report, it is likely that two key features are robust.

First, because sea level exhibits a lagged response to emissions, the rate of GSL and LSL rise at all sites increases with time. The magnitude of sea level change (at any likelihood) at all locations is thus expected to be far larger over the second half of the century than the first half. Uncertainty also grows over time.

Second, US east coast sea level rise is almost certain to be higher than the global mean over the 21st century, due to ongoing land subsidence and projections of enhanced dynamic sea-level rise in the mid-Atlantic. Southern sites are expected to continue to experience greater rates of subsidence, but lower rates of dynamic sea level rise. At the four tide gauges considered here, the median LSL projections in 2100 range from 90-110 cm, substantially higher than the global mean value of 78 cm. High-end (95th percentile) LSL projections (145-165 cm) exhibit a larger divergence from GSL (120 cm) because these low-likelihood outcomes are driven by Antarctic ice loss which has a large "fingerprint" on the east coast. Low-end (5th percentile) projections of LSL range from 20-30 cm, reflecting: 1) very high confidence in at least a continuation of current trends and 2) disparities resulting from spatial variation in subsidence rates.

For design efforts that seek to be robust to lower-probability outcomes, these results suggest that regional differences in LSL rise over the study region may not be as important as the uncertainty in GSL sources that are largely common among the sites. However, we caution that the findings shown in this section apply only to the mean rate of sea level rise and may not indicate trends in flood risk. Projections of food heights and recurrence will require the combination of these projections of mean sea level with those for storm surge.

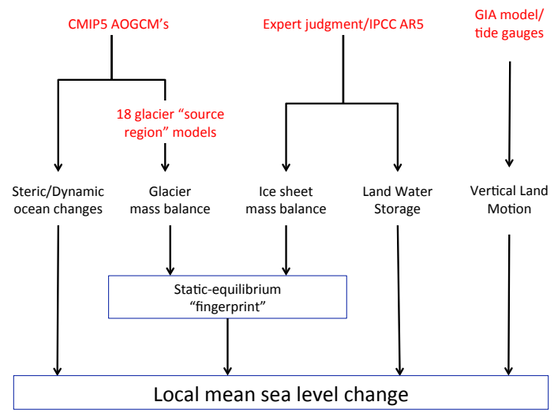

Figure 4.2: Schematic illustration of the sources of information (red) and physical processes (black) included in the mean sea level projections.

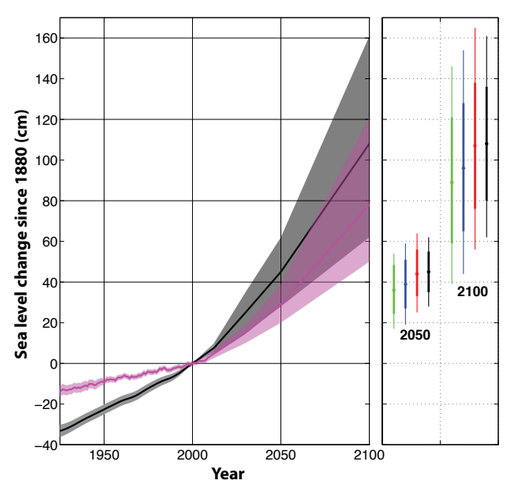

Figure 4.3: Observations (to 2011) and preliminary projections (to 2100) of sea level (relative to 2000) for RCP 8.5. Solid lines in the left panel show the historical trend and median projection of local sea level for Norfolk (Sewell's Point, in black) and the global mean (purple). Shading encompasses 2-sigma uncertainty ranges for observations and 5-95th percentile ranges of relative sea level. The right panel shows median (circles), 17-83rd percentile (thick bars), and 5-95th percentile (thin bars) ranges of local sea level change in 2050 and 2100 for all four sites (colors correspond to those in figure 4.1).

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05

Designing Structures of Coastal Resilience

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5.1 Introduction

What is 'resilience'? What is resilient design and what does it 'look' like? To answer this question, the Rockefeller Foundation recently asked a group of architecture and design critics to share their thoughts about the term.[1] And though the responses covered both historical and current examples—everything from the rebuilding of Lisbon in the aftermath of the 1755 earthquake, to one of the first known uses of the term (by the architect George Martin Huss in 1924), and finally to the chilling footage of Toyo Ito's Sendai Mediatheque withstanding the successive shocks of a 9.0 magnitude earthquake—all seemed to agree that 'resilience' described the ability to survive amidst environmental and natural catastrophes. To view resiliency in such a manner is to view our buildings and cities as first and foremost responsive to change. This is the approach informing the spectrum of Rockefeller Foundation projects centered on the concept of resiliency, from '100 Resilient Cities', to 'Rebuild by Design', and this project, Structures of Coastal Resilience.

Structures of Coastal Resilience (SCR) is a collaborative research study bringing together architects and landscape architects with engineers and climate scientists. The purpose of the project is to promote a design-based approach to resiliency based on the latest and best scientific thinking related to climate change and storm modeling to develop strategies and structures to resist the effects of catastrophic coastal flooding. The work is undertaken in collaboration with the United States Army Corps of Engineers (USACE) and is intended to provide alternative designs that incorporate nature and nature-based infrastructures as well as structural and non-structural measures.[2]

5.2 The USACE and Technical Expertise

The USACE has been at the forefront of Federal initiatives to develop appropriate and robust coastal risk reduction strategies as well as responsive frameworks to climate change. On 18 September 1930, the Office of the Chief of Engineers issued Special Order No. 72, authorizing the formation of the Beach Erosion Board (BEB), a sub-agency dedicated to providing technical assistance on beach erosion matters. Special Order No. 72 also established the Shore Protection Board (SPB), entrusted with investigating the efficacy of shore protection and USACE dredging projects. From the 1930s, throughout the Second World War, and until the early 1950s, the BEB established its leading role in coastal risk reduction by building hydrodynamic testing facilities and issuing a series of pioneering technical manuals related to issues of shore protection. These manuals, beginning with Special Bulletin No. 2 of the BEB (1953), through Technical Report No. 4, or TR-4, 'Shore Protection and Design' (1954), continued to be published even as the US Army Coastal Engineering Research Center (CERC) replaced the BEB in 1973.[3] The CERC published its own series of 'Shore Protection Manuals' from 1977 until 1984, many of which are still in use today. And with the establishment of the Coastal Hydraulics Laboratory and Engineer Research and Development Center, this work has continued primarily through the publishing of a comprehensive Coastal Engineering Manual (CEM), last updated in 2008.[4]

The USACE's technical expertise in coastal risk reduction matters also came on the heels of a developing engagement with issues of global climate change. From 1953 to 1956, Chief Engineer Lt. General Samuel D. Sturgis, Jr. developed policy priorities for conserving coastal and internal waters. This continued into the 1960s, with the creation of the Institute for Water Resources (IWR), which initiated groundbreaking studies in 1977 and 1992 concerning hydrological changes caused by climate change. And today, the USACE's latest on this matter is a document entitled 'Coastal Risk Reduction and Resilience: Using the Full Array of Measures' (CRRR) that sets a framework for coastal protection strategies that take into account waves and surges associated with sea level change and catastrophic storms.

5.3 USACE Terminiology

Currently, the USACE uses the terms natural, nature-based, non-structural, and structural in its CRRR publication to outline different methods for confronting coastal flood risk and erosion. These terms are different from the definitions used by White House and the Environmental Protection Agency (EPA), such as green infrastructure, and are meant to provide greater precision to an evolving terminology. The terms continue to be employed in the North Atlantic Coast Comprehensive Study (NACCS) and associated USACE workshops. These terms and concepts are to be used alongside each other.

Natural Features are features that are 'created and [that] evolve over time through the actions of physical, biological, geologic, and chemical processes operating in nature.'[5]

Nature-Based Features are features that "may mimic characteristics of natural features but are created by human design, engineering, and construction to provide specific services such as coastal risk reduction. Nature-based features are acted on by the same physical, biological, geologic, and chemical processes operating in nature, and as a result, they generally must be maintained in order to reliably provide the intended level of services."[6]

Nonstructural Measures are measures that comprise "complete or partial alternatives to structural measures, including modifications in public policy, management practices, regulatory policy, and pricing policy. Nostructural measures essentially reduce the consequences of flooding, as compared to structural measures, which may also reduce the probability of flooding. Nonstructural measures addressed by the USACE National Nonstructural Floodproofing Committee include structure acquisitions or relocations, flood proofing of structures, implementing flood warning systems, flood preparedness planning, establishment of land use regulations, development restrictions within the greatest flood hazard areas, and elevated development."[7]

Structural Measures are measures that can be designed "to decrease shoreline erosion or reduce coastal risks associated with wave damage and flooding. Traditional structures include levees, storm surge barrier gates, seawalls, revetments, groins, and near-shore breakwaters. The purpose of levees, seawalls, and storm surge barrier gates is to reduce coastal flooding, while revetments, groins, and breakwaters are typically intended to reduce coastal erosion."[8]

Integration is a term referring to "reducing coastal risks and increasing human and ecosystem community resilience through the full array of natural, nature-based, nonstructural, and structural measures, including combinations of measures. The types of measures employed, their configuration within the network of features, and the USACE has long recognized the planning and engineering approaches that are applied in developing the integrated system will depend on the geophysical setting, desired level of risk reduction, constraints, objectives, cost, reliability, and other factors."[9]

This terminology and the carefully defined options that are described in the CRRR report—from oyster and coral reefs and dunes and beaches, to floodplain management and building codes, and to levees and storm surge barriers—have yet to be integrated into combined structures or into methods of design and analyses that can be confidently applied to provide reliable coastal protection and resilience, especially in the context of climate change and sea level rise. In principle, a structure of layered protection is possible that can attenuate wave energy as a storm surge advances over offshore reefs and breakwaters, across wetlands, beaches and dunes before reaching structural barriers, seawalls or levees with diminished impact. One can envision this 'tri-layer' approach to combined structural and nature-based systems such that the performance might satisfy a set of three performance criteria such as:

For a storm with a 82 to 64% probability of exceedance in 50 years (30 to 50 year average return period) there would be no damage to offshore reefs and breakwaters, limited dune and beach erosion, and no on land flooding behind structural barriers, seawalls or levees. Recovery would take a matter of days.

For a storm with a 39 to 10% probability of exceedance in 50 years (100 to 500 year average return period) there would be some damage to offshore reefs and breakwaters, considerable dune and beach erosion, and a foot or less of on land stillwater flooding behind structural barriers, seawalls or levees. Recovery would take a matter of weeks.

For a storm with a 5 to 2% probability of exceedance in 50 years (1000 to 2500 year average return period) there would be considerable damage to offshore reefs and breakwaters, complete dune and beach erosion, and several feet of on land stillwater flooding behind structural barriers, seawalls or levees. Recovery would take a matter of months.

A performance-based design approach such as this is common in earthquake and wind resistant design and could also be applied to coastal protection and resilience design. The notion of combining energy dissipation and damping with more static structural means of protection has also been successfully applied in earthquake resistant design and to reduce and attenuate the wind induced vibrations of structures. In this sense resilience is provided across the two axes of (1) the range of demands associated with moderate to extreme, low probability storms and (2) the depth of protection provided by wave attenuating offshore features as well as static barriers.

5.4 Designing Coastal Resilience

Though the USACE has been in the business of creating specifications and planning technical solutions for coastal resiliency for over 80 years, its approaches and procedures often invoke a language that is virtually unrecognizable to architects and landscape architects. Consistent throughout early USACE manuals and even until the CEM is the depiction of the design of structures as a conjunction of 'planning and design' or 'functional planning.' This terminology resulted from a trend towards depicting design projects as technical, as opposed to aesthetic or intuitive solutions. During the Second World War, the design professions were mobilized in service of the war effort, and often the term 'planning' was used not just as code for 'postwar planning', but also for design as a kind of technical expertise to be used in the reconstruction of cities of the development of national and international infrastructures. This kind of expertise evolved, however, into something different with the advent of microcomputers from the 1950s until the 1980s. During this time, a preference for sophisticated modeling techniques meant that the creation of design narratives, a kind of expertise or shared domain between architects and landscape architects, was abandoned in favor of data generation and scenario planning.[10]

"A performance based design approach such as this is common in earthquake and wind resistant design and could also be applied to coastal protection and resilience design."

5.5 Structures of Coastal Resilience

The term 'Structures of Coastal Resilience' was inspired by Todd Shallat's authoritative history of the first century of the USACE. Called 'Structures in the Stream: Water, Science, and the Rise of the US Army Corps of Engineers' (1994), this remarkable book provides an expansive interpretation of 'structures.' It considers the USACE's engineering methods as literal and figurative interventions, all part of a systematized techno-bureaucratic means of ordering the landscape and the waters as well as the very institutions that give shape to the landscape and waters.[11] To paraphrase Carl Schmitt, the law is a structural system[12], and it is in this sense that Shallat uses the word 'structure.' For him, a structure can be a revetment, bulkhead, or levee, but it can also mean the United States of Congress or the USACE. In any of these cases, these are structures that encountered and overcame hydrodynamic and institutional resistance. Also embedded in this notion of 'structures' is a conflict between architecture (or landscape architecture), engineering, and their respective institutional backgrounds.

This expansive notion of 'structures' is central to SCR's purpose and goals. The four design teams that are part of this study bring an unparalleled level of expertise skill and intelligence to bear on sites in Rhode Island, New York, New Jersey, and Virginia. Though their methods may vary, and though they deploy their own visual language in order to present their research and analysis in the following sections and in the design appendices, their designs should not be construed as comprising four separate projects. Instead, they should be considered as four balanced approaches that together will not only augment and complement previous USACE work in Rhode Island, New York, New Jersey, and Virginia, but that will also do so while keeping in mind the 'full array of measures' as described in the CRRR report.

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06

Ocean State: Research and Site Characterization, Greater Narragansett Bay

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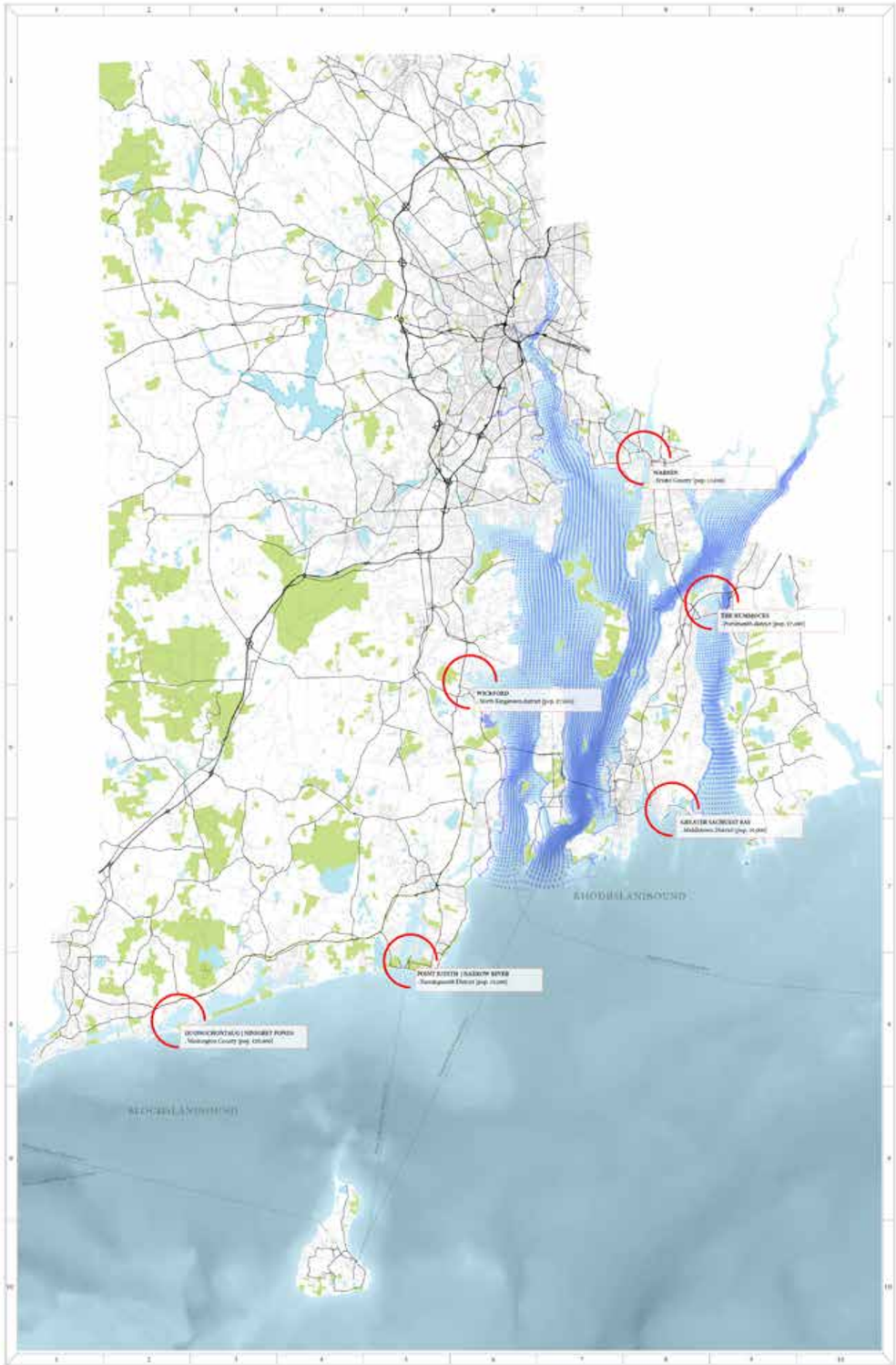


Figure 6.1: Ocean State Study Sites

6.1 Introduction

Rhode Island is a small state with a long shoreline. Also known as the Ocean State, its shoreline extends inland to include multiple waterways including large bays, rivers, coves and streams. Residents are quick to claim that no one lives further than half an hour from the shore. One consequence of this awareness is a community mindful of the immediacy of littoral shifts and aware of their vulnerability within the context of coastal dynamics and seasonal hurricanes. This is especially the case in Narragansett Bay, a mixed estuary that bisects Rhode Island in a north-south direction, with Providence lying at its northern reaches and Newport on its southern periphery. The bay extends approximately 45 km along this north-south axis, reaches 18 km at its widest point, and covers an area of 342 square kilometers. Shoreline types include fringing and meadow salt marshes, bulkhead and other modified perimeters, which comprise 25% of Narragansett Bay's perimeter. Its coastal areas feature a combination of drastically disturbed sites, preserved marshland or post-industrial fill. Coastal planting strategies offer few solutions within a variety of conditions, and tend to be overinvested in replacing iconic species or renewing marshlands, rather than creating a functional coastal space. Though predictions may fail and local species can wilt, what remains standing should serve as a model of coastal resilience for an uncertain future. Since Rhode Island lies at the northernmost extent of Sandy's devastation, it offers an exemplary site for developing structures of coastal resilience that are not based on typical responses and reactions, but rather on approaches rooted in systematic evaluation and adaption. The USACE has an opportunity to study this site—an area that has only flirted with the potential of disaster, and that remains vulnerable to extreme weather events in the future.

"Rather than defining sites through purely analytical methods, the team will establish a series of intersecting relationships that move beyond traditional considerations of site—extending instead to reveal the interconnected virtues of conditions."

Purpose

The Harvard University Graduate School of Design (GSD) team is strategizing resilience using an articulated and integrated infrastructure of transformation that takes two main perspectives into account: the storm and the species. Rather than defining sites through purely analytical methods, the team will establish a series of intersecting relationships that move beyond traditional considerations of site—extending instead to reveal the interconnected virtues of conditions. Sites are no longer fixed points; they emerge out of the assembly of essential conditions, the confluence of processes, as well as engagement with stakeholders—factors that require new models of practice and cooperation.

Our perspective recognizes two general storm tracks that have traversed Narragansett Bay and considers their shared characteristics in order to narrow site selection (Figure 6.1). The aim is not to identify and compare levels of devastation, but rather to qualify the connections between sites and the surge patterns of the greater Rhode Island coastal zone. This involves acknowledging the range at which benthic slope, bed form, and coastline material composition become relevant and contributing factors to data such as the inundation elevations pulled from averaged data sets from the National Oceanic and Atmospheric Administration (NOAA) and the Federal Emergency Management Agency (FEMA). This data will be utilized to explain how areas of low income, high commercial activity, and/or potentially relevant ecological structure will be affected by surge patterns. To exploit the trajectory of the storm in this manner requires a different perspective on coastal development, because the creation of a portfolio of interventions located on the shore is not as critical as defining the powers and processes that combine to form an appropriate response. Therefore, the strategy of the GSD team is to create a method that combines the ephemeral (weather), the submerged (bathymetry), and the terrestrial (plants) in order to approach issues of such scale and complexity.

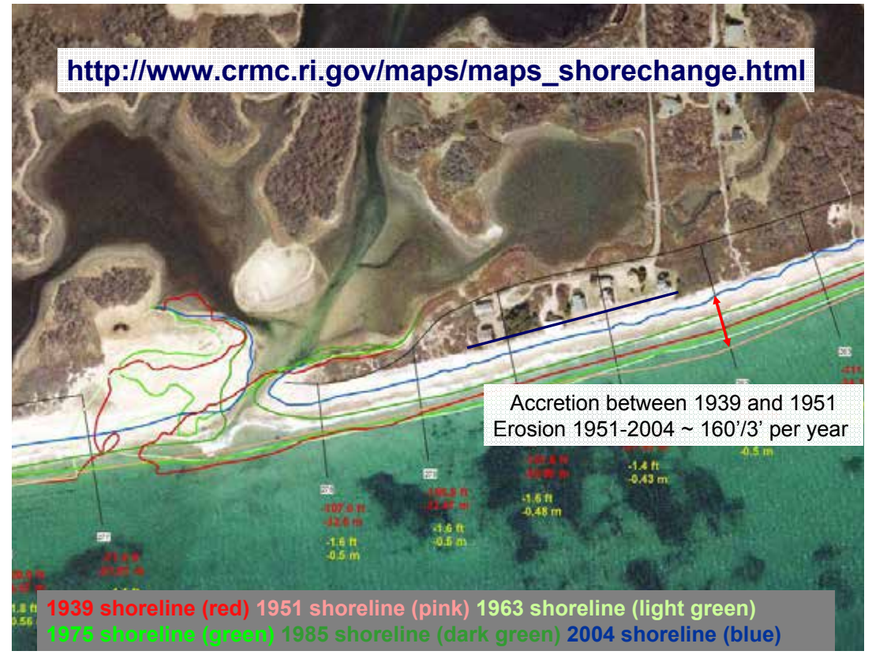


Figure 6.2: CRMC Coastal Erosion Aerial. If we are entering a time where active words such as surge, flood, migration, attenuation, transformation and erosion hold meaning within the contexts of this discussion, then it is easy to imagine how site becomes process and places are defined through conditions. In light of this, "static is no longer a paradigm we can trust".

Method

Our methodology acknowledges resilience as a biological trait as opposed to an ecosystem value. By nature, competitive plants emerge and 'spring back' based on regimes of disturbance that warrant their use and exploitation, rather than eclipsed by the discourses of native or restorative environmentalism. The GSD team's strategy proposes an alternative perspective in the study and treatment of plants: the environment does not shape plants; rather, plants help to shape the environment. Understanding plant behavior is crucial to the principles of design and fluctuations that are part of coastal ecology. For the purposes of this study, it is critical to see the plant unit as a scalar device that creates relationships and that provides the foundation for a portfolio of interventions that can be manipulated and controlled alongside typical construction materials. As designers, the GSD team considers this study an opportunity to offer a vision of community-based resilience, with the aim of creating a public resource without resorting to the restrictive procedures associated with conservation.

Objective

The objectives outlined for Phase 1 were specific about 1) soliciting a research agenda and 2) narrowing site selection. As a result, these initial months were an opportunity to re-formulate the role for designers within the undertaking of parceling sites. Instead of offering a fixed location to insert design ideas, our objective was to generate a research agenda based on site selection. According to The Coastal Engineering Manual (CEM) "Many coastal failures can be traced to inadequate site characterization analysis." [1] Due to the scale and complexity of the topic, we have deliberately disassociated ourselves from the misconceptions embedded in reactionary tactics that position designers towards the aesthetic end of the process, which is predicated on offering a fixed location, a planning document and the limitations of short-term disaster capital. Avoiding the term "site" also allows us to re-locate a physical response through conditions, instead of offering a fixed formal solution, which is the root of dated, static infrastructure. We are entering a time where active words and processes such as surge, flood, migration,

Figure 6.3: Eastern and Western Passage to Narragansett Bay

attenuation, transformation and erosion, hold more meaning than fixed ideas that do not offer elasticity in the face of change. In a time when methods are shifting along with the climate, we believe the "solutions" would be more successful if they were equally flexible and active.

6.1.1.1 Watershed

Within such a small state, water quality and assessment issues inform most decision-making processes. This is compounded by the fact that 60% of Rhode Islands Watershed Area lies in Massachusetts[2], creating another level of complexity within the associated boundaries of coastal dynamics and land-sea exchange. This means that Narragansett Bay and Estuary host dynamic hydrological and aeolian exchanges. Sea borne surge and upland flooding are both considerably extreme to the numerous coastal towns dotted along the Bay.

Within the framework of site characterization, it is critical to consider ground-level specifications at a variety of scales in order to consider the effects of upwelling in inland waters. Imagining the estuary as the end point of waters that extend miles beyond the town ultimately affected by the events. This turns surge into a major social concern, demanding a telescopic perspective of the issues. In this regard, the sites become hinged both on time (slow erosion, fast surge) and space (extents of watershed).

Rhode Island also boasts 420 miles of coast, making it the second longest coastline in America (after Hawaii) in relation to its land area (Figures 6.3 and 6.4). The intricacy of the hydrological cycle is the motivation for the intensive integrity and management of the water supply, facilities, beaches and associated infrastructure. The General Assembly recognized that Rhode Island's water resources are among the state's most valuable—if not the most valuable—of all of its natural resources.[3] This extends to the great range of recreational and tourism-based economies that are sustained by the various water types.

6.1.1.2 Land Use

Most of Rhode Island's ocean front property is privately owned. In theory, this leaves proprietors with only two options for their parcel: sell their lot at a net loss or build vertically (Figure 6.5). The municipality is also left with few actionable options: defend the beach for its economic value, protect the road for its community, or appeal for a planning strategy that acknowledges retreat. The notion of retreat is not currently considered part of USACE CEM manual despite the fact that 'do nothing' is a viable option. Future scenarios will have to study subtraction as an option and expedite the process of turning over land use as shoreline erosion increases. Embedded in the terms "retreat" and "relocate" are design opportunities that consider long term scenarios of transformation. Erosion is only a peril to property.

The role and coverage of the National Flood Insurance Program (NFIP) is changing dramatically following the passage of the Bigger-Waters Flood Insurance Reform Act of 2012. Of principle concern for the Rhode Island region is the stipulation that "grandfathered" properties will experience 25 percent rate increases starting this year, with a continuous incremental yearly rate hike[4]. Existing owners who were compliant in prior years are no longer due to storms such as Hurricane Sandy, and face a serious challenge of selling homes that they

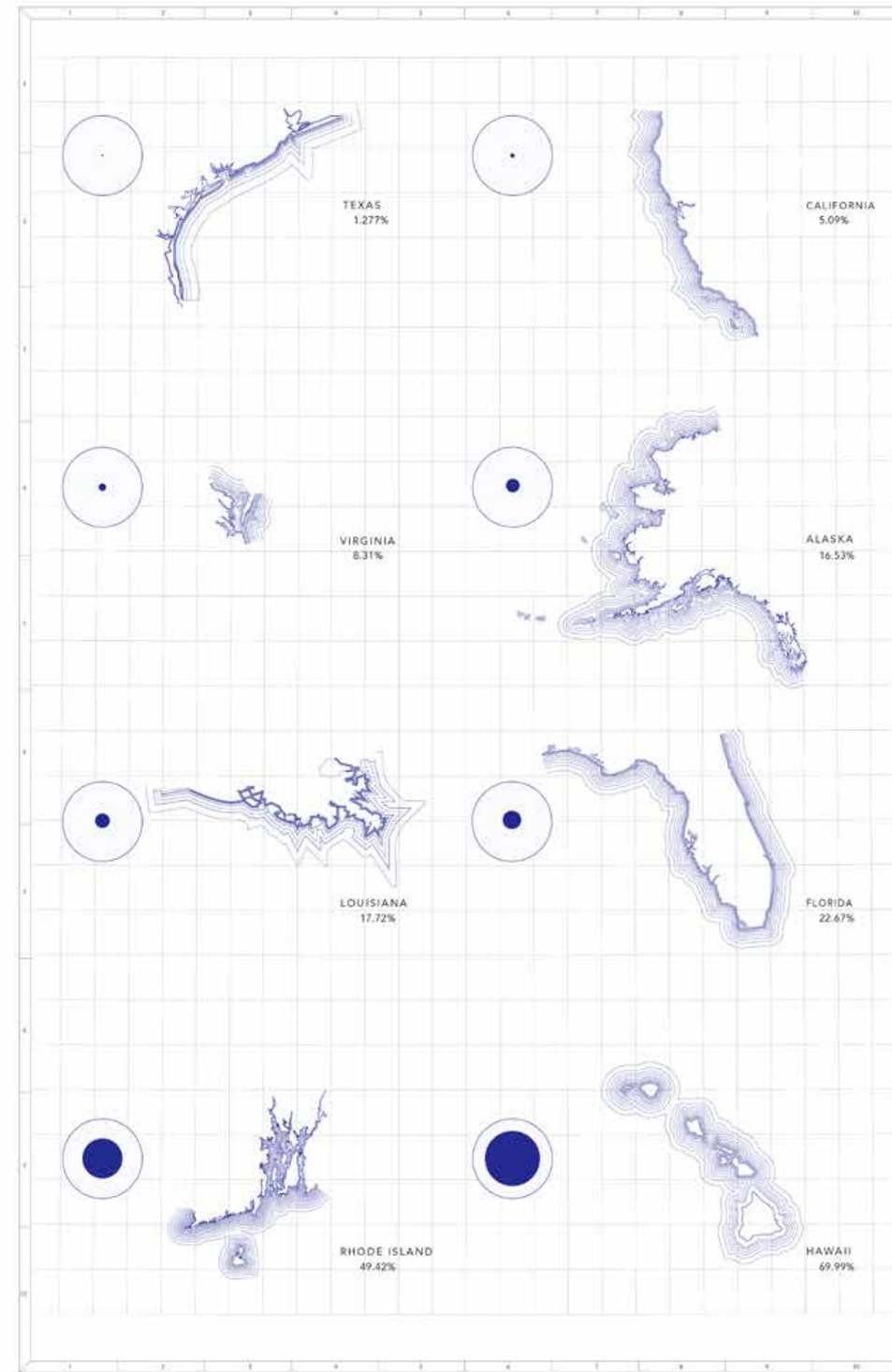


Figure 6.4: Coastline Length by Area of State

can no longer afford. FEMA and its Flood Insurance Rate Maps (FIRMs) play a large role in delineating the application of higher rates based on its storm and flooding projections—a point of political and economic contention in the face of emergency management and long term coastal planning. As a result of this long-term expense and uncertainty, many leaders in Rhode Island have begun to make other considerations public:

"Relocation is something we are going to have to seriously consider in the near future."
-Grover Fugate (Director, CRMC)

For future planning and design work to be applicable and relevant in areas such as this, the options surrounding "retreat" and "relocate" must be well developed and appealing to the public. Further, the land-use that is offered in the place of dwelling must be public and accessible, in both short and long term scenarios, as any major change in land-use will take time for communities to support. In this regard, the role of the 'do nothing'—a viable and existing option in CEM—merits greater development, as there are actually design potentials latent in exercising purposeful relinquishment of control. It is critical that the role of prevention not be applied to inherited notions of preservation or conservation, rather inspired to welcome new customs and principles. A first step in that regard are honest accounts of "flood lines" and their relevance to land ownership policy, to the realities of natural and nature-based features (NNBF) as a phased indication that requires community participation.

Uplands

The range of eco-tones existing at the land-sea (aquatic-terrestrial) interface in particular includes estuaries, salt marshes, and coastal dunes. As a result, this interface is also a critical tourist destination and a popular setting for second homes. Therefore, development

Figure 6.5: Elevated Home Post Sandy, Charlestown Beach

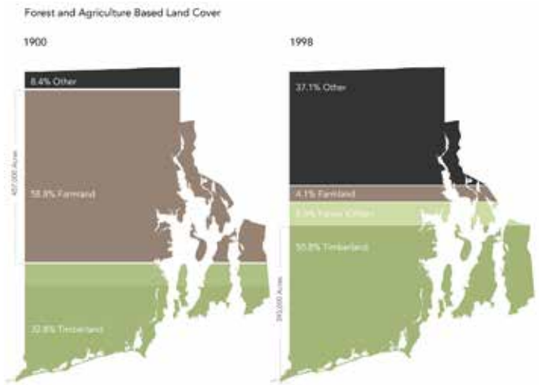


Figure 6.6: Land Use Transition, Agriculture to Forest between 1900 – 2000

and urbanization follow a range of fragile ecosystems. This transition also influences the next manifestation of vegetation types, which can also determine land use in the future. The feedback between ecology and geomorphology forms this critical eco-tone, which is clearly transforming due the likelihood of inundation.

Consider the transformation over the last century alone (Figure 6.6). Most of the forests in the state are only 60 years old[5], having only recently replaced Rhode Island's vast agriculture industry. Additionally, the state's current land use is comprised of 4% agriculture, while data indicates use in 1900 at 59%, outlining a trend of land turnover that is affiliated with other contemporary

"The upland condition is changing, almost as rapidly as the coast due to the increase in impervious surfaces and rising seas which have shrunk the brackish zone-but we think the two systems might be able to start trading cards–anticipating another considerable shift in land use."[5]

trends. Within current forest cover, the dominant forest is typified by oak and hickory, though that, too is changing to maple/birch and oak/pine communities that are well-adapted to disturbed, moist soils. "The upland condition is changing, almost as rapidly as the coast due to an increase in impervious surfaces and rising seas which have shrunk the brackish zone—but we think the two systems might be able to start trading cards—anticipating another great shift in land use."[5]

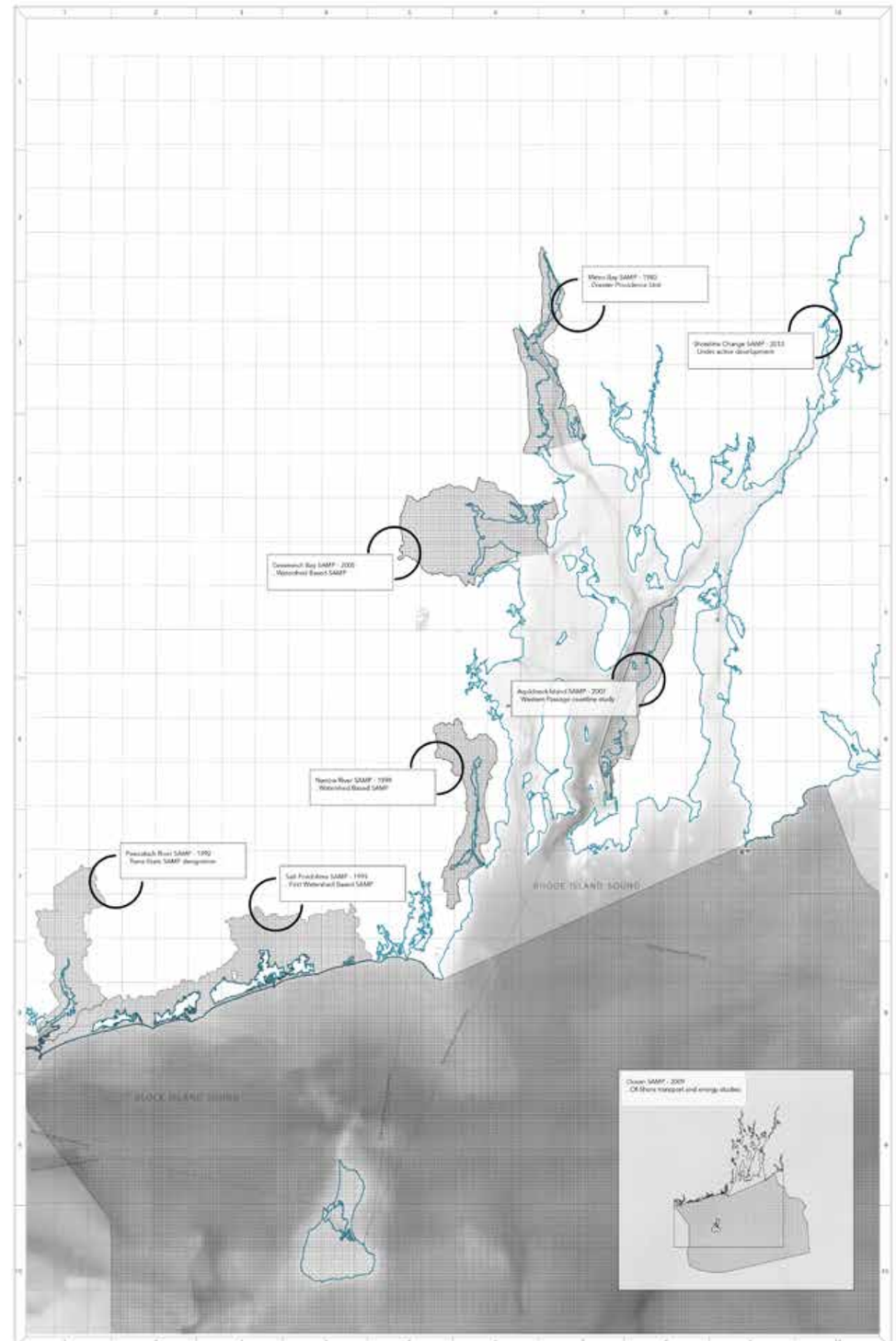


Figure 6.7: SAMP Coverage in Rhode Island

Another topic of land use transformation lies within category "other" at 8.4% in 1900 and transitioning to over 37% in the same period, a category that implies urbanization and settlement. While this is consistent with other contemporary trends of sprawl, it was likely inconceivable at the turn of the century. With this in mind, it is not implausible to imagine a future in which another transformation occurs; one that conceives of Rhode Island—the Ocean State—with fewer sandy beaches and a very different waterfront charm. The ocean character is amplified, while the accessibility to and fringes of its relationship to the land is altered. This also instigates a change of cultural and social behavior, generating new ecologies and economies. It is this long-term transformation that frames the design scenarios we are proposing.

6.1.1.3 Seal Level Rise and Inundation

Marsh

The transition from marsh to upland represents a semi-continuous condition that functions on a horizontal spectrum. Marshes have been repeatedly filled or drained due to development on the coast, and are predictably mobile. Due to impervious development, these terrestrial ecologies are left inert, and will retreat as a result. Natural forces such as longshore current, outflow, prevailing wind and overwash are agents of littoral transformation, offering a form of disturbance that is critical to the ecology of the coastline. Ocean transport erodes and accumulates sediment, which can be perceived opportunity to develop new typologies and foster spectacular change.

"... Invasive species are too entrenched in many systems to consider their presence a restoration failure, particularly when some may have similar roles as native species. Providing for alternative solutions to future conditions by setting multiple end points implicitly increases resilience by increasing the adaptive capacity and response diversity of the system."[6]

Our methodology acknowledges resilience as a biological trait, rather than an ecosystem value. By nature, competitive plants emerge and spring back based on regimes of disturbance that ought to be acknowledged and exploited rather than eclipsed by the discourse of restoration.

6.1.1.4 Population

Historically, Rhode Island's economy was based overwhelmingly in manufacturing and agriculture. The shift towards a more service-oriented economy is well known; less known is the fact that the tourist industry is still growing. A study from 2007 indicated that every 1 in 10 Rhode Islander is employed within the tourism sector [7]. Residents are quick to claim that no one lives further than half hour from the shore. This pride, coupled with a wealth of natural features and a strong network of environmental stewardship, positions the state to become a leader in coastal resilience, offering an exemplary model to other coastal and estuarine populations that are facing similar risk.

6.1.1.5 Legislation and Regulation

Special Area Management Plans (SAMP) serve as a federally recognized management and regulatory tools. Rhode Island has a long history of employing this tool to designate coastal regions with innovative boundaries and extents to best capture the inherent ecological and economic functions of each site (Figure 6.7). From the 1983 Urban SAMP that engaged the Providence region, to the Greenwich Bay SAMP that covered the entire watershed in order to address water quality and water based economic concerns in one study, the SAMP has been a well-used tool that merits examination with respect to NNBF planning and design strategies. The SAMP(s) continue to be produced and employed with some of the most recent being the most aggressive. The extension of planning jurisdiction some 25 miles off the coast of southern Rhode Island in accordance with the Ocean SAMP represents an interest in engaging multiples scales of planning for the next phase of ecological, economic and infrastructural measures.

6.1.1.6 Infrastructure

Energy production and the infrastructure that supports its production are found in two very distinct positions on the map—in both time and space: 1) The existing energy system is based out of the largest coal-fired power plant in the northeast at Brayton Point. Set on the Massachusetts/Rhode Island boarder, the power plant abuts the coast of Mt Hope Bay and faces considerable short and long-term risk for inundation. The plant is expected to shut down in the near term due to the environmental tax burden of operating a coal-fired

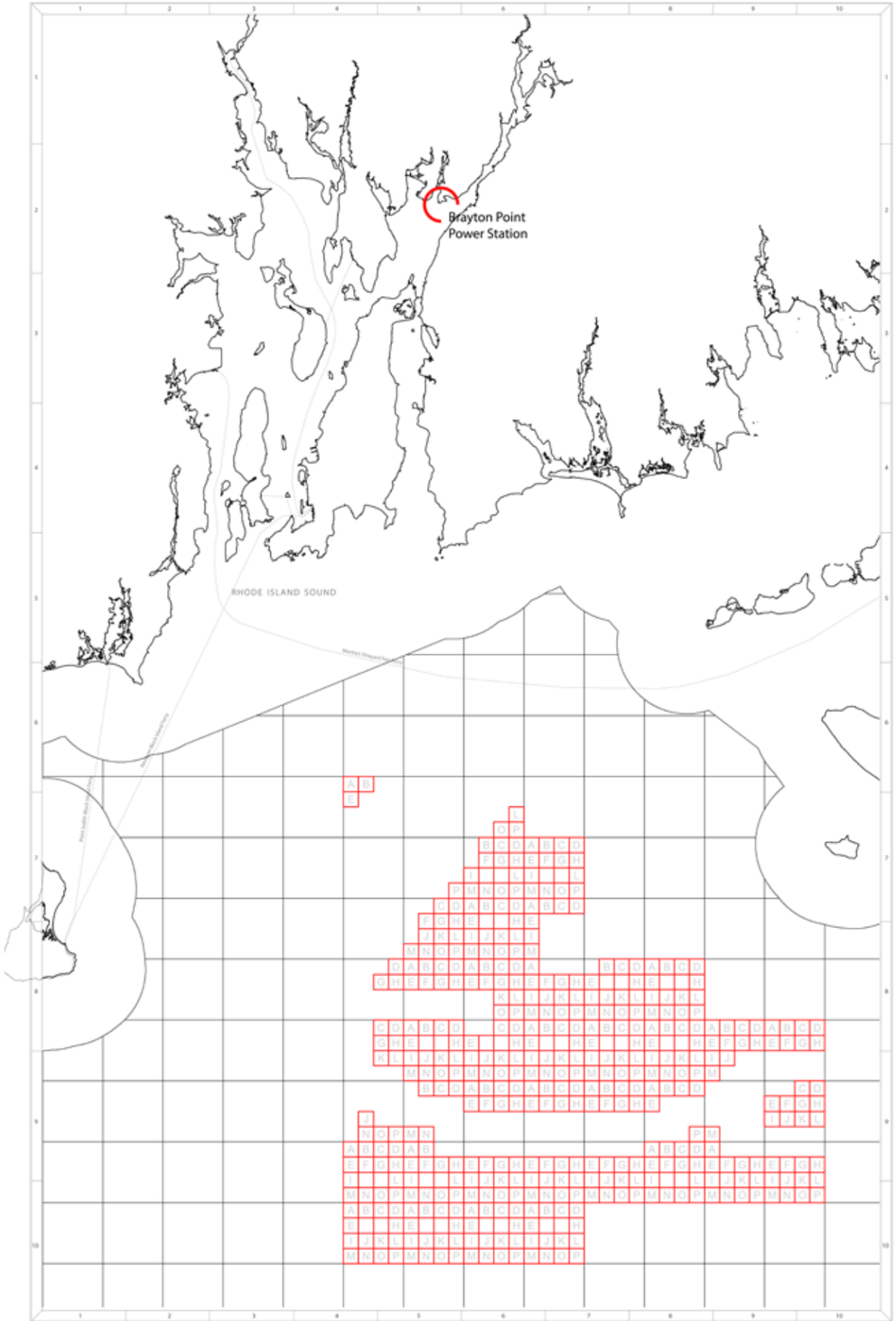


Figure 6.8: Ocean SAMP Outlay

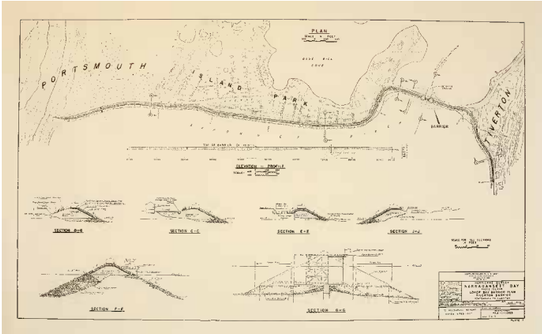


Figure 6.9: Hummocks Detail Plan

plant. 2) The other position is the future interest and investment in a similar trans-state energy production system, conceived of as a wind field off the southern shore of Rhode Island, in the ocean. The aforementioned Ocean SAMP (Figure 6.8) enables approved funding to be applied to study and develop the area in an ecologically sensitive manner. The ability for the region to shift its energy production in typology, source and location does not represent an imperially better or worse set of concerns, but rather an opportunity to develop similar networks at similar scales—in a different site.

6.1.1.7 Historic Planning in Narragansett Bay

In reaction to the damage from the 1938 and 1954 Hurricanes, which effected wide swaths of Narragansett Bay, one of the more ambitious plans was put in place to attenuate future storm surge in the region. Rather than speak to a long history of headwater restriction, bay filling, dredging, and ecological retreat; the brief outlay of the 1957 planning effort provides direct insight into the hydrodynamics of the region and its perception as a series of sub units. The overall mapping of the bay region (Figure 6.10) breaks down the region into non-additive hydrological units based on percentage population and damage, rather than categorical build-up of surge. While the eastern and western passages are front loaded with population in cities such as Wickford, Jamestown and Newport which benefit and require immediate barriers to surge, the Sakonnet River's headlands (which contain Island Park and the Hummocks) were designated as a final barrier site. The proposal for The Hummocks and Island Park included a barrier system spanning the southern face of Island Park, across the Sakonnet River at the Sakonnet Bridge and terminating along the southern coast of Tiverton (Figure 6.9). The position of this barrier is such that the potentially unmanageable inflow of approximately 22 feet of surge and waves above mean high water (September 1938 flood) entering the Sakonnet River

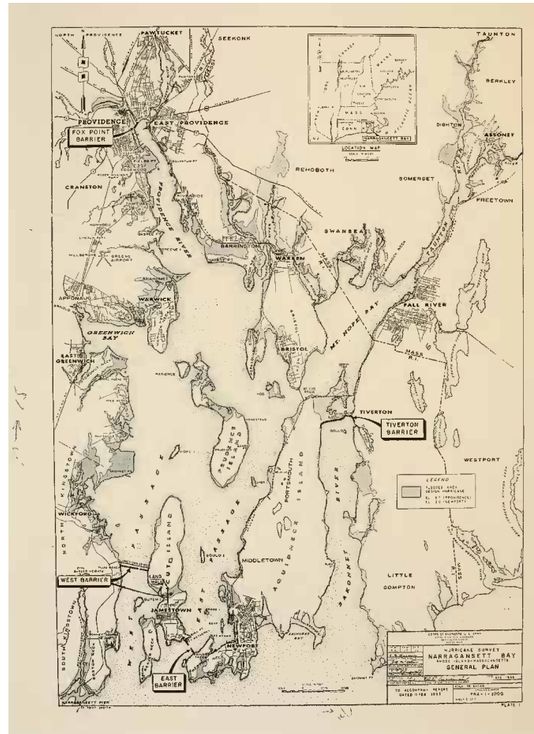


Figure 6.10: Bay-wide Damage Assessment

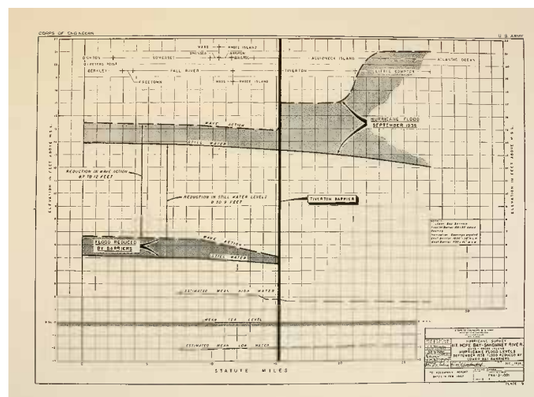


Figure 6.11: Surge Calculations

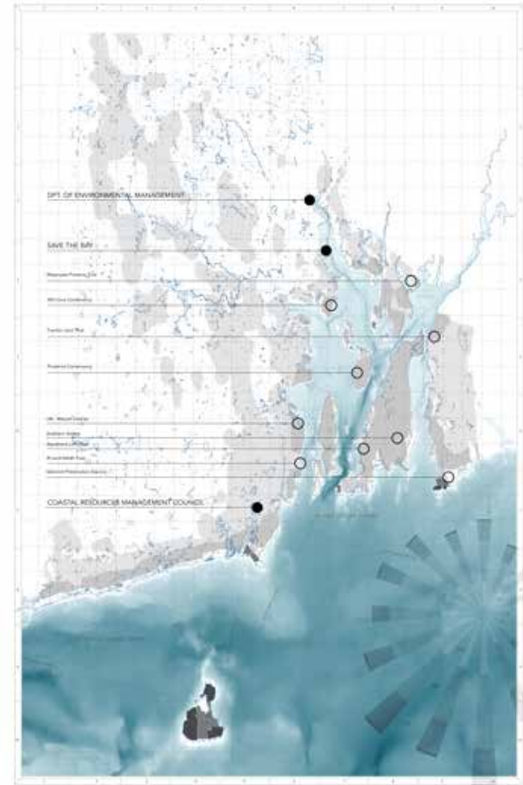


Figure 6.12: Agencies of Narragansett Bay

at Sachuest would have dissipated to 18 feet by the leading edge of Island Park (Figure 6.11). Yet, as surge is typically additive from South to North in Narragansett Bay, more could be done to work with and through this water system. Much like the considerations for the North Atlantic Coast Comprehensive Study's (NACCS) 'Reach' and 'Length' in relation to the effective range of NNBF, the assessment of a barrier at the Hummocks is important to study as it positions the same mentality as places such as Newport while lying in a very different hydrologic position. The larger planning effort for a coordinated assessment of surge in Narragansett Bay is a unique example of estuary planning in totality. Yet, as we acknowledge in Section 1.1.1, the watershed's impact on many aspects of the hydrodynamics of the bay require this distributed approach demonstrated in the 1957 plan to expand to fit the total region with respect to both water and plant material.

6.1.2 Local Affiliations

In framing the project as a statewide strategy (Figure 6.12), it is critical to work respectfully with the associations, agencies and people that are actively engaged in the specifics of the region. Following the exceptional practices of stewardship in the state, the number of organizations, both non-governmental and governmental is of note. These agencies have emerged from the high level of cognizance towards sea level rise and environmentalism, and are as dynamic as the systems they defend. For the purposes of this project, we are currently consulting with three organizations in particular that that we have identified as being proactive, engaged and visionary.

6.1.2.1 CRMC - Rhode Island Coastal Resources Management Council

Statement: "To preserve, protect, develop, and where possible, restore the coastal resources of the state for this and succeeding generations through comprehensive and coordinated long-range planning and management designed to produce the maximum benefit for society from such coastal resources; and that the preservation and restoration of ecological systems shall be the primary guiding principal upon which environmental alteration of coastal resources shall be measured, judged and regulated."

Hurricane Carol (1954) prompted a series of state and federal studies on the future of RI shorelines, and this coupled with tremendous local pressure, generated the formation of a technical committee in 1969. At the time, the idea of managing a resource was a new and not universally popular one. With expanded notions of representation, legislation was passed in the General Assembly in 1971, which established Coastal Resources

Figure 6.13: Janet Freedman (CRMC) explaining the Charlestown Breachway construction history and its role in coastal management to the GSD team.

Management Council, of 17 members. In 1971, CRMC became responsible for the management and long term planning of all coastal resources. The area extending from the territorial sea limit, 3 miles offshore, to 200 hundred feet inland from any coastal feature, generally defines the regulatory authority of the CRMC. After water types, coastal features are the most identifiable element of the CRMC's jurisdiction. In addition, natural features such as coastal beaches, dunes, barriers, coastal wetlands, cliffs, bluffs, and banks, rocky shores, and manmade shorelines all have an extended contiguous area of 200 hundred feet from their inland borders which falls under the authority of the council. Cultural features of historical or archaeological significance are also within the jurisdiction of the council as required by the federal government. CRMC have been extremely innovative with managing development and creating jurisdictions—in its capacity as the sole regulatory authority of all coastal and inland waters and their adjacencies.

Contacts:
Grover Fugate, Executive Director
Janet Freedman, Coastal Geologist

6.1.2.2 Save The Bay

Statement: "Save The Bay protects, restores and improves the ecological health of the Narragansett Bay region, including its watershed and adjacent coastal waters, through an ecosystem-based approach to environmental action; defends the right of the public to use and enjoy the Bay and its surrounding waters; and fosters an ethic of environmental stewardship among people who live in or visit the Narragansett Bay region."

Save the Bay is a privately held company, incorporated from its outset. A brief history reveals that this not-for-profit was formed in 1970 through their motivation in opposing proposed development of energy facilities along Narragansett Bay. In 1972, they were successful in halting the construction of a proposed nuclear facility in North Kingstown, which begins its long history of environmental leadership. They were strong advocates for the formation of Rhode Island's Coastal Resources Management Council (CRMC).

Contacts:
Jonathan Stone, Executive Director
Wenley Ferguson, Restoration Coordinator

6.1.2.3 Department of Environmental Management

Statement: "We are committed to preserving the quality of Rhode Island's environment, maintaining the health and safety of its residents, and protecting the natural systems upon which life depends. Together with many partners, we offer assistance to individuals, business and municipalities, conduct research, find solutions, and enforce laws created to protect the environment."

Rhode Island Department of Environmental Management (RIDEM) is a state agency which provides oversight for a wide variety of environmentally tied issues—from boat permits to air quality monitoring. Their inter-agency cooperation has afforded the ability to produce important studies ranging from detailed botanical studies of natural communities in the state to joint work with USFS assessing forests to work with the USACE and CRMC on water quality and flooding. DEM's current efforts and scope of work in the Narrow River Watershed is of particular interest.

Contacts:
Janet Coit, Director
Elizabeth Scott, Deputy Chief for Water Surface Protection

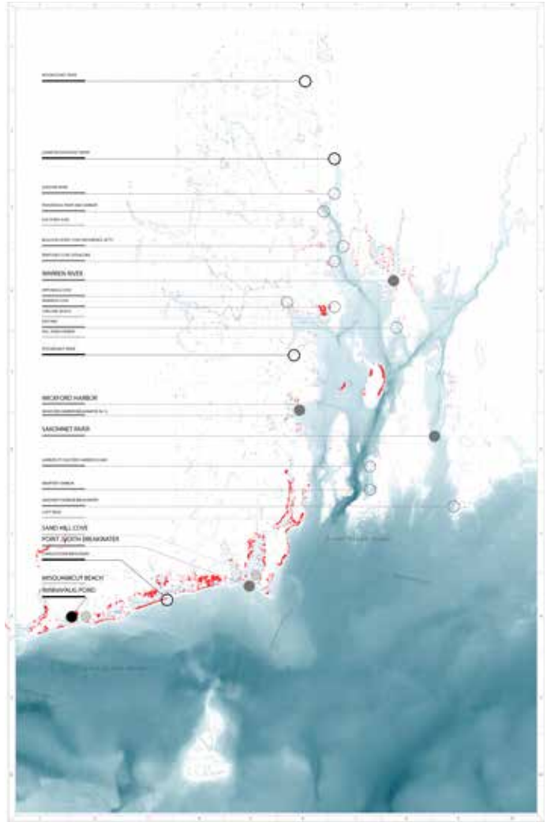


Figure 6.14: USACE Projects of Narragansett Bay

6.1.3 Existing USACE

Stewardship and natural forces alike actively manage the Rhode Island coastline, with the USACE as an additional and active support in the region. As noted in Figure 6.14, the USACE has approximately thirty long-term contracts including projects in each of the six areas we have noted to be of interest to Phase 1 of this study. From Flood Risk Management to Navigation to Shore and Bank Protection, many of these projects are associated with a regime of maintenance following a historical build out. The project is interested in both locations the USACE has found to be of importance as well as areas that are currently not holding contracts.

When comparing existing contracts with the State of Rhode Island's current planning and legal structure for coastal reconstruction as represented by the red areas in Figure 6.14, several areas are in direct conflict between USACE contracts and Rhode Island legislation. When pairing this information with surge projections, areas such as the Oakland Beach area of Warwick will most likely not be rehabilitated, but will have existing contracts with the USACE. The alignment of these three components—Rhode Island legislative intentions, USACE projects, and trends in surge and sea level rise—offer an opportunity to reconsider the scale and types of projects slated for these areas. They are direct examples of 'do nothing' and we have deemed suitable for the testing of ideas surrounding retreat, deconstruction and NNBF implementation.

On the other hand, there are several areas of certain inundation such as the Hummocks (Island Park Cove), which do not have a contract with the USACE but are slated for rehabilitation based on current legislation. The long term non-viability of regions such as these represents another opportunity to reconsider the alignment of the previously mentioned three components. This revelation brings with it an important question: What is 'rehabilitation', and how might alternative definitions help push the role of NNBF and property ownership with respect to its definition and as a function of a 'reach'?

6.2 Methodology

6.2.1 Scales of Landscape Function

Defining Site

Static is no longer a paradigm we can adhere to. From the smallest section of barrier beach retreating over the years to the erosion of an entire coastal cliff, both the pressure from flow inland and the coastal pressure from the ocean sets the stage for a very dynamic coastal zone in both form and delineation. Rhode Island grows in complexity from two directions; for every Hurricane Carol there is a Hurricane Irene that results in a massive freshwater influx into the watershed of Narragansett Bay. Sea borne surge and upland flooding pose a considerable risk to the numerous coastal towns along the Bay. Addressing questions of storm surge must consider both the bathymetric and the topographic scales of water in the region before determining areas of interest in which design might intervene (Figure 6.15). Levels of inundation in the upland regions of Narragansett Bay are more severe economically and socially than many of the coastal threats. Because design cannot engage such a massive region in totality, the strategic analysis of the total salt and fresh watershed gives us the opportunity to pare down sub regions that are interrelated. Within the sub-region a distinct hydrologic pattern represents the opportunity to design with and for hotspots at the scale of NNBF effectiveness.

Landscape Architecture and the CEM

In order to be methodical about developing areas of interest and exacting our terminology, it is critical to examine the working relationship between the agencies at play, and their order of operations. In this regard, visualization of the CEM manual was an important step (Figure 6.16). An analysis of this manual revealed the absence of a listed role for designers—landscape architects or architects within the evaluation of regions or in the creation of built work. Our role in this process would generate an impact on both ends of this spectrum, including the work of 'site characterization'. As noted in the CEM, "Many coastal failures can be traced back to inadequate site characterization analysis."[8] The definition of scopes and scales of work through landscape analysis would allow designers to be positioned between scientist and engineers, currently the only two types of professionals employed by prescribed process of the manual. Through increased efforts in site characterization analysis and greater trans-disciplinary interaction, offer the opportunity work with alternative zero, 'do nothing'. While this is a common framework in engineering evaluation, we believe the term could be extended to explore the concept of retreat and the role of NNBF in facilitating this transition. Rather than deterring surge, we are inviting its role in the alteration of land that can be prepared and aided in its transition so as to serve a greater good for a broader region.

NACCS Hotspots

The formulation and GIS process outlining the NACCS construction offers opportunities to further expand on the definitions of 'reach', 'length' and 'hot spot' in relationship to NNBF usage. The current 'hot spot' designation fails to account for the scale of space needed to gain functional return from an NNBF. The scale of 'reach' designations are more appropriate to begin the task of planning NNBF systems. The scale of the 'length' may be appropriate for implementation, allowing for multi-reach coordinated efforts. As NNBF implementation is a large scale project, the sub-area designation of a 'length' could be an important tool for evaluating a multi-partite approach to the function of a reach and the effect such projects would have on a hotspot. It is important that hot spot designations be given time frames and markers for minimum function to which phasing out, doing nothing, and other "non-options" as listed in the Coastal Engineering Manual might follow.

Coordinated 'length' designation throughout the watershed and estuary that lessen such direct impact on hot spots would be ideal, and would be more in line with the scale of NNBF function. As mentioned in section 2.12, proposed interjections into the Coastal Engineering Manual are well framed at this scale of site definition and concept of intervention. The merging of NACCS and CEM methods might provide regional sensitivity to design specifications while maintaining a general and uniform process of evaluation, a dynamic that would benefit the transferal and applicability of the Coastal Engineering Manual.

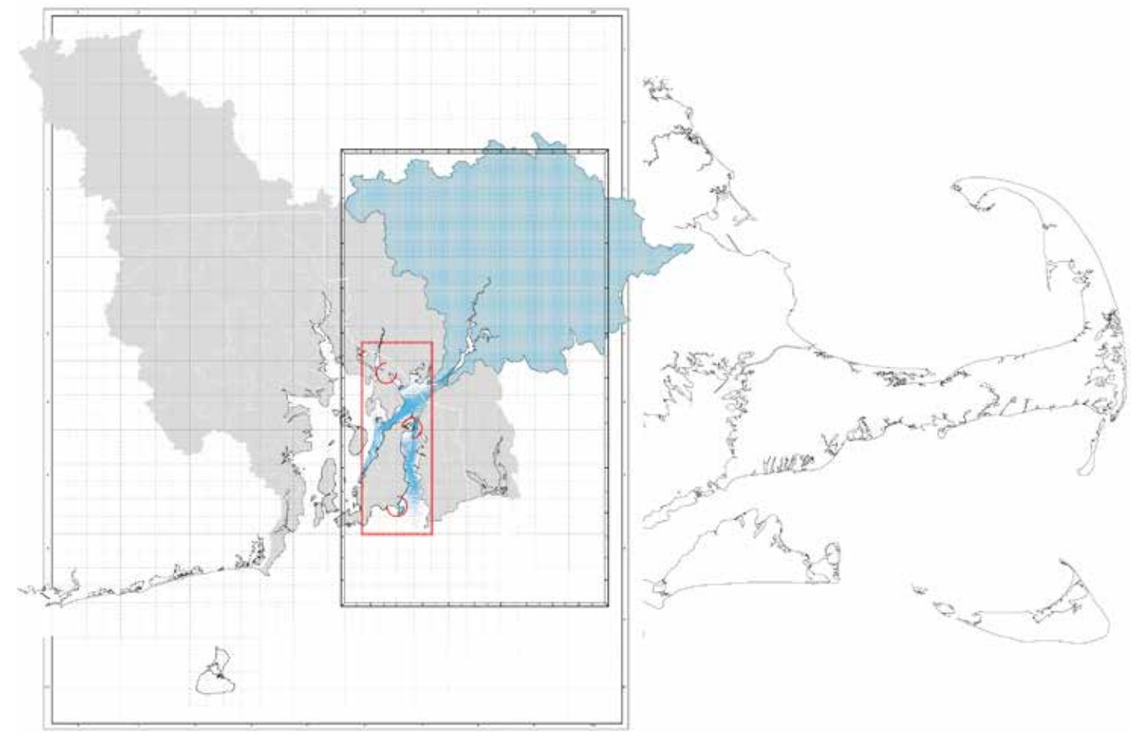


Figure 6.15: Scales of Study, Narragansett Bay

Figure 6.16: Coastal Engineering Manual Operational Diagram

Potential Scales for NNBF

One method for determining the factors that impact the use, placement and bulk of NNBF is to reverse-engineer the factors of a current storm surge model. In "Modeling the Physics of Storm Surges"[9], Resio and Westerink list the following eleven factors of attenuation:

1. Momentum balance
2. Storm track
3. Forward speed
4. Duration
5. Size
6. Associated waves
7. Regional bathymetry and topography, including shelf width and barrier islands
8. Local geometry
9. Levee and raised feature elevations
10. Inland bathymetry and topography, including the channels that interconnect water bodies
11. Local surface roughness

Roughly half of the list are factors that affect the form of NNBF, while the other half are factors that can be designed with, upon, or anew in a region. No one factor is more important a consideration than the next; consequently, how each is addressed or designed will have in kind effects on the others. The context in which these conditions are being addressed will dictate which factors are constants and which are variables that can be manipulated to address surge. According to Resio and Westerlink, surge is determined by several factors including the geometry of the greater bathymetric basin, the local geometry of the coastal zone and the speed/ direction of the wind.

The 'Effective Range', or distance and scale at which NNBF provide a form of attenuation remains a debate for several reasons. The considerable number of variables that go into evaluating attenuation (as noted in the list above) make examining a non-uniform living system very challenging. It is difficult to evaluate the impact of NNBF on active storms that exceed the height of vegetation. From the computer model to low intensity in-field testing to lab simulations, the history of such evaluations and the metrics that accompany them can be noted in Figures 6.17 and 6.18. More significant than any one figure is the fact that we can identify an attenuating effect as well as a rough average quantity. Pairing such quantities with the factors contributing to the attenuation of surge gives us a basic set of tools with which to evaluate the region and hypothesize the impacts of intervention.

The components of an attenuation plan must address each of these factors, but rather than attempting to localize all problems and solutions, we might parse out the elements of singular importance along the course of water movement to create a distributed effect. In concept, a distributed model works much like the federal standard for anti-ram barriers. While the total displacement of the vehicle is assigned a terminal point that it cannot breach, many great designs work to build up protection that engages distance as barrier. Our thoughts on NNBF go one step further to acknowledge that moving outward off the coast may not be an option, and so the features within the bay and lagoon region must serve as a kit of parts.

A storm of a northeastern track making land fall in Connecticut may require some NNBF to function in direct relation to surge, while the same NNBF might later serve a role in wind reduction or land building. Each NNBF must be designed in a way that it can engage multiple aspects of the above list to varying degrees of effectiveness in varying directions and intensities of storms. When laying the range of distances over the region as listed, (Figure 6.19) provides a sense of scale for the amount of protection versus surface area needed to attenuate surge. This is but a start to a working model and method for NNBF employment.

Not all aspects of NNBF should be considered inherently positive. The externalities of intervening in a changing hydrologic system, whether with a wall or a marsh, should be noted and designed for. Several recurring themes were inherent in the survey of studies listed in Appendix A. The open water leading edge impacts of intertidal zones are relevant and have a potentially dramatic lateral impact. McIvor and her team in the Natural Coast Protection Series notes:

"In contrast, the amplitudes of storm surges at the front of the mangrove zone increase by about 10–30% because of the "blockage" of mangroves to surge water, which can cause greater impacts on structures at the front of mangroves than the case without mangroves." [10]

This has been shown to be true for many hummocky coastal zones which are land additive. Several studies cite both the increase in vegetal/ substrate shelf and resulting general increase in leading edge pool depth as sources for the increase in surge. The siting and modification of lateral transitions between NNBF and settlement or any kind appears to be imperative considerations when examining the development of these types of NNBF.

While high plant density has shown important for single direction surge dissipation, this is not necessarily ideal for ebb outflow. An NNBF's ability to consolidate and retract is essential for its resiliency and long term function. As noted in Song and Hoffmann's riverine study,

"The riparian forest management practice examined here was the tree thinning activities. With this selected method, the authors demonstrated that specific tree thinning practices could improve the carrying capacity in the study reach."[11]

As they note, carrying capacity considers a total water pattern, where drainage is as essential as attenuation. As noted in prior sections of the report, the 'double sided' nature of Narragansett Bay requires that NNBF be capable of aiding in both attention an evacuation of water. Finally, depending on the time line and layered composition to an NNBF, the rate of establishment for any species should come under consideration. The potential for shorter term conventional barriers and attenuating features to 'buy time' for longer term NNBF opens up the opportunity to not only layer features in a storm track but also in a time sequence that allows for turnover and reuse.

USACE	1963	US	SURGE	1M : 14.3 KM
USGS	1994	US	SURGE	1M : 20 KM
RESIO & WESTERINK	2008	US	SURGE	1M : 14.5 KM 1M : 7 KM
LODER and WAMSLEY	2009	US	SURGE	1M : 25 KM 1M : 4 KM
USACE	2011	US		
Florida International University	2012	US	SURGE	1M : 20 KM (10-30% INCREASE AT HEAD)
Chatagnier	2012		SURGE	1M : 5KM 1M : 20 KM

Figure 6.17: Surge Attenuation by Vegetation Chart

WAYNE	1976		WAVE		
KNUTSON ET AL.	1982	US	WAVE	.2 M : 2.5 M	UNKNOWN
SHUTO	1987	JP	WAVE	3M : 20 M 6M : 100 M	MANGROVE
FONSECA AND CAHALAN	1992				NATURAL
DUBI AND TORUM	1996				ARTIFICIAL
MAZDA ET AL	1997	VTN	WAVE		
MÖLLER ET AL.	1999	EN	WAVE		
LOVAS AND TORUM	2000				ARTIFICIAL
TSCHIRKY ET AL.	2000				NATURAL
MÖLLER AND SPENCER	2002	EN	WAVE		
COOPER	2005	EN	WAVE		
LIMA ET AL.	2006				ARTIFICIAL
MÖLLER ET AL.	2006	EN	WAVE	.114 M : 10 M .212 M : 10 M	
MAZDA ET AL	2006	VTN	WAVE		
QUARTEL ET AL.	2007	VTN	WAVE		
MORGAN ET AL.	2009				
AUGUSTIN ET AL.	2009				ARTIFICIAL
BRADLEY AND HOUSER	2009	US	WAVE		
CAVALLARO ET AL	2010				ARTIFICIAL
LOVSTEDT AND LARSON	2010	SW	WAVE		

Figure 6.18: Wave Attenuation by Vegetation Chart

Figure 6.19: Effective Range for NNBF Super imposed on Narragansett Bay

6.2.2 NNBF Design Concepts

NRCS Plant Materials Resource Stations

The creation of the USDA-NRCS Cape May Plant Materials Center was prompted by the March 1962 Nor'easter that hit Long Island and New York City. With a mission to advance plant science and increase availability of coastal species for distribution, the NJPMC works across the spectrum from cultivar development and distribution to field observation to community planting instruction. American Beachgrass was NJPMC's first developed cultivar for stabilization, yet it remains the only beach grass in production 41 years later [12]. Mostly focused around more conventional notions of restoration, it is not the specific content of their nursery crop but rather the process of research, production and partnership that is of interest to this proposal. The NRCS PMC's have a history of partnering with other federal programs and institutions as a way of incorporating botanical knowledge into both project design but also through delivery. The current exchange between the Department of the Interior and the NJPMC for Gateway National Recreation Area is but the most recent example of such collaboration.

The NJPMC as a model for research and distribution of nursery stock lends itself well to the discussion of NNBF creation for several reasons. The legislative factors stemming from Public Law 84-99 [13] the role of restoration and its impacts on USACE project boundaries and extents could be engaged through the field work approach of the NRCS. By partnering with a research based resource station, a recurring analysis of the project enables the creation of a shifting base line to which 'restoration' can be pinned. As coastal conditions and bounds change, so too will the condition of the NNBF, and so too will the recommendations stemming from the monitoring. In addition to the legislative considerations, the creation of stock within the region it will be planted allows for short and long term plant acclimation. A long and productive history of such methods can be seen in Figures 6.20 and 6.21, in which sites for production and planting were well intertwined into the production of jobs and regional traditions—in this case the CCC at Cape Cod in the 1930's and 1940's. To study and grow species intended for a changing coastline within the region is a vital part of the supply chain's potential effectiveness in the wake of increased NNBF implementation.

6.2.3 Siting

Marsh and dunes continue to recede while weedy forest cover continues to creep closer to the beach front. The plants capable of rapid establishment and high salt tolerance have begun to colonize portions of the region, especially those with soils that will percolate and flush salts. Much like the depiction of Ailanthus trees root suckering into a barrier beach and creating the necessary coverage for beach grasses to establish the emergence of these species afford more traditional species a chance at survival in considerably different and rapidly changing conditions. *Phragmites australis*, or Common Reed, is one such species deemed as "opportunistic" that utilizes a hardy rhizomatic root system to form extensive stands in wet and inundated, saline, and/or compacted soils, including sandy beaches characteristic to parts of the Rhode Island coast .[3] Though typically labeled as "invasive," *P. australis* performs an essential ecosystem service via prevention of erosion vis-à-vis its extensive root system, which, in turn, can create opportunities for the influx of other, less hardy plants. Species such as *P. australis* that display high tolerance of salinity, compaction, inundation, drought and that sprout, seed and reproduce effectively under stress should be deployed as a agents of change and effectively celebrate erosion as a pattern of productive movement.

The composition of these naturally occurring communities is an important point of study when considering NNBF methods, techniques and locations for implementation. The project has begun to examine several species (Figures 6.22-6.31) through their growth rate, root morphology and pattern of agglomeration. These plants have been observed in the local condition of the Rhode Island coastline and are believed to be excellent candidates for further research and potential cultivation. The spatial distributions of their growing patterns are in a position to take advantage of traditionally poor conditions including excessive shade and low moisture. Predicting the future of any given species represents an unprecedented challenge in light of the many environmental and biological factors that affect their performance. Acknowledging current conditions also forces a recognition of which species demonstrate resilience in the face of extreme weather and anthropogenic influence. As increased urban runoff and higher salt water levels merge on the coastal zone, the number of species capable of dealing with a diminished gradient shrinks. The siting of NNBF and the knowledge gleaned from these emergent species groups provides insight that will be carried into our design work.

6.3 Areas of Interest

6.3.1 Sector A – The Rhode Island Lagoon Region

Highway 1A-Senic runs the length of the lagoon region, winding through the terminal moraine at an elevation of approximately 25 feet above sea level. The rest of the landscape, a patchwork of maritime forest, agricultural land and developments, sits in a low and gradually sloping coastal outwash plain. Dominated by lagoons, this dynamic landscape traditionally frequently experienced changes in salinity, tidal exposure, and inundation—very much a disturbance-dependent landscape (Figure 6.32). As investment has continued to fight these tendencies, communities now find themselves with a low-lying, retreating coastline, degraded wetlands, and few dunes. The historic value of the structures and composition of the communities are deemed of high value, and the response to such change is best characterized as incrementally minimal. Elevating houses in a piecemeal fashion while the shifting of land ownership is transpires through insurance premiums—the agency of individuals to respond in the short term is the only viable option, while radical change over the long term is imminent. This is not socially or economically accommodating to many locals and wealthy vacationers alike.

While Sector B focuses on an interconnected hydrologic system, Sector A engages the challenge of straddling two geologically differing coastal conditions and the role of a fall line-coastline in Highway 1A-Senic. The

Figure 6.20: DuneStabilization

Figure 6.21: Historic Nursery Production

difficulty of integrating this region into a coherent coastal zone poses many challenges, as it is noted in the CEM:

"Rhode Island is a hybrid coastal system with glacial imposition producing two distinct coastal systems—the extent of a coastal zone should be tied to an additional variable in both cases; the portfolio of coastal management practices become vastly more diverse and difficult given the extreme differences in the coastline of Rhode Island". [14]

The transitions in geology between Misquamicut, Point Judith, and Wickford are immense. Yet, the probability of future hydrologic conditions dramatically changing this region and its infrastructure is likely and therefore merit further exploration.

6.3.1.1 Misquamicut—Winnapaug Pond

The land straddling the Pawcatuck River, Highway 1A-Scenic and the Winnapaug Pond is a low, marshy set of kettle ponds and estuary inlet coves, amongst

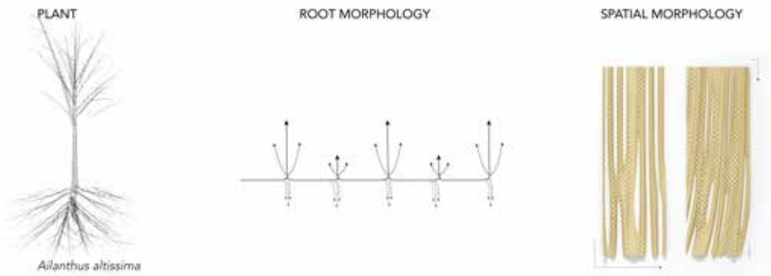


Figure 6.22: *Ailanthus*

Figure 6.23: *Amelanchier*

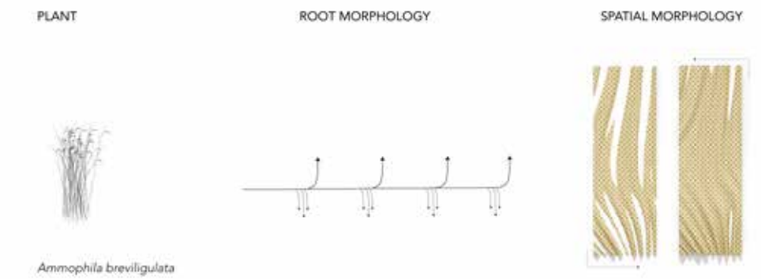


Figure 6.24: *Ammophila*

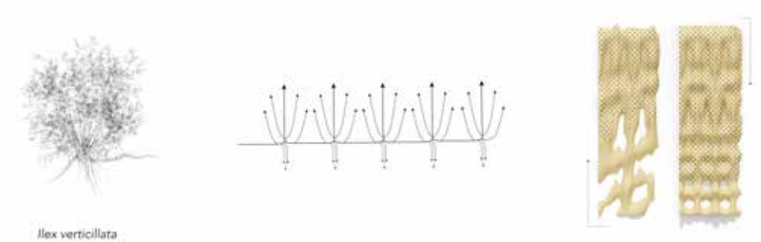


Figure 6.25: *Ilex*

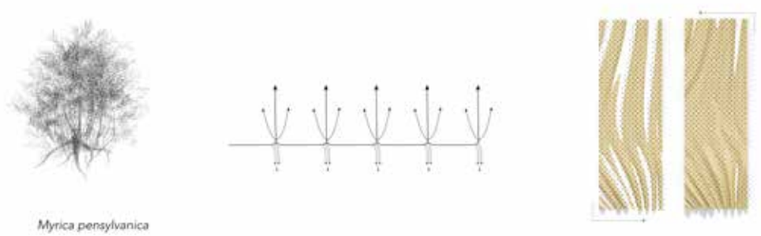


Figure 6.26: *Myrica*

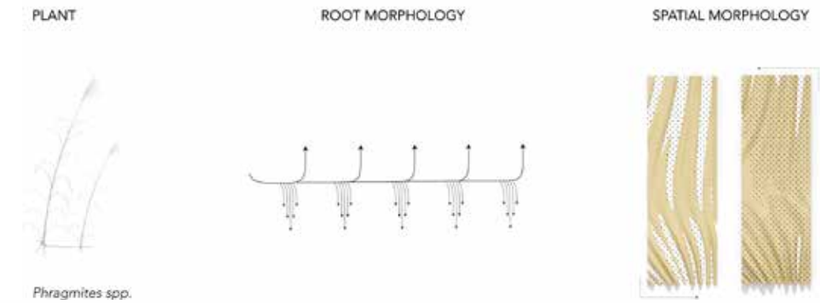


Figure 6.27: *Phragmites*

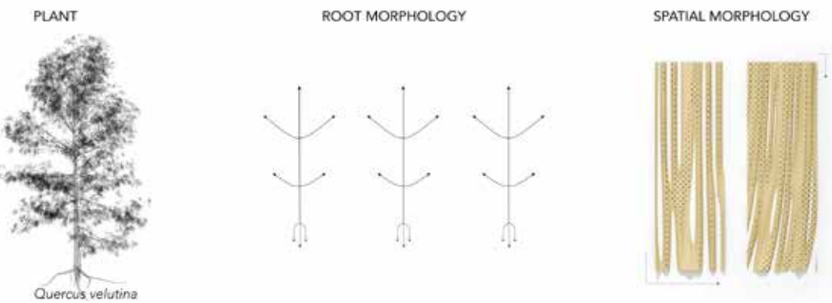


Figure 6.28: *Quercus velutina*

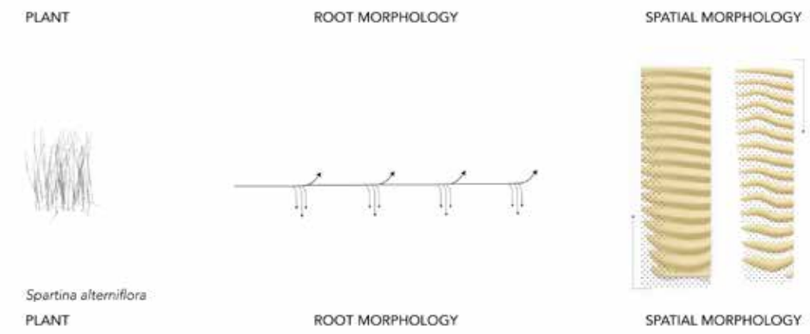


Figure 6.29: *Spartina alterniflora*

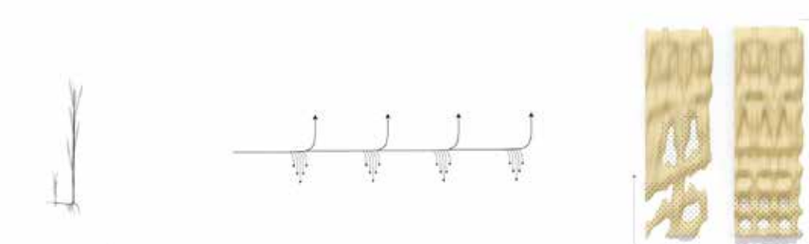


Figure 6.30: *Typha angustifolia*

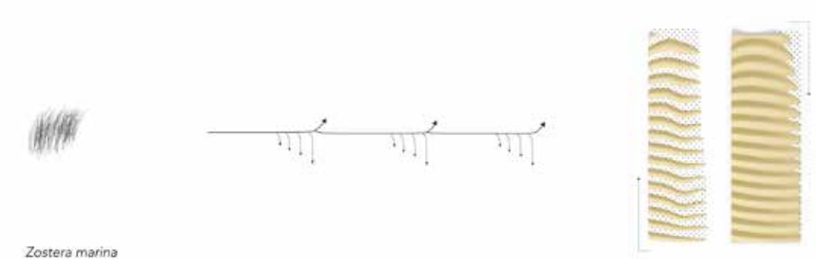
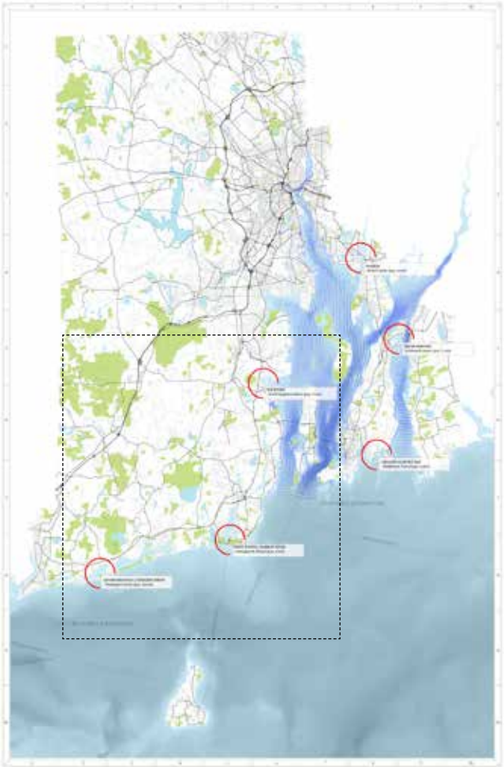


Figure 6.31: *Zostera Marina*



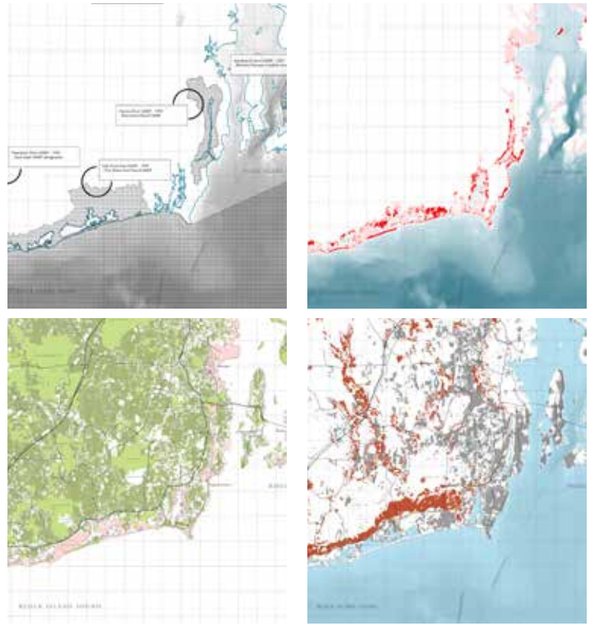


Figure 6.32: Sector A, Areas of Interest in a SLOSH Model

which is situated the Pleasant View neighborhood of Westerly at an average elevation of ~10' (Figure 6.33). Current surge (SLOSH) projections show that category 1 and 2 hurricanes would cover a significant portion of the community, and categories 3 and 4 hurricanes would have total coverage. With only an un-vegetated sand berm standing between the ocean and Highway 1A-Scenic, a dramatic evolution seems inevitable (Figure 6.34). The Winnapaug Lagoon is experiencing degradation of its marshlands due to septic nitrification, yet its surge attenuation qualities are not of benefit to Pleasant View, which occupies the land due west of the lagoon. Atlantic Beach/ Misquamicut Beach, is the closest public beach for many in both Rhode Island and Connecticut, and draws large seasonal crowds from the region. This places great demand on local economies including lodging, food and other beachfront structures or activities. The short-term gain of seasonal demands have kept the region from engaging in a more serious discussion about the long term viability of their coastal position.

What if the role of Highway 1A-Senic shifted from a distribution system for tourists to the next threshold that articulates the coastline? How could planting engage a transition to a lagoon region with longer-term inundation cycles, forest, and inward facing recreational coastlines? Our design scenario projects a waterfront highway sponsored by a variety of rich, inland forest features.

6.3.1.2 Greater Point Judith

Point Judith Road is the approximate seam connecting the two aforementioned coastal systems and water-sheds. The narrow river and its fjord like composition sits in juxtaposition to the Point Judith Lagoon with a barrier beach and very large tidal pond. The town and commercial port of Galilee sits at the mouth of the Point Judith Pond Breachway at an elevation of ~10' above sea level. Current SLOSH projections list the towns of Galilee, Jerusalem and Great Island as inundated, representing a population of approximately 50,000 (Figure 6.35). Point Judith is also the terminal gateway to the ocean, from the Narrow River Watershed. This places distinct pressure on the quality of water, dredging activities and ecology of the river basin, as it approaches the coast.

6.3.1.3 Wickford

The historic town of Wickford is set between a popular

Figure 6.33: Misquamicut Site Map

Figure 6.35: Greater Point Judith Site Map

Figure 6.34: Misquamicut Beach Sand Berm

recreational coastal forest (John H. Chafee Nature Preserve), and a site for military technology (Quonset Point). The northern reach of this zone offers a tremendous set of dynamics with which to research and investigate the areas of influence beyond "hot spots." The historic (1637) town of Wickford rests at ~5' above sea level with many of its limits corresponding with and below sea level during high tide (Figure 6.37). Any amount of surge would inundate nearly all of the historic fabric up to Highway 1A-Scenic. With a population of approximately 26,000 people [15], Wickford remains a commercially viable and active harbor and port, with 50 vessels operating in the west passage and points further. Projections for surge are some of the lowest in Greater Narragansett Bay due to a combination of its due east position and the breakwaters fronting its eastern passage. What is more of a threat to the region is sea level rise and overland wind and water. Often referred to as the "Venice of Rhode Island", its position in a lagoon complicates the ability for design to engage the rise of the water table (Figure 6.36).

What if Wickford added inundation to its historic catalogue, increasing the size of its port and its recreational harbor activities? Floating amenities, flexible structures and the crafting of a new history based on embracing the future. Our design scenario projects a diverse set of recreational and seasonal economies that offers a dynamic water-land associations and advanced albeit temporary dwelling.

6.3.2 Sector B—The Sakonnet River and Mt. Hope Bay

Sector B offers an opportunity to study an interconnected hydrologic system in which the areas of interest within the region will contribute to a distributed attenuation network. Based on the study of current MEOW and MOM projections for the region (Figure 6.38) four of six generalized storm directions induce an amplified effect through the Sakonnet River, and consequently Mt. Hope Bay and the Bristol Narrows. The position of each of the three areas of interest (Figure 6.39) has been chosen to study potential impacts associated with distributed attention, deconstruction and the effective range of NNBF.

6.3.2.1 Sachuest Bay and Reserve

At an average elevation of five feet above sea level, the peninsula of land situated at the convergence of Rhode Island Sound and the Sakonnet River consists of a shrubland and salt marsh wildlife refuge, public beach, and drinking water reservoir (Figure 6.40). Gardiner Pond and Nelson Pond, two of nine former salt marshes on the island, have been drained and repurposed for drinking water supply, while the reservoir delivers

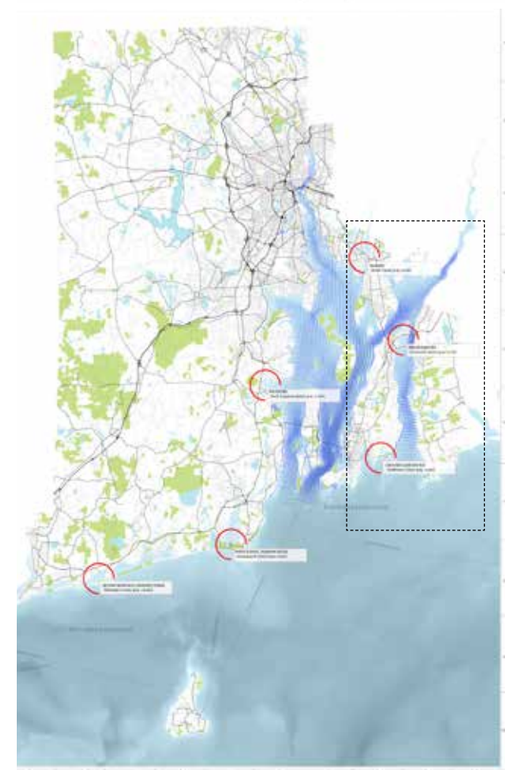
Figure 6.36: Wickford Cove

drinking water to the main towns of Newport, Portsmouth and Middletown. The ponds also connect the Maidford River, which helps balance their supply line, but adds burden to the water quality as the headwaters of the river originate in the agricultural heart of Middletown, Aquidneck Island [17] (Figure 6.41). Water levels frequently reach the uppermost level of the berm, which is the only interface between the wild life refuge and Newport east, and will become increasingly higher with sea level rise. This longer-term increase in direct water flow between Sachuest/ Rhode Island Bay(s) and the Sakonnet River intensifies the implications of surge funneling. Yet, given its position at the base of the Sakonnet River and its assumed long-term fate as frequently to continuously inundated, could design allow for the pond to have larger, positive impacts further up the river?

What if a dense, rhizomatic substrate could temper outwash and reduce wave action while at the same time offering the community a palette of species that could rebound after a storm event? How might the interplay between the USFWS, the USACE and the RIDEM engage the structural evolution of local habitat while addressing issues of surge funneling for the greater Sakonnet River Basin?

6.3.2.2 The Hummocks and Tiverton

At an elevation of only 20' at its highest point, the Hummocks, a former marsh, is home to a community dependent on saltwater fishing and aquaculture—a livelihood that is increasingly threatened due to water quality issues associated with growing population density (Figure 6.42). A long history of building on what was once a continuously evolving piece of land, cottages were initially constructed only for summer use, but have since evolved into permanent dwellings. The reality of houses that are of poor construction value



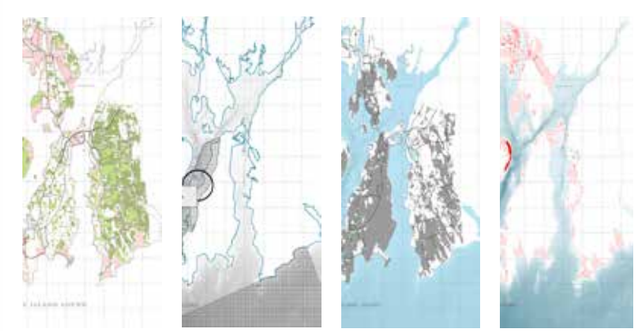
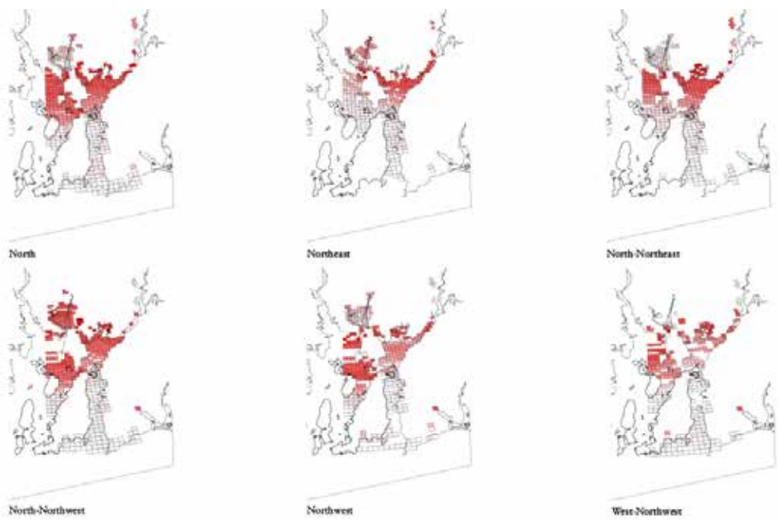


Figure 6.37: Wickford Site Map

Figure 6.38: Sector B, Areas of Interest in a SLOSH Model



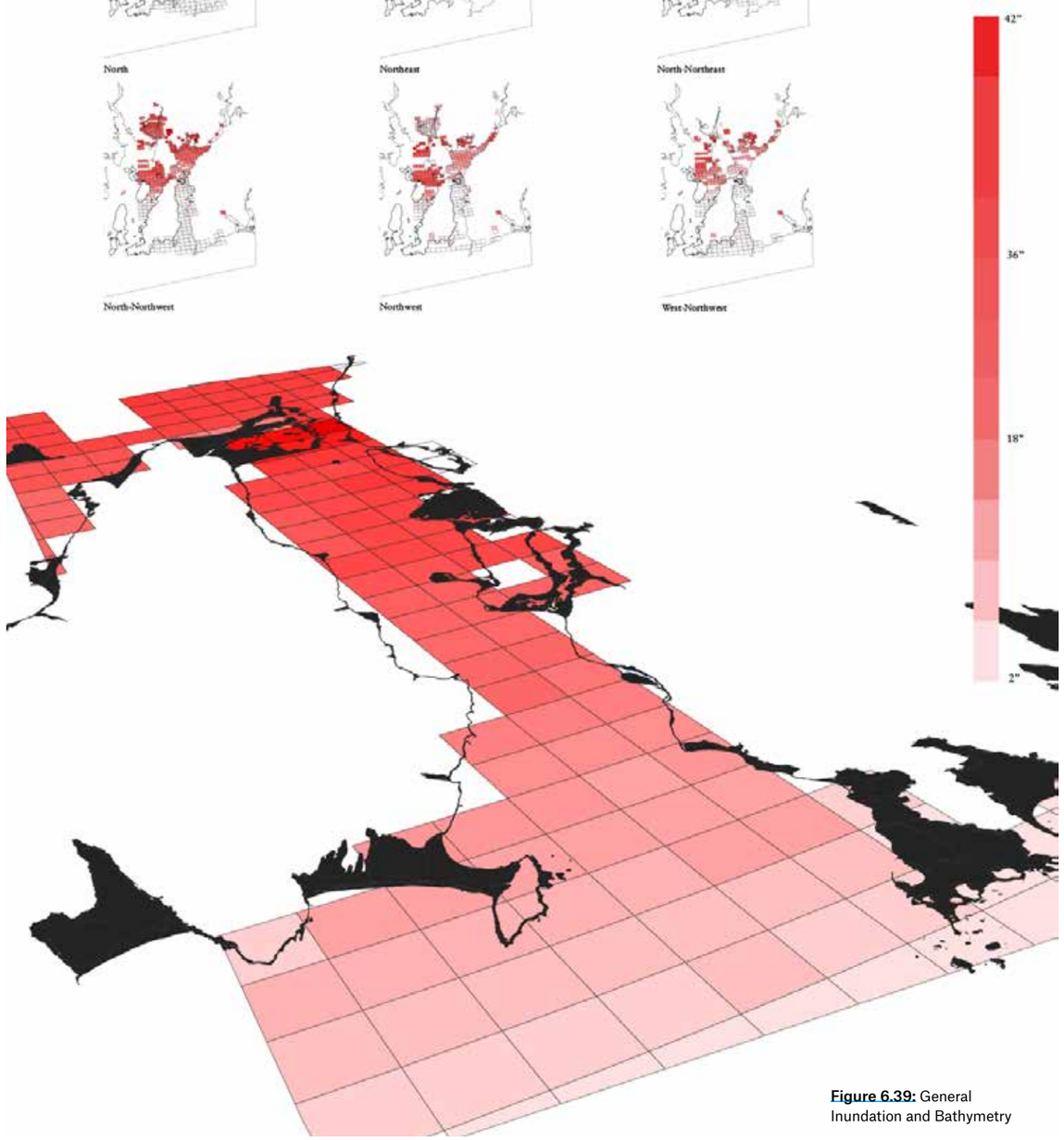


Figure 6.39: General Inundation and Bathymetry

and in low-lying areas is an example of property with a high short-term risk (Figure 6.43). The process of individuals building additions and supported by ad hoc infrastructure has produced a condition in which the current sewers cannot support year-round occupancy. Of the many externalities from its evolution, the intense nitrification of the interior coves and upper reach of the Sakonnet has resulted in 289 acres of impaired waterways now closed to swimming and aquaculture. Many homes are for sale, but many are not selling due to factors including poor water quality and the impending rise in the cost of flood insurance discussed in Section 1.1.6. Yet, given its position at the head of the Sakonnet River and preceding Mt. Hope Bay, a different way of considering buyouts, property ownership and regional flood management may be available.

What if the Hummocks could become an example of remote ownership patterns, aqua-cultural production, and subtraction urbanism—and in the event of a storm be completely submerged without social consequence?

What if it was designed to weather floodwaters?

Figure 6.40: Sachuest Base Map and Section

Figure 6.41: Gardiner Pond, Sachuest Bay Rhode Island

6.3.2.3 Warren and the Bristol Narrows

With a high point of approximately 90 feet above sea level, Warren's low lying area between the Warren River and the Bristol Narrows is home to several neighborhoods, a military post, and the Warren Reservoir. The historic town has a mixed-use character, with a mill-based industrial past. Most of Warren is built out, and is fulfilling the role of an up-and-coming RISD outpost. As part of a typical urbanization pattern in a postindustrial context, the municipality of Bristol has the highest percentage of impervious surface in RI, even higher than Providence. While Providence is a larger city, it boasts a robust street tree program and an integrated urban park system, which is not a part of Warren's current redevelopment pattern.

Located in the upper part of Narragansett, Warren experiences extensive surge dynamics due to a funneling effect of the Bay, as articulated by the Sakonnet River channel (Figure 6.44). The western edge of Warren, concerned with conserving ties to its postindustrial past, has limited foresight for inundation, while its eastern lowlands face more serious inundation projections. Elevations from Hurricane Carol in this region were approximately 13 feet.

What if Warren became a pervious and forested community that flipped its industrial past and turned towards an agrarian future? Why not grow and cultivate resilient species here, offering new economic incentives, a setting for future lifestyles and a percentage of ground that could tolerate seasonal floods and an industry regularized by surge?

6.4 Vision

The Harvard University Graduate School of Design (GSD) team is committed to a dialogue that applies resilience to an optimistic and articulated quality of transformation. Rather than deploying fear tactics or images of flood inundation to garner public support, we would like to offer a vision that is both revolutionary and firmly grounded in social and economic opportunity. Since 420 miles of Rhode Island coastline have been proven unsuitable for hard infrastructure, the state offers an exciting prospect to test and apply new structures of coastal resilience. As an ideal case study for developing NNBF—the estuary and its diverse ecologies offer a chance to profit from the embedded local stewardship and cognizance of climate change.

By working with a variety of allied disciplines, we have been able to develop ideas that are interrelated in geographic and time scales; through which the complexity of the issue inspires new models of practice and cooperation across a range of perspectives, from ecological to economic. In order to complement and augment initiatives already put forth by the USACE (United States Army Corps of Engineers), we have started our work with the principles of their operation including manual annotations and future iterations. Structures of Coastal Resilience (SRC) is instigated with the understanding that an interdisciplinary approach to the topic of coastal resiliency is essential, and Harvard's role expands that notion by calling on the free minds of well trained students to assist in the development of concepts and critical questions within the project.

6.4.1 Conclusions

As we have seen repeated in the past, the notion of 'solution' is predicated upon a definitive question. A consistent aim within this research project has been to formulate the right questions before attempting to provide any answers. While certainty has absolutely yielded some worthy endeavors, it now fails to respond to the complications of both time and space. Fixed solutions are not part of an ecological vocabulary, and so we are confident in determining that NNBF—while in a nascent stage—is promising as it applies to encouraging approaches that may not have been tested to scale. In order to avoid "new and improved" versions of the same designs that end up performing similar roles albeit in novel ways, we acknowledge that improvements will only emerge from testing and failing. Since sea level rise and climate change are not parameters that lend themselves easily to novelty, we are launching into Phase 2 by considering how we can actually

Figure 6.42: The Hummocks and Tiverton Base Map and Section

Figure 6.43: Step-Down Housing, The Hummocks – Island Park

Figure 6.44: Warren Base Map and Section Housing, The Hummocks – Island Park

propose something new in the face of uncertainty, where the only certainty is risk. The scale of space, the scale of modeled and tested features, and the scale of implemented works are interrelated in a ways that have not been fully enunciated thus far. It is our aim to articulate these in Phase 2.

6.4.2 Phase 2

NNBF will create a new landscape. Our preconceptions of natural or nature guide our senses, as such, we cannot presume or pretend that what we propose is in any way "natural". Innovation is not a smart way to learn from complexity. We have to test to learn. Our main conclusion is that the scale of effectiveness is based in our ability to accept change. If NNBF is to perform, it needs to start to hit the scale of implementation and examination. We propose that Rhode Island is the perfect case in point.

A major challenge of this project will be finding a method to make operational the sheer volume of information, most of it highly technical/scientific, in the service of making landscapes. This challenge comes in addition to the fact that the nature of landscape-making is disrupted in areas that are so highly vulnerable to storm surge and so likely to transmute into variable versions of itself in the coming decades. What this might all point to is a design philosophy that anticipates multiple revisions to (or outcomes for) the locations of interest, rather than the creation of a particular end state. For example, some sites may be washed away within a certain time frame. Reactions will be calibrated to the time frame that fits individual conditions. The need for iteration and phasing is forced by the conditions that will be transformed in the next century and before. The design work in phase 2 will be centered on guiding the interpretation of these evolving modes of knowledge and testing and retesting ideas for the physical forms of the site: anticipating the incremental changes that will happen in coming decades and shaping an evolving landscape based response. We will be working towards a vision of the future that encompasses durable and smart ideas of resilience. These ideas should be visibly transformative, but elemental, achieving 'pilot project' status in the short term.

6.5 References

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07

Shifting Sands: Sedimentary Cycles for Jamaica Bay, New York

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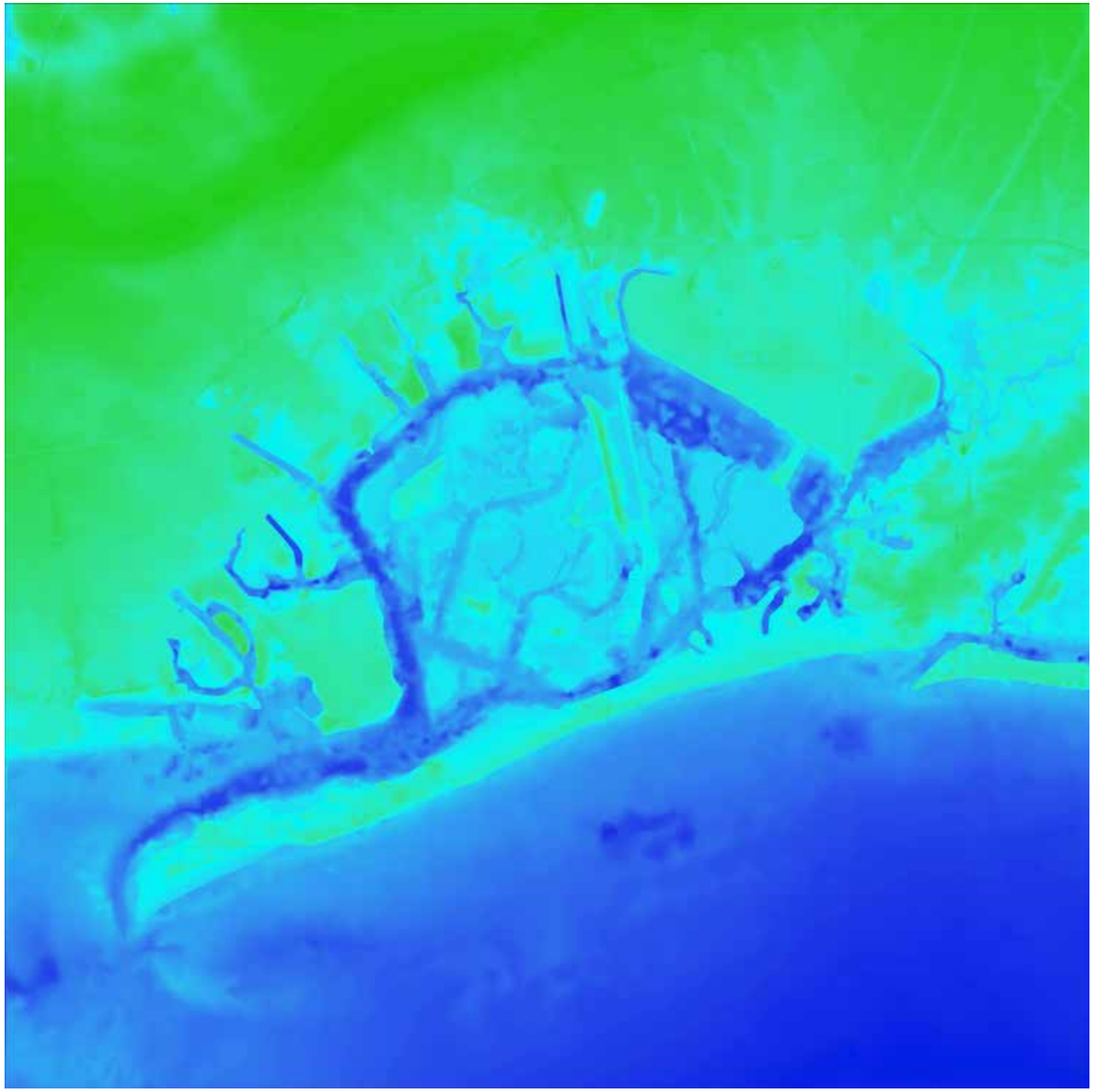
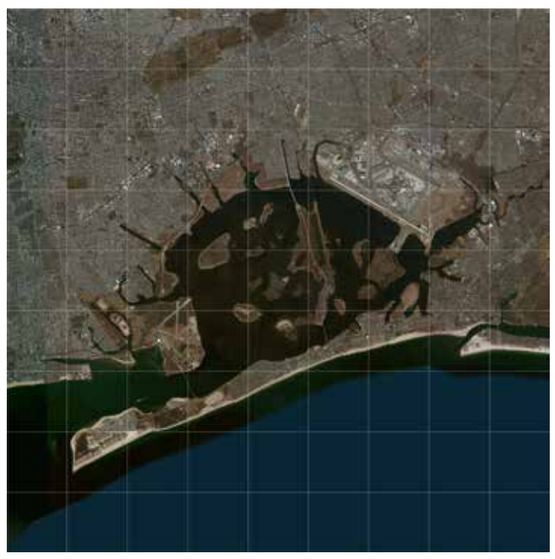


7.1 Introduction and Purpose

7.1.1 Structures of Coastal Resilience / North Atlantic Coast Comprehensive Study

The purpose of the Structures of Coastal Resilience grant is to supplement the work of the United States Army Corps of Engineers' North Atlantic Coast Comprehensive Study (NACCS), authorized in January 2013. The goals of the Comprehensive Study are to provide risk reduction strategies for vulnerable coastal populations within the North Atlantic Division of the USACE, and to ensure a sustainable and robust coastal landscape system given future sea level rise and climate change. It will also consider natural and nature-based features (NNBFs) to enhance the resilience of coastal systems, and study the role of NNBFs in reducing the impacts of coastal storm flooding and other impacts at a larger scale.



7.1.2 City College of New York / Mission

The Structures of Coastal Resilience grant has tasked the City College of New York's Graduate Program in Landscape Architecture with a design research project focusing on Jamaica Bay, New York. This is one of four study sites along the North Atlantic coast; each site is to be studied by one of four university research teams. The goal is to partner with the United States Army Corps of Engineers (USACE) to develop a comprehensive, resilient vision for the transformation of Jamaica Bay, exploring the possible paradigm shift of coastal storm protection that is being explored through the work of the NACCS. This research grant, led by Principal Investigator Catherine Seavitt, Associate Professor of Landscape Architecture, and her team of research associates, Kjirsten Alexander, Danae Alessi, and Eli Sands, is highly relevant to the missions of both The City College of New York and the Graduate Program in Landscape Architecture at the Spitzer School of Architecture. Founded in 1847, City College was the first public institution of higher learning in the United States; its mission was to provide an excellent education to students from all socio-economic and cultural backgrounds. Guided by this ideal, the college has evolved into a unique learning environment that draws energy from and contributes to the global metropolis of New York City. The program in landscape architecture aims to prepare students to design environmentally and socially vibrant landscapes for twenty-first century cities. The program addresses issues of increasing globalization, expanding urbanization, environmental and social system sustainability, the promotion of social and environmental justice, the need for transformed land management practices in response to diminishing natural resources, and the mitigation and adaptation to climate change.

Figure 7.0: Jamaica Bay, New York

Figure 7.1: Volunteers plant Spartina alterniflora plugs at Rulers Bar restoration, June 2013 (Source: Jamaica Bay Ecowatchers)

Figure 7.2: Jamaica Bay view of JoCo Marsh, JFK Airport runway, Brooklyn terminal moraine, and Manhattan skyline (Photo: Catherine Seavitt)

7.1.3 City College of New York / Approach

The City College of New York team is approaching Jamaica Bay as a holistic and comprehensive site, addressing the bay as an interconnected hydrologic, ecologic, and highly managed urban system, with the capacity to enhance coastal storm risk reduction and to provide for adaptive transformation given climate change, sea level rise, and heightened risk of flooding from hurricane storm surge and extropical storms. The team also supports the goals of identifying the vulnerable populations and ecosystems of Jamaica Bay, as well as enhancing social resiliency and environmental stewardship in these communities.

Many projects have been proposed, and some successfully implemented, to support both the environmental and social resiliency of the Jamaica Bay region. Prior to Hurricane Sandy, USACE worked closely with the local environmental groups American Littoral Society and Jamaica Bay Eco-Watchers, initiating restoration projects to counteract salt marsh loss at several islands within the bay, through both beneficial placement of dredge materials and strategic hand-planting of sea grasses. New federal and city initiatives are directed at improving the collaboration between the New York City Department of Parks and Recreation and the National Parks Service, whose Gateway National Recreational Area includes parcels throughout the Jamaica Bay region, including Floyd Bennett Field, the Jamaica Bay Wildlife Refuge, and Jacob Riis Park. The integration of improved opportunities for community and recreational uses for the adjacent dense and underserved communities of Brooklyn and Queens is another significant strategy for enhancing both environmental stewardship and social resiliency.

The impact of Hurricane Sandy on Jamaica Bay, the Rockaway Peninsula, and the surrounding communities in October 2012 was extensive. Urban development in the region has stressed and compromised the protective capacity of the marsh islands to reduce wave impact, surge velocity, wind forces, and the extent of flooding. Multiple layers of infrastructures, both "soft" and "hard," may be deployed to protect and transform the dense communities around the bay's perimeter, particularly vulnerable low-lying communities. As sea levels rise and the risk of storm surge and flooding from hurricanes and other storm events increases, the vast scale of Jamaica Bay allows this region of the city to be recast and re-structured as an impactful ecological, infrastructural, and community asset, reducing vulnerability and enhancing the region's resiliency.

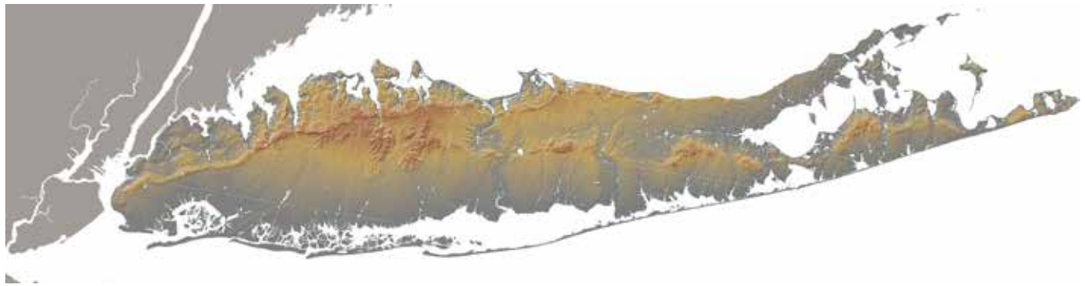


Figure 7.3: Long Island relief showing glacial moraine and outwash plain (Source: US Geological Survey)

7.2 Context

7.2.1 Geomorphology and Ecology

Jamaica Bay, located in the New York City boroughs of Brooklyn and Queens, is a 36-square mile water body (approximately 20,000 acres) and the westernmost embayment along the south shore of Long Island. The Rockaway Peninsula, a narrow barrier island, frames the bay's southern edge. The bay's waters connect to the Lower Bay of New York and the Atlantic Ocean via the Rockaway Inlet, at the western end of the peninsula. Jamaica Bay's historic watershed captured approximately 142 square miles from the terminal moraine ridge southward across the outwash plain, with numerous upland streams from the west, north, and east providing fresh water and sediment to the bay. Extensive low-lying salt marsh islands and intertidal flats dominate the center of the bay. A rich ecological resource for the greater region, this estuarine area provides a diverse habitat complex for fish, birds, and plants, including salt marsh, grasslands, maritime forest, and woodlands.

Historically, Jamaica Bay was an abundant shellfishery, but as the city around it expanded, pollutants were discharged into the bay via its tributary streams, resulting in poor water quality and disturbed habitat areas as well as a loss of upland and wetland buffer zones. The mollusk population was essentially depleted by the 1920s. As extensive urban development and impervious land cover in the upland zones of the Jamaica Bay region increased, the historic watershed was redefined as a constructed sewershed, including inputs from much of Brooklyn and Queens as well as parts of Nassau County at the eastern end of the bay. Most storm water is now channeled through storm sewers, removing input from its previous freshwater tributary sediment sources, producing a sediment-starved bay system. Pollutants delivered directly to the bay from both point and nonpoint sources in the sewershed include municipal waste water discharge from four treatment plants (approximately 340 million gallons per day), combined sewer overflow (CSO) outfalls, and untreated direct storm water runoff (including de-icing chemicals used on the runways at John F. Kennedy International Airport).

Nutrient and organic matter inputs result in phytoplankton blooms, low levels of light transmission, and low bottom dissolved oxygen concentrations. Increased levels of nitrogen in the bay have caused an enormous loss of acreage of the bay's salt marsh islands; as sea levels rise, these wetland ecosystems will be further compromised. Three closed and capped landfills (Edgemere, Fountain Avenue, and Pennsylvania Avenue) and historic dumping sites ring the bay's perimeter; leaching toxic and heavy metal contaminants are a risk. In addition, substantial water transportation of oil and chemical products in the bay creates an added potential risk of spills. These many pollutants continue to affect the sustained health of Jamaica Bay's marsh islands, water quality, and benthic environment, compromising the ecological health of the bay.

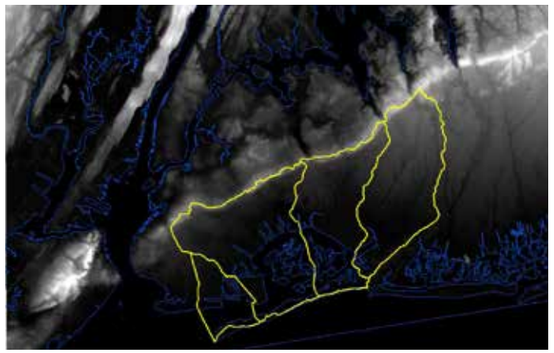


Figure 7.4: Digital Elevation Model (DEM) with Jamaica Bay Watershed

Figure 7.5: Topographic relief model of Jamaica Bay Watershed

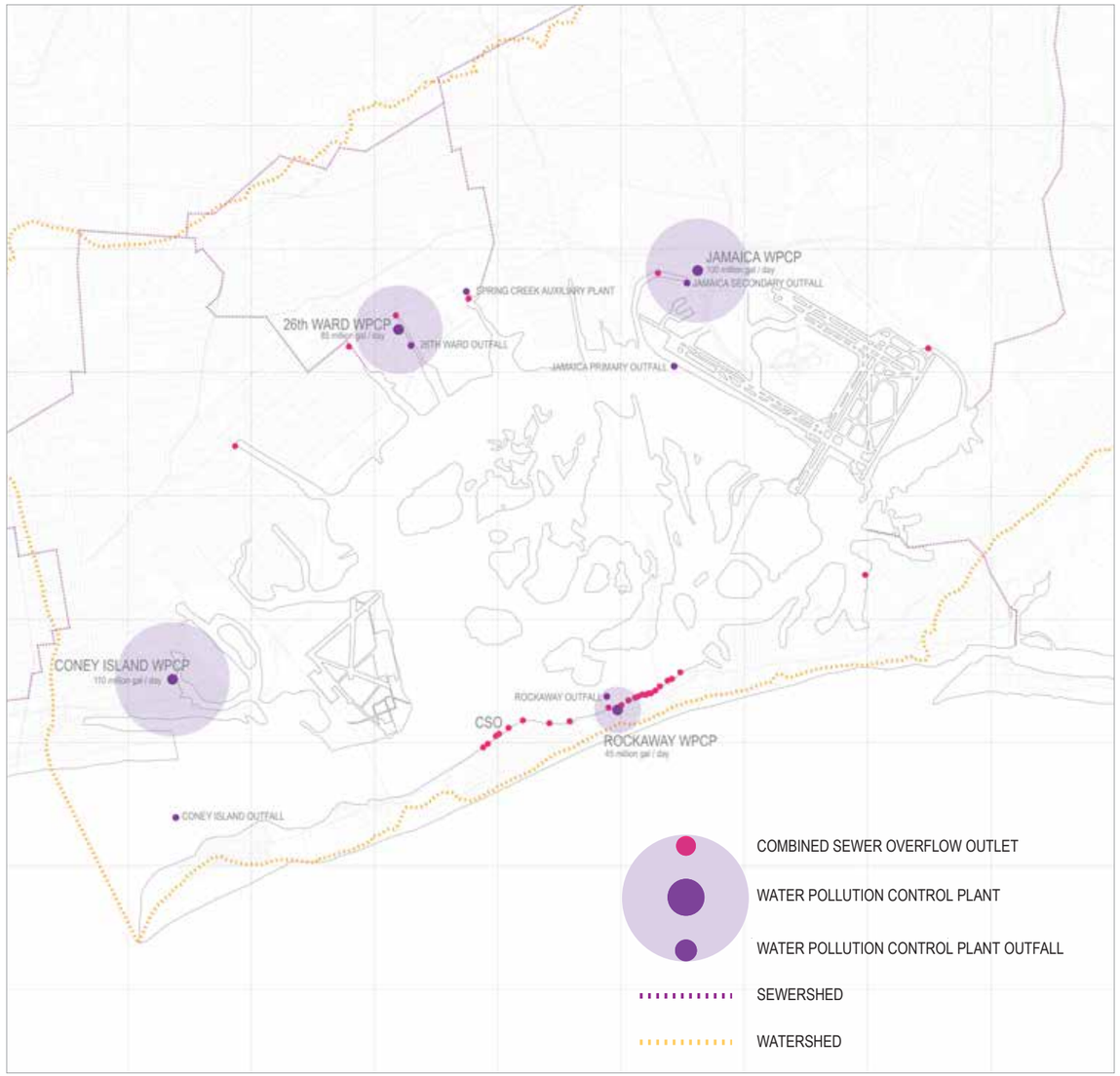


Figure 7.6: Jamaica Bay watershed, sewershed, and related infrastructure

Jamaica Bay was once comprised of natural dendritic channels, approximately 10-25 feet deep, meandering through shallower marshy areas. Navigational dredging began in the early twentieth century, producing channels of a minimum depth of 15 feet (and often up to 40 feet deep) wrapping the west / north-west edge of the bay and along the bayside edge of the Rockaway Peninsula. During the 1920s, several of the tributary streams were dredged to create one-mile long channels for a proposed municipal port. Borrow pits, exceeding forty feet in depth in some locations, are located at the bayside margins of both of the municipal airports that

frame the site, the disused Floyd Bennett Field to the west (closed as a municipal airport in the early 1940s) and the John F. Kennedy International Airport to the east (opened in the mid-1940s). Dredge material from these pits served to fill and level the wetlands at these two sites. The deep borrow pits in the bay exacerbate poor water quality by increasing residence time and causing hypoxic (low dissolved oxygen) or anoxic (no dissolved oxygen) conditions, particularly at Grassy Bay.

Currently the US Army Corps of Engineers dredges only the wastern entrance channel to Jamaica Bay, the Rockaway Inlet (Jamaica Bay Federal Channel), to a working depth of approximately 20 feet and width of 1000 feet. In 2009, USACE maintenance dredging removed approximately 330,000 cubic yards of sand from Rockaway Inlet, which was beneficially reused for capping at the Historic Area Remediation Site (HARS) and beneficially placed at White Island, Gerritsen Creek. In 2012, approximately 350,000 cubic yards of sand were removed and beneficially reused at HARS.

Most recently, sand was removed from the channel for the shore protection of the Rockaway Peninsula and Coney Island beaches using Flood Control and Coastal Emergencies (FCCE) funding made available in the aftermath of Hurricane Sandy. The next maintenance dredging will likely be scheduled for 2015 / 2016. Navigation in the channel has a five-year average annual commercial tonnage of 560,683 tons; major commodities transported through the inlet include petroleum and petroleum products, chemicals, and sand, gravel, and stone.

Other navigational channels within the bay are used by the New York City Department of Environmental Protection (NYCDEP) sludge barges serving the municipal waste water treatment plants, as well as by other commercial and non-commercial vessels, but at the moment these interior channels are not dredged by the USACE. Sedimentation of the interior channels appears to occur extremely slowly, due to the lack of any significant sediment input from the Jamaica Bay watershed.

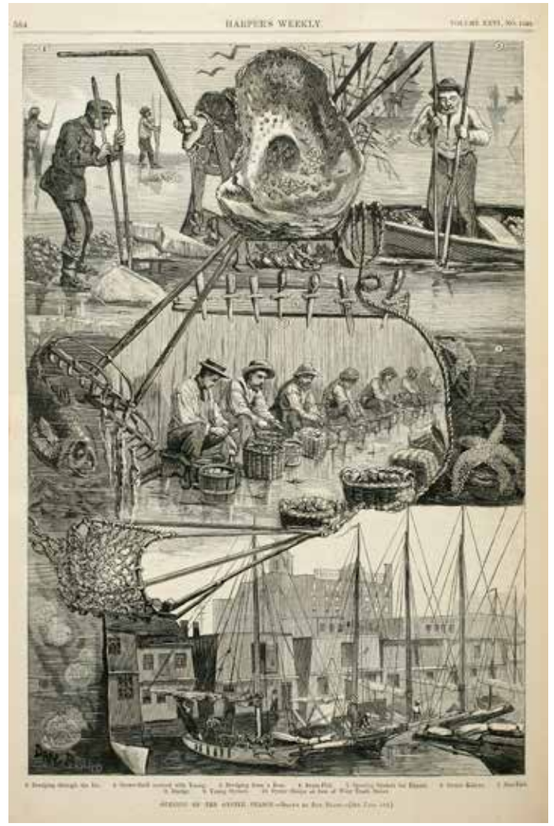
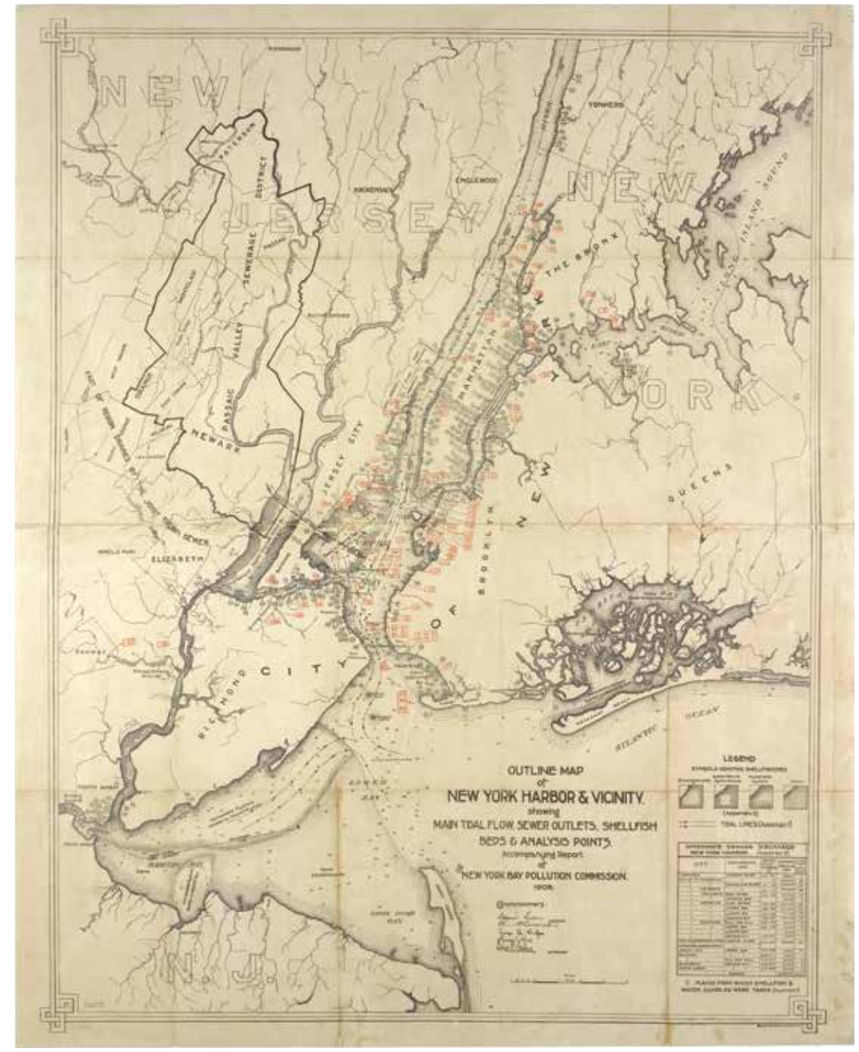


Figure 7.7: Daniel Beard, "Opening of the Oyster Season," in *Harper's Weekly*, September 16, 1882 (Source: New-York Historical Society, negative no. 82152d)

7.2.2 Social and Cultural History

The historic and prehistoric use of Jamaica Bay by humans has been extensively studied by Frederick Black, as part of his 1981 report to the National Park Service's Division of Cultural Resources, "Jamaica Bay: A History." Much of Jamaica Bay was acquired by the Department of the Interior's National Park Service with the creation of the Gateway National Recreation Area in 1972. The relationship of cultural and natural phenomena at Jamaica Bay from prehistoric time through the present is an intricate and transforming relationship, reflecting the changing demographics and ecological health of the environment. Further studies on the contemporary relationship of culture and nature in the Jamaica Bay region have been undertaken by the National Park Service's Northeast Region Ethnography Program, documented in William Kornblum and Kristen Van Hoorewegh's 2012 report, "The Changing Traditional Uses of Jamaica Bay, New York." Additional studies on the environmental stewardship of parks and



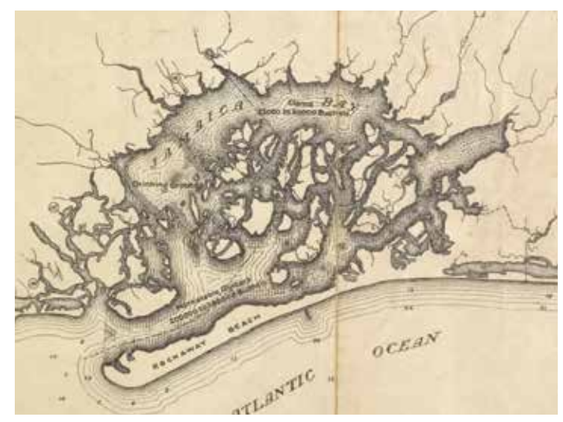


Figure 7.8: New York Bay Pollution Commission, "Outline Map of New York Harbor and Vicinity, showing Main Tidal Flow, Sewer Outlets, Shellfish Beds and Analysis Points," 1905 (Source: The Lionel Pincus and Princess Firyal Map Division, The New York Public Library)

open spaces in the highly urbanized landscape of Jamaica Bay are currently being undertaken by the USDA Forest Service's New York City Urban Field Station.

Dutch settlers arrived to Jamaica Bay in the early seventeenth century, sharing "de Baye" with several Native American tribes, including the Canarsie and Rockaway. Their settlement on the western shore of Jamaica Bay fell into the jurisdiction of the town known as "Flatlands" after the English conquest of 1664. A naturally rich fishery, diverse finfish and shellfish were extracted from the bay for consumption, and its upland borders were used for agricultural purposes, particularly the harvesting of salt hay, which was used as livestock feed. Prior to the Civil War, commercial shellfishing became much more significant, thriving into the second half of the nineteenth century. This commercialization of the region's natural fishery led to localized alteration of the bay through the establishment of seed oysters and hard clams in artificial beds as well as the increased use of dredges for harvesting. The oyster and clam industry was relatively short-lived, particularly as increasing urbanization at the bay's margins in the flatlands led to significant sewage inputs via the freshwater tributary streams. Typhoid and other water-borne diseases led to official municipal closure of all shellfish beds by 1921.

In the second half of the nineteenth century, the Rockaway Peninsula developed as a popular seaside resort for the growing middle-class New Yorkers, who filled its seaside bungalows and amusement parks. Transportation access to the oceanfront beaches became an issue. Ferry service and deepened navigational channels were established by the Canarsie Railroad Line, and by 1887 a cross-bay train trestle was constructed by the New York, Woodhaven, and Rockaway Railroad. This line was sold in 1886 to the Long Island Railroad, which renamed it the New York and Rockaway Beach Railway. It was purchased in 1955 by the City of New York, reconstructed, and incorporated into the city's subway service as the IND Rockaway Line; it now carries the Metropolitan Transportation Authority's A and S trains across Jamaica Bay. The trestle pilings caused some obstruction of the bay's creeks and waterways, as did the development of the Flynn Cross-Bay Roadway (now the Cross Bay Boulevard) traversing the bay. Yet the Canarsie Line, the train trestle, and the Cross Bay Boulevard led to the transformed perception of the

Figure 7.9: Goose Creek stop on Long Island Railroad, c. 1914 (Arthur John Huneke arrts-arrchives.com)

Figure 7.10: Jacob Riis Park traffic circle location, 1936 (Source: New York City Parks Photo Archive)

Figure 7.11: Jacob Riis Park, new beach retaining wall to be completed, 1936 (Source: New York City Parks Photo Archive)

Figure 7.12: Parking lot at Jacob Riis Park, 1956 (Source: New York City Parks Photo Archive)

bay itself as an enjoyable place of recreation. Many believed that the waters of the bay were healthier and safer for swimming than the Atlantic beachfront of the Rockaway Peninsula. And recreational fishing grew, along with the development of the Canarsie area as a small resort, leading to the construction of hundreds of fishing shacks which eventually developed into the marsh island communities along the trestle such as Broad Channel and the Raunt. Mounting pollution led to the decline of fishing and the eventual deterioration of Canarsie Landing as a pleasure spot.

Yet Jamaica Bay has also been historically perceived as a dumping ground, and pollution from sewage, municipal refuse, and industrial waste has a long legacy. Near the mouth of the Rockaway Inlet, Barren Island became the site of two industrial factories in the late 1850s, producing fish-oil and fertilizer from the city's dead carriage horses, transforming the character of the area now known as Dead Horse Bay. The accessibility of Barren Island to commercial shipping was ideal, as these products were generally exported to Europe. The noxious odors from horse-rendering and the first-generation immigrant and African-American labor force at the factories enhanced the perception of the bay as a place held in low esteem.

After the consolidation of Jamaica Bay into Greater New York in 1898, proposals were made by Comptroller Edward Grout and others in 1905 to transform the bay into an international deep-water port with man-made industrial manufacturing islands at its center. The relatively shallow waters of the bay would require significant dredging for such a port enterprise, and alterations were initiated in 1912 by the Department of Docks. A navigational channel was dredged at the Rockaway Inlet, and Mill Basin, a main shipping channel, was created, along with the channelization of several other existing tributary streams. Floyd Bennett Field was created through the filling of the marsh islands near the inlet, including Barren Island. Yet by the 1930s, the shortcomings of the port proposal became evident.

Robert Moses, the New York City Department of Parks Commissioner from 1934-1968, offered a radically alternative vision of the bay as a public park, a place for recreation and wildlife, in a 1938 booklet entitled "The Future of Jamaica Bay." He wrote, "Jamaica Bay faces today the blight of bad planning, polluted water, and garbage dumping. Are we to have here another waterfront slum, depriving millions of future inhabitants of Brooklyn and Queens of the advantages of boating, fishing and swimming in safe inland waters?" With financing from the Marine Parkway Authority in 1937, Moses began construction of the Belt Parkway, which linked the greater city to the Rockaway Peninsula via the Flatbush Avenue extension and the new Marine Parkway-Gil Hodges Memorial Bridge, opened in 1937, as well as the Cross Bay Bridge and Parkway, completed in 1939. The Shore Parkway, the Belt Parkway's section at the northern edge of the bay, was completed by 1940, providing direct automobile access to the recreational opportunities at Jamaica Bay and the Rockaway Peninsula.

Moses also built sewage treatment plants and constructed two artificial freshwater ponds in the 1950s, East Pond (100 acres) and West Pond (45 acres), as part of the Jamaica Bay Wildlife Refuge. Anchored amidst the salt marsh islands of the bay north of Broad Channel, the ponds were constructed from the excavation of dredge material for use as part of the reinforcement and reconstruction of the Long Island Railroad trestle by the city, after it was nearly destroyed by fire in 1950. This perception of the bay as a park continues today as part of the National Park Service's vision of the Gateway National Recreation Area. Yet Moses' legacy at Jamaica Bay had a darker aspect as well, particularly as he shaped public housing locations as a replacement for the then-struggling seaside resorts of the Rockaway Peninsula in the 1950s. Through his control of the New York City Housing Authority, Moses marginalized the city's poorest population in isolated towers far from the center of the city. Despite the consensus by the mid-1960s that these imposing towers were substandard when considered from positions of both urban planning and social justice, the construction of high rise low-income housing continued in the Rockaways until the last project, the Beach 41st Street Houses, was completed in 1972.

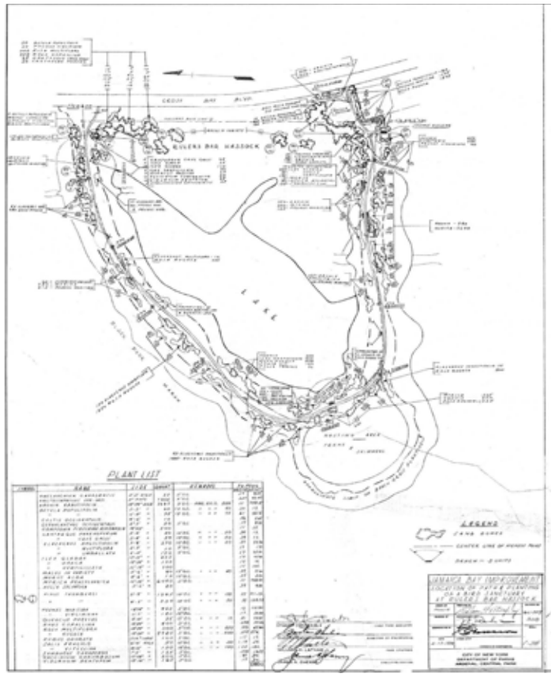


Figure 7.14: Planting Plan for Jamaica Bay Wildlife Refuge, 1954 (Source: NYC Parks Map Division)

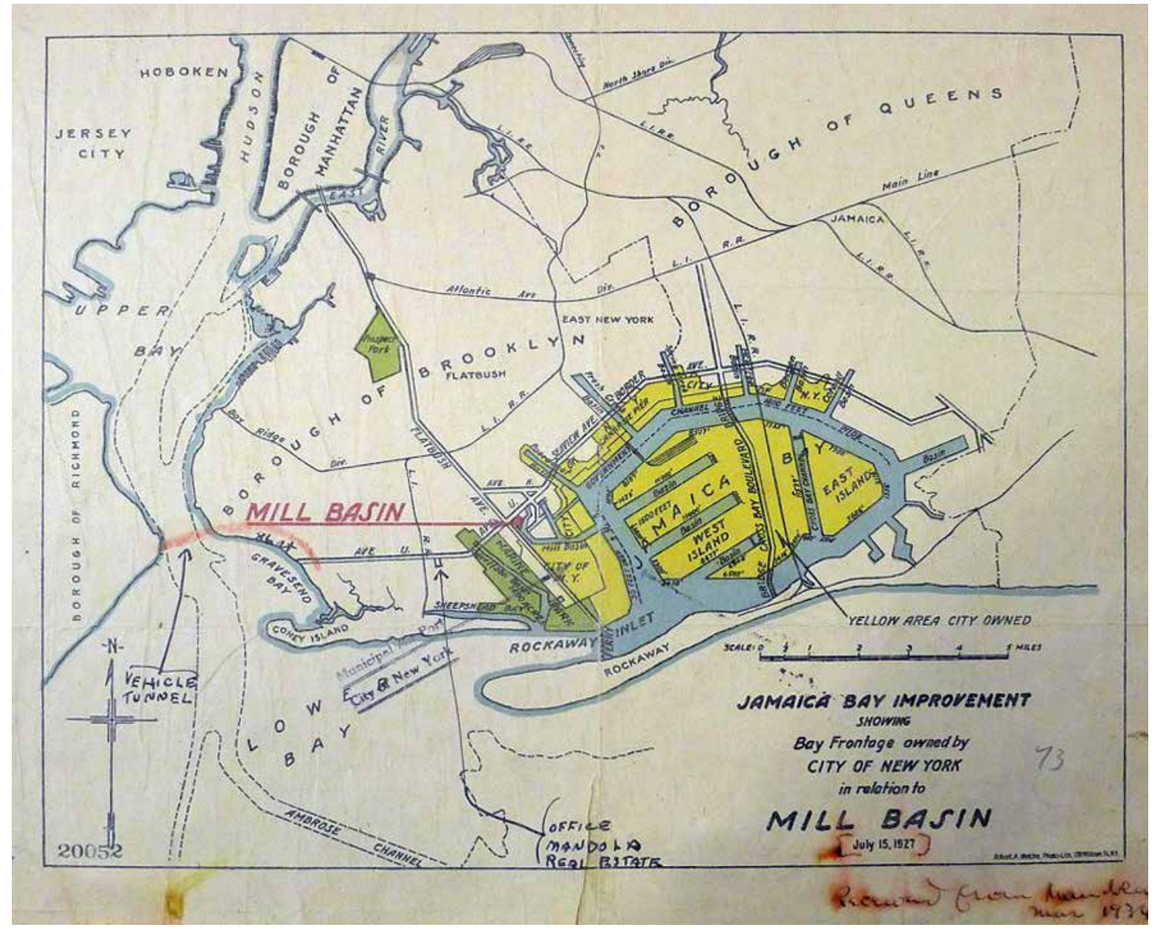


Figure 7.15: Jamaica Bay Improvement Plan, 1927 (Source: The Lionel Pincus and Princess Firyal Map Division, The New York Public Library)

Figure 7.13: Plan for Jamaica Bay Wildlife Refuge, 1959 (Source: NYC Parks Map Division)

Figure 7.16: Barren Island Factories, 1916 (Source: Brooklyn Public Library Image Archive)

The National Park Service's Gateway National Recreation Area was authorized in 1972. Recently, in support of a new General Management Plan for Gateway, research for the 2012 report "The Changing Traditional Uses of Jamaica Bay, New York" was undertaken to study how people perceive and use the park's natural resources. Perhaps most importantly, the report identifies the significant demographic changes and community characteristics that have changed so rapidly in the forty-two years since the establishment of Gateway. The communities in the Jamaica Bay region have a rich cultural, racial, and religious diversity, and each of these cultures brings different values and needs to the bay. A deep understanding of these traditional cultural practices, values, and identities is critical to the National Park Service as it assesses its visitors and neighbors in this complex urban environment. The NPS also seeks to understand those who are attached, for diverse reasons, to Jamaica Bay, its lands, and its waters, to better understand how their stewardship of this place can support Gateway's mission.

Stewards are not always adjacent neighbors, but they may be drawn culturally to the space of Jamaica Bay from afar. For example, Native Americans have been using Floyd Bennett Field every summer for nearly fifteen years to host their annual Powwow festival. Participants come from throughout North and South America, and the site is associated with the reinforcement of Native American cultural traditions such as music, dancing, and prayers.

Yet the neighborhoods adjacent to the bay, particularly the older and more stable communities, play a very important role because of their historical and cultural attachment to Jamaica Bay's natural resources. The Sebago Canoe Club at Paerdegat Basin, Canarsie, for example, is one of the oldest canoe clubs in the Northeast, and has been actively rowing on the waters of Jamaica Bay since 1933. Communities such as Howard Beach, Broad Channel, and the enclave communities of the Breezy Point Cooperative (Roxbury and Breezy Point) are home to many fishermen, boating families, naturalists, and increasingly, a strong representation of environmental activists. These individuals have formed influential environmental groups such as the Eco-Watchers, the American Littoral Society, and the Floyd Bennett Gardens Association, and they play an important role on Jamaica Bay task forces and advisory boards.

Figure 7.17: Powwow at Floyd Bennett Field, 2012 (Source: Goldberg Report blogspot)

Figure 7.18: Sandy relief volunteers at Rockaway Beach Surf Club, 2012 (Source: Chris Tackett for Treehugger)

Since the 1990s, however, the demographics of communities around Jamaica Bay have been rapidly transforming. The older white populations of Irish and Italian middle class neighborhoods are diminishing, while Hispanic populations are increasing, as are those of West Indian, Caribbean, and Asian origins. Interestingly, these new cultural groups are often drawn to the resources of Jamaica Bay through religious associations. The proximity to water for ritual purposes has been particularly noted in the cultural use of the Bay by Hindi congregations, particularly the Guyanese and South Asian residents of Richmond Hill, Queens, who often gather near the North Channel Bridge at Howard Beach. Hindu ritualism focuses on the balance of purity and impurity, and placing offerings into a water body, considered a thing of pure status, serves as a blessing to increase purity. Recognizing the cultural and ecological issues shared by both religious and environmental awareness must be sensitively addressed as populations in Jamaica Bay are transformed.

The Rockaway Peninsula has also been the site of rich social and community activism, often addressing the social justice issues that were the legacy of Robert Moses and others. Groups such as the Rockaway Waterfront Alliance work to strengthen local waterfront communities and to sustain environmental, economic, and social health by supporting environmental education and stewardship. More recently, spurred by the conditions in the aftermath of Hurricane Sandy, the Rockaway Beach Surf Club became a networked center of relief, support, and leadership for the greater Rockaway Beach community.

Figure 7.19: Hindu ceremony at Jamaica Bay, 2011 (Source: Sam Dolnick for the New York Times)

Figure 7.20: Offering remnant, 2012 (Source: LittleIndia.com)

7.3 Storm Risk Reduction at Jamaica Bay, 1964-2014

7.3.1 Catalog of Protective Strategies: Singular vs Multiple

The Jamaica Bay research team has analyzed both historic USACE storm risk reduction proposals for Jamaica Bay from 1964 and 1986, as well as those for "South Queens" appearing in the recent New York City Special Initiative for Rebuilding and Resilience (SIRR) report, published in July 2013 as PlaNYC: A Stronger, More Resilient New York. Despite this span of 50 years, two alternative strategies for Jamaica Bay have emerged: a singular large-scale protective initiative for the entire bay, versus a suite of smaller, local scale initiatives for vulnerable communities within the bay and along its margins.

The singular large-scale protection initiative is represented by a massive storm surge barrier at the Rockaway Inlet, together with full beach protection along the Atlantic coast of the Rockaway Peninsula. The barrier location varies; the USACE report of 1964 locates it at the Gil Hodges Memorial Marine Parkway Bridge, while the SIRR report of 2013 places it along a transect from Coney Island's Manhattan Beach to Rockaway Peninsula's Breezy Point, increasing the protected area. By contrast, the strategy of multiplicity works to protect individual communities at a smaller scale (Howard Beach, Breezy Point, Canarsie, Broad Channel, Far Rockaway, etc). These smaller-scaled initiatives allow the scale and fetch dimension of the bay, as well as nature-based storm protection features such as the nourished marsh islands, to operate performatively as a component of local storm risk reduction. A similar strategy of multiplicity may be noted in the fifty-five restoration sites at Jamaica Bay identified in the USACE's Draft Hudson-Raritan Estuary Comprehensive Restoration Plan of 2009.

Both of these strategic approaches (the singular and multiple) will be examined in light of both ecosystem services and protective capacity given implementation times, performance of nature-based features, sea level rise, new risk maps, and the possibility of future retreat scenarios. A combination of approaches, as suggested by the SIRR report, is certainly a possibility. Most recently, the USACE's recasting of its current set of ecosystem restoration projects and coastal storm protection initiatives in Jamaica Bay as part of a unified suite of storm protection strategies will be studied.

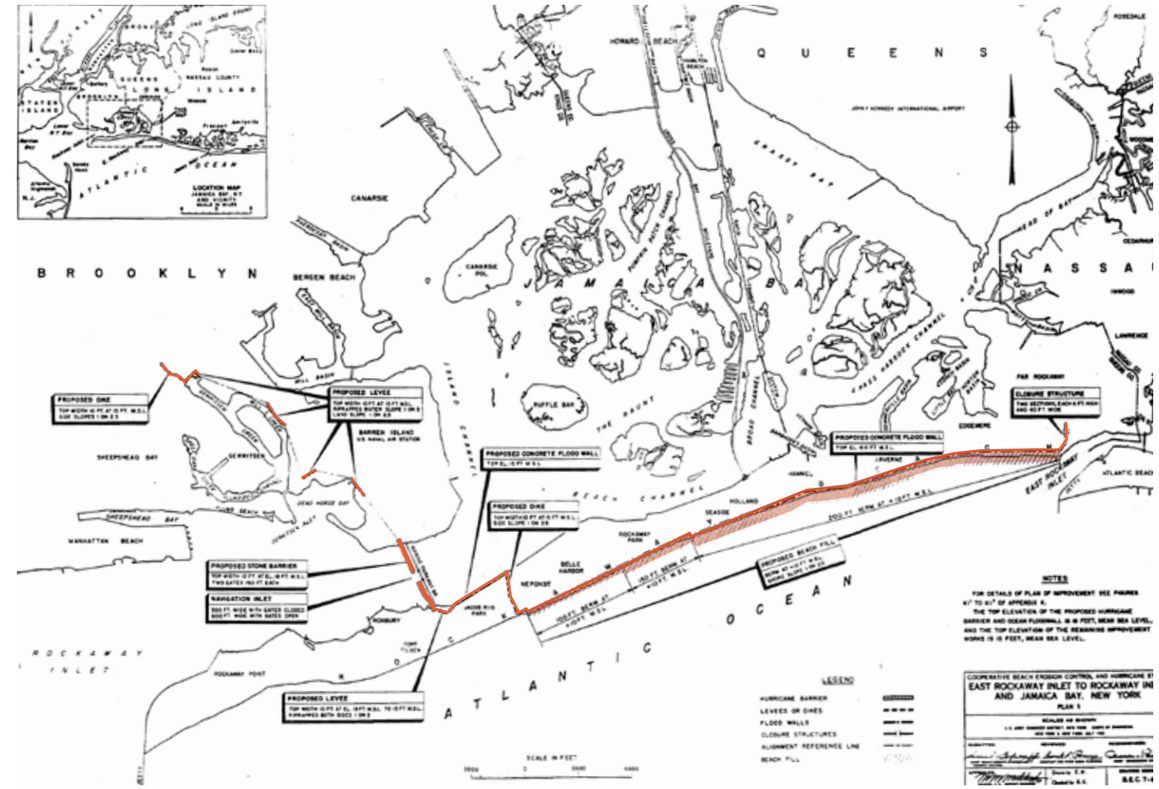


Figure 7.27: 1964 Plan One: Continuous linear protection for Jamaica Bay (Source: US Army Corps of Engineers)

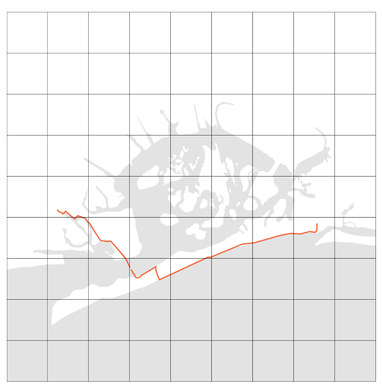


Figure 7.21: 1964 Plan One: Continuous linear protection for Jamaica Bay (Source: US Army Corps of Engineers)

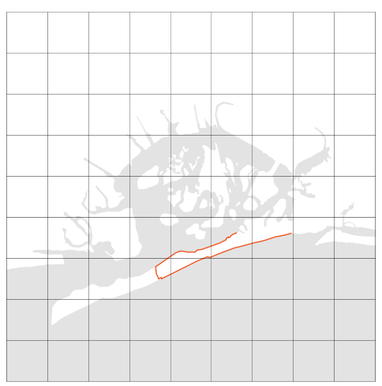


Figure 7.22: 1964 Plan Two: Continuous linear protection for Rockaway Peninsula (Source: US Army Corps of Engineers)

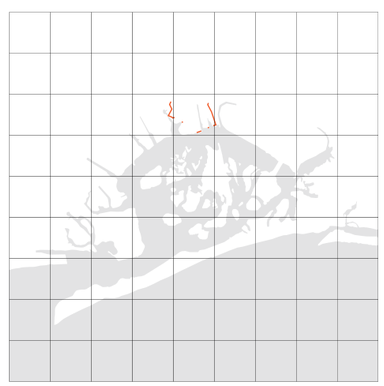


Figure 7.23: 1964 Plan Three: Local protection for Howard Beach (Source: US Army Corps of Engineers)

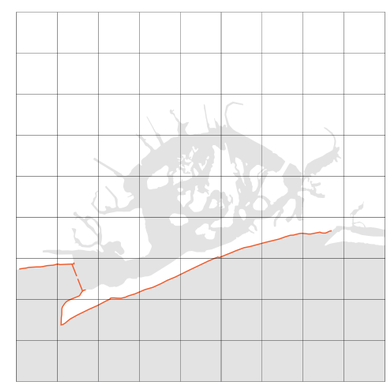


Figure 7.24: 2013 SIRR continuous protection plan (Source: The City of New York)

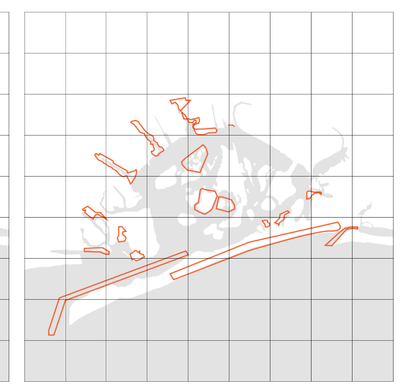


Figure 7.25: 2014 USACE ongoing projects (Source: US Army Corps of Engineers)

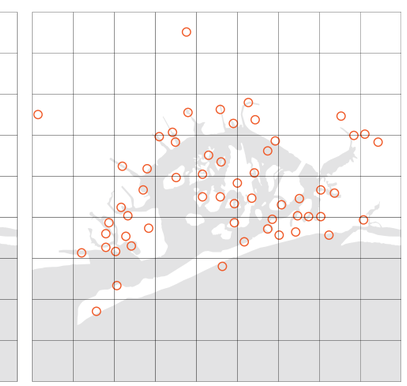


Figure 7.26: 2009 Draft Hudson-Raritan Estuary restoration opportunities (Source: Harbor Estuary Program and US Army Corps of Engineers)

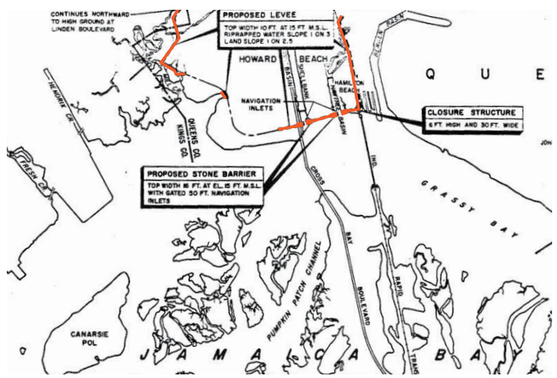


Figure 7.28: 1964 Plan Three: Local protection for Howard Beach (Source: US Army Corps of Engineers)

7.3.2 1964 Cooperative Beach Erosion Control and Hurricane Study

Plan One: Continuous linear protection for Jamaica Bay

Continuous berms at 10′ above MSL in front of concrete sea walls at 18′ above MSL on the Atlantic Coast of Rockaway Peninsula, a sea wall 10′ above MSL crossing the peninsula west of Neponsit and continuing west on the bayside shore to the Marine Parkway Bridge, a stone storm surge barrier 16′ above MSL across Rockaway Inlet, and local levees 15′ above MSL at Dead Horse Bay, Mill Creek, and Gerritsen Creek.

Plan Two: Continuous linear protection for Rockaway Peninsula

Continuous berms at 10′ above MSL in front of concrete sea wall at 18′ above MSL on the Atlantic Coast of Rockaway Peninsula, a 10′ - 15′ sea wall across the peninsula west of Neponsit and continuing east on the bayside shore to Edgemere.

Plan Three: Local protection for Howard Beach

Stone barriers from 10′ to 15′ at Shellbank Basin, Hawtree Basin, and Spring Creek provide protection for the low lying community of Howard Beach.

7.3.3 1977-2004 East Rockaway Inlet to Rockaway Inlet and Jamaica Bay (Rockaway Beach)

The USACE's East Rockaway Inlet to Rockaway Inlet project study area is located along the shoreline on the Rockaway Peninsula in New York City, and was authorized by Congress as a 100-200 foot wide beach at an elevation of ten feet above Mean Low Water from Beach 149th Street to Beach 19th Street, approximately 6.2 miles. From 1977 until 2004, the Corps of Engineers designed, constructed, and maintained the project. Because of the high cost of the construction, continued nourishment, and the continued challenge of the eroding shoreline, the Corps was directed to "reformulate" the original plan, with the objective of finding a long term, cost-effective solution to the effects of continued erosion on the Rockaway peninsula.

Source: USACE Fact Sheet: East Rockaway Inlet to Rockaway Inlet (Rockaway Beach), New York District. Current as of Nov 2013.

7.3.4 2003-2015 East Rockaway to Rockaway Inlet Reformulation Report

The Corps was directed to commence a Reformulation Study and signed a Design Agreement with the New York State Department of Environmental Conservation (NYSDEC) in 2003. The study would consider long-term protection for the project area. Preliminary alternative and existing conditions were developed by 2011, but now require significant revision after the Sandy storm. The Draft Reformulation Report for the first phase of this project (Atlantic Coastline) will be available for public review by November 2014. The Phase 2 Draft Reformulation Report (Jamaica Bay) requires additional detailed data gathering, and will be ready for public review by November 2015. This project is considered Authorized but Unconstructed by P.L. 113-2 (The Disaster Relief Appropriations Act of 2013). Because of this, the project will be funded at 100% federal expense.

Source: USACE Fact Sheet: East Rockaway Inlet to Rockaway Inlet (Rockaway Beach), New York District. Current as of Nov 2013.

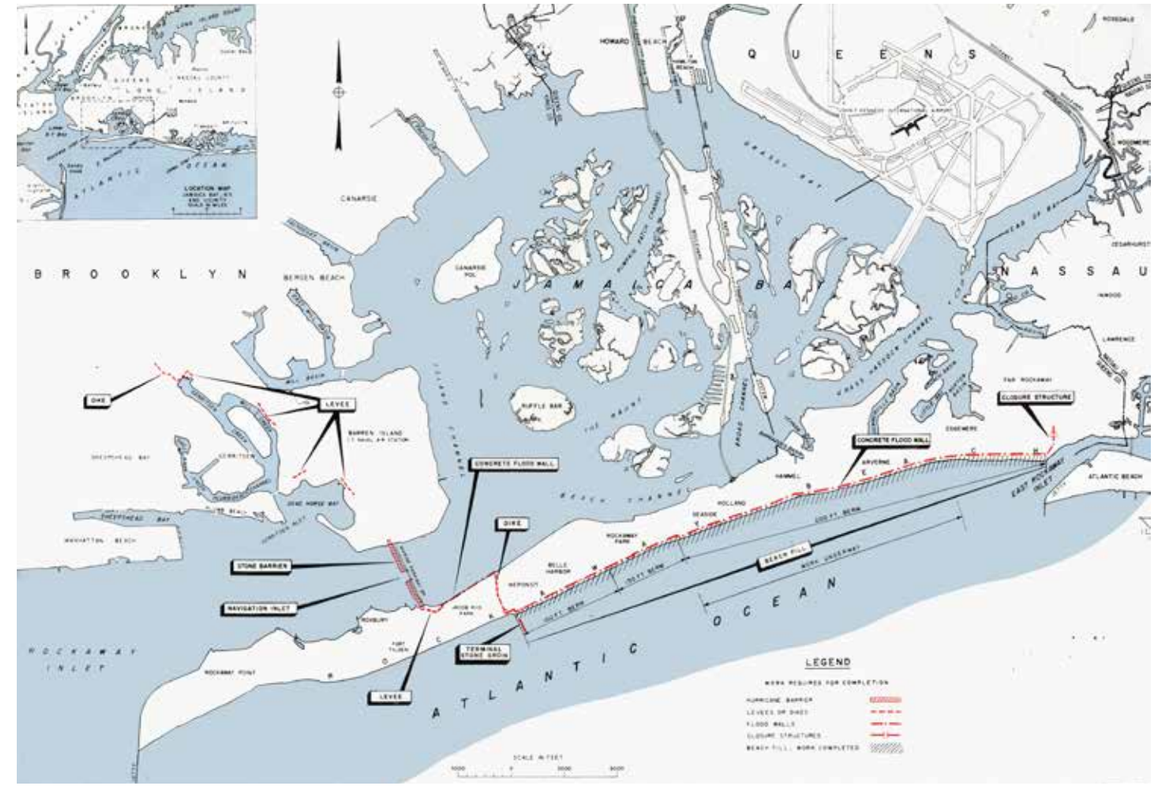


Figure 7.29: 1984 East Rockaway Inlet to Rockaway Inlet and Jamaica Bay, Flood Control Project: Continuous linear protection plan reexamined (Source: US Army Corps of Engineers)

Figure 7.30: 2009 Draft Hudson-Raritan Estuary restoration opportunities at Jamaica Bay (Source: US Army Corps of Engineers)

7.3.5 2009 Draft Hudson-Raritan Estuary Comprehensive Restoration Plan

As part of the Hudson Raritan Estuary Ecosystem Restoration Feasibility Study, the US Army Corps of Engineers and The Port Authority of New York and New Jersey prepared the Draft Hudson-Raritan Estuary (HRE) Comprehensive Restoration Plan (CRP) in 2009. The CRP was developed in collaboration with federal, state, municipal, non-governmental organizations and other regional stakeholders, and sets forth a consensus vision, master plan, and strategy for future ecosystem restoration in the New York / New Jersey Harbor. An estuary-wide initiative to identify goals and objectives for successful restoration, the CRP program aims to develop a mosaic of habitats that will provide society with renewed and increased benefits from the estuary

environment. Eleven Target Ecosystem Characteristics (TEC) were identified and prioritized within each of the eight watershed-based planning zones of the estuary. Fifty-five CRP sites have been identified in the Jamaica Bay planning region. There is widespread potential for the creation and restoration of a variety of habitats including coastal wetlands, oysters, eelgrass beds, islands for water birds and maritime forests, as well as complex habitats involving combined Target Ecosystem Characteristics. In this region there is also the potential to reduce the effects of human disturbance by improving water and sediment quality in the former tidal creeks that are now enclosed basins and in the bathymetric depressions that experience hypoxic conditions.

Source: Hudson-Raritan Estuary Comprehensive Restoration Plan Executive Summary, April 2010.

7.3.6 2013 New York City Special Initiative on Rebuilding and Resiliency (SIRR)

In December 2012, Mayor Michael Bloomberg created the Special Initiative for Rebuilding and Resiliency (SIRR) to address how to create a more resilient New York City in the wake of Hurricane Sandy, with a long term focus on preparing for and protecting against the impacts of climate change. A final report, released in June 2013, presents actionable initiatives for communities impacted by Sandy, increasing the resilience of infrastructure and buildings citywide. The report includes a city-wide Comprehensive Coastal Protection Plan, indicating Full-Build and Phase 1 initiatives. Protection measures include strategies for increasing coastal edge elevations, minimizing upland wave zones, and protecting against storm surge. At Jamaica Bay, the plan includes the study of a storm surge barrier at

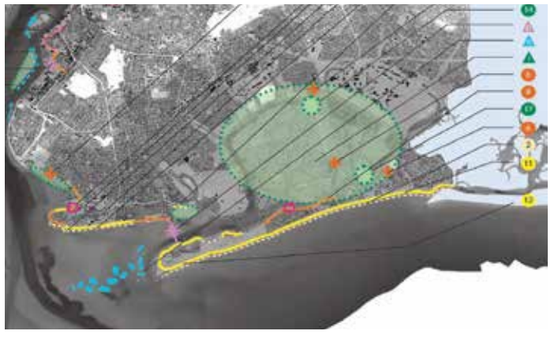


Figure 7.31: 2013 SIRR Full Build Recommendations, detail at South Queens (Source: NYC Special Initiative for Rebuilding and Resiliency)

Figure 7.32: 2014 USACE Ongoing Jamaica Bay Studies (Source: US Army Corps of Engineers)

the mouth of the Rockaway Inlet, traversing from Coney Island's Manhattan Beach to the Rockaway Peninsula's Breezy Point; as well as coastal protection measures including dunes, bulkheads, tide gates, wetlands, living shorelines, reefs, and offshore breakwaters.

Source: NYC Special Initiative for Rebuilding and Resiliency

7.3.7 2014 USACE Ongoing Jamaica Bay Studies, Beach and Bay

As the US Army Corps of Engineers continues its work on the East Rockaway to Rockaway Inlet Reformulation Report, it is re-evaluating its former focus on the Rockaway Beach nourishment project and incorporating the entirety of Jamaica Bay. This shift to a more holistic approach, encompassing both beach front and back bay, allows the projects formerly considered to be ecosystem restoration projects to be recast as elements of a comprehensive plan for coastal storm protection. By understanding the regional scope of the Reformulation Study as the area captured by the orange outline shown in Figure 7.32, a paradigm shift in thinking may be achieved—individually delineated, local projects may now be seen as valuable contributors to a larger-scaled, comprehensive initiative to improve both coastal storm risk management and the ecological health of Jamaica Bay.

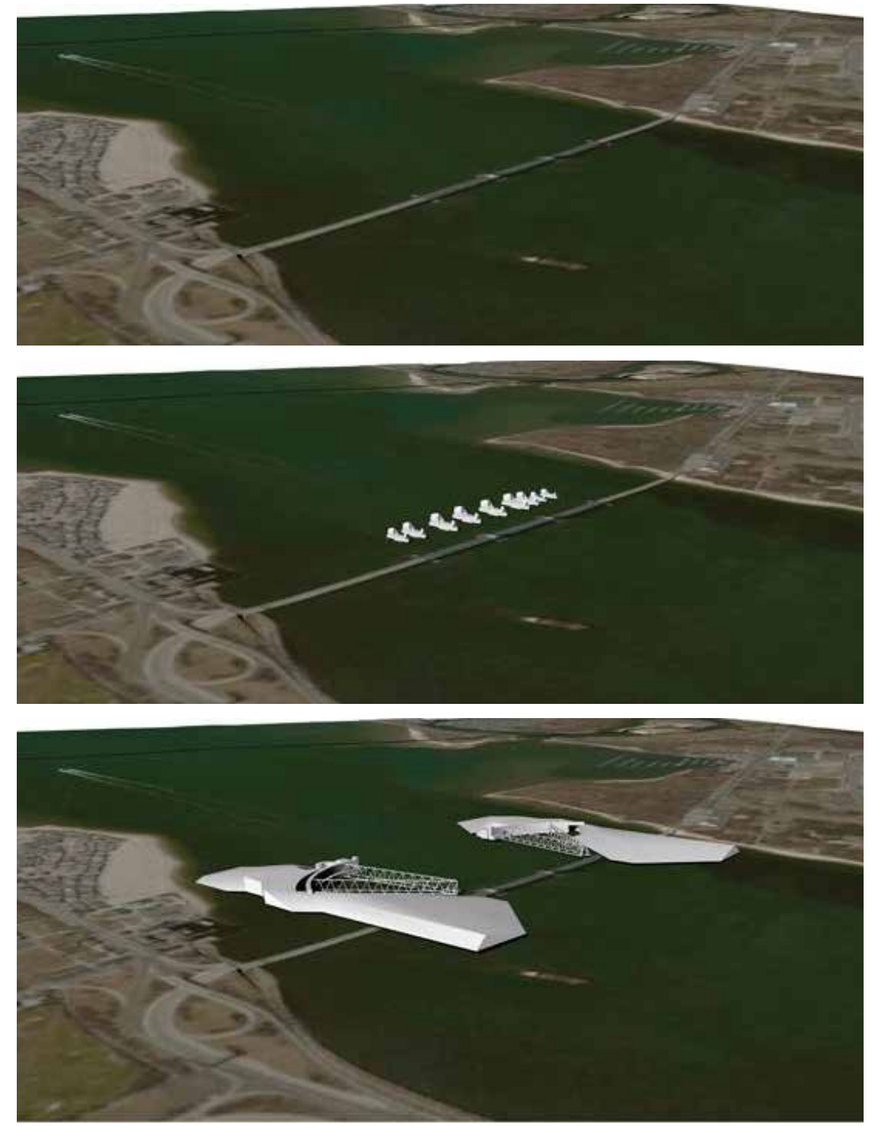


Figure 7.33: Rockaway Inlet and Marine Parkway Bridge

Figure 7.34: Thames River flood barrier to scale in Rockaway Inlet

Figure 7.35: Maeslantkering flood barrier to scale in Rockaway Inlet

7.3.8 Rockaway Inlet Storm Surge Barrier

The span of the SIRR-proposed storm surge barrier shown in purple (Figure 7.31) from Manhattan Beach to Breezy Point is approximately 5,500 feet, or 150% longer than the approximately 4,000 foot span proposed by the US Army Corps of Engineers in 1964 near the Marine Parkway Bridge. This longer span allows for a continuous line of surge protection from East Rockaway Inlet to Coney Island. Many more communities would be included in the safe zone with this proposal including Gerritsen, Manhattan Beach, and Breezy Point. Given the environmental impacts, capital cost, vast scale and long time frame for permitting and construction of such a storm surge barrier, it is beyond the scope of this study to determine its feasibility. The team will focus instead on designing smaller scale initiatives that can be quickly tested, funded, and constructed. These initiatives will provide both immediate and long term ecological benefits as well as enhance coastal storm protection for communities around Jamaica Bay.

7.4 Post-Sandy Case Studies

7.4.1 New York Rising Community Reconstruction Program

Governor Andrew M. Cuomo established the New York Rising Community Reconstruction program in response to recent severe storms that have severely impacted communities around New York State. The program is intended to help communities that suffered a great deal of damage to rebuild and revitalize their neighborhoods. Communities that successfully work together with the state to create plans that encompass current damage, future threats, and economic opportunities are eligible for funding to carry out their plan. The plan can include innovative reconstruction projects and other initiatives to make the community more resilient to future extreme events.

7.4.2 Rebuild by Design

Rebuild by Design is an initiative of the President's Hurricane Sandy Rebuilding Task Force. Ten design teams were asked to submit proposals for areas that were greatly impacted by Hurricane Sandy in the regions of Connecticut, Maryland, New Jersey, New York, and Rhode Island. The designs will be evaluated by a jury and the selected solutions have the potential to be implemented through grants and other funding sources.

Two design teams with proposals focusing on the Jamaica Bay area are SCAPE / Landscape Architecture and OMA, shown in Figures 7.36 and 7.39-7.40 respectively. SCAPE / Landscape Architecture's design proposes the shallowing of Jamaica Bay through marsh restoration and a protective dune system along the Far Rockaway Peninsula. A Resiliency Institute for research and environmental education and improved water access are also part of the proposal. OMA's design proposal looked at encompassing JFK International Airport as a "larger tiered defense system" for Jamaica Bay by means of sand nourishment, marsh restoration, and hardened infrastructure near the airport, along with increased opportunities for recreation in the region.

Figure 7.36: SCAPE design proposal for Jamaica Bay (Source: SCAPE for Rebuild by Design)

Figure 7.37: New York State community planning areas (Source: New York Rising)

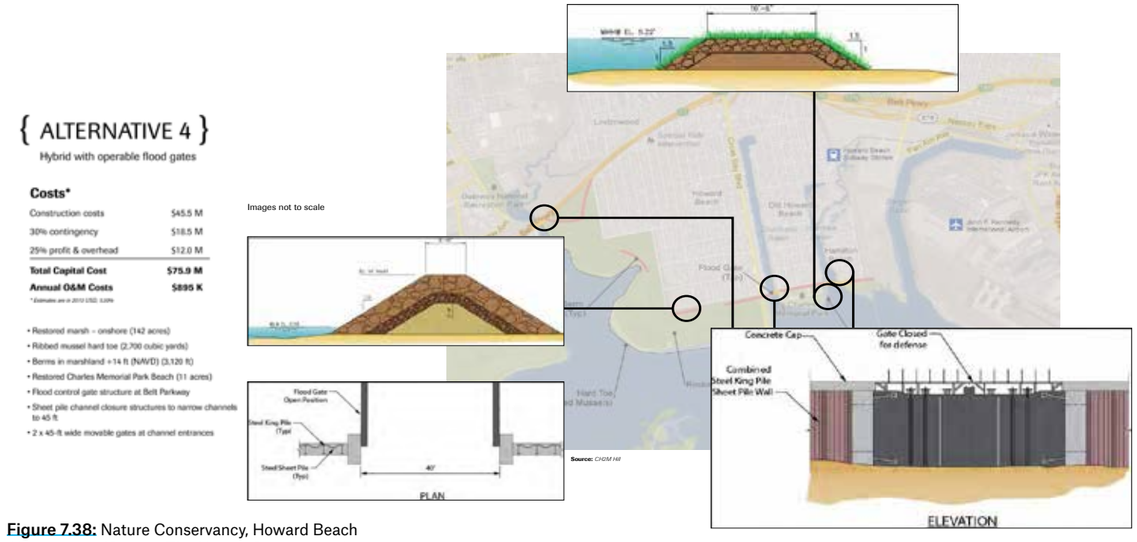


Figure 7.38: Nature Conservancy, Howard Beach Alternative 4 (Source: The Nature Conservancy)

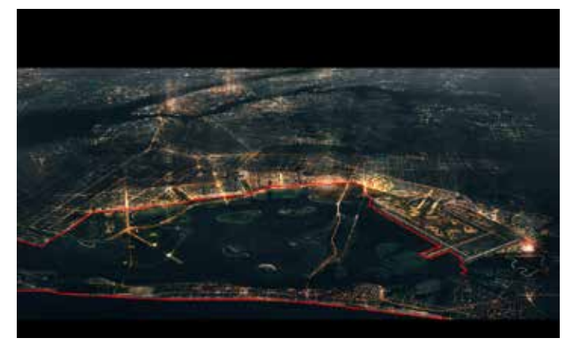


Figure 7.39: OMA design proposal for Jamaica Bay (Source: OMA for Rebuild by Design)

Figure 7.40: Plan view of OMA design proposal for Jamaica Bay (Source: OMA for Rebuild by Design)

7.4.3 Nature Conservancy / Howard Beach

In response to Hurricane Sandy, The City of New York invited The Nature Conservancy to perform a neighborhood scale case study examining Howard Beach. The findings were issued in a report entitled "Integrating Natural Infrastructure into Coastal Resilience" in December 2013. The study explores how natural features and built infrastructure can collectively help protect communities from the effects of climate change. While Howard Beach was selected as the initial NYC case study site, the report indicates that these methodologies could be applied to other communities at similar risk for coastal flooding. The report concluded that "hybrid" infrastructural approaches at a neighborhood scale in lieu of individual home assessments may be a cost-effective way to address coastal flood risk and offset building/upkeep costs. After assessing the neighborhood demographics, social vulnerability, infrastructure, and the natural environment, four potential strategies were outlined: natural infrastructure—shoreline (B/C Ratio of .73), natural infrastructure—wetlands (B/C Ratio of 0.36), hybrid with removable walls (B/C Ratio: 1.39) and hybrid with operable flood gates (B/C Ratio: 6.08). Modeling, initial cost/benefit analysis, and funding were also examined as part of the study.

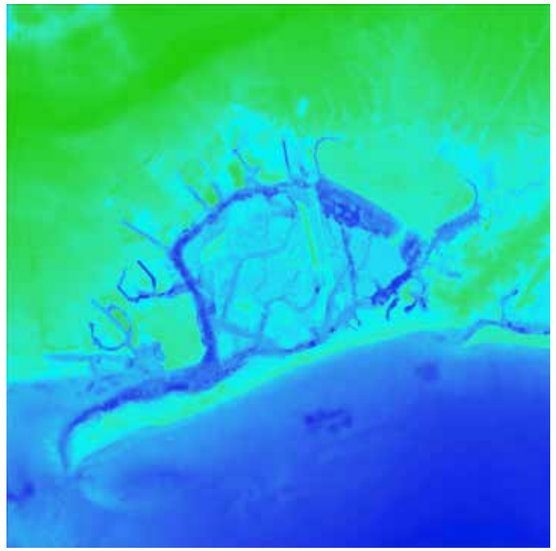


Figure 7.41: Merged topographic - bathymetric Digital Elevation Model (DEM)

7.5 Bathymetric / Topographic Merged Model

7.5.1 Creating a Merged Model

Understanding the morphology of the bay and its surroundings as a continuous surface is essential to the team's approach. Visualizing the land as a vessel that holds constantly fluctuating amounts of moving water—levels and direction change daily with tides, periodically with storms and steadily over the long term with sea level rise—enables one to study and design for dynamic conditions and a range of future possibilities. The land is continually shaped by the water in this basin, particularly in the Jamaica Bay region where the sandy substrate erodes and accretes rapidly with both the dynamic flow of water and human activity.

To visually represent this continuous surface, digital elevation data of the land topography was merged with bathymetric point soundings. Both the topographic and bathymetric datasets are referenced to the 1988 North American Vertical Datum (NAVD88).

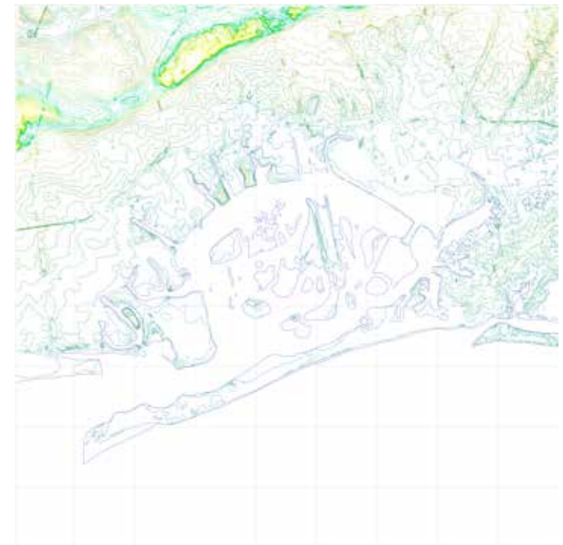


Figure 7.42: Elevation above 0' (NAVD 88 datum) in five foot contour intervals (Source: USGS National Elevation Dataset)

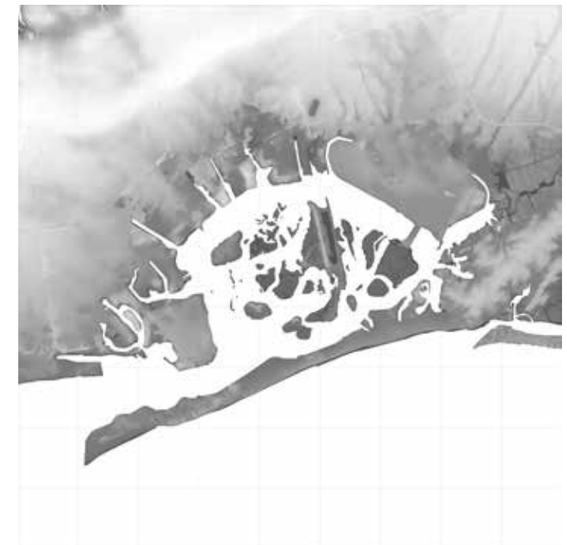


Figure 7.43: Digital Elevation Model (DEM) of land above 0' (NAVD 88 datum)

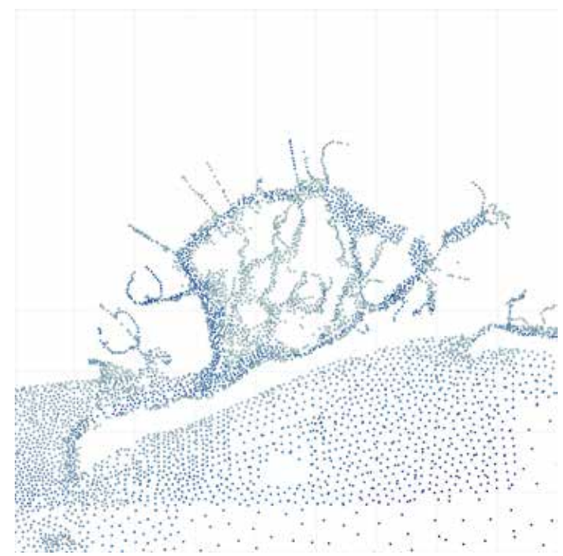


Figure 7.44 Bathymetric point soundings (MLLW datum) (Source: NOAA Chart 12350, 2011)

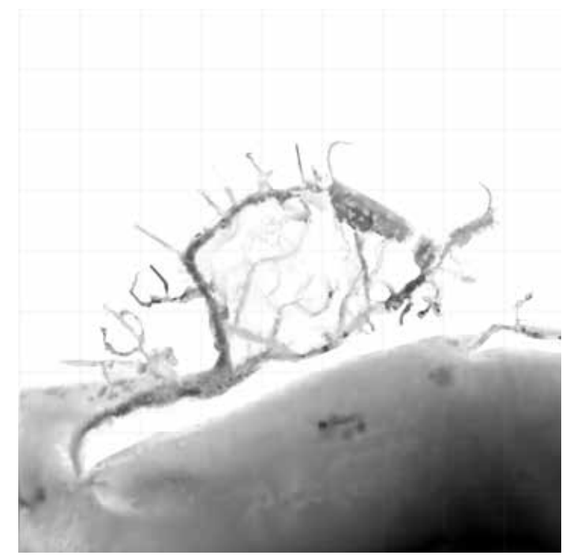
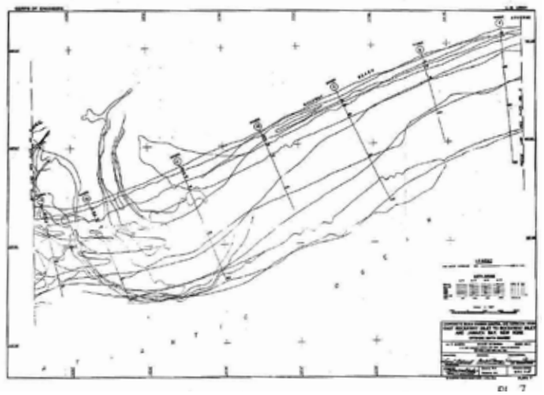
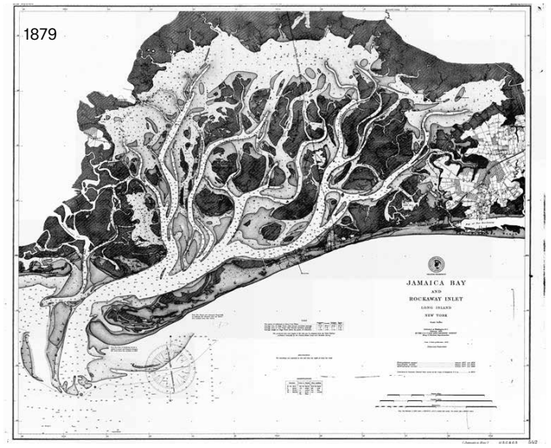
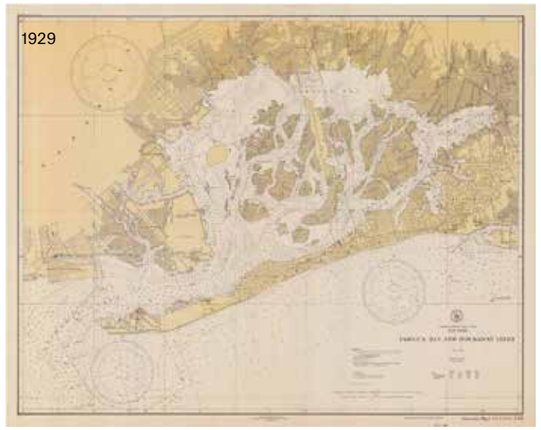


Figure 7.45: Digital Elevation Model (DEM) of land below 0' (NAVD 88 datum)







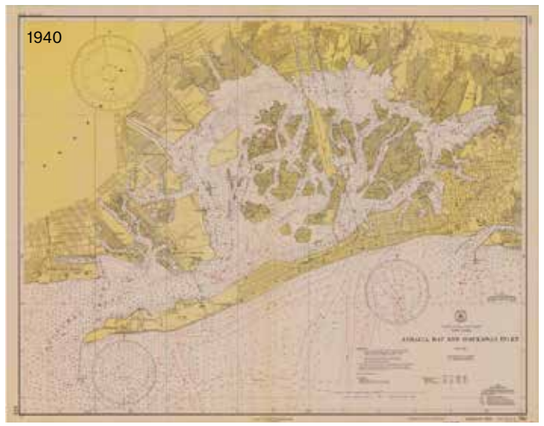


Figure 7.46: (top left) Evolution of Rockaway Spit morphology, 1964 (Source: US Army Corps of Engineers)
Figures 7.47-7.49: Historic nautical charts (Source: NOAA)

Figure 7.50: (left) Aerial photo of constructed jetty at Rockaway Spit, 1932 (Source: US Army Corps of Engineers, Coastal Engineering Manual)

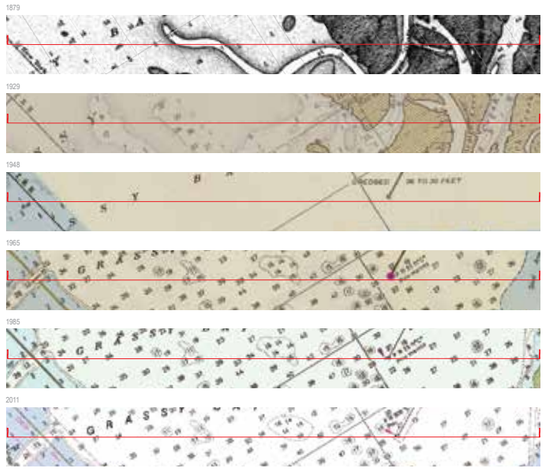
Figure 7.51: Aerial photo of constructed jetty at Rockway Spit, 1938 (Source: New York City Parks Photo Archive)

7.6 Jamaica Bay Morphology

7.6.1 Evolving Sedimentary Morphology

Historic National Oceanographic and Atmospheric Administration (NOAA) nautical charts reveal the continuously evolving morphology of Jamaica Bay. By the late 1800s, Jamaica Bay was already a seasonal destination with hotels, casinos and a commercial fishing industry established. Expanding transportation such as the Long Island Railroad line and Flatbush Avenue made the area more accessible to visitors as well as year-round residents. Channel deepening and the dredging of Rockaway Inlet commenced during the early twentieth century to accommodate larger ships and promote commercial activity in the area. Dredge material extracted from the bay during this deepening process was used to create Canarsie Pol. By 1929, the northern periphery of Jamaica Bay, much of which was previously marsh or grassland, was slated for residential development, and Barren Island and its adjacent marsh islands were filled for the future site of the Floyd Bennett airfield.

Cyclical natural processes such as wave currents, tides and wind also shape the morphology of Jamaica Bay. Humans play a major role in manipulating these systems. An historic example is the stone jetty constructed at the Rockaway Spit by the US Army Cops of Engineers in 1933, which enabled sand moving westward via littoral drift to accrete and become the area now known as Breezy Point. From 2006 through 2012, USACE has partnered with the National Park Service and local non-governmental organizations to restore approximately 154 acres of salt marsh islands at Elders East and West, Yellow Bar Hassock, Black Wall and Rulers Bar Hassock.



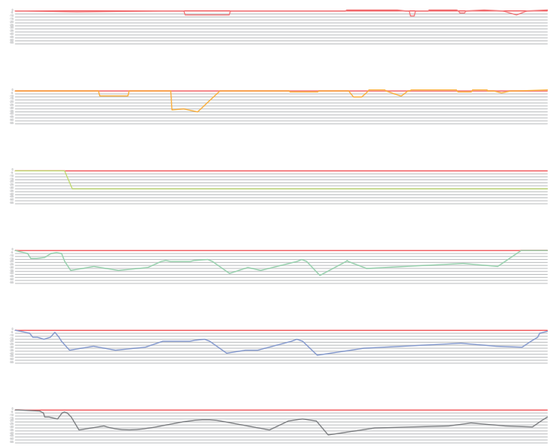


Figure 7.52: Sectional evolution of Grassy Bay borrow pits, 1879 - 2011

7.6.2 Bathymetric Change Over Time

These sections and corresponding plans show the evolving bathymetry of two key areas in the bay from 1879 – 2011 and were drawn with information derived from historic NOAA maps. This subset of maps was chosen because each reveals a significant development near the Bay, such as Flatbush Avenue, the Marine Parkway-Gil Hodges Memorial Bridge, Belt Parkway construction, and the John F. Kennedy Airport runway extension at JoCo Marsh. 1879 is the earliest NOAA nautical chart available showing soundings in the bay, and 2011 is the most recent. The historic edge and channel evolution overlay (Figure 7.54) from 1879 and 1929 begins to reveal substantial changes that took place in the area.

Figure 7.53 shows the evolution of Rockaway Inlet, the naturally deep entrance to Jamaica Bay that widened significantly over time, likely from scour, and was also deepened from dredging. The channel at the center of the inlet continues to be dredged to a depth of 18 feet approximately every three years for navigational purposes.

Figure 7.52 demonstrates the deepening of Grassy Bay, a historically shallow area that was dredged to provide fill for the development of the JFK airfield on former marsh land. These "borrow pits" remain very deep, and there is ongoing discussion of the benefits that could be derived from partially filling these borrow pits with locally-sourced and strategically placed clean dredge material.

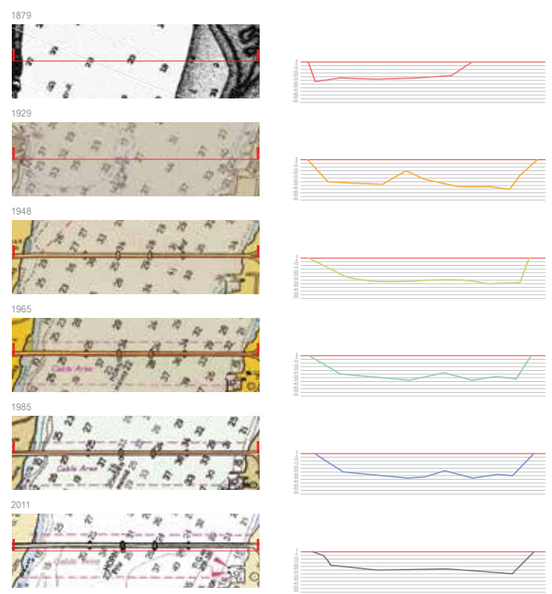
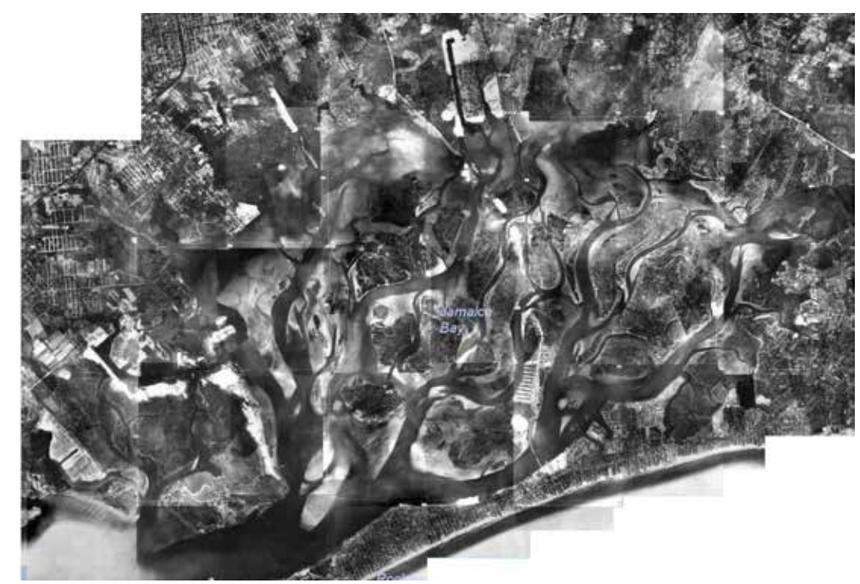


Figure 7.53: Sectional evolution of Rockaway Inlet at Marine Parkway - Gil Hodges Memorial Bridge, 1879 - 2011

Figure 7.54: Historic edge and channel evolution 1879 - 1929

Figure 7.55: Aerial imagery at Jamaica Bay, 1924 (Source: NYC DoITT Map)



7.6.3 Dredge and Fill at Jamaica Bay

Jamaica Bay has a long history of disturbed substrate both above and below the water. As shown in Figure 7.57, the bay is part of an extensive network of navigational channels maintained by the USACE in the New York-New Jersey Harbor.

The bay has numerous deep borrow pits and dredged navigation channels. With the exception of Rockaway Inlet which is dredged approximately every three years, the channels within the bay are no longer actively maintained. However due to the lack of sediment input from former tributaries and the sheltered nature of the bay, these channels and borrow pits have not silted in over time. The channels remain deep enough to accommodate the New York City's Department of Environmental Protection's sewage sludge vessel, numerous barges and oil tankers that service JFK Airport and nearby facilities, as well as many small recreational craft. The United States Congress continues to authorize funding to dredge the Rockaway Inlet channel due to its demonstrated economic importance.

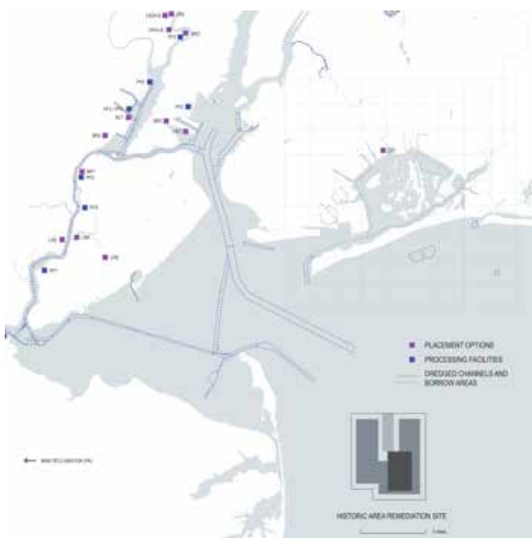


Figure 7.57: Current and historic dredged channels and dredge placement sites in the New York Bight

Figure 7.56: Aerial photo of Howard Beach, Cross Bay Boulevard, and Broad Channel looking north, 1938 (Source: New York City Parks Photo Archive)

In addition to these anthropogenic bathymetric alterations, Jamaica Bay and the Rockaway Peninsula are also evolving under natural forces. Littoral drift moves sand from east to west along the beach of the Rockaway Peninsula, with surface currents at their strongest near the western tip at Breezy Point. A jetty installed by the US Army Corps of Engineers in 1932 catches this drifting sand, simultaneously preventing the barrier island from migrating westward as it once did and preventing the Rockaway Inlet navigational channel from silting in.

At the mouth of the inlet, the prevailing currents bend eastward and slow significantly as water flows into Jamaica Bay. There are no other tidal inlets entering into the bay. As a result, there is comparatively low water circulation and little movement of existing sediment within the bay. This has an impact on water quality, particularly in the deepest borrow pits where dissolved oxygen tends to be lower and the residence time of water, and thus the concentration of pollutants, is highest.

Mapping these underwater cut, fill, drift, and accretion dynamics reveals important possibilities for the management of sediment and circulation in Jamaica Bay. The team is examining specific sites where additional channels leading into the bay could improve circulation and decrease residence time, thereby improving water quality and habitat.

The US Army Corps of Engineers currently utilizes dredge placement sites as far away as Pennsylvania. Placement sites in the New York area include sanitary landfill caps and the approximately thirty square mile Historic Area Remediation Site (HARS) located offshore near Sandy Hook, NJ.

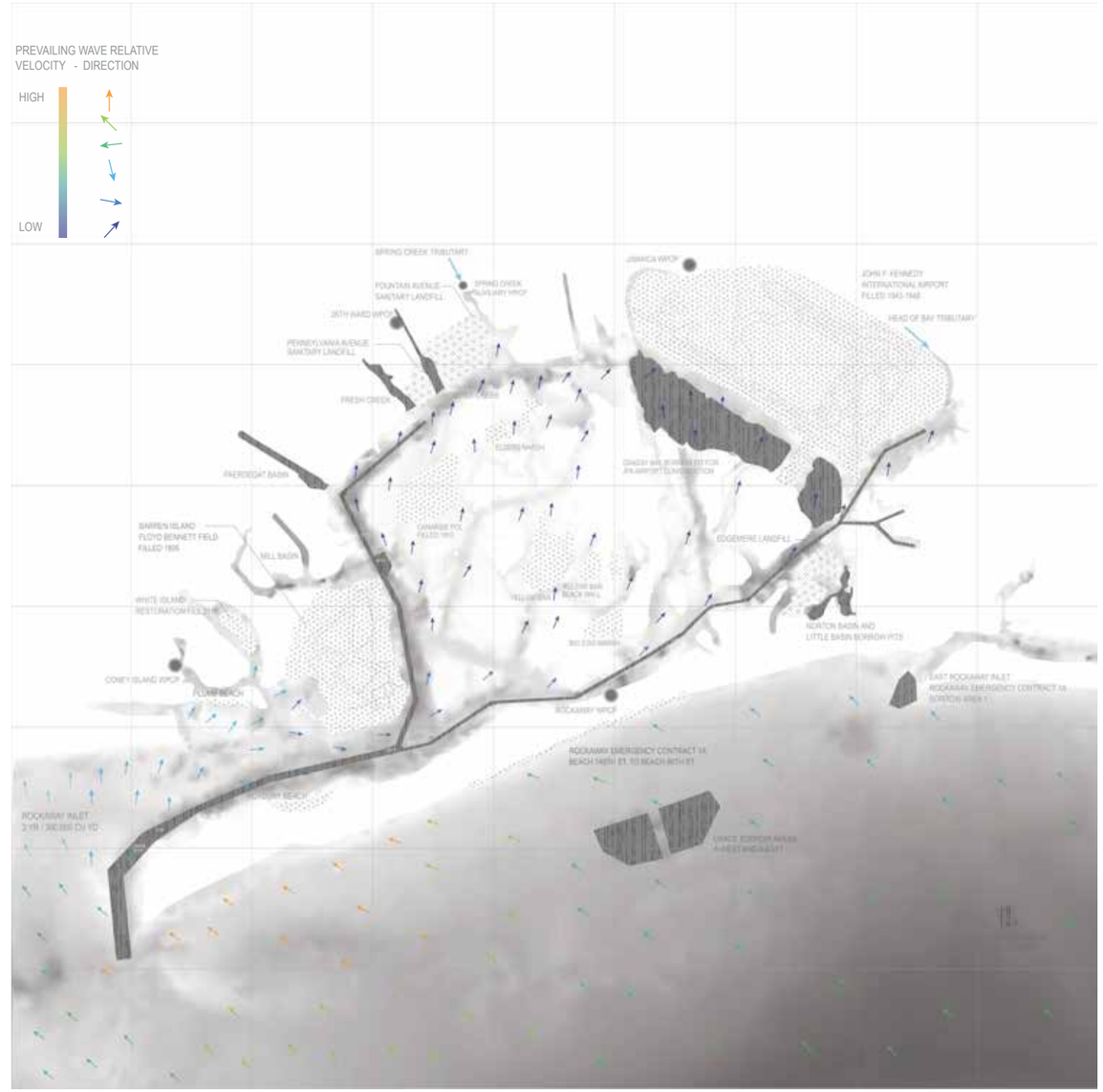


Figure 7.58: Cut, fill, erosion, and accretion in Jamaica Bay

Strategic placement of local, clean dredge material for beneficial use could support and nourish marshes and beaches within Jamaica Bay and along the Rockaway Peninsula. The possibility of a coordinated dredge management plan, synchronized with the nesting and feeding cycles of sensitive species that rely on the unique and diverse habitats of Jamaica Bay, will be explored.

Figure 7.59: Generalized diagram of sand - silt gradient in Jamaica Bay overlaid with impervious land surface (Source: USDA/New York City Reconnaissance Soil Survey)

Figure 7.60: Disturbed and filled land in Jamaica Bay area (Source: USDA/New York City Reconnaissance Soil Survey)

7.6.4 Water Quality

Jamaica Bay is a 36-square mile estuarine lagoon including 16,000 acres of open waters and 3,000 acres of islands and marshes. The water is characterized as saline to brackish with salinity ranging between 20.5 and 26 parts per thousand. The dissolved oxygen is between 3.5 and 18.5 mg/L, and the pH varies between 6.8 and 9. The residence time varies by depth and location, but averages approximately 33 days. This is higher in the back bay areas near JFK airport and lower near the one opening to the ocean at Rockaway Inlet. The annual water temperature ranges between 34 degrees Fahrenheit and 79 degrees Fahrenheit. The open water is classified as Class SB, which is acceptable for primary and secondary contact recreation and fishing. Most of the inlets are classified as Class I, appropriate only for secondary contact recreation and fishing.

In dry weather the bay receives treated effluent from four sewage treatment plants totaling 340 million gallons per day. In wet weather the capacity of these treatment plants is overwhelmed, and untreated runoff from 91,000 acres of land enters the bay via nearly thirty combined sewer overflow (CSO) outfalls. Both treated and untreated effluent contributes to high nutrient levels in the bay, particularly nitrogen, which causes algae blooms and eutrophication. The water also has high turbidity and low dissolved oxygen near the bottom, resulting in impaired habitat.

In 1992 the New York City Department of Environmental Protection (DEP) first entered into a consent order with the New York State Department of Environmental Conservation to bring the waters of New York City into compliance with the Federal Clean Water Act and the New York State Environmental Conservation Law. Under this consent order, the DEP has taken various initiatives to improve the water quality through upgrades to the waste water treatment plants, storm water management such as swales and infiltration around the Belt Parkway, and ecological restoration of sites around the bay such as Paerdegat Basin. Since 2007, NYC DEP has been developing a comprehensive Watershed Protection Plan for Jamaica Bay.

7.6.5 Soils

Because of the slow currents within the bay, a sediment gradient has developed over time. Near the Rockaway Inlet the benthic layer is made up of coarser sand particles that wash in from the ocean. As water enters the inlet, its velocity decreases significantly and the larger sediments drop out. Towards the eastern reaches of the bay, finer silt sediments are undisturbed. In the deepest borrow pits, such as those at Grassy Bay and Norton Basin, these fine sediments are bound with toxins and have developed into a dark sludge commonly referred to as "black mayonnaise."

Part of developing a holistic strategy for Jamaica Bay may include plans to cap the worst of these sediments

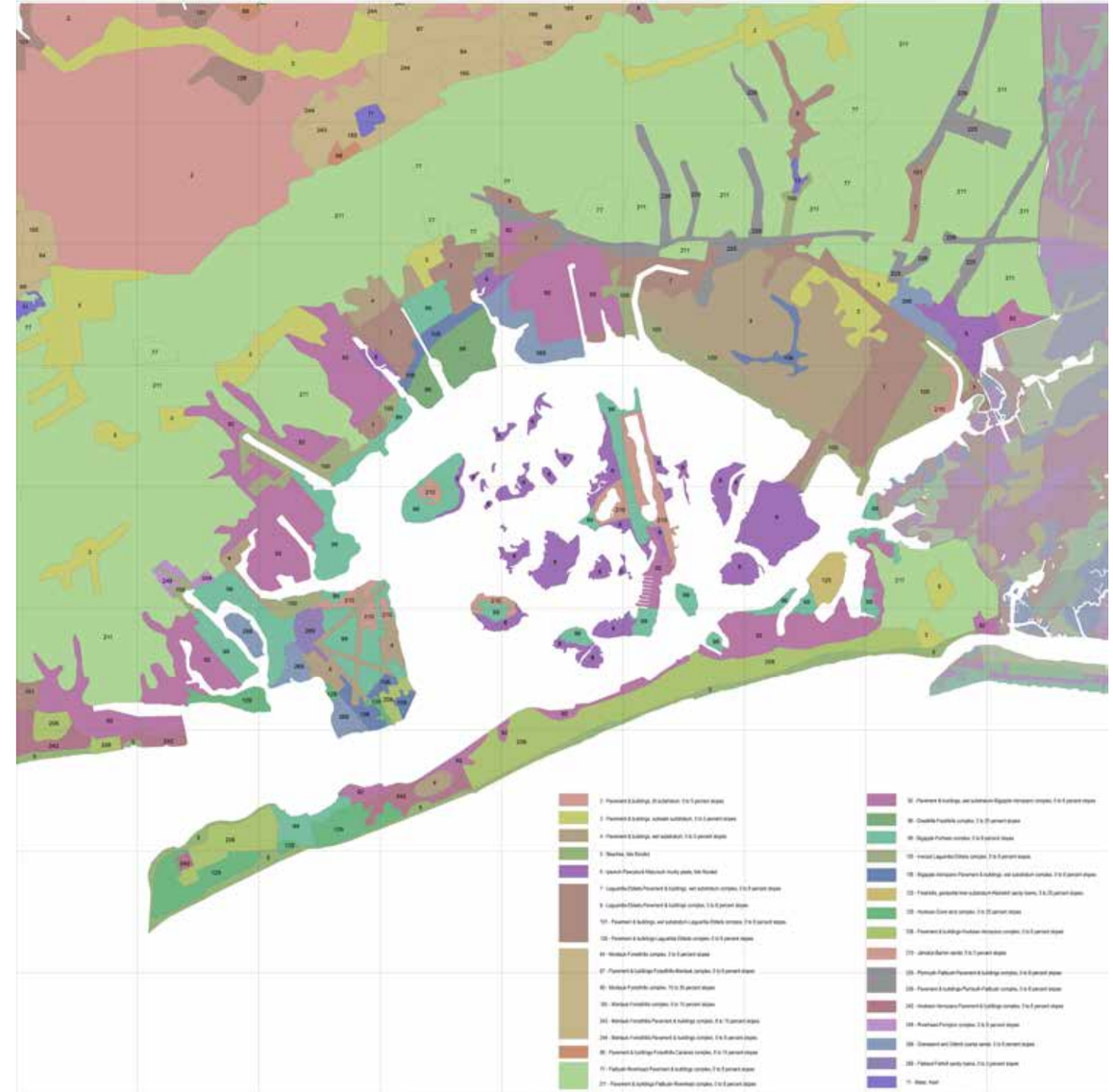


Figure 7.61: Soil types in Jamaica Bay area (Source: USDA/New York City Reconnaissance Soil Survey)

with clean fill and increase flushing within the bay to improve water quality and allow for larger sediment particles to circulate, thereby nourishing the marshlands.

The soils of the terrain surrounding Jamaica Bay are almost entirely categorized as anthropogenic fill by the New York Soil and Water Conservation District (Figure 7.60). Along the perimeter of the bay there are large swaths of solid land that were once marshland, filled with soils categorized as dredge deposits and construction debris. Three recently closed municipal landfills—Pennsylvania Avenue, Fountain Avenue and Edgemere—occupy former marshland. Dead Horse Bay is a historic landfill that is currently eroding away at the edges. Glass bottles, polished horse bones, and other debris can be easily found along the beach.

7.7 Jurisdictional Dynamics

7.7.1 Communities

Jamaica Bay is located in the State of New York, and encompasses the counties of Kings, Queens, and Nassau. Towns include the boroughs of Brooklyn and Queens (New York City), and Hempstead (Nassau County). Many communities are distributed around the perimeter of the bay and along the Rockaway Peninsula. These include Gerritsen Beach, Mill Basin, Bergen Beach, Canarsie, East New York, Howard Beach, and Old Howard Beach at the bay's northern perimeter; and Inwood, Far Rockway, Bayswater, Edgemere, Arverne, Rockaway Beach, Rockaway Park, Belle Harbor, and the two cooperatives Roxbury and Breezy Point along the Rockaway Peninsula. The community of Broad Channel, located in the middle of the bay's marshes along the Cross Bay Boulevard, is the only inhabited island.

7.7.2 Publicly Owned Lands

The majority of land in the Jamaica Bay region is publicly owned by the federal government and the City of New York. There is also one New York State Park, Bayswater Point State Park. Much of Jamaica Bay proper, including portions of the uplands (to the south of the Belt Parkway), the marsh islands at the center of the bay, and the western end of the Rockaway Peninsula, is part of the Gateway National Recreation Area, administered by the Department of the Interior's National Park Service. Gateway National Recreation Area includes the Jamaica Bay Wildlife Refuge and marsh islands; Breezy Point, at the western tip of the Rockaway Peninsula; Fort Tilden and Jacob Riis Park; Plumb Beach and Dead Horse Bay; Floyd Bennett Field, a former airfield; Bergen Beach; Canarsie Pier; Pennsylvania and Fountain Avenue landfills, Spring Creek, Frank Charles Memorial Park, and Hamilton Beach Park.

There are also many city parks within the Jamaica Bay region (generally to the north of the Belt Parkway and along the eastern end of the Rockaway Peninsula), including the Rockaway Beach and Boardwalk, Marine Park, Four Sparrows Marsh, McGuire Fields, Paerdegat Basin Park, Canarsie Park, Fresh Creek Nature Preserve, Spring Creek Park, Idlewild Park, Hook Creek Wildlife Sanctuary, Jamaica Bay Park, Bayswater Park, Rockaway Community Park, Dubos Point Wildlife

Figure 7.62: Plan of cooperative agreement between National Parks Service and New York City Parks Department (Source: National Parks Service)

Sanctuary, Thursby Basin Park, Brant Point Wildlife Sanctuary, Vernam Barbadoes Peninsula, Tribute Park, Beach Channel Park, Broad Channel American Park, and Broad Channel Wetlands, as well as several smaller parcels of city-owned lands. John F. Kennedy International Airport, at the eastern edge of Jamaica Bay, is owned by the City of New York and operated by the Port Authority of New York and New Jersey.

7.7.3 Cooperative Management Agreement

In 2012, a "Cooperative Management Agreement" between the US Department of the Interior, National Park Service, Gateway National Recreation Area and the City of New York Department of Parks and Recreation was signed to enhance the cooperative management of Jamaica Bay's parks for visitors and residents. This historic agreement cites that the Department and the City will jointly manage and enhance programming for more than 10,000 acres of city and National Park Service lands in and around Jamaica Bay, creating a seamless and interconnected network of recreational spaces. Both parties agreed to enhance natural recreational opportunities and improve facilities within their collective properties. The vision for a "Jamaica Bay Science Center" was launched as part of this cooperative agreement. A map of the Cooperative Park Lands (CPL) of the National Park Service and the NYC Department of Parks and Recreation has been created.

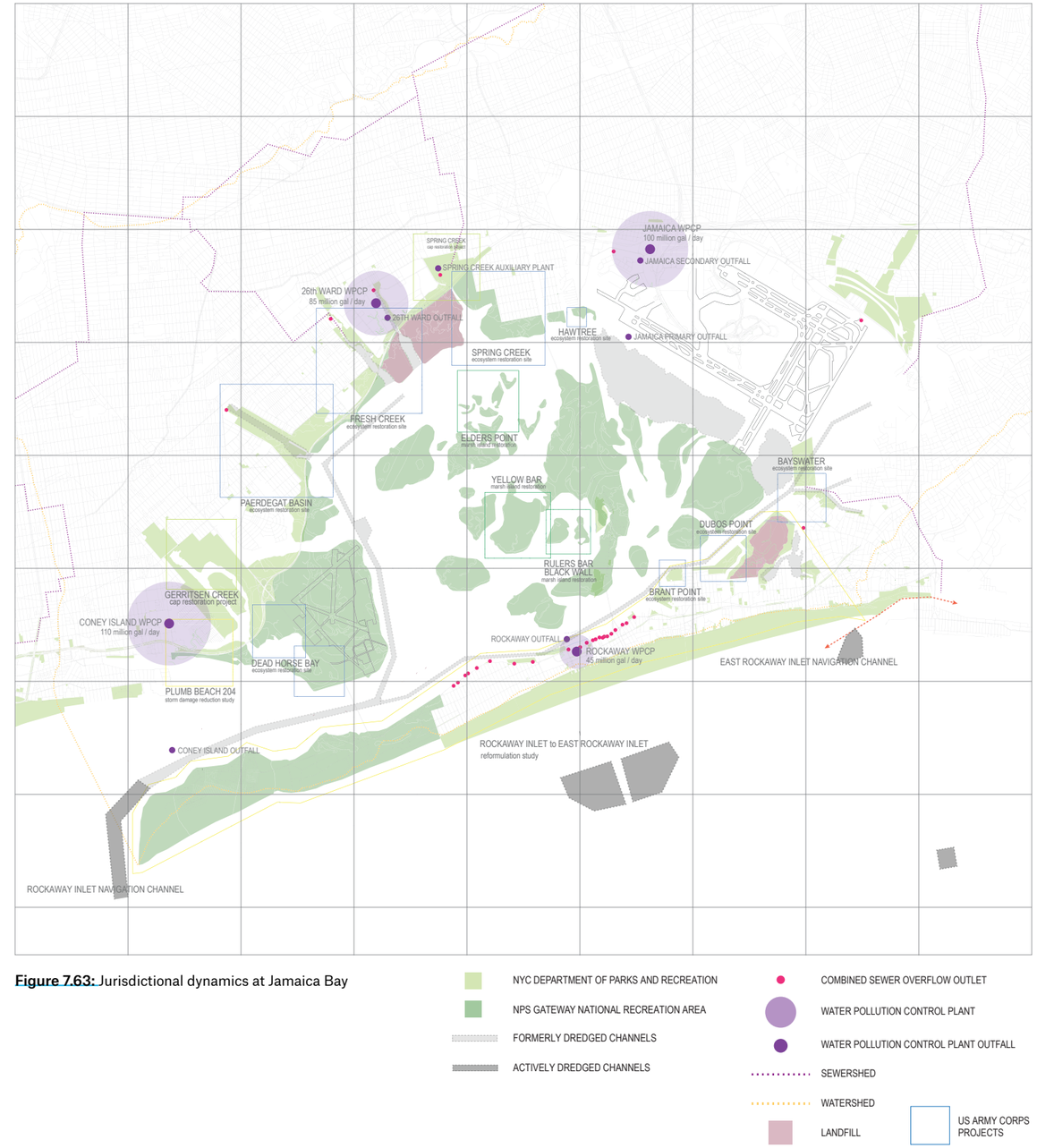


Figure 7.63: Jurisdictional dynamics at Jamaica Bay

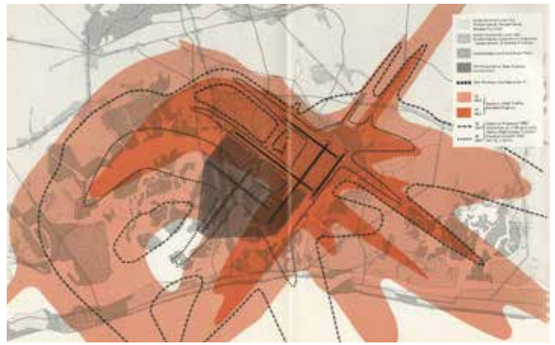


Figure 7.64: Noise exposure of 30 and 40 NEF or greater from 1968 standard engines (Source: 1971 Jamaica Bay and Kennedy Airport Multidisciplinary Environmental Study)

7.7.4 John F. Kennedy International Airport

Since World War I, there have been several aviation sites within Jamaica Bay, including the Rockaway Naval Air Station (1917-1930); Floyd Bennett Field (1931-1972), which served as New York City's first municipal airport until the 1940s and was later used in World War II as a naval air station; and New York International Airport (also known as Idlewild Airport), which opened in 1948 and was renamed John F. Kennedy International Airport in 1963. JFK Airport is situated on 4,930 acres in Queens, and is one of the major stakeholders in Jamaica Bay. The airport is directly adjacent to the NPS's Gateway National Recreation Area and its marshes, with one of its extended runways even projecting into JoCo Marsh. Gateway includes an array of wildlife species and habitats, including the Jamaica Bay Wildlife Refuge, an important migratory bird sanctuary.

Part of JFK's mission is to protect human health and safety, which includes limiting the potential for bird strikes—collisions between airborne animals and aircraft. This includes the use of lethal and non-lethal control measures by the JFK Wildlife Management Unit, such as data collection, vegetation management, discouraging the feeding of wildlife, bird-frightening devices, bird capture and euthanasia, nest/egg destruction, and controlled shooting. In addition to onsite "wildlife hazard management," JFK also has jurisdiction to manage identified bird hazards within a five-mile radius of the airport. In April of 2012, a report entitled "Bird Hazard Reduction Program: John F. Kennedy International Airport" was published by the USDA and APHIS Wildlife Services, which proposed to extend the hazard scope for Canada Geese to a seven-mile radius as needed. This extended radius includes new bird management within the Gateway National Recreation

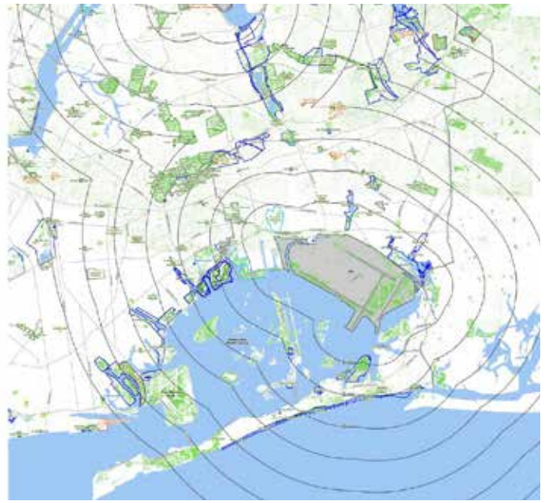


Figure 7.65: Bird hazard management areas in 1-mile concentric rings (Source: USDA and APHIS)

Area, including the Fountain Avenue and Pennsylvania Avenue capped landfills (now public parks under NPS jurisdiction) and Rulers Bar Hassock. While sites within close proximity to JFK are not mandated to adhere to airport recommendations, they could be subject to litigation if a bird strike were connected to property owned by them. The issues surrounding bird hazards are nuanced and difficult to solve; however there is an ongoing dialog between stakeholders. For example, the Gateway National Recreation Area stated in 2011 at the Harbor Herons Conference that they were monitoring numbers of large bird species such as the Canada Goose and Laughing Gull at multiple locations within Jamaica Bay since 2005 year-round, and agreed to limit salt marsh restoration to two miles outside of JFK. The FAA also limits the US Army Corps of Engineers from restoring high marsh habitat, which would support larger avian species, in Jamaica Bay in the zone between JFK Airport and the Cross Bay Boulevard.

Each circle in Figure 7.66 identifies the MSL ceiling and floor altitudes with the bar graph underneath illustrating the vertical height of each sector. The ceiling is capped at 7,000' with the controlled airspace starting as low as surface level within close proximity of the airports. The diagrammatic section below the plan illustrates that almost all areas of Jamaica Bay reside within restricted Class B airspace. The airspace is uncontrolled up to 1,500' at the Rockaway Inlet; progressing toward the east and JFK, the rings of controlled airspace lower before rising again beyond the airport.

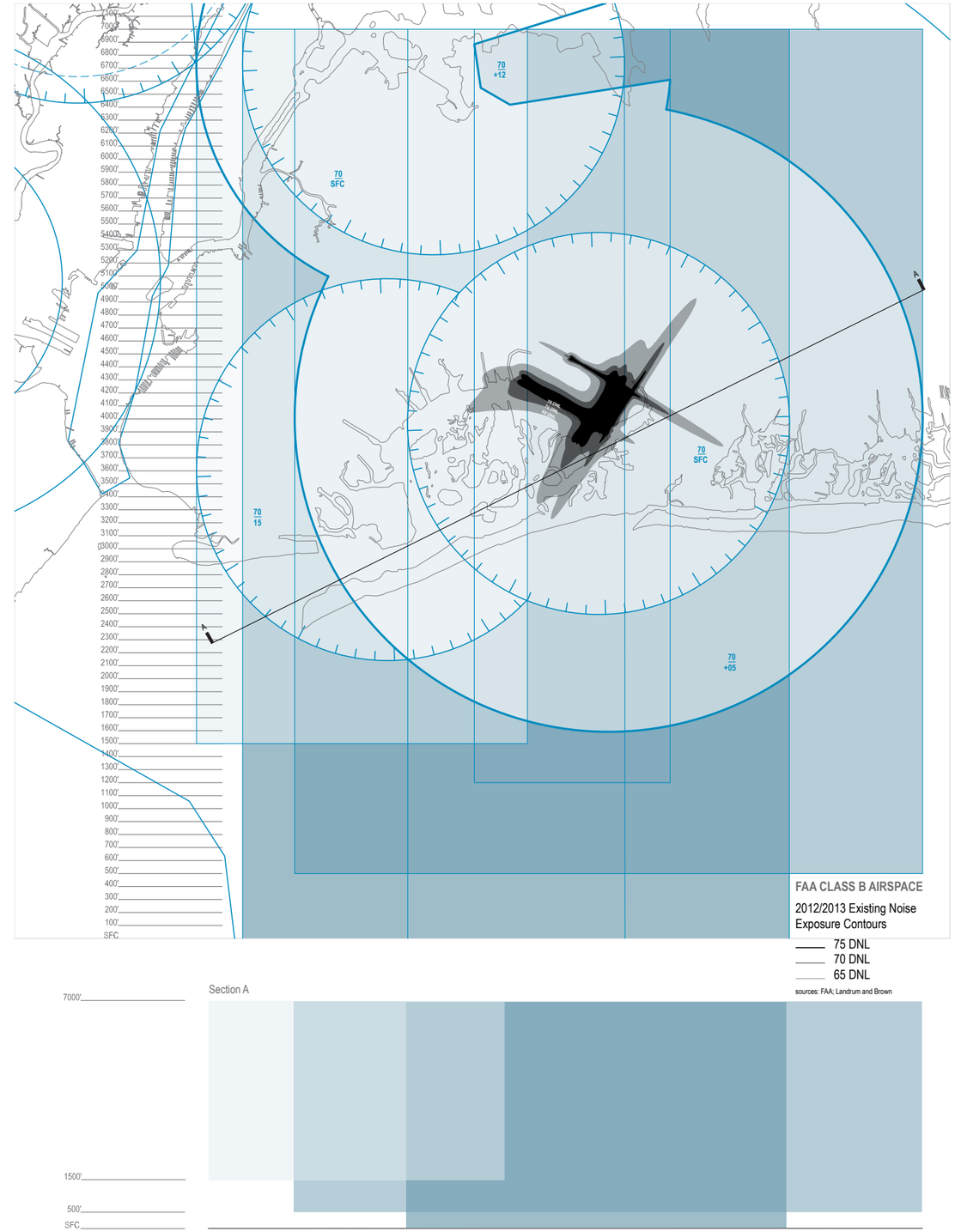


Figure 7.66: FAA Class B airspace and noise impact (Source: Landrum & Brown for FAA)

7.8 Vulnerability and Risk

7.8.1 Sea Level Rise and Flood Risk

This project will support the USACE North Atlantic Coast Comprehensive Study's vulnerability and risk analyses by providing a finer-grained study using the specific metrics of Jamaica Bay to examine social, environmental, and infrastructural risk. Vulnerability, as defined by Ty Wamsley, Chief, Flood and Storm Protection Division, Coastal and Hydraulics Laboratory, ERDC / USACE, is a function of the hazard to which a system is exposed, the sensitivity of the system to the hazard, and the system's adaptive capacity. All three of these categories—the social, environmental, and infrastructural—are at risk and vulnerable to the hazard of sea level rise. Sea level rise is the overarching metric affecting all three categories, and it has been studied here carefully in the Jamaica Bay region.

The first map image (Figure 7.68) shows New York City's evacuation map, revised in 2013 from a three-zone system to a six-zone system, including an additional 600,000 residents. Certain very low-lying communities at Jamaica Bay—including the entire Rockaway Peninsula—one 1, the lowest threshold for evacuation in case of a major storm. The entire perimeter of the bay as well as JFK Airport are included in evacuation Zones 1, 2, and 3 which encompass an area comparable to the former Zones A and B. Zone A and parts of the Rockaways in Zone B were evacuated in October 2012 for Hurricane Sandy. The second image (Figure 7.69) examines the FEMA Preliminary Work Maps (PWMs) for New York City, released in June 2013. The PWMs precede FEMA's Preliminary Flood Insurance Rate Maps (FIRMs), which upon becoming effective will determine the extent of floodplains, Base Flood Elevations (BFEs), and flood insurance rates. These new FIRMs for New York City are estimated to become effective in 2015.

Next, the extent of the 2013 PWM 100-year floodplain is compared with the projected 2020 100-year floodplain (given the IPCC sea level rise projection of 11 inches) and the projected 2050 100-year floodplain (given the IPCC sea level rise projection of 31 inches). Projected 500-year floodplains for 2020 and 2050 are also compared with the 2013 PWM 500-year floodplains.

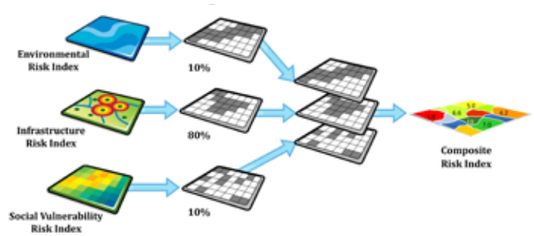


Figure 7.67: US Army Corps of Engineers' process for creating Composite Risk Index, 2013 (Source: US Army Corps of Engineers)

Source: The SLR floodplain projection datasets shown here were developed by the CUNY Institute for Sustainable Cities at Hunter College, for the New York City Panel on Climate Change; these datasets are used with their permission.

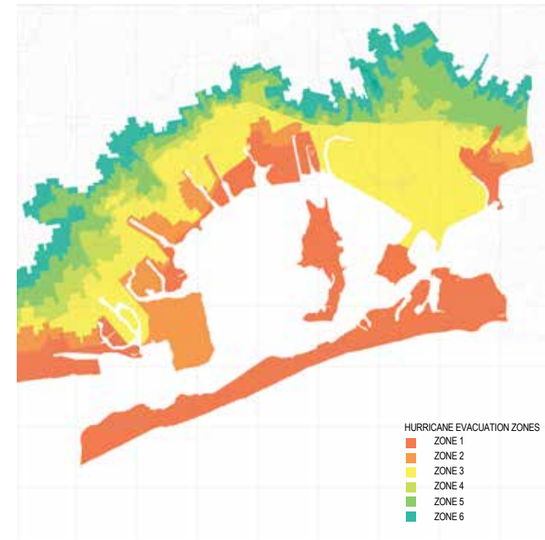


Figure 7.68: New York City evacuation zones, 2013 (Source: New York City Office of Emergency Management)

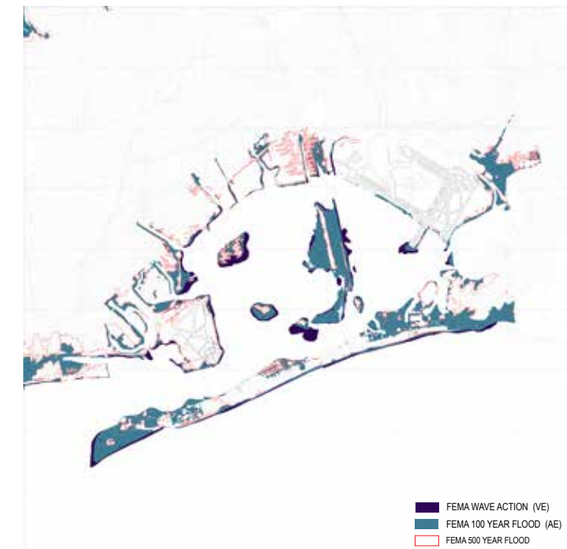


Figure 7.69: FEMA Preliminary Work Maps (PWM), 100-year and 500-year floodplains, 2013 (Source: FEMA)

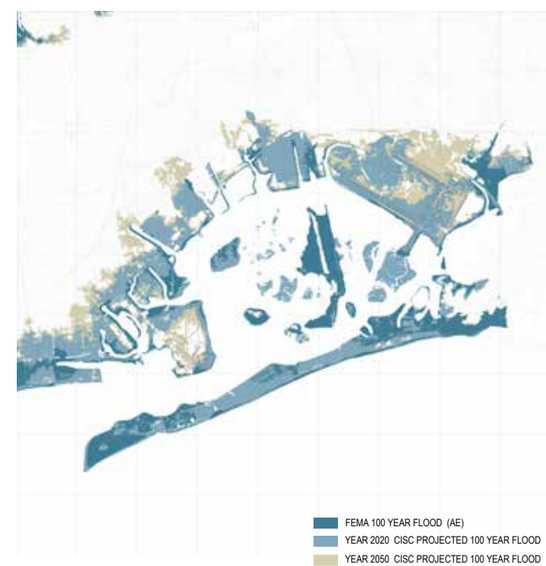


Figure 7.70: FEMA 2013 PWM 100-year floodplains with IPCC projections for 2020 and 2050 100-year floodplains (Source: CUNY Institute for Sustainable Cities)

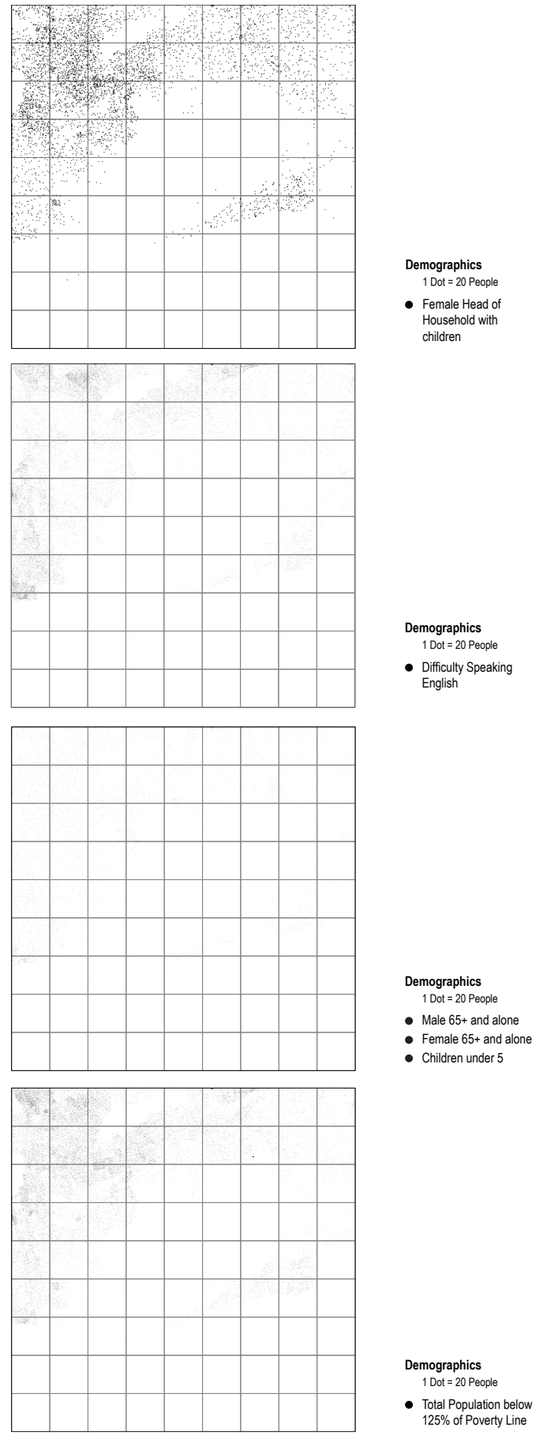
Figure 7.71: FEMA 2013 PWM 500-year floodplains with IPCC projections for 2020 and 2050 500-year floodplains (Source: CUNY Institute for Sustainable Cities)

7.8.2 Social Vulnerability

The social vulnerability index of New York City will be examined and specific metrics Jamaica Bay will be developed. Communities most vulnerable to surge and sea level rise due to socio-economic status and other metrics will be identified. Resilient community networks will be identified. Environmental vulnerability, including the loss of fragile ecosystems and habitat, will also be considered.

Figure 7.73 shows the current population density and racial makeup of the communities around the bay. Historical census tract data from the past four decades reveals how rapidly these demographics shift. Other social risk factors were also mapped to delineate vulnerable populations. These factors include female head of household with children, lack of English language proficiency, children under five, people over age 65 living alone, and families living below 125% of the federal poverty line.

Mapping these social vulnerability metrics will enable the study to ensure that vulnerable populations are prioritized as protective strategies are developed.



Figures 7.72: Social vulnerability: population density and risk factors (Source: 2010 US Census tracts)

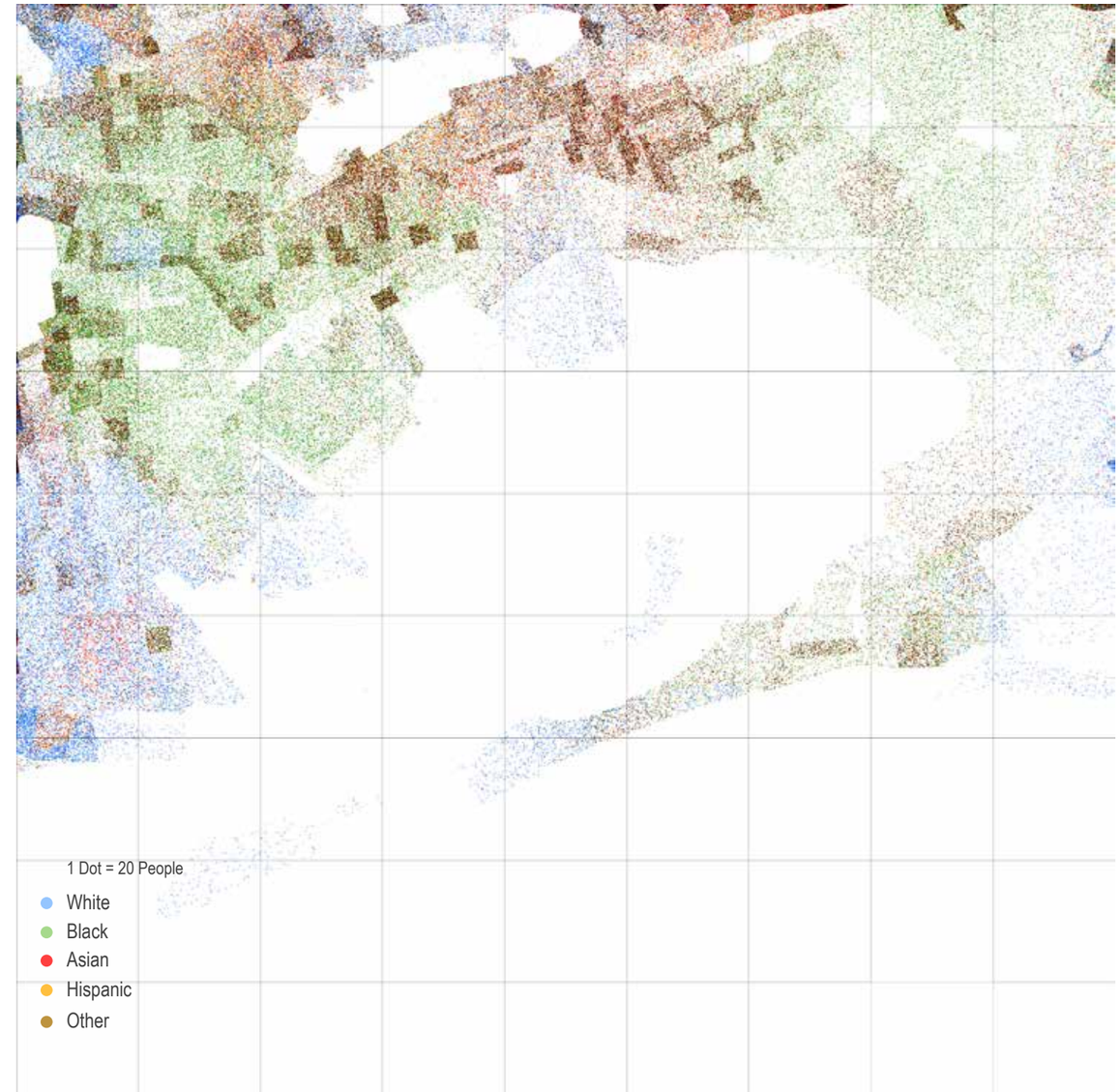


Figure 7.73: Social vulnerability: population density and ethnicity (Source: 2010 US Census blocks)

7.8.3 Environmental Vulnerability

The rare and sensitive ecosystems map (Figure 7.77) was derived by combining two sets of data that highlight areas of environmental value and sensitivity within Jamaica Bay. Shoreline types were extracted from the NOAA Environmental Sensitivity Index for at risk shorelines. The Large Tract Ecosystems were located using the EPA's EnviroAtlas Macroform Rarity index toolset. This index locates native large-tract ecosystems using USGS land use data and the National Vegetation Index to classify each ecosystem tract's size and rarity.

The NOAA Environmental Sensitivity Index Map identifies both federal and New York State-listed threatened and endangered species, along with New York State-listed species of special concern. These species' habitat locations, as well the times of the year during which these species are present in Jamaica Bay, have been studied.

Figure 7.75: Environmental Sensitivity Index (Source: NOAA ESI)

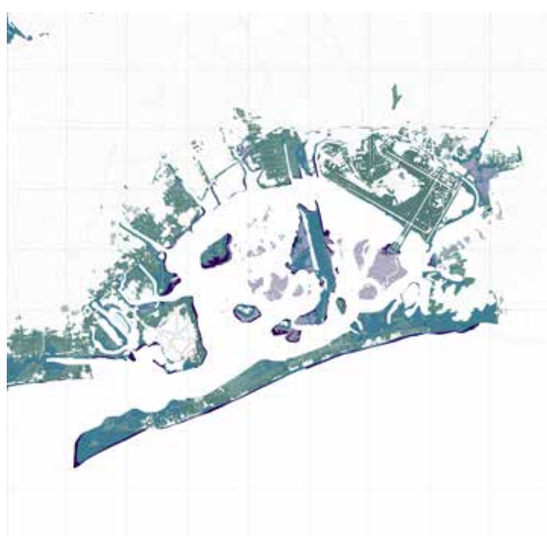


Figure 7.74: FEMA 2013 PWM 100-year and 500-year floodplains with Sandy hindcast, October 29, 2012 (Source: FEMA)

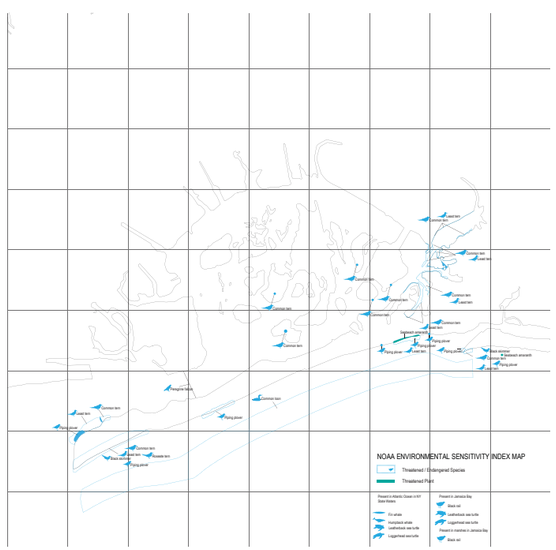


Figure 7.76: Environmental Sensitivity Index Map (Source: NOAA ESI)

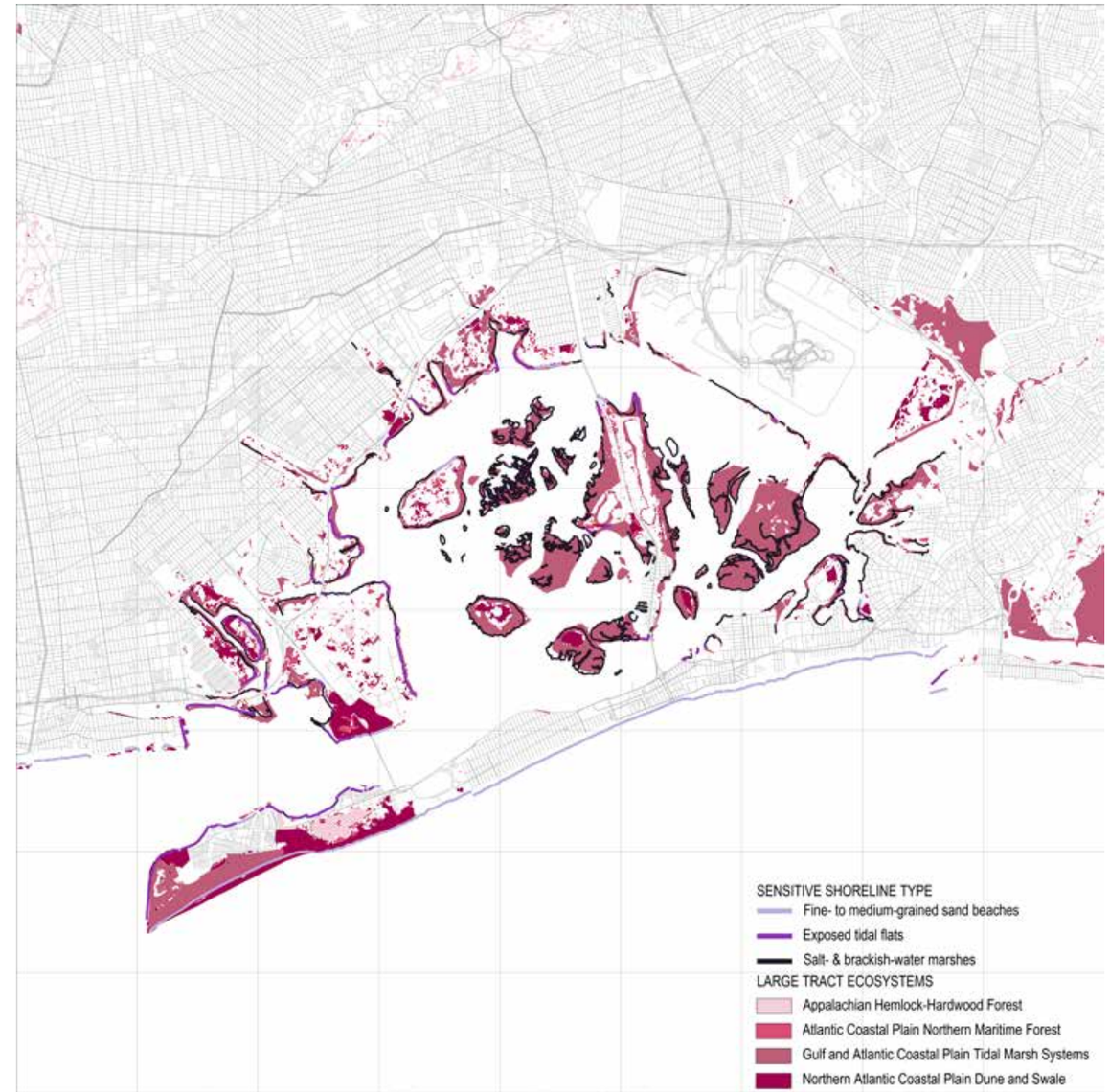


Figure 7.77: Rare and sensitive ecosystems at Jamaica Bay (Source: NOAA ESI and EnviroAtlas)

7.8.4 Infrastructural Vulnerability

Communities in and around Jamaica Bay host significant infrastructure. In addition to remnants from the bay's history as an industrial processing and dumping area, the bay currently has four active waste water treatment plants, three recently closed sanitary landfills, a power generation station, myriad fuel storage tanks, and one of the world's busiest airports.

Figure 7.80 shows the presence of important infrastructure at Jamaica Bay. The A and S subway trains cross the bay parallel to the Cross Bay Boulevard, a major roadway leading from Howard Beach over a causeway, through Broad Channel, and on to the Rockaway Peninsula. Flatbush Avenue leads to the Gil Hodges Memorial Marine Parkway Bridge to Breezy Point; this is the only roadway to and from the western end of the Rockaway Peninsula.

While communities on the bay are served by smaller-scale social infrastructure such as schools, police, and fire stations, these services are more highly concentrated north of the bay at higher ground. The larger circles in Figure 7.80 show one- and two-mile radii from evacuation centers, many of which are located in public schools, and all of which are beyond Zone 6 of New York City's revised six-tiered hurricane evacuation maps.

From this map it becomes clear that those living around the entire perimeter of the bay, and especially those on the Rockaway Peninsula, are likely to confront evacuation orders and will need to move at least a few miles to the nearest evacuation center. In the event of a major storm or other emergency, the existing transportation infrastructure of Jamaica Bay becomes a lifeline.

For those that can evacuate by car, the Cross Bay Boulevard, the Gil Hodges Memorial Marine Parkway Bridge, and the Nassau Expressway all lead out of the flood zones. For those who are unable or unwilling to evacuate, smaller-scale social infrastructure such as police, fire, medical centers, and schools become important nodes for gathering, communication, and resource distribution.

From a design and planning perspective it is important to protect these major evacuation arteries as well as the smaller nodes for refuge, relief and recovery efforts.

Figure 7.78: View of Brooklyn facing south showing spine of Flatbush Avenue leading to Rockaway Peninsula, 2014 (Photo: Danae Alessi)

Figure 7.79: View of protective Corten steel retaining wall at the A train trestle at Jamaica Bay, 2013 (Photo: Kjirsten Alexander)

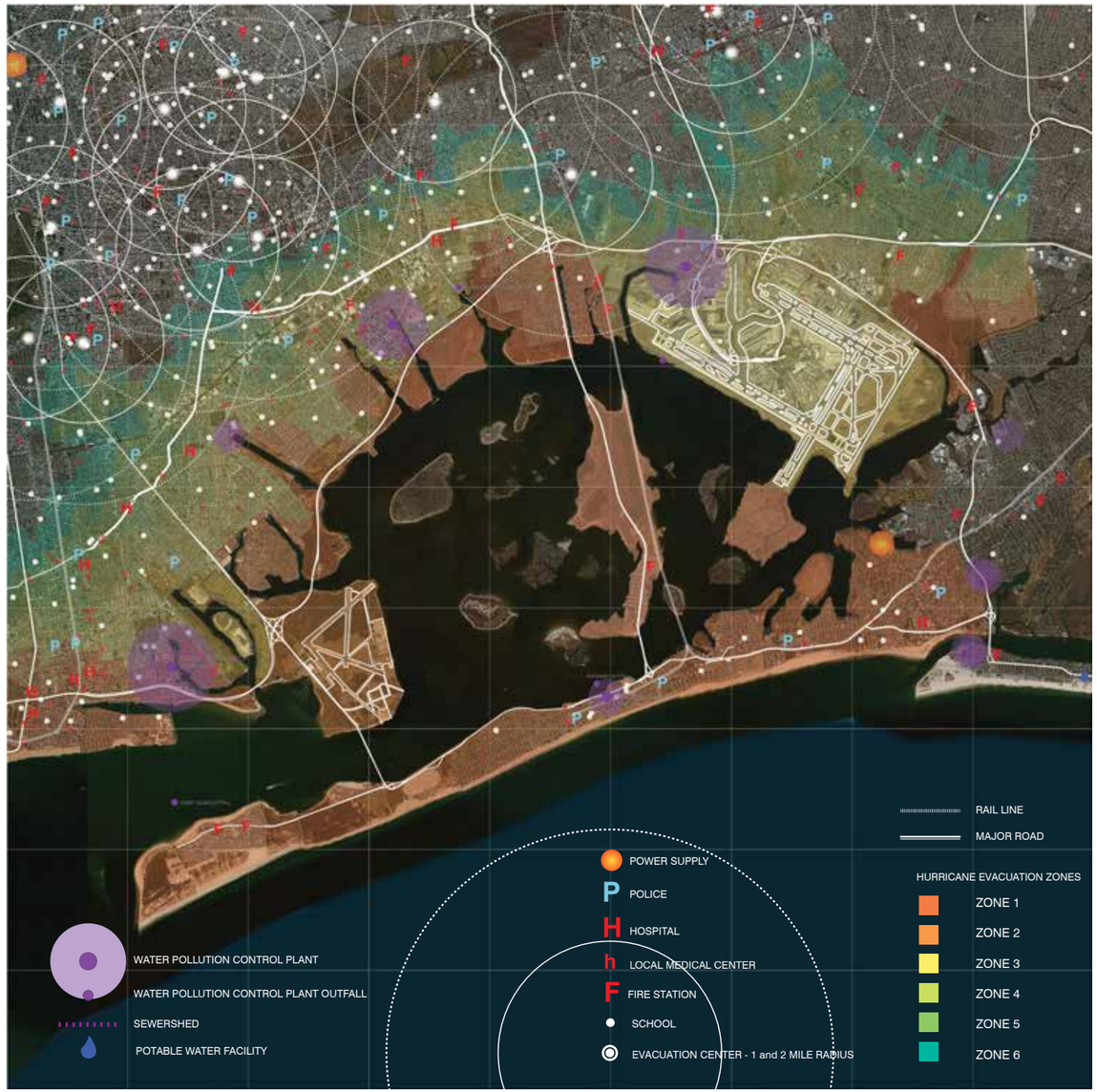


Figure 7.80: Infrastructure assets and vulnerability

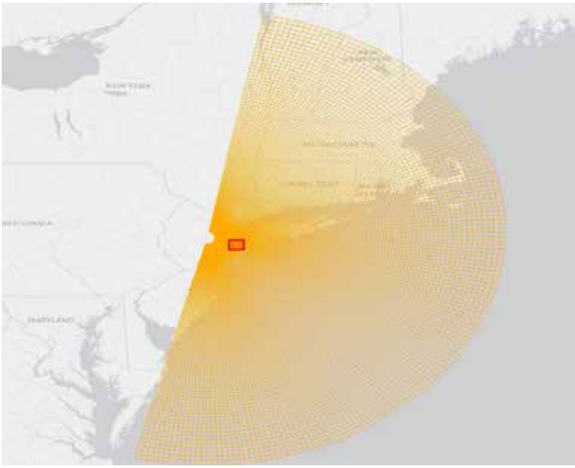


Figure 7.81: Radial grid of NOAA SLOSH Model, New York Basin (NY3) (Source: NOAA)

7.9 Methodology

7.9.1 Projection

The Jamaica Bay region analyzed in this study lies within the following USGS 7.5 Minute Quarter Quadrangle Boundaries:

Brooklyn, NY (40073-68)

Jamaica, NY (40073-67)

Lynbrook, NY (40073-66)

Coney Island, NY (40073-58)

Far Rockaway, NY (40073-57)

Lawrence, NY (40073-56)

Horizontal Project Datum is the North American Datum of 1983 (NAD83). The Jamaica Bay study area is represented with a Projected Coordinate System, New York State Plane East. Units are feet. Vertical Project Datum is the North American Vertical Datum of 1988 (NAVD88). Units are feet. All coordinated vertical datums reference NOAA's National Data Buoy Center, Station BATN6 —8518750, The Battery, NY, at 40.701 N 74.014 W (40°42'2" N 74°0'52" W).

7.9.2 GIS Analysis

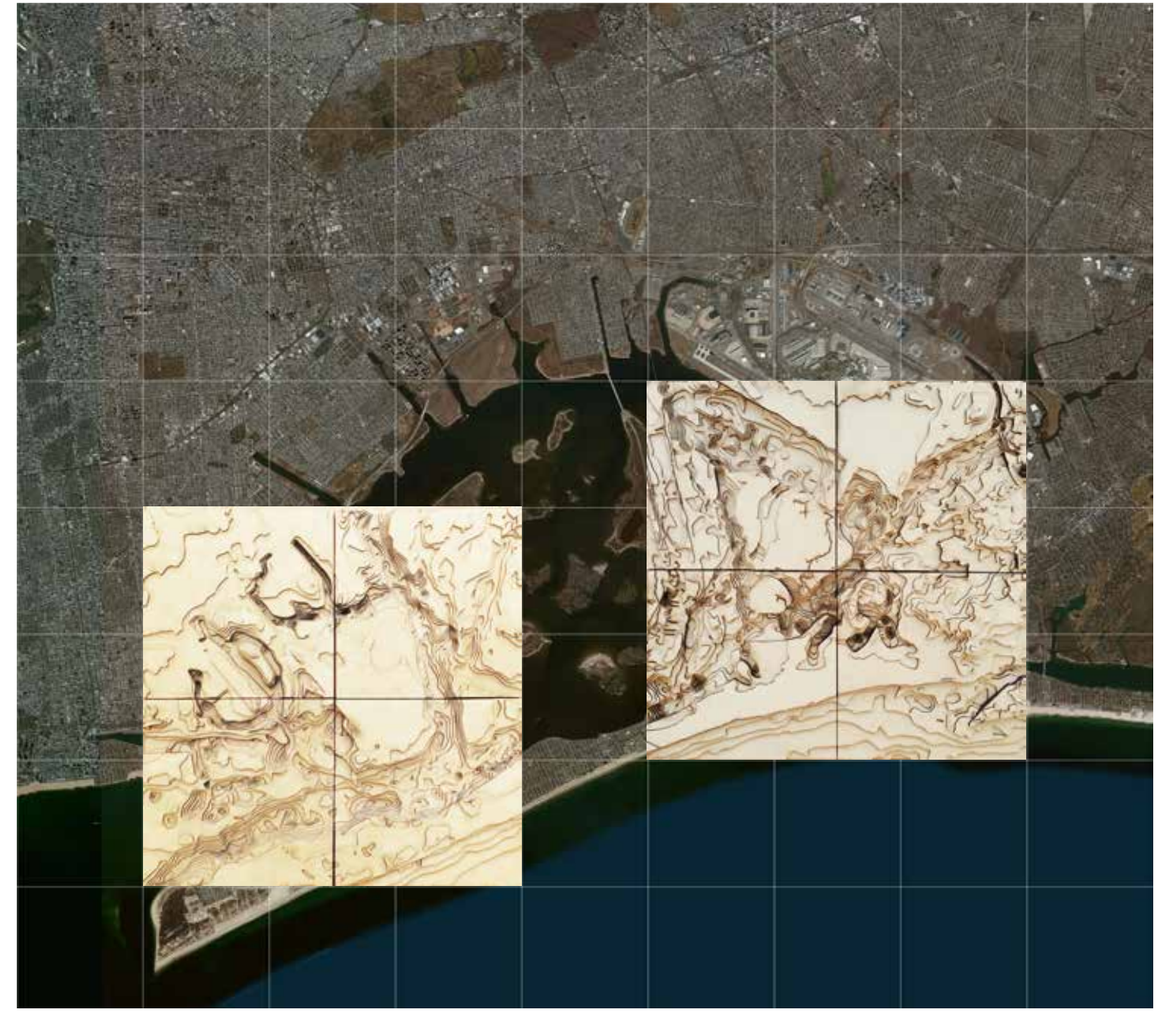
Much of the analytic work in to date is geo-referenced through the use of Geographic Information Systems (GIS), incorporating geographical data as shape files, base maps, digital elevation models, point data, and raster imagery. The software used is ESRI ArcGIS 10.1.

7.9.3 Numerical Models

In addition to the continuous topographic / bathymetric merged Digital Elevation Model (DEM) created as part of the first phase of study, work will continue with the topographic transformation of this continuous surface as design proposals are examined. Numerical storm modeling being developed by the SCR Science and Engineering research team at Princeton University, using ADCIRC (Advanced Circulation Model) and SLOSH (Sea, Lake, and Overland Surges from Hurricanes) modeling, will be incorporated into the ongoing study. Numerical sediment transport modeling is also being studied for possible application in this ongoing research.

7.9.4 Physical Models

The project is working extensively with physical hydraulic models of Jamaica Bay to test conditions of water flow, surge, residence time, and breaching. Several methods of model construction are being employed, including topographic contour models, casts of inverse topographic models, and Computer Numerical Control (CNC) milling of continuous topographic / bathymetric models. These physical models then serve as test beds for water tank studies, injected dye studies, and sediment transfer studies. An overall model of the entire Jamaica Bay system and detailed models of specific areas of Jamaica Bay are being developed.



Figures 7.82-7.85: Physical test models and process photos

7.10 Strategic Approaches for Storm Risk Reduction

7.10.1 Bay and Beach Nourishment with Strategic Placement and Beneficial Use of Local Dredge Material

The study will examine and propose a cycle of both bay and beach nourishment at the regional scale of Jamaica Bay. Dredge and drift cycles will be studied to develop a local dredge material management plan that uses a balanced cut / fill ratio. USACE has expressed interest in the use of local dredge materials, drawn from the Rockaway Inlet and East Rockaway Inlet navigational dredging as well as offshore borrow areas A-West and A-East. This material can be used in a cyclical schedule to nourish coastal beaches, bay marsh islands, and living shorelines.

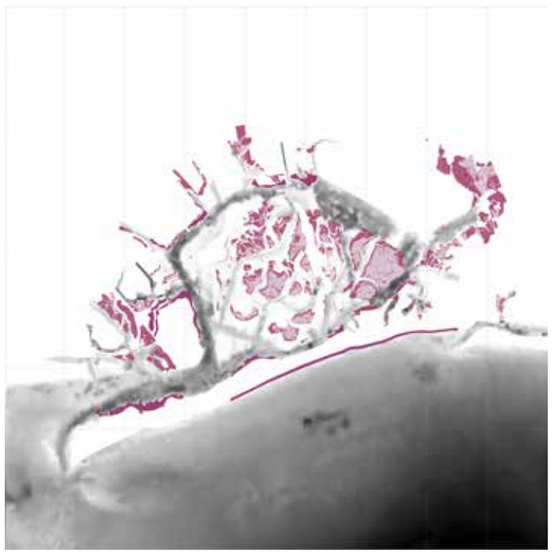


Figure 7.86: Opportunities for dredge placement

Figure 7.87: Rainbowing / thin layer dispersal method of dredge placement (Source: Golder Associates)

Figure 7.88: Equipment for USACE Plumb Beach nourishment, 2013 (Photo: Kjirsten Alexander)

Figure 7.89: John James Dredge at Rainey Wildlife Sanctuary (Source: MississippiRiverDeltaProject.org)

Figure 7.90: Sifted sand stockpiles for Rockaway Beach restoration placed temporarily on Jacob Riis Park parking lot, December 2012 (Source: Stephane Missier aka Charles le Brigand)

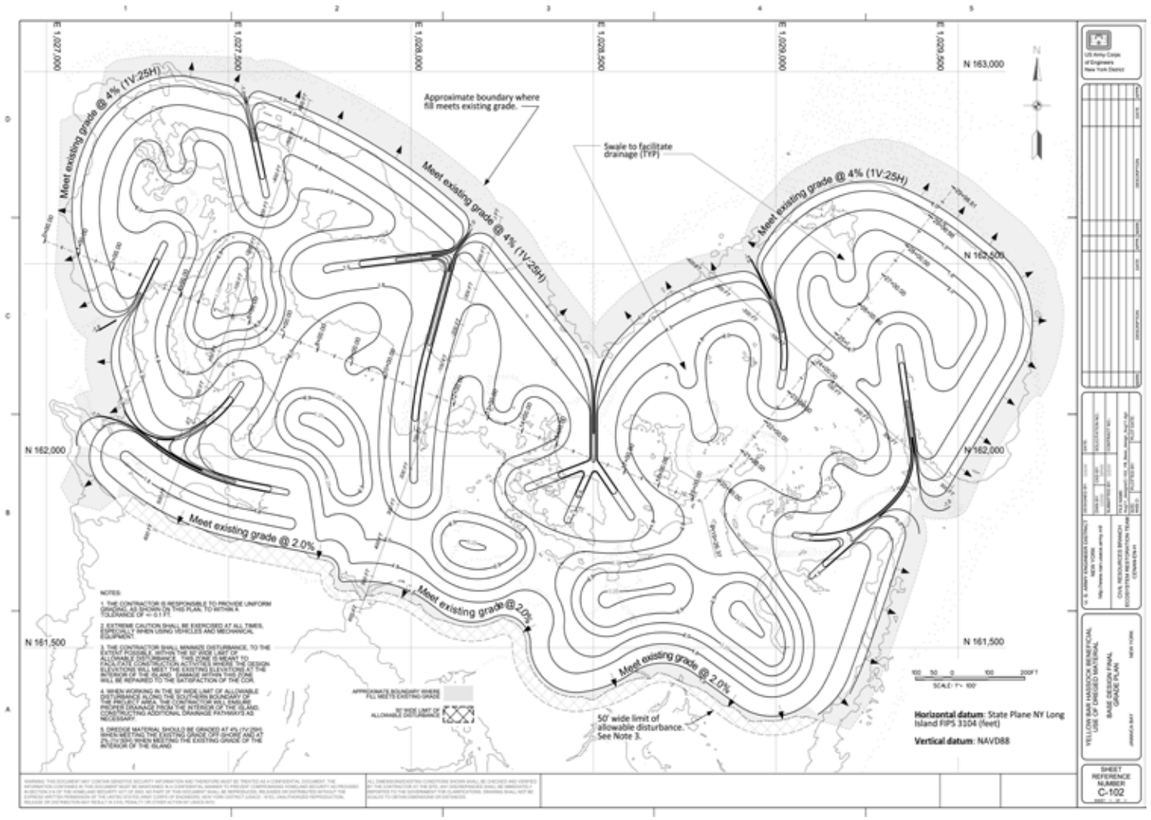


Figure 7.91: Yellow Bar Hassock Base Design Final Grade Plan, 2011 (Source: US Army Corps of Engineers)

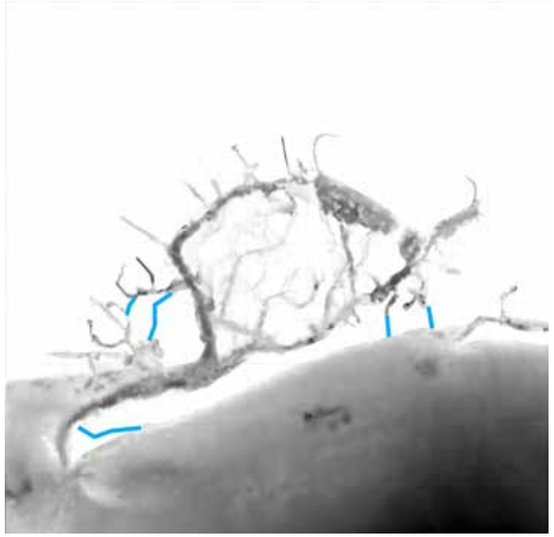


Figure 7.92: Opportunities for land breaches

7.10.2 Land Breaches to Improve the Water Quality, Circulation, and Flushing of Jamaica Bay

The study will examine and test recommendations to improve the flushing of Jamaica Bay via land breaching. The residency time of water is significant in the easternmost reaches of the bay; improved ecological health within the bay is dependent on the reduction of this residency time. In addition, it has been observed that the surge of water that entered the bay during Hurricane Sandy retreated slowly from the bay; additional outlets may improve the retreat of floodwaters.

Three zones will be considered as possible locations for land breaches / channels: the northern part of the Floyd Bennett Field peninsula, the eastern end of the Rockaway Peninsula, and the westernmost end of the Rockaway Spit. These passages may be developed as navigational channels, opportunistic locations for wetland development, or outfall points for high tides or retreating floodwaters.

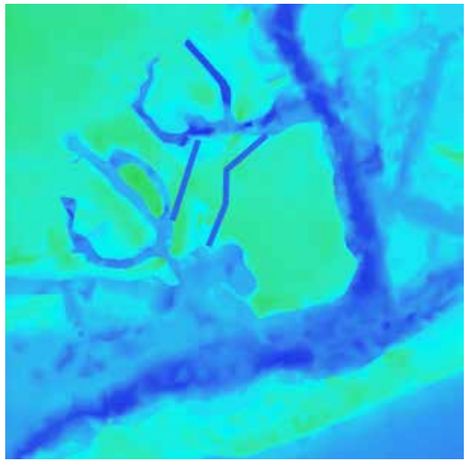


Figure 7.93: Floyd Bennett Field

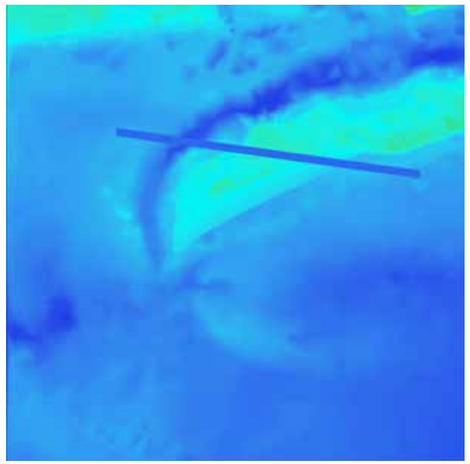


Figure 7.94: Rockaway Spit

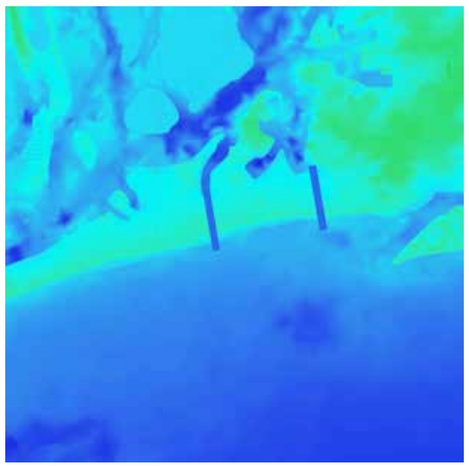
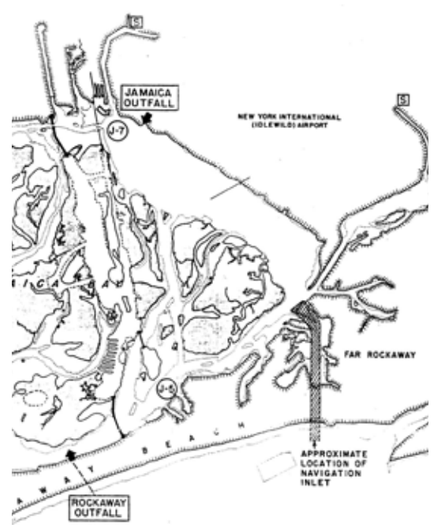


Figure 7.95: Arverne / Edgemere

Figure 7.96: Conceptual physical model demonstrating potential cuts at Floyd Bennett Field



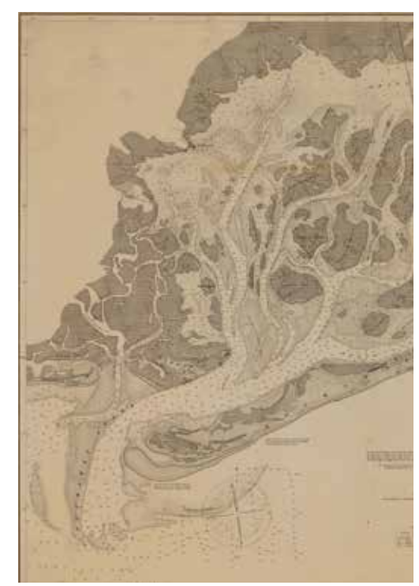


Figure 7.97: Proposed navigational inlet at Far Rockaway, 1964 (Source: US Army Corps of Engineers)

Figure 7.98: Detail of Rockaway Spit, US Coast and Geodetic Survey, 1899 (Source: NOAA)

7.10.3 Local Protection of Vulnerable Communities, Infrastructure, and Ecologies Using Innovative Natural and Nature-Based Features

Historic flood extents and social vulnerability analyses reveal communities most in need of heightened protection from coastal storms and sea level rise. Among these are Broad Channel, Howard Beach, Breezy Point, Far Rockaway and Canarsie. Instead of waiting for a single large-scale project such as the proposed surge barrier at Rockaway Inlet, vulnerable communities may be immediately protected with multiple layers of nature-based features. Natural and nature-based features offer both ecological benefits and storm risk reduction, outlined in Figure 7.100.

Supporting a healthy marsh ecology is necessary for the bay as both an ecological and coastal storm protection measure. The study will continue to support initiatives to nourish and reconstruct the marsh islands within the bay, and will examine the restoration of the deep channel passages between them. Alternative planting methods (seed / plug / spontaneous growth) and armoring methods (foundation support / perimeter armoring / sedimentary drift) will be studied and evaluated.

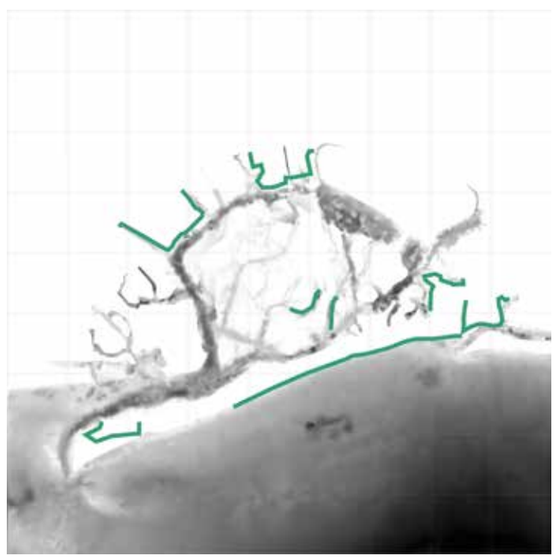


Figure 7.99: Opportunities for natural and nature-based features

Oyster and Coral Reefs

source: http://aquaviews.net

Benefits / Processes
- Break offshore waves
- Attenuate wave energy
- Slow inland water transfer

Performance Factors
- Reef width, elevation and roughness

Maritime Forests/Shrub Communities

Benefits / Processes
- Wave attenuation and/or dissipation
- Shoreline erosion stabilization
- Soil retention

Performance Factors
- Vegetation height and density
- Forest dimension
- Sediment composition
- Platform elevation

Vegetated Features:
Salt Marshes, Wetlands, Submerged Aquatic Vegetation (SAV)

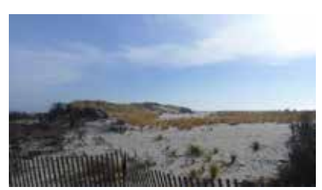
Benefits / Processes
- Break offshore waves
- Attenuate wave energy
- Slow inland water transfer
- Increase infiltration

Performance Factors
- Marsh, wetland, or SAV elevation
- Vegetation type and density

Barrier Islands

Benefits / Processes
- Wave attenuation and/or dissipation
- Sediment stabilization

Performance Factors
- Island elevation, length, and width
- Land cover
- Breach susceptibility
- Proximity to mainland shore



Dunes and Beaches

Benefits / Processes
- Break offshore waves
- Attenuate wave energy
- Slow inland water transfer

Performance Factors
- Berm height and width
- Beach slope
- Sediment grain size and supply
- Dune height, crest, width
- Presence of vegetation

Figure 7.100: USACE Natural and Nature-Based Features

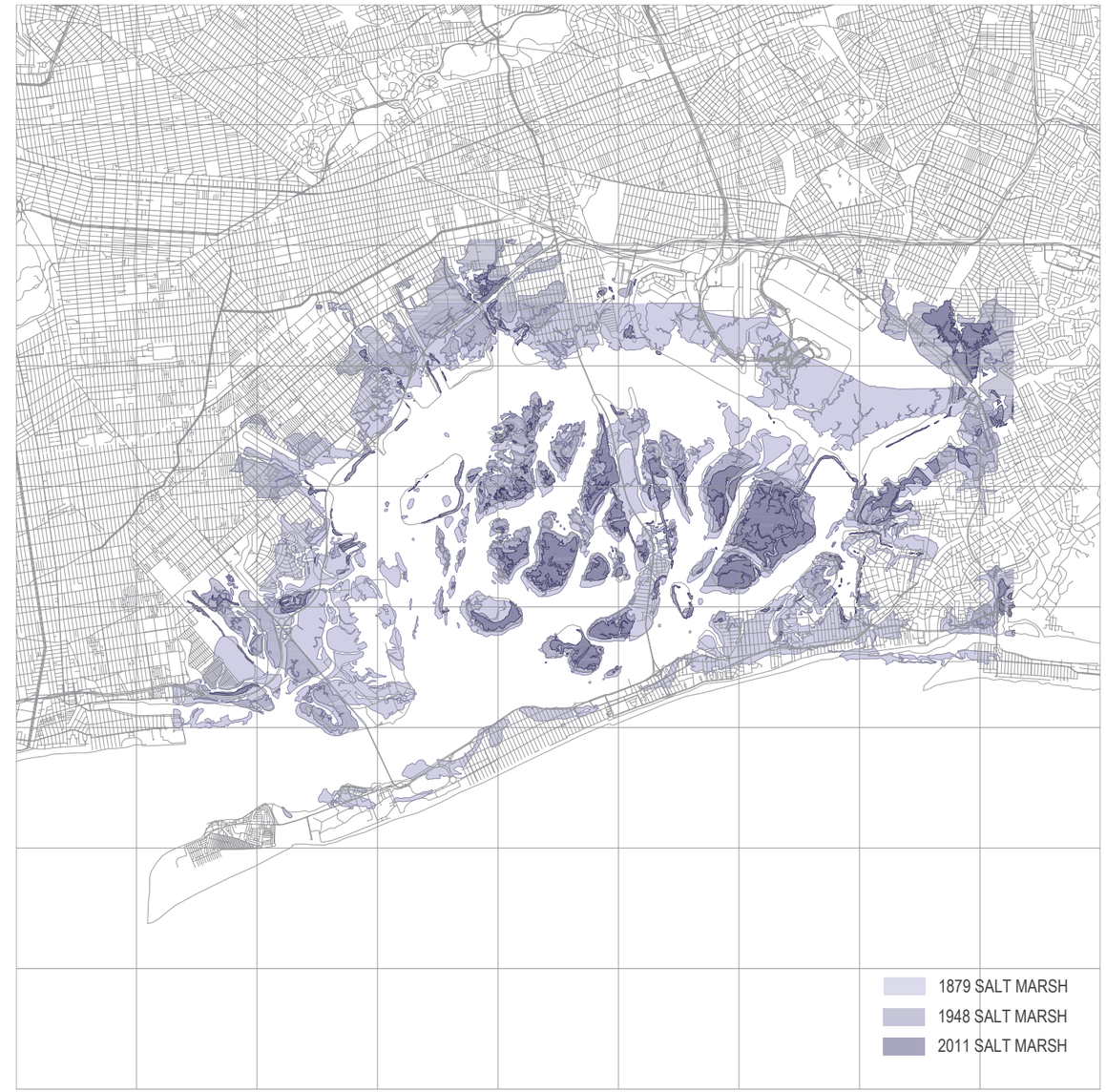


Figure 7.101: Salt marsh at Jamaica Bay, 1879 - 1948 - 2011

7.11 Proposal for Structures of Coastal Resilience, Jamaica Bay

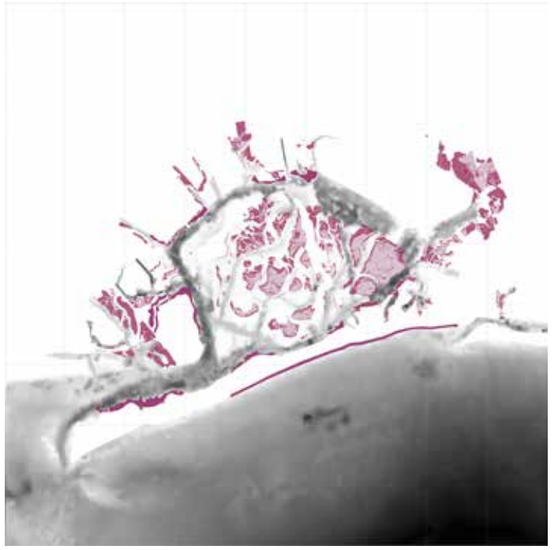


Figure 7.102: Structure 1: Bay and beach nourishment

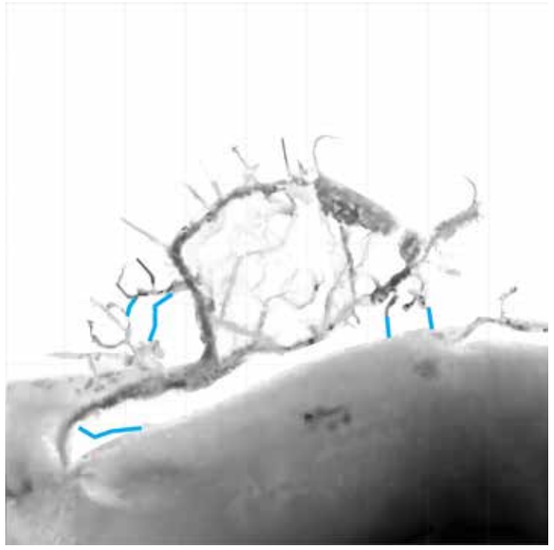


Figure 7.103: Structure 2: Land breaches

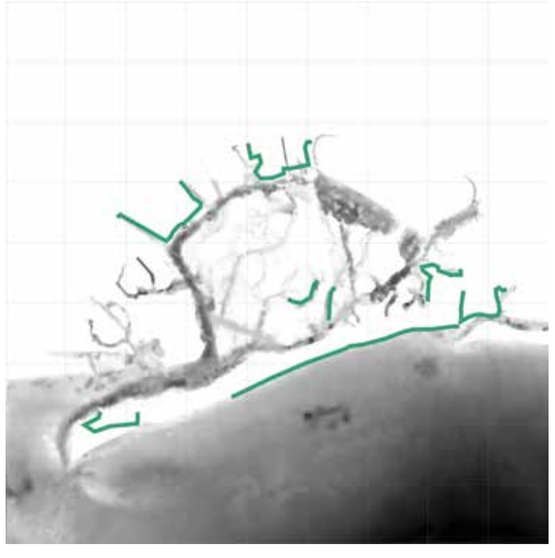


Figure 7.104: Structure 3: Natural and nature-based features

Figure 7.105: Structures of Coastal Resilience: Jamaica Bay, New York

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Resources

American Littoral Society, Northeast Chapter

Brooklyn Public Library, Brooklyn Collection Image Archives http://www.bklynpubliclibrary.org/brooklyncollection/

Brooklyn Public Library, Brooklyn Daily Eagle Online

http://eagle.brooklynpubliclibrary.org/Default/Skins/BEagle/Client.asp?Skin=BEagle

Brooklyn Public Library, Historic Brooklyn Photo Gallery

http://www.bklynpubliclibrary.org/brooklyncollection/historic-brooklyn-photo-galleries

CUNY Institute for Sustainable Cities http://www.cunysustainablecities.org/

Environmental Protection Agency, EnviroAtlas Macroform Rarity Index: http://www.epa.gov/research/enviroatlas/

Federal Emergency Management Agency Preliminary Work Maps, New York City, June 2013 http://www.region2coastal.com/preliminaryfirms

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New York Public Library, Digital Gallery http://digitalgallery.nypl.org/nypldigital/index.cfm

New York City Department of Parks and Recreation, Photo Archive

New York City Department of Parks and Recreation, Arsenal Library

New York City Department of Parks and Recreation, Map Division

New York City Department of Parks and Recreation, Natural Resources Group

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New York City Office of Emergency Management, Hurricane Evacuation Map http://maps.nyc.gov/hurricane/

New York Rising Community Reconstruction Project

http://stormrecovery.ny.gov/community-reconstruction-program

NYCity Map http://gis.nyc.gov/doitt/nycitymap/

National Data Buoy Center http://www.ndbc.noaa.gov/

National Oceanic and Atmospheric Administration, Tides and Currents - Datums http://tidesandcurrents.noaa.gov/datums.html?id=8518750

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Figure 7.106: Proposal to Beautify Jamaica Bay, Claus Oldenburg, 1964 (Source: ArtStor)

08

Atlantic City's Amphibious Back Bay

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Figure 8.1: The North Atlantic Coast with areas of social vulnerability (high population density and low median household income) highlighted within the FEMA FIRM flood zone

8.1 Vulnerable Sites Assessment

In considering a study area, the Princeton team sought a site whose densely urban development came together with ecological systems and the threat of natural hazards. We sought a community which, due to its social and economic vulnerability, has been outside the logic of cost benefit analysis often required to initiate coastal protection projects. As New York City has been the focus of much attention post-Sandy, we investigated four other sites in the NJ-NY area: Newark Bay, Villas and Vicinity, Mastic Beach and Atlantic City.

Though Newark Bay was of early interest, the presence of heavy industry and its legacy of toxicity problemitized intervention in the area. And in looking farther to the north and south along the northeast coast, we found few sites which had the desired confluence of urban density, social vulnerability, and the potential for a heterogenous approach to coastal protection.

It struck us odd that Atlantic City has largely been overlooked by highly-publicized post-Sandy comprehensive plans and ideas competitions, such as Rebuild by Design, in which attention has overwhelmingly been paid to the New York City metropolitan area and Barnegat Bay further north on the Jersey Shore. Furthermore, though the city government had issued a Storm Damage Mitigation Project marked with thick indistinct areas for necessary intervention, neither the city nor the county government had a detailed and comprehensive plan for the state's most densely developed barrier island.

Atlantic City emerged as the ideal site on which to considers the vital relationship between city and water and develop interventions which perhaps interrogate the conventional wisdom used to initiate and develop coastal protection measures.

Figure 8.2: Mastic Beach lacked urban density and diversity of coastal conditions. Additionally, the site was too near Jamaica Bay, another SCR study area.

Figure 8.3: Newark Bay was complicated by issues of heavy industry and toxicity.

Figure 8.4: Villas and Vicinity along the Delaware Bay lacked urban density and year-round residents. The scope of projects appeared limited to beach nourishment.

Figure 8.5: Atlantic City emerged as the most promising site with a rich history of urban development and social vulnerability. Its low elevation as a barrier island exposes the city to storm damage on several fronts.

Figures 8.2-8.5: Maps on the left hand side indicate the FEMA FIRM flood zone; maps in the center indicate social vulnerability measured by population density and median household income; bird's eye sections on the right are of typical coastal conditions

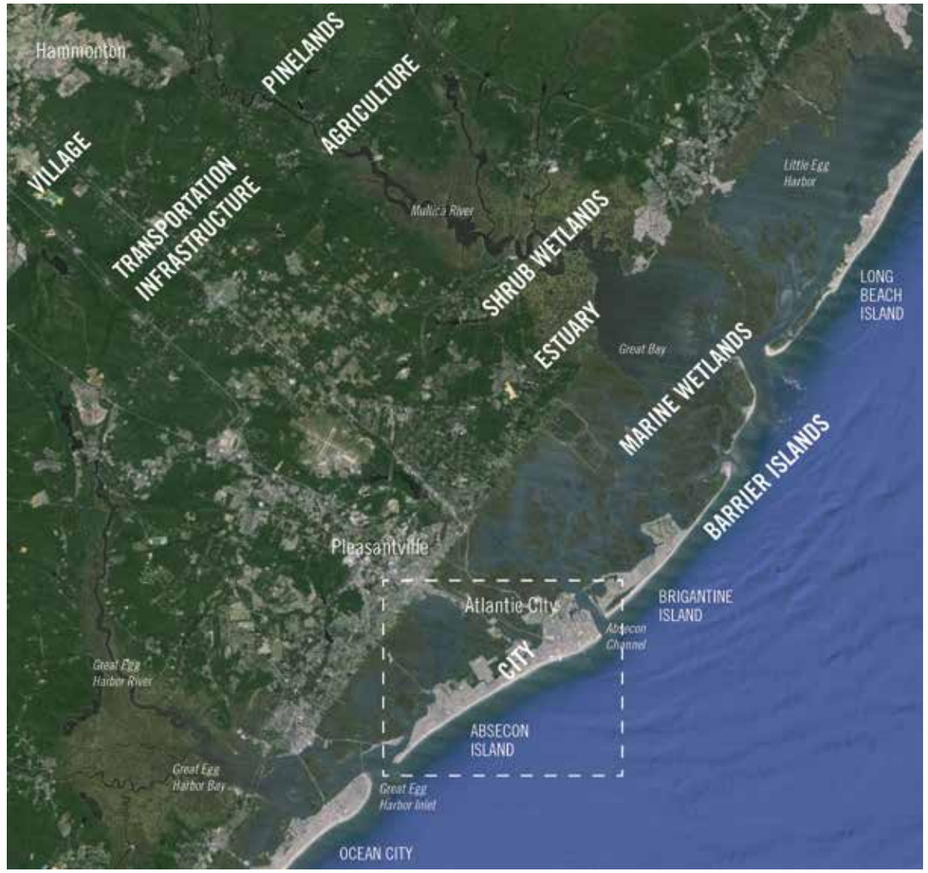


Figure 8.6: Regional map of South New Jersey coast. The dashed bounding box indicates the study area

8.2 The New Jersey Coast and Atlantic City

Barrier islands, narrow offshore deposits of sand and sediment, extend from New England down the Atlantic Coast, and stretch around the Gulf of Mexico. The islands are separated from the main land by a shallow bay or lagoon and separated from each other by narrow tidal inlets. Barrier islands serve two main functions. First, they protect the coastline from severe storm damage. Second, ecologically, they host habitats important for wildlife. They are fragile, constantly changing ecosystems that are important for coastal geology and ecology. Barrier islands have long been developed as beach communities and often this practice has frozen their dynamic coastal morphology in place, posing dangers to the larger ecosystem and increasing the risk of property damage from coastal storms. While most barrier islands have been developed for seasonal tourism, Atlantic City stands apart as the most densely populated community on New Jersey's outer coast.

Much like the rest of the southern shore, Atlantic City is situated at the seaward edge of a larger ecological system which extends inland and upland. The Pinelands, punctuated by villages and townships, give to agricultural development and regional growth at the coast. The Mullica and Great Egg Harbor Rivers on either side of Absecon Island provides the principal drainages of the extensive Pinelands into the Atlantic Ocean. The wetlands at the mouth of each river serve to purify water, control flooding and stabilize the coast. The Mullica estuary on Great Bay is considered one of the least-disturbed and healthiest marine wetlands habitats in the northeastern United States.

Absecon Island, which is home to Atlantic City and a number of other communities, offers both specific and generic conditions. Its form, including a sporadically developed back bay, inlets fixed by human intervention, and marine wetlands that link it ecologically to neighboring islands and the mainland, is much like the other dozen or so barrier islands in New Jersey. However,

Figure 8.7: USGS Quarter Quad Grid of study area

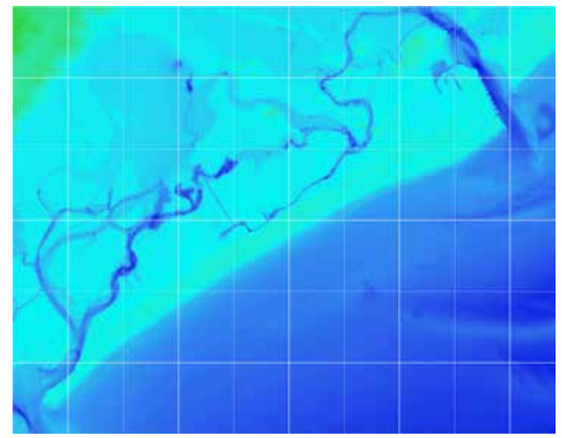


Figure 8.8: Merged topographic and bathymetric Digital Elevation Model of study area

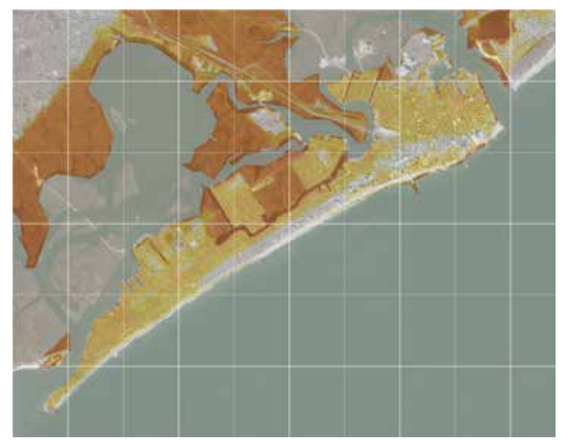


Figure 8.9: Hurricane Sandy inundation

Atlantic City's highly urbanized fabric gives the Princeton team a site where the balance between city and water affects the lives of a more diverse and vulnerable population.

8.3 Legacy Of Social Vulnerability

Atlantic City is economically and geographically vulnerable. As a low-lying barrier island, this city has been in the path of several historic storms and has sustained significant alterations to its coastal morphology. Additionally, Atlantic City is the only barrier island in New Jersey with densely developed urban fabric. With one quarter of its population living below the poverty line, and with a per capita income of $15,402, Atlantic City is also one of the state's poorest communities.[1]

This legacy of social and economic vulnerability can be mapped on to Atlantic City's history of boom and bust, reinvention and decline. Beginning in the mid-19th century, the city grew as a resort destination. Though the beach provided the initial draw for visitors, Atlantic City entrepreneurs developed attractions along the coast to keep up with the demand from seasonal tourists. The city's iconic boardwalk, built in 1870 to keep guests from tracking sand into hotel lobbies and railroad cars, hosted popular amusements as well as the nation's largest hotels and resorts—outfitted with modern amenities. By 1925, ninety-nine trains full of visitors arrived and departed daily throughout the summer months. [2]

The post-war era saw an increasingly mobile generation of tourists seeking destinations farther afield. With air conditioning becoming widely available in urban and suburban areas, Atlantic City was no longer a necessary reprieve from the heat of nearby Philadelphia and New York. In the 1960s the city fell into deep decline; its formerly rich urban fabric became dilapidated and was razed in hopes of later redevelopment.

In 1976, a referendum permitted casino gambling in Atlantic City, which precipitated a new era of rapid growth. Despite its forecasted financial benefits, the gambling industry did little to spur economic growth beyond the casinos, hotels, and shopping malls clustered around the boardwalk. Throughout the '80s, belief in the casino industry as a viable economic anchor for the city began to recede, and has continued to wane. New casinos in the underdeveloped marina district briefly garnered enthusiasm for wider economic growth, but revenues began falling immediately due to the legalization of gambling in nearby states and the 2008 recession. Between 2006 and 2010, profits fell by 30%. Additionally, government programs financed by those revenues were struggling, crippling the city further. [3]

Figure 8.10: In the mid-19th century, the city grew as a resort destination with tourists arriving by train. Though the beach provided the initial draw, the city's boardwalk, built in 1870 hosted amusements as well as hotels and resorts.

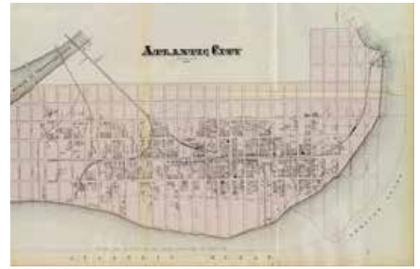


Figure 8.10a: 1880

Figure 8.10b: 1900

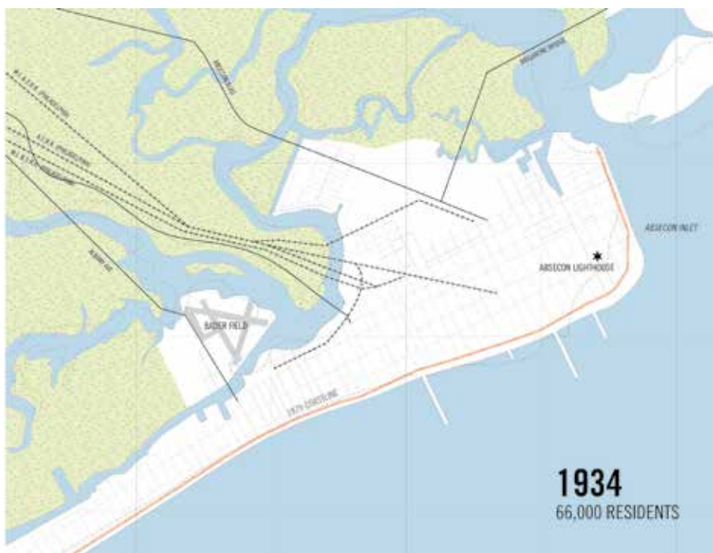


Figure 8.11: The first half of the 20th century saw explosive growth. City fabric densified alongside the growing boardwalk. In the back bay, wetlands were filled and converted to infrastructure and housing.

Figure 8.11a: Aerial View of the South Inlet (1963)

Figure 8.11b: Aerial View of the Atlantic City boardwalk, looking towards Ventnor City (1944)

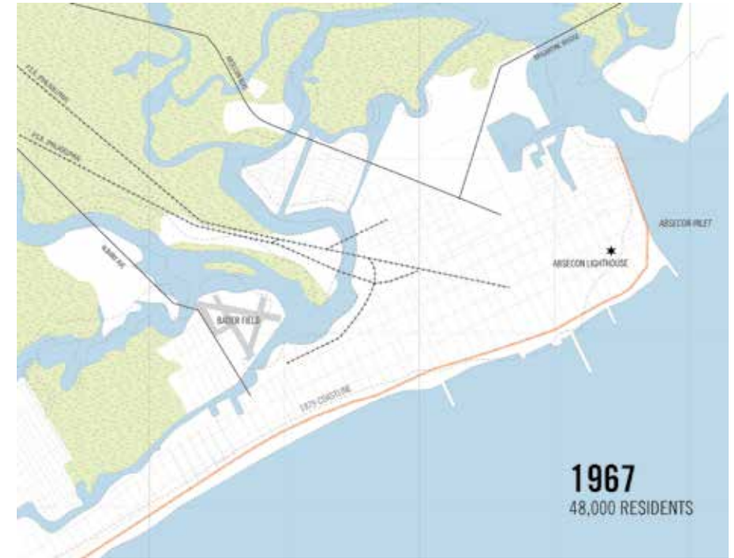


Figure 8.12: In the 1960s the city fell into deep decline; its formerly rich urban fabric became dilapidated and was razed in hopes of eventual redevelopment.

Figures 8.12a-b: Aerial Views of the South Inlet (1977)

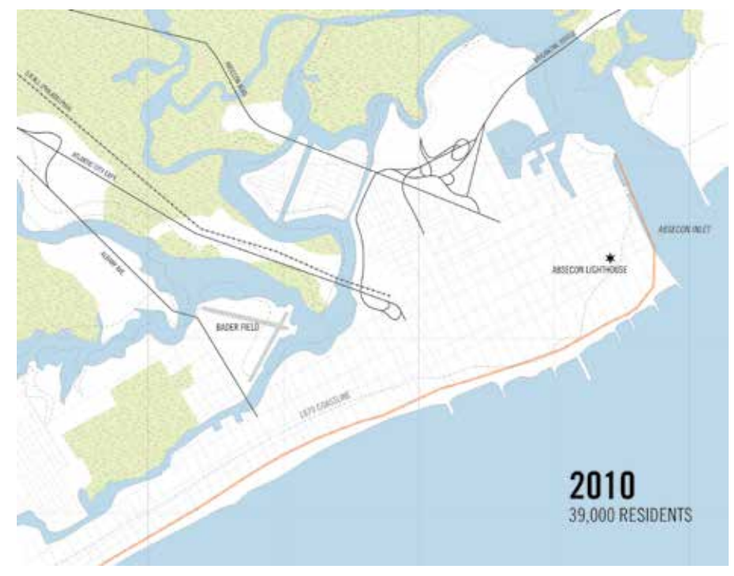


Figure 8.13: Since 1976, the city has used the gambling industry to spur wider economic development. Though experiencing brief periods of success, the recent recession and spread of gambling to other states has undermined casinos as a viable source of growth.

Figure 8.13a: Aerial view of the inlet (1995)

Figure 8.13b: Aerial view of the inlet Pre-Sandy (2012)

Figure 8.13c: Aerial view of the inlet Post-Sandy (2013)

8.4 Coastal Resilience as Economic Resilience

Storms have caused significant damage to Atlantic City's iconic boardwalk throughout its existence. Among the earliest recorded hurricanes, the 1889 storm destroyed the city's boardwalk and inundated most of the avenues approaching the beach. Later hurricanes beached and destroyed ships. In keeping with the city's spirit of amusement, entrepreneurs built docks out to scuttled and abandoned ships and charged admission. [4] Most recently, the widely-seen images of the Absecon Inlet gave potential tourists the impression that the Atlantic City boardwalk had been destroyed during Hurricane Sandy. In truth, the section of the boardwalk shown on news outlets was already abandoned and in disrepair. Hurricane Sandy merely accelerated the destruction of the blighted boardwalk.

The State of New Jersey has tailored its economic policies to meet the challenges brought by catastrophic storm damage. Some of these initiatives gave the state a stronger role in the governance and promotion of Atlantic City. For example, the New Jersey Casino Redevelopment Authority (NJCRDA), an important and active agent in the city's plans for economic growth since 1984, released a flood mitigation plan shortly before Hurricane Sandy. The NJCRDA is just another instance demonstrating how the economic health of Atlantic City has always been dependent on coastal engagement. With increasing threats of catastrophic storms and sea level rise comes a reenergized concern for resiliency. The city must reconsider its natural features and vulnerabilities in order to survive as a destination and to grow as a community.

Figure 8.14: South Inlet during the Great Atlantic Hurricane of 1944

Figure 8.15: South Inlet during Hurricane Sandy (2012)

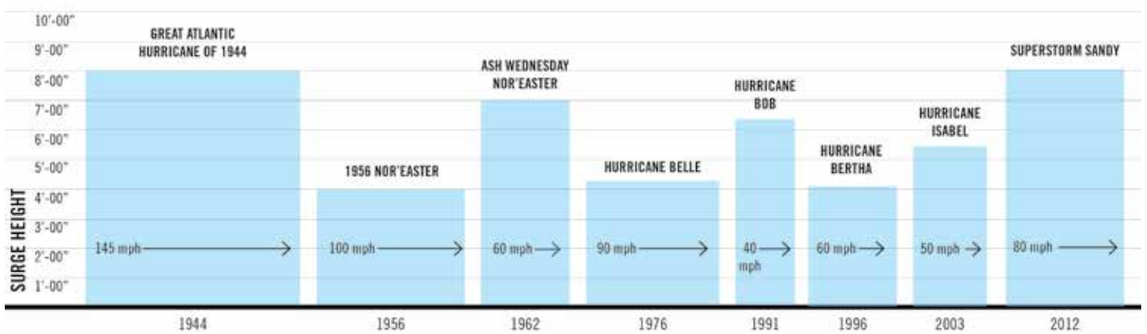


Figure 8.16: A timeline of recent storm events in Atlantic City

Figure 8.17: The Tourism District as defined by the 2012 Casino Redevelopment Authority Masterplan

Figure 8.18: The 2012 Atlantic City Storm Mitigation Plan

Figure 8.19: Near Term Phase of the 2012 Casino Redevelopment Authority Masterplan

Figure 8.20: Long Term Phase of the 2012 Casino Redevelopment Authority Masterplan

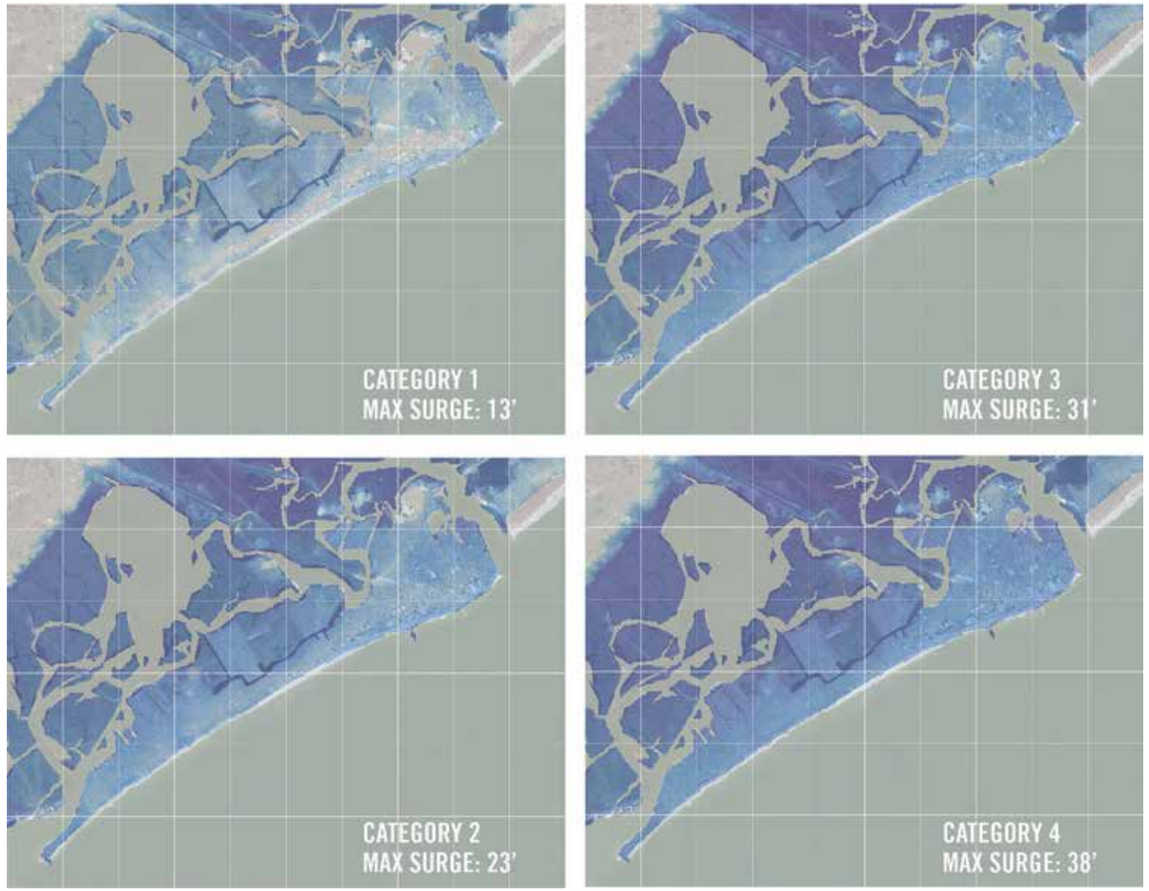


Figure 8.21: Storm surge is the depth of inundation from SLOSH Maximum of Maximums (MOMs) outputs per hurricane category. Source: Coastal Flood Loss Atlas (CFLA), which is developed by Federal Emergency Management Agency (FEMA)

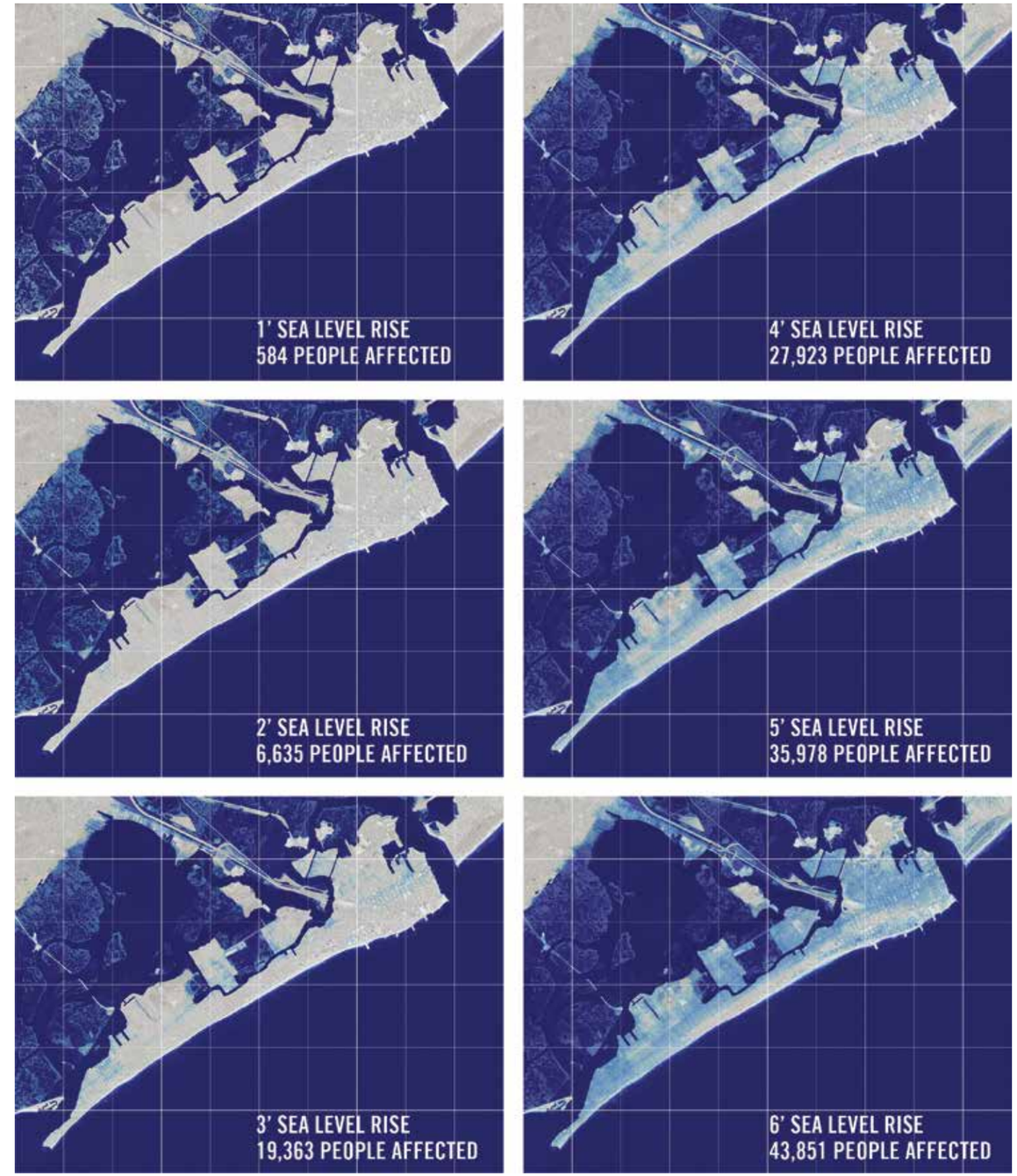


Figure 8.22: Sea Level Rise scenarios and areas of impact. Sources: National Oceanic and Atmospheric Administration Coastal Services Center with population estimates from Climate Central Surging Seas Risk Finder

Figure 8.23: South Inlet and Chelsea Heights are typical inlet and back bay conditions additionally plagued by economic and social vulnerability. Source: United States Census.

8.5 Back Bay Vulnerability

The projected effects of sea level rise and storm surge reveals a particularly vulnerable back bay. Where the nourished beach and dunes on the ocean side effectively stem inundation, at least in the short term, the inlet and back bay are persistently most threatened. These conditions provide areas of study that are repeated along both the New Jersey shoreline and much of the Atlantic coast.

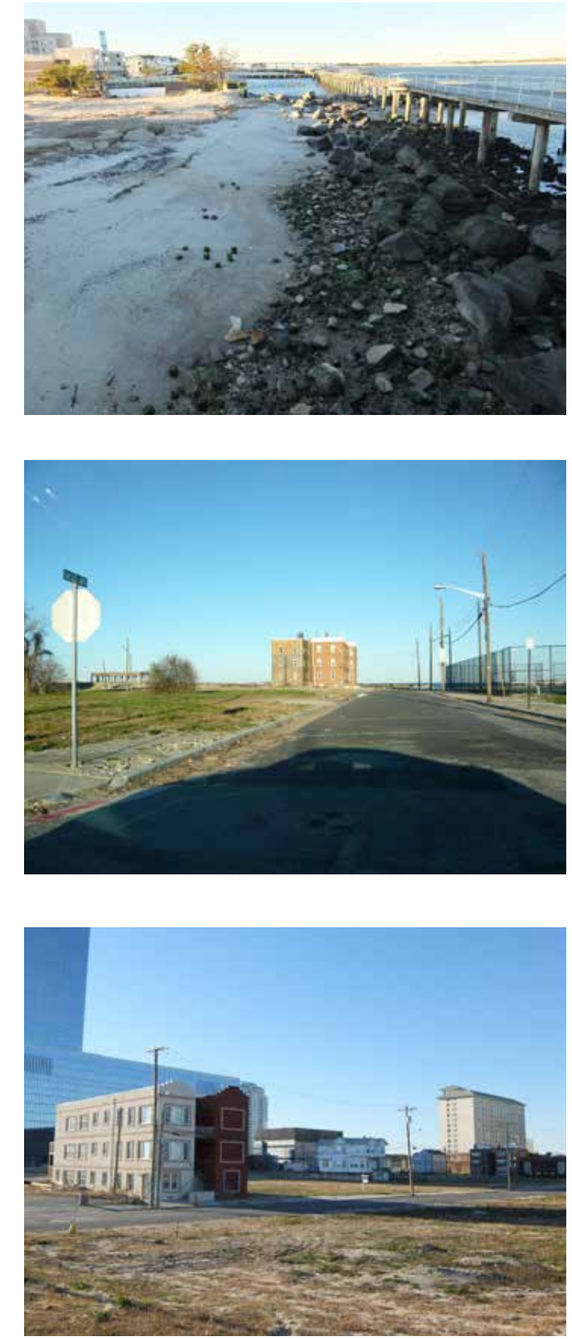
Importantly, the South Inlet neighborhood along on the Absecon Channel and Chelsea Heights, a community in the back bay built on filled wetlands, are also plagued by economic and social vulnerability.

Despite increasing blight and vacancies, particularly in parts of the inlet, both neighborhoods are among the most densely populated in the city. While both neighborhoods report relatively low median incomes, the South Inlet reports some areas of extreme poverty.

Chelsea Heights is a post-war residential area, bookended by the Ventnor Protected Wetlands on one side and a decommissioned airport, Bader Field, on the other. Many homes directly border wetlands and marine thoroughfares. The very proximate threat of rising water has lead a number of residents to lift their homes. And though the city's main evacuation route cuts through the neighborhood, there is no otherwise city- or community-led flood mitigation or preparedness plan for the area.

While Chelsea Heights is a functional and diverse neighborhood, the South Inlet has a remarkable number of vacant lots and blighted properties, many having been that way since the 1960s. Some properties were cleared by the city's planning office in hopes of development. Much of that land remains vacant with the exception of the Revel Casino. Other properties were simply abandoned or burned by their owners. The neighborhood's relationship to the water is characterized by its outboard, and nearly entirely demolished boardwalk and a nearly continuous bulkhead which bars most visibility and access.

Figures 8.24a-c: Chelsea Heights' protected wetlands, raised homes, and adjacent marine thoroughfares



Figures 8.25a-c: South Inlet's partially demolished boardwalk, vacant properties, and casino backdrop

8.6 Sea Walls and Extruded Sections: The USACE in Atlantic City

Since 2003, the United States Army Corps of Engineers (USACE) has undertaken a program of beach nourishment and dune systems along Absecon Island's Atlantic coast. The enhanced beach profiles (with an elevation of +14.75 and a beach width of 200 feet) designed by the USACE, effectively protected much of Atlantic City's seaside properties during Hurricane Sandy. However, significant storm surge entered through the inlets at both ends of Absecon Island, flooding much of the city's back bay. Flood and erosion protection features along the city's inlet and back bay edges are a collage of engineered bulkheads and revetments implemented by various federal, state, and municipal agencies, as well as private interests. A number of weak points or unprotected edges undermine the function of all other barriers around them. The USACE has approved plans to fill a number of the major gaps on the inlet side of the city, but has yet to begin construction.

The beach nourishment program in Atlantic City is indicative of the USACE's approach to the issue, centered on the use of a prototypical cross-section. A profile is first developed, following precedent and conventional practices, then extruded, creating a singular solution often miles long, regardless of the immediately adjacent urban forms. The USACE regards the city too closely as a measure of economic impact—does the value of property sufficiently justify a coastal intervention? Instead, the very logic of urban form could be integrated into the USACE's newly reformulated "full array of measures" which combines natural, nature-based, structural, and nonstructural solutions in order[5] to add economic and social value.

In the wake of recent storm events, the USACE is supporting a greater integration of natural or nature-based features, such as wetlands and dunes, with structural interventions and other engineered solutions, such as seawalls and breakwaters. Along with non-structural solutions, the full array of measures hopes to layer these interventions to achieve an approach to risk reduction which can simultaneously improve natural, social, and economic conditions.[6]

In preliminary information sessions for the NACCS, the

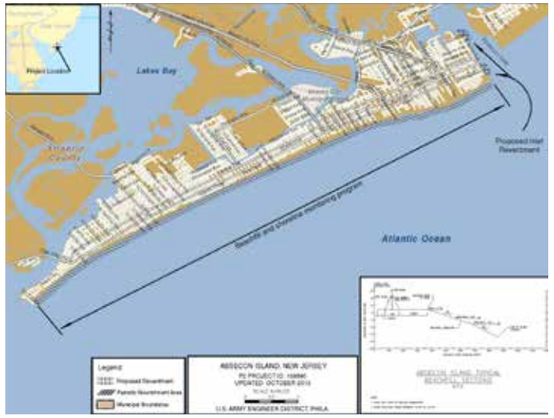


Figure 8.26: Recent and current USACE work on Absecon Island

Figure 8.27: Beach nourishment completed in Atlantic City, showing the direct extrusion of beachfill and dune section

USACE has offered "combined profiles"[7] that mobilize a number of natural and nature-based features in conjunction with structural interventions. However, this strategy may be repeating the shortcomings of conventional and singular profiles. Strategies are aggregated by adjacency; for example, a submerged breakwater, a seawall, and a meadow shrubland are placed in a linear sequence. The benefits of each remain isolated. In evaluating these combined scenarios, only individual effects of individual features can ever be measured, as there is no metric for a potentially multiplied or layered system.

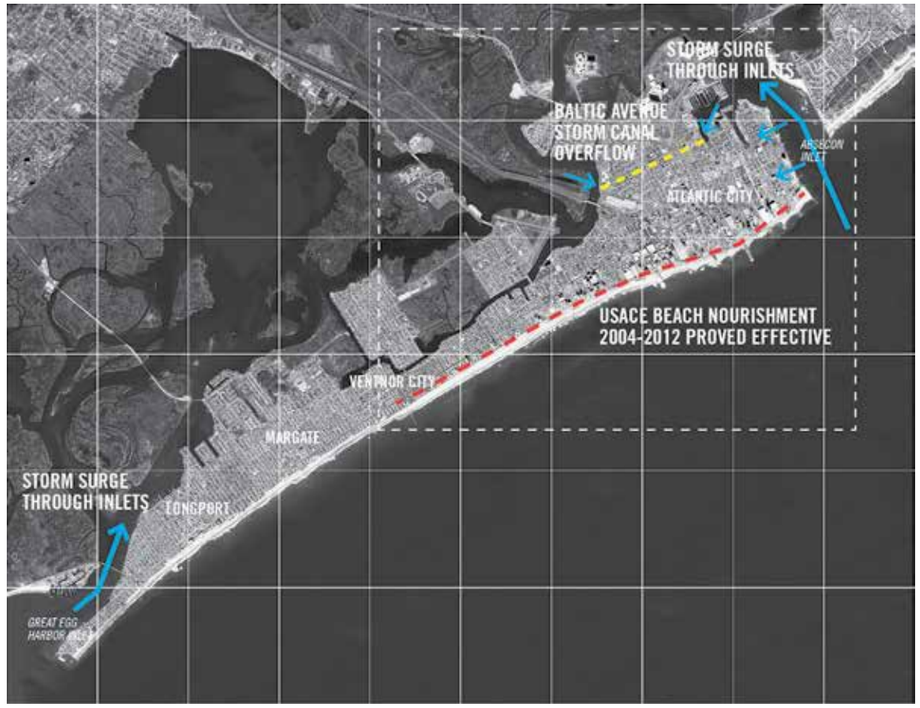


Figure 8.28: Though Atlantic City's seaside coast is protected by USACE Beach Nourishment, storm surge enters through the inlets, saturating the back bay and much of the city.

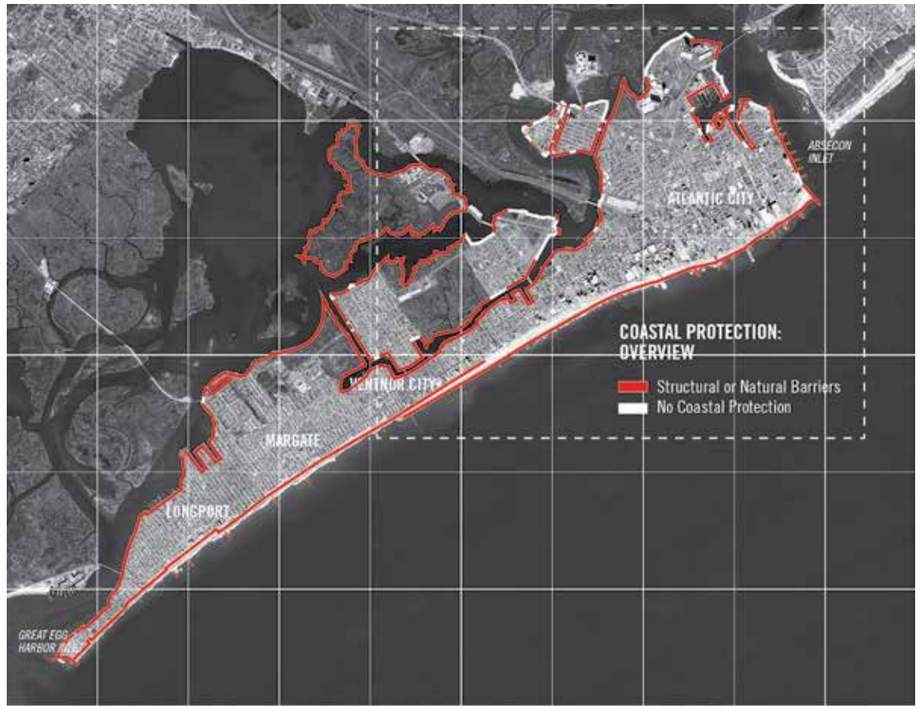


Figure 8.29: Current coastal barriers protecting Absecon Island have been built over the decades by a number of federal, state, and city agencies, as well as private interests.

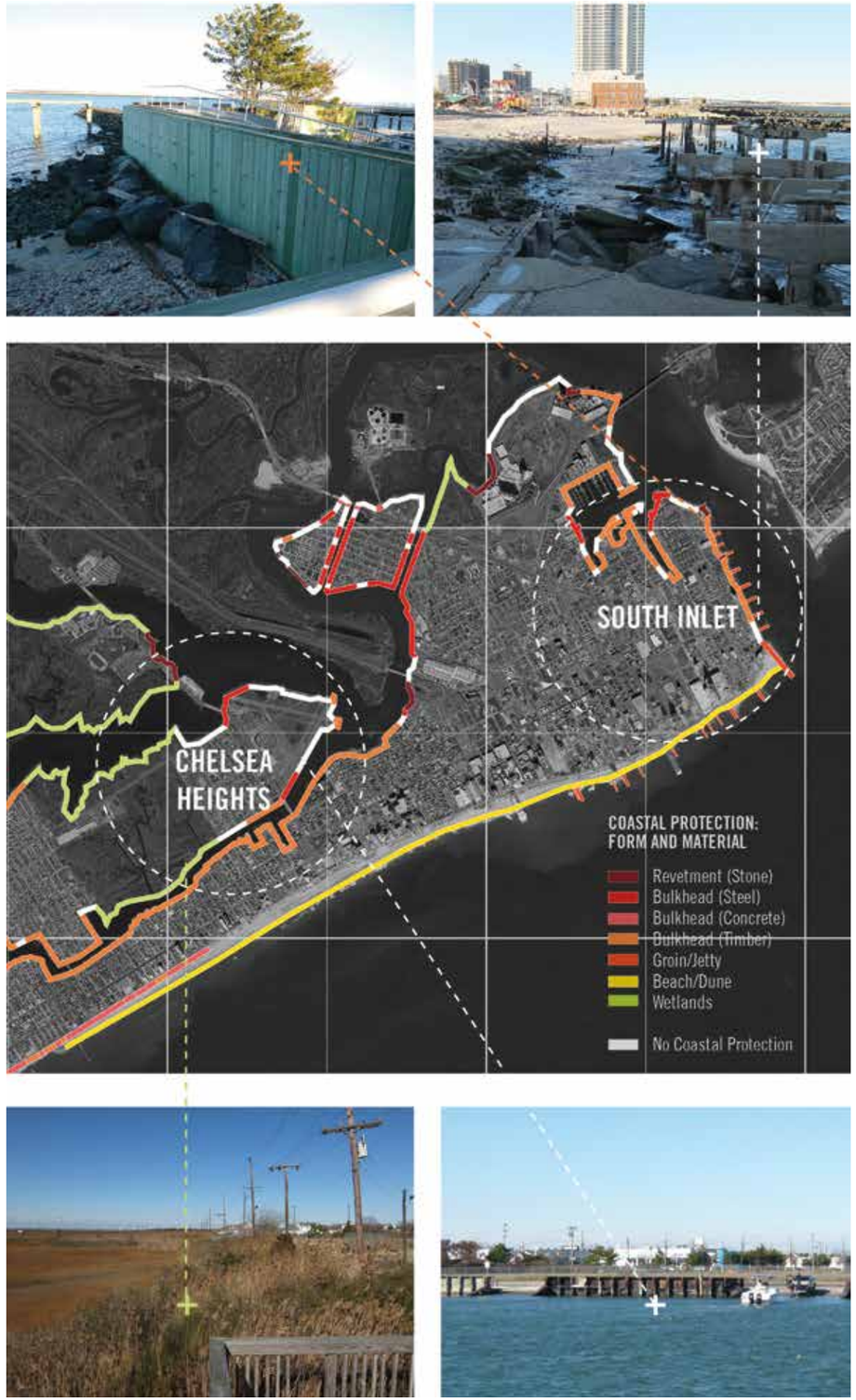


Figure 8.30: Coastal barriers, mapped by form and material, focusing on Chelsea Heights and South Inlet areas of Atlantic City

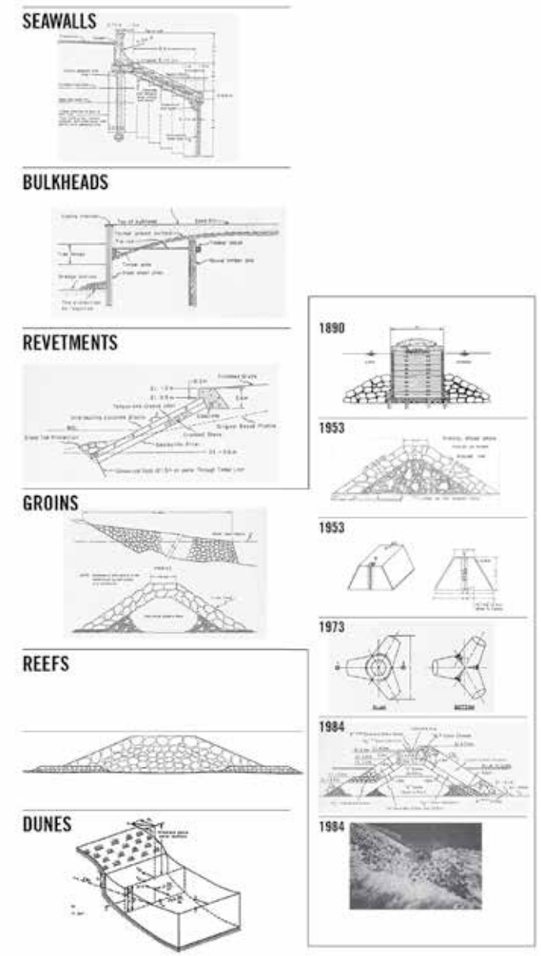


Figure 8.31: Typological analysis of USACE manuals, with historical evolution of groin typology

Table 1: Natural and nature-based features at a glance. For more detailed information, see Appendix A. The vegetated features include salt marshes, wetlands, and submerged aquatic vegetation (SAV).

GENERAL COASTAL RISK REDUCTION PERFORMANCE FACTORS:
STORM INTENSITY, TRACK, AND FORWARD SPEED; SURROUNDING LOCAL BATHYMETRY AND TOPOGRAPHY

Dunes and Beaches	Vegetated Features	Oyster and Coral Reefs	Barrier Islands	Maritime Forests/Shrub Communities
Benefits/Processes	**Benefits/Processes**	**Benefits/Processes**	**Benefits/Processes**	**Benefits/Processes**
Breaking of offshore waves	Breaking of offshore waves	Breaking of offshore waves	Wave attenuation and/or dissipation	Wave attenuation and/or dissipation
Attenuation of wave energy	Attenuation of wave energy	Attenuation of wave energy	Sediment stabilization	Shoreline erosion stabilization
Slow inland water transfer	Slow inland water transfer	Slow inland water transfer		Soil retention
	Increased infiltration			
Performance Factors	**Performance Factors**	**Performance Factors**	**Performance Factors**	**Performance Factors**
Berm height and width	Marsh, wetland, or SAV elevation and continuity	Reef width, elevation, and roughness	Island elevation, length, and width	Vegetation height and density
Beach slope	Vegetation type and density		Land cover	Forest dimension
Sediment grain size and supply			Breach susceptibility	Sediment composition
Dune height, crest, and width			Proximity to mainland shore	Platform elevation
Presence of vegetation				

Figure 8.32: Natural and Nature-Based Features

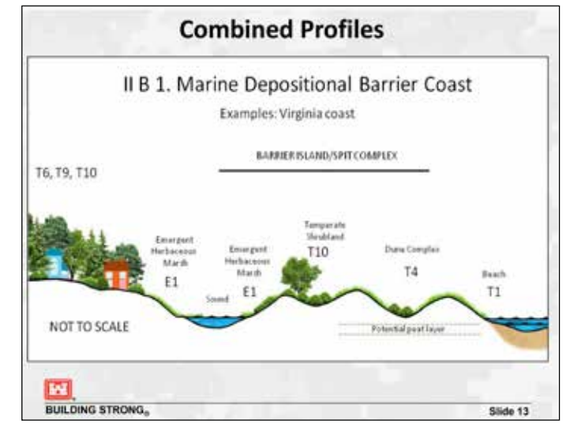


Figure 8.33: Composition of Parts

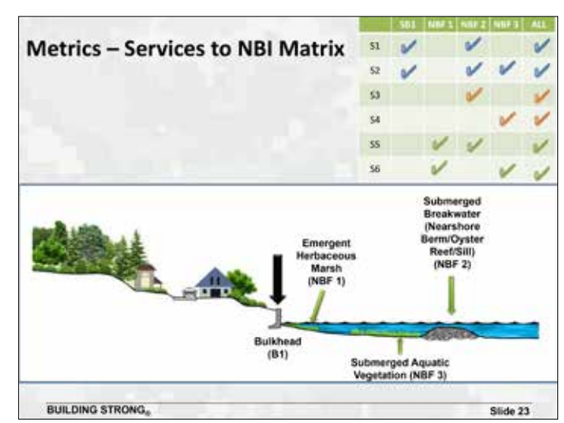


Figure 8.34: Composition of Parts, Evaluation Metrics

8.7 Speculative Matrix and Next Steps

Atlantic City provides an opportunity to combine existing USACE typologies with unique complexities of natural resiliency and urban organizational logics that can contribute to a more dynamic system. These typologies can be integrated with other existing urban infrastructure in order to create scenarios that enhance the quality of urban life.

Protective measures—seawalls, bulkheads, revetments—have the tendency to break the city's relationship with the coast. Though they often defend the city from wave action and storm surge, they cut off the urban from the natural, visually and physically. Because these measures are inhibitive, the Princeton team favors an approach that considers the vital relationship between city and water, one where the complexities and logic of each are fully hybridized to improve the quality of life.

A combination of natural, structural, and urban features yields a broad range of rich scenarios at the city's edge. Certain hybrids between structural interventions and natural features of course already exist: for example, a living shoreline is a hybrid wetland and revetment. These combinations may potentially reveal the internal logic of each ingredient more clearly. What value might a wetland block or a breakwater yard hold?

Atlantic City is newly mindful of the role coastal storms and rising sea levels may play in the immediate future. The sea is the city's signature amenity which harkens back to its early days as a summer resort. Its low elevation means that the city will continue to be grievously vulnerable. Though the USACE has protected much of the seaside coast with beach nourishment, conditions along the inlet and back bay remain unaddressed. Moreover, these are typical conditions found throughout the Northeast Coast. Atlantic City is an ideal testing ground for the tactical implementation of the array of measures the USACE intends to develop. Could more radically combined measures, further enriched by urban fabric, yield scenarios in which water is more fully and beneficially lived with?

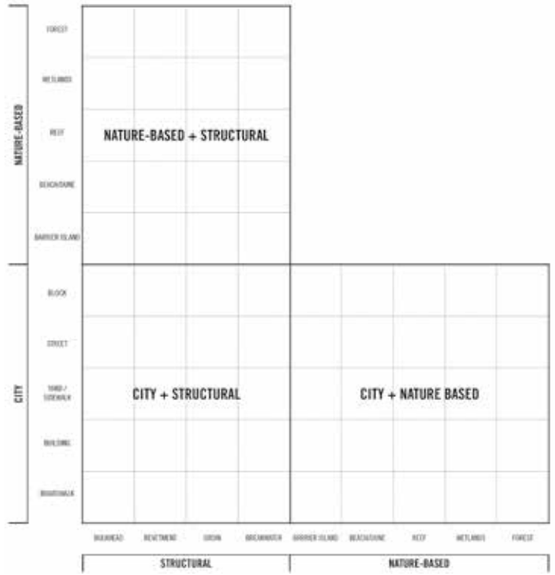


Figure 8.35: Speculative matrix for exploring hybridization of the full array of available measures and city-based features

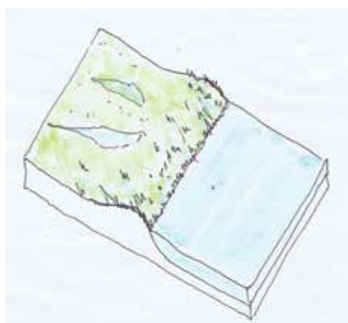


Figure 8.36: In a few cases, the matrix yielded existing typologies such as a living shoreline (a combination of wetland and revetment).

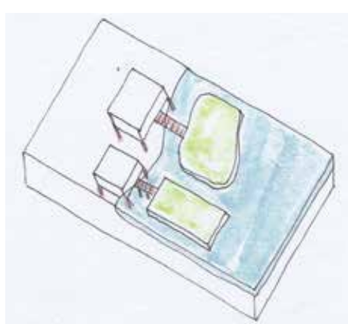


Figure 8.37: The matrix also revealed hybrids with unexpected potential, for example the combination of breakwater and yard.

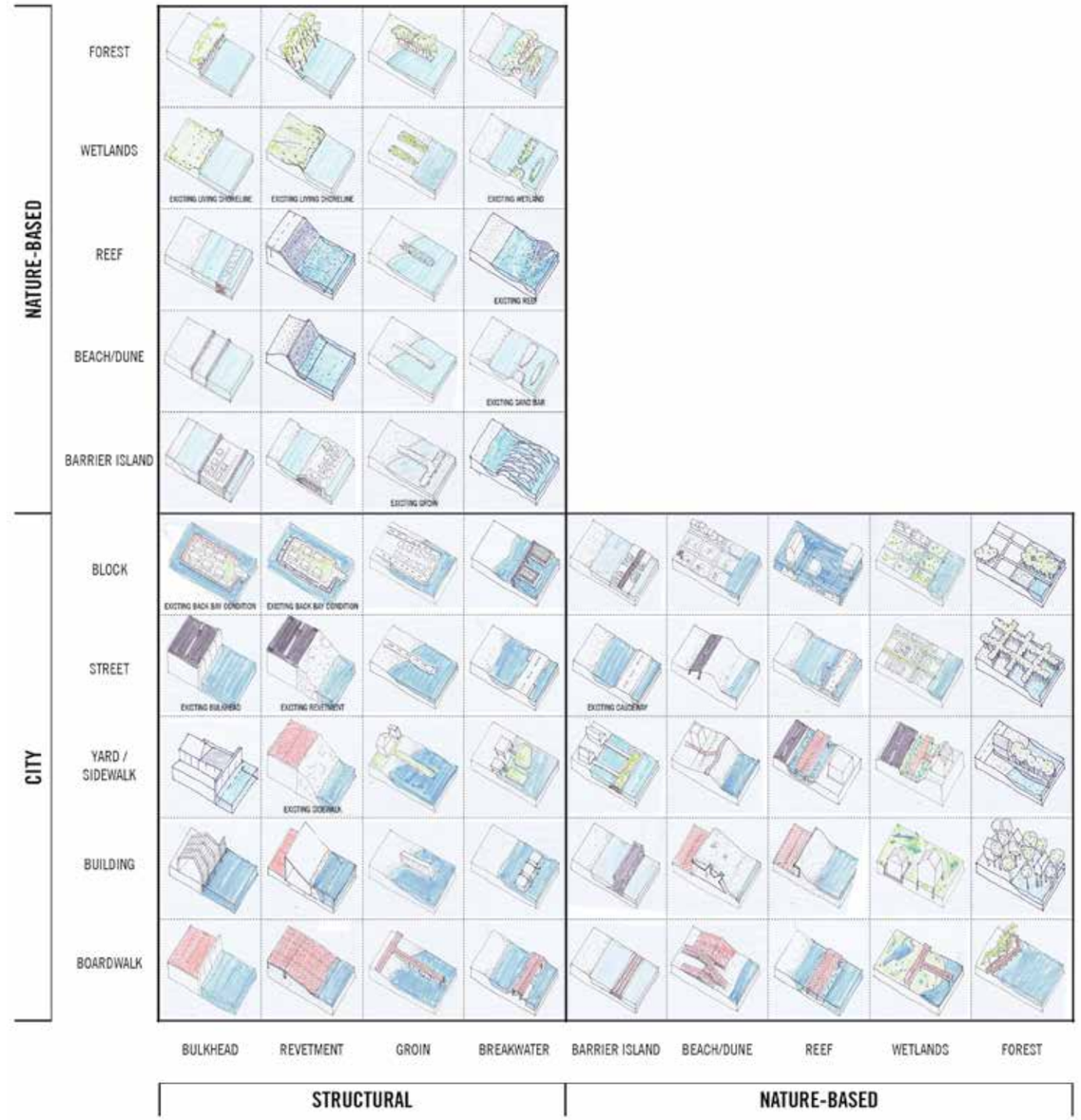


Figure 8.38: An initial suite of hybrids. While some are either existing or completely illogical, others open up interesting possibilities.

Figures 8.39-8.44: Hybrids which begin to combine three or four major features from the original matrix and initial studies on how they might function in the back bay and inlet areas of Atlantic City.

Moving forward, the Princeton team will continue to use the hybrid matrix as a design methodology, developing new typologies in parallel to site specific investigations. Each combination of nature-based, structure, or urban features yields not a singular solution, but multiple possibilities. With each permutation, the organizational logic and integral character of each feature is pushed further and further. We plan to test various hybrids in two ways: by developing them to the degree of technical precision that we have studied in the Army Corps manuals, and by applying them to the back bay and inlet conditions of Atlantic City.

According to projected sea level rise, Chelsea Heights will likely be inundated in a number of decades, and in danger of significant surge from coastal storms in the nearer future. Considering that the neighborhood is overwhelmingly residential, we must imagine scenarios phased over time and which take into account the behavior of individual homeowners. Will storm damage and eventual retreat leave the area to return to wetlands? Should this attrition be engineered? Or should it be an opportunity to live in concert with the wetlands? What role could FEMA grants and insurance incentives play in strategically raising home above the flood plain? And how could the city's infrastructure be orchestrated to tactically organize newly elevated homes? Could all these features be designed to allow water to flow between or below them, achieving a larger wetlands footprint?

The South Inlet suffers from a decimated urban fabric with no signs of dramatic and large-scale reinvestment in its immediate future. Would a block by block conversion to wetlands or polders be capable of sufficiently absorbing flood waters and preventing damage to neighboring developed areas? Could a natural habitat, attractive to both residents and tourists, be created as a nearby counterpoint to the vast interiors of casinos?

These are some of the key questions we will be addressing as we develop the more design intensive phase of the project.

Figure 8.39: Groin + Wetland

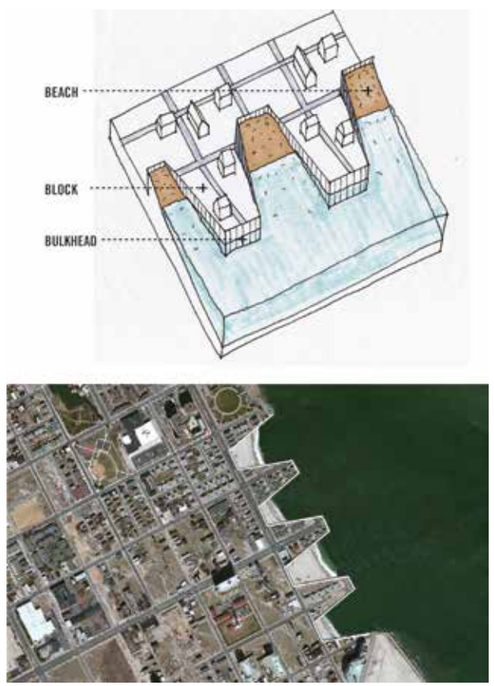


Figure 8.40: Block + Bulkhead + Beach

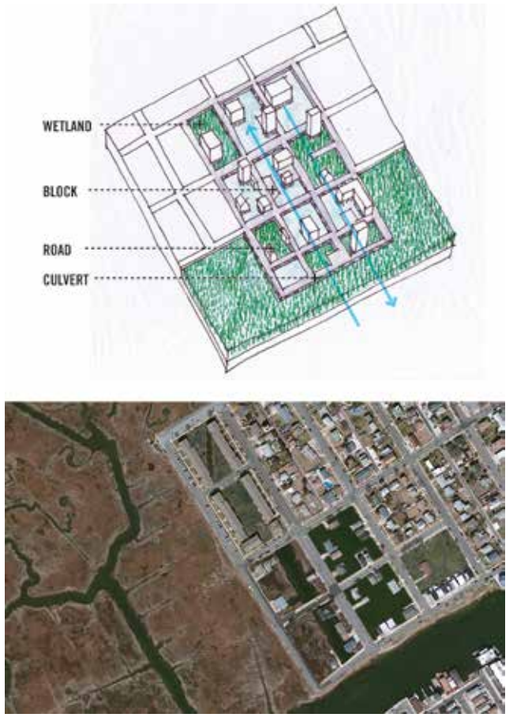


Figure 8.41: Block + Wetland + Road

Figure 8.42: Block + Wetland

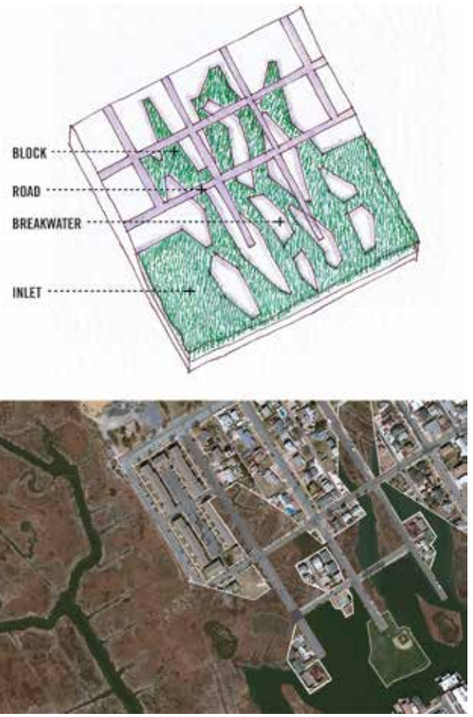


Figure 8.43: Block + Barrier Island + Wetland

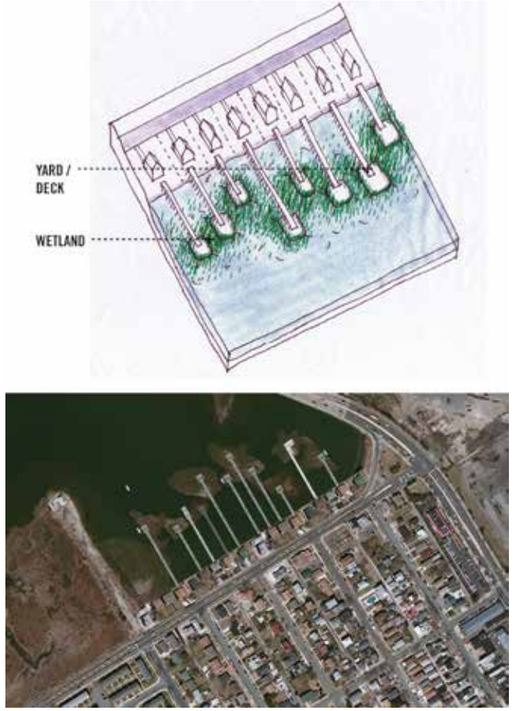


Figure 8.44: Yard + Wetland

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09

Turning the Frontier
Norfolk and Hampton Roads, Virginia

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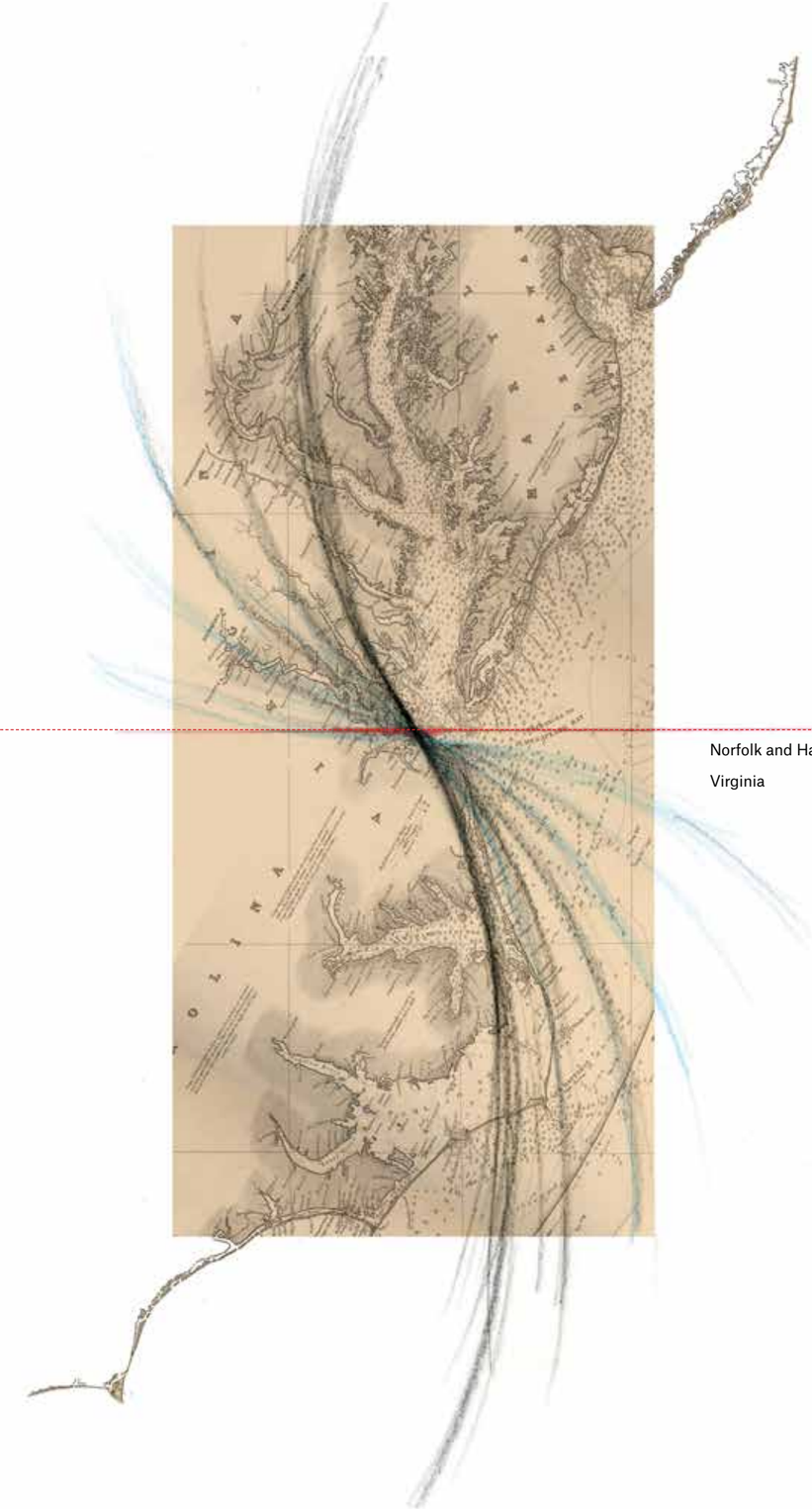


Norfolk and Hampton Roads
Virginia

9.1 Introduction and Context: Norfolk / Hampton Roads, VA

Sea level rise in Norfolk, perhaps more than most places on the east coast of the United States, is so real, close, extensive, and existential that it cannot be seen as a problem to solve; it needs to be seen as an opportunity to reimage, reimagine, and reconstitute settlement on the ground of water. It makes this part of Virginia, also referred to as 'Tidewater Country', an opportune place to investigate 'Structures of Coastal Resilience.'

The strategic, economic, cultural and ecological importance of this region is built on the presence of the Naval Station at Norfolk and the Langley Air Force Base near Poquoson, the Port of Norfolk on the Elizabeth and James Rivers, as well as the tourist economy of Virginia Beach, historic Jamestown, and Williamsburg. It is also home to a number of economically vulnerable communities, and is adjacent to notable federally owned and managed lands such as the Plum Tree National Wildlife Refuge and the Great Dismal Swamp Wildlife Refuge. Records at the National Oceanic and Atmospheric Administration's Sewell's Point Monitoring station located at Norfolk show sea level rise of 14.5 inches since the late 1920s and, "scientists predict a local relative SLR of 1.5-feet in the next 40 years and three feet by 2100".[1] The pillars of Norfolk's economy, coupled with its local communities and natural ecosystems share this widely acknowledged exposure to storms, sea level rise and related threats.

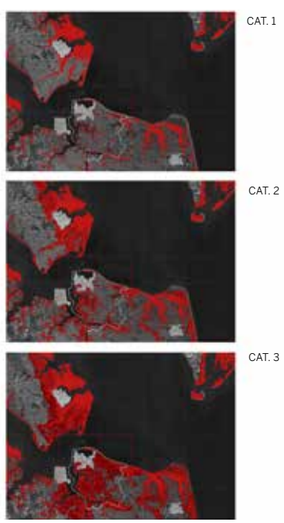


Figure 9.1: Norfolk has been listed as subject to High Levels of Impact from storm surge by the FEMA Modeling Task Force [2]. These maps demonstrate the expected inundation under different storm categories, ranked according to the Saffir-Simpson Scale.

Figure 9.2: Hampton Roads

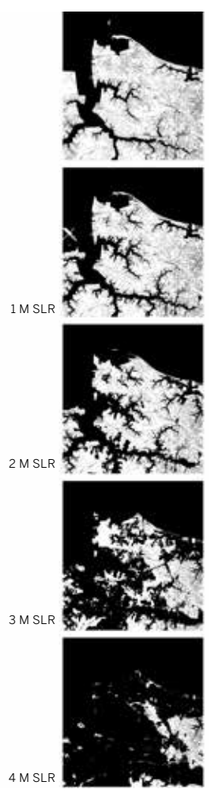


Figure 9.3: Due to Norfolk's low-lying topography, the long-term impacts of expected sea level rise threaten much of the city, its infrastructure, and population.

Figure 9.4: Norfolk 1902

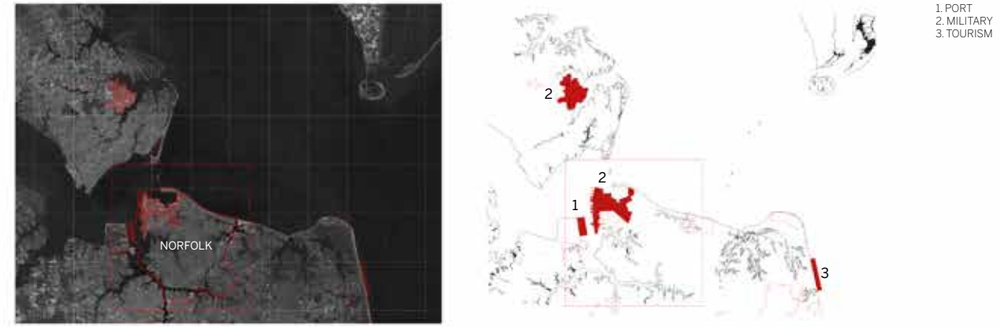


Figure 9.5: Economic Pillars

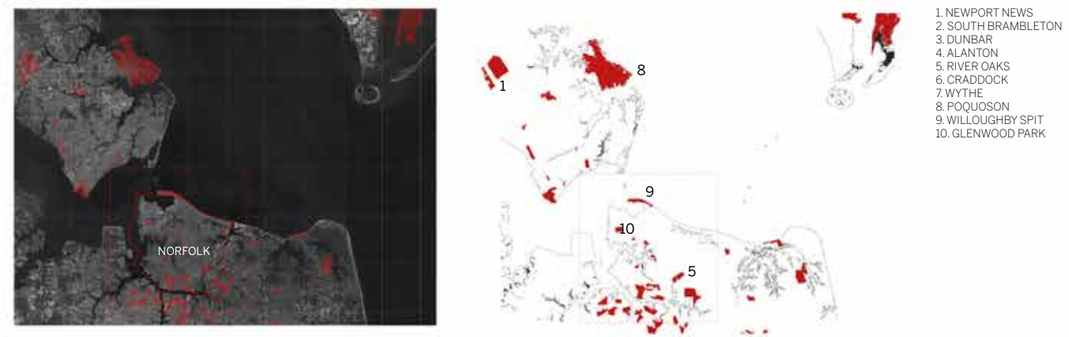


Figure 9.6: Social Vulnerability

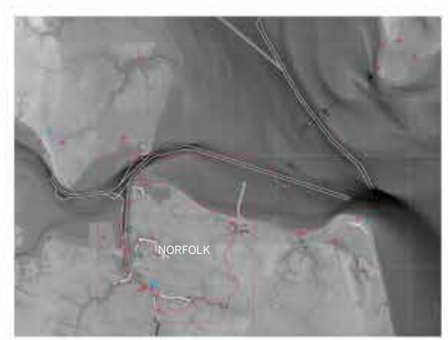


Figure 9.7: USACE Projects

NAVIGATION:
+ Thimble Shoal Channel
+ Entrance Reach
+ Lynnhaven Inlet Jetties
+ Lynnhaven Inlet
+ Little Creek
+ Fisherman's Cove
+ Hampton Road's 50' Anchorage
+ Sewell's Point Anchorage
+ Portsmouth Harbor
+ Craney Island
+ Craney Island Rehandling Basin
+ Western Branch
+ Scott's Creek
+ Elizabeth River Deepening
+ Eastern Branch
+ Lafayette River Channel
+ East Haven Creek
+ Knitting Mill Creek
+ Hampton Creek
+ Channel from Phoebus
+ Willoughby Channel
+ Cavalier Yacht Club, Inkhorn Bay
+ Rudee Inlet
+ Smith Island Inlet
+ Bungalow Inlet
+ Magothy to Chesapeake Bay Cut
+ VA Pilots Dock

TIDAL GAUGES:
+ Cape Henry
+ Lynnhaven Inlet
+ Carter's Point
+ Little Creek
+ Norfolk AMC
+ Portsmouth Naval Yard
+ Old Point Comfort, Fort Monroe
+ Newport News, Birdella Lake
+ Huntington Park, James River
+ Fisherman's Island
+ Kiptopeke Beach
+ Topping Creek
+ Sewell's Point

ENVIRONMENTAL:
+ Grandy Village
+ ODU Drainage Channel
+ Woodstock Park
+ Carolanne Farms
+ Lynnhaven River Basin
+ Feasability Study
+ Oyster Restoration (NORM
+ Lynnhaven River Basin)

FLOOD PROTECTION:
+ New Market Creek
+ Willoughby Spit Hurricane Damage
+ Reduction
+ Pretty Lake Flood Protection
+ Fort Story Revetment
+ Hauge Flood Protection
+ City of Norfolk Floodwall
+ Anderson Park Revetment
+ Fort Norfolk Waterfront

9.2 Point of Departure: Frontier Imagination

The tidewater country is a place where the idea of the frontier and its associated notions of front, confront, and battlefront took root in a line drawn by European settlers between land and sea in the 1500s. This line moved west from here across tidewater country, the fall line, the Blue Ridge, the Mississippi River, the Rocky Mountains, all the way to the Pacific Coast. Each threshold fulfilled prospects and opened new horizons, but each also reinforced and hardened that 'first' line that would become the East Coast of the United States. When this first line was consolidated on the ground, in maps, and in the mind, the immediate impulse in the face of a rising sea was to enforce and reinforce its act of separation.

This, however, is a difficult task in an unequal fight between local land and global seas made even more difficult in Norfolk by land that is subsiding. In low-lying tidewater country where the coast turns into numerous creeks, Norfolk does not call for barriers and protection; it calls for design interventions on the basis of a new visualization of the coast as a place where land meets sea, not across a line, but in a field of points.

9.3 Project: Turning the Frontier

The University of Pennsylvania team's project, then, is to turn the coast of Norfolk and its environs so that land does not meet sea across a 'front', but rather through a number of discrete fingers of high grounds. Each finger is a unique gradient or a unique gathering of gradients between land and sea, working to structure a coast that is more fractured, cumulative and diverse than it is continuous, linear and absolute.

The inspiration for a coast that is cumulative rather than continuous comes from the tidewater country of Virginia itself. Here rivers meet the sea, creeks meet rivers, and rills meet creeks between fingers of high ground that are endlessly fractured by ever smaller runs of water and wetness. To those who seek a coastline, this complex estuary provides something of an obstacle. Here, the sea extends deep into the continent and retracts into an ever-transforming pattern of shoals, marshes, sand bars, and islands. To the Penn Team, this complexity is a defining characteristic of the Norfolk area: a coast with a dynamic and shifting reciprocity

Figure 9.8: John Smith, A Map of Virginia: With a Description of the Countrey, the Commodities, People, Government and Religion, 1612.

Figure 9.9: E. & G.W. Blunt, Map of Part of Virginia, Maryland and Delaware, 1861.

Figure 9.10: U.S. Coast Survey, Sketch C, Section No. III, 1875.

Figure 9.11: Chesapeake & Ohio Railway Co. Map Showing the Location of Battlefields of Virginia, 1891.

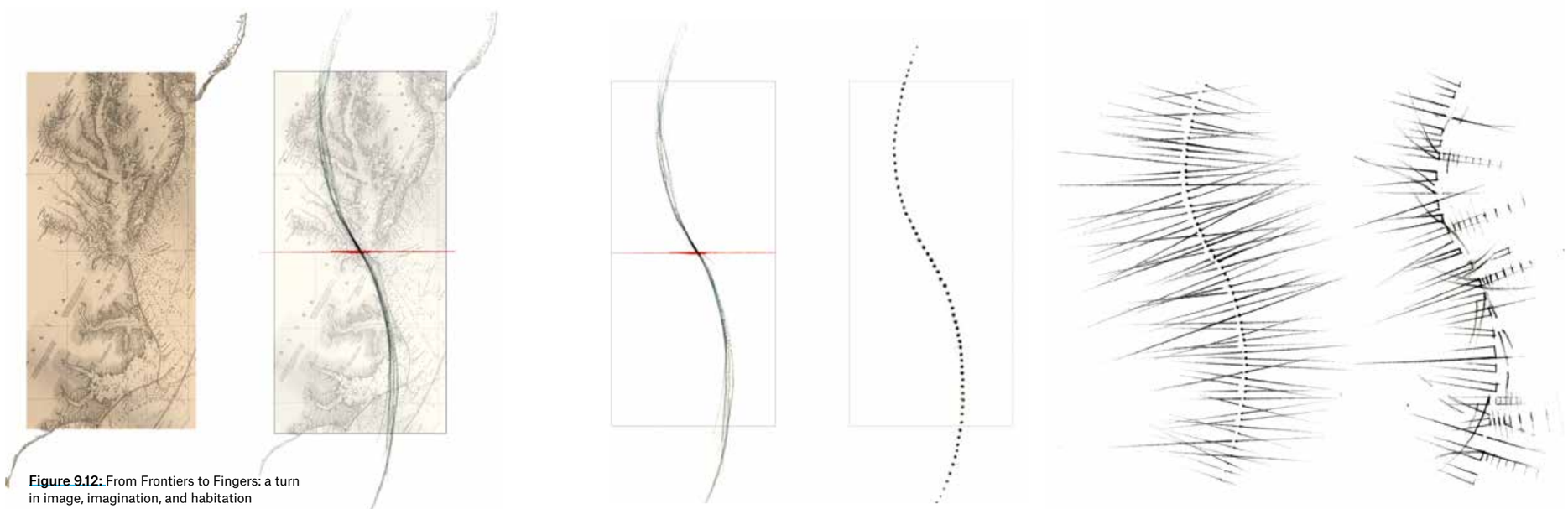


Figure 9.12: From Frontiers to Fingers: a turn in image, imagination, and habitation

between land and sea, a field of gradients in space and time enjoyed by numerous animals and plants. We see in this complexity an intrinsic and powerful ability to not just withstand or recover from the shock of events such as hurricanes, but also an ability to accept and take in stride what are really natural events—even if they are made more frequent and severe by human interventions. This is resilience as a proactive design sensibility rather than a reactive tendency of settlement, more aligned to 'natural' trajectories across land and sea than to defense mechanisms against a sea that has been made an 'unnatural' enemy.

9.3.1 Fingers of High Ground

We propose 'fingers of high ground' as a unique typology of design interventions that fall under the Army Corps category of nature-based features. They "mimic characteristics of natural features but are created by human design, engineering, and construction to provide specific services such as coastal risk reduction."[3]

Fingers of high ground will perform the critical task of raising low-lying ground and providing opportunities for the short and long term survival of ecosystems and species populations in the face of storm events and sea level rise:

They point, extend, bend, reach, fold, grow, nudge and retract.

They gather and work a number of gradients—dynamic and shifting reciprocities and trajectories between land and sea. These gradients are operational, material, temporal, spatial and ecological.

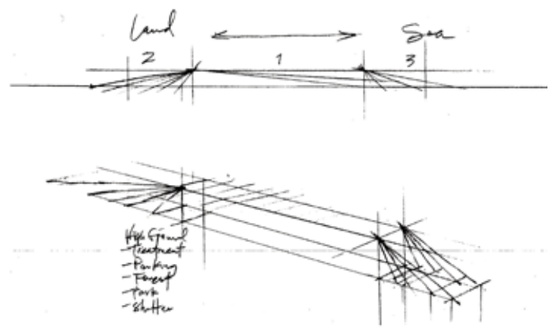


Figure 9.13: Diagrammatic Finger Gradients

Figure 9.14: High Grounds Hampton Roads: 2200

They make a porous, tentative, diverse, and cumulative edge that can better withstand and recover from the shock of storm events and perhaps improve the ability not to be shocked in the first place.

They offer a range of programmatic and ecological possibilities along their length, on their surface, in their depth, and in time.

In the short term they can serve as islands of refuge and protective barriers in times of storm and surge.

In the long term they are raised grounds of settlement that turn the frontier but also allow new ecologically sensitive and economically productive infrastructures and practices to infiltrate human habitation.

9.4 Methodology: Design as Research

It is often assumed that the design process involves analyzing a site and laying out a design in response to that analysis. In the face of storm events and sea level rise there is the added challenge of identifying, mapping and modeling sites based on their vulnerability. This approach front-loads the design process with measures of a problem that design must address and to which design is held responsible. But sea level rise, even more perhaps than storm events, calls for more than addressing the vulnerability of sites; it calls for seeing the coast differently, in ways that challenge its visualization and the language of design that made sites vulnerable in the first place.

The Penn team's approach has been to visualize an alternate coast, a coast that is latent in the tidewater region of Virginia where land meets sea not in a continuous line but in discrete points, in a multiplicity of land-sea gradients. The team explores the possibilities of this visualization through the playing out of design for sites chosen not only for their vulnerability in the face of sea level rise, but also for their problems of low income, pollution, subsidence, and their unique cultural and ecological complexities. Through actual design engagement of these particular places the team has developed a language of design, a typology, by which to re-construct a coast that meets the sea in multiple and diverse 'fingers of high ground' rather than a frontier.

Engaging places through design and working out design solutions, often in conversation with people who live there and experts who study these places, gives us a practical and contextual knowledge of a coast that is not just on the edge, but extends deep inland and out to sea. Importantly, it opens new horizons, new forms of settlement, new ecologies, and new economies. To us it is important to the larger aspiration of coastal resilience that fingers of high ground do much more than raise land above the sea in response to inundation models or maps of risk; they must perform richly as the future DNA of settlement on the coast.

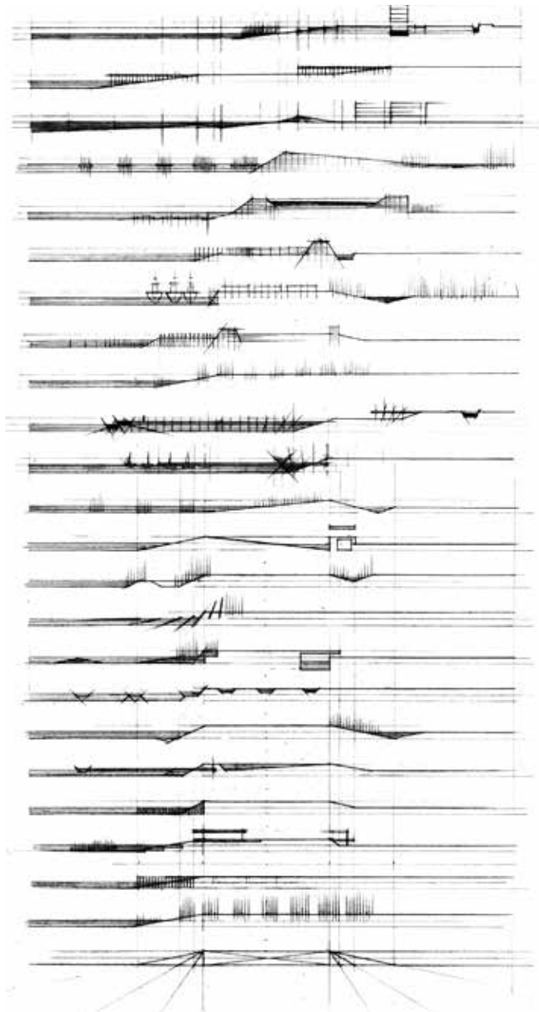


Figure 9.15: Typological Finger Sections

9.5 Off-Sites: Anchoring Norfolk

Norfolk is not at the 'bottom' of the Chesapeake Bay as it is shown in most maps of the area. It is rather a place where many ecological, economic, historical and, importantly for us, operational gradients converge. These gradients are initially gathered along lines of four 'local' design fields (off-sites): the Fall Line to the west, the Intracoastal Canal to the south, the Beach Front to the east, and the Eastern Shore to the north. Each design-field gives us programmatic possibilities and a design language for conceiving and initiating fingers of high ground in selected vulnerable off-sites in Poquoson, Jamestown, Portsmouth, Chesapeake, Virginia Beach and Tangiers Island. Each off-site facilitates a learning through design that we then bring to fingers of high ground (in-sites) in Norfolk.

The challenges faced in these off-sites, not just from sea level rise but also from low income, pollution, subsidence, et cetera, allow us to broaden our conception and programming of fingers, their gradients, and their possibilities.

- West: The Fall Line extended by scarps down James River / Off-Sites: Terraces in Jamestown and Poquoson
- South: Intracoastal Canal from the Dismal Swamp to Craney Island / Off-Sites: Voids along infrastructural lines in Portsmouth.
- East: Beachfront from Virginia Beach to Willoughby Spit / Off-Sites: Routes I-64, I-264, and Route 58, rail line between Norfolk, Virginia Beach and the beach front.
- North: The Eastern Shore gathered by Route 13 / Off-Sites: Ditches, sounds and islands in the bay.

Figure 9.16: In-Sites

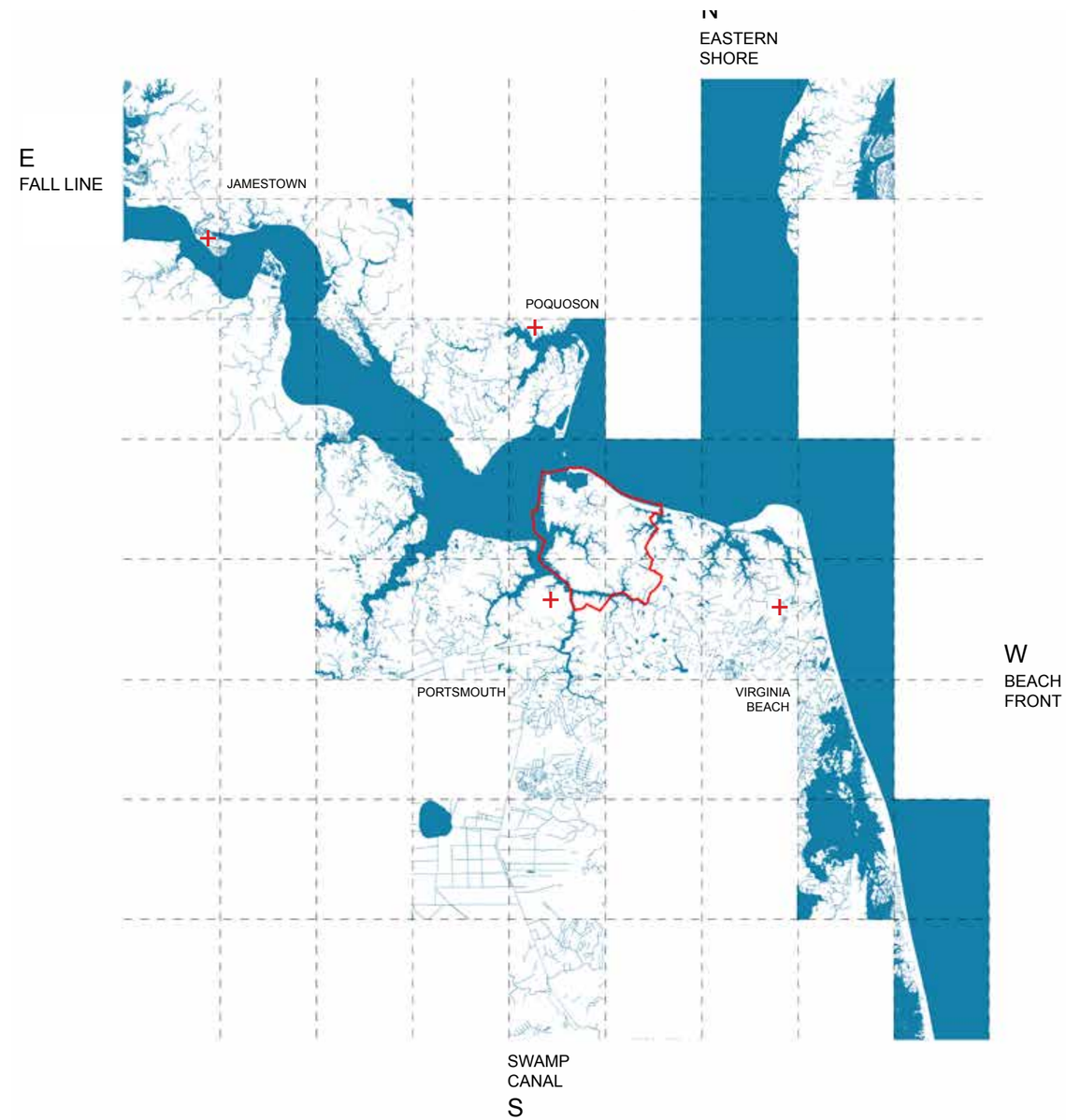
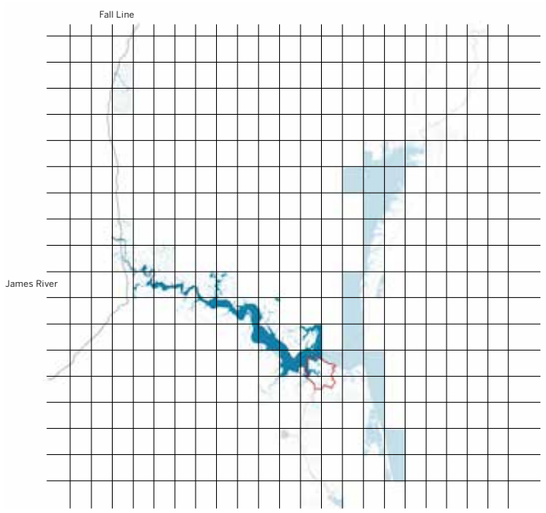


Figure 9.17: Off-Sites

9.5.1 Fall Line

Most people know the fall line as a geomorphological rupture between the metamorphic rock of the Piedmont plateau and the sedimentary ground of the coastal plains. It is visible and dramatic in places like Washington, Fredericksburg, and Richmond. But the fall continues down from there across a number of terraces each defined by a scarp until it reaches the Chesapeake Bay.

As the James River traverses this thickened fall line, it traces a gradient from holding across a rocky surface to flowing nearer the sea, transitioning from a world of bedded rocks to buoyant ships. It is a gradient repeated in smaller measure by the numerous creeks that enter these rivers and by the streams that enter those creeks. It is also a gradient traversed by a number of organisms including the shad, blueback herring, and menhaden.



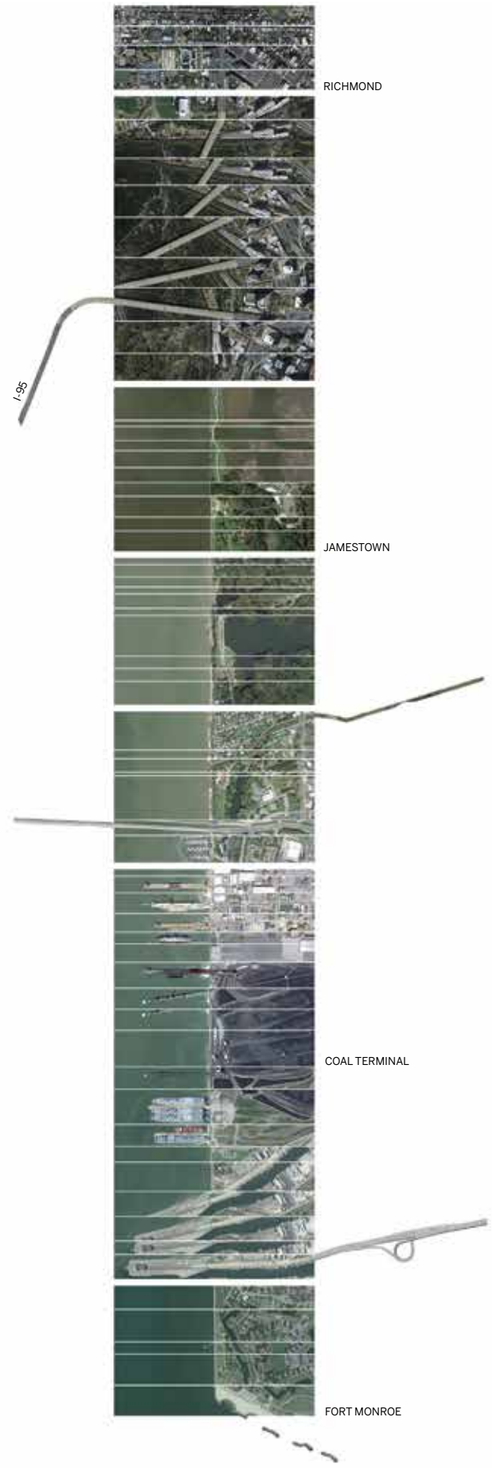


Figure 9.19: West Frontier: James River via the Fall Line

Figure 9.18: Fall Line Frontier

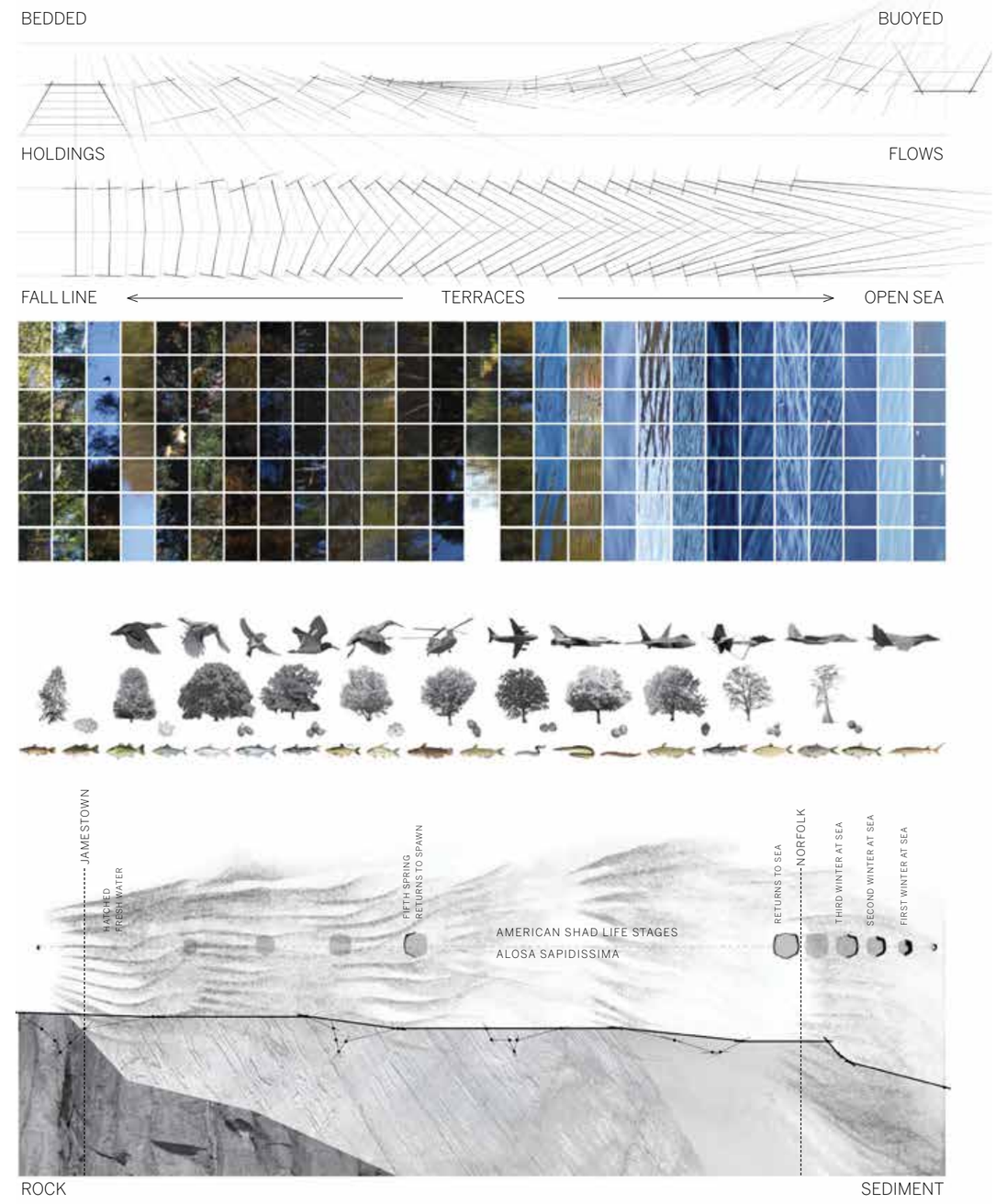


Figure 9.20: Fall Line Gradients: Operational, Material, Temporal, Spatial, and Ecological

Off-Sites: Terraces in Jamestown and Poquoson
Along the James River to the Chesapeake Bay are a series of marshy terraces striated by marginally higher grounds inhabited by communities—human, animal and plant—that are vulnerable to sea level rise and subsidence. These striations of firmer sediment can be raised and new ones laid to protect historic sites such as Jamestown, enhance inland and off-shore habitats (particularly oyster reefs that have anchored here for millennia), use dredge spoils from adjacent navigation channels, and provide new grounds for socially and physically vulnerable communities in Poquoson. At Poquoson there is the opportunity of building up these striations, not merely for each to be a gradient from land to sea or bedded grounds to surface attenuators; but also for them to perform cumulatively as a protective barrier for communities inland. This multi-layered protective barrier begins at Plum Tree Island National Wildlife Refuge on the Bay, a critical point on the Atlantic Flyway and site of unexploded ordnance from the 1950s that can be defused strategically and the Refuge made available gradually to the public. It works from here inland across a series of fingers of high ground to the City of Poquoson and Langley Air Force Base.

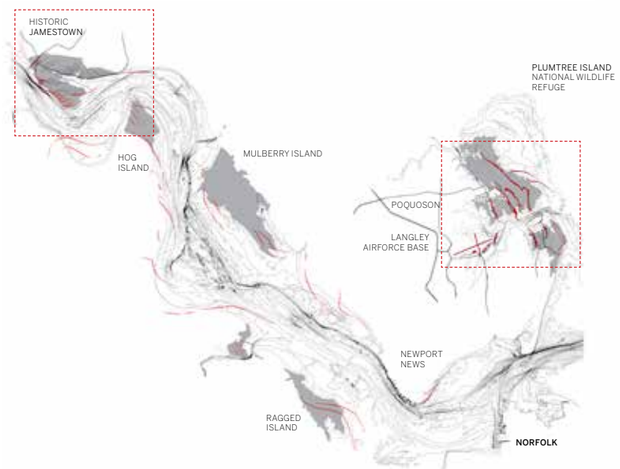


Figure 9.22: James River terraces and potential high grounds.

Figure 9.21: Fall Line Research Plot

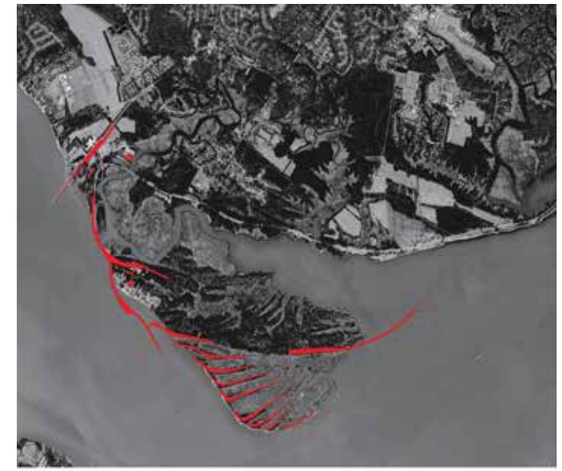


Figure 9.23: Historic Jamestown

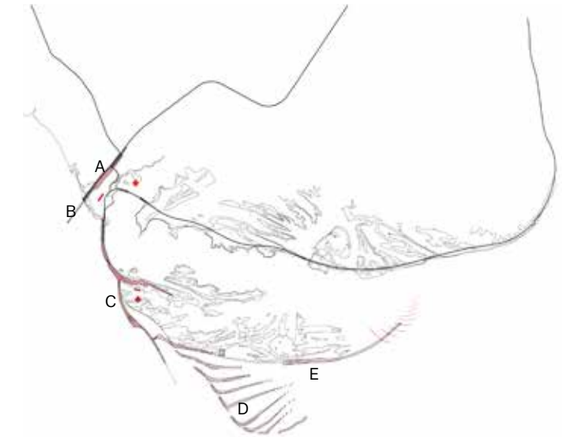


Figure 9.24: Plan and Sectional Index

Figure 9.25: Poquoson and Plum Tree National Island Wildlife Refuge

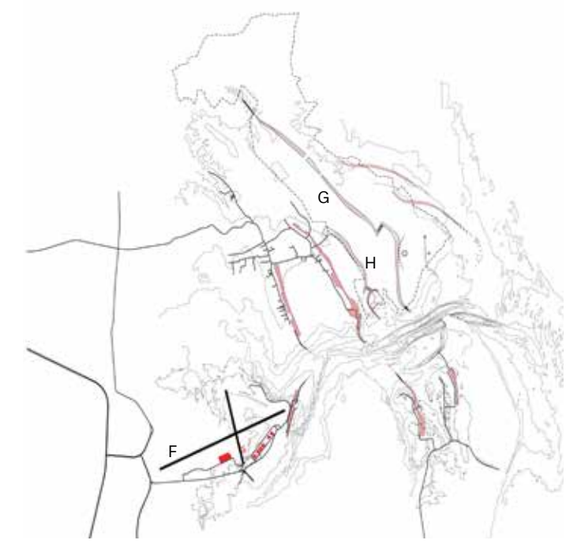


Figure 9.26: Plan and Sectional Index

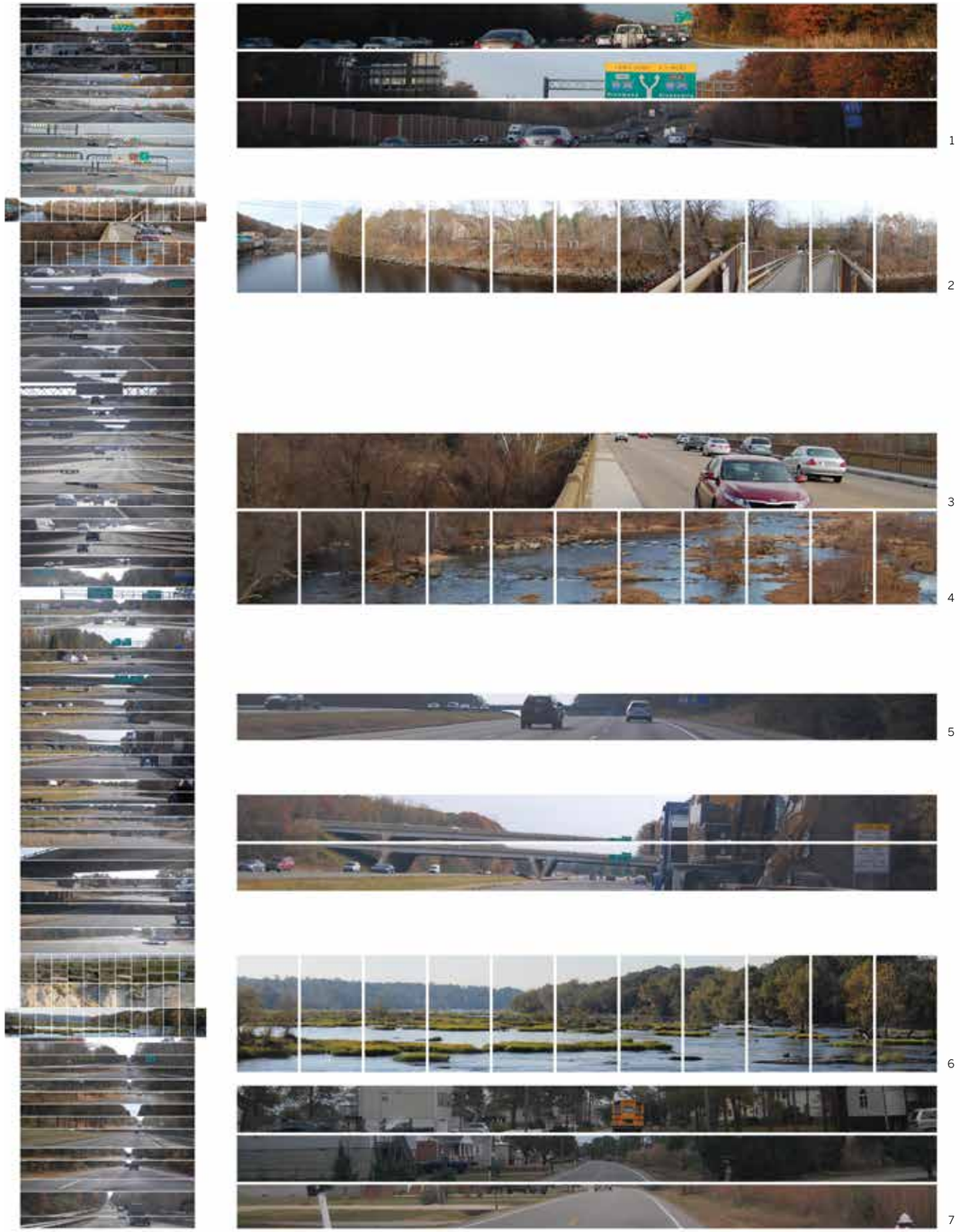


Figure 9.27: Fall Line Horizons: I-95, Route 1 and River Crossings

1 Interstate-95
2 Occuquan River
3 Fredericksburg, Virginia
4 Rappahannock River
5 Route 1
6 James River
7 Richmond, Virginia

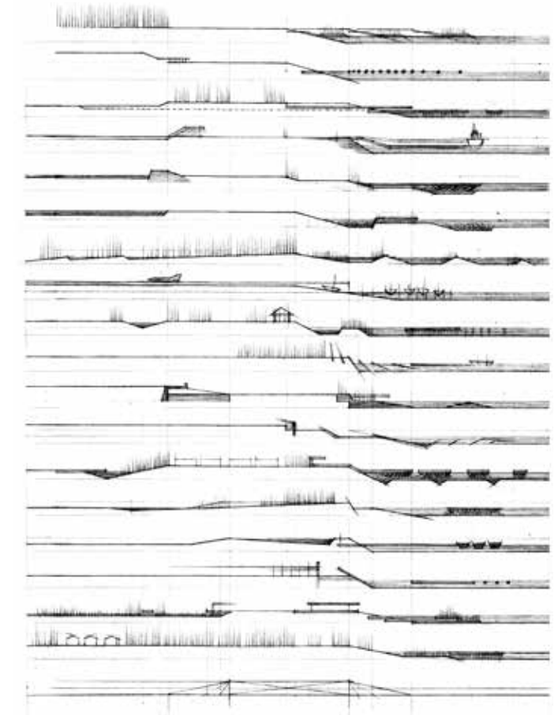


Figure 9.28: Typological Sections

A Farm
Upland Forest
Ferry Jetty
B Algae Raceway
Jetty
Oyster Shoals
C Historic Jamestown
Lookout
Living Levee
D Algae Raceway
Migratory Bird Nesting Ground
Algae Flume
E Upland Pine Forest
Overlook
Biotic Cleansing
Naval Ghost Fleet
Spartina Gradient
F Airforce Runway
Public Boat Ramp
Marina
G Salt Marsh
Upland Forest
Lowland Forest
H Shelter in Place
Future Housing
Boat Ramp
Lookout
Pier

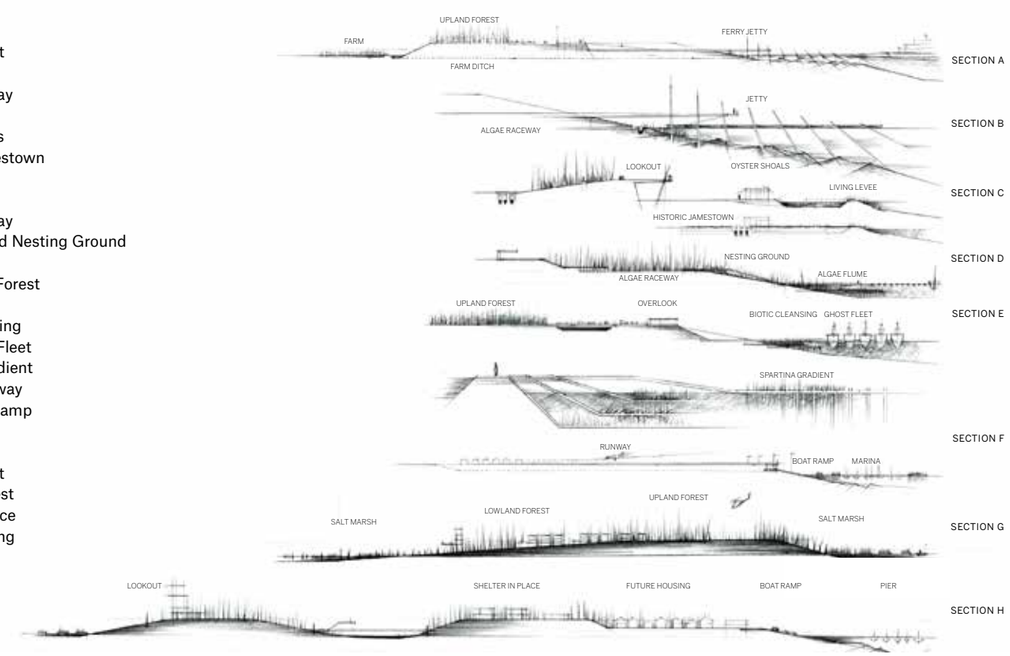


Figure 9.29: Project Gradients

9.5.2 Swamp Canal

The Atlantic Intracoastal Waterway passes through the natural harbor of the Elizabeth River and enters the Swamp Canal along the edge of the Dismal Swamp southwest of Norfolk. The swamp is a place of subversive history, a ground for the Atlantic white cedar that once supplied the shipyards of Norfolk and Portsmouth, a perennial source of fresh water in the Elizabeth, and a survivor of numerous efforts to destroy it.

From the intertwining and collective stands of vertical cedars the Intracoastal Canal transitions to the vast horizontal fill of dredge spoils that have extended Craney Island at the mouth of the Elizabeth, constructing a gradient from a field of pins anchored in a resilient web to a consolidating fill of displaced soil.

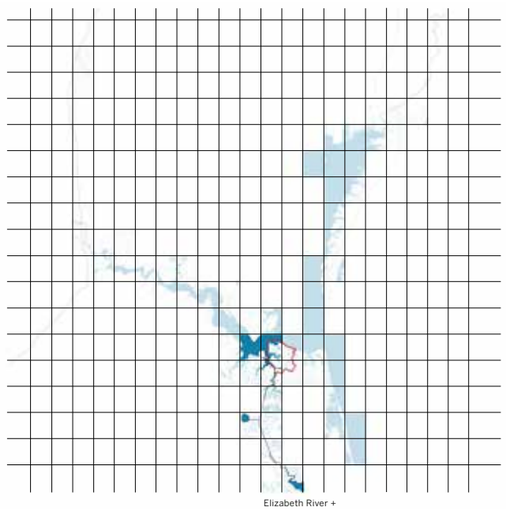


Figure 9.31: South Frontier

Figure 9.30: Swamp Canal Frontier

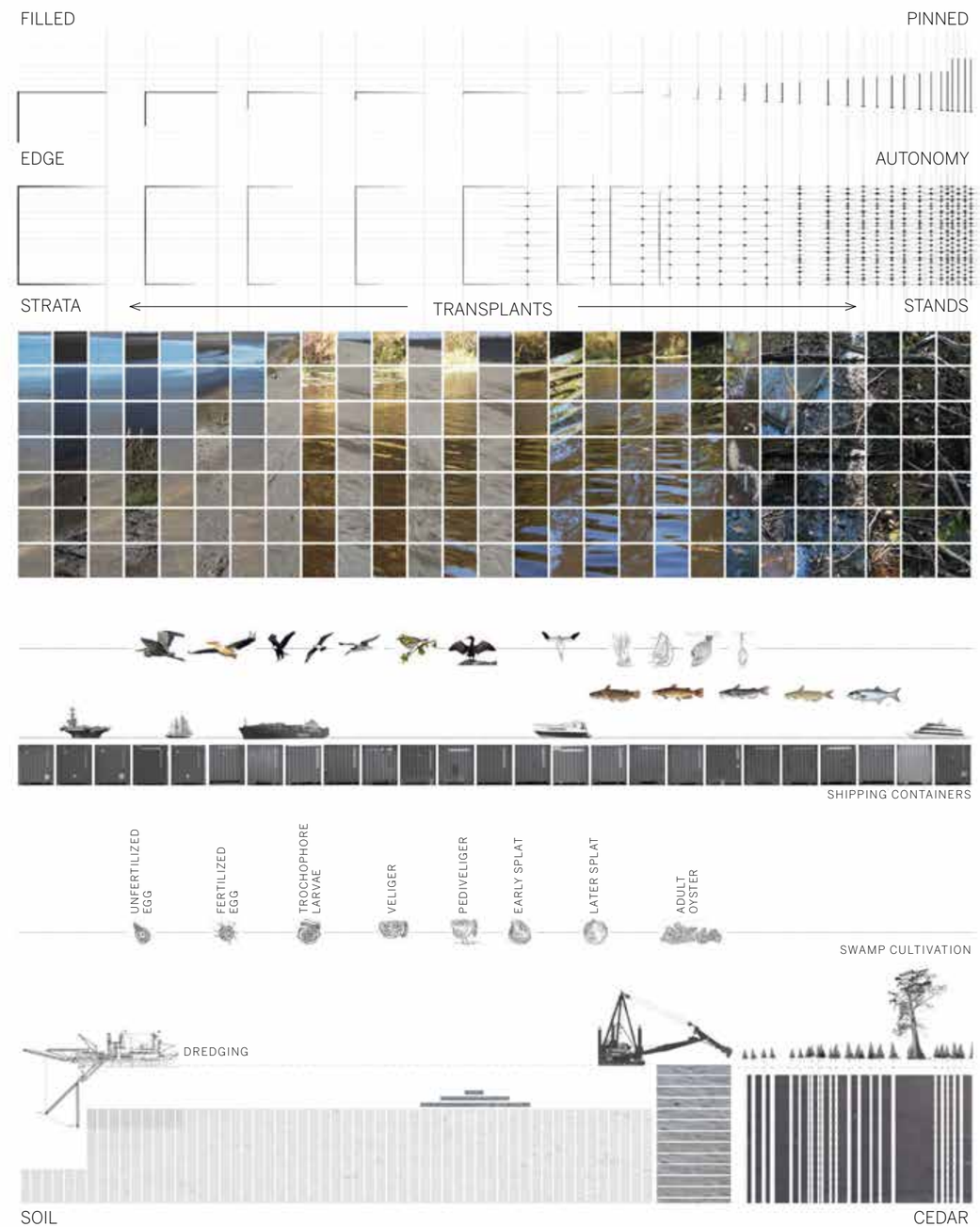


Figure 9.32: Swamp Canal Gradient: Operational, Material, Temporal, Spatial, and Ecological

Off-Sites: Elizabeth River and Portsmouth Voids

Between the Dismal Swamp and Craney Island are numerous voids—cracks in a city's fabric with a potential and opportunity to begin something new. These voids tend to be adjacent to infrastructural lines of rail and road that crisscross the region, perpendicular to waterways. The part of these voids that interests us are those that extend from the estuarine waters of the Elizabeth River that have suffered the loss of numerous animal and plant communities, deep inland into neighborhoods of Portsmouth and Chesapeake where economically weaker communities are often trapped by the backing up of rain. We propose raising the ground of these voids to construct new gradients between land and sea, accommodating the needs of communities at both ends, working with the dredged soil of Craney Island which we see becoming a remediating ground and working park, and plots of cedar cultivation and conservation in the Dismal Swamp.

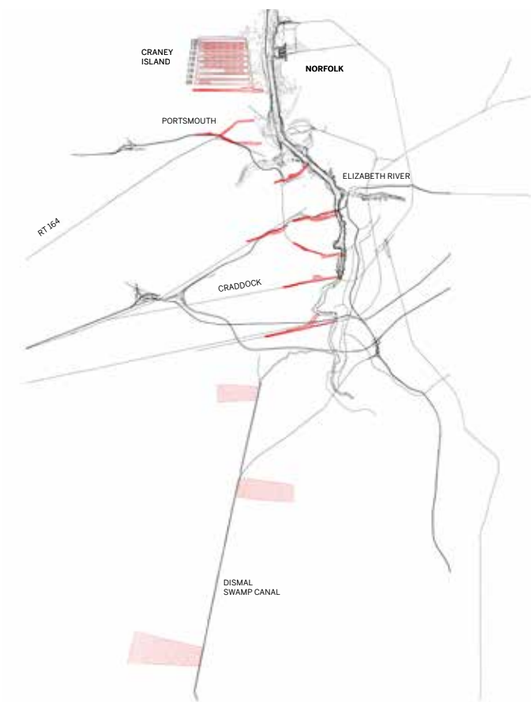


Figure 9.34: Swamp Canal Voids

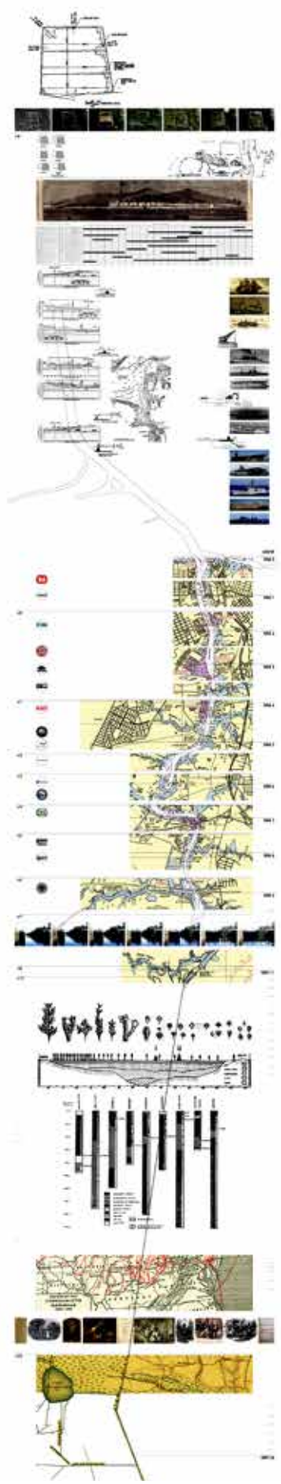


Figure 9.33: Swamp Canal Research Plot

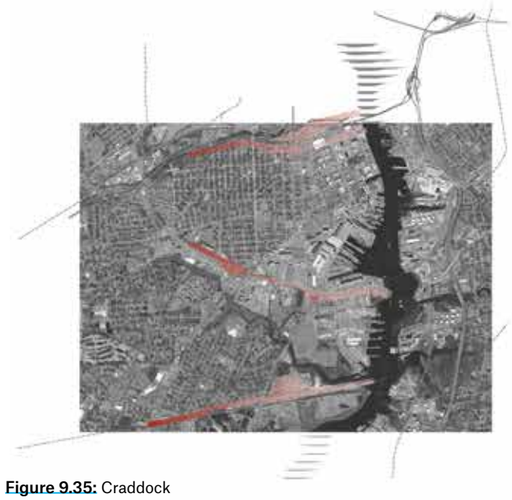


Figure 9.35: Craddock

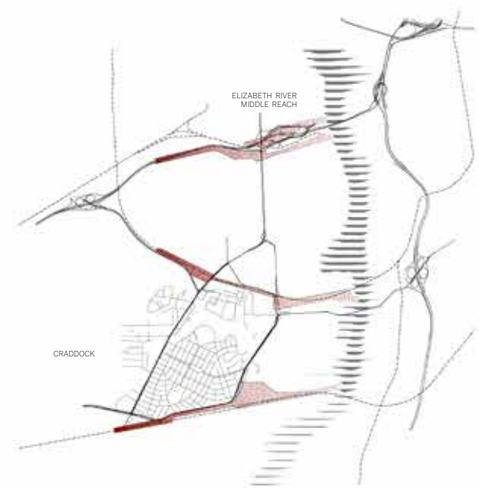


Figure 9.36: Craddock Plan

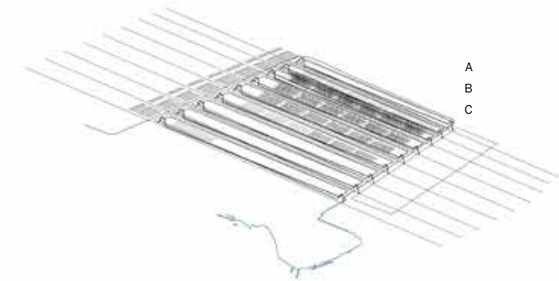


Figure 9.37: Craney Island Dredge Facility—Material Placement, Sorting, Remediation, Soil Transfer

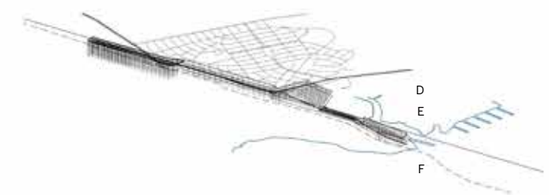


Figure 9.38: High Ground: Craddock—Oyster Reef/Wetland Biofilter, Access Berm/Water Retention, Upland Planting/ Slope Stabilization, Raised Berm/Shelter-in-Place

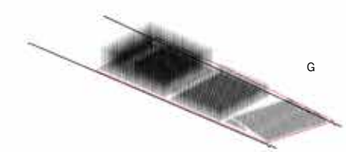


Figure 9.39: Cultivation: Dismal Swamp—Cedar Plots/Soil Transfer, Swamp Canal

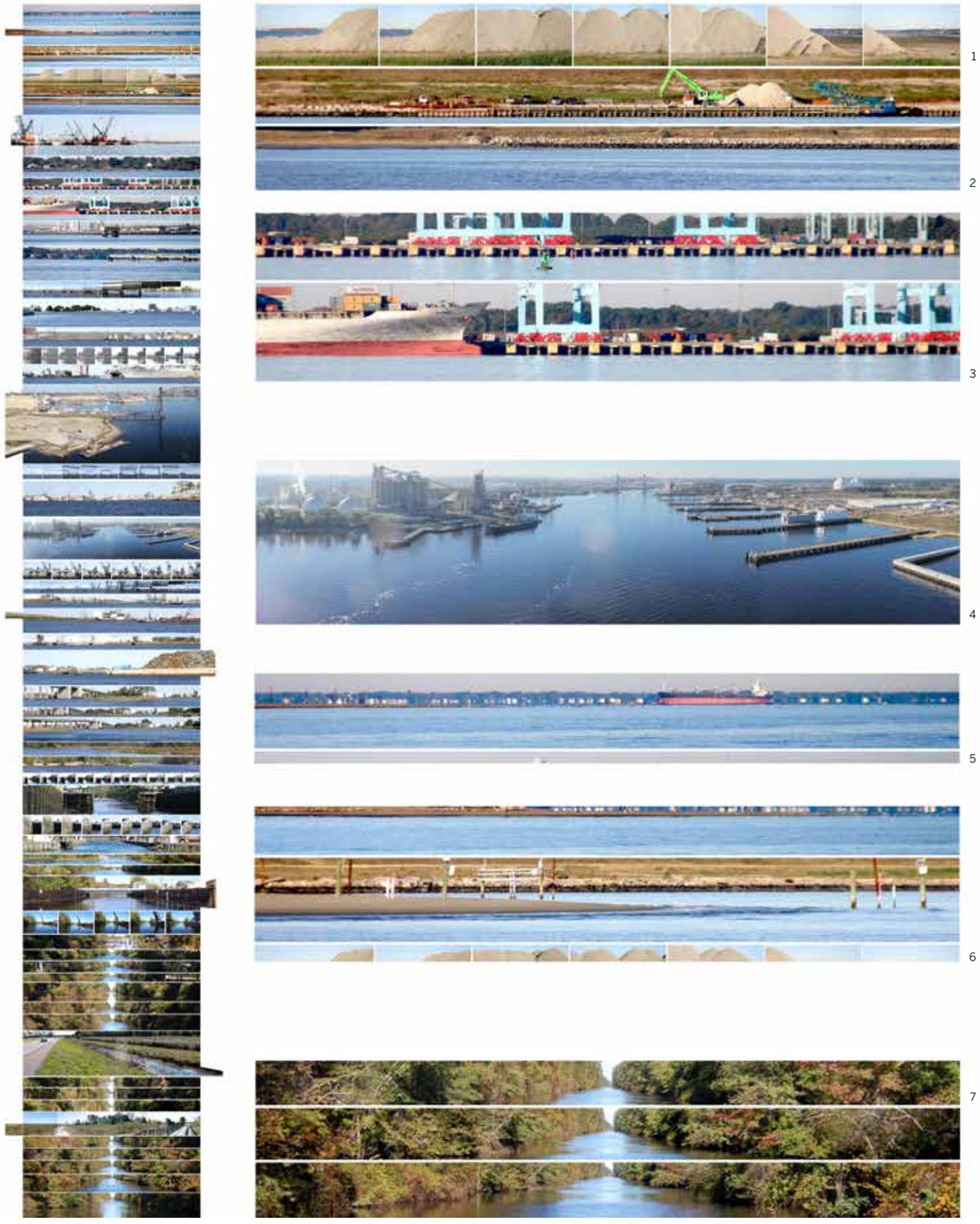


Figure 9.40: Swamp Canal Horizons: Elizabeth River and Voids

1 Craney Island
2 Craney Island Future Eastward Expansion
3 Port of Norfolk
4 Elizabeth River
5 Paradise Creek Park
6 Deep Creek Lock
7 Dismal Swamp Canal
8 To Lake Drummond

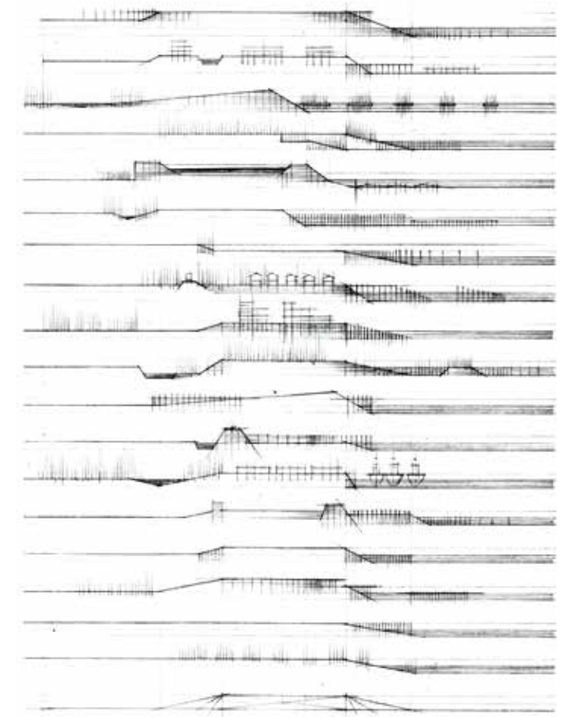


Figure 9.41: Typological Sections

A Settling Basin
Dredging Channel
B Outflow Polishing
Soil Remediation
C Soil Mining
Jetty
Stepped Berms
D Cedar Planting
Oyster Stands
Rail Line
E Pinned/Filled Ground
Stands
Raised Berm
F Shoals
Raised Berm/Housing
G Dismal Swamp Canal
Cedar Lots

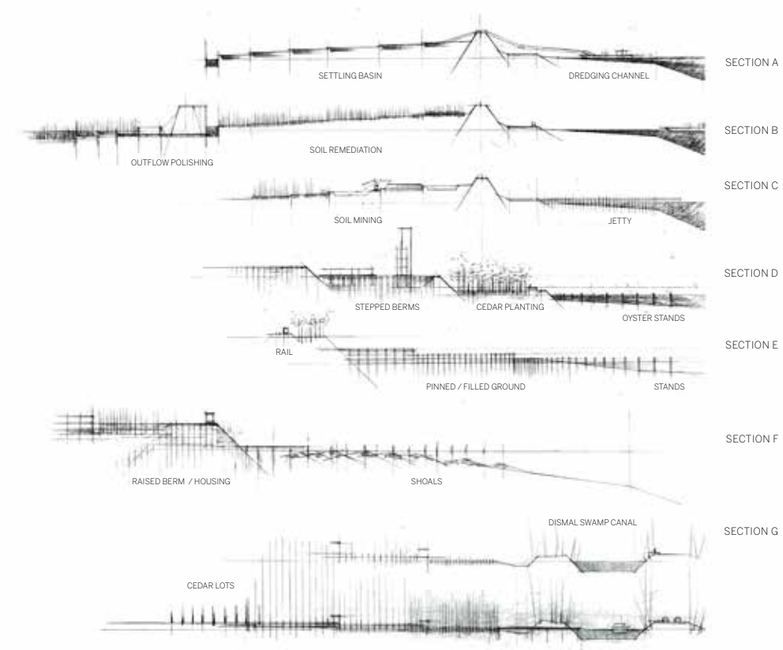


Figure 9.42: Project Gradients

9.5.3 Beach Front

The beachfront of southern Virginia extends from Willoughby Spit, which rose from the Chesapeake during a hurricane in the 1700s, to the barrier islands south of Virginia Beach. Spits and barriers are two closely related sand formations that register and are shaped by the waves of the sea.

Today, they register not just the rhythms, directions and intensities of the sea, but also the relatively new recreational landscape of the beach frequented by seasonal waves of people from far inland. The temporal relationship between the many waves—tourists, ocean, recreation, precipitation, shopping, wind, and hurricanes—offer opportunities for designs predicated upon dynamic and complementary possibilities, programs, and functions.

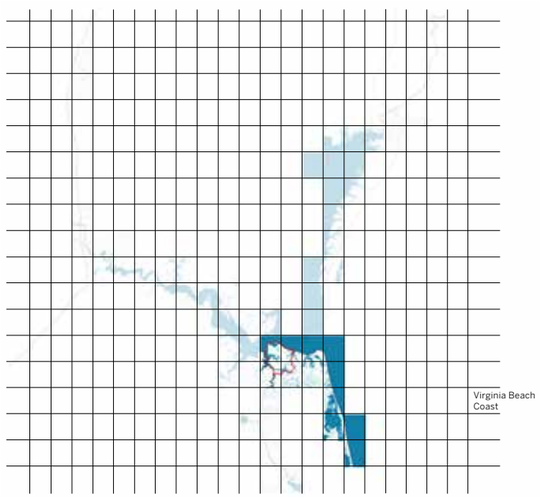


Figure 9.44: East Frontier

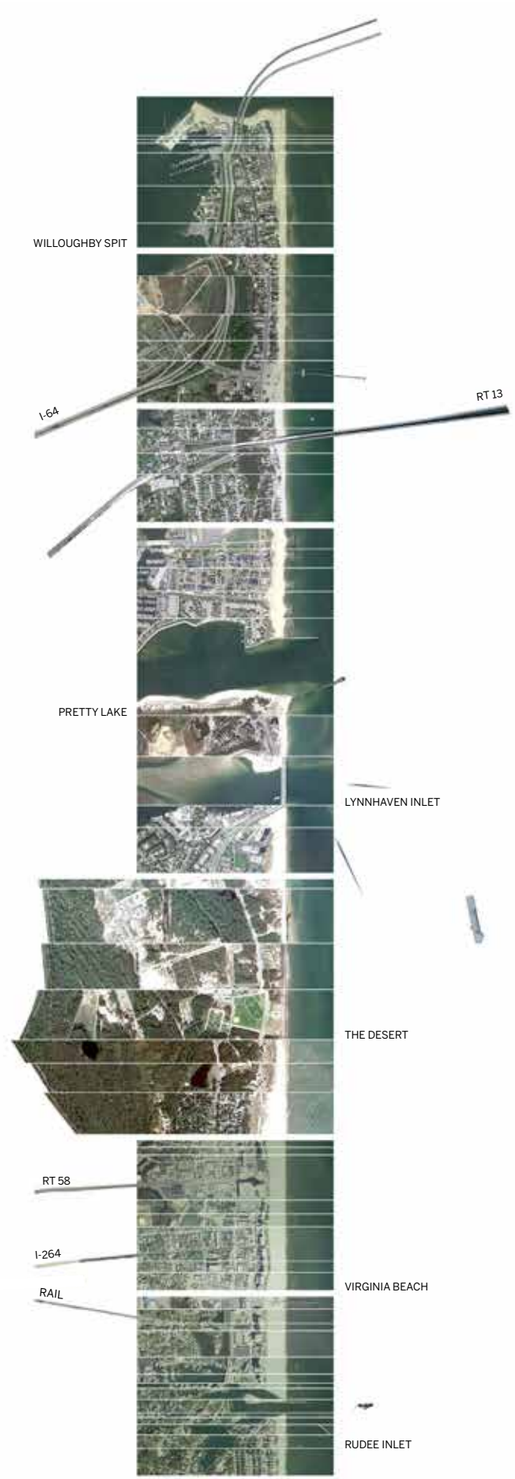


Figure 9.43: Beach Front Frontier

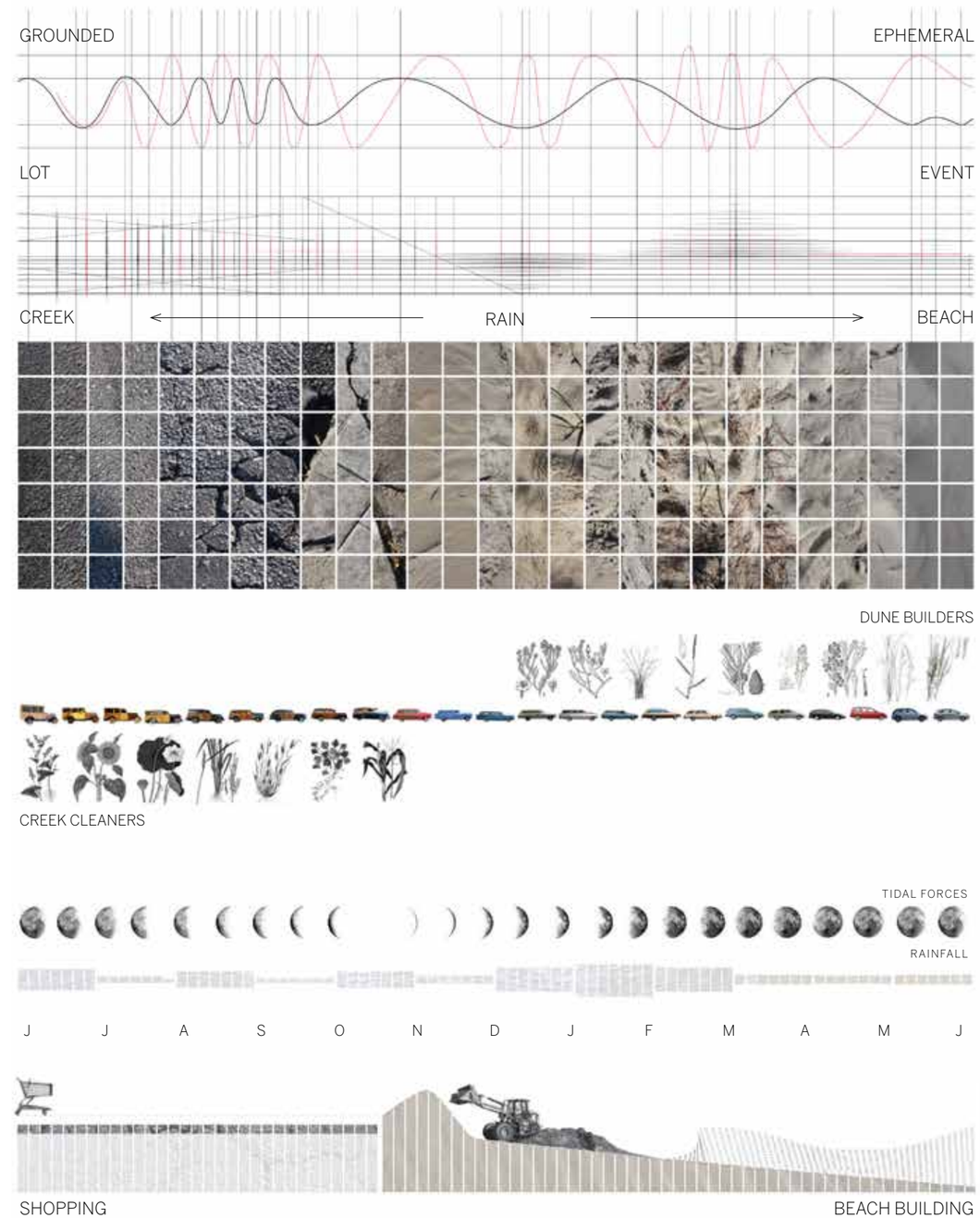


Figure 9.45: Beach Front Gradients: Operational, Material, Temporal, Spatial, and Ecological

Off-Sites: Routes, Railroads, and the Beach Front

The abandoned Norfolk Southern Rail, I-264, and Route 58, which are currently populated by commercial buildings and vast asphalted parking lots, comprise a finger of high ground coming off the coast. This ground is one of interweaving waves of the sea, beachgoers, shoppers, rain and wind. We propose that this ground be designed to hold rains in reservoirs beneath buildings, roads, and highways; and to make the grounds of lots available to accommodate the rise of creeks when necessary. We also propose connecting creeks with a canal along a revived rail connection between Norfolk and Virginia Beach, creating, perhaps re-creating, a network of creeks and allowing them multiple outlets. On the beachfront itself, we turn and raise development to meet the sea in fingers of high ground, fingers connected by infrastructures such as boardwalks, roads, shoals, and a shelf that harnesses wind at sea. These are infrastructures designed to attenuate waves and to collectively protect.

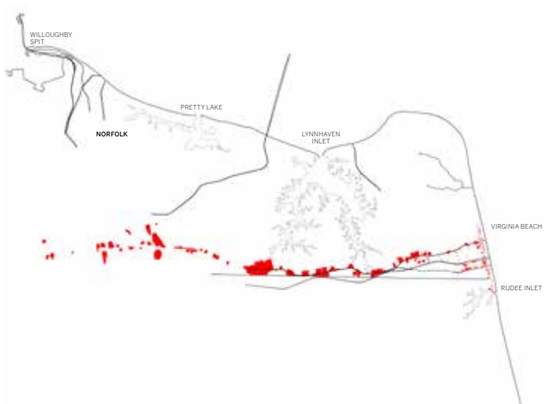


Figure 9.47: Beach Front Parking Lots

Figure 9.46: Beach Front Research Plot

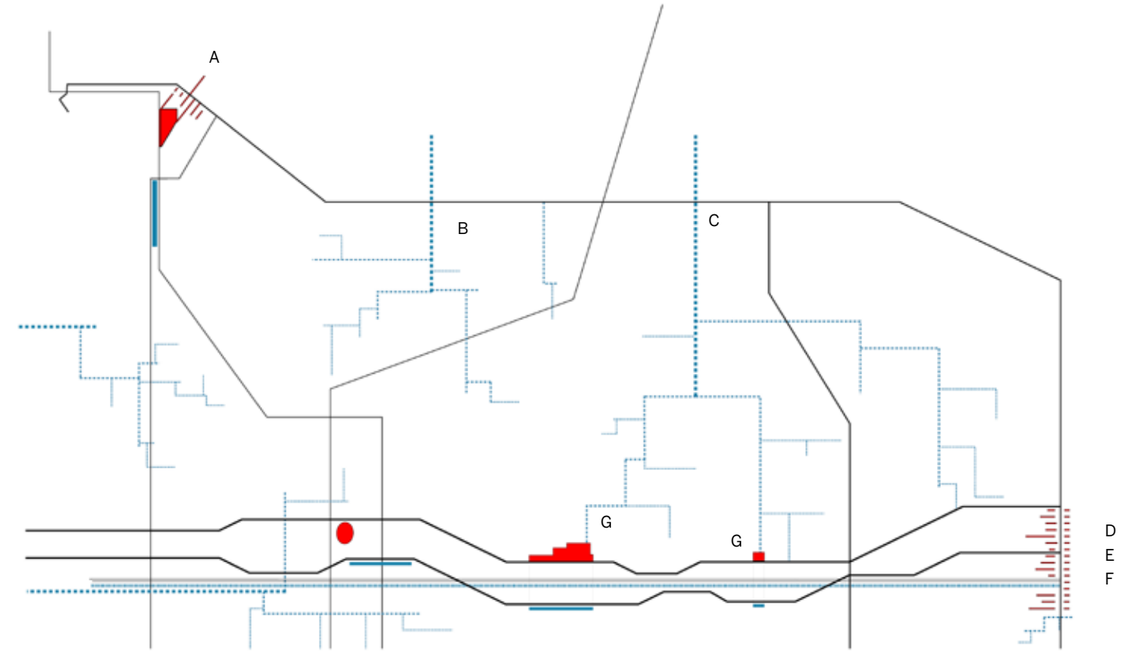


Figure 9.48: Virginia Beach System Diagram and Sectional Index

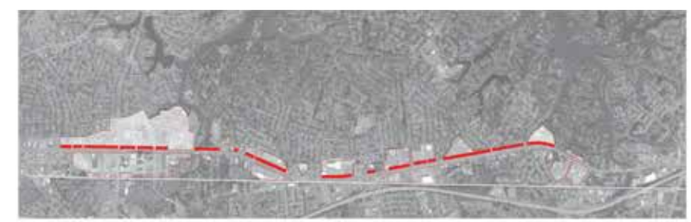


Figure 9.49: Route 58

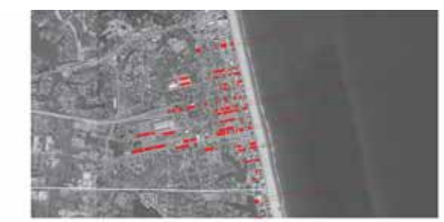


Figure 9.50: Virginia Beach

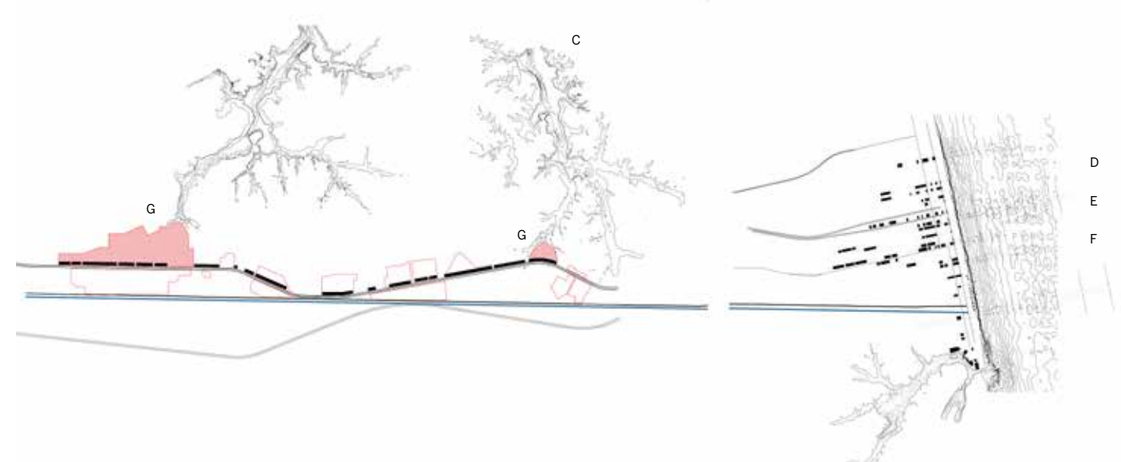


Figure 9.51: Plan and Sectional Index

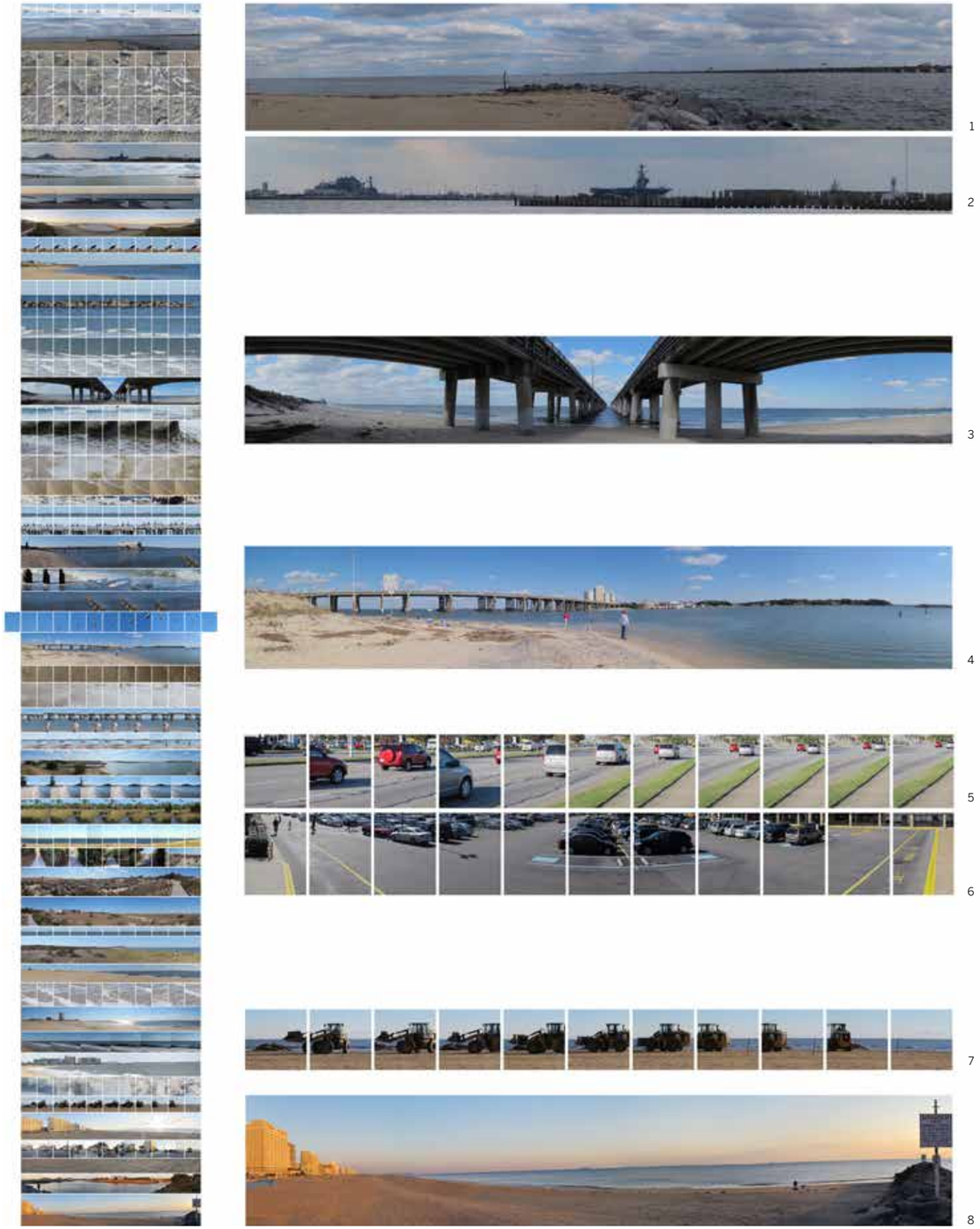


Figure 9.52: Beach Front Horizons: Beaches and Parking Lots

1 Willoughby Spit
2 Willoughby Bay and Naval Station Norfolk
3 Chesapeake Bay Bridge Tunnel
4 Lynnhaven Inlet
5 Route 58
6 Parking Lots
7 Virginia Beach
8 Rudee Inlet

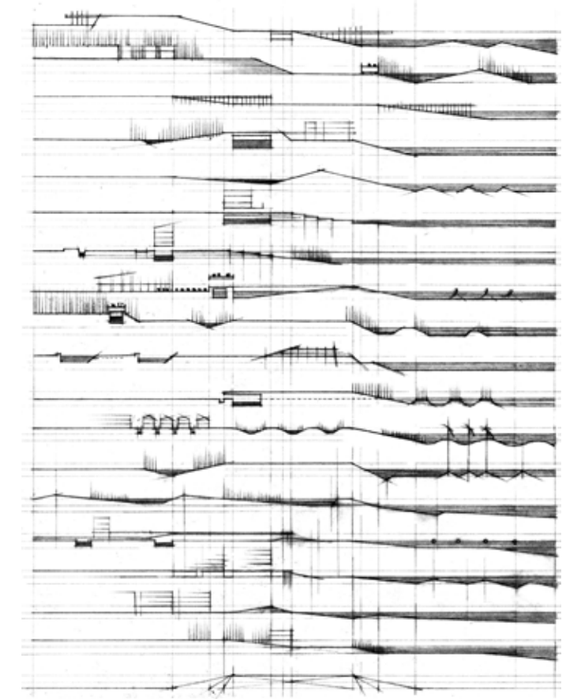


Figure 9.53: Typological Sections

A Shoal/Wavebreak
B Forest Stands
Fishing Pier
Wave Attenuators
C Inlet and Marina
Fishing Piers
D Rain/Holding
Flexible Boardwalk
Dune
E Hotels
Fixed Boardwalk
Windpower Generators
Wave Attenuators
F Rain Holdings
Elevated Ground
Beach
G Shopping/Shelter
Rail/Creek Collector
Creek Expansion
Rain Holdings
Highway Tanks
Parking

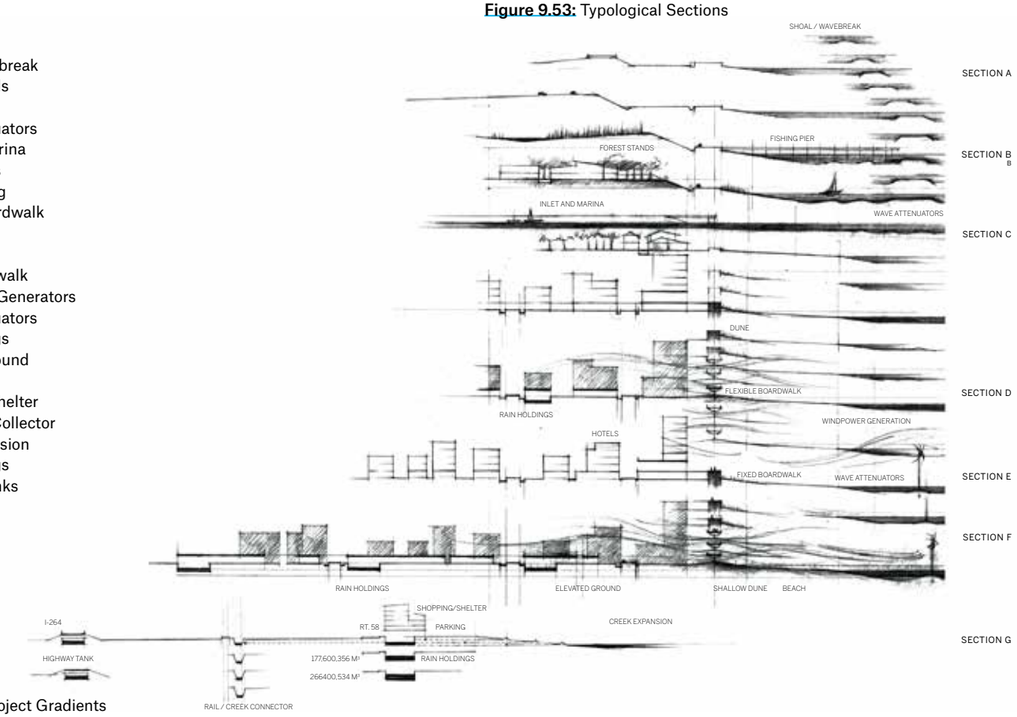


Figure 9.54: Project Gradients

9.5.4 Eastern Shore

The Eastern Shore of the Chesapeake Bay, carried on the spine of Route 13, is fractured by numerous rivers, sounds and islands that are disappearing with a combination of rising waters and subsiding land. Rain that falls here is held in interstices, pores, fields, depressions, fissures, but most significantly in a network of ditches through which it overflows its ways to the bay.

It is a gradient from containment to open waters that is today polluted by the poultry industry and agricultural fields. This pollution makes its way into the bay, causing excessive algae blooms while also endangering resident and migrant populations of blue crab and menhaden among others, and with them the culture and economy of the watermen who have lived on these shores for centuries.

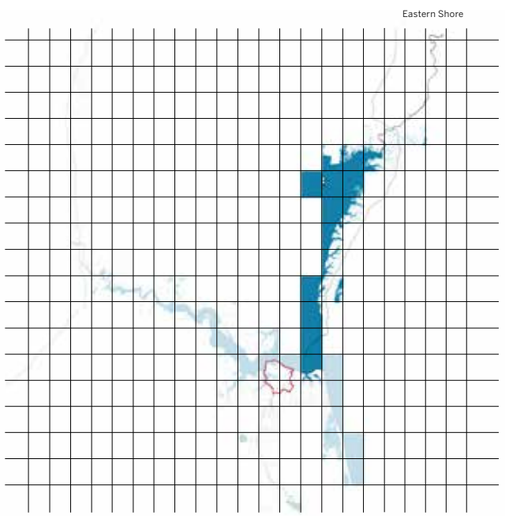


Figure 9.56: North Frontier

Figure 9.55: Eastern Shore Frontier

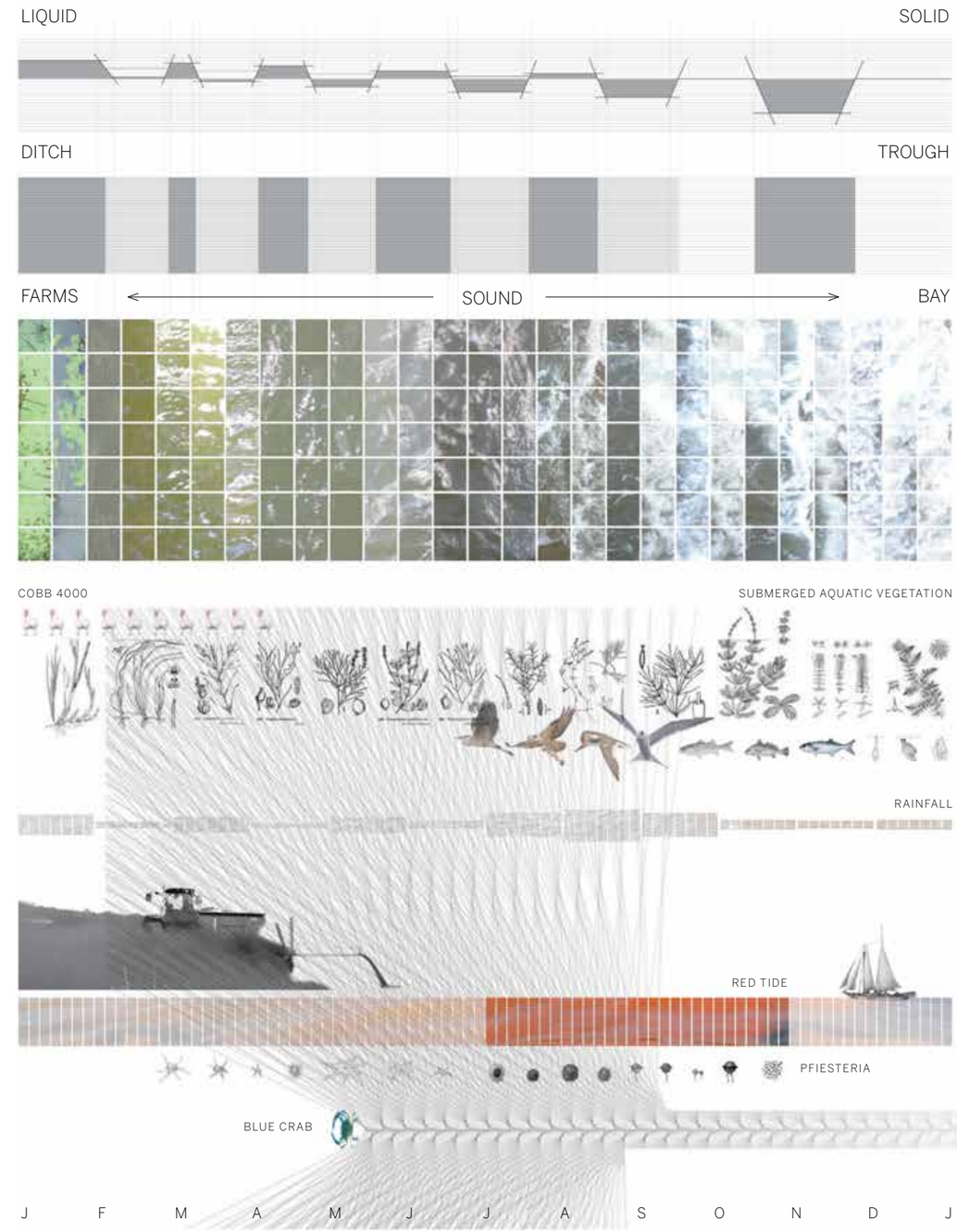


Figure 9.57: Eastern Shore Gradient: Operational, Material, Temporal, Spatial, and Ecological

Off-Sites: Ditches, Sounds, and Islands in the Bay

The estuaries off the eastern shore extend between the polluted waters of farms draining through rivers and Chesapeake Bay islands endangered by these waters as well as by sea level rise. We propose fingers of high ground in the mouths of these rivers, intercepting their flow, operating as troughs that hold, sieve, treat, and clean runoff by biotic means. This interception reaches deep inland through the network of ditches, in some instances turning the ditches themselves into troughs that hold before they drain. This interception also reaches into the sound, to islands such as Tangiers, where troughs work to build ground and hold and nurture fragile habitats. Beyond the islands, fingers of troughs work to attenuate waves. On Tangiers Island, we use troughs to build on an existing configuration of shallow ridges of firmer sediment, stitching, extending and raising them to become new grounds for settlement, saltmarshes, and submerged aquatic environments.

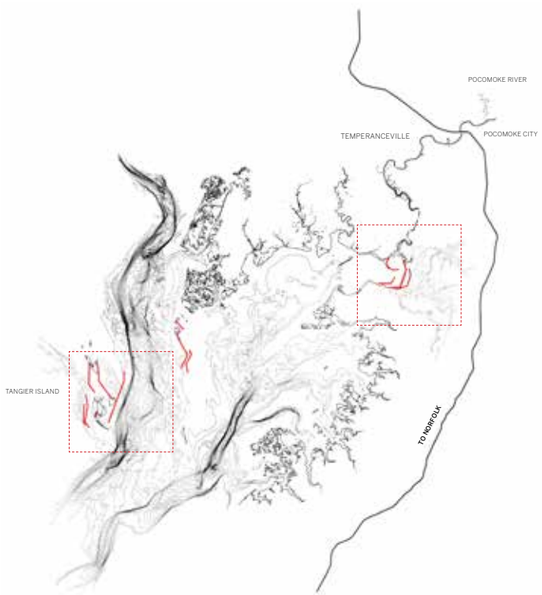


Figure 9.59: Eastern Shore Ditches

Figure 9.58: Eastern Shore Research Plot

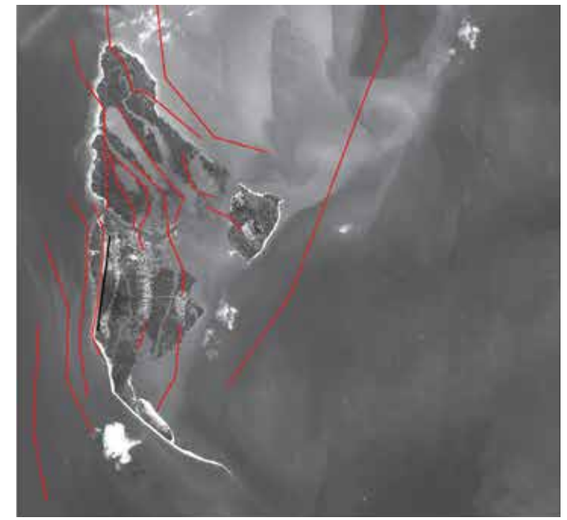


Figure 9.60: Tangier Island

Figure 9.61: Pocomoke River Mouth

Figure 9.62: Plan and Sectional Index

Figure 9.63: Plan and Sectional Index

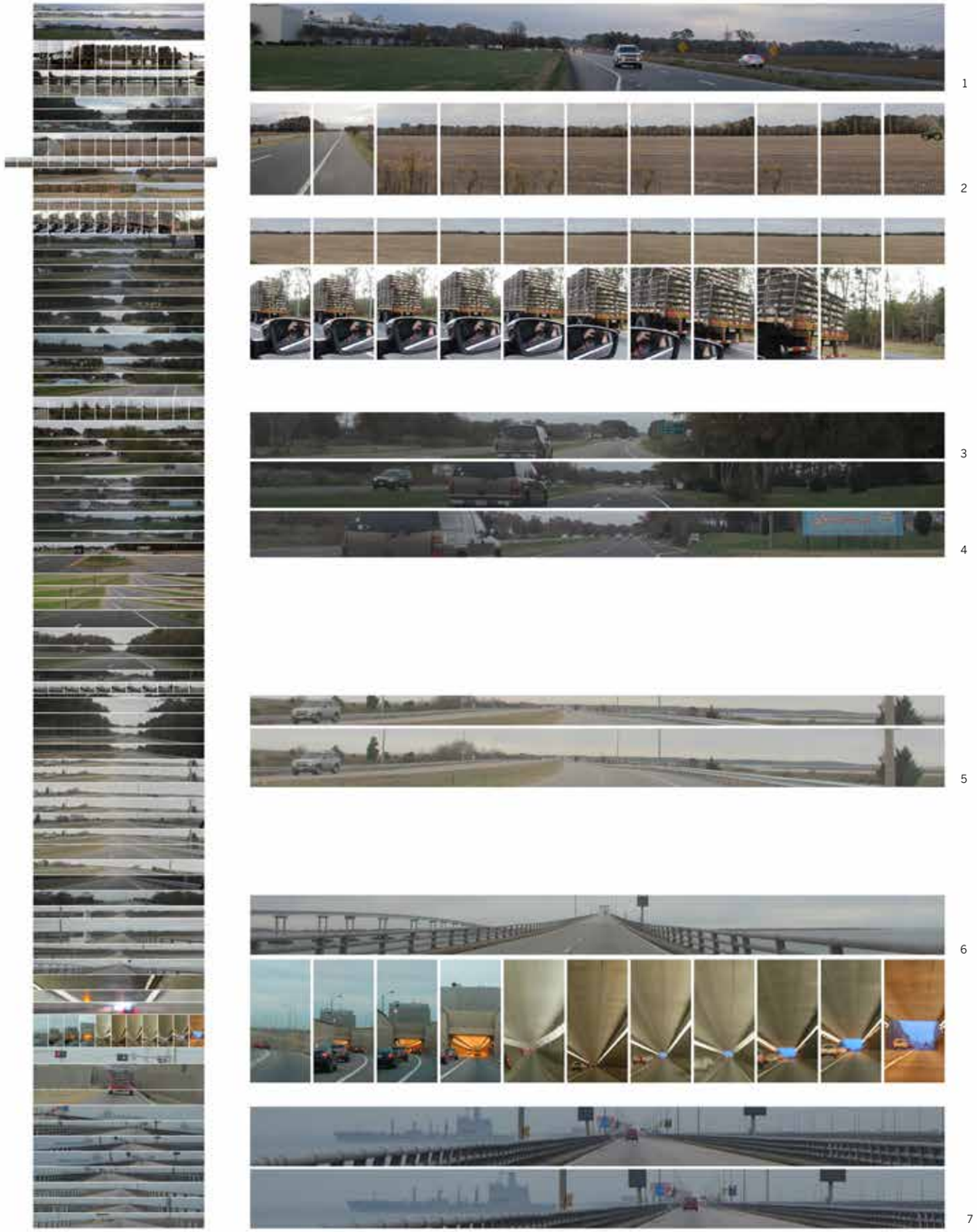


Figure 9.64: Eastern Shore Horizons: Route 13 and Chicken Farms

1 Purdue Processing Plant
2 Temperanceville
3 Route 13
4 Cape Charles
5 Fisherman's Island
6 Chesapeake Bay
7 Chesapeake Bay Bridge Tunnel

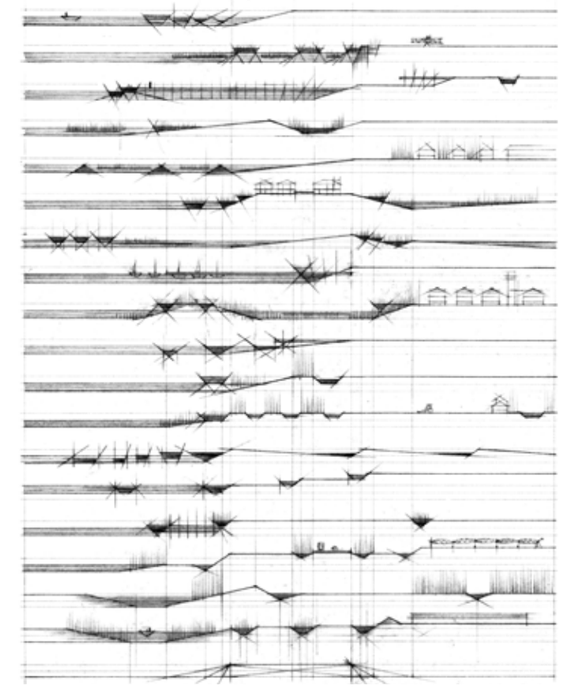


Figure 9.65: Typological Sections

A Jetty
Dredged Channel
Boat Landing
Nutrient Capture Troughs
B Spartina Marsh Troughs
Submerged Aquatic Vegetation
Tangier Housing
Living Jetty
C Water Aeration Troughs
Algal Raceway
Cleaning Sieve
D Farm Overflow
Water Holding Trough
E Runway
Submerged Aquatic Vegetation
F Land Building Troughs
Submerged Aquatic Vegetation
Oyster Stands
Crab Habitat

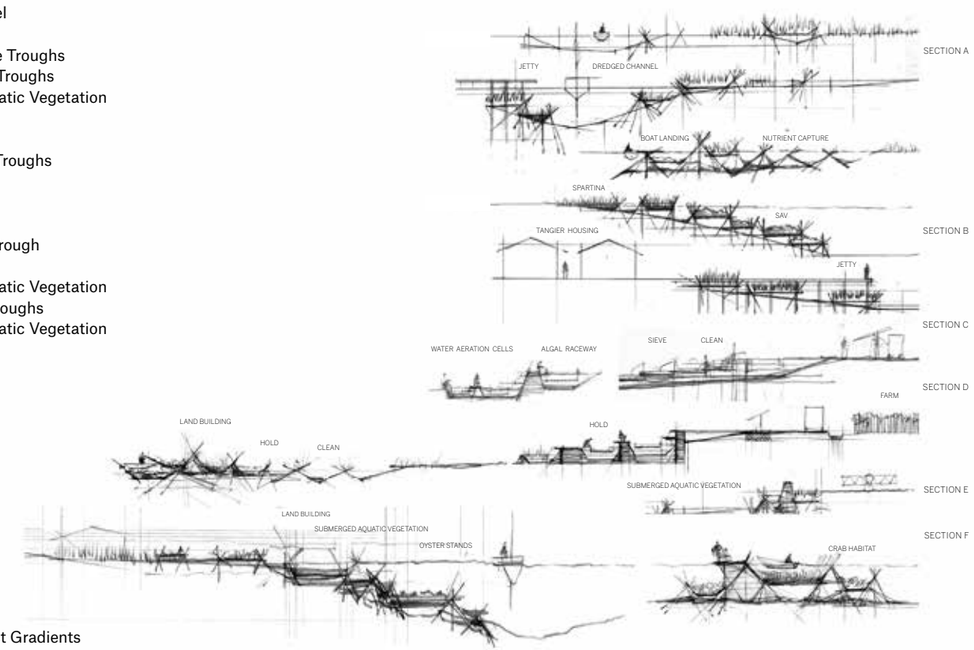


Figure 9.66: Project Gradients

9.6 In-Sites: A Convergence of Four Design Fields

The four frontier-fields converge on in-sites in Norfolk, providing material and operational possibilities for designing fingers of high ground that engage, on the one side, a sea that is in the bay to the north, the Elizabeth River to the west and south and in numerous creeks within, and, on the other side, a land that is low-lying and not easy to drain.

Norfolk has little choice other than building higher ground. The alternative that is being considered on the basis of frontier-thinking—walls, gates, and pumps in various areas—may work in the short term, but in the long term will surely create an even more vulnerable and dangerous situation in the face of sea level rise. In fingers of high ground, Norfolk has both a long-term strategy and many short-term possibilities.

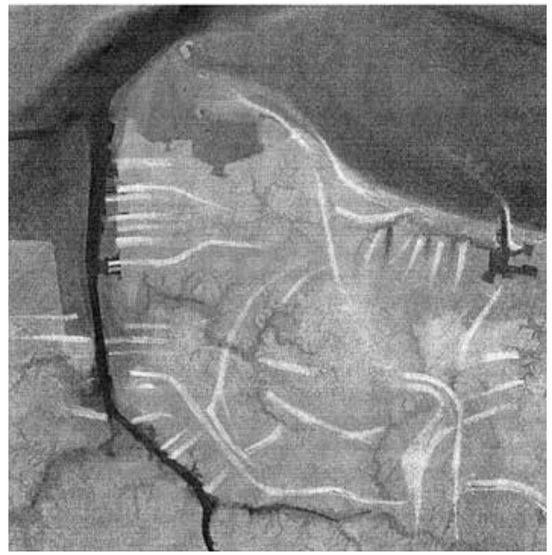


Figure 9.67: Raising Ground in Norfolk

Figure 9.68: Converging Design Fields—Fingers of High Ground

The case for constructing fingers of high ground in Norfolk is strengthened by the strategic importance of the city as home to the largest naval station in the world and one of the most important commercial ports on the East Coast. Indeed, the port and naval station are two pillars of Norfolk's economy. The case for building high ground is even further strengthened by Norfolk's place at the center of extensive dredging operations in the bay up to Baltimore, Hampton Roads, the Elizabeth River, and the James River. These are operations for which Craney Island across the mouth of the Elizabeth River from Norfolk was extended into a massive soil-processing field. It offers a unique opportunity for remediation and use.

We choose three potential sites in Norfolk to turn from vulnerable frontiers to resilient fingers of high ground, bringing to them the sensibilities and possibilities of the four fields we have investigated through design. We choose these sites for the challenges they present on the sides of land and sea, which in largely low-lying Norfolk can be read as the sides of rain and sea. We also choose them for the potential of being infrastructural, ecological and productive, sites that are currently interstitial, such as between the naval station and the port, adjacent to freeways and rail lines, and adjoining treatment plants.

We see these in-sites beginning the strategic raising of ground in Norfolk. But we also see in the public exhibition of their design the beginning of a process that carries the public along in a new visualization and engagement of the coast.

Figure 9.69: Three Potential In-Sites for Norfolk

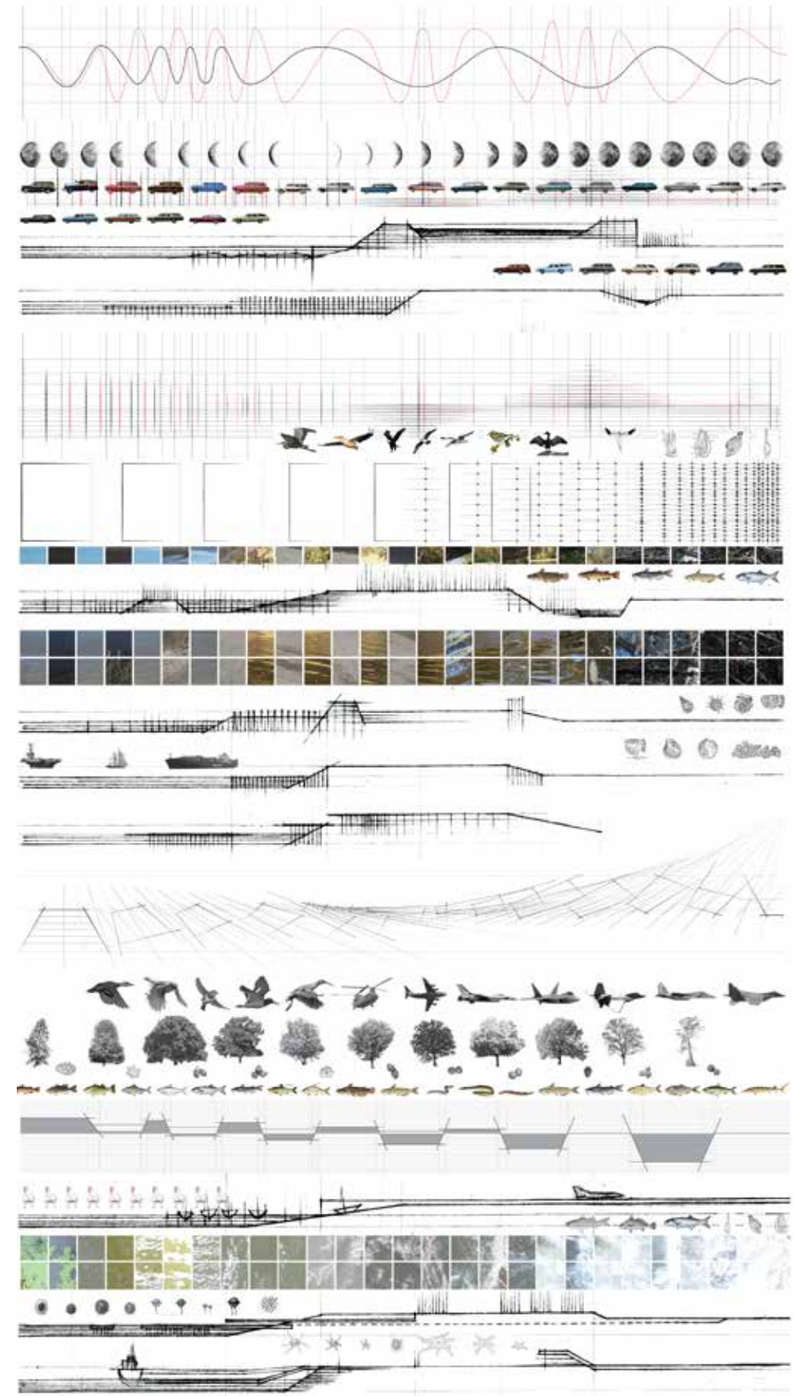


Figure 9.70: Converging Operational, Material, Temporal, Spatial, and Ecological Gradients.

9.6.1 In-Site 1: Lambert's Point to Downtown Norfolk

Figure 9.71: In-Site 1

1 Lambert's Point Golf Course
2 Water Treatment Plant
3 Lambert's Point Rail Yards
4 ODU Rec Facility
5 Water Filtration Plant
6 Community Garden
7 Robertson Park
8 Warehouse Corridor

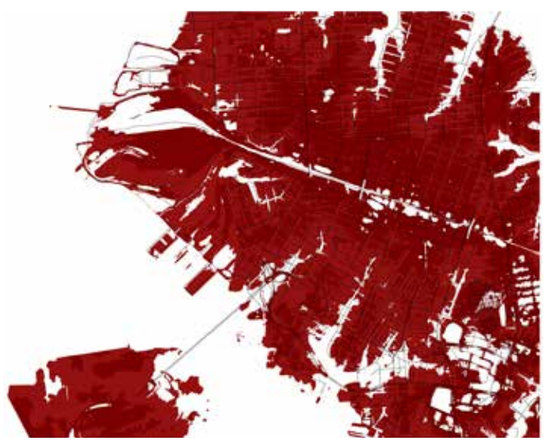


Figure 9.72: Category 3 Storm Surge

Figure 9.73: In-Site 1 Horizons

9.6.2 In-Site 2: Norfolk International Terminals to I-564

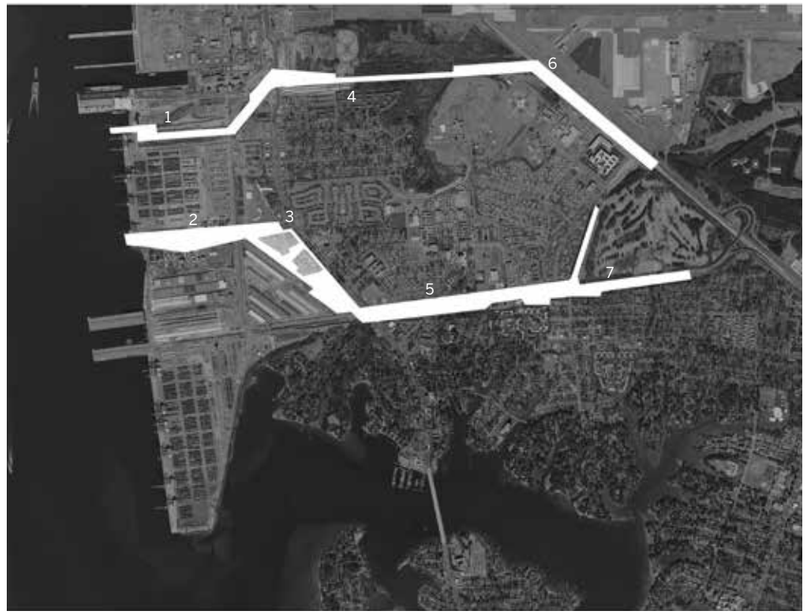


Figure 9.74: In-Site 2

1 Norfolk International Terminals
2 Water Treatment Plant
3 Fleet Family Support
4 Glenwood Park
5 Terminal Boulevard
6 I-564
7 Sewell's Point Golf Course

Figure 9.75: Category 3 Storm Surge

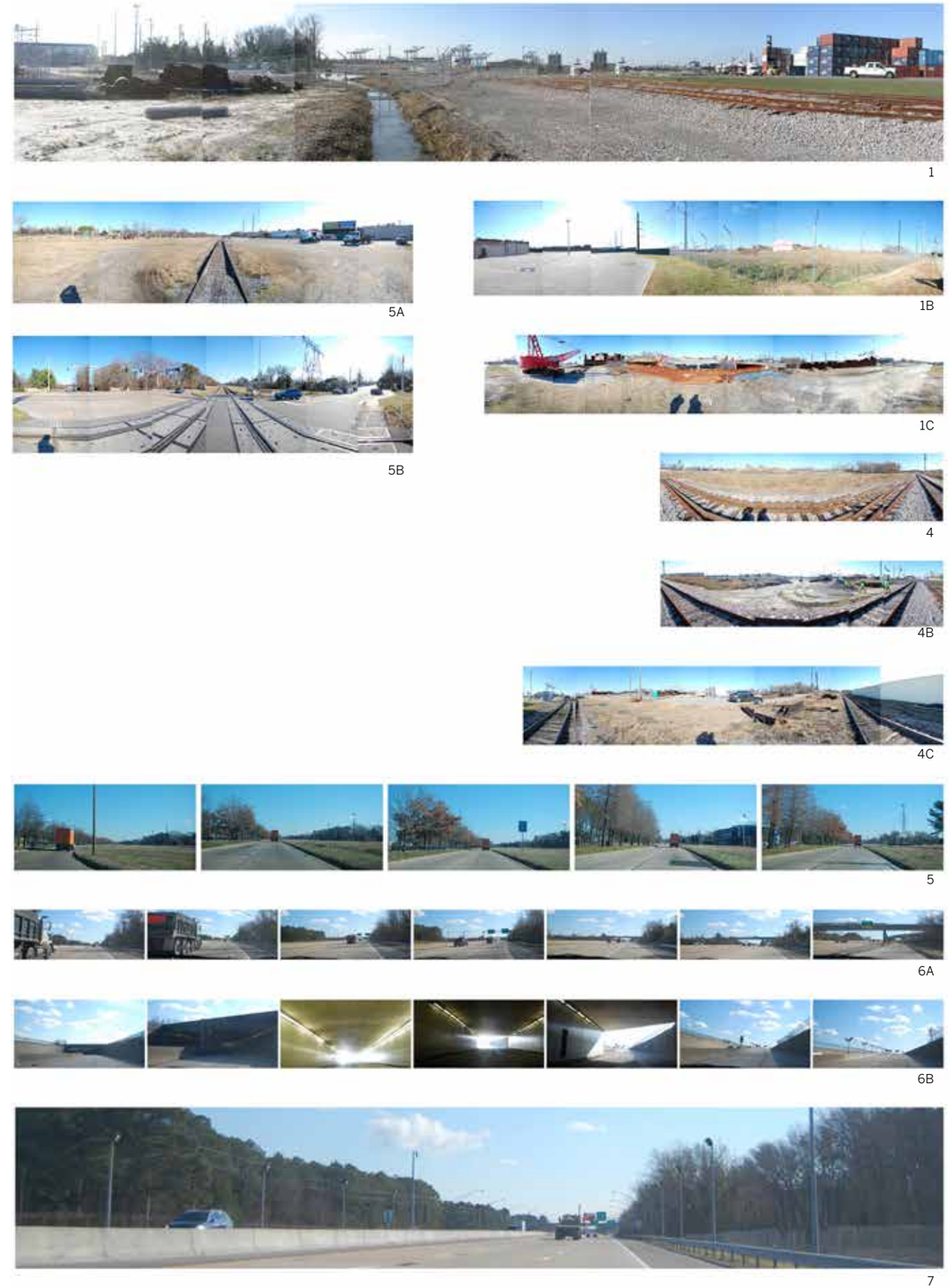


Figure 9.76: In-Site 2 Horizons

9.6.3 In-Site 3: Fishing Pier to Mason's Creek

Figure 9.77: In-Site 3

1 Ocean View Fishing Pier
2 Parking Lot
3 Willoughby Elem. School
4 I-64 Interchange
5 Water Discharge
6 Masons Creek Water Retention

Figure 9.78: Category 3 Storm Surge

Figure 9.79: In-Site 3 Horizons

9.7 Conclusion

The objective for the first stage of the project has been to hone in on complementary sites in Norfolk, sites to be carried into detailed design and programming in stage two. Our objective has also been to open key players, organizations and communities in the region to the possibilities of a new visualization of the coast as a cumulative field of gradients rather than a continuous line.

Turning this line will necessarily need to gather multiple publics on the ground of a new visualization of the coast and unique gradients of an estuary—Virginia Institute of Marine Science (VIMS), Wetland Watch, Elizabeth River Foundation, US Navy and the USACE. This visualization will be the platform for presentations, publications and exhibitions that engage those in a position to affect people's lives as well as those affected: experts and children, activists and policy-makers, those in power and those in need of empowerment.

The University of Pennsylvania Team's process has been to look at the larger region with an eye to call out:

- Vulnerable frontiers that can be turned into potential gradients between land and sea
- Programmatic possibilities and operational languages of gradients that can be deployed in the design of fingers of high ground
- Sites in Norfolk that can serve to demonstrate the many possibilities that these gradients offer in the short and long terms.

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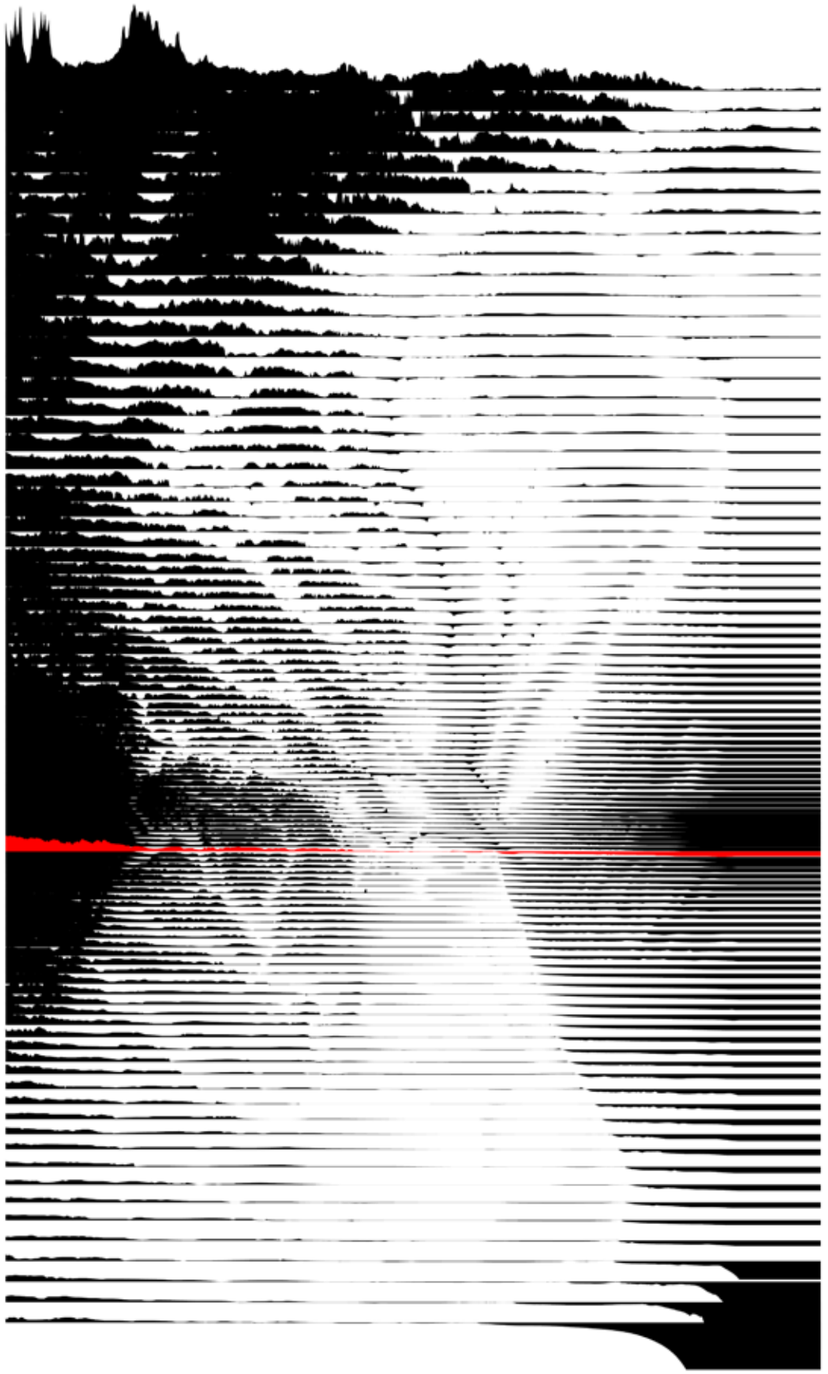
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