COASTAL CLIMATE RESILIENCE

Urban Waterfront Adaptive Strategies

NYC PLANNING
DEPARTMENT OF CITY PLANNING CITY OF NEW YORK

NEW YORK & CONNECTICUT
SUSTAINABLE COMMUNITIES

This study was funded through a U.S. Department of Housing and Urban Development (HUD) Sustainable Communities Regional Planning Grant to the New York-Connecticut Sustainable Communities Consortium.

Waterfront Vision &
Enhancement Strategy

NYC™PLANNING
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COASTAL CLIMATE RESILIENCE

Urban Waterfront Adaptive Strategies

A guide to identifying and evaluating potential strategies for increasing the resilience of waterfront communities to coastal flooding and sea level rise.

THE CITY OF NEW YORK

MAYOR MICHAEL R. BLOOMBERG

DEPARTMENT OF CITY PLANNING

AMANDA M. BURDEN, FAICP, COMMISSIONER

JUNE 2013

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FOREWORD

New York is and will always be a waterfront city. The city's 520 miles of shoreline—its harbors, beaches, and marshes—are central to the city's history, essential to its economy and livability, and crucial to its future. In 2011, we celebrated the history of the City's waterfront and planned for its future by issuing *Vision 2020, the New York City Comprehensive Waterfront Plan*, a framework for ensuring the health of our waterways, the strength of our port, the ecological vitality of natural habitats, the public's enjoyment of the shoreline, and the economic benefits of public and private investment in our waterfront. *Vision 2020* also recognized the challenges and increasing risk that climate change, sea level rise and coastal storms pose to our city, and the importance of resilience – being able to withstand and recover quickly from coastal flooding.

During the course of this study, Hurricane Sandy's devastation served as a stark reminder that climate risks are not just a concern of the future. The storm has provided an important rallying call for all levels of government to take stronger measures to plan for coastal risks. As the city recovers and rebuilds from Sandy, this report will aid in short- and long-term decisions about the design of our waterfront and communities. We can increase our resilience while realizing the broad range of goals articulated in *Vision 2020*, transforming our waterfront in ways that make the city not only safer, but also more vibrant, healthy, and prosperous.

While New York City is unique in many respects, the challenges we face are shared by many communities in the region, as well as elsewhere around the world. Our future vitality and sustainability depends on our ability to foster livable neighborhoods built around a robust transit infrastructure. At the same time, we must address the significant flood risks that face urban waterfront communities. Though New York City is the focus of this report, we drew on global precedents and consultation with experts from around the world, and developed this guide as an informational resource for any city confronting these complex issues.

Creating more resilient and livable waterfront cities is a critical element of planning for our future, and I am proud to advance this work through this report.

Amanda M. Burden, FAICP
Director, Department of City Planning
Chair, New York City Planning Commission

ABOUT THIS STUDY

This study was funded through a U.S. Department of Housing and Urban Development (HUD) Sustainable Communities Regional Planning Grant to the New York-Connecticut Sustainable Communities Consortium. This Consortium includes local governments, Metropolitan Planning Organizations, and regional planning groups working to develop livable communities and cultivate sustainable growth around the region's commuter rail network. This study, *Urban Waterfront Adaptive Strategies*, along with *Designing for Flood Risk*, complements the other work of the Consortium by identifying resilience strategies and a framework for analysis specific to urban coastal communities. These studies describe a means of managing flood risk guided by the six Livability Principles of the Partnership for Sustainable Communities, reconciling the need to adapt to the unavoidable effects of climate change with smart-growth concepts that are key to reducing climate change-inducing greenhouse gas emissions.

This study, which began in May 2012, builds upon New York City's work through *PlaNYC*, the City's long-term sustainability plan; *Vision 2020,* the City's comprehensive waterfront plan; and numerous other projects and initiatives to increase the resilience of the city's built environment, infrastructure, and natural resources. In addition, this study played a key role in Mayor Bloomberg's *Special Initiative for Rebuilding and Resiliency* (SIRR), launched in December 2012 following Hurricane Sandy to address the city's long-term rebuilding and resiliency. During its development, this study informed the SIRR's coastal protection analysis, and this report complements the final SIRR report, *A Stronger, More Resilient New York*, released in June 2013.

This study was guided by regular input from a Technical Advisory Group comprised of technical experts in climate science and coastal engineering, practitioners of waterfront planning and design, and representatives of community groups and the environmental justice community. In addition, the Department of City Planning's research involved consultation with experts on a range of relevant topics from around the world.

The major goals of this study are:

1. To identify the range of adaptive strategies that can increase the resilience of urban coastal areas to coastal hazards associated with sea level rise;
2. To understand the type and magnitude of costs and benefits associated with each strategy;
3. To establish a framework by which communities can evaluate the effectiveness and appropriateness of different approaches for particular coastal areas.

This report is intended as a resource and reference guide for use by a wide range of audiences, including government officials, planners, designers, civic groups, and communities. The report provides information useful for many different types of projects that seek to enhance coastal climate resilience at various scales—from a site-specific development project to a neighborhood, city, or regional study. **Part 1** provides an overview of coastal hazards as they relate to waterfront planning and design. **Part 2** describes different coastal area typologies and the exposure of each to different types of coastal hazards. **Part 3** includes a catalog of adaptive strategies that can be applied at various physical scales, and provides information that can guide readers toward strategies that are most likely to be suited to different sites and conditions. **Part 4** outlines the process by which alternative adaptive approaches can be evaluated, including across physical scales and over time.

Sand Dunes Coney Island Creek, Brooklyn

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Jamaica Bay, Queens

EXECUTIVE SUMMARY

New York City's waterfront faces risks from coastal hazards today. With sea level rise and greater frequency of the most intense coastal storms, these risks will increase.

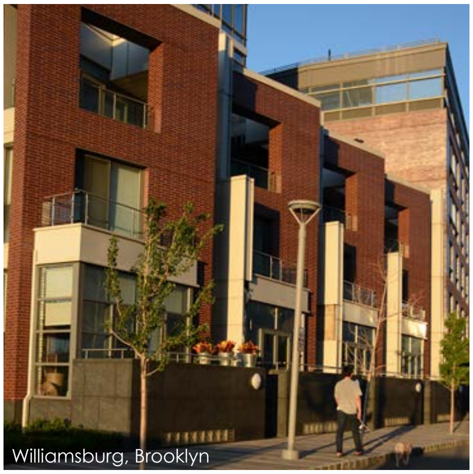
On October 29, 2012, Hurricane Sandy flooded nearly 50 square miles of New York City, and caused tremendous damage in the city, as well as in Long Island, New Jersey, and other coastal communities. Sandy was the most destructive storm in the region's history, but is far from the only storm to have affected the coastline, and will not be the last. Smaller nor'easters and tropical storms regularly cause coastal flooding and erosion. Flooding from high tides even affects portions of the city today. Sea levels have risen by roughly a foot in the last century, and according to the New York City Panel on Climate Change (NPCC), a group of leading scientists and risk management experts convened by Mayor Bloomberg, they are extremely likely to continue to rise in the future. Middle range projections for sea level rise in New York City range from 4 to 8 inches by the 2020s and 11 to 24 inches by the 2050s. Similarly, high end projections for those same periods are 11 inches and 31 inches, respectively.

As sea levels rise, the lowest-lying areas of the city will gradually become more vulnerable to regular flooding from daily and monthly high tides. Unreinforced shorelines and weakened shoreline structures will become more vulnerable to erosion. Sea level rise will mean that coastal storms will create higher storm surges that will flood larger areas, and changes in storm activity will lead to a greater number of the most intense hurricanes.

Lower Manhattan

South Beach, Staten Island

Broad Channel, Queens



Williamsburg, Brooklyn

New York City's 520 miles of waterfront are incredibly diverse. Each of these areas face specific types and levels of risks, and therefore require different strategies.

New York City's coastal zone encompasses the extensive wetlands of Jamaica Bay and Long Island Sound, dense commercial centers and industrial areas, beachfront residential communities, and myriad other neighborhoods. Much of the literature on coastal resilience in the United States, however, is focused primarily on relatively low-density communities. This study aims to explore the range of coastal management and protection options that are suited to urban areas with large existing populations in flood zones, limited space, and shorelines that have been altered and often hardened in a variety of ways. Given the diversity of geography and uses within urban areas, there is no one size fits all approach to climate resilience, nor is there one "silver bullet" solution to managing risks. Each stretch of the waterfront faces specific types and levels of risk and presents different opportunities and constraints.

As evidenced by Hurricane Sandy, coastal storms can have wide-ranging and devastating effects on waterfront communities. Although Sandy was unique in many ways, she demonstrated how storms affect various sections of the city's waterfront in different ways and with a range of consequences. As the storm surge reached the city's oceanfront coast, large waves crashed onto the shoreline, scouring beaches, and damaging homes and structures. In some areas, like the East Shore of Staten Island, low-lying topography meant that surge waters extended far into the neighborhood, while in other areas, such as some neighborhoods on Staten Island's South Shore, steep shorelines and bluffs protected all but the first few rows of homes from the water. As the surge entered the Upper Harbor, the largest waves had generally broken and dissipated, so while many of these areas were flooded and buildings damaged, there was not the same structural damage to buildings as in the southern parts of the city. However, the concentration of critical infrastructure facilities, such as subway and roadway tunnels, electrical infrastructure, and hospitals in these areas meant that flooding had major consequences for the whole city's ability to recover, as well as for many individual homes and businesses.

There are a variety of potential strategies to adapt waterfront areas to be more resilient in the face of increasing coastal hazards.

These strategies include actions at various scales, from a single component of a piece of infrastructure, to a building or development site, to an entire stretch of coastline. At each scale, there are a variety of actors and stakeholders involved, including local communities, private landowners, infrastructure owners and operators, and city, state, and federal agencies.

Site strategies include various means of preventing damage to buildings and their contents. Since 1983, when FEMA issued the first Flood Insurance Rate Maps for New York City, the City's Building Code has required buildings within the flood zone to incorporate such measures. During Hurricane Sandy, newer buildings built to these standards fared much better than older buildings, demonstrating the effectiveness of such strategies when they are in place. However, 84percent of the nearly 90,000 buildings in the area inundated by Hurricane Sandy in New York City were built before such standards were required for new construction. The costs of retrofitting buildings to higher standards is typically significant, and many buildings within older urban centers, such as historic brick structures, attached buildings and buildings with ground-floor retail, present many technical and urbanistic challenges.

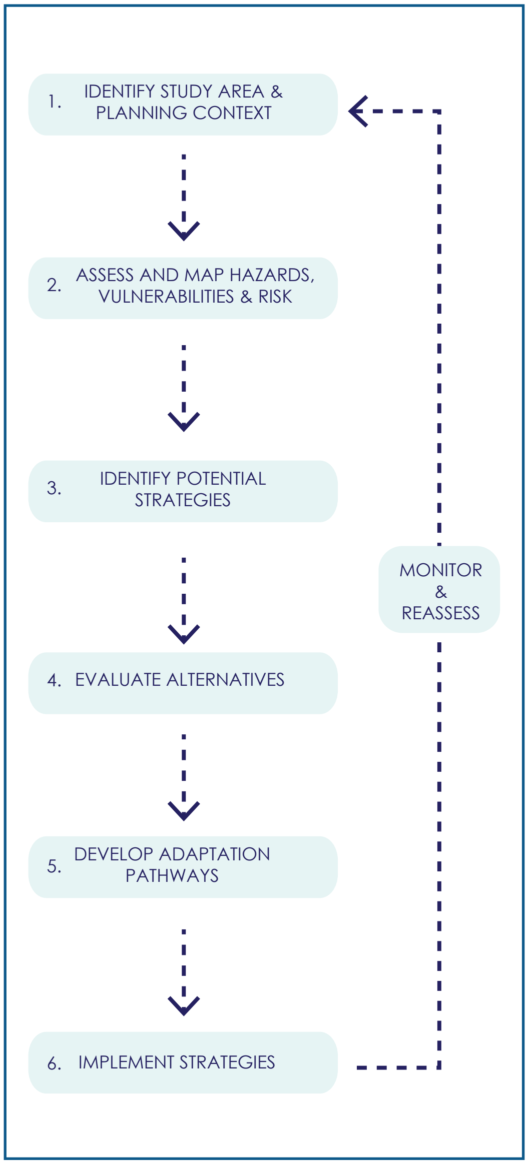
Reach strategies include interventions upland, at the shoreline, or in the water, which affect a larger stretch of shoreline, frequently involve many individual sites and landowners, and are often built and maintained by public agencies. The objectives of various reach strategies include stabilizing land against erosion and daily tide levels, reducing wave forces, blocking the flooding of upland neighborhoods, and removing development from vulnerable areas. Some strategies can reduce risks from multiple hazards, while others may not. For instance, an armored dune can absorb wave forces and prevent inland inundation from coastal storms, while other strategies such as salt marshes or oyster reefs can reduce wave forces but do not prevent flooding. Construction and maintenance costs are relatively high for most of these strategies, and the permitting and regulatory process required for implementation can be time-consuming and extensive. To be fully effective, reach strategies require consistent application across property lines and jurisdictional boundaries.

In addition to these site and reach strategies, which are the primary focus of this report, there are a variety of other avenues for increasing coastal climate resilience, including preparing for extreme events through developing plans for evacuation, emergency response, and recovery, and adapting infrastructure systems to the impacts of climate change. Taken together, these strategies can be part of a multi-layered approach to reducing risks. Yet, it would be impossible to fully eliminate all risks, not only because of the immense sums of money required, but also because there could always be a storm larger than or different from what was planned for, and there is potential for failure in any strategy.

Each strategy carries with it costs and benefits, which should be broadly defined. Potential costs include financial costs, both to construct and maintain new pieces of infrastructure, as well as indirect costs, such as environmental degradation, impacts on neighborhood vitality, economic activity and tax revenues, or the quality of public space and urban design. The benefit of a strategy can be measured in terms of risk reduction, as well as the potential co-benefits associated with it, such as environmental improvements, economic development, and the improvement of the city's public realm.

Resilience is commonly defined as the ability to withstand and recover quickly from disturbance. In terms of urban planning, resilience also encompasses a broader notion about ensuring a city's vibrancy, livability, and equity in the near and long term. While planning to withstand climate events is very important, a community's other goals, such as economic prosperity, job opportunities, sustainability, quality of the public realm, affordability, and livability for its residents are also important to ensure that the community can meet the needs and values of its residents in ordinary circumstances, as well as when climate events occur.

EVALUATION PROCESS



Creating a more resilient city is a long-term, on-going process of assessing risks, developing and evaluating alternatives, and implementing flexible and adaptive strategies.

Potential strategies for adaptation are numerous. A significant challenge facing coastal communities is determining which strategies should be pursued, why, and what potential funding for such measures exist. The intention of this report is to not only to present information on a wide range of potential strategies, but also to help narrow the list of strategies to consider for a given geography, and to lay out a framework to determine which strategies provide the greatest range of benefits with respect to direct and indirect costs. This is a complicated process that must take into account many considerations, is highly dependent on specific factors at multiple geographic scales, and is subject to changes over time.

The steps shown on the left are intended to be a flexible and replicable process to identify strategies that can be implemented across various physical and time scales. As described in more detail in Part 4, it is intended to be an iterative process with opportunities for continual monitoring and re-evaluation as new information is available.

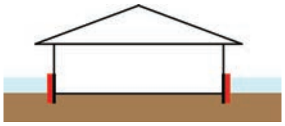
The evaluation process should be based on a risk-management approach that takes into account a wide range of potential costs and benefits, and is informed by stakeholder input. The nature of the risk from coastal hazards will vary from neighborhood to neighborhood, requiring a geographic analysis to understand which strategies are applicable where. In addition, as the climate and the city change over time, so too will the costs and benefits of strategies, requiring analysis of multiple time horizons to understand during what timespan a strategy will be effective. Despite the rigorous science on which climate projections are based, they contain uncertainties. Accordingly, developing multiple possible future scenarios that assume different ranges of sea level rise and trends in land use and population changes, and considering how various strategies may be adapted to be effective in different future conditions, can steer decisions toward robust strategies.

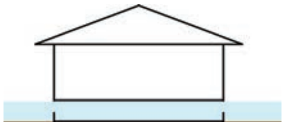
As coastal communities plan for rising sea levels and increased risk, they will continue to be faced with many decisions on how best to make use of finite resources. While the short term needs and resources of the community must be considered, it is also important to plan with the long-term in mind. These decisions will have great ramifications on the future health and well-being of the community. The key considerations and evaluation framework described in this report can guide a thoughtful and ongoing planning process for increasing climate resilience in the urban context.

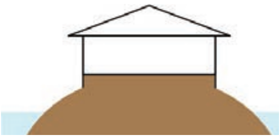
INVENTORY OF ADAPTIVE STRATEGIES

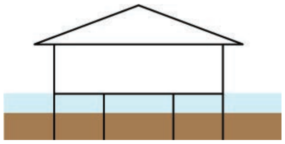
There are a wide-range of potential adaptive strategies at various scales. Each strategy is explored in depth in Part III.

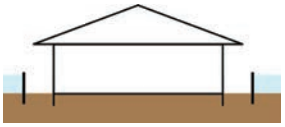
SITE

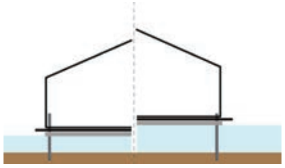

Dry Floodproofing

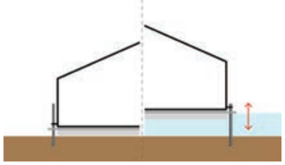

Wet Floodproofing


Elevate on Fill or Mound


Elevate on Piles


Site Protection


Floating Structures


Amphibious Structures


Building System Protection

OTHER

Emergency Management

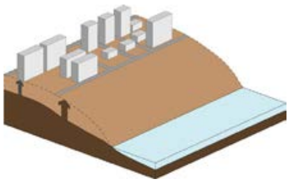
Insurance

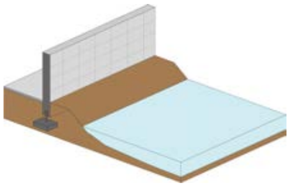
Land Use Management

Infrastructure Protection

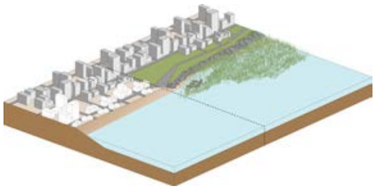
REACH

UPLAND

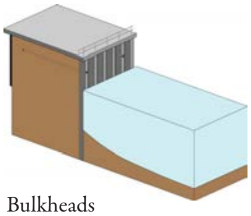

Elevation of Land and Streets

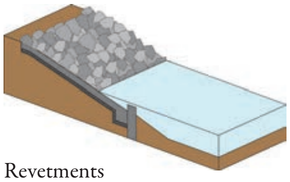

Floodwalls

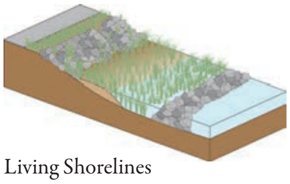

Waterfront Parks

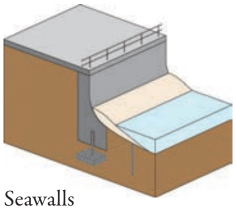

Strategic Retreat

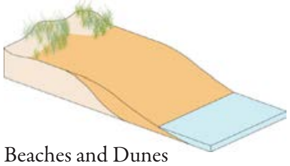
SHORELINE

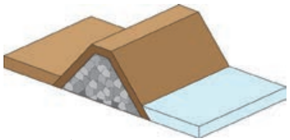

Bulkheads


Revetments


Living Shorelines

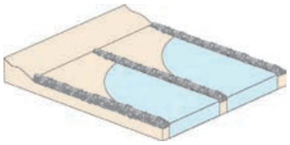

Seawalls

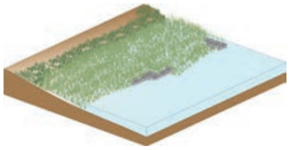

Beaches and Dunes

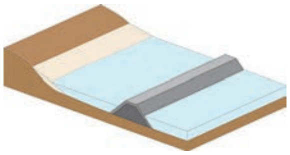

Levees (or Dikes)

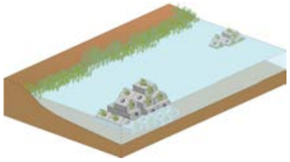

Multi-purpose Levees

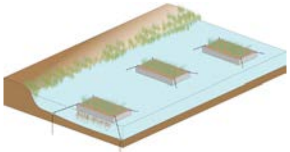
IN-WATER

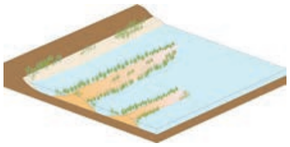

Groins

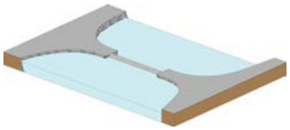

Constructed Wetlands

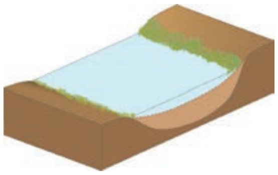

Breakwaters

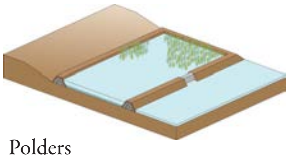

Artificial Reefs


Floating Islands


Constructed Breakwater Islands


Surge Barriers


Coastal Morphology Alteration


Polders

PART I

COASTAL HAZARD CONCEPTS & TERMS

There are inherent risks to living and working on the coast, from rare and infrequent events such as hurricanes, to everyday hazards such as erosion and waves.

Coastal areas are, by definition, exposed and shaped by coastal hazards and processes. Coastal communities have developed a variety of mapping and regulatory mechanisms to manage and communicate these risks and to enable the development and use of the coast for a variety of purposes. Due to climate change, extreme events are likely to become more frequent and their impacts more severe. In addition, sea level rise will gradually increase high tides and may lead to frequent flooding and erosion. This section is intended to serve as a background and overview of coastal hazard terms and concepts. The adjacent page describes five hazards common to coastal areas and how they are likely to change in the future due to climate change. The following section defines key terms related to coastal hazards, as well as related mapping and regulatory tools.

Coastal hazards range from sudden and severe events to gradual changes in conditions.

Event-Based Hazards

Event-based hazards are those hazards associated with a sudden event, such as earthquakes, tornadoes, or, for the purpose of this report, coastal storms, which result in storm surge, wave action, and erosion. Storm surge is a rise in coastal water level associated with a hurricane or other strong coastal storm. In New York City, storm surges are caused by both hurricanes and Nor'easters. The New York Bight, the right angle formed by Long Island and New Jersey, can act to funnel storm surge into New York Harbor. The largest storm surges are associated with hurricanes, though the region also experiences Nor'easters, which are typically smaller but occur more frequently. Storm surge can cause extensive flooding throughout the low-lying parts of the city. Along the ocean, storm surge can bring large, crashing waves that create an additional hazard and may lead to sudden erosion of beaches and bluffs.

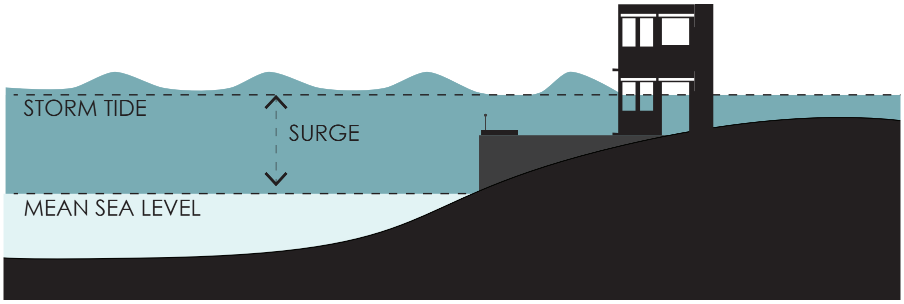
According to the New York City Panel on Climate Change, sea level rise is very likely to result in increased frequency of coastal flooding. Flood elevations associated with recurrence intervals, such as the 1-in-100 year storm, will be higher, and the area affected will also increase. Throughout the North Atlantic region, the number of intense hurricanes is likely to increase in the future.

Gradual Hazards

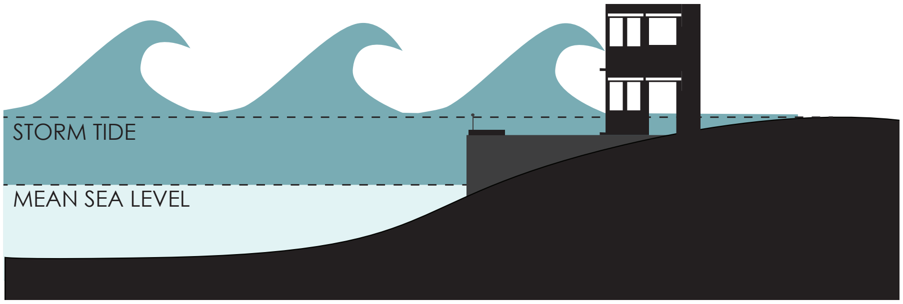
Gradual hazards are those hazards that slowly present themselves over time, as opposed to all at once with a sudden, extreme event. Coastlines are shaped and modified continually over time by processes such as winds, waves, tides, and currents. These processes gradually erode soft shorelines, wear on shoreline structures, and move sediment from one place to another, continually reshaping the landscape. Coastal landforms are also affected by localized gradual changes in sea level caused by subsidence or glacial processes.

Climate change is likely to result in increases in sea levels that could lead to flooding of low-lying areas by daily or monthly high tides. In areas with gradual sloping shorelines, such as beaches and marshes, sediments will erode as the high tide line advances landward and some of the intertidal zone will be permanently submerged. The New York City on Panel Climate Change projects that sea levels in New York City will rise between 4 and 11 inches by the 2020s and 11 and 31 inches by the 2050s.

EVENT-BASED HAZARDS



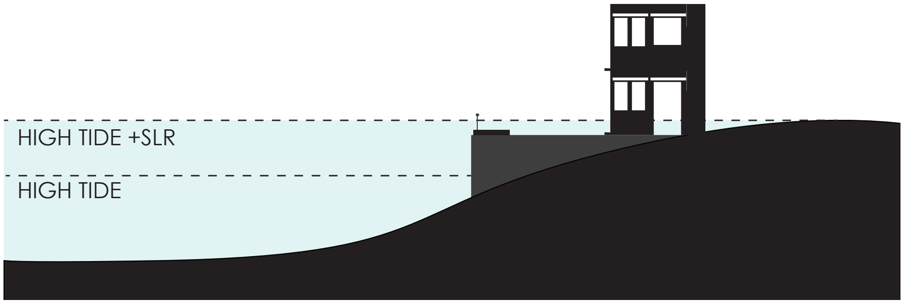
STORM SURGE FLOODING



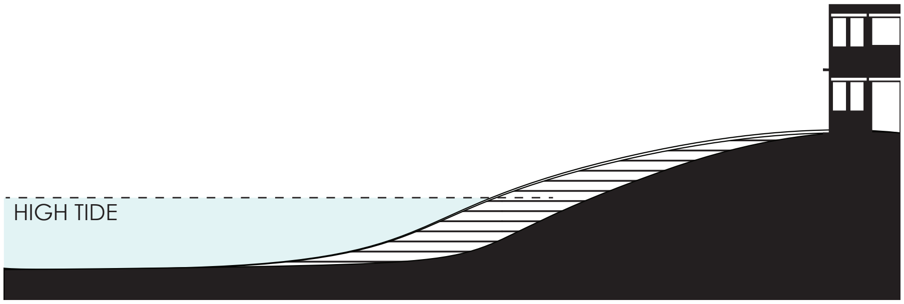
WAVE FORCE

SUDDEN EROSION

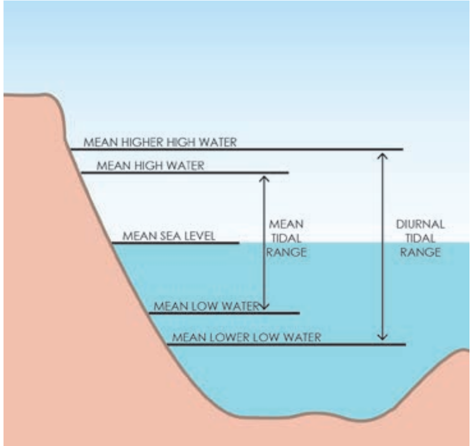
GRADUAL HAZARDS



HIGH TIDE FLOODING DUE TO SEA LEVEL RISE



GRADUAL EROSION



Tidal Range and Datums

Tides

Sea levels fluctuate daily due to gravitational forces and the orbital cycles of the Moon, Sun, and Earth. The following are specific datums, or vertical benchmarks in sea level that are commonly used to measure tides levels:

- **Mean Higher High Water** (MHHW): The average of the higher range of high water height of each tidal day observed over the National Tidal Datum Epoch, a 19-year period defined by the National Ocean Service as the official time segment for deriving mean values for tidal datums.
- **Mean High Water** (MHW): The average of all high water heights observed over the National Tidal Datum Epoch.
- **Mean Sea Level** (MSL): The arithmetic mean of hourly heights observed over the National Tidal Datum Epoch.
- **Mean Lower Low Water** (MLLW): The average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch.

Currents

Currents are movements of water created by tides, winds, or by the general circulation of the sea.

Waves

Ocean waves are the oscillating motion of a water surface. There are many types of waves, such as:

- **Breaking waves:** When a wave collapses or breaks because it can no longer support itself, it is a breaking wave. This typically occurs when waves reach shallow water.
- **Wind Waves**: Locally generated, wind-driven waves are called wind waves. The waves resulting from hurricanes and other storms are wind waves.
- **Swells**: Swells are wind-generated waves that have traveled beyond their origin area. They can be observed hundreds of miles beyond their starting point and are typically characterized by smoother, more uniform crests and a longer period between waves than wind waves.

Fetch

Fetch is the horizontal distance over which wave-generating winds blow. When areas have more fetch, such as those exposed to the open ocean, winds will generate larger waves.

Erosion

Erosion is the wearing away of land caused by waves and currents. Erosion can occur gradually over time; however, storm surge and wave action resulting from hurricanes and other coastal storms can accelerate erosion. Erosion can cause damage and increase the vulnerability of waterfront property to storm surge, as well as threaten natural resources.

Global Sea Level Rise

Sea levels rise and fall in localized areas due to a variety of forces. Global sea level rise is the mean rise in sea level over time attributed to climate change as global temperatures increase, seawater warms and expands, mountain glaciers melt, and ice sheets from Greenland and Antarctica melt and flow into the ocean. Sea level rise projections are based on multiple, complex scenarios of global temperature change and greenhouse gas emissions.

Hurricane

A hurricane is the strongest type of tropical cyclone, with wind speeds of 74 miles per hour or higher. “Hurricane” is a term commonly used in the Western Hemisphere, in the Atlantic and eastern Pacific. They are often known as “typhoons” or simply “cyclones” in the north and south Pacific, and Indian Oceans.

Tropical Storm

A tropical storm is a type of tropical cyclone with wind speeds ranging from 39 to 73 miles per hour. A tropical cyclone is a "warm core" low pressure system, meaning its center is warmer than its surroundings at any height in the atmosphere, distinguishing it from other types of cyclones. Tropical storms are characterized by thunderstorms that produce strong winds and heavy rain. They usually originate in tropical regions of the globe.

Nor'easter

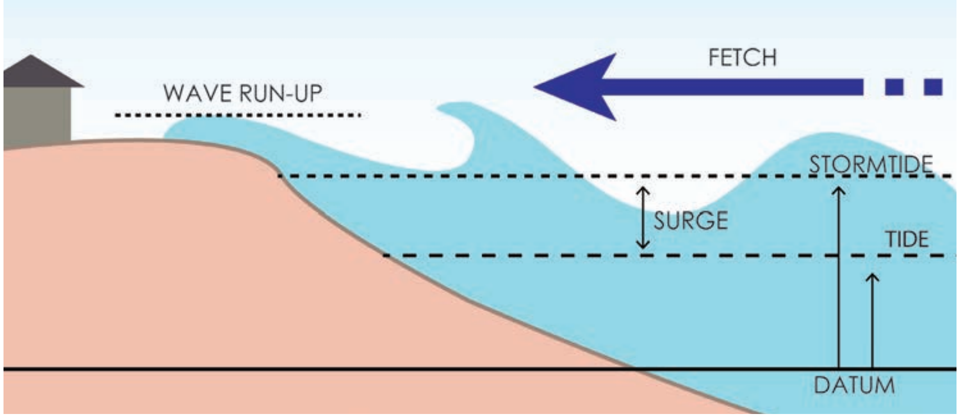
A Nor'easter is a strong low pressure system that typically affects Mid-Atlantic and New England states during the months of September through April, producing strong winds, heavy snow and rain, and large waves on Atlantic beaches. These storms commonly cause beach erosion and structural damage. The storm gets its name from the northeasterly winds that blow in from the ocean over coastal areas during the storm.

Storm Surge

Storm surge is a rise in coastal water level associated with a hurricane or other strong coastal storm above the level associated with normal astronomical tides. The storm surge height is the difference between the observed storm tide (see below) and the astronomic or normal tide. Surge is produced by a combination of low pressure and the force of winds associated with intense storm systems. When a storm approaches the land, the storm surge "piles up" and leads to coastal flooding. This is distinct from riverine flooding, or inland flooding from precipitation overwhelming the base flow capacity of a watershed's rivers and streams.

Storm Tide

Storm tide is the total water level due to a combination of storm surge and normal astronomical tide levels.



Storm Surge

Stillwater Flooding

One aspect of coastal flooding is the amount of "stillwater" flooding, or the rise in waters due to storm surge not including the height of waves.

Wave Run-up

Wave run-up refers to the vertical rush of water up the face of a beach, vertical surface, or sloping structure, measured as the height above the stillwater flood level that a wave will reach. Wave run-up thus causes flooding of land areas higher than the stillwater flood elevation.

Wave Action

Waves have characteristics and effects as they move inland from an ocean, bay, or other large body of water. Large, fast-moving waves can cause extreme erosion and scour, and their impact on buildings can cause severe damage.

Flood Impacts

The types of impacts flooding and waves have on structures can be classified into the following categories:

- **Debris Impact Load:** The impact from flotsam materials and objects carried by floodwaters. Debris may include tree trunks, fuel tanks, piers, building elements, boats, and barges.
- **Hydrostatic Force**: The force due to standing or slowly moving water created when flood levels are unequal on different sides of a structure. This can cause vertical buoyancy and flotation of structures.
- **Hydrodynamic Force:** The force from floodwaters moving at high velocity which exert frontal impact forces while creating drag along the sides and suction on the downstream side. High-velocity flows can destroy solid walls and dislodge inadequate foundations.
- **Scour:** Erosion created from water and wave action across unstable ground, combined with turbulence with foundation elements. Scour can impact a structure's lateral stability.
- **Uplift Force:** The force generated by waves beneath elevated structure such as a dock or pier lifting from pilings and beams.

Coastal communities manage risks from coastal hazards through a variety of mapping and regulatory tools.

Many public agencies, private companies and individuals within a coastal community have a role in managing risk from coastal hazards. Through the Federal Emergency Management Agency (FEMA), the U.S. federal government sets standards for floodplain management which are enforced through state and local regulations. Public and private development projects within the floodplain must adhere to these standards. The federal government also underwrites flood insurance which is purchased by private homeowners from private insurance companies.

National Flood Insurance Program (NFIP)

NFIP sets national building design and construction standards for new construction and substantial improvements (including buildings that have been substantially damaged) more than or equal to 50 percent of the value of the building in Special Flood Hazard Areas. NFIP underwrites flood insurance coverage only in communities that adopt and enforce floodplain regulations that meet or exceed NFIP criteria.

FEMA FIRM (Federal Emergency Management Agency Flood Insurance Rate Map)

FIRMs are FEMA's official maps of special flood hazard areas and risk premium zones for flood insurance applicable to a specific community. Flood zones shown on the map are geographic areas classified according to levels of flood risk, with each zone reflecting the severity and/or type of flooding.

- **V Zone:** Areas along coasts subject to inundation by the 1 percent annual chance flood event with additional hazards associated with storm-induced waves over 3 feet high.
- **Coastal A Zone:** Areas landward of a V Zone or landward of an open coast without a mapped V-Zone, subject to inundation by the 1 percent annual chance flood event with additional hazards associated with storm-induced waves between 1.5 and 3 feet high. (These zones are not mapped in the 2007 effective FEMA FIRMs, but are included in the Preliminary Work Maps and will be included in future FEMA FIRMs for the New York Region.)
- **A Zone:** Areas subject to inundation by the 1 percent annual chance flood event without wave action. Mandatory flood insurance purchase and floodplain management standards apply.
- **B/X (shaded) Zone:** Areas of moderate flood hazard subject to inundation by the 0.2 percent annual change flood event. Also called the 500 year flood zone.

FEMA Special Flood Hazard Areas (SFHA)

The SFHA is the portion of the floodplain subject to a 1 percent or greater change of inundation by the base flood, designated Zone A, AE, V, VE on a FIRM. Mandatory flood insurance purchase requirements and floodplain management standards apply. It is also called the 100 year flood zone or the base flood.

Base Flood Elevation (BFE)

The BFE is the computed elevation in feet to which floodwater is anticipated to rise during the base flood, or the 1 percent annual chance storm. It is the regulatory requirement for the elevation or floodproofing of structures. A building's flood insurance premium is determined by the relationship between the BFE and a structure's elevation. BFE includes the storm tide elevation plus the wave crest height.

Freeboard

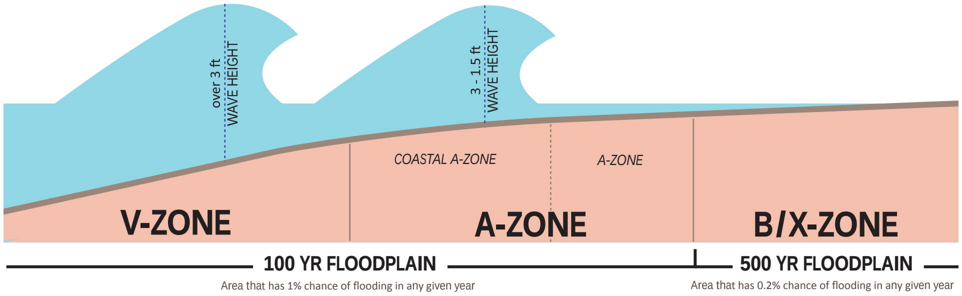
Freeboard is an additional amount of height above the BFE to provide an additional factor of safety. Freeboard, which in some cases is required through building code, provides an added margin of safety to address the flood modeling and mapping uncertainties associated with FIRMs. Since elevations on FIRMs do not include sea level rise, freeboard can help keep structures above floodwaters as storm surge elevations increase. Recognizing that freeboard reduces flood risk, FEMA provides substantial reductions in flood insurance premiums for structures incorporating freeboard.

Design Flood Elevation (DFE)

The elevation above the BFE including the height of freeboard.

North American Vertical Datum of 1988 (NAVD88)

NAVD88 is a vertical control datum of land elevation above sea level established for surveying in North America. Mean sea level varies by location, but by using this datum, which establishes a fixed point of mean sea level, elevations of different locations can be compared to one another. NAVD88 replaced the National Geodetic Vertical Datum on 1929 (NGVD29).



FEMA FIRM Designations

FEMA Advisory Base Flood Elevation

Following severe flood events, FEMA creates Advisory Base Flood Elevations (ABFEs) to show a more current picture of flood risk for certain affected communities. Following Hurricane Sandy, the known flood risk has changed since the last effective community Flood Insurance Rate Map (FIRM) for many communities in New Jersey and New York. The Advisory information can help communities better understand current flood risks and ensure structures are rebuilt stronger and safer to reduce the impact of similar events in the future. Adopting standards based on Advisory information will not change current flood insurance rates within a community. Flood insurance policies are rated using the zones and flood elevations on the current effective FIRM.

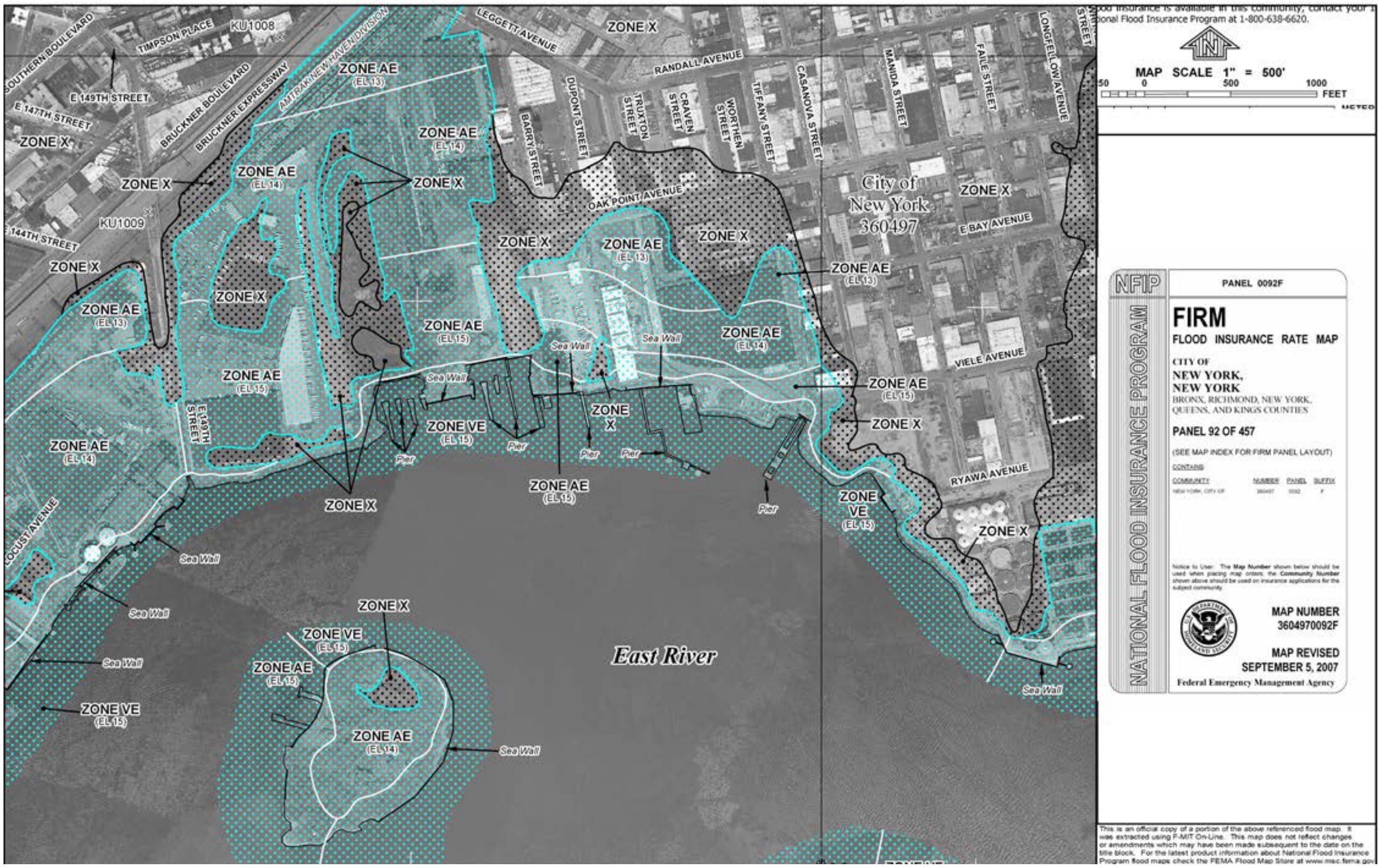
FEMA Preliminary Work Maps

The Preliminary Work Maps are an interim step in the process of developing updated Flood Insurance Rate Maps (FIRMs) for New York City. They are considered the best available data until FEMA releases the Preliminary FIRMs. The Preliminary FIRMs are maps to allow for public review of flood hazard risk before the issuance of effective FIRMs.

Hurricane Evacuation Zones

The NYC Office of Emergency Management designates areas of the city potentially subject to storm surge into different Hurricane Evacuation Zones based on how storms will affect them. The mapping of these zones is based on a different storm modeling system than the FEMA FIRMs.

Example FIRM Panel (Effective 2007 FIRM)



Source: FIRMETTE, FEMA Map Service Center

South Shore, Staten Island following Sandy

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Credit: Hudson River Park Trust

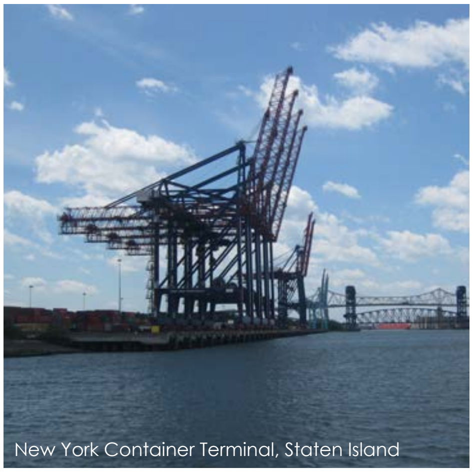
PART II

COASTAL AREA TYPOLOGY ANALYSIS

New York City's 520 miles of waterfront are incredibly diverse. Each of these areas face specific types and levels of risks, and therefore require different strategies.

New York City is highly vulnerable to coastal hazards due to both its geography and its density of population and infrastructure. In addition, different areas of the coast are vulnerable in different ways due to variation in geography and land use. There are the dense commercial and residential areas along the Hudson and East Rivers, industrial districts along the Long Island Sound and Upper Bay, residential neighborhoods along oceanfront beaches, and stretches of coastal marshland, just to name a few. Each of these areas faces unique risks and demand different types of strategies to make them more resilient to coastal hazards and increasing risks due to climate change.


Credit: NYC DPR
Pelham Bay Lagoon, The Bronx


New York Container Terminal, Staten Island


Riverside Park South, Manhattan


Rockaway Peninsula, Queens

To understand the range and nature of hazards and vulnerabilities throughout the city, this study set out to develop a set of coastal area typologies representative of the range of conditions found in New York City that would reflect the metropolitan region as well. The 520 miles of shoreline within New York City were analyzed through two distinct lenses: coastal geomorphology, or the physical landforms that relate to coastal processes, and the built environment, or the uses and their density that are found throughout the coastal zone. The coastal geomorphology is a composite of the glacial landforms, slope, elevation, shoreline condition and wave exposure which together depict the exposure of a given reach to the coastal hazards identified: event-based storm surge, wave forces, and erosion, and gradual flooding and erosion due to sea level rise. Land uses and density, including the types of uses, functions, infrastructure, and populations, are a measure of an area's vulnerability to the coastal hazards that are present. This gives an indication of the magnitude of the consequences should the area be impacted by a coastal storm or gradual sea level rise.

This analysis identified nine types of geomorphology and eight types of land use. The geomorphology types vary in terms of the degree and nature of exposure to different coastal hazards, for instance whether or not there are significant wave forces and how high potential flooding is likely to be. The land use types range from open space, to lower-density residential areas, to medium density areas with a mix of uses, to high density commercial areas. Nine combinations of land use and geomorphology that were commonly found in New York City and which represented a range of conditions were chosen. These resulting "coastal area typologies" are presented to understand the nature and extent of risk from coastal hazards and what sort of strategies would be most suitable and effective.

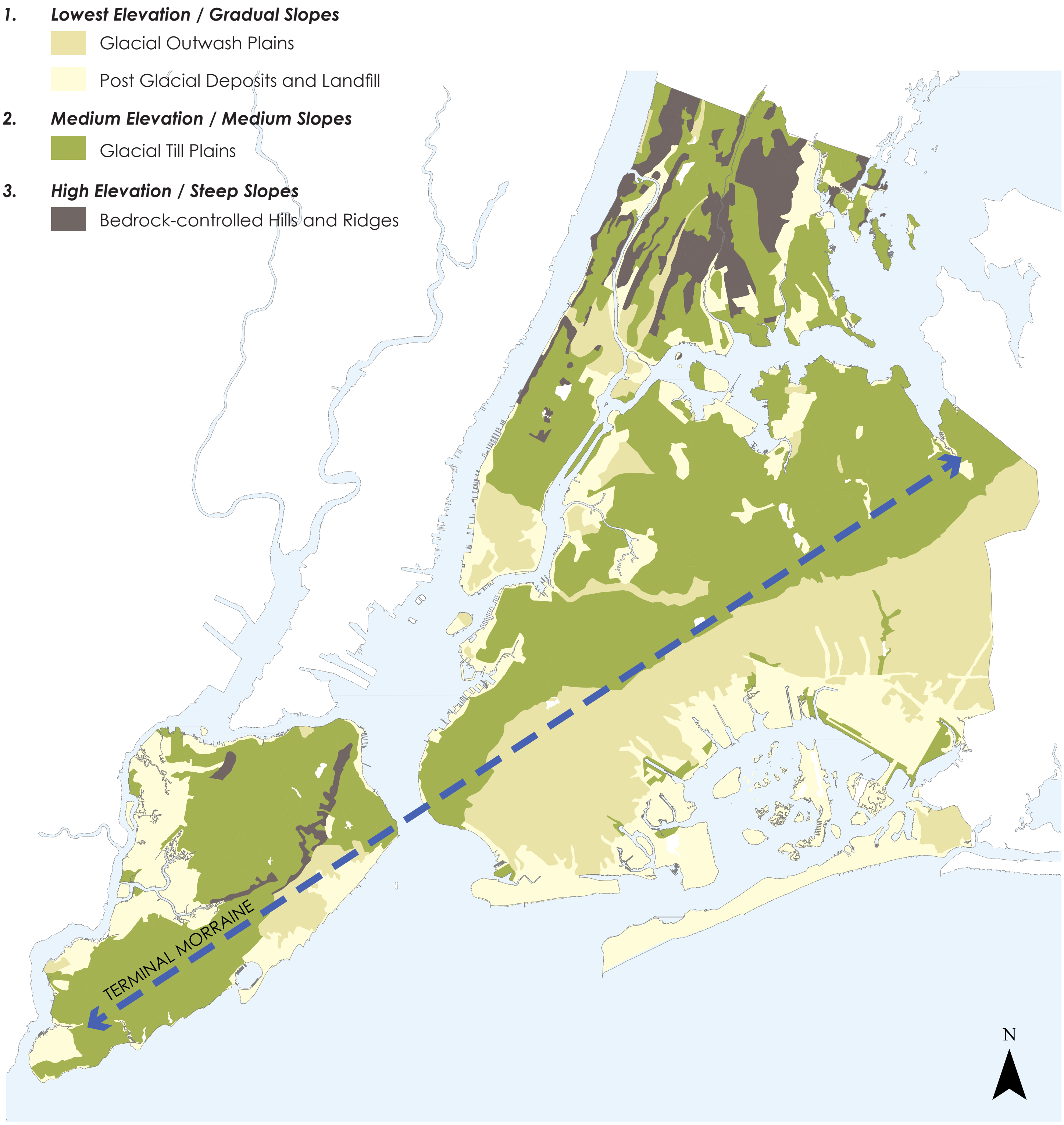
Coastal Geomorphology Mapping

Coastal geomorphology is the study of coastal features and landforms and the processes that have shaped them over time and continue to alter them. For the purposes of this report, geomorphology is a lens to examine the physical characteristics of a coastal area irrespective of its land use that influences both an area's exposure to coastal hazards and what type of adaptations may be feasible there, for instance, where expanded beaches and dunes would be feasible. The following factors were mapped and analyzed in order to develop a set of types representative of different ranges in geomorphological conditions. Each is explored in depth on the following pages.

- **Geologic Landforms:** These are the base geologic landform as shaped by underlying bedrock, glacial processes, and the filling of water and wetlands over the city's history. These landforms vary greatly in terms of elevation and slope, and are a relevant indicator to how exposed an area is to inundation from storm surge and gradual sea level rise.
- **Shoreline Condition:** Shorelines are either "soft," meaning they are marshy or sandy with little reinforcement, or "hardened," meaning they have been reinforced with structural elements such as rock, concrete, and/or sheet pile. Soft shorelines are more vulnerable to erosion, though also present numerous benefits in terms of public access and ecological function.
- **Exposure to Wave Forces:** The geography of a coastline, and whether or not it is exposed to the open ocean or is on a narrow creek or inlet, can determine how exposed an area is to destructive wave forces that erode shorelines and can cause significant damage in the event of a coastal storm.

GEOLOGIC LANDFORMS

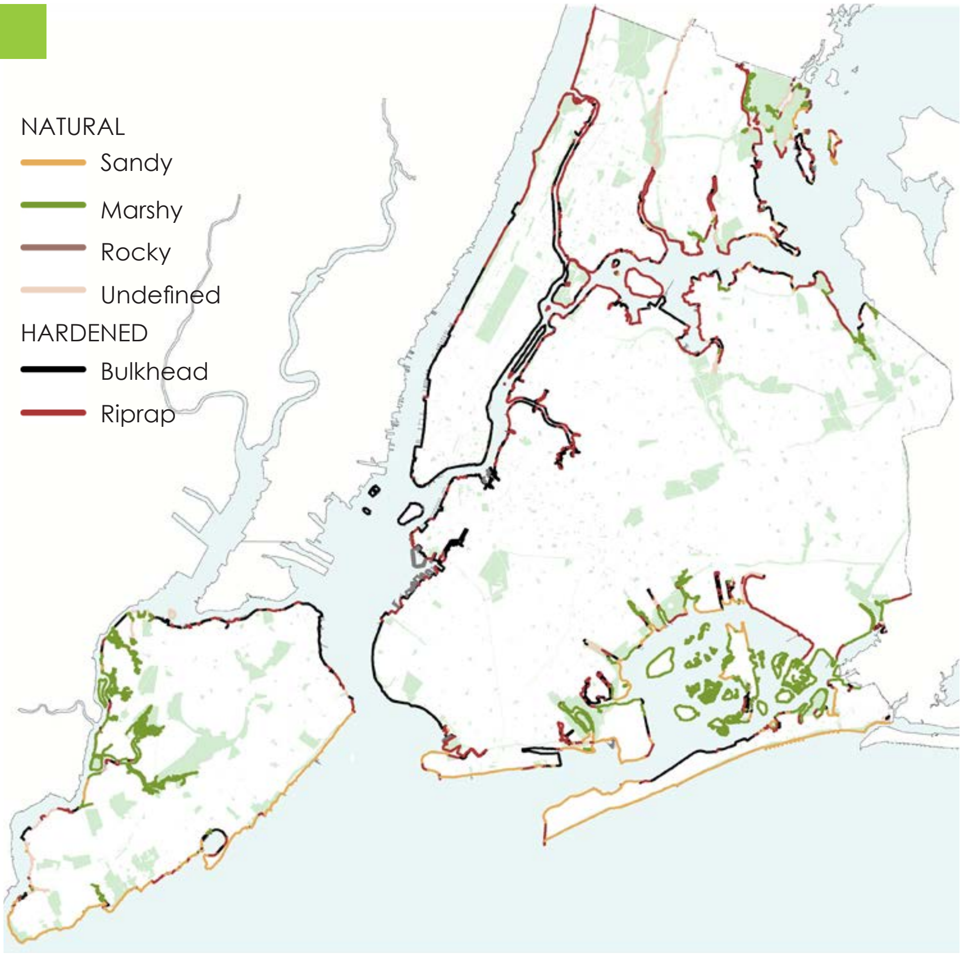
The Wisconsin Ice Sheet was a giant glacier that stretched from Canada to New York City. It is estimated it reached New York City about 20,500 years ago, and began its retreat about 18,000 years ago. The glacier ground up rock as it traveled south and carried chunks of gravel, pebbles, and sand with it. When the glacier began to melt, this rock debris was deposited at its southernmost end, forming the "terminal moraine," the hilly area of the city that stretches through Staten Island and Central Brooklyn/Queens. Streams from the melting glacier carried deposits of sand, silt, and clay which formed today's "outwash plains," the low-lying areas of the city in Staten Island's East Shore and South Brooklyn and Queens. This is relevant to coastal hazard vulnerability because these low-lying areas are generally more vulnerable to surge and gradual sea level rise. Other areas of the city, largely in Northern Manhattan and the Bronx are generally higher in elevation, due to the presence of bedrock closer to the earth's surface. These areas are generally less vulnerable to flooding and sea level rise due to their elevation. Geologic landforms can be broken down into three basic categories:



Source: New York City Soil Survey Staff. 2005. New York City Reconnaissance Soil Survey. United States Department of Agriculture, Natural Resources Conservation Service, Staten Island, NY.

SHORELINE CONDITION

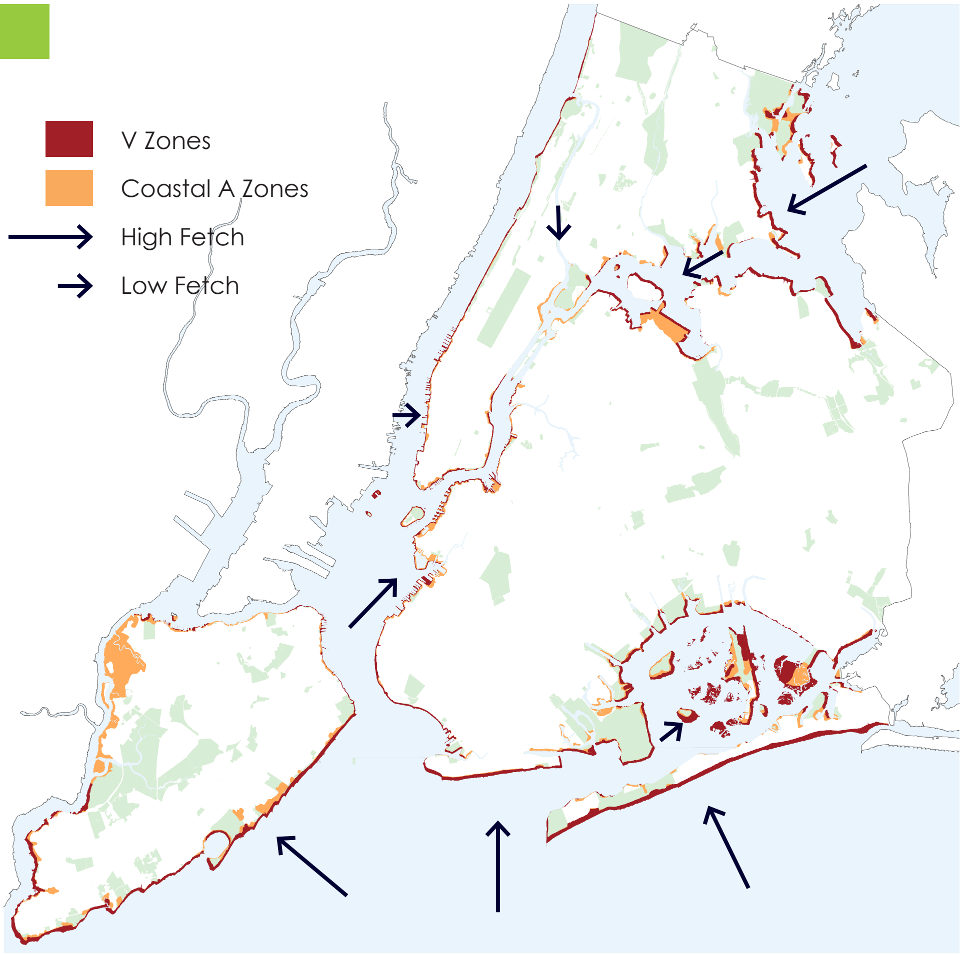
Shorelines can be characterized as either natural edges or hardened edges. Natural, or "soft," edges may be human-constructed, but also may exist where the shoreline is composed primarily of materials such as sand, mud, vegetation, and naturally-occurring rock. Hardened edges are those that have been reinforced with bulkhead or rip-rap to control erosion. Soft shorelines are most vulnerable to erosion, which could lead to the loss of land directly inland of the shoreline during a severe storm.



Source: DCP, 2011. Based off of interpretation of aerial imagery.

EXPOSURE TO WAVE FORCE

Areas of the city exposed to the open ocean have very large "fetch," meaning there is a great distance to any adjacent shoreline and ocean-going waves can generate extensive energy before breaking on the shores. The large waves along the Atlantic oceanfront are daily evidence of this. In the event of a storm, these areas experience much larger and more destructive waves than other areas. In places that are more sheltered from the open ocean, or have shorter fetch, such as bays, harbors, inlets, and creeks, the narrowing of the water body means that major waves are generally smaller and carry less force. The strength and direction of waves is highly dependent on a variety of factors for each storm, including storm track, speed, and winds. FEMA's flood maps identify V zones and Coastal A zones through modeling potential storms to identify areas where the 1 percent annual chance storm will likely be accompanied with wave action. The V zone is mapped in areas where wave hazards are most pronounced. The Coastal A zones are areas that will likely see waves of 1.5-3 feet .



Source: FEMA Preliminary Work Maps, June 2013.

COASTAL GEOMORPHOLOGY CATEGORIES

Based on the mapping of geologic landforms, shoreline condition, and wave exposure, nine geomorphology types emerged as representative of the range of factors present in New York City. Each type is a composite of these three factors. These types can be analyzed for their degree of exposure to sudden and gradual coastal hazards.

🟩 **Oceanfront Beaches**
Glacial outwash plains, High fetch,
Low elevation / gradual slopes,
Unreinforced shorelines, Fine sediment

⬛ **Hardened Oceanfront Plains**
Glacial outwash plains, High fetch,
Low elevation / gradual slopes,
Reinforced shorelines, Fine sediment

🟩 **Coastal Marshes**
Glacial outwash plains, Low fetch,
Low elevation / gradual slopes,
Unreinforced shorelines, Fine sediment

🟩 **Hardened Sheltered Bay Plains**
Glacial outwash plains, Low fetch,
Low elevation / gradual slopes,
Reinforced shorelines, Fine sediment

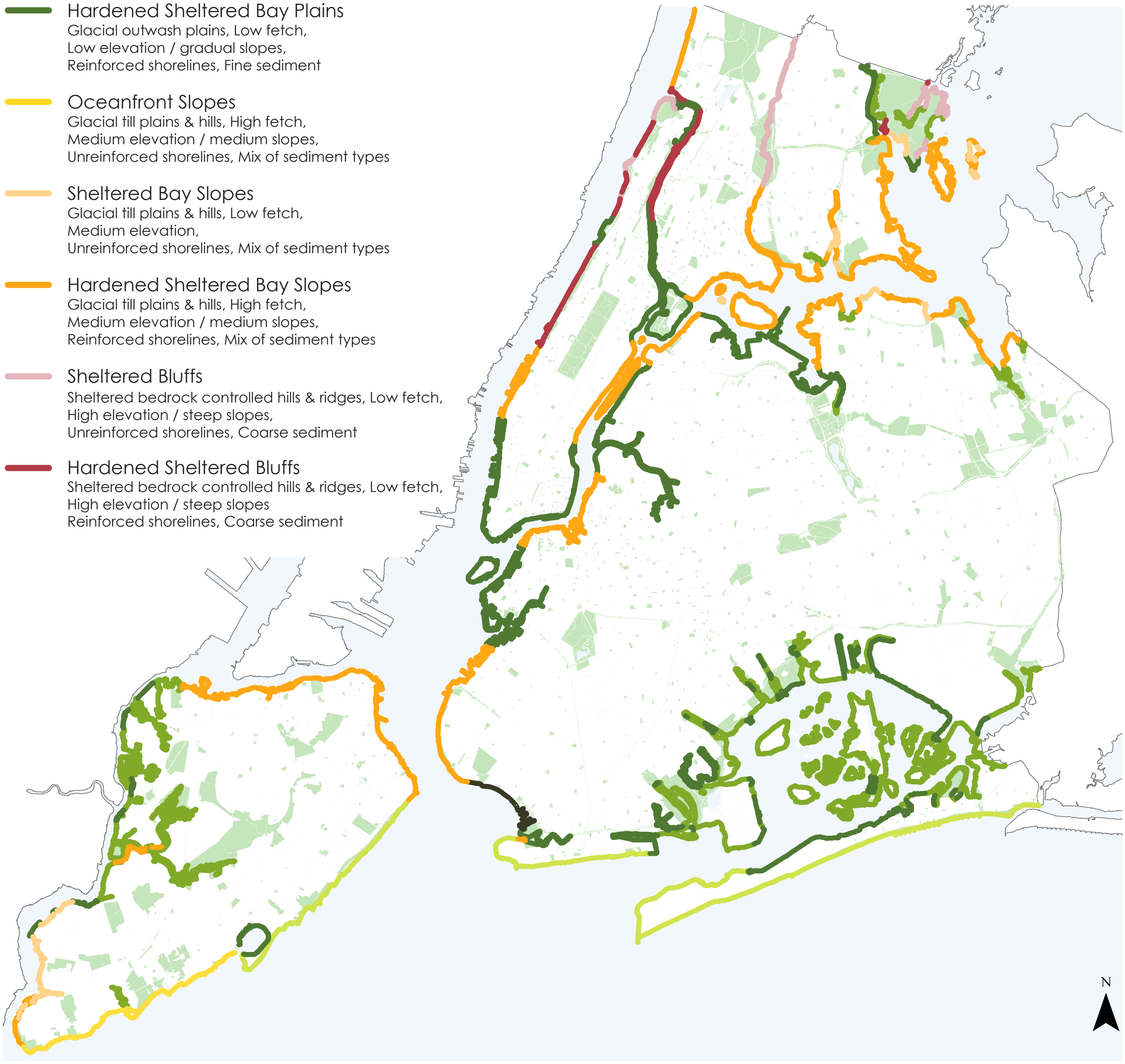
🟨 **Oceanfront Slopes**
Glacial till plains & hills, High fetch,
Medium elevation / medium slopes,
Unreinforced shorelines, Mix of sediment types

🟧 **Sheltered Bay Slopes**
Glacial till plains & hills, Low fetch,
Medium elevation,
Unreinforced shorelines, Mix of sediment types

🟧 **Hardened Sheltered Bay Slopes**
Glacial till plains & hills, High fetch,
Medium elevation / medium slopes,
Reinforced shorelines, Mix of sediment types

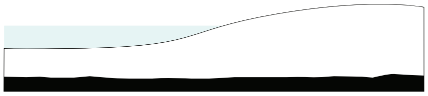
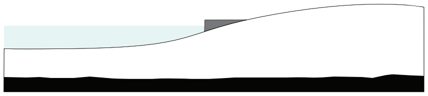
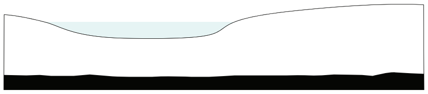
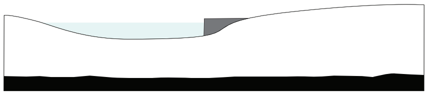
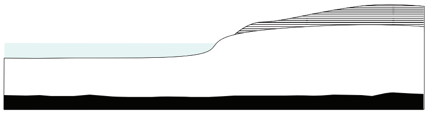
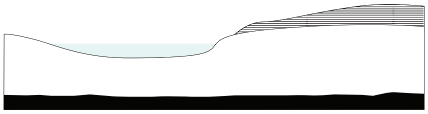
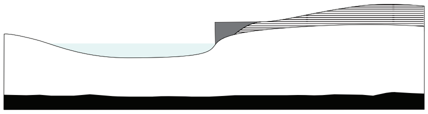
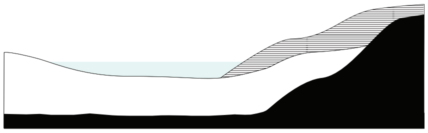
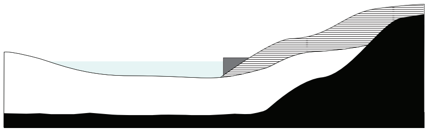
🟪 **Sheltered Bluffs**
Sheltered bedrock controlled hills & ridges, Low fetch,
High elevation / steep slopes,
Unreinforced shorelines, Coarse sediment

🟥 **Hardened Sheltered Bluffs**
Sheltered bedrock controlled hills & ridges, Low fetch,
High elevation / steep slopes
Reinforced shorelines, Coarse sediment



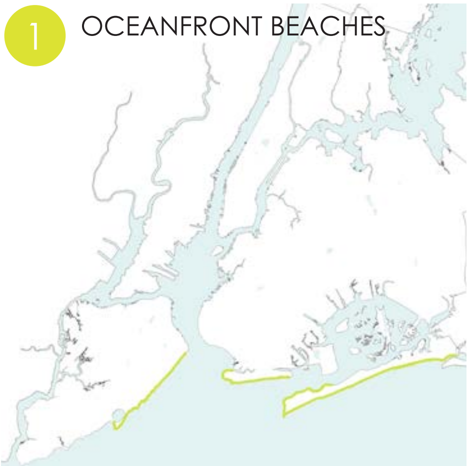
GEOMORPHOLOGY CATEGORIES

● HIGH ◐ MEDIUM ○ LOW

	DEGREE OF EXPOSURE TO COASTAL HAZARDS				
	EVENT BASED			GRADUAL	
	Storm Surge	Wave Action	Sudden Erosion	Sea Level Rise	Erosion
1  Oceanfront Beaches	●	●	●	●	●
2  Hardened Oceanfront Plains	●	●	◐	●	○
3  Coastal Marshes	●	○	○	●	●
4  Hardened Sheltered Bay Plains	●	○	○	●	○
5  Oceanfront Slopes	◐	●	●	◐	●
6  Sheltered Bay Slopes	◐	○	○	◐	◐
7  Hardened Sheltered Bay Slopes	◐	○	○	◐	○
8  Sheltered Bluffs	○	○	○	○	◐
9  Hardened Sheltered Bluffs	○	○	○	○	○

▤ Till plains / Hills ▨ Outwash plains / Post glacial deposits ■ Bedrock

1 OCEANFRONT BEACHES



Seagate, Brooklyn

2 HARDENED OCEANFRONT PLAINS

Gravesend Bay, Brooklyn

3 COASTAL MARSHES

Broad Channel, Queens

4 HARDENED SHELTERED BAY PLAINS

Newton Creek, Brooklyn

5 OCEANFRONT SLOPES

South Shore, Staten Island

6 SHELTERED BAY SLOPES

Hutchinson River, The Bronx

7 HARDENED SHELTERED BAY SLOPES

Whitestone, Queens

8 SHELTERED BLUFFS

Northern Manhattan

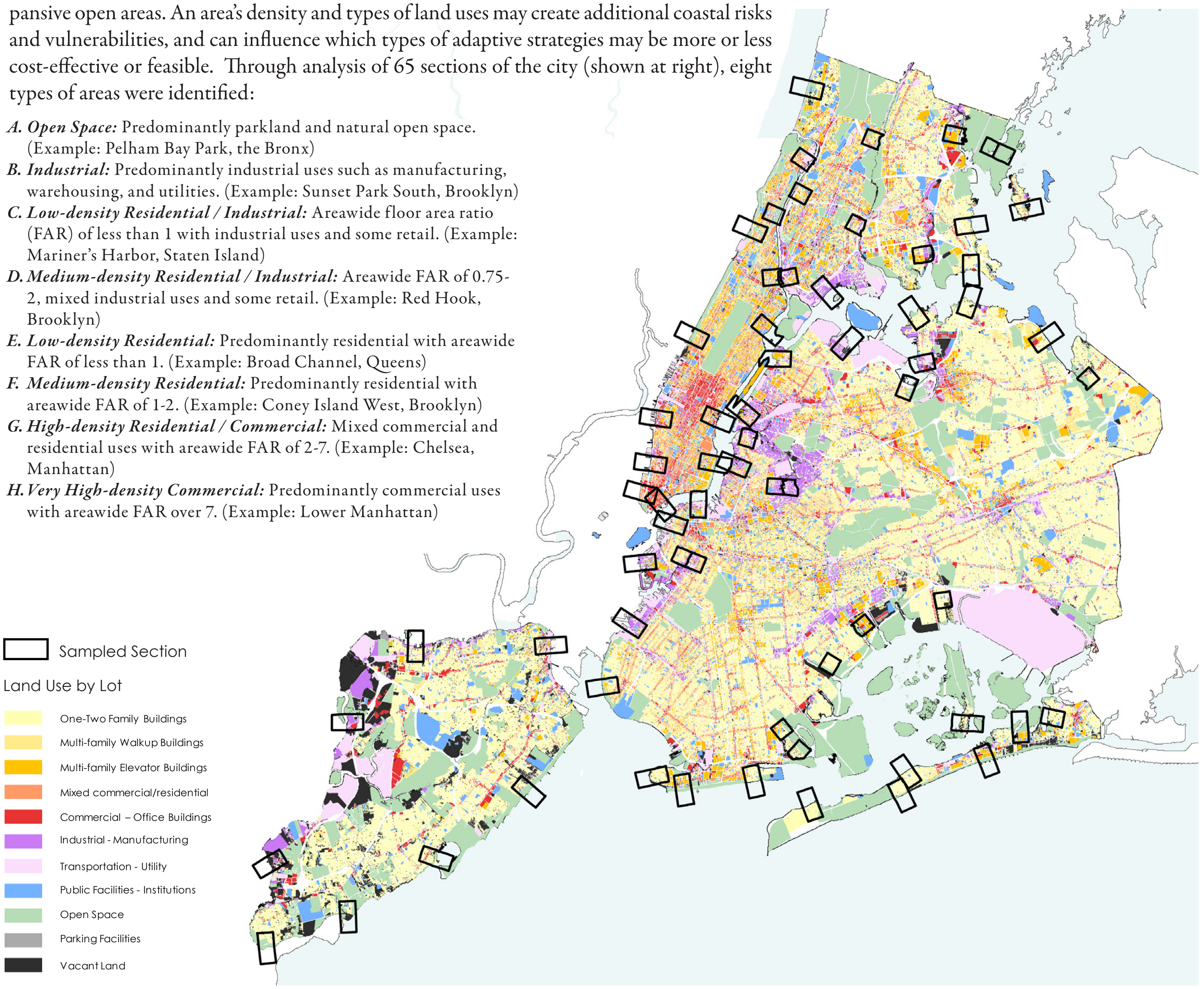
9 HARDENED SHELTERED BLUFFS


Riverside Park, Manhattan

COASTAL LAND USE & DENSITY

New York City's land use is also incredibly diverse throughout its coastal zone. Although the city is home to some of the densest settlement and largest commercial districts in the country, there are also many low-rise residential neighborhoods, industrial districts, and expansive open areas. An area's density and types of land uses may create additional coastal risks and vulnerabilities, and can influence which types of adaptive strategies may be more or less cost-effective or feasible. Through analysis of 65 sections of the city (shown at right), eight types of areas were identified:

A. ***Open Space:*** Predominantly parkland and natural open space. (Example: Pelham Bay Park, the Bronx)
B. ***Industrial:*** Predominantly industrial uses such as manufacturing, warehousing, and utilities. (Example: Sunset Park South, Brooklyn)
C. ***Low-density Residential / Industrial:*** Areawide floor area ratio (FAR) of less than 1 with industrial uses and some retail. (Example: Mariner's Harbor, Staten Island)
D. ***Medium-density Residential / Industrial:*** Areawide FAR of 0.75-2, mixed industrial uses and some retail. (Example: Red Hook, Brooklyn)
E. ***Low-density Residential:*** Predominantly residential with areawide FAR of less than 1. (Example: Broad Channel, Queens)
F. ***Medium-density Residential:*** Predominantly residential with areawide FAR of 1-2. (Example: Coney Island West, Brooklyn)
G. ***High-density Residential / Commercial:*** Mixed commercial and residential uses with areawide FAR of 2-7. (Example: Chelsea, Manhattan)
H. ***Very High-density Commercial:*** Predominantly commercial uses with areawide FAR over 7. (Example: Lower Manhattan)



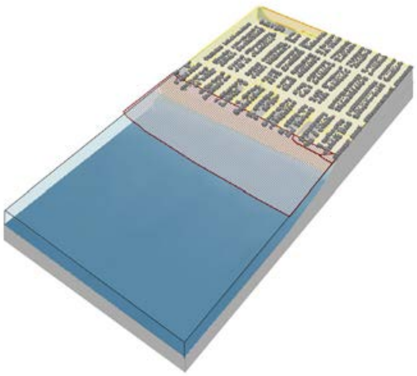
Source: PLUTO, Department of City Planning

COASTAL AREA TYPOLOGIES

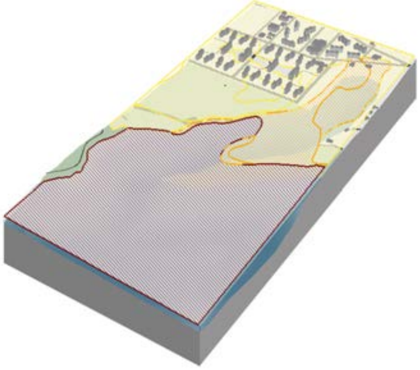
The following nine "Coastal Area Typologies" represent a range of geomorphology and land use conditions. The diagrams are based on actual areas in New York City that were selected based on their coastal geomorphology and land use, but are meant to be representative of a type of area. See appendix for a matrix showing full list of coastal geomorphology type, land use types, and example neighborhoods that drove this selection. This selection is not meant to be exhaustive of the types of coastal areas that exist throughout the city and region, but rather to serve as points of reference to analyze variation in coastal hazard exposure and land use factors, and how to identify an area's vulnerabilities, risk, and potential strategies. On the following pages, each typology is further described in terms of land use and density, as well as coastal hazard exposure. Flood elevations for today's 1 percent annual chance storm and a potential future flood elevation due to level rise are shown, along with current and future high tides. This information is based on data from FEMA, the New York City Panel on Climate Change, and NOAA's Center for Operational Oceanographic Products and Services. It is shown here to be illustrative of the range of current and future conditions within the city's coastal zone. For more information on how to use these typologies in order to identify potential strategies and evaluate their costs and benefits, see Part 4 of this report.

FLOOD ZONES
▨ V Zone
▨ Coastal A Zone
▨ A Zone

Source: FEMA Preliminary Work Maps, June 2013.



OCEANFRONT BEACHES
LOW DENSITY RESIDENTIAL



COASTAL MARSHES
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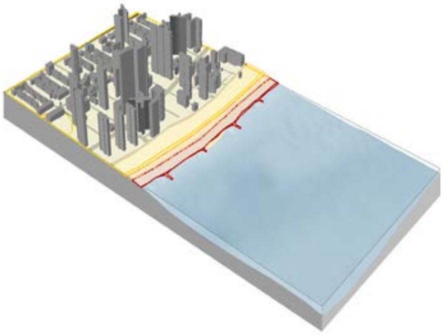

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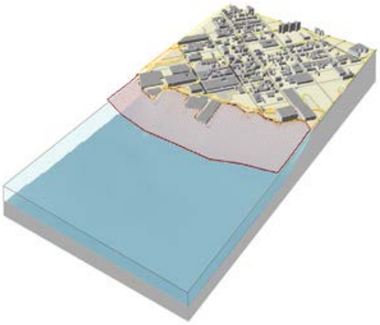

HARDENED SHELTERED BAY PLAINS
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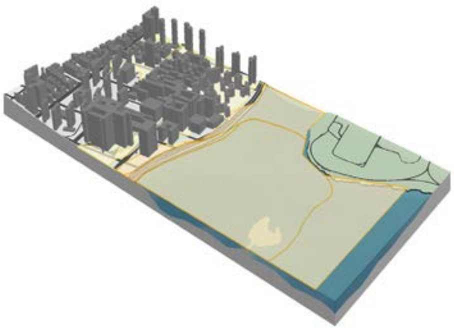
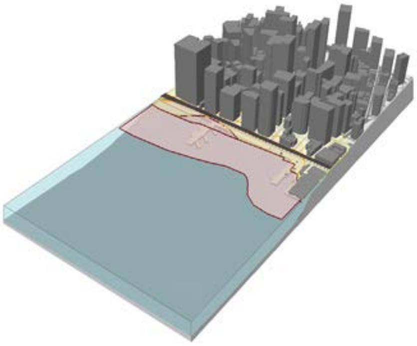
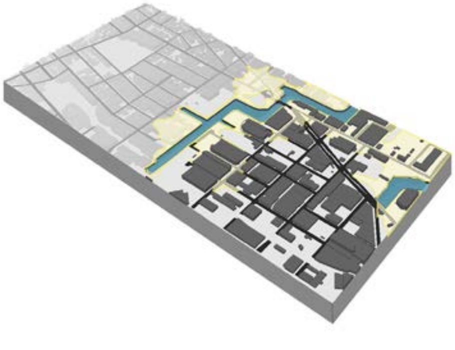


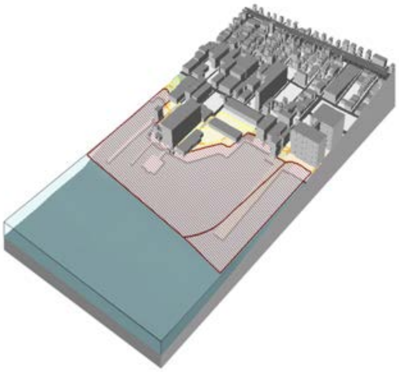
HARDENED SHELTERED BAY PLAINS
MEDIUM DENSITY RESIDENTIAL



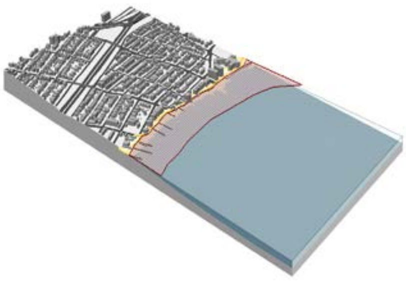
HARDENED SHELTERED BAY PLAINS
VERY HIGH DENSITY COMMERCIAL



HARDENED SHELTERED BAY PLAINS
INDUSTRIAL

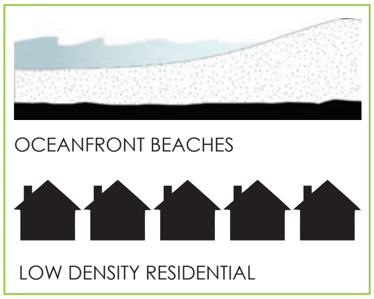


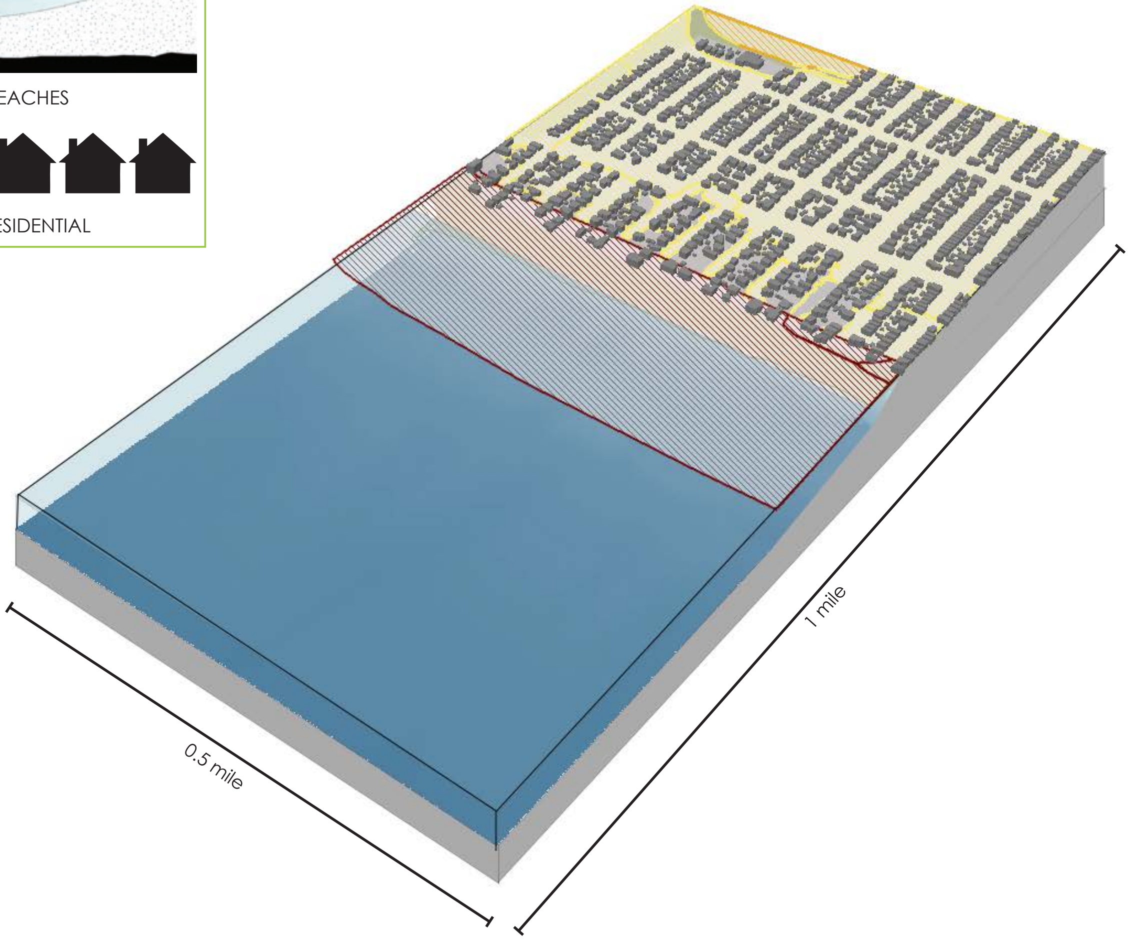
HARDENED SHELTERED BAY SLOPES
INDUSTRIAL

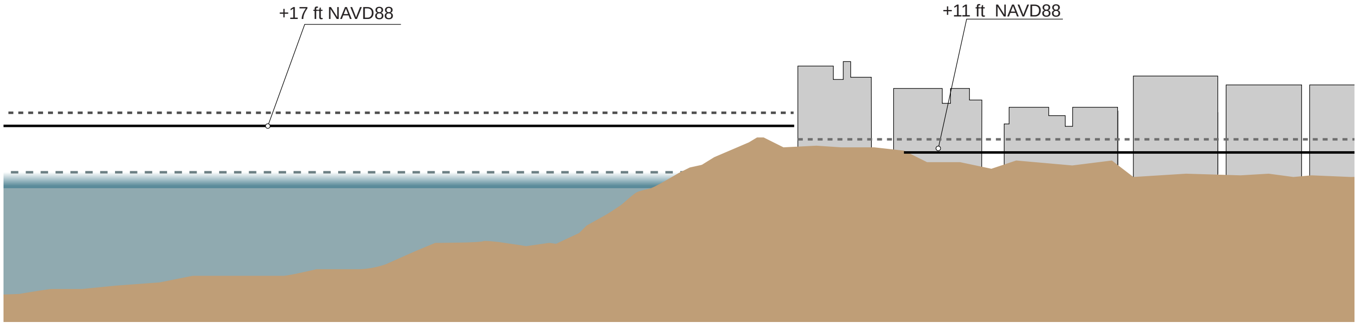


HARDENED SHELTERED BAY SLOPES
LOW DENSITY RESIDENTIAL

OCEANFRONT BEACHES / LOW DENSITY RESIDENTIAL







LAND USE / DENSITY FACTORS

Building Types	1-2 story Detached Homes 1-2 story Semi-detached Homes Community Facilities
Open Space	Beach Neighborhood Park
Infrastructure	Roads
Built Area	1.7 M ft² Floor Area 1 M ft² Ground Floor Area
Land Area	7 M ft² Total Land Area 3.9 M ft² Total Lot Area (excluding water)
Density	0.5 Dwelling Units Per Acre 0.45 FAR[1]

HAZARD EXPOSURE

EVENT-BASED	Storm Surge (High)	●
	Storm Surge (Low)	●
	Wave Force	●
	Sudden Erosion	●
GRADUAL	Frequent Flooding due to Sea Level Rise	◐ [2]
	Gradual Erosion	◐

FLOOD ZONES[3]

▨	V Zone
▨	Coastal A Zone
▨	A Zone

FLOOD LEVELS[4]

········	Future Base Flood Elevation
———	Current Base Flood Elevation

SEA LEVELS[4]

- - - -	Future High Tide
▬	High Tide

---

[1] FAR based on total floor area over total lot area, excluding open space, vacant, and unknown land uses.

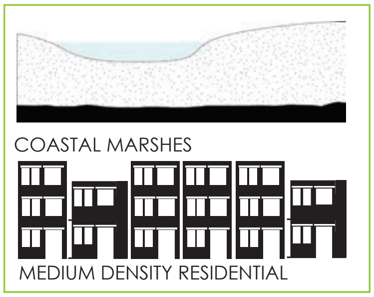
[2] The beach may be regularly inundated due to increasing sea level rise, but developed areas are on ground above the expected heights of sea level rise.

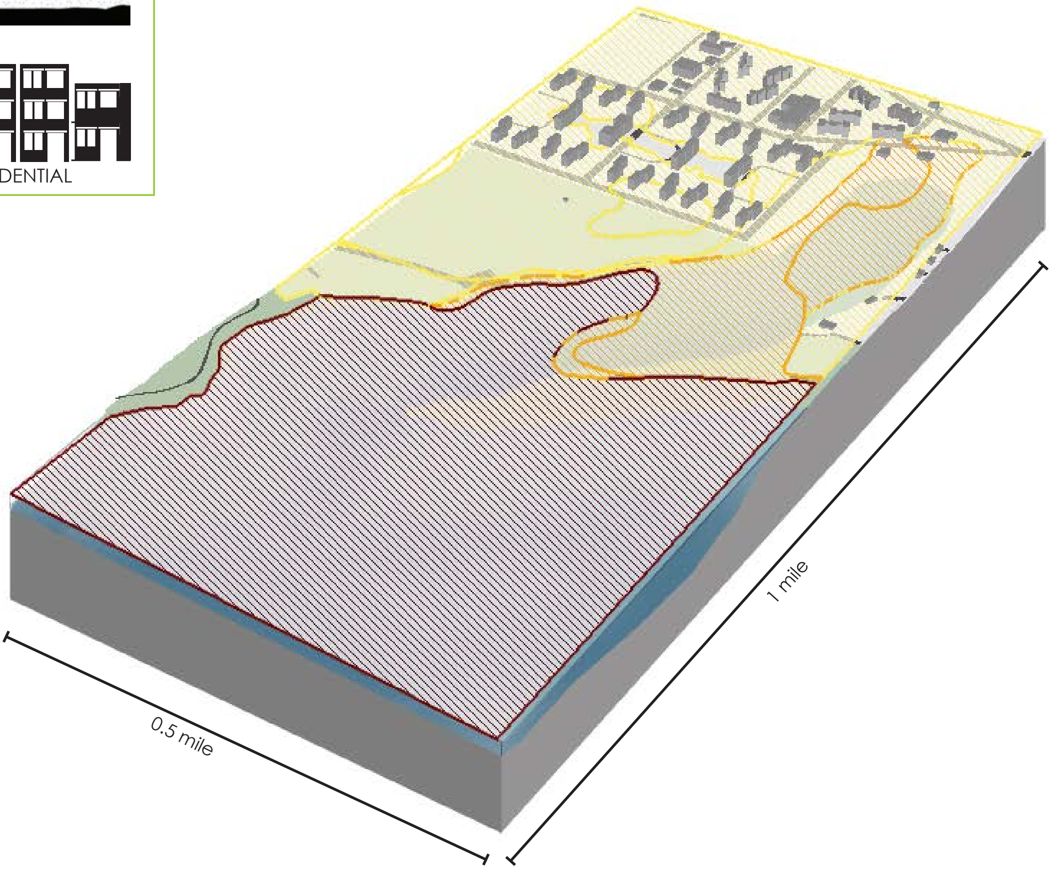
[3] Source: FEMA Preliminary Work Maps, June 2013

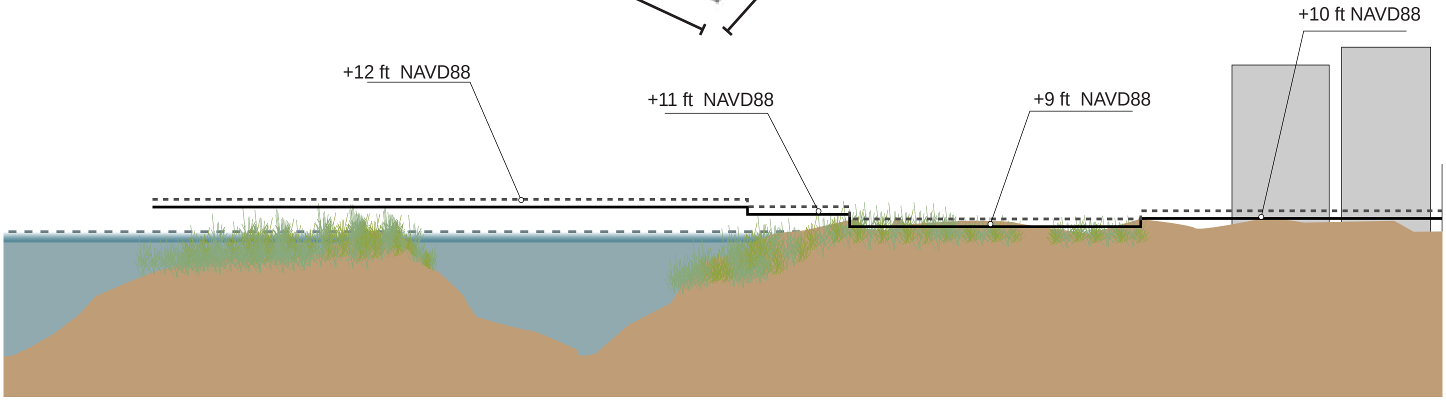
[4] Source: NPCC, 90th Percentile Projections, 2013

* Vertical exaggeration in sections

COASTAL MARSHES / MEDIUM DENSITY RESIDENTIAL







LAND USE / DENSITY FACTORS

Building Types	High-Rise Residential Buildings Low-Rise Commercial Buildings Community Facilities Marinas
Open Space	Wetlands Active Recreation parkland Unimproved parkland
Infrastructure	Roads
Built Area	2 M ft² Floor Area 400,000 ft² Ground Floor Area
Land Area	7.5 M ft² Total Land Area 2.8 M ft² Total Lot Area (excluding water)
Density	13 Dwelling Units Per Acre 0.75 FAR[1]

HAZARD EXPOSURE

EVENT-BASED	Storm Surge (High)	●
	Storm Surge (Low)	●
	Wave Force	○
	Sudden Erosion	◐
GRADUAL	Frequent Flooding due to Sea Level Rise	◐
	Gradual Erosion	●

FLOOD ZONES[2]

▤	V Zone
▤	Coastal A Zone
▤	A Zone

FLOOD LEVELS[3]

....	Future Base Flood Elevation
———	Current Base Flood Elevation

SEA LEVELS[3]

- - - - -	Future High Tide
▬	High Tide

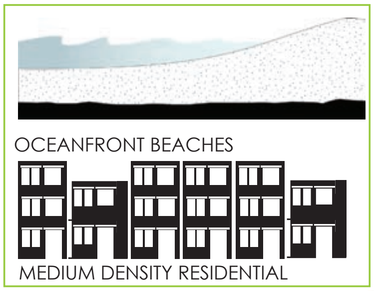
---

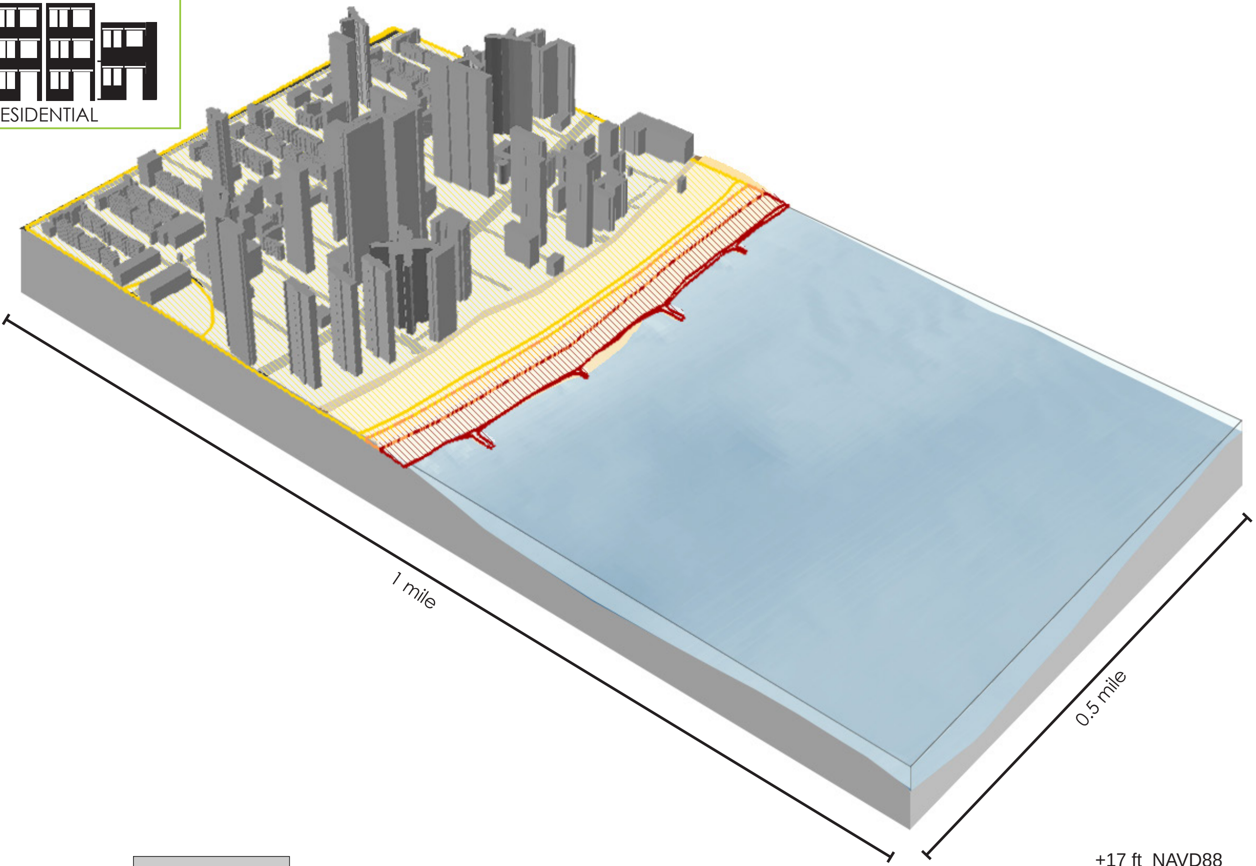
[1] FAR based on total floor area over total lot area, excluding open space, vacant, and unknown land uses.

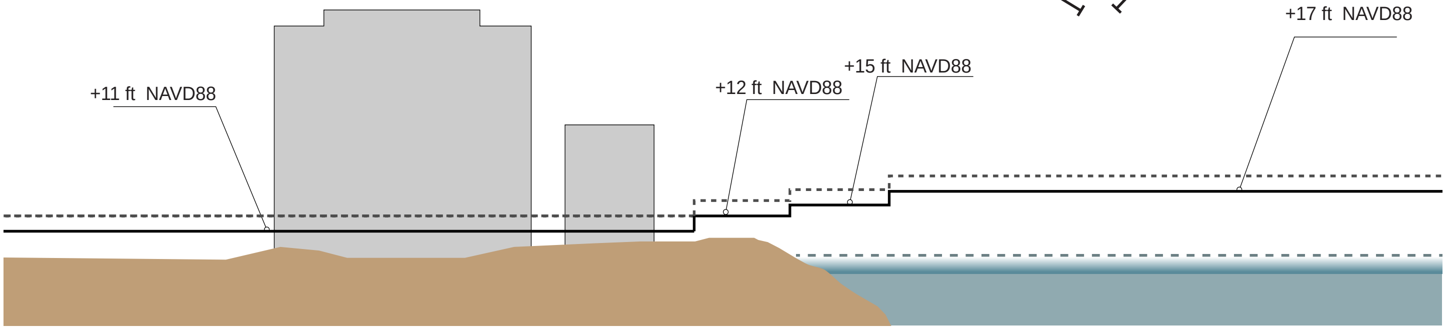
[2] Source: FEMA Preliminary Work Maps, June 2013

[3] Source: NPCC, 90th Percentile Projections, 2013

OCEANFRONT BEACHES / MEDIUM DENSITY RESIDENTIAL







LAND USE / DENSITY FACTORS

Building Types	Low-rise Commercial Buildings 3-5 story Mixed-use Buildings 2-4 story Residential Attached High-rise Residential Buildings Nursing Homes
Open Space	Parking, Neighborhood Parks, Athletic Fields, Beach
Infrastructure	Roads, Boardwalk, Elevated Subway, Station
Built Area	6 M ft² Floor Area 1 M ft² Ground Floor Area
Land Area	7.2 M ft² Total Land Area 3.4 M ft² Total Lot Area (excluding water)
Density	30 Dwelling Units Per Acre 1.76 FAR[1]

HAZARD EXPOSURE

EVENT-BASED	Storm Surge (High)	●
	Storm Surge (Low)	●
	Wave Force	●
	Sudden Erosion	●
GRADUAL	Frequent Flooding due to Sea Level Rise	◐[2]
	Gradual Erosion	◐

FLOOD ZONES[3]

- ▤ V Zone
- ▤ Coastal A Zone
- ▤ A Zone

FLOOD LEVELS[4]

- ┈┈ Future Base Flood Elevation
- ── Current Base Flood Elevation

SEA LEVELS[4]

- - - - Future High Tide
- ▬ High Tide

---

[1] FAR based on total floor area over total lot area, excluding open space, vacant, and unknown land uses.

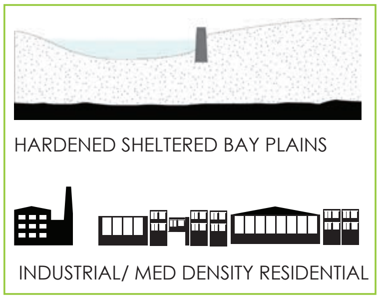
[2] The beach may be regularly inundated due to increasing sea level rise, but developed areas are on ground above the expected heights of sea level rise.

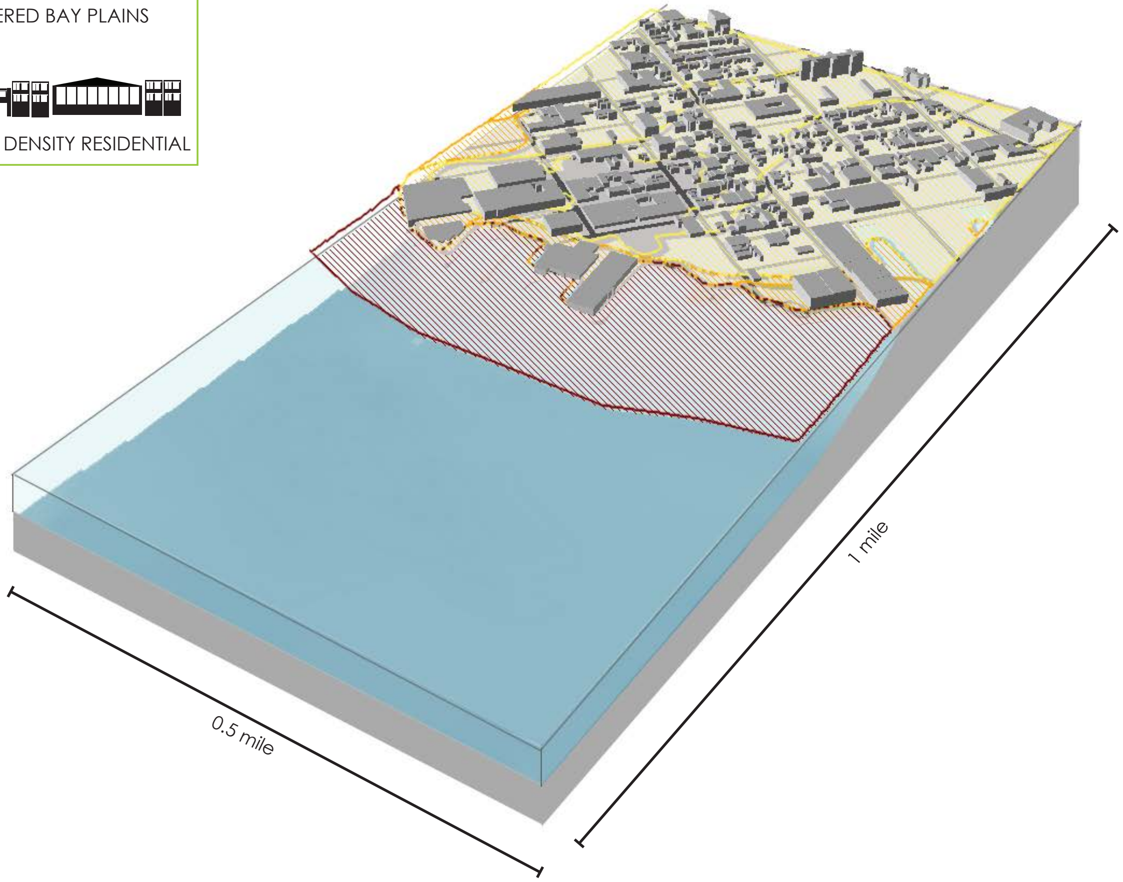
[3] Source: FEMA Preliminary Work Maps, June 2013

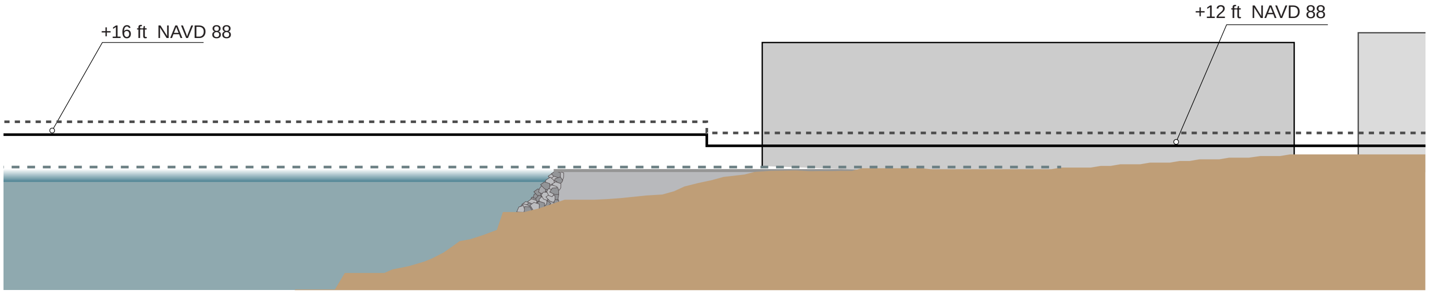
[4] Source: NPCC, 90th Percentile Projections, 2013

* Vertical exaggeration in sections

HARDENED SHELTERED BAY PLAINS / INDUSTRIAL / MEDIUM DENSITY RESIDENTIAL







LAND USE / DENSITY FACTORS

Building Types	Low-rise Industrial Buildings Low-rise Retail Buildings 2-4 story Residential attached 3-5 story Mixed-use Buildings High-rise Residential Buildings Community Facilities Parking
Open Space	Neighborhood Parks Piers
Infrastructure	Roads
Built Area	7M ft^2 Floor Area 2M ft^2 Ground Floor Area
Land Area	7 M ft^2 Total Land Area 3.4 M ft^2 Total Lot Area (excluding water)
Density	13 Dwelling Units Per Acre 2 FAR[1]

HAZARD EXPOSURE

EVENT-BASED	Storm Surge (High)	●
	Storm Surge (Low)	●
	Wave Force	◐
	Sudden Erosion	○
GRADUAL	Frequent Flooding due to Sea Level Rise	●
	Gradual Erosion	◐

FLOOD ZONES[2]

- ▤ V Zone
- ▤ Coastal A Zone
- ▤ A Zone

FLOOD LEVELS[3]

- ·········· Future Base Flood Elevation
- —— Current Base Flood Elevation

SEA LEVELS[3]

- - - - - Future High Tide
- ▆ High Tide

---

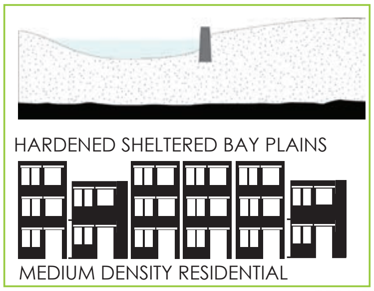
[1] FAR based on total floor area over total lot area, excluding open space, vacant, and unknown land uses.

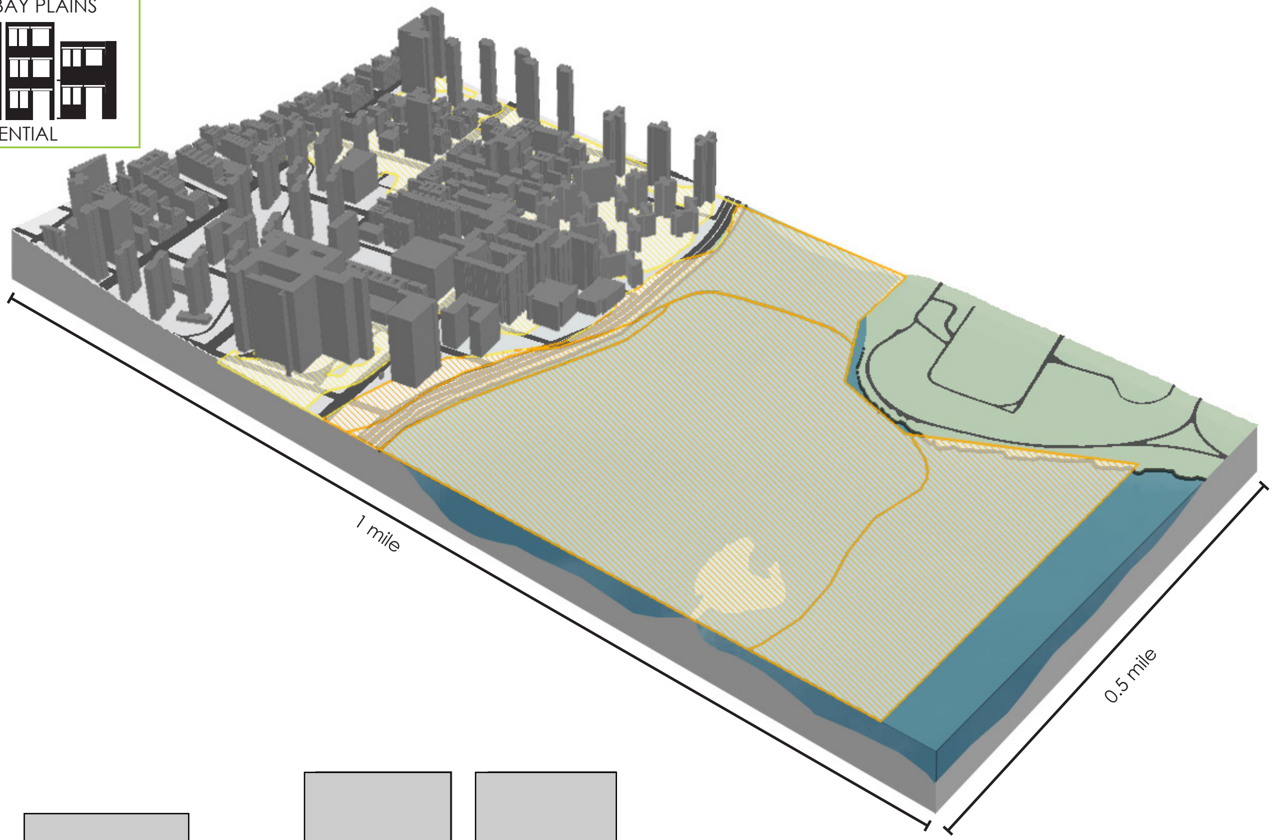
[2] Source: FEMA Preliminary Work Maps, June 2013

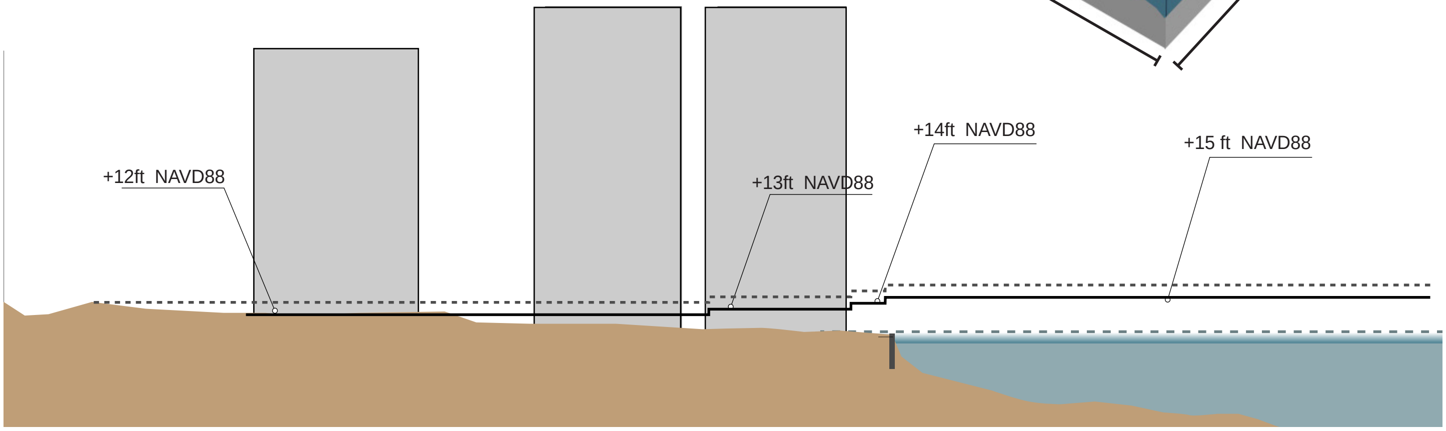
[3] Source: NPCC, 90th Percentile Projections, 2013

* Vertical exaggeration in sections

HARDENED SHELTERED BAY PLAINS / MEDIUM DENSITY RESIDENTIAL







LAND USE / DENSITY FACTORS

Building Types	3-5 story Mixed-use Buildings High-rise Residential Buildings High-rise Mixed-use Buildings Community Facilities
Open Space	Parking, Neighborhood Parks, Active Parkland
Infrastructure	Local Roads, Highway
Built Area	14 M ft^2 Floor Area 1.7 M ft^2 Ground Floor Area
Land Area	7.4 M ft^2 Total Land Area 4.4 M ft^2 Total Lot Area (excluding water)
Density	13 Dwelling Units Per Acre 3 FAR

HAZARD EXPOSURE

EVENT-BASED	Storm Surge (High)	●
	Storm Surge (Low)	●
	Wave Force	○
	Sudden Erosion	○
GRADUAL	Frequent Flooding due to Sea Level Rise	●
	Gradual Erosion	◐

FLOOD ZONES[2]

▤	V Zone
▤	Coastal A Zone
▤	A Zone

FLOOD LEVELS[3]

┈┈	Future Base Flood Elevation
──	Current Base Flood Elevation

SEA LEVELS[3]

- - -	Future High Tide
▬	High Tide

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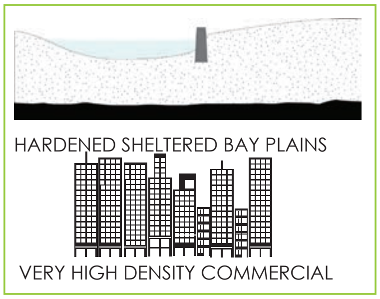
[1] FAR based on total floor area over total lot area, excluding open space, vacant, and unknown land uses.

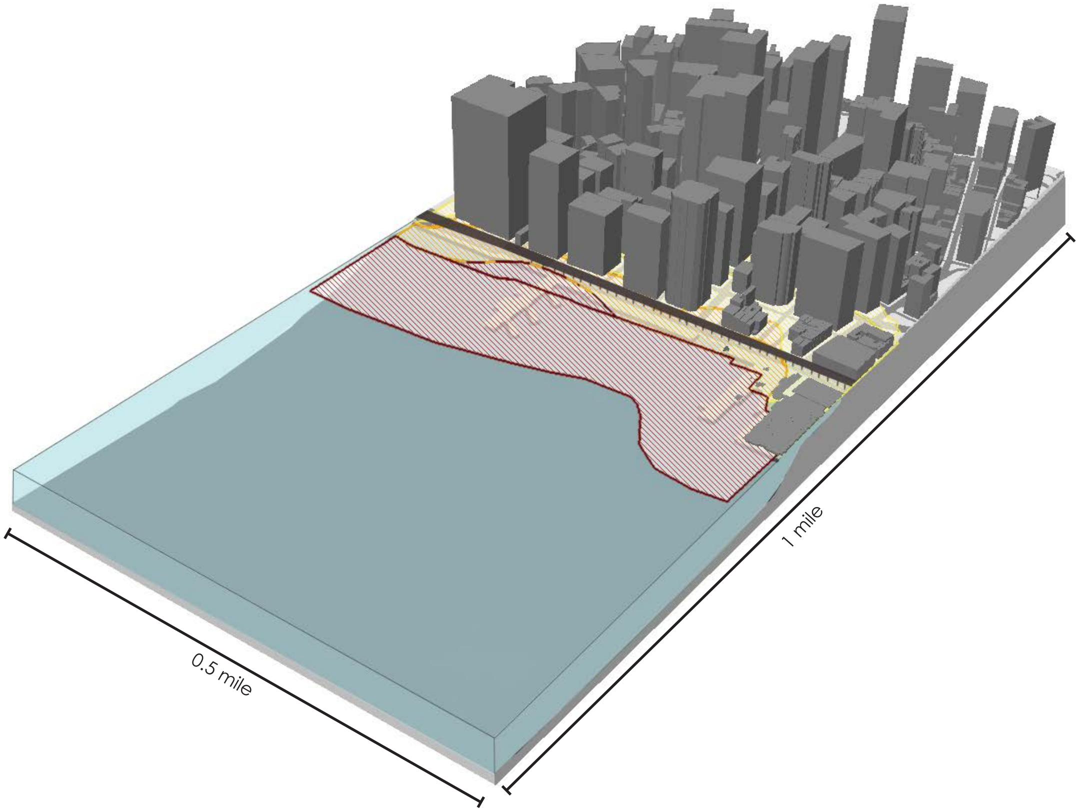
[2] Source: FEMA Preliminary Work Maps, June 2013

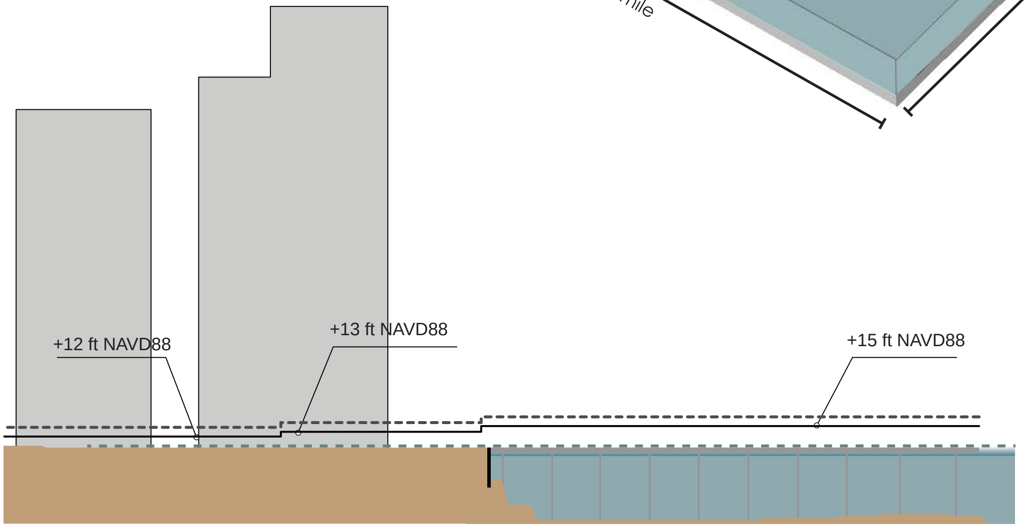
[3] Source: NPCC, 90th Percentile Projections, 2013

* Vertical exaggeration in sections

HARDENED SHELTERED BAY PLAINS / VERY HIGH DENSITY COMMERCIAL







LAND USE / DENSITY FACTORS

Building Types	3-5 story Mixed-use Buildings High-rise Residential Buildings High-rise Mixed-use Buildings
Open Space	Public Piers and Esplanade Neighborhood Parks
Infrastructure	Elevated Highway, Subways, Piers
Built Area	70 M ft^2 Floor Area 3 M ft^2 Ground Floor Area
Land Area	7.4 M ft^2 Total Land Area 6 M ft^2 Total Lot Area (excluding water)
Density	90 Dwelling Units Per Acre 11.5 FAR[1]

HAZARD EXPOSURE

EVENT-BASED	Storm Surge (High)	●
	Storm Surge (Low)	●
	Wave Force	◐
	Sudden Erosion	○
GRADUAL	Frequent Flooding due to Sea Level Rise	●
	Gradual Erosion	◐

FLOOD ZONES[2]

▨ V Zone

▨ Coastal A Zone

▨ A Zone

FLOOD LEVELS[3]

- - - - Future Base Flood Elevation

—— Current Base Flood Elevation

SEA LEVELS[3]

- - - - Future High Tide

▬ High Tide

---

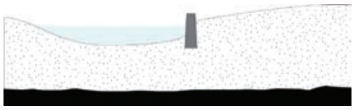
[1] FAR based on total floor area over total lot area, excluding open space, vacant, and unknown land uses.

[2] Source: FEMA Preliminary Work Maps, June 2013

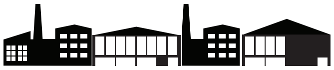
[3] Source: NPCC, 90th Percentile Projections, 2013

* Vertical exaggeration in sections

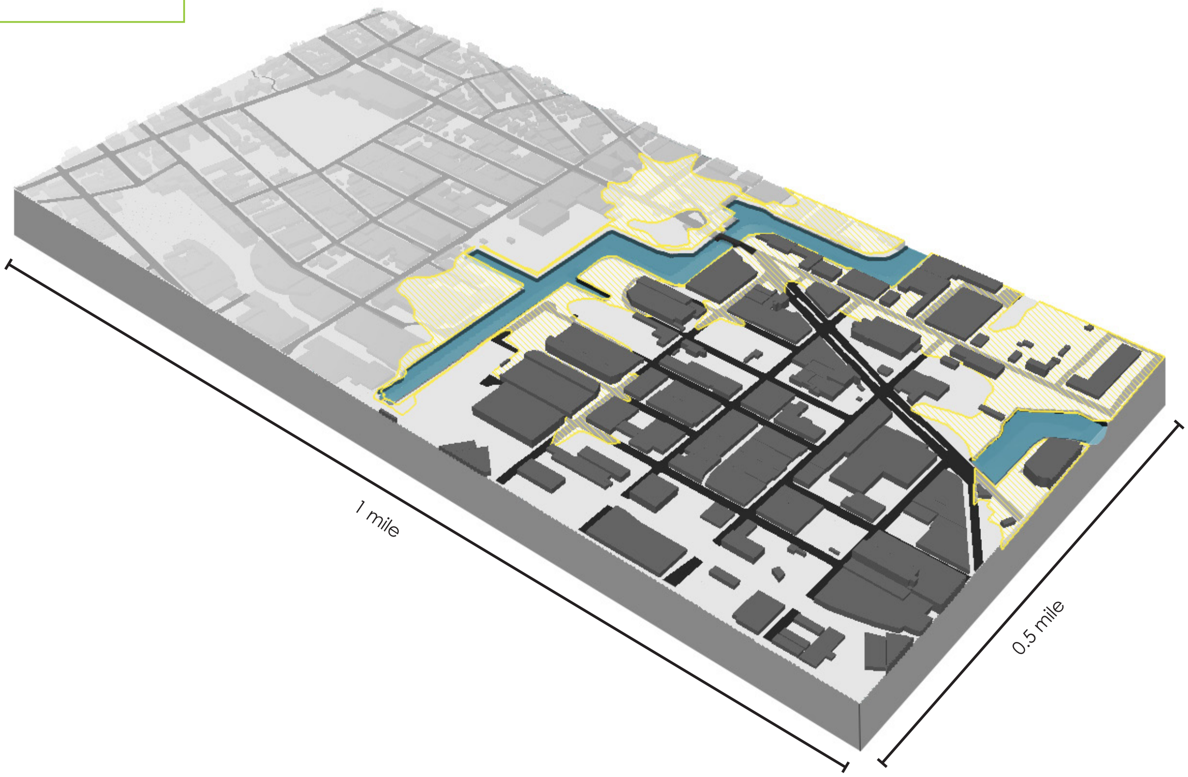
HARDENED SHELTERED BAY PLAINS / INDUSTRIAL

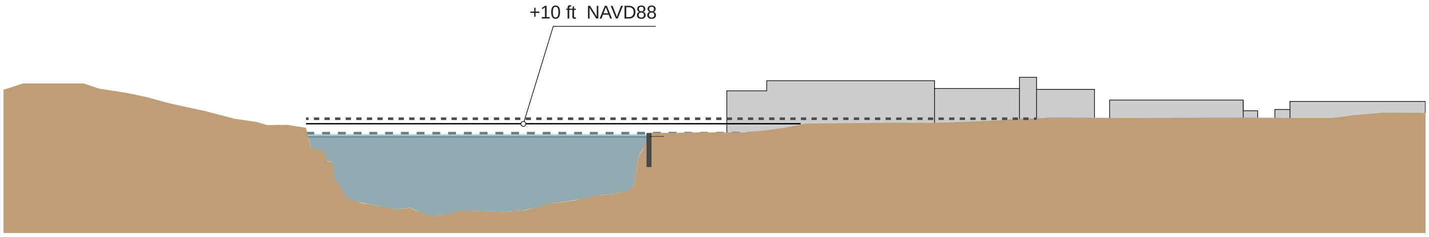


HARDENED SHELTERED BAY PLAINS



INDUSTRIAL





LAND USE / DENSITY FACTORS

Building Types	Low-rise Industrial Buildings Low-rise Retail Buildings
Open Space	Parking, Vacant Land, Open Industrial Uses
Infrastructure	Roads, Elevated Rail Tracks, Bulkheads
Built Area	3 M ft² Floor Area 2 M ft² Ground Floor Area
Land Area	5.7 M ft² Total Land Area 3.4 M ft² Total Lot Area (excluding water)
Density	0 Dwelling Units Per Acre 1 FAR[1]

HAZARD EXPOSURE

EVENT-BASED	Storm Surge (High)	●
	Storm Surge (Low)	●
	Wave Force	○
	Sudden Erosion	○
GRADUAL	Frequent Flooding due to Sea Level Rise	◐
	Gradual Erosion	◐

FLOOD ZONES[2]

- ▤ V Zone
- ▤ Coastal A Zone
- ▤ A Zone

FLOOD LEVELS[3]

- ┈┈┈ Future Base Flood Elevation
- ─── Current Base Flood Elevation

SEA LEVELS[3]

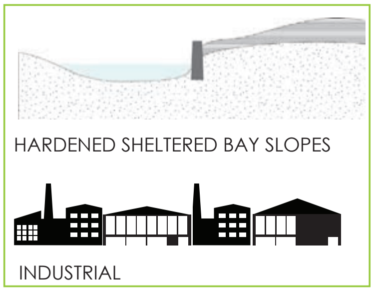
- - - - Future High Tide
- ▆ High Tide

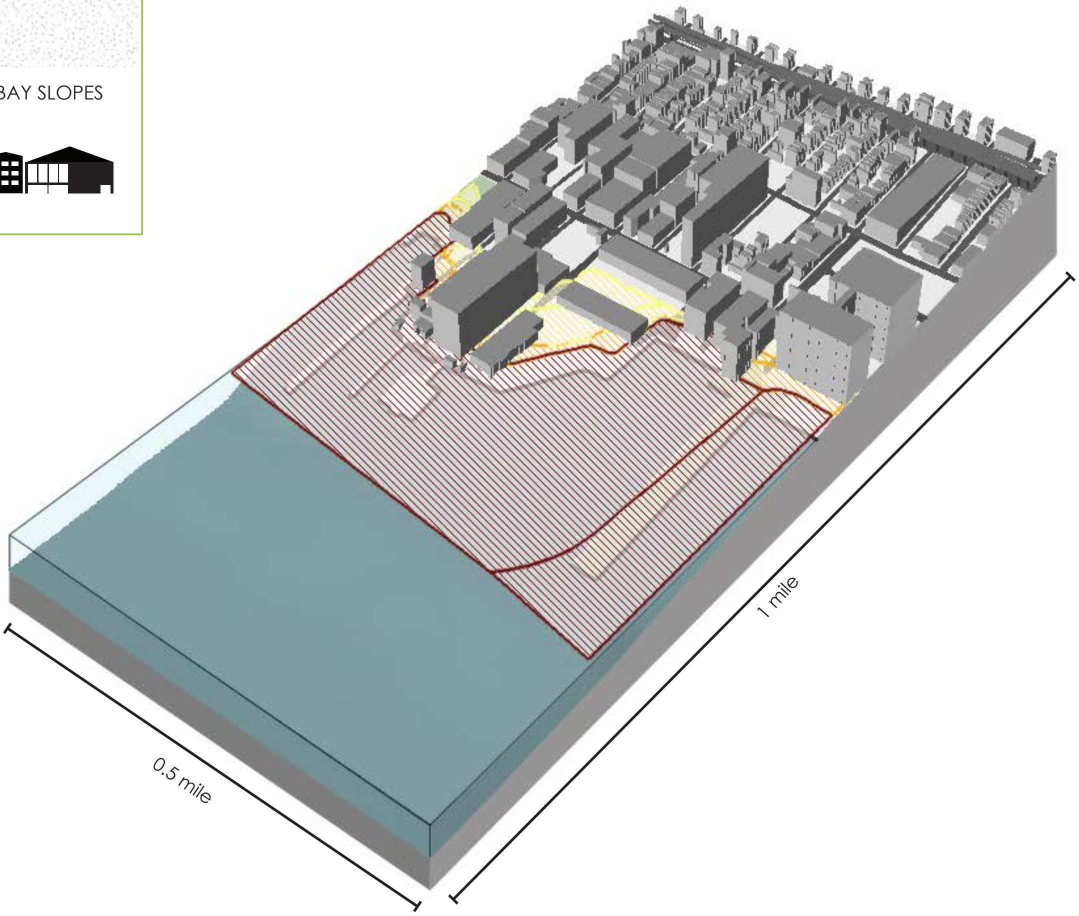
---

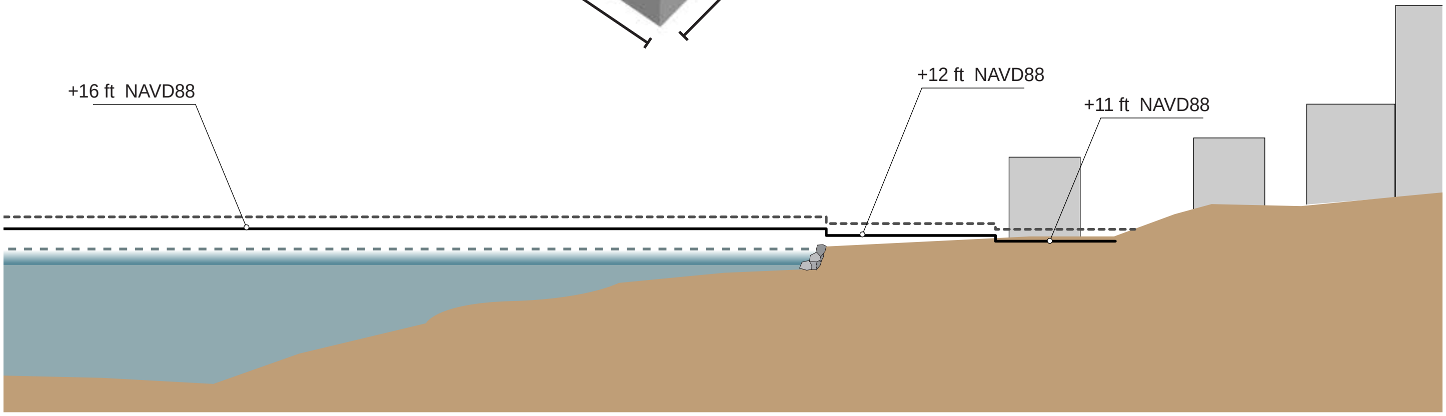
[1] FAR based on total floor area over total lot area, excluding open space, vacant, and unknown land uses.
[2] Source: FEMA Preliminary Work Maps, June 2013
[3] Source: NPCC, 90th Percentile Projections, 2013

* Vertical exaggeration in sections

HARDENED SHELTERED BAY SLOPES / INDUSTRIAL







LAND USE / DENSITY FACTORS

Building Types	1-2 story Industrial 2-4 story Residential Attached 3-5 story Mixed-use Buildings Community Facilities
Open Space	Parking, Neighborhood Parks
Infrastructure	Piers, Elevated Highway, Roads, Rail Tracks
Built Area	11 M ft² Floor Area 2.5 M ft² Ground Floor Area
Land Area	7.2 M ft² Total Land Area 5.9 M ft² Total Lot Area (excluding water)
Density	1.75 FAR[1] 7.5 Dwelling Units Per Acre

HAZARD EXPOSURE

EVENT-BASED	Storm Surge (High)	◐
	Storm Surge (Low)	◐
	Wave Force	○
	Sudden Erosion	○
GRADUAL	Frequent Flooding due to Sea Level Rise	○
	Gradual Erosion	○

FLOOD ZONES[2]

- 🟥 V Zone
- 🟧 Coastal A Zone
- 🟨 A Zone

FLOOD LEVELS[3]

- .... Future Base Flood Elevation
- ——— Current Base Flood Elevation

SEA LEVELS[3]

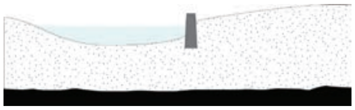
- - - - - Future High Tide
- 🟦 High Tide

---

[1] FAR based on total floor area over total lot area, excluding open space, vacant, and unknown land uses.
[2] Source: FEMA Preliminary Work Maps, June 2013
[3] Source: NPCC, 90th Percentile Projections, 2013

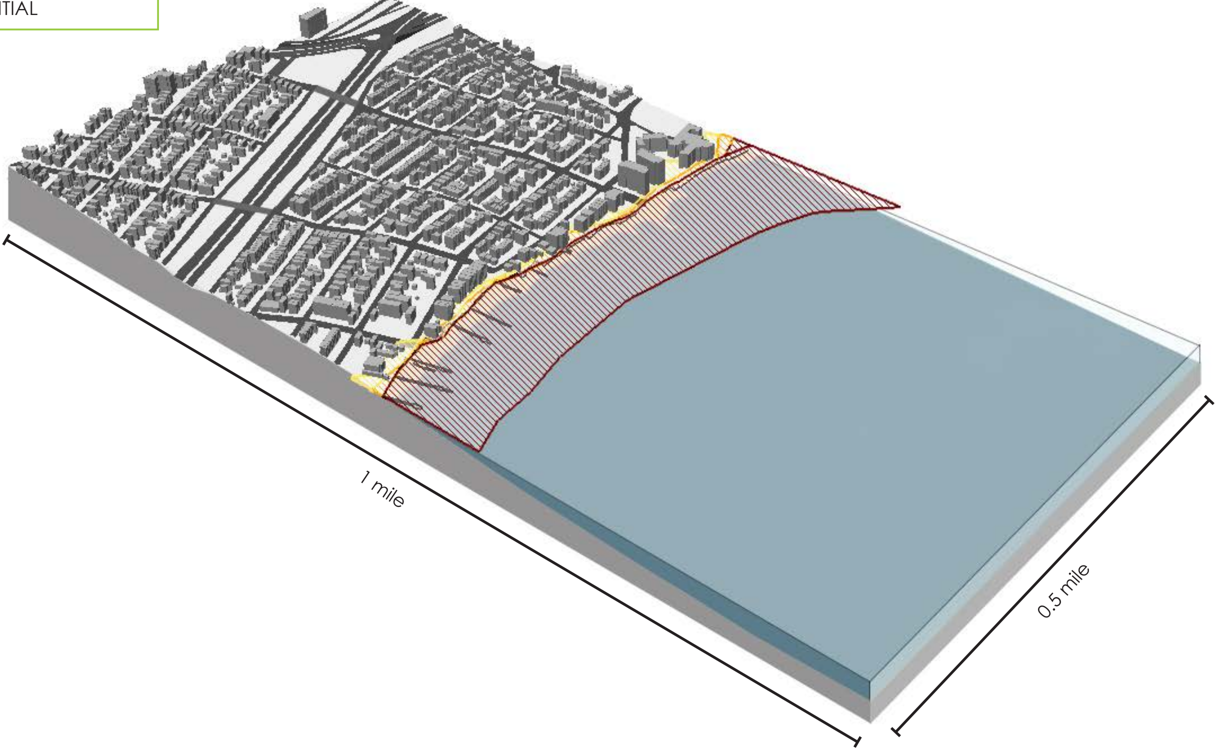
* Vertical exaggeration in sections

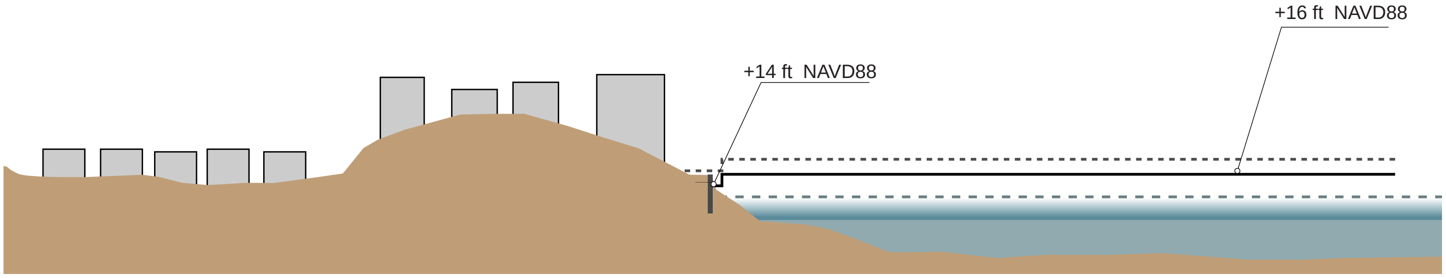
HARDENED SHELTERED BAY SLOPES / LOW DENSITY RESIDENTIAL



HARDENED SHELTERED BAY PLAINS

LOW DENSITY RESIDENTIAL





LAND USE / DENSITY FACTORS

Building Types	1-2 story Detached Homes 1-2 story Semi-detached Homes 3-4 story Residential/Comm. Community Facilities
Open Space	Parking, Vacant Land, Beach
Infrastructure	Roads, Highways, Piers
Built Area	3 M ft^2 Floor area 1 M ft^2 Ground Floor area
Land Area	7 M ft^2 Total Land Area 3.9 M ft^2 Total Lot Area (excluding water)
Density	13 Dwelling Units Per Acre 0.75 FAR[1]

HAZARD EXPOSURE

EVENT-BASED	Storm Surge (High)	◐
	Storm Surge (Low)	◐
	Wave Force	○
	Sudden Erosion	○
GRADUAL	Frequent Flooding due to Sea Level Rise	○
	Gradual Erosion	○

FLOOD ZONES[2]
- ▨ V Zone
- ▨ Coastal A Zone
- ▨ A Zone

FLOOD LEVELS[3]
- ········ Future Base Flood Elevation
- ——— Current Base Flood Elevation

SEA LEVELS[3]
- - - - - Future High Tide
- ▨ High Tide

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[1] FAR based on total floor area over total lot area, excluding open space, vacant, and unknown land uses.
[2] Source: FEMA Preliminary Work Maps, June 2013
[3] Source: NPCC, 90th Percentile Projections, 2013

* Vertical exaggeration in sections

East River Waterfront Esplanade, Manhattan

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Brooklyn Bridge Park, Brooklyn

PART III

INVENTORY OF ADAPTIVE STRATEGIES

There are a variety of potential strategies to adapt waterfront areas to be more resilient in the face of increasing coastal hazards.

These strategies involve resiliency actions at various scales, from a single component of a piece of infrastructure, to a development site, to a coastal reach. At each scale, there are many actors involved, from the private landowner, to infrastructure owners and operators, to city, state, and federal government agencies, to local communities and the public at large.

Each strategy has costs and benefits, which should be broadly defined. Potential costs include the financing to construct and maintain new pieces of infrastructure, as well as indirect costs to the quality of the public realm and the environment. Benefits include addressing a coastal hazard, as well as co-benefits that achieve other goals, such as public access, economic development, or ecosystem restoration.

SITE

Site strategies include various means of preventing damage to buildings and their contents through incorporating floodproofing measures that either keep flood waters out ("dry floodproofing"), avoid flood waters through elevation, or to allow water but take actions to minimize damages ("wet floodproofing").

Forest Hills, Queens

REACH

Reach strategies include interventions upland, at the shoreline, or in the water, which affect a larger stretch of coastline, involve many individual sites and landowners, and are often built and maintained by public agencies. The objectives of various reach strategies are to stabilize land against erosion and daily tide levels, mitigate wave forces, block the flooding of upland neighborhoods, or to remove development from vulnerable areas.

Williamsburg, Brooklyn

SITE STRATEGIES

There are many ways to protect an individual building or site from flood damage. The decision of an individual property owner of whether to do so or what strategy to pursue is heavily influenced by federal, state, and local regulatory requirements. New construction (or substantial improvements where the cumulative costs equal or exceed 50 percent of the market value of the building) within the 1 percent flood zone as designated by FEMA on the Flood Insurance Rate Map (FIRM) are required to be in compliance with the New York City Building Code requirements for flood-resistant construction. The code requires that buildings be floodproofed to the design flood elevation, which is the elevation of the base flood as indicated on the FIRM including freeboard (an additional height of floodproofing to provide additional safety). There are additional requirements depending on the building type and its location within the flood zone, for instance, whether or not it falls within the FEMA V Zone, or the portion of the 1 percent flood zone where there is additional risk of damage from wave forces.


Beach 119 St, , Queens

These requirements are based on FEMA's national standards which are required to be incorporated into local building codes as part of a municipality's participation in the National Flood Insurance Program (see page111 for more on Insurance). Such requirements have been in place in New York City since the first FIRMs were issued in 1983. However, the vast majority of the thousands of buildings within the City's flood zone was built prior to 1983 and is unlikely to have been built to flood-resistant standards. Many property owners have opted to retrofit their buildings to improve their ability to withstand and recover from flood events. While substantial improvements within the 1 percent flood zone are required to be brought into full compliance with New York City Building Code and FEMA standards, there are means of retrofitting buildings to be more flood-resilient which may not bring a building into full compliance, but may increase its resilience. For such measures to provide a reduction in flood insurance premiums through the National Flood Insurance Program, they must align to FEMA's standards.

While site strategies are implemented on a site-by-site basis, they can greatly affect the character of a street or neighborhood. Many of these strategies may alter how buildings meet the sidewalk, a critical element of a street's walkability. Consideration of the impact of a given strategy on the public realm from the perspective of a person walking down the street should be considered to ensure an active street life that supports the neighborhood's livability, economic vitality, and safety.

The first section of this chapter describes strategies for new developments, followed by strategies for retrofitting existing buildings.

Each potential strategy is described and analyzed for the following:

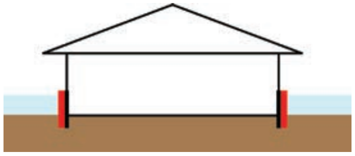
- ***Hazards Addressed:*** The ability of the strategy to address coastal hazards, such as flooding from high or low flood events, and whether or not a strategy can protect against wave action or high-velocity flooding, such as would be expected in the V zone.
- ***Applicability:*** Factors which determine a strategy's applicability to various types of buildings and sites.
- ***Costs:*** Estimates of direct construction costs are provided when available. Cost estimates are pulled from multiple sources and through consultation with the Special Initiative for Rebuilding and Resiliency and the Housing Recovery Office. They are provided for descriptive purposes only, as the costs of each strategy are highly dependent on various site-specific factors. For new construction, the incorporation of floodproofing elements is estimated to be approximately 3 to 5 percent of the total project cost. Indirect costs are also described, such as lost opportunities for usable space and impacts on urban design or community character.
- ***Potential for Co-Benefits:*** In addition to flood protection, some strategies offer opportunities for co-benefits that may factor into the decision-making process to make a strategy more beneficial.
- ***Additional Considerations:*** For all of these strategies, there are a variety of additional considerations including design, technological, regulatory, or implementation factors that should be considered in the decision-making process.

This information is provided for planning purposes only. Property owners should consult relevant regulators and an architect or engineer before making a decision on what is best for a specific site.

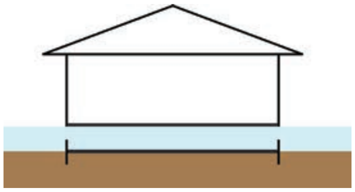
SITE STRATEGIES

New Construction

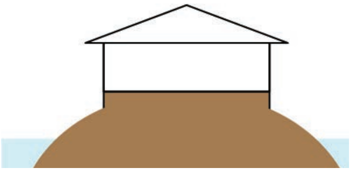
01 Dry Floodproofing



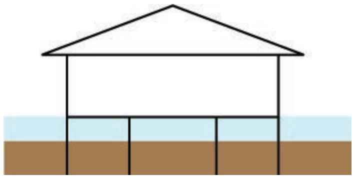
02 Elevate on Enclosure/ Wet Floodproofing



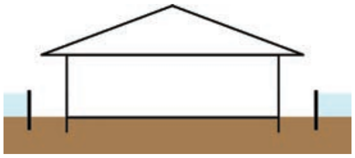
03 Elevate on Fill or Mound



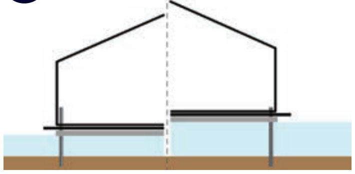
04 Elevate on Piles



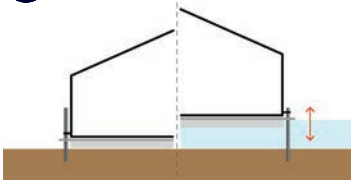
05 Site Protection



06 Floating Structures



07 Amphibious Structures

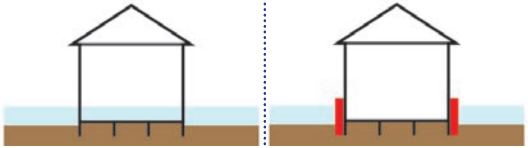


Retrofitting Existing Buildings

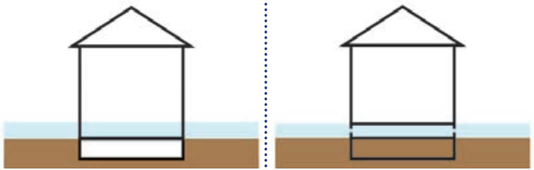
Before

After

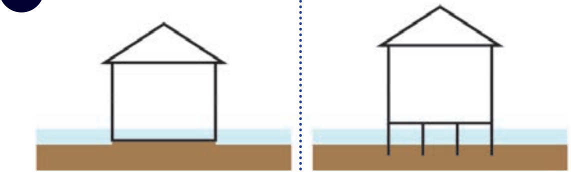
08 Dry Floodproofing



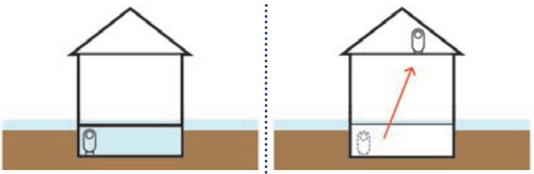
09 Wet Floodproofing



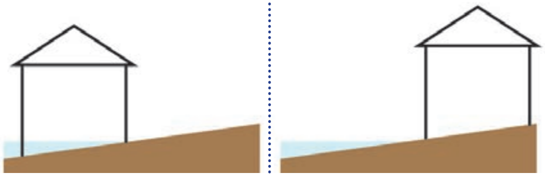
10 Elevate on Piles



11 Protect Building Systems

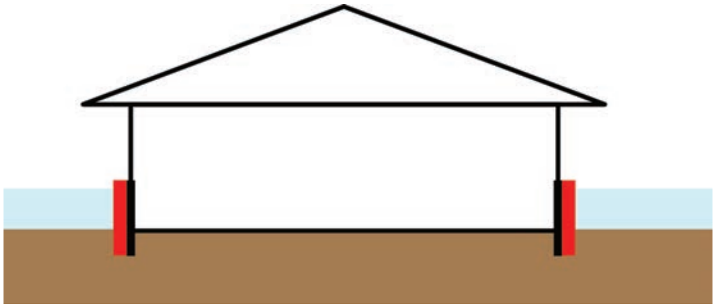


12 Relocate / Demolish



01. DRY FLOODPROOFING

In dry floodproofing, the building structure is designed to resist water loads and infiltration. Water resistant materials are used, in combination with water-tight gates at entry points.



Dry floodproofing aims to inhibit the infiltration of water by designing the exterior of a building with waterproof coatings, impermeable membranes, aquarium glass, or additional layers of exterior concrete or masonry. Doors, windows, and other openings below the design flood elevation are sealed through permanent flood gates, often made from sheet metal with reinforcement and rubber joints, or deployable shields that are installed in advance of a flood event. When utilizing dry floodproofing, a building must also be designed to resist water loads and buoyancy forces.

Dry floodproofing is the only strategy in which the space at or below the design flood elevation can be occupied and protected from flood damage. However, FEMA standards do not recommend dry floodproofing for residential uses. As a result, dry floodproofing is not allowed by New York City Building Code for new construction of purely residential buildings, or for the residential portion of a mixed-use building. According to FEMA, the danger of dry floodproofing strategies for residential buildings is that they may contribute to a false sense of security before and during storm conditions, encourage residents to not evacuate before a storm, and inhibit evacuation during a flood. Dry floodproofing is well-suited for commercial and institutional buildings.

Dry Floodproofed building in HafenCity, Hamburg, Germany

Hazards Addressed

- Dry floodproofing prevents damage to the building and its contents by preventing the flooding of interior spaces. It is best-suited to address surge heights of three to four feet above grade.
- Dry floodproofing does not typically protect against wave forces.

Applicability

- Best suited for commercial, mixed use, or community facility buildings. FEMA standards do not consider dry flood-proofing to be appropriate for purely residential buildings.
- Not allowed in V zones by FEMA standards.
- When dry floodproofing is used, the structure must be designed to resist water loads on the exterior walls and buoyant forces on the foundation. For some construction types, this may preclude the use of dry floodproofing for more than 3 feet above grade.
- Dry floodproofing is not recommended for areas which experience prolonged flood events because most sealing systems will begin to leak after prolonged exposure to water.
- Dry floodproofing is likely cost-prohibitive for low-rise retail or industrial buildings.

Costs

- Dry floodproofing is generally more expensive than wet floodproofing for new construction.
- Cost increases as height of design flood elevation increases and for larger structures.
- Any flood shield that requires installation requires advance planning and preparation and relies on human intervention before the flood event.
- As with any strategy that seeks to keep water out, the costs of failure are higher as it may create a false sense of security.

Potential for Co-Benefits

- Dry floodproofing allows for active uses of the lowest floor, thereby avoiding the impacts on the public realm of elevating the lowest occupiable floor and restricting the ground floor to parking, storage, and access.
- Allows for below grade basements and underground parking, though foundations must be designed to withstand water loads and buoyant forces.

Additional Considerations

- Allowing for a means of egress that is ADA-accessible during a flood event is a design challenge.
- Flood gates at the building perimeter may infringe on the sidewalk right-of-way, requiring a revocable consent license.
- Dry floodprofing should consider design strategies to avoid monotonous lengths of blank walls which would negatively impact the pedestrian experience.

Ability to Address Coastal Hazards

Storm Surge (High)	◐
Storm Surge (Low)	●
Wave Force	○

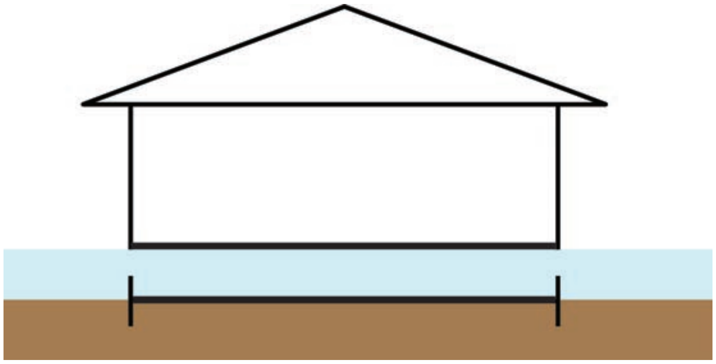
Applicability to Building Type

A	1-2 Family Detached	○
B	1-2 Family Attached	○
C	Low-Mid Rise Residential, Commercial, Mixed	◐
D	High-Residential, Commercial, Mixed	●
E	Industrial	○

● HIGH ◐ MEDIUM ○ LOW

02. ELEVATE ON ENCLOSURE / WET FLOODPROOFING

The space below the design flood elevation is constructed with flood-damage resistant materials in combination with flood vents to allow water to enter the structure and allow hydrostatic pressures to equalize.



In this strategy, the structure is built on an enclosure elevated to a design flood elevation. The enclosed space is designed to be flooded in the event of a flood and is limited to building access, parking, and minor storage. The enclosed space is built with flood damage resistant materials that do not need to be replaced if flooded, including pressure-treated plywood, concrete, and cement board. Flood vents are installed in the walls of the enclosure to let flood waters enter and leave by gravity, which allows forces on either side of the structure's walls to equalize. This prevents the structure and foundation from collapsing in the event of a flood. Below-grade spaces which could trap flood waters are not allowed. Building utilities are either elevated or dry floodproofed.

Elevated home with flood vents.

Hazards Addressed

- Wet floodproofing protects buildings from structural damage due to flooding, but still allows for flood waters to enter the space below the design flood elevation.
- Wet floodproofing does not protect the building against wave action or high-velocity flood flows.

Applicability

- Wet floodproofed spaces have limited uses because the contents may be inundated in the event of a flood. It is typically used for unfinished crawlspaces below the lowest occupiable floor, but can be used for minor storage, building access, and parking.
- In combination with elevation of the lowest occupiable floor, this strategy can work well for low-density residential buildings; however, elevation for larger structures or industrial buildings would require a larger lot to allow room for building access.
- This strategy is best suited for A zones. Wet floodproofing and elevation on enclosed spaces is not allowed for new construction or substantial reconstruction in V zones by FEMA standards.

Costs

- Wet floodproofing is generally less expensive than dry flood-proofing.
- When combined with elevation, building access must be provided to an elevated ground floor, which also adds additional costs and may pose negative impacts on the pedestrian realm of the street through obtrusive ramping and loss of active uses.
- Wet floodproofed spaces require extensive cleaning and/or replacement of finishes following flooding, and may present exposure to sewage, chemical, or other hazardous materials in floodwaters.

Potential for Co-Benefits

- A wet floodproofed entryway could be combined with an elevated interior space to allow floodproofed buildings to be entered at grade minimizing effects on streetscape.
- For detached or semi-detached buildings, elevating the ground floor can provide area for a parking space, which can free up other open space on the lot, though may create unwanted impacts on the streetscape.
- Wet floodproofing, unlike dry floodproofing, does not rely on advanced planning or preparation.

Additional Considerations

- Flood vents must be engineered to comply with energy code requirements for the building envelope.

Ability to Address Coastal Hazards

Storm Surge (High)	●
Storm Surge (Low)	●
Wave Force	○

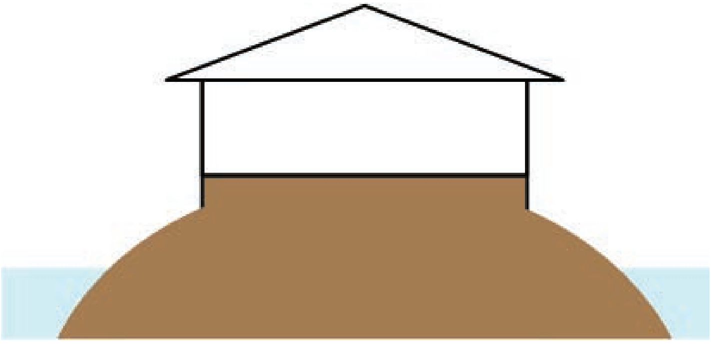
Applicability to Building Type

A	1-2 Family Detached	●
B	1-2 Family Attached	●
C	Low-Mid Rise Residential, Commercial, Mixed	◐
D	High-Residential, Commercial, Mixed	◐
E	Industrial	◐

● HIGH ◐ MEDIUM ○ LOW

03. ELEVATE ON FILL

The building site is raised to a height above the design flood elevation through the addition of fill.



Elevating a site above the design flood elevation can provide protection from flooding in the event of a coastal storm. It may also be used to elevate a site high enough to prevent frequent flooding at high tide due to sea level rise. In some instances the ground below the building is elevated through the addition of fill, while in other instances the entire site's topography is altered and the whole development site is raised (See Elevation of Land on page 66).

CASE STUDY: SIMS MUNICIPAL RECYCLING FACILITY, BROOKLYN

Industrial sites on the working waterfront face unique economic and environmental risks associated with climate change, storm surge, and flooding. When Sims Metal Management, a global recycling firm, reached an agreement with New York City to construct and operate a new municipal recycling facility on a waterfront site in Sunset Park, Brooklyn, elevating critical portions of the site was essential to the planning and design for the facility. While the project is intended to be a state-of-the-art "green" facility, according to Tom Outerbridge, manager of the Municipal Recycling division of Sims, the decision to elevate the site was a business one, as the company wants to protect its investment from rising seas and intensifying storms over the course of its 40-year contract with the City.

In 2004, when initial planning for the facility began, the draft sea level rise projections from the New York City Panel on Climate Change had recently been completed, and the development team was able to see that by the end of the century, between 1 and 4.5 feet of sea level rise were projected. Balancing these projections with the intended lifespan of the project and its operational needs, including waterfront barging activity, the team agreed that FEMA's flood elevations would not serve as the design basis. Instead, it was agreed that all areas of the site allocated for buildings and recycling equipment would be increased by four feet above the base flood elevation to 14+ NGVD 1929. The fact that the site was vacant – essentially a "clean slate" – made designing for current and expected flooding easier. The new topography was achieved with blended crushed glass from the City recycling program and crushed stone from 2nd Avenue Subway and East Side Access tunneling operations, which helped keep the costs down. The elevation changes also allowed for the integration of a gravity-based stormwater system through manipulation of the site grading, eliminating the need for pumps.

Other aspects of the design, while not specifically aimed at reducing exposure to flooding and storms, are intended to not only mitigate the impacts of the facility on surrounding habitat, but also use the new development as a way to promote a cleaner industrial district and contribute positively to a degraded marine environment. Three off-shore artificial reefs, constructed from blasted stone from a navigational channel deepening project elsewhere in the harbor, were constructed as intertidal habitat. However, they not only function as a marine habitat by attracting seaweed, shellfish, other marine life, but also act as wave attenuation on the shoreline, reducing wave impacts on the intertidal and lower-lying portions of the site. Likewise, a "fuzzy rope" network suspended under a portion of the new pile support dock structure is a pilot project aimed to see whether naturally-occurring oyster spats in the harbor will populate the rope, increasing the ecological richness of the intertidal area directly beneath the pier. If successful, the project could be replicated throughout the harbor as a way to encourage marine life in an otherwise environmentally-stressed harbor condition.

While only 50 percent of the project was complete when Hurricane Sandy hit New York in Fall 2012, the site work and grading in the areas of the buildings had been completed, as well as the shells of the large recycling buildings and pier. According to Sims, those areas that were elevated at +14 NGVD did not incur any flooding, while the lower lying areas of the site experienced as much as 2.5 feet. In addition, preventative measures prior to the storm to protect the equipment on site meant that just two days after the storm, construction was able to resume. Small modifications to the remaining construction, including elevating the electrical substations and a guard booth two additional feet to +16 NGVD, were made. "This may seem overly cautious," said Outerbridge, "but when you compare the minor cost of this change to the potential damage costs and the associated time that we'd be out of operation, it seemed like the right thing to do."

Hazards Addressed

- Elevating a site above the design flood elevation can provide protection from flooding in the event of a coastal storm. It may also be used to elevate a site high enough to prevent frequent flooding at high tide due to sea level rise.

Applicability

- Small sites may not have enough space to grade up to higher design flood elevations, and large sites may require a substantial amount of fill, which increases costs. Accordingly, this strategy is most likely to be cost-effective for large lots with low design flood elevations or sites with some existing topography. For small, infill sites, the elevation of the lowest occupiable floor with a wet floodproofed crawlspace is probably more feasible than elevation on fill.
- Structural fill is not allowed in V zones by FEMA standards due to the potential for scour in the event of a storm.
- Site adjacencies and access implications may also limit the use of this strategy.
- Elevating sites more than three feet is not recommended, as it may channelize flood waters and could exacerbate flooding of adjacent sites.

Costs

- The cost of fill to elevate is the major cost associated with this strategy. Retaining walls may also be necessary.
- Accessibility from the street and sidewalk is another challenge which may result in additional costs to provide for ADA access and may pose urban design issues. The extent of necessary ramping increases as the height of the design flood elevation increases.

Potential for Co-Benefits

- When a site is large enough to move the building back from the street, elevation on fill allows room for landscaping which can create a gradual transition in grade changes, provide a usable open space, and mitigate the impact of a raised ground floor on the streetscape.
- Elevating a site may provide reductions in flood insurance, or may allow for the entire site to be removed from the flood zone through a letter of map revision.

Additional Considerations

- Implications for drainage and impacts on adjacent sites must be examined.
- Landscape and site design should consider means of mitigating any negative impacts on the streetscape and adjacent sidewalks.

Ability to Address Coastal Hazards

Storm Surge (High)	●
Storm Surge (Low)	●
Wave Force	○

Applicability to Building Type

A	1-2 Family Detached	◐
B	1-2 Family Attached	◐
C	Low-Mid Rise Residential, Commercial, Mixed	◐
D	High-Residential, Commercial, Mixed	◐
E	Industrial	◐

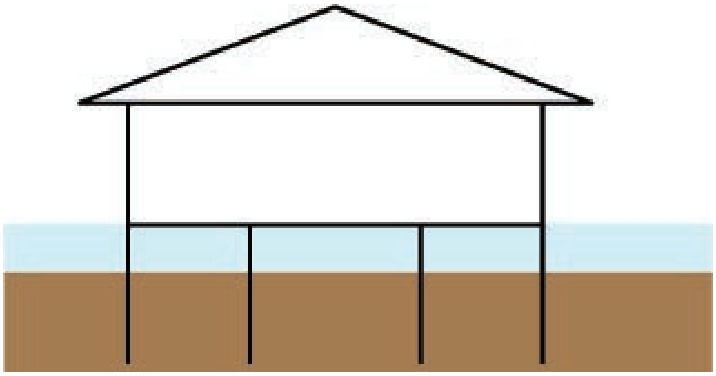
● HIGH ◐ MEDIUM ○ LOW

Sims Metal Management Facility, Brooklyn

Credit: NYC Economic Development Corporation

04. ELEVATE ON PILES

The building is raised above the design flood elevation through construction on piles that extend below ground.



This option allows flood water and waves to pass below the building. It is mandated for new construction in V zones by FEMA standards. Uses are limited below the design flood elevation to minor storage, parking, and building access. Frequently breakaway walls or lattice walls are used below the first floor to enclose the space. Elevator cores are allowed below the design flood elevation if dry floodproofed.

Throggs Neck, The Bronx

Hazards Addressed

- Protects building and contents (above the design flood elevation) from flooding and associated wave forces.

Applicability

- Open foundations are best suited for areas that are vulnerable to strong ocean-generated waves in the event of a storm. This strategy is mandatory for new construction within the V zone.
- As uses are limited below the design flood elevation to parking, minor storage, and building access, this strategy is less preferable when active uses at grade are desired, such as along a retail corridor.

Costs

- Pile-driving adds additional construction costs for this strategy, though money that would have been spent on a foundation is saved.
- May pose negative impacts on pedestrian realm of the street through obtrusive ramping and loss of active uses at the street level.

Potential for Co-Benefits

- Elevating on piles may provide for additional parking space under the building, though it may create unwanted impacts on the streetscape.

Additional Considerations

- Pile-driving requires specialized machinery that is expensive. It may also be more difficult in areas with extensive subgrade infrastructure networks or soil conditions. Site access for piling equipment may pose challenges for small sites and narrow streets with limited accessibility for the necessary machinery. In addition, pile-driving must consider the potential for vibration and damage to adjacent structures.
- Innovative ideas for the use of the space below the design flood elevations, such as pop-up retail, in order to maintain active, safe, and engaging ground floor uses, should be explored.
- Consider design strategies to avoid negative impacts on the sidewalk and neighborhood context.

Ability to Address Coastal Hazards

Storm Surge (High)	●
Storm Surge (Low)	●
Wave Force	●

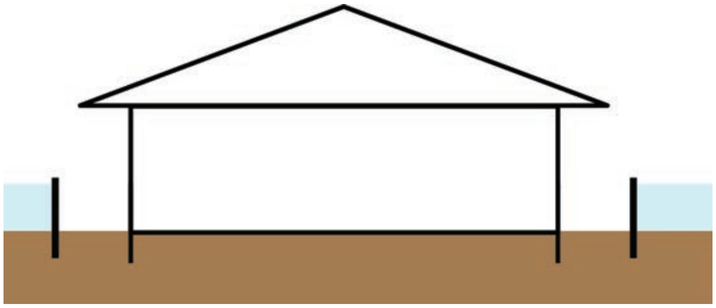
Applicability to Building Type

A	1-2 Family Detached	◐
B	1-2 Family Attached	◐
C	Low-Mid Rise Residential, Commercial, Mixed	◐
D	High-Residential, Commercial, Mixed	◐
E	Industrial	◐

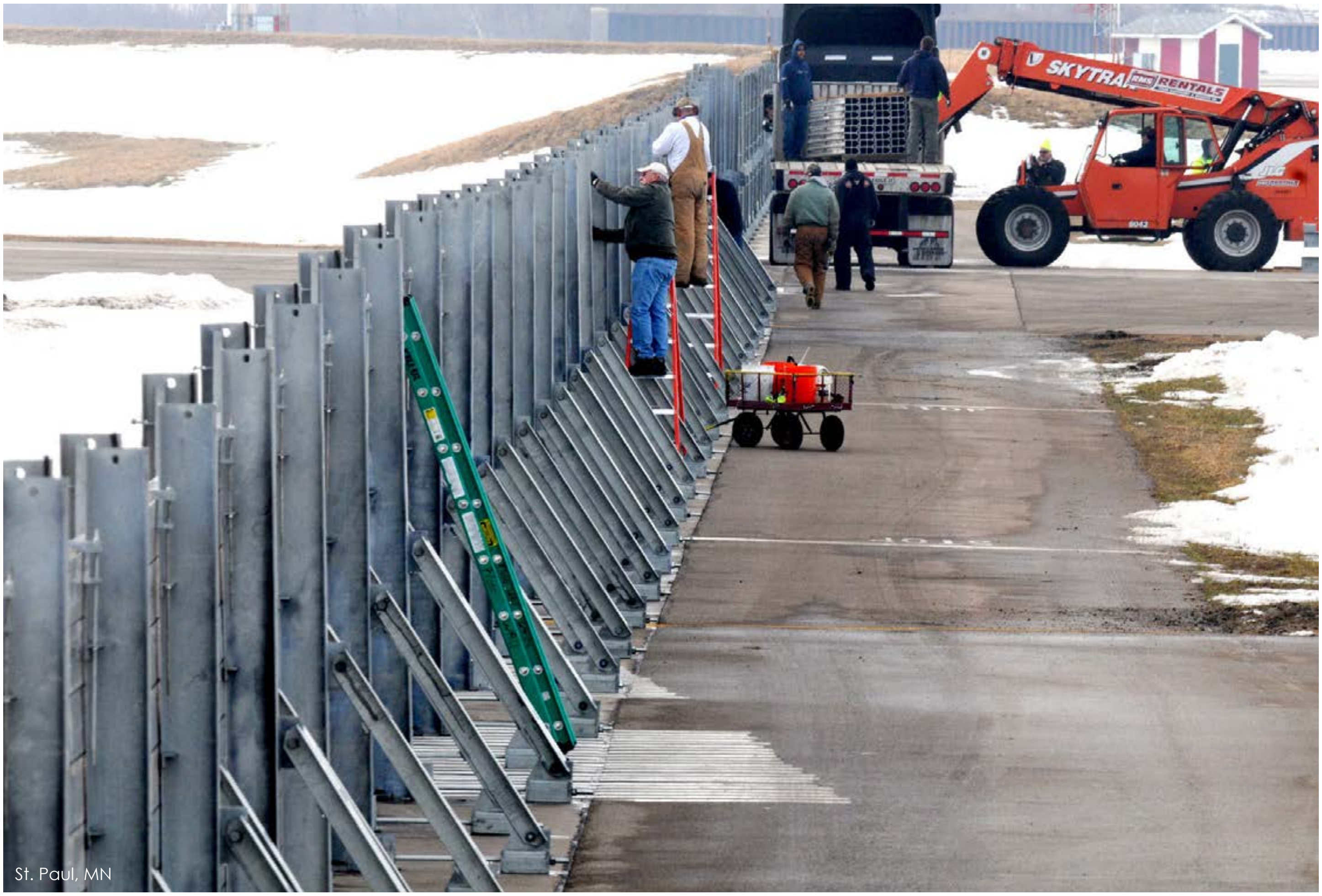
● HIGH ◐ MEDIUM ○ LOW

05. SITE PROTECTION

The use of floodwalls (deployable or permanent) or a berm on the exterior of building or around the site's perimeter to prevent water infiltration.



Floodwalls can be built around a building (not as part of the building as in dry floodproofing) to protect it from water infiltration in areas exposed to flooding. Floodwalls are either designed to be permanent structures always in place, or can be deployable, where most of the time they are stored away but are installed in advance of a storm. Berms are earthen mounds that can also afford site protection by blocking flood waters. Other forms of site protection may involve the use of a bulkhead or revetment at the shoreline to break waves and mitigate wave action, though these strategies are most relevant to large scale, reachwide protection (see page 66-109).



St. Paul, MN

Credit: St. Paul Pioneer Press

Hazards Addressed

- Site protection can help to protect buildings and contents from flooding from low and high levels of storm surges and associated wave forces. However, site protection is not recognized by FEMA standards.

Applicability

- This strategy is most applicable for larger sites with multiple buildings where there is ample open space to incorporate floodwalls or berms, and where site protection has the potential to be more cost-effective by protecting multiple buildings.
- For areas that experience wave action, site protection measures must be designed to withstand forces of waves.

Costs

- The cost of site protection increases with larger sites, for higher design flood elevations, and for buildings with many openings.
- Some site protection measures, such as permanent floodwalls, may pose design challenges and create conditions unfavorable for pedestrian street life.
- Systems with moving elements require maintenance costs which may exceed construction costs.
- Deployable floodwalls require space for storage and add additional operation costs to deploy in the event of a storm. In addition, they require advance planning, institutional memory, and human intervention.

Potential for Co-Benefits

- Permanent floodwalls may also double as security measures.
- Landscaped berms and floodwalls can create an additional site amenity.

Additional Considerations

- Floodwalls must be designed to avoid trapping stormwater behind the wall.
- Site protection should consider design strategies to avoid monotonous lengths of blank walls which would negatively impact the pedestrian experience.

Ability to Address Coastal Hazards

Storm Surge (High)	◐
Storm Surge (Low)	◐
Wave Force	◐

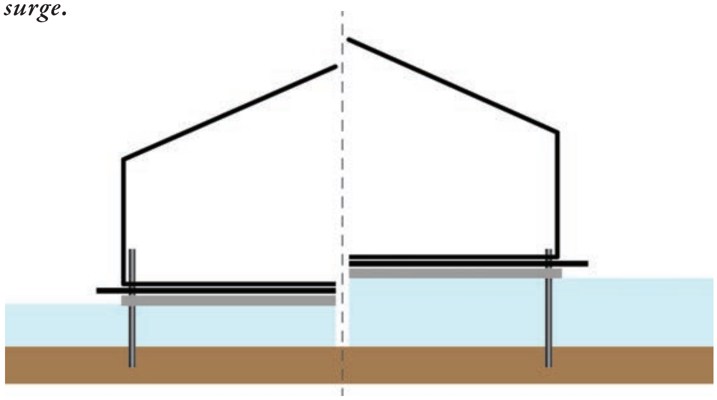
Applicability to Building Type

A	1-2 Family Detached	○
B	1-2 Family Attached	○
C	Low-Mid Rise Residential, Commercial, Mixed	●
D	High-Residential, Commercial, Mixed	●
E	Industrial	●

● HIGH ◐ MEDIUM ○ LOW

06. FLOATING STRUCTURES

A floating structure is one that floats on the water at all times and is designed to move vertically with tidal fluctuations and storm surge.



Floating buildings are habitable structures built on floating barges that are anchored to piles. Unlike houseboats, they have no motoring or steering capabilities and cannot move through the water on their own. Utility connections are flexible to allow the structure some movement. Parking is typically located off-site or at the street. Floating structures can rise and fall with changes in tide conditions and, with adequate piles, can withstand storm surge levels as well. However, they require calm water sheltered from the ocean, major currents, and storm waves. In advance of a major storm, they may be relocated to sheltered waters.

Permanent floating residential structures are rare in the New York area as they are effectively prohibited through various regulations. However, they are found elsewhere in the world, including the Netherlands, Germany, and Australia. In the U.S., floating homes are found in several cities mainly along the Pacific ocean, namely Sausalito, CA, Portland, OR, and Seattle, WA. They have raised issues in some areas as waterfront and environmental planning advocates push for maintaining waterfront space for water-dependent or public recreational uses.

Ijburg, Amsterdam, The Netherlands

Hazards Addressed

- Floating structures are a potential adaptation to deal with rising tides due to sea level rise, though adjacent shorelines may still be vulnerable.
- Floating structures can withstand high and low storm surge events as long as the pile-supports are designed appropriately.
- Floating structures are vulnerable to wave forces and require additional breakwaters to shelter from waves and wakes.

Applicability

- Due to regulatory restrictions and issues regarding eligibility for insurance coverage, this strategy has limited applicability.
- Typical floating structures from the U.S. are low density detached residential homes. Utility and access connections for higher density and commercial/industrial structures are problematic, though this has been resolved in some places.

Costs

- Additional expenses beyond the costs of a typical home include the cost of a floating platform (estimated at approximately $60 per square foot according to IMF, a Canadian manufacturer of floating platforms) and any additional costs for access ramps and utility connections.
- Floating structures, depending on their location and size, may have impacts on aquatic and intertidal ecosystems.
- Floating construction is not recognized by FEMA standards for flood resilience so may pose additional insurance costs or be difficult to get insured.

Potential for Co-Benefits

- Floating homes offer a unique way of living near the water.

Additional Considerations

- There are many considerations in finding an appropriate site for floating structures, including wave and wake limitations, conflicts with shipping channels and harbor traffic, and having sufficient upland space for access.
- Securing a mooring site may be difficult. While floating homes were once widespread in some places in the Pacific Northwest, such as Seattle, available mooring spaces have been decreasing as the attractiveness of the waterfront for higher density building and recreational space has increased.

Ability to Address Coastal Hazards

Storm Surge (High)	●
Storm Surge (Low)	●
Wave Force	○

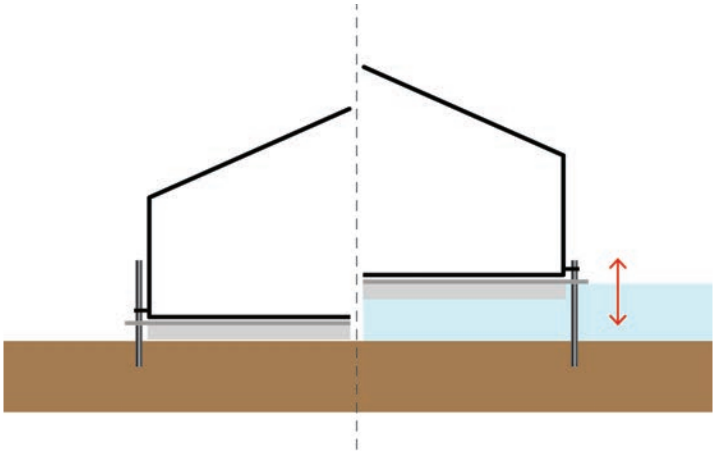
Applicability to Building Type

A	1-2 Family Detached	○
B	1-2 Family Attached	○
C	Low-Mid Rise Residential, Commercial, Mixed	○
D	High-Residential, Commercial, Mixed	○
E	Industrial	○

● HIGH ◐ MEDIUM ○ LOW

07. AMPHIBIOUS STRUCTURES

An amphibious structure is a building built on dry land that can float in the event of the site being flooded.



Amphibious structures differ from floating structures because they are positioned on dry land, yet designed with a buoyant foundation and pile supports to allow the entire structure to float up when the site is flooded. Anchored piles keep the structure in place. Utility connections are designed to either breakaway or are within long, coiled lines. The primary advantage to an amphibious structure is that it avoids the issues concerning elevating the ground floor of a house, including design and access concerns. Additionally, an elevated home may always be flooded by a storm with a flood level above the design flood elevation. For an amphibious structure, a design flood elevation is flexible, allowing the structure to be resilient to a wider range of flood levels. There are a few examples of amphibious homes in the Netherlands and Louisiana; however, this strategy is largely conceptual and has not gained mainstream or regulatory acceptance as a strategy for flood resilience.

CASE STUDY: AMPHIBIOUS FLOAT HOUSE, NEW ORLEANS, LA

Among the colorful and architecturally striking new homes sprouting up in New Orleans' Lower 9th Ward, one stands out for its innovative approach to flood plain construction. Rather than propping the house on stilts, like most of its neighbors, the architecture firm Morphosis, in collaboration with the Make It Right Foundation and UCLA Architecture and Urban Design, designed a per-fabricated "amphibious" house that sits close to ground level on dry days, but in the event of a flood will respond by floating up to 12 feet above grade. The house's base functions as a raft guided by steel masts, which are anchored to the ground by two concrete pile caps each with six 45-foot deep piles. In addition to its flood responsiveness, the house is designed to be contextually appropriate by incorporating architectural features of the New Orleans' "shotgun" house, such as a front porch and typical floor plan, as well as facilitating accessibility for elderly and disabled residents. At 945 square feet, FLOAT House also strives to be affordable and reproducible, through prefabricated modular construction components, and sustainable, by incorporating a variety of energy efficient and stormwater control features.

Hazards Addressed

- Amphibious structures can withstand high flood levels, but are not suitable in areas with waves or where flooding in accompanied with fast-moving water.

Applicability

- This strategy is relatively untested and does not meet FEMA standards for flood zone construction.
- Existing examples are limited to one to two family detached residential homes.

Costs

- According to the Buoyant Foundation, a non-profit organization in Louisiana, an amphibious foundation costs $20,000 - $25,000 for an average single-family home in the region. These costs are likely much higher in New York City.
- Amphibious construction is not recognized by FEMA standards for flood resilience purposes so may pose additional insurance costs.

Potential for Co-Benefits

- Amphibious structures provide the flood protection of elevation without consequences on building access.

Additional Considerations

- Further research and development of this strategy is needed. Some of the concerns include the ability to test and maintain the technology, and the risk of failure.

Ability to Address Coastal Hazards

Storm Surge (High)	●
Storm Surge (Low)	●
Wave Force	○

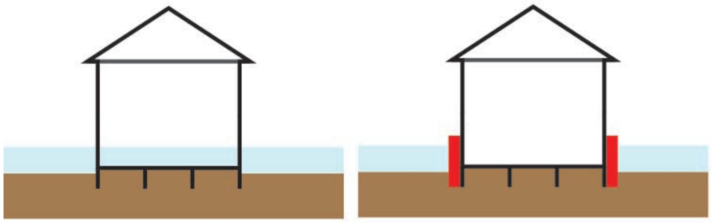
Applicability to Building Type

A	1-2 Family Detached	○
B	1-2 Family Attached	○
C	Low-Mid Rise Residential, Commercial, Mixed	○
D	High-Residential, Commercial, Mixed	○
E	Industrial	○

● HIGH ◐ MEDIUM ○ LOW

08. DRY FLOODPROOFING

Retrofitting a building to be dry floodproofed means to seal a building's exterior and openings to inhibit water infiltration in the event of a storm.



There are a number of techniques for retrofitting an existing building that seek to resist the infiltration of water during a storm event. These include physical barriers such as shields or gates, sealing strategies for utilities as well as building envelopes, and pumping strategies to remove any floodwater that does enter the building. In many cases, dry floodproofing a building is desirable not only because of the unknown quality of floodwater and the likelihood that flood-borne objects will enter and damage a building, but also because it means the space at or below the design flood elevation can be occupied, conditioned, and secured.

FEMA standards do not recognize dry floodproofing strategies for purely residential buildings, meaning that incorporating these strategies will not bring an existing residential building into compliance with the National Flood Insurance Program and will not reduce insurance premiums. Additionally, this approach may encourage the storage of valuable commodities at a vulnerable elevation.

To be effective, all potential means of floodwaters entering a building must be blocked, including below grade entry points and utility connections. Below grade spaces common in New York City such as sidewalk vaults, electrical substations, and basement-level mechanical, electrical, vertical transport, and fire protection equipment require consideration and protection.

When utilizing dry floodproofing, a building's structural resilience to resist water loads and buoyancy forces must be reinforced through such measures as adding bulk to a foundation or perimeter wall or reinforcing columns. The necessity of additional structural reinforcing depends largely on the construction type and varies with building type and age. The design and engineering of modern medium and tall buildings in New York City result in structures that have a much greater capacity to withstand flood loads than smaller, unreinforced (and often single-family) dwellings. Wood frame construction, on the other hand, is not suitable for dry flood proofing because of the lack of structural reinforcement.

Flood Shield

Image courtesy of www.floodpanel.com

Hazards Addressed

- Dry floodproofing is most effective at flood elevations one to three feet above grade, but can provide some protection up to much greater heights.
- Dry floodproofing does not typically protect structures from high-velocity flood waters or wave action.

Applicability

- Dry floodproofing is best suited for commercial, mixed-use, or community facility buildings in areas with low risk from wave action, or A zones. FEMA standards do not consider this strategy to be appropriate for purely residential buildings though it may be an effective strategy to provide some degree of protection as long as egress in the event of a storm is maintained. FEMA standards do not consider dry floodproofing to be appropriate in V zones.
- Dry floodproofing is likely cost-prohibitive for low-rise retail or industrial buildings.
- When dry floodproofing is used, the structure must be designed to resist water loads on the exterior walls and buoyant forces on the foundation. For some construction types, this may preclude the use of dry floodproofing for more than 3 feet above grade.
- Dry floodproofing is not recommended for areas which experience flood events of a significant duration because most sealing systems used will begin to leak after prolonged exposure to water.
- Dry floodproofing is not recommended for existing unreinforced buildings with basements because of the potential for saturated soils to exert lateral loads on basement walls and for buoyant forces to put pressure on foundations and slab, resulting in structural failure.
- Dry floodproofing a single attached or semi-attached building does not address structural or sealing issues that occur with party walls.

Costs

- The cost of dry floodproofing will vary widely depending on the size of the building and the height of floodproofing, the types of seals and barriers, and the number of openings that must be protected. Dry floodproofing is typically more expensive than wet floodproofing, but less expensive than elevating structures. Cost estimates for retrofitting an existing building with dry floodproofing range from approximately $1.5 million for a low-rise retail or industrial building to $6 million for a commercial high-rise.
- For purely residential buildings, dry floodproofing will not bring a building into compliance with FEMA standards for flood zone construction so insurance premiums will not be reduced.
- Dry floodproofing may require the installation of flood barriers in advance of a storm through human intervention and ongoing maintenance and storage of barriers.
- Flood shields may conflict with the exterior design of a building and public space, and may infringe upon the sidewalk right-of-way.
- Flood gates and sealed membranes may leak causing damage to structure and contents.

Potential for Co-Benefits

- Dry floodproofing allows for active uses of the lowest floor, thereby avoiding the impacts on the public realm of elevating the lowest occupiable floor and restricting the ground floor to parking, storage, and access.
- Allows for below grade basements and underground parking, though foundations must be designed to withstand water loads and buoyant forces. Dry floodproofing an existing building with a basement can significantly reduce flood insurance premiums.
- Dry floodproofing may improve a building's insulation and reduce energy consumption.

Additional Considerations

- Adequate advance preparation and warning time is required to install any deployable flood barriers and evacuate the building.
- Dry floodproofing may require reinforcement of the foundation system, which requires excavation of sidewalk for the construction of a new footing and additional drainage along the exterior of the foundation.
- Dry floodproofing should consider design strategies to avoid monotonous lengths of blank walls which would negatively impact the pedestrian experience.

Ability to Address Coastal Hazards

Storm Surge (High)	○
Storm Surge (Low)	◐
Wave Force	○

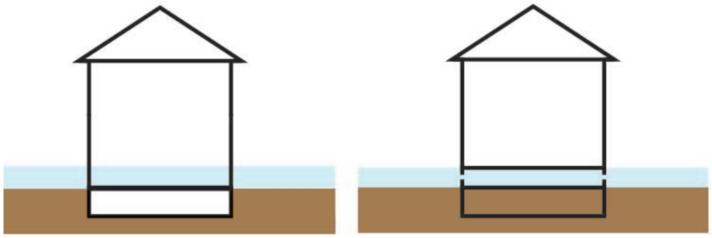
Applicability to Building Type

A	1-2 Family Detached	○
B	1-2 Family Attached	○
C	Low-Mid Rise Residential, Commercial, Mixed	◐
D	High-Residential, Commercial, Mixed	●
E	Industrial	○

● HIGH ◐ MEDIUM ○ LOW

09. WET FLOODPROOFING

Retrofitting a building to be wet floodproofed means to incorporate measures that allow a building to accommodate flood waters.



The goal of wet floodproofing is to minimize damage from flood loads by permitting water to flow through crawl spaces, parking garages, and around vertical structures below the design flood elevation. One possible approach to use wet floodproofing to retrofit an existing building is to raise the ground floor within a building envelope to the design flood elevation and incorporate wet floodproofing below. This would require substantial headroom within the ground floor, and additional access elements. Flood vents are installed throughout the exterior walls which are designed to let water enter the building and allow water forces to equalize on either side of the exterior wall. Surfaces within the wet floodproofed spaces are refinished with flood-damage resistant materials.

Although wet floodproofing is preferable to dry floodproofing for residential buildings, it has serious implications for the use of the wet floodproofed space. Spaces that are designed to be wet floodproofed will not be protected during a flood and FEMA standards limit these spaces to non-occupiable access or storage. Wet floodproofing may necessitate the abandonment of the ground floor, resulting in the loss of retail or residential units, or introduce new challenges for protecting building contents or equipment. If the building is substantially damaged or is being substantially improved, wet floodproofing requires that subgrade spaces are filled and utilities are elevated, increasing costs (see Protect Building Systems, page 58).

Before and After Images

Credit: Roubion Construction Co.

Hazards Addressed

- Wet floodproofing protects buildings from structural damage due to flooding, but it does not protect contents from flood damage.
- Wet floodproofing does not protect the building from wave action or high-velocity flood flows.

Applicability

- Wet floodproofed spaces have limited uses because the contents may be inundated in the event of a flood. It is typically used for the crawlspace below the ground floor which is not finished for occupiable uses, but can be used for minor storage, building access, and parking .
- Wet floodproofing to allow a subgrade basement to flood is a cost-effective way to protect a building from structural damage; however, to bring a building into compliance with FEMA standards, the basement would need to be filled in.
- In combination with elevation, this strategy can work well for low-density residential buildings; however, elevation for a larger structure or industrial uses requires a large lot to allow room for building access.
- This strategy is best suited for A zones. Wet floodproofing is not recommended in V zones by FEMA standards.

Costs

- Wet floodproofing is typically the least expensive option for retrofitting. Cost estimates for wet floodproofing of existing buildings range from approximately $100,000 for a detached one to two family house to $1.5 million for a high-rise residential or commercial building.
- Extensive clean-up after flooding may be required to make the wet floodproofed space usable after a storm.
- Wet floodproofing may necessitate the abandonment of the ground floor, resulting in the loss of retail or residential units.

Potential for Co-Benefits

- Wet floodproofing is less likely to significantly alter the exterior appearance of a building as compared to elevation or dry floodproofing.

Additional Considerations

- Utility equipment located below the design flood elevation should be elevated or otherwise protected.
- Wet floodproofed spaces and any contents within them will get wet and possibly be contaminated with chemical, sewage, or other materials in floodwaters
- Consider design strategies to avoid negative impacts on the sidewalk and neighborhood context.

Ability to Address Coastal Hazards

Storm Surge (High)	◐
Storm Surge (Low)	◐
Wave Force	○

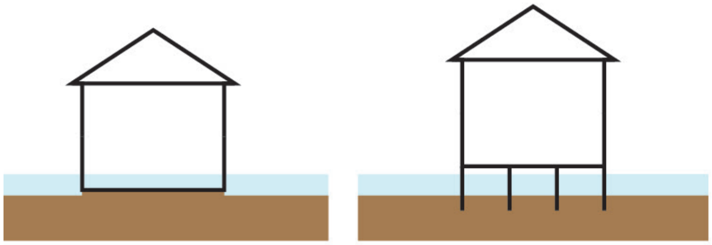
Applicability to Building Type

A	1-2 Family Detached	◐
B	1-2 Family Attached	◐
C	Low-Mid Rise Residential, Commercial, Mixed	◐
D	High-Residential, Commercial, Mixed	◐
E	Industrial	◐

● HIGH ◐ MEDIUM ○ LOW

10. ELEVATE

Elevating a building involves raising the structure on piles or columns so that the lowest occupied floor is above the design flood elevation.



For one to two family detached residential homes, elevating the structure so that lowest occupied floor is above the design flood elevation is the most commonly pursued retrofitting strategy. However, elevation poses substantial technical difficulties for many urban buildings and is likely to be very expensive. Elevation of the entire building creates challenges for urban design because it divorces buildings from the streetscape. Elevation of the ground floor also poses difficulties for providing ADA access and allowing for visible retail space.

To elevate a structure, it is separated from the foundation, raised on hydraulic jacks and held in place while a new or extended foundation is constructed below. There are several variations of potential elevation strategies. One is to elevate a home on continuous walls by extending the existing foundation with masonry block or cast-in-place concrete. The crawlspace created would likely be wet floodproofed (see previous strategy). This method is recommended within A zones, where risk from wave action is low. Another method is to elevate the structure on an open foundation made of individual vertical structures such as piers, columns, or piles. Piers are vertical structures built of masonry or cast-in-place concrete that sits in a concrete footing. Columns (also called posts) are usually made of wood, steel, or reinforced concrete/masonry set in holes encased in concrete or on concrete pads, and are required to connect to each other for support through additional bracing. Piers and columns are not designed to withstand horizontal pressures from wave action or high-velocity flooding, so are not appropriate for V zones. The use of piles to elevate a home is the recommended strategy for V zones.

A final variation on elevation is to build a new raised floor within the existing building envelope to the design flood elevation. This could involve the raising of the roof and walls if there is not adequate space to accommodate the necessary headroom. The space below the design flood elevation becomes a crawlspace and is wet floodproofed as described in the previous strategy. If there is a basement, it may be filled in. In addition, all utilities must be elevated to the new first floor or an upper floor.

Sea Bright, New Jersey NJ

© FEMA / Steven Zumwalt

Hazards Addressed

- Elevating a structure can protect a building and its contents from flooding of high and low surge events.
- Elevating a structure on piles can provide structural protection from wave action and high-velocity flood waters.

Applicability

- This is the only retrofit option that will bring a residential structure into compliance with FEMA standards. It is most feasible for detached, low-rise structures.
- For larger buildings, there are a variety of issues relating to access, ground floor uses, and design.
- Attached structures must be elevated at the same time, raising issues of coordination among adjacent property owners.
- Site access for piling equipment may pose challenges for small sites. In addition, pile-driving must consider the potential for vibration and damage to adjacent structures.
- Elevating to a high design flood elevation requires sufficient space for access elements, such as stairs, ramps, and elevators.

Costs

- Costs depend on the size of the building elevated and its foundation type. Slab-on-grade structures are typically more expensive to elevate than those with an existing open foundation or crawlspace.
- Pile-driving adds additional costs.
- Elevating the lowest occupied floor within a building envelope will result in the loss of some usable space.
- For all elevation strategies, there will be additional costs to add access elements and relocate building systems.
- May have negative impacts on pedestrian realm of the street through obtrusive ramping and loss of active uses.
- To elevate an entire 1-2 family detached building it may cost approximately $60,000 to $200,000, depending on site-specific factors.

Potential for Co-Benefits

- Most elevation strategies maintain the building's floor area.
- Elevating a residential home may reduce insurance premiums.
- Space below the elevated structure may be used for additional storage and parking, though it is not protected from flooding.

Additional Considerations

- In some cases, demolishing a building and constructing a new one may be more cost-effective that elevating an entire structure, unless the building is subject to historic preservation ordinances.
- Consider design strategies to avoid negative impacts on the sidewalk and neighborhood context.

Ability to Address Coastal Hazards

Storm Surge (High)	●
Storm Surge (Low)	●
Wave Force	●

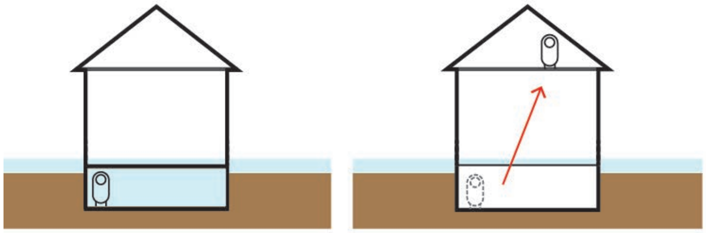
Applicability to Building Type

A	1-2 Family Detached	◐
B	1-2 Family Attached	○
C	Low-Mid Rise Residential, Commercial, Mixed	○
D	High-Residential, Commercial, Mixed	○
E	Industrial	○

● HIGH ◐ MEDIUM ○ LOW

11. PROTECT BUILDING SYSTEMS

There are a variety of specific measures designed to protect a building's electrical and mechanical utilities from flooding.



Building systems, including mechanical, electrical, fuel, HVAC systems, plumbing, elevator, and fire protection systems are highly vulnerable to flood waters, which can short circuits, render equipment unusable, or damage systems beyond repair. Strategies for protecting these systems aim either to relocate vulnerable equipment or conduits, secure specific components, or adapt their functioning to minimize damage. Similar to those strategies aimed at preventing water infiltration, they must not be misconstrued as eliminating the need to evacuate buildings in the flood zone. Except for the case of critical facilities, the primary purpose of protecting building systems is to prevent their costly and difficult replacement following a storm event and to allow a building to be reoccupied sooner.

Measures to protect building systems include relocating or sealing external utilities, anchoring, elevating, or constructing a floodproof enclosure around equipment, elevating mechanical equipment and electrical wiring, installing ground fault circuit interrupters in potential wet locations, and converting to a tankless water heater. Some measures may include the installation of floodwalls, shields, or floodproof doors to protect building systems while the building itself is wet floodproofed. As with dry floodproofing, the building's structural ability to withstand hydrostatic pressure must be examined. Backflow valves are a measure to ensure sewer systems do not flow backward through drains and toilets during a flood. There are various types of backflow valves, some which require manual operation and others which work without human intervention. While some measures are relatively straightforward, the relocation of equipment may require extensive work throughout a building and may be constrained by codes, ceiling heights, or the availability of space for ductwork, pipes, etc.

Raised Air Conditioner

Hazards Addressed

- Floodproofing building systems can provide an additional layer of protection in combination with other strategies to protect buildings from low and high levels of flooding.
- Specific measures can be implemented to allow a building to recover quicker from a storm, though such measures alone do not protect building contents or the structure from flood damage.

Applicability

- The applicability of building system strategies vary widely depending on the construction type of each building and the way the utilities are configured.
- The feasibility of elevating system equipment inside the building depends on the height of the design flood elevation and the space available within the building envelope. Buildings that are substantially damaged or substantially improved are required to relocate or protect utilities

Costs

- Protecting building systems is likely more expensive for larger buildings with more equipment and more complications. Elevating building equipment above the design flood elevation is typically more expensive than protecting the equipment in place, especially for high-rise buildings. For a high rise commercial building, it may cost approximately $1M to protect all building systems through enclosures and floodproofed risers or approximately $20 M to make space for and elevate all equipment. For a one to two family detached building, the cost to protect all equipment is approximately $85,000, while the cost to relocate it to a higher floor is approximately the same.
- Protecting building systems alone is not recognized by FEMA standards and will not lead to reductions of flood insurance premiums.
- Raising utility equipment from the basement to an upper floor may decrease the amount of livable space, which for rental properties means a loss of income generating floor area.

Potential for Co-Benefits

- Retrofitting fuel equipment may provide an opportunity for conversion to a cleaner fuel source.

Additional Considerations

- Elevating some elements of building systems may be in conflict with certain codes or standards, such as the fire code. In addition, some utility companies may not allow a property to raise electric or gas meters.
- Large equipment on elevated platforms may be more vulnerable to wind and earthquake damage.

Ability to Address Coastal Hazards

Storm Surge (High)	●
Storm Surge (Low)	●
Wave Force	●

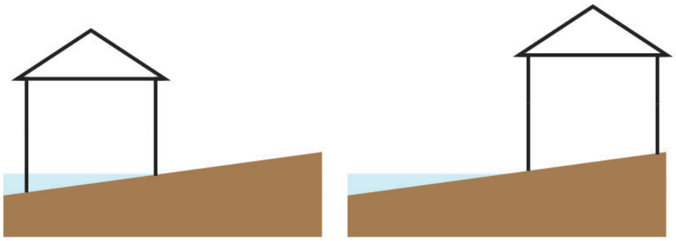
Applicability to Building Type

A	1-2 Family Detached	●
B	1-2 Family Attached	●
C	Low-Mid Rise Residential, Commercial, Mixed	●
D	High-Residential, Commercial, Mixed	●
E	Industrial	●

● HIGH ◐ MEDIUM ○ LOW

12. RELOCATE / DEMOLISH

Relocating or demolishing a structure removes the building from the area vulnerable to flooding.



Relocation can protect a building from flooding entirely, though it is often the most expensive alternative and presents many additional issues. To relocate a building, the structure is lifted off its foundation and placed on a flatbed trailer to move to a new site or new location on the same site, where a new foundation is built. All utility systems must be disconnected and require reconnection at the new site. Only buildings in strong structural conditions can be moved. Smaller structures with simpler foundations, such as wood-frame homes over a crawlspace or basement are the easiest to relocate. Larger multistory or solid masonry structures are more complicated to move due to their weight and size. Brick facades are particularly hard to move as they may crack or peel when disturbed. Finding a route to move a structure can be very complicated, especially for a large structure within an urban area where there are many narrow streets and confined clearances.

Similar to relocations, demolishing a building is pursued because the structure has been damaged to such an extent that it is more practical to demolish and rebuild, or in accordance with an acquisition program where the state or local government purchases the property, demolishes any buildings, and maintains the land as open space (see Strategic Retreat, page 72-73).

Hazards Addressed

- Protects from all hazards.

Applicability

- Relocation is most feasible for 1-2 story detached buildings of light construction and crawlspace or basement foundation in areas where space exists to move or transport the structure, though is unlikely to be cost-effective.
- Structures such as historic landmarks that cannot be easily protected otherwise may be worth the expense of relocation.

Costs

- According to FEMA guidance documents, relocation is usually the most expensive option for single-family homes.
- Additional costs beyond relocation expenses include purchasing a new property. The sale of the existing property may be restricted by flood insurance and construction requirements.
- There may be indirect impacts on property values and local economies to adjacent sites and in the neighborhood as a whole.

Potential for Co-Benefits

- Sites left as open space may offer recreation benefits, drainage improvements, flood buffering, and habitat enhancement.

Additional Considerations

- To understand the full range of considerations for relocation and or demolition, these strategies should be considered at the neighborhood scale (see page 72-73).

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SITE STRATEGIES SUMMARY

● HIGH ◐ MEDIUM ○ LOW

	ABILITY TO ADDRESS COASTAL HAZARDS			APPLICABILITY TO BUILDING TYPE				
	Storm Surge (HIGH)	Storm Surge (LOW)	Wave Force	1-2 Family Detached	1-2 Family Attached	Low-Mid Rise Residential, Commercial, Mixed	High-Rise Residential, Commercial, Mixed	Industrial
NEW CONSTRUCTION								
01. Dry Floodproofing	◐	●	○	○	○	◐	●	○
02. Elevate on Enclosure / Wet Floodproofing	●	●	○	●	●	◐	◐	◐
03. Elevate on Fill or Mound	●	●	○	◐	◐	◐	◐	◐
04. Elevate on Piles	●	●	●	◐	◐	◐	◐	◐
05. Site Protection	◐	◐	◐	○	○	●	●	●
06. Floating Structures	●	●	○	○	○	○	○	○
07. Amphibious Structures	●	●	○	○	○	○	○	○
RETROFITTING EXISTING BUILDINGS								
08. Dry Floodproofing	○	◐	○	○	○	◐	●	○
09. Wet Floodproofing	◐	◐	○	◐	◐	◐	◐	◐
10. Elevate	●	●	●	◐	○	○	○	○
11. Protect Building Systems	●	●	●	●	●	●	●	●
12. Relocate / Demolish	●	●	●	N/A				

NEW CONSTRUCTION

Dry floodproofing prevents damage to a building and its contents through preventing the flooding of interior spaces. It is best-suited to address surge heights of several feet above grade and potentially higher in some situations. It does not typically protect against wave forces. FEMA standards do not consider dry floodproofing to be appropriate for purely residential buildings, though it may be provide some additional value if issues of egress in the event of a storm are resolved. Dry floodproofing is likely cost-prohibitive for low-rise retail or industrial buildings.	01. Dry Floodproofing
Wet floodproofing protects buildings from structural damage due to flooding, but it doesn't protect the interior from flood damage. In combination with the elevation of habitable spaces on columns or walls, buildings contents and systems are protected as well. Wet floodproofing does not protect the building from wave action or high-velocity flood flows. Wet floodproofed spaces have limited uses, but in combination with elevation this can work well for low-density residential buildings. Elevation for larger structures or industrial uses requires a large lot to allow room for building access.	02. Elevate on Enclosure / Wet floodproofing
Elevating a site above the design flood elevation can provide protection from flooding in the event of coastal storm. It may also be used to elevate a site high enough to prevent frequent flooding at high tide due to sea level rise. Fill may be eroded by waves or scour if not properly designed. This may be an effective strategy for any building type. The size of the lot and the height of the design flood elevation are the primary factors in determining the applicability of this strategy.	03. Elevate on Fill or Mound
Elevating on piles protects the building and its contents from flooding of low and high surge events and associated wave forces. This strategy is technically simpler for smaller buildings, but since it is one of the more expensive strategies, it is more likely to be cost-effective for larger buildings.	04. Elevate on Piles
Site protection can help to protect buildings and contents from flooding from low and high levels of storm surges and associated wave forces. Site protection is not recognized by FEMA standards for residential construction. It is more expensive on larger sites or buildings with many openings.	05. Site Protection
Floating structures can withstand high and low surge levels and can move with rising tides, however they cannot withstand significant wave forces. Due to regulatory restrictions and insurance eligibility this strategy has limited applicability. Utility and access connections for higher density and commercial/industrial structures are problematic.	06. Floating Structures
Amphibious structures can withstand high and low surge events in areas protected from wave forces. This strategy is relatively untested and does not meet FEMA standards.	07. Amphibious Structures

RETROFITTING EXISTING BUILDINGS

Dry floodproofing prevents damage to a building and its contents through preventing the flooding of interior spaces. It is best-suited to address surge heights of several feet above grade and potentially higher in some situations. It does not protect against wave forces. FEMA standards do not consider dry floodproofing to be appropriate for purely residential buildings, though it may be cost-effective, particularly for higher density structures.	08. Dry Floodproofing
Wet floodproofing protects from structural damage in the event of a flood, but does not protect the building contents, and does not provide protection from wave forces. This strategy is a less expensive alternative though the uses of wet floodproofed spaces are limited.	09. Wet floodproofing
Elevation protects a building from flooding of high and low surge events and can be designed to withstand wave action. This is the only retrofit option that will bring a residential structure into compliance with FEMA standards. It is most feasible for detached, low-rise structures. For larger buildings, there are a variety of issues relating to access, ground floor uses, and design.	10. Elevate
Protection of building systems can provide an additional layer of protection in combination with other strategies, or can be used on its own to allow a building to recover quicker from a storm. This generally works for all building types though complications depend on how building utility systems are designed which can vary widely.	11. Protect building systems
	12. Relocate / Demolish

REACH STRATEGIES

In many locations, particularly in high density areas, it is often more practical to approach resilience through such larger scale adaptation measures, or "reach" strategies, rather than at the individual property level. Reach strategies to increase coastal climate resilience involve upland measures that affect multiple sites, such as elevating land or changing land uses, as well as shoreline or in-water strategies, such as levees, bulkheads and breakwaters which affect a long stretch of shoreline. Since reach strategies affect an area greater than one individual site, they require a greater level of coordination among affected individuals and multiple government agencies with overlapping jurisdictions. Government agencies play an important role in the implementation of reach strategies, as public funding is often necessary to carry them out. The U.S. Army Corps of Engineers is often the agency charged by Congress to lead such efforts, but state and local capital agencies can also implement reach strategies.

The appropriateness of a reach strategy depends greatly on the specific coastal environment, and their design must consider environmental conditions such as shoreline composition, sediment transport, wave force and heights, and water depth, among other factors. Many reach strategies can have negative environmental impacts on tidal and freshwater wetlands and water quality, and government plays an important role as regulators to ensure the protection of natural resources. Environmental permits are required for practically all of the reach strategies and in New York, the Department of Environmental Conservation is responsible for issuing permits. U.S. Army Corps permits are also necessary for any work, including construction and dredging, in navigable waters. Furthermore, projects are required to show consistency with the policies of the New York State Coastal Management Program and, in New York City and other municipalities, a local *Waterfront Revitalization Program*, as a way of balancing competing land and water uses in the coastal zone. The costs and timing associated with permitting can be significant and must be factored into project budgets.

Recently, there has been growing interest in creating softer, more natural shorelines, and several of these strategies, such as living shorelines and artificial reefs are discussed in this section. These strategies, however, remain relatively untested in the New York region, and therefore may require further pilot projects and research to determine their effectiveness.

In the following section, the reach strategies are divided into the following categories:

A. Upland Strategies: These are strategies that do not involve direct impact on the water or the shoreline, but involve changes to areas inland of the shoreline.

B. Shoreline Strategies: Coastline strategies are measures to armor or reinforce the shoreline to protect from erosion, block storm surge, or attenuate waves.

C. In-Water Strategies: These are strategies that are primarily deployed seaward of the shoreline and act to protect upland areas from erosion and wave forces by attenuating waves, or to reduce the height of storm surge.

Each potential strategy is described and analyzed for the following:

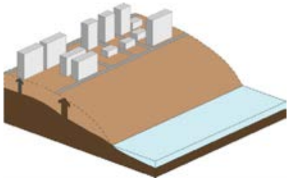
- ***Hazards Addressed:*** The ability of the strategy to address coastal hazards that are both "event based" (storm surge, wave action, sudden erosion) and "gradual" (frequent flooding due to sea level rise, gradual erosion).
- ***Applicability:*** Factors which determine a strategy's applicability to various geomorphology categories and other site-specific factors.
- ***Costs:*** When available, estimates of costs are general and consist of ranges or estimates that include soft, hard, and contingency costs based on 2013 dollars. Many of the costs were developed for the *Special Initiative for Rebuilding and Resiliency* as preliminary ranges for parametric costs. The costs of each strategy are highly dependent on various site-specific factors and should be evaluated on a case by case basis. The potential for indirect costs, such as potential impacts on water quality or the amount of land available for other uses are also discussed.
- ***Potential for Co-Benefits:*** In addition to flood protection, some strategies offer opportunities for co-benefits that may factor into the decision-making process to make a strategy more beneficial.
- ***Additional Considerations:*** For all of these strategies, there are a variety of additional considerations including design, technological, regulatory, or implementation factors that should be considered in the decision-making process.

All of these strategies require extensive site-specific analysis to determine their suitability and more precise costs and benefits before being pursued for a given site. This section is intended to give a broad overview of the types of strategies available and an understanding of the major issues associated with each.

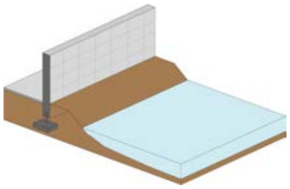
REACH STRATEGIES

Upland

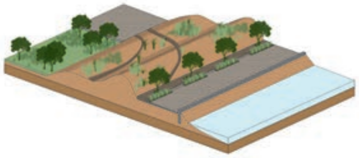
01 Elevation of Land and Streets



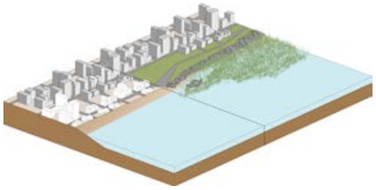
02 Floodwalls



03 Waterfront Parks

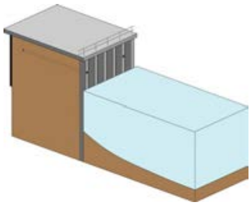


04 Strategic Retreat

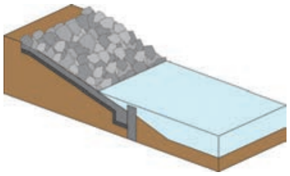


Shoreline

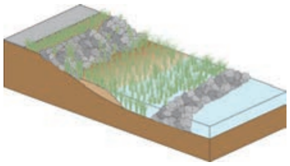
05 Bulkheads



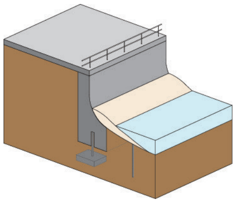
06 Revetments



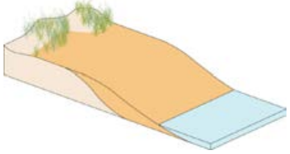
07 Living Shorelines



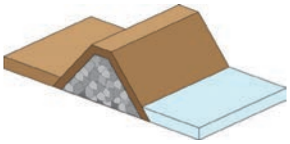
08 Seawalls



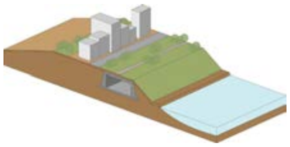
09 Beaches and Dunes



10 Levees (or Dikes)

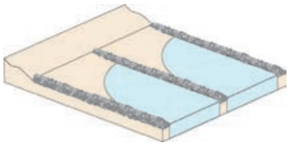


11 Multi-purpose Levees

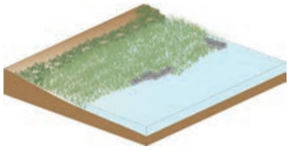


In-Water

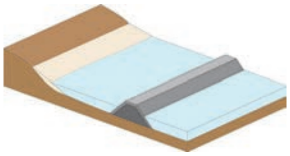
12 Groins



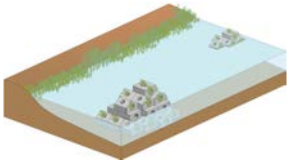
13 Constructed Wetlands



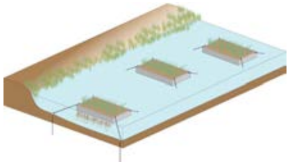
14 Breakwaters



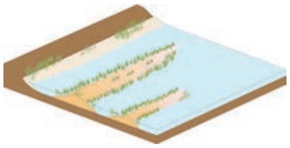
15 Artificial Reefs



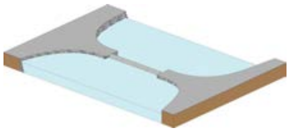
16 Floating Islands



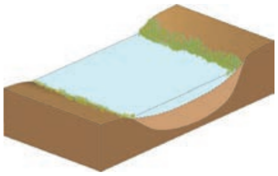
17 Constructed Breakwater Islands



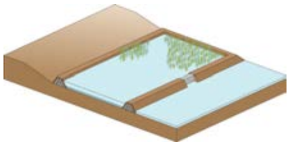
18 Surge Barriers



19 Coastal Morphology Alteration

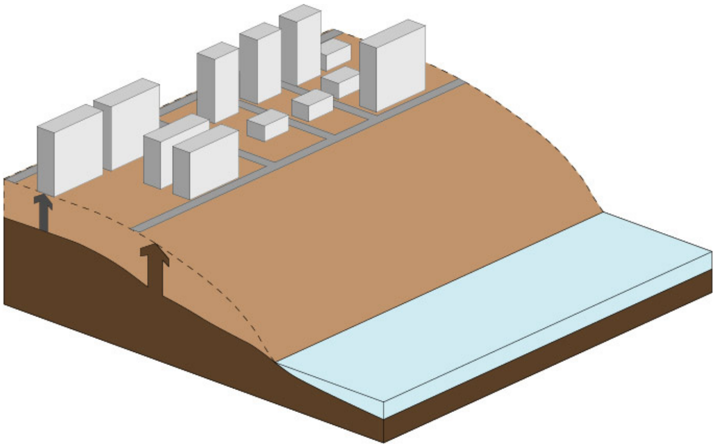


20 Polders



01. ELEVATION OF LAND & STREETS

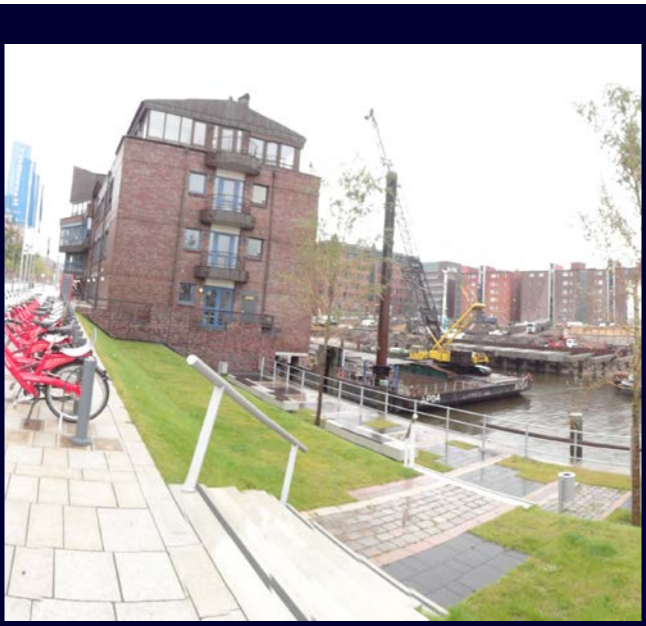
Elevation existing or new development sites and streets above the expected storm level to protect from flooding.



Elevating land and streets to protect from flooding has numerous benefits. Given that it is initially costly and potentially disruptive, it is a strategy that works best on large development sites or at a neighborhood scale, where both lots and streets can be raised in a coordinated manner. Once constructed, however, raised land requires virtually no unusual ongoing capital or maintenance costs. Flood insurance can become more widely available to affected areas, and at reduced rates. Grade raising also offers an opportunity for municipalities looking to update and rationalize subsurface utilities and infrastructure. However, unless working on a undeveloped site, significant engineering and design issues may arise, such as resolving connections between existing buildings and new grades, and addressing connections to adjacent infrastructure and underground utilities such as sewers, stormwater drainage, and subways. There may also be clearance issues with overhead infrastructure, such as elevated subways and highways, and access points to adjacent sites would also need to be addressed.

Elevating land to protect it against flooding has historic precedents. The oldest major domestic example is Chicago, which did so along parts of its South Side and in the Loop between roughly 1855 and the 1870s. Approximately 500 blocks of Galveston, TX, which lost over 6,000 of its 44,000 residents in the Hurricane of 1900, were raised by up to 11 feet between 1903 and 1911. Seattle, WA , Sacramento, CA, and Chattanooga, TN also embarked on major grade elevation projects. All of these cities did so in response to either natural disaster or chronic poor drainage in downtown and riverfront areas.

Elevation of vulnerable land has been pursued in New York City as well. Arverne By The Sea, a 117-acre oceanfront development on the Rockaways, was raised approximately 5 feet prior to construction, and for the most part, experienced significantly less flooding during Hurricane Sandy compared to many of its neighbors. Other recently approved large-scale projects in flood zones include the raising of sites. A component of the *Coney Island Comprehensive Rezoning Plan* approved by the NYC City Planning Commission in July 2009 raised legal street grades to enable ground-floor commercial spaces to be closer to or at FEMA's Base Flood Elevations for that portion of Coney Island. The Willets Point development in Queens will also require raising the grade of the existing land by up to 6 feet within its boundaries.



Credit: Alex Washburn

CASE STUDY: HAFENCITY, HAMBURG, GERMANY

Hafencity, Europe's largest inner-city redevelopment underway, aims to transform a former industrial port area into a flood resilient, mixed use quarter that will expand central Hamburg by 40%. By building on warfts (artificial compacted mounds), Hafencity's urban design concept aims to connect residents with the waterfront while providing protection from increasingly frequent extreme flooding due to climate change. Rather than constructing levees or seawalls that would cut off the public's experience of the water, a multi-tiered urban network includes low-lying, floodable public spaces and waterfront promenades at the pre-existing elevations (approximately 5 meters above sea level) and raised buildings, streets, bridges and infrastructure (approximately 8 to 8.5 meters above sea level). The fine-grained mix of uses and the public character of ground floor uses aims to ensure that street level activity remain active.

With an anticipated completion date of 2025, Hafencity will occupy 157 hectares and include 2.32 million square meters of gross floor area, 6,000 residential units, 26 hectares of public space, and will yield an anticipated 45,000 jobs. The development of Hafencity is managed by Hafencity Hamburg GmbH, a subsidiary of the City of Hamburg. With many similar prevailing characteristics as New York City in terms of density, land use and urban form, Hafencity offers a compelling model for how a dense urban center can coexist with coastal floodwaters and adapt to rising sea levels.

Hazards Addressed

- Elevating land and streets reduces risk from frequent inundation and surge events by elevating land to above expected flood levels.
- It can be combined with shoreline armoring to protect from erosion and wave forces.
- The feasibility of elevating land to protect from very high surge elevations is dependent on existing grades of sites, size of the area, and ability to access adjacent sites.

Applicability

- This strategy is most suitable for low-lying areas that are vulnerable to surge. In medium elevation areas, there may be some opportunities to increase elevations to provide protection.
- Given the challenges of retrofitting underground infrastructure, land elevation is best suited for large areas with multiple sites in concert with a large-scale redevelopment and/or infrastructure project.

Cost

- There are high initial costs in terms of construction and disruption, but low maintenance costs once completed.
- Costs vary significantly based on the availability of a source of fill. Additional costs include transportation of the fill to the site and the replacement/alteration of existing subsurface utilities and transit.
- Implementation poses significant disruption to existing uses and may require relocation of current residents and business, and impacts on existing natural and historic resources.

Potential for Co-Benefits

- Elevating land and streets allows for neighborhood investment in otherwise undevelopable areas. It can have widespread positive impact on flood insurance rates and stabilization of the local tax base.
- It offers an opportunity to improve subsurface utilities and infrastructure.
- Elevation of land could be done in concert with brownfield remediation.

Additional Considerations

- Connections with subsurface utilities and transit, including subway entrances, would need to be maintained or reconfigured, at an additional cost. In addition, clearance issues beneath elevated subway and highway structures would need resolving to maintain minimum clearance.
- Elevated sites would need to be engineered to resolve any potential drainage issues or negative impacts on adjacent, lower elevation areas.
- Public space and infrastructure connections beyond the project area may be complicated by the changes in elevation, as well as connections to individual privately owned lots.
- Street or grade raising projects may require coordination of large numbers of affected private property owners.

Ability to Address Coastal Hazards

EVENT-BASED	Storm Surge (High)	◐
	Storm Surge (Low)	●
	Wave Force	◐
	Sudden Erosion	n/a
GRADUAL	Frequent Flooding due to Sea Level Rise	●
	Erosion	n/a

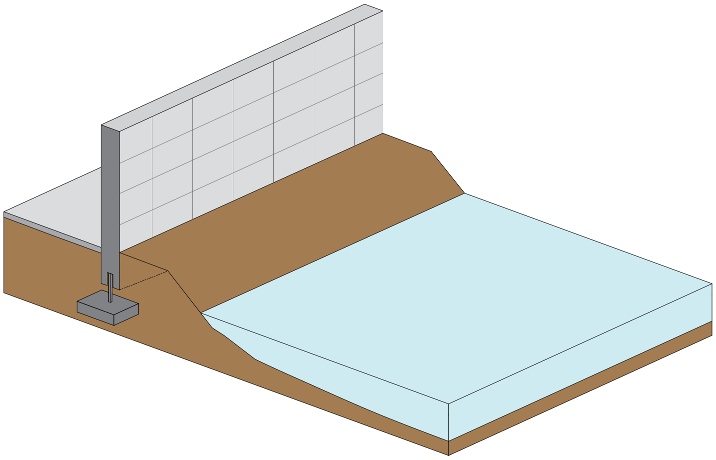
Applicability to Geomorphology Type

1	Oceanfront Beaches	●
2	Hardened Oceanfront Plains	●
3	Coastal Marshes	●
4	Hardened Sheltered Bay Plains	●
5	Oceanfront Slopes	◐
6	Sheltered Bay Slopes	◐
7	Hardened Sheltered Bay Slopes	◐
8	Sheltered Bluffs	○
9	Hardened Sheltered Bluffs	○

● HIGH ◐ MEDIUM ○ LOW

02. FLOODWALLS

Floodwalls are permanent or deployable walls used at the shoreline or upland to prevent flooding.



Floodwalls are vertical structures anchored into the ground that are designed to withstand flooding from either rivers or storm surge and prevent areas behind the wall from flooding. Permanent floodwalls are used on top of or as an extension of a levee, such as in New Orleans, to add additional protection or provide protection where there is not enough land for a levee. Floodwalls sometimes have gates to allow access for a roadway or other right-of-way, which can be closed in advance of a flood event. There are also deployable floodwalls, which require wall slats to be installed in preparation for a coming flood event and can be inserted into either permanent ground fixtures or vertical posts. Most deployable floodwalls require human intervention to install, though there are some designs that automatically rise in response to flood conditions. The benefits of having visual and physical access to the waterfront during non-storm times needs to be balanced against the logistical challenges that can be associate with installing a deployable wall in advance of a storm. Deployable floodwalls are found throughout the Midwest to protect critical infrastructure sites, such as airports, from riverine flooding, as well as in urban waterfront areas, such as along the Potomac in the Georgetown neighborhood of Washington, DC.

Kampen, The Netherlands

Hazards Addressed

- Deployable floodwalls are most suitable for low to moderate surge events and in areas that experience low to moderate wave action in the event of a storm. Since they must be installed prior to an event, they are not suitable to protect from daily tidal inundation.
- Permanent floodwalls can be designed to address high and low surge events in moderate to high wave action environments. Since they are in place all the time, they could protect from frequent flooding due to sea level rise, but are not designed to be permanently at the shoreline.

Applicability

- Permanent floodwalls are most suitable for sheltered areas that experience less wave action, but may be engineered to work in oceanfront areas.
- Deployable floodwalls are not suitable for areas along the oceanfront, which experience high wave action in the event of a storm. Deployable floodwalls are best suited for areas where space is in high demand, and are desirable in situations where a permanent barrier would conflict with the use of sites along the reach. They are well-suited for areas with a single landowner or organization that could be charged with storing and installing them.

Cost

- Permanent floodwalls cost an estimated $8,000 per linear foot. Deployable floodwalls cost an average of $10,000 per linear foot. The cost for deployment is approximately $200,000 per mile of deployable wall.
- Floodwalls require anchoring into the ground by pile-driven supports, which adds costs.
- Permanent floodwalls may potentially separate areas from the waterfront both physically and visually. This may result in reduced space for uses that are either water dependent or enhanced by the proximity of the waterfront, such as boating, maritime industries, esplanades, waterfront parks, and commercial areas.
- Deployable floodwalls require extensive manpower and operational costs to install in advance of a storm and on-going testing.

Potential for Co-Benefits

- Floodwalls could be incorporated into the design of open space to create a flood protection system integrated into the urban fabric.
- Deployable floodwalls allow areas to remain otherwise accessible and unobstructed from the waterfront. This may have significant co-benefits for uses such as waterfront parks, retail districts, and maritime facilities that are substantially more viable with direct visual and physical access to the waterfront during normal conditions and protection in the event of a storm.

Additional Considerations

- Floodwalls must be designed along with drainage considerations to prevent stormwater from backing up behind the wall and creating flooding.
- For deployable floodwalls, extensive coordination is needed to install in the event of the storm. Organizational management of their installation and storage is complicated, particularly for reaches with diverse ownership. Test installations should be conducted regularly to ensure that the operation functions properly in the event of a storm.
- Picking an appropriate design flood elevation for floodwalls is a challenge, given the uncertainty associated with even the best sea level rise projections and the costs associated with increasing design. When the design level is exceeded, the results can be catastrophic. Decisions about the design elevation and other complementary strategies must consider the potential for overtopping or failure.

Ability to Address Coastal Hazards

EVENT-BASED	Storm Surge (High)	○
	Storm Surge (Low)	●
	Wave Force	○
	Sudden Erosion	n/a
GRADUAL	Frequent Flooding due to Sea Level Rise	○
	Erosion	n/a

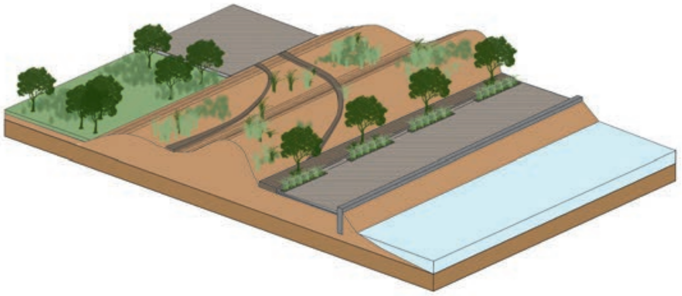
Applicability to Geomorphology Type

1	Oceanfront Beaches	○
2	Hardened Oceanfront Plains	○
3	Coastal Marshes	●
4	Hardened Sheltered Bay Plains	●
5	Oceanfront Slopes	○
6	Sheltered Bay Slopes	●
7	Hardened Sheltered Bay Slopes	●
8	Sheltered Bluffs	●
9	Hardened Sheltered Bluffs	●

● HIGH ◐ MEDIUM ○ LOW

03. WATERFRONT PARKS

Waterfront parks are open spaces designed with landscape features such as floodable areas, elevated land masses and other adaptive park design features that can quickly recover following storm events and help protect upland areas from coastal flooding.



Waterfront open spaces provide an opportunity to integrate flood protection measures into public spaces to help reduce the impacts of flooding on upland areas. Through site planning design that considers programming, topography, and natural resources, park designers can weave coastal resiliency measures into the fabric of parks by identifying which portions of parks can accommodate flooding and which elements should be elevated out of the flood zone, such as buildings, comfort stations, and certain active recreational uses. Furthermore, mechanical equipment, such as lighting and underground utilities, can be flood-proofed and synthetic play surfaces designed in ways to ensure that the parks can quickly return to public use and avoid costly repairs after storms.

Certain natural areas can be allowed to flood, provided that safety measures are in place to keep people away during flood events. Although accommodation of flood waters in parks is a concept more typically associated with riverine flooding or stormwater flooding, rather than storm surge, the integration of intentionally floodable spaces into a passive park's design can help reduce the overall stress from various hydrological forces and help reduce impacts on upland communities. Plantings must be salt-tolerant and resistant to erosion.

By understanding the subtleties of topography, park designers can also integrate flood protection elements into parks through berms, terracing, and flood walls in order to provide protection while also ensuring a positive connection between the shoreline and the urban fabric. Several of New York's newer waterfront parks have already begun to incorporate elevation modification into their designs, such as at Brooklyn Bridge Park and Governor's Island. Both parks include topographical features that raise key portions of the park above the future flood plains based on sea level rise projections.

CASE STUDY: MITIGATION PARK CONSTITUCION

Constitucion, one of Chile's many coastal cities, was severely affected by the 2010 tsunami. As a response, a group of agencies such as the Housing Ministry, the Municipality and local businesses, along with Elemental Chile and Arup, joined efforts to develop a Sustainable Reconstruction Plan, called *PRES Constitucion*. Developed over the course of 90 days after the tsunami, the plan focuses on building a climate resilient city. One of the main components of this plan is a coastal park that works as a mitigation strategy for both frequent flooding and sudden events. Promoted through a public participation mechanism, the first of its kind in Chile, the park was supported by 94 percent of the attendees, even though the creation involves the relocation of more than 114 families. To date approximately 165 properties have been expropriated. The 15.23 hectare coastal park will cover 2.8kms of Constitucion's waterfront. Divided into three sections –north, center, and south-, it aims to protect the city from both recurring flooding and wave force, and simultaneously increasing overall public space. Each section has a series of revetment walls along the edge paired with walkways and bike paths. The inner layer is composed of a series of hills and floodable areas that are designed to alleviate the force of tsunami waves while allowing the water to flow through.

Credit: ELEMENTAL S.A.

Hazards Addressed

- Parks can be designed to withstand and recover from a variety of coastal hazards and can offer some protection to adjacent inland areas from moderate surge levels, wave action, erosion, and frequent flooding.
- Waterfront parks can mitigate the impacts of coastal flooding on upland communities by buffering, elevating, and accommodating flood waters. These strategies also allow parks to recover quickly after storms and prevent costly repairs. However, measuring a precise protective value of this strategy may be a challenge.

Applicability

- The improvement or creation of a waterfront park to serve as a flood buffer is suitable for nearly any geomorphology category, though it requires the presence of a substantial amount of open space.
- Park buffers can be incorporated into the redesign of existing waterfront open spaces or to new open space design at underused waterfront areas. Many of these concepts could be incorporated into the design of Waterfront Public Access Areas.
- This strategy can be combined with other shoreline stabilization strategies, such as bulkheads, rip rap, floodwalls, and living shorelines.

Cost

- This strategy includes various elements, which have different costs associated:
  - Elevation – See Elevation of Land and Streets, page 66.
  - Floodable areas are typically wetlands or other natural areas – see Constructed Wetlands, page 90.
  - Integration of flood protection elements - see Floodwalls , page 68, and Levees, page 84.
  - Flood-proofing park elements – see Building Scale strategies, pages 36-63 and Infrastructure Protection, page 114.
- Maintenance costs for these elements, as well as general park maintenance requirements, must be accounted for.
- Topographic features require a large amount of clean fill, which may be difficult to come by, expensive, and costly to transport.

Potential for Co-Benefits

- Waterfront buffer parks can provide public access to the waterfront in areas previously inaccessible, and can improve existing public access areas by redesigning them so that they can quickly recover from a flood event.
- There are abundant opportunities to combine with ecological enhancement. For example, allowing natural areas to flood can enhance the functionality of wetlands and natural areas.
- This strategy allows for the integration of gravity-based stormwater management systems, limiting the amount of runoff into the waterways and into the combined sewer system.

Additional Considerations

- There are limited locations where large areas of open space are available. In dense areas, there will be competition with other land uses.

Ability to Address Coastal Hazards

EVENT-BASED	Storm Surge (High)	◐
	Storm Surge (Low)	●
	Wave Force	◐
	Sudden Erosion	◐
GRADUAL	Frequent Flooding due to Sea Level Rise	●
	Erosion	●

Applicability to Geomorphology Type

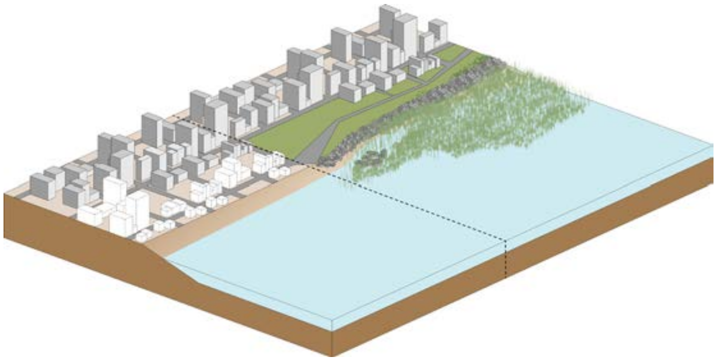
1	Oceanfront Beaches	●
2	Hardened Oceanfront Plains	●
3	Coastal Marshes	●
4	Hardened Sheltered Bay Plains	●
5	Oceanfront Slopes	●
6	Sheltered Bay Slopes	●
7	Hardened Sheltered Bay Slopes	●
8	Sheltered Bluffs	●
9	Hardened Sheltered Bluffs	●

● HIGH ◐ MEDIUM ○ LOW

Queens West public open space, Long Island City, Queens

04. STRATEGIC RETREAT

Strategic retreat is the process of removing development from areas vulnerable to flooding and the prevention of future development.



Retreating, or removing development, from an area vulnerable to flooding is a way of reducing risk by reducing exposure to a hazard. This strategy can be effective, but has many secondary implications that require careful consideration.

In areas of high flood risk that are sparsely developed and not served by substantial existing infrastructure, avoiding future development is a means of limiting exposure to increasing coastal hazards. In existing communities, however, retreat implies the gradual or sudden withdrawal of support for the maintenance or growth of neighborhoods. The effects on the livability and economic viability of existing communities must therefore be considered. A policy that properties should not be occupied or rebuilt in the future carries implications for the willingness of individuals or institutions to invest in them, and for the value of properties. Piecemeal or haphazard retreat could have collateral effects on quality of life and the value of nearby properties. The nature and severity of these issues is highly dependent on context and scale. For instance, in a rural or low-density environment, it may be possible to move buildings to another location on the same property, and returning properties to an undeveloped condition may not have serious adverse effects on neighboring properties. In contrast, in an urban area, on-site retreat is unlikely to be feasible, and "gap-toothed" neighborhoods with vacant lots interspersed among occupied buildings can present security, public health, and nuisance issues, as well as increase the average cost of delivering public services. Retreat can be highly controversial even where some owners favor the strategy, because it has effects on those who remain. The scale at which retreat is pursued is also important: elimination of several dozen homes within a large, dense urban area will have a much smaller overall adverse effect than elimination of thousands of homes. Means of relocating populations and replacing in other locations the housing units, jobs, or services removed through retreat should be considered. Retreat can also raise legal questions. Regulations that sharply limit the economic use of properties can trigger takings challenges.

Because of all these factors, strategic retreat should be pursued only as part of a well-considered plan for a community in an urban area. Planning should identify a desired end use (e.g., open space, wetlands) for properties that would be the subject of retreat, and consider coastal hazard risk in the context of a wide range of other factors, including housing and economic development, infrastructure investment, neighborhood character, urban design, and environmental sustainability. A plan may result in the larger reshaping of areas with retreat in some areas and increased growth in others. This section focuses primarily on proactive retreat through programmatic measures to remove existing development. For a related discussion of land use planning and regulatory tools that can be used to implement a policy of strategic retreat, see "Land Use Management" on page 112.

"Buyout" programs, in which properties are acquired on a voluntary basis to remain undeveloped, are the most common means of removing development from highly vulnerable areas. Often programs are designed for government or conservation entities to strategically obtain developed or undeveloped land by voluntary real estate transactions and preserve the land as natural open space or recreational lands. Similarly, conservation easements are sometimes used to keep land in private ownership but with restrictions on the site's uses. Success of a buyout program depends in part on the number of property owners that choose to participate. In both buyout and easement programs, property owners receive compensation for the value they forgo. These programs can be very expensive, especially in denser communities. For this reason, buyouts are more common after damage from multiple events has already reduced the value of properties. Governments pursuing buyout strategies may need to prioritize based on factors such as the vulnerability of the property to coastal and other natural hazards, the potential value of the site for habitat improvement or stormwater management, or the ability of the site to act as a buffer to reduce coastal hazards to adjacent sites.

Hazards Addressed

- Strategies that remove development from vulnerable areas reduce risk through avoidance of all coastal hazards.

Applicability

- The applicability of a program for strategic retreat varies depending on the scale of the community and its context. Generally, acquisition is most likely to be cost-effective when targeted towards low-density areas highly vulnerable to coastal hazards where strategies to protect or accommodate flooding are technically ineffective, would be very intensive and pose significant environmental impacts, and where acquisition would substantially benefit habitat protection, drainage, or protective buffers, and where there is widespread support or consensus.
- Other factors to consider in determining if strategic retreat is applicable include the presence of existing infrastructure and the vulnerability of the area to additional natural hazards.

Costs

- Acquisition of private property requires large up-front expenditures to purchase properties. Ongoing maintenance and management is also required, which will vary depending on the end use.
- Acquisition programs carry with them costs for public agencies to administer. Relocation assistance may be provided as part of a buyout program, which presents an additional cost.
- Strategies that restrict investment in land are likely to reduce property values and may have adverse effects on neighborhood vitality, housing supply, jobs, and economic development. Relocation of residents and replacement of housing can be difficult in a tight real estate market such as the New York City metropolitan area.

Potential for Co-Benefits

- Retreat can be used strategically to benefit hazard mitigation in addition to open space preservation, habitat protection, and recreational networks.

Additional Considerations

- Regulatory measures often present complex legal questions and may be subject to legal challenge.
- Strategic retreat should be pursued as part of a well-considered plan for a community.

Ability to Address Coastal Hazards

EVENT-BASED	Storm Surge (High)	●
	Storm Surge (Low)	●
	Wave force	●
	Sudden Erosion	●
GRADUAL	Frequent Flooding due to SLR	●
	Gradual Erosion	●

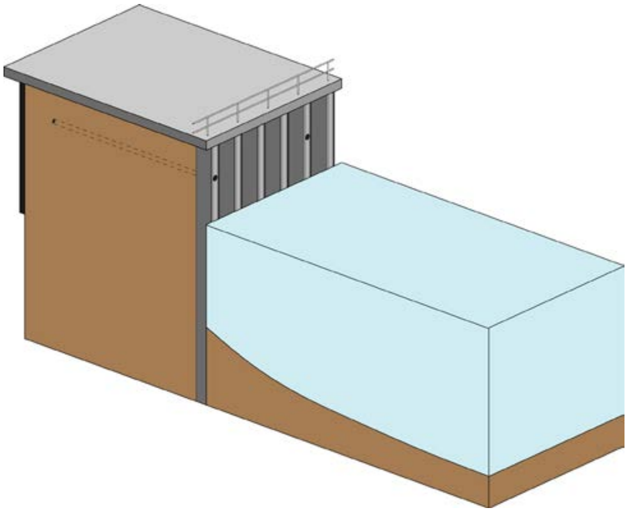
Applicability to Geomorphology Type

1	Oceanfront Beaches	●
2	Hardened Oceanfront Plains	●
3	Coastal Marshes	●
4	Hardened Sheltered Bay Plains	●
5	Oceanfront Slopes	◐
6	Sheltered Bay Slopes	◐
7	Hardened Sheltered Bay Slopes	◐
8	Sheltered Bluffs	○
9	Hardened Sheltered Bluffs	○

● HIGH ◐ MEDIUM ○ LOW

05. BULKHEADS

Bulkheads are vertical retaining walls intended to hold soil in place and allow for a stable shoreline.



Approximately 25 percent of the New York City shoreline has a bulkhead. This includes the city's waterfront industrial areas as well as built-up commercial and residential areas and parkland. Many stretches of the Upper Bay and Hudson shoreline have been bulkheaded since the early 20th century. New bulkheads are most often made from steel sheet piles, but other materials include timber, concrete, composite carbon fibers and gabions. There are many types of bulkheads commonly found in the New York City area, including cantilevered bulkheads, anchored bulkheads, gravity bulkheads, cribbing, low level relieving platforms and hoop structures/circular cofferdams.

The primary function of a bulkhead is to retain land and resist erosion in order to create stable site, and, in some instances, access to a vessel. Bulkheads are not typically designed to prevent flooding from surge. In the event of a coastal storm, surge from the ocean may overtop bulkheads which can lead to structural failure when the soil behind the bulkhead becomes saturated and water levels recede creating pressure between the soil water and sea water. While this is a relatively uncommon occurrence, the repair from this sort of damage is costly and could place the upland facilities in danger of flooding and collapse from erosion. Many newer bulkheads are designed with a drainage mechanism to release pressure on the wall to avoid this danger, but the historic bulkheads present around the city are not designed with such a mechanism.

Gradual sea level rise may require additional bulkhead maintenance in the future. Rising sea levels will likely not have a significant impact on bulkheads until the point where sea levels are high enough to create a recurrent flooding problem where the bulkhead is overtopped on a regular basis, in which case bulkhead collapse may occur. The height of a bulkhead above mean high water varies greatly in New York City, so as bulkheads reach their structural life, they may need to be adapted to meet increasing sea levels.

Historic bulkhead, Manhattan

Sheet pile bulkhead, Williamsburg, Brooklyn

Hazards Addressed

- Bulkheads protect sites from erosion and moderate wave action. They are not designed to protect from major flood events but do manage daily and monthly fluctuations in tide levels.

Applicability

- Bulkheads are most suitable for sites with pre-existing hardened shoreline structures. On unreinforced sites, particularly low-lying marshes, they may lead to loss of intertidal habitat and may accelerate erosion of adjacent, unreinforced sites. For oceanfront areas, bulkheads may be torn apart creating debris and leading to additional damage.
- Bulkheads are best suited for locations where space is in high demand or where water-dependent uses, such as barge loading and unloading, require a steep vertical shoreline.
- Cantilevered and anchored bulkhead types require stable soils suitable for pile-driving. Timber sheet piles require more extensive drainage systems due to higher propensity for erosion losses. Gravity bulkheads require foundations strong enough to support weight.

Costs

- Costs vary widely depending on site-specific factors, but in general, a new sheet pile bulkhead can cost from $5,000 to $7,000 per linear foot. Raising bulkheads, where feasible, costs about $2,000 to $5,000 per linear foot, with generally higher costs for older structures. The excavation of older structures, drilling depth, labor costs, and site logistics for material delivery are all factors that can greatly increase the cost.
- Maintenance and inspection requirements are also highly structure and site specific. It is considered good practice to inspect bulkheads every 3-5 years. Inspection and maintenance requires divers and costs vary depending on the complexity of the coastal structure.
- By fixing the shoreline and increasing wave reflection and turbulence, bulkheads can cause the erosion of the seabed seaward of the structure, reducing the intertidal zone. Bulkheads can also lead to erosion of shorelines of adjacent properties and disrupt ecosystems by preventing natural littoral sand movement.
- The construction of a new bulkhead on a marshy or vegetated shoreline leads to the loss of the intertidal zone, which is highly ecologically productive and provides other ecosystem services including water quality improvement and wave and wake attenuation.
- In New York City, the construction of new bulkheads or the replacement and repair of existing structures requires permits from NYS Department of Environmental Conservation and the U.S. Army Corps of Engineers. The environmental consequences are largely site-specific and therefore require extensive research and investigation before they can be built.

Ability to Address Coastal Hazards

EVENT-BASED	Storm Surge (High)	○
	Storm Surge (Low)	◐
	Wave Force	◐
	Sudden Erosion	◐
GRADUAL	Frequent Flooding due to Sea Level Rise	●
	Gradual Erosion	●

Applicability to Geomorphology Type

1	Oceanfront Beaches	○
2	Hardened Oceanfront Plains	◐
3	Coastal Marshes	○
4	Hardened Sheltered Bay Plains	●
5	Oceanfront Slopes	○
6	Sheltered Bay Slopes	○
7	Hardened Sheltered Bay Slopes	●
8	Sheltered Bluffs	○
9	Hardened Sheltered Bluffs	●

● HIGH ◐ MEDIUM ○ LOW

Potential for Co-benefits

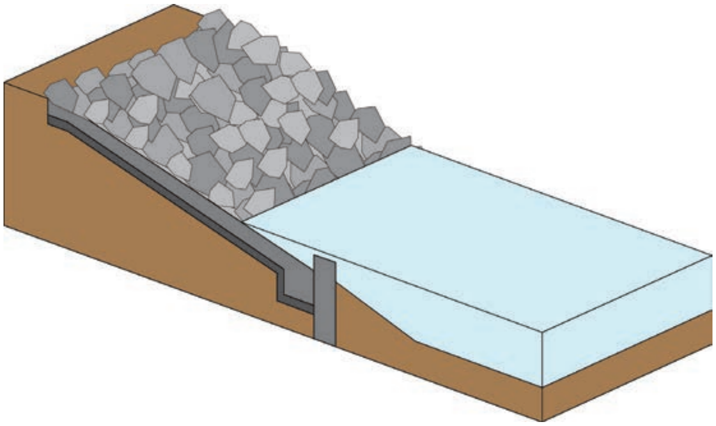
- By providing a sheer surface between the land and water, bulkheads facilitate maritime vessel access.
- Bulkheads are space efficient, as they do not require an extensive footprint.
- In the right situation, bulkheads can be constructed with a public esplanade, boardwalk, or roadway on top, allowing for public access, recreation, and transportation along the shoreline.
- Reinforcement and repair is relatively simple.
- Bulkheads can be designed to reduce or compensate for ecological impacts through incorporating surfaces and permeable elements that can support intertidal habitat and vegetation, improve water quality, and slow water velocity. (See Living Shoreline, page 78, for more on bulkhead enhancements).

Additional Considerations

- Because of the environmental impacts and regulatory impediments to new bulkheads, and because much of the city's shoreline is already bulkheaded, it is rare in New York City for a new bulkhead to be built on an undisturbed site. The great majority of bulkhead construction is the replacement or repair of an older bulkhead. Due to regulatory requirements and site constraints, it is often very challenging to replace a bulkhead with a structure that does not conform to what was there previously. As such, new bulkheads are typically built to match existing grade.
- The incremental raising of new bulkheads to account for sea level rise can be difficult. The concept of adaptable bulkheads, where the height of the wall could be raised to protect from future higher sea levels, potentially through the use of interlocking blocks, is one way bulkheads can be better designed to account for sea level rise. This would require additional upfront costs to create a large enough foundation base to support the structure, as well as additional engineering analysis, but is less expensive than upgrading later. Also the land behind the bulkhead would also need to be addressed, with ramps, fill, or additional landscaping likely required to meet adjacent grade.
- Historic bulkheads in NYC may be protected as historic resources by the State Historic Preservation Office (SHPO) and may trigger mitigation requirements.

06. REVETMENTS

Revetments (also called "rip-rap") are shoreline structures typically made of stone rubble or concrete blocks placed on a sloped surface to protect the underlying soil from erosion and reduce the forces of wave action.



Revetments are used commonly throughout New York City as an alternative to bulkheads, as they tend to be relatively low cost and environmentally more sensitive than a hard, vertical wall. However, the environmental impacts of revetments on natural shorelines can still be significant. An array of materials can be used to construct revetments, including quarrystone, fieldstone, cast concrete slabs, sand or concrete-filled bags, rock-filled gabion baskets, concrete armor units, and concrete blocks. Loose or interlocking units such as stone or concrete blocks are the most common. At the seaward end of a revetment, a "toe," usually made of heavy stone or concrete, prevents the rock or other material from sliding.

Increasingly, revetments are used as a way to make the waterfront more accessible. For example, they can be designed to incorporate large stones that allow people to get close to the water edge. They can also be designed to include an adjacent upland vegetated area, and, as opposed to traditional hardened structures such as bulkheads and seawalls, can accommodate some shoreline vegetation as well.

Fort Totten, Queens

Hazards Addressed

- Revetments are used to stabilize shorelines to prevent erosion but do not provide protection from storm surge. They are often used in concert with seawalls, bulkheads, or levees to add additional armoring protection from waves and wakes.
- The use of rip rap, concrete blocks, or other units allow for more settlement and readjustment after a wave action than a vertical wall and can absorb wave energy. As a result, such structures are unlikely to fail catastrophically even when wave damage occurs.

Applicability

- Revetments are most suitable for sites with pre-existing hardened shoreline structures. On unreinforced sites, particularly low-lying marshes, they may lead to loss of intertidal habitat. On sandy shorelines, revetments may accelerate erosion of adjacent, unreinforced sites. They are well-suited to mitigate wave action on ocean-fronting bluffs and provide erosion protection on steeper slopes. Revetments are most effective in areas with stable foundation soil.
- They are more suitable in confined areas where maritime access is not desired but there is not sufficient space for a more ecological shoreline treatment.
- Revetments are increasingly used to stabilize shorelines in parks and other publicly accessible areas where bulkheads need replacement.

Costs

- Revetments are generally less expensive than bulkheads. While costs vary significantly based on site-specific factors, construction costs generally range from $2,000 to $5,000 per linear foot.
- As long as heavy currents, waves, or wakes do not wash a revetment away, they require little maintenance and have an indefinite lifespan.
- Revetments require more land area compared to other vertical shoreline structures (such as bulkheads and seawalls) because of sloped design (usually a 2:1 slope). Many waterfront sites are brownfields, and soil remediation may be required if revetments require excavation.
- The construction of a new revetment on a marshy or vegetated shoreline degrades the intertidal zone, which is highly ecologically productive. Like with all shoreline hardening, it may disrupt sediment transport and starve beaches downdrift of the hardened edge.
- In New York City, the construction of new revetments or the replacement and repair of existing revetments requires permits from NYS Department of Environmental Conservation and the U.S. Army Corps of Engineers. The environmental consequences are largely site-specific and therefore require extensive research and investigation before they can be built.

Potential for Co-benefits

- The sloped design and rough surface of most revetments have a lesser erosion and scour impact on adjacent sites as compared to completely vertical structures such as bulkheads and seawalls.
- In publicly accessible waterfront areas, revetments can be designed to allows people to get close to the water and have a more direct experience with the waterfront.
- Revetments may provide more opportunities for intertidal habitats than completely vertical structures, but nevertheless still act as a barrier between upland and aquatic habitats and are not a suitable alternative to natural intertidal habitats provided by natural, vegetated shorelines. The use of more ecologically enhancing materials, such as ecologically sensitive concrete, may be a way of enhancing the impacts on intertidal habitat.
- The diversity of materials used to construct revetments makes this strategy one of the more flexible options for shoreline armoring. Materials can be adjusted depending on specific site conditions and aesthetics considerations.

Additional Considerations

- The appropriate size of stone and slope of the revetment depend on site conditions and regulatory requirements.
- Revetments are often constructed by individual property owners, with little design consistency along a given shoreline.

Ability to Address Coastal Hazards

EVENT-BASED	Storm Surge (High)	○
	Storm Surge (Low)	◐
	Wave Force	●
	Sudden Erosion	●
GRADUAL	Frequent Flooding due to Sea Level Rise	●
	Gradual Erosion	●

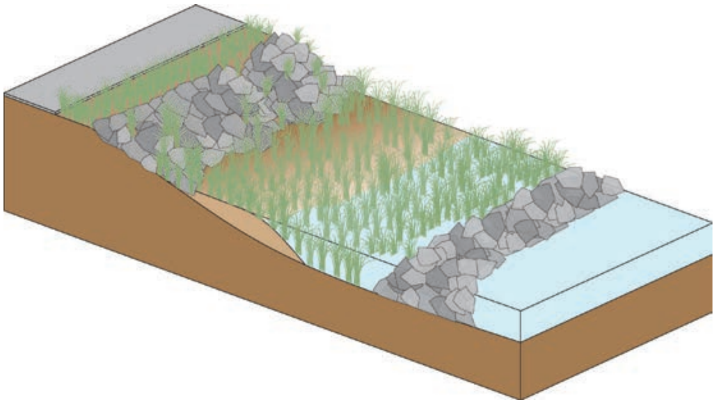
Applicability to Geomorphology Type

1	Oceanfront Beaches	○
2	Hardened Oceanfront Plains	●
3	Coastal Marshes	○
4	Hardened Sheltered Bay Plains	●
5	Oceanfront Slopes	◐
6	Sheltered Bay Slopes	●
7	Hardened Sheltered Bay Slopes	●
8	Sheltered Bluffs	○
9	Hardened Sheltered Bluffs	●

● HIGH ◐ MEDIUM ○ LOW

07. LIVING SHORELINES

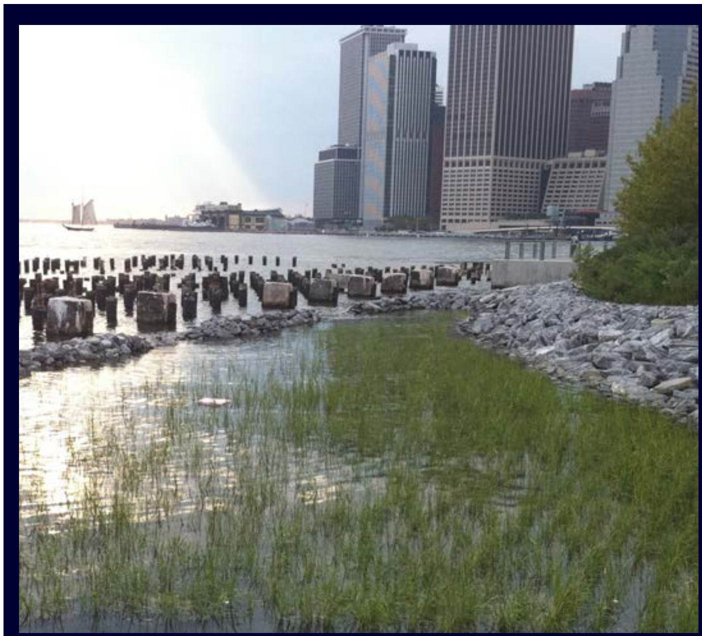
Living shorelines are a bank stabilization technique that use plants, sand/soil, and limited use of hard structures to provide shoreline protection and maintain valuable habitat.



Living shorelines are an alternative to bulkheads or revetments that provide for a stable shoreline resistant to erosion while also providing for intertidal habitat and coastal vegetation. Living shoreline design remains an emerging field, and as such, what is often called a "living shoreline" can vary greatly and is a topic of much discussion among practitioners.

A defining feature, however, is the fact that living shorelines incorporate ecological function in addition to shoreline stabilization. For example, a living shoreline can include the creation of a man-made intertidal zone with wetland vegetation or integrate oyster or mussel habitat into a vertical bulkhead. Breakwaters, sills, and beaches are other potential elements. In an urban context, living shorelines are often previously hardened shorelines, and are becoming more common as a way to create a more naturalized edge where space constraints do not allow for full restoration. Living shorelines often, through not always, include some form of breakwater structure to create a zone with water calm enough to allow for vegetation to take hold.

While a relatively new technology, efforts are underway in the mid-Atlantic region and the Gulf Coast to establish clear guidance for living shorelines, including legislation on living shorelines in states such as Virginia and Maryland. In New York City, very different types of living shorelines can be found in Brooklyn Bridge Park and Harlem River Park.



CASE STUDY: BROOKLYN BRIDGE PARK

At Brooklyn Bridge Park, one of New York's newest waterfront parks, climate resilience was not an afterthought but was incorporated into the planning and design of the park from the early stages. As a low-lying formerly industrial waterfront, Michael Van Valkenburgh Associates (MVVA), the park's landscape architects, designed the park to withstand storm impacts and flooding. Features such as the site's elevation, newly installed rip-rap shoreline and a saltwater wetland, pier stabilization, as well as specifications for salt-tolerant vegetation and soil and planting techniques were all carefully designed and selected with an eye towards increasing the park's resiliency to a changing coastal environment.

As a former port facility, much of the site's original relieving platforms were removed and replaced with rip-rap slopes during park construction, which are considered to be more durable than vertical walls in providing shoreline stability, reducing scour and dissipating wave energy. At the southern end of Pier 1 a constructed salt marsh designed to mimic a naturally occurring wetland plays the dual role of both lessening the impacts of waves and filtering and cleaning storm water runoff as it reentered the waterway. By elevating portions of the park high above the predicted 100-year storm level, including 30' high topographical features created by importing thousands of cubic yards of fill from the East Side Access subway tunnel project, the impacts of flooding on the park are further reduced.

This was tested when, in October 2012, Hurricane Sandy made its way into New York Harbor. The elevated landforms acted as barriers to coastal waters and floating debris on the rest of the park. The salt-tolerant plant species, such as Rosa rugosa, and cottonwood, and the planting of trees with root balls at an elevation above the flood elevation appear to date to be healthy despite the salt- water inundation. Although the long-term effects on vegetation remain to be seen, the fact that park's crews flushed the salts from the soil following the storm using the park's irrigation system should have offset some of the impact.

Hazards Addressed

- As the designs of living shorelines vary, so does their ability to address coastal hazards. Generally living shorelines are used to control erosion and stabilize a shoreline. They may provide some wave attenuation benefits as well.
- Living shorelines may reduce risk from frequent inundation and periodic low surge flooding, although they not typically used to do so.

Applicability

- Living shorelines are suitable for most types of areas except in high wave energy environments where wave action and fast currents are typically too strong for vegetation to be established. In areas where fetch is less than 1 mile, vegetated living shorelines, such as fringe marshes, can survive. Beyond 1 mile of fetch, living shorelines typically require hard structural components, such as a rock sill or timber wall placed seaward of the marsh to function as a breakwater and reduce the forces from winds and waves.
- Living shorelines are best suited for areas with flat to moderate slopes to allow for structural stability and a surface where vegetation can be established.
- Living shorelines are typically more space intensive than bulkheads. Creating a living shoreline where a bulkhead current exists requires either extending the shoreline seaward, which is highly discouraged by environmental regulations concerned with new fill placed in the water, or taking away upland space from the site, which means less usable space on the site.

Costs

- Living shoreline costs vary greatly depending on design and site factors. Some of the common elements include: shoreline planting and wetland restoration (estimate costs $25-45/sq. ft.), geotextile grid shoreline stabilization (estimated costs $30/sq. ft.), and aquatic vegetation (estimated costs $2,000/sq. ft.), according to estimates from the NYC Department of Parks and Recreation (see Constructed Wetlands for additional cost estimates for wetlands). Once structural features are introduced, costs can increase significantly (see Breakwaters, Artificial Reefs, Constructed Breakwater Islands, and Floating Islands).
- Structural features may prevent wetland migration and may lead to loss of adjacent sandy beaches. If substantial hardening is involved, a living shoreline may disrupt sediment transport and starve beaches downdrift of the hardened edge.
- In New York City, the construction in water or at the shoreline requires permits from NYS Department of Environmental Conservation and the U.S. Army Corps of Engineers. The environmental consequences are largely site-specific and therefore require extensive research and investigation before they can be built. The placement of stone in the water is likely to present environmental consequences and may increase permitting time, though they may be necessary to realize the benefits of vegetation growth.

Potential for Co-benefits

- Living shorelines can retain and create a diversity of habitat types, allow for links between aquatic and upland habitats, restore or maintain spawning and nursery areas for fish and crabs, and maintain natural shoreline dynamics and sand movement.
- Living shorelines may also help improve water quality by filtering nutrients and other pollutants through wetlands or filter feeders.
- Living shorelines can provide educational opportunities about the marine environment by allowing people to get close to an intertidal habitat in otherwise urbanized areas.
- They can also be designed to accommodate flooding when integrated into landscape design. (See Waterfront Park).

Additional Considerations

- As an emerging technology, expertise and knowledge on living shorelines is not always readily available. There is a lack of clear guidelines for implementation in New York City and a lack of clarity in how they relate to the permitting process.
- Shoreline areas may change significantly with sea level rise, and living shoreline installations may need to be adapted to accommodate changes in sea level.

Ability to Address Coastal Hazards

EVENT-BASED	Storm Surge (High)	○
	Storm Surge (Low)	◐
	Wave Force	◐
	Sudden Erosion	●
GRADUAL	Frequent Flooding due to Sea Level Rise	●
	Gradual Erosion	●

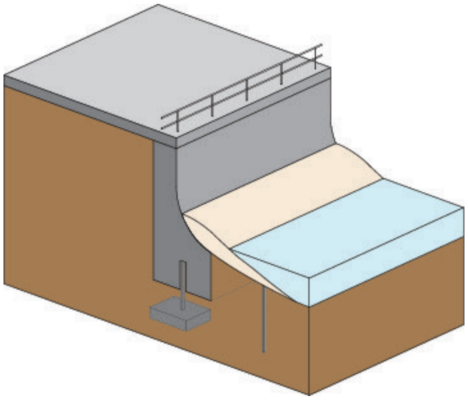
Applicability to Geomorphology Type

1	Oceanfront Beaches	○
2	Hardened Oceanfront Plains	○
3	Coastal Marshes	●
4	Hardened Sheltered Bay Plains	●
5	Oceanfront Slopes	○
6	Sheltered Bay Slopes	●
7	Hardened Sheltered Bay Slopes	●
8	Sheltered Bluffs	●
9	Hardened Sheltered Bluffs	●

● HIGH ◐ MEDIUM ○ LOW

08. SEAWALL

Seawalls are massive stone, rock or concrete structures built parallel to the shoreline that are designed to resist the forces of heavy storm waves and prevent coastal flooding of upland areas.



Seawalls can be found throughout the world in coastal areas where protection from wave forces is desired. While the term is often used interchangeably with "bulkhead," for the purposes of this report a seawall is defined as a structure specifically designed to block storm surge from flooding upland areas. The key functional element in the design of a seawall is the crest elevation, which is selected to minimize the overtopping from storm surge and wave run-up. As seawalls are located in high wave energy environments, the typical causes of damages are toe scour leading to undermining, overtopping and flanking, rotational slide along a slip-surface, and corrosion of any steel reinforcement.

Seawalls can have different profiles and structural components. The types most commonly found across the region include:

- **Curved:** Curved seawalls better absorb wave energy reducing deflection of wave forces and scour at the base of the wall. The well-known Galveston Texas Seawall and San Francisco's Great Highway Seawall are examples of curved seawalls.
- **Vertical:** Vertical seawalls are pile-supported and are made from concrete or interlocking steel or vinyl sheets driven deep into ground and stabilized with tie-backs extending away from the water and into the ground. Sheet-pile seawalls visually resemble many bulkheads, but are designed to withstand heavy wave forces, unlike bulkheads.
- **Gravity**: Gravity seawalls rely on the weight of the wall and stability of construction to protect the shoreline. Rubble mound seawalls are a type of gravity seawalls made from large stones. They appear similar to a revetment, but typically use larger stones and do not require an existing sloped surface.

Blackpool seawall, United Kingdom

Credit: AECOM, Dixi Carrillo

Credit: Havenbedrijf Rotterdam N.V.

CASE STUDY: MAASVELKTE II

To meet growing demand at the Port of Rotterdam, Europe's largest port, an enormous land reclamation and coastal protection project is underway. Called Maasvlakte 2, the project cost amounts to almost $3.67 billion. A seawall composed of a "hard" seawall on the north-western rim and a "soft" seawall on the western and southern sides is intended to protect the 2,000 hectares of reclaimed land. According to the Maasvlakte II project organization, the design is based on the principal of "soft where soft is possible and hard where hard is required." A far cry from a typical vertical seawall, the 3.5 km hard seawall occurs where the waves are the highest. Designed as a "stony dune with block dam," it consists of a gently sloping sand core covered with cobblestones, which are considered to be more dynamic in response to wave forces and currents as well as less expensive to maintain. At the underwater foot of the structure, heavy stone materials, including recycled stone from a nearby dismantled dam, prevent the structure from eroding.

In addition to being designed for the 1-in-10,000-year storm, the seawall design also takes into account a rise in the sea level of 0.30 m for the next 50 years for 2060. To allow for future improvements over the next 50 years, space has been reserved for raising the crown of the seawall by another 0.50 m. To the south and west, the 7.5 km soft seawall is, in essence, a wide sandy beach flanked by a row of planted dunes. The new beach area will provide ecosystem services, as well as a range of recreational programming including a more passive leisure beach and an area for active recreation and water sports.

Hazards Addressed

- Seawalls are designed to resist wave forces to protect upland areas from flooding during major surge events.

Applicability

- Seawalls are most applicable to areas highly vulnerable to storm surge and wave forces. They are less suitable for areas with higher elevation where surge heights are lower and for natural shorelines. The applicability along oceanfront beaches is limited, as seawalls may disrupt sediment transport leading to the loss of adjacent sandy beaches.
- Seawalls can require significant land area to construct. In developed areas, this may require either the relocation of landward structures or extension of the structure into the waterway, which brings along higher environmental costs and more regulatory issues.
- Local wave energy and soil type should determine the most appropriate materials and type of seawall to be constructed. For example, sheet pile seawalls are most appropriate for sand or earth bottoms where they can be driven deep into the ground. For rock bottoms, above-ground gravity structures are most economical, though the intensity of waves might demand pile-supported structures. Piles can be driven into soft rock but bedrock requires drilling and anchoring piles.

Costs

- Estimated costs per linear foot for seawalls vary widely from approximately $5,000 to $15,000 per linear foot depending on foundation and height.
- In general, seawalls have higher up-front construction costs due to the greater level of engineering required, but lower maintenance costs in the long term than some other coastal armoring methods, such as beach nourishment and levees. However, given the natural forces to which seawalls are constantly subjected, inspection and maintenance are necessary if they are to provide an effective long-term solution, and should be factored into the budget. With regular maintenance seawalls can have a lifespan of over 100 years.
- If not designed correctly, seawalls can increase wave reflection and turbulence, and can allow a sandy beach to eventually erode completely beyond the placement of the structure, resulting in loss of the beach unless sand is regularly replaced.
- Like with all shoreline hardening, seawalls may disrupt sediment transport and starve beaches downdrift of the hardened edge.
- Depending on height, they may be visually obstructive or in some cases block physical access to shoreline.
- The construction of a new seawall on a marshy or vegetated shoreline leads to the loss of the intertidal zone, which is highly ecologically productive and provides other ecosystem services including water quality improvement and wave and wake attenuation.
- In New York City, the construction of new seawalls or the replacement and repair of existing seawalls requires permits from NYS Department of Environmental Conservation and the U.S. Army Corps of Engineers. The environmental consequences are largely site-specific and therefore require extensive research and investigation before they can be built.

Ability to Address Coastal Hazards

EVENT-BASED	Storm Surge (High)	●
	Storm Surge (Low)	●
	Wave Force	●
	Sudden Erosion	●
GRADUAL	Frequent Flooding due to Sea Level Rise	●
	Gradual Erosion	●

Applicability to Geomorphology Type

1	Oceanfront Beaches	◐
2	Hardened Oceanfront Plains	●
3	Coastal Marshes	◐
4	Hardened Sheltered Bay Plains	◐
5	Oceanfront Slopes	●
6	Sheltered Bay Slopes	● ◐
7	Hardened Sheltered Bay Slopes	◐
8	Sheltered Bluffs	○
9	Hardened Sheltered Bluffs	○

● HIGH ◐ MEDIUM ○ LOW

Potential for Co-benefits

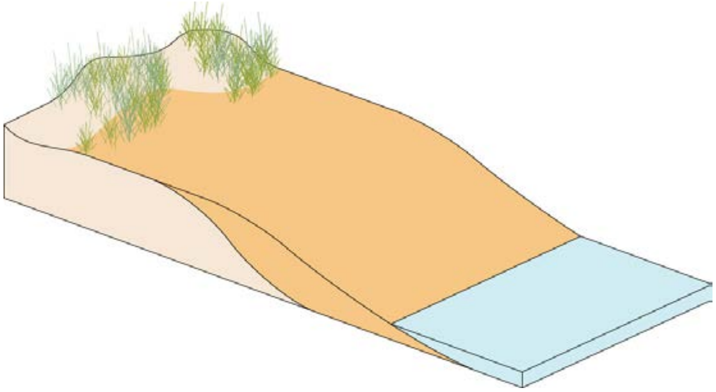
- Seawalls tend to be less space intensive as other measures, such as beach nourishment and levees.
- Seawalls can be designed to allow for public access or maritime use of the waterfront, such as in Blackpool, United Kingdom (see photo, page 80).

Additional Considerations

- Seawalls are typically constructed by the U.S. Army Corps of Engineers as part of a larger flood control project, with a mix of federal, state, and local funding. In order for the Army Corps to build such a project, the U.S. Congress must authorize the funding of a feasibility study that examines the costs of benefits and alternatives. If the study finds there is sufficient reason to move forward, Congress then must authorize funding the eventual construction.
- Picking an appropriate design flood elevation for seawalls is a challenge, given the uncertainty associated with even the best sea level rise projections and the costs associated with increasing design. When the design level is exceeded, the results can be catastrophic. Decisions about the design elevation and other complementary strategies must consider the potential for overtopping or failure.
- Seawalls are relatively inflexible and unadaptable on their own, although there are examples of building in future adaptability as a way of addressing uncertainty (see Maasvelkte II).
- Like with bulkheads, overtopping of seawalls can result in catastrophic failure if proper drainage mechanisms are not in place. Massive, monolithic forms of coastal armoring may be initially stronger than those made of smaller units, but may fail prematurely due to lack of structural flexibility and adaptation.
- Protective coastal infrastructure, such as seawalls, levees, and surge barriers, may encourage development in areas vulnerable to coastal flooding. This can inadvertently increase a community's vulnerability, as it may lead to an increase in population, and give a false sense of protection from coastal hazards, resulting in complacency about taking mitigation actions.

09. BEACHES AND DUNES

Beaches and dunes are natural protective features that provide a sandy buffer to protect from waves and flooding, and are sometimes reinforced with vegetation, geotextile tubes, or a rocky core.



Man-made shaping of beaches and dunes to reduce coastal storm impacts is practiced widely throughout the United States to reduce the impacts of coastal storms, as well as to improve the recreational value of beaches. Also known as beach nourishment, sand is placed on beaches to increase the elevation and distance between upland areas and shoreline, which acts as a buffer to dissipate storm wave energy and block rising water from inundating lower elevation areas. Among the various shoreline alternatives, it is considered a "soft" shoreline alternative by the Army Corps of Engineers, compared to armoring of shorelines with hardened structures such as seawalls. While the sand erodes during intense storms, it is designed to be sacrificial and can be replenished afterward. A beach nourishment project typically lasts between three and ten years depending on the site, plan and number and intensity of storms (NOAA, 2000). Sand is sometime placed updrift at a "feeder beach" or underwater at a "nearshore berm" to provide for additional replenishment. Geotextile tubes filled with sand or dredged material can be used to supplement beach nourishment projects. Another variation is a "perched" beach, which involves the construction of a low retaining sill to trap sand to create a beach elevated above its original level. This can be used as an erosion control measure for recreational beaches where beach nourishment would not be economical.

As part of beach nourishment, existing dunes can be reinforced or new ones created to provide additional protection. Vegetation further increases the longevity of dunes by trapping and stabilizing sediment, as well as providing beach habitat. Double dune systems, which more closely mimic naturally occurring dune fields, are preferable because it allows the primary dune to break waves, and a secondary dune to reduce surge and replenish the front dune. Sand fences and groins are also often installed in concert with dunes to increase their longevity. In some instances, dunes are reinforced with a rock or stone interior cavity that is covered in sand, which can be more cost-effective since it minimizes replenishment costs, but may lack the ecological benefits of more natural dune.

Credit: Rijkswaterstaat. https://beeldbank.rws.nl

CASE STUDY: SAND MOTOR

Based on the concept of designing with nature, the Dutch Rijkswaterstaat and the South Holland provincial authority are experimenting with a coastal protection strategy called the "sand motor" as a way of enhancing the shoreline. Typically, beach nourishment—adding sand to beaches as a way to enhance shore up flood protection – requires mechanically dumping or pumping of sand onto beach areas. As an alternative, in 2011, a huge volume of dredged sand was placed in an artificial 1 km long and 2 km wide peninsula into the sea at the village Ter Heijde, allowing for the processes of wave action and along-shore currents to redistribute it to build sand dunes and beaches to protect the coast over time. By harnessing the natural dynamic forces of wind and water to modify the morphology of the coastline, the project will also create an additional 250 acres of wildlife and recreation area.

Hazards Addressed

- Beaches and dunes in combination can protect inland areas from flooding, waves, and erosion, though the beach itself is a sacrificial element and may be lost to erosion in a storm or gradually over time if not replenished.
- Beaches act as a buffer between breaking waves and upland structures, reducing the force of waves and reducing amount of damage from a storm.
- Dunes offer additional protection by strengthening the ability to dissipate waves and can offer additional height to protect from surge. Reinforced or "armored" dunes act as sand-covered seawalls to protect from surge events and can withstand heavy wave action.

Applicability

- Beaches and dunes are most suitable for low-lying oceanfront areas with existing sources of sand and sediment transport systems to provide ongoing replenishment.
- Beaches require continual maintenance in the form of nourishment. In general, shorelines with very high erosion rates are not suitable for beach nourishment because maintenance becomes too costly.
- For barrier islands, beach nourishment is only feasible for the oceanfront side and will not protect from inundation from the bay side.
- When considering sea level rise, dunes may be more sustainable where there is space to re-establish the dune and in locations that reflect the dynamic progression of the dune due to hydrodynamic changes.

Costs

- An average beach nourishment project costs $20 to $50 per cubic yard (including transportation of sand). Costs vary based on the width and profile of the beach. Sand dune construction costs approximately $150,000/acre. Reinforced dune costs vary based on their core, and can range from approximately $300 linear feet for a simple reinforced dune to $10,000 per linear foot for a rock reinforced dune. The mode of sand transport can also affect the costs.
- Beach nourishment has relatively low initial costs, but requires continual monitoring and maintenance.
- Lifespan of beach projects vary based on the nourishment cycle and the frequency of major storms. After initial placement, some re-nourishment of 10-30 percent of the original volume is needed every 3-10 years, depending on local climate conditions.
- The construction of structures such as groins or breakwaters to complement beach nourishment is often necessary along developed shorelines. This significantly increases costs.
- There are potential negative environmental impacts at the site of beach nourishment, borrow site, nearby water column and water bottom due to disturbance of habitats, increased turbidity, and sedimentation (although negative impacts are temporary compared to hard structures). While sand it being placed, there is temporary disturbance of near-shore environment. Beach nourishment also alters the natural flow of sediment across a beach with environmental consequences. Beach projects require permits from NYS Department of Environmental Conservation and the U.S. Army Corps of Engineers. The environmental consequences are largely site-specific and therefore require extensive research and investigation before beach projects can proceed.

Ability to Address Coastal Hazards

EVENT-BASED	Storm Surge (High)	●
	Storm Surge (Low)	●
	Wave Force	●
	Sudden Erosion	◐
GRADUAL	Frequent Flooding due to Sea Level Rise	●
	Gradual Erosion	◐

Applicability to Geomorphology Type

1	Oceanfront Beaches	●
2	Hardened Oceanfront Plains	◐
3	Coastal Marshes	○
4	Hardened Sheltered Bay Plains	○
5	Oceanfront Slopes	◐
6	Sheltered Bay Slopes	○
7	Hardened Sheltered Bay Slopes	○
8	Sheltered Bluffs	○
9	Hardened Sheltered Bluffs	○

● HIGH ◐ MEDIUM ○ LOW

Potential for Co-benefits

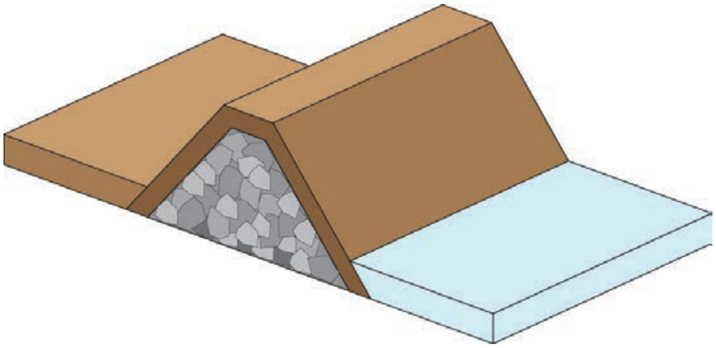
- Beach nourishment expands the usable beach area, improving public access and recreational use.
- It has a lower environmental impact compared to hard coastal armoring structures. Because beach nourishment does not involve constructing a physical, permanent structure, it is a relatively flexible strategy while it lasts and can be redesigned with relative ease.
- Use of suitable dredged material for beach fill when possible is mutually beneficial to both dredging and beach nourishment projects.

Additional Considerations

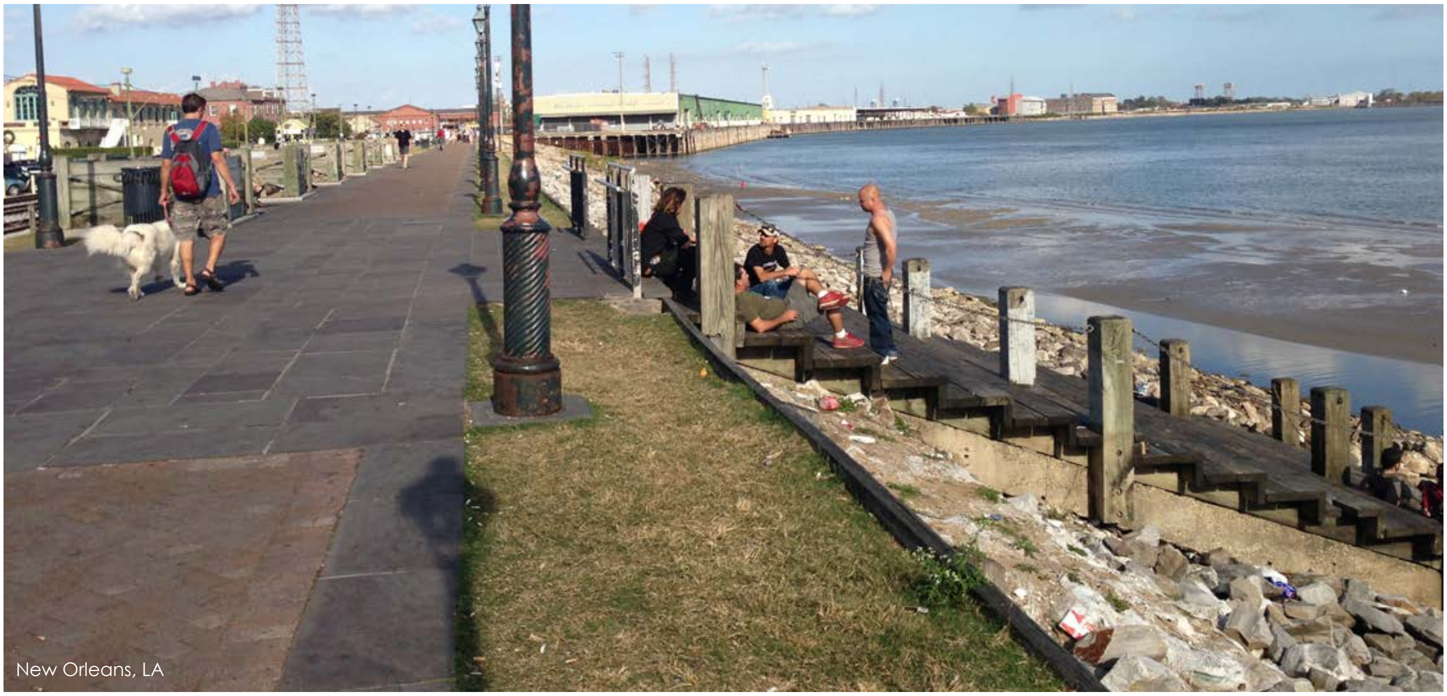
- Beach nourishment projects are often constructed by the U.S. Army Corps of Engineers as part of a larger flood control project, with a mix of federal, state, and local funding. In order for the Army Corps to build such a project, the U.S. Congress must authorize the funding of a feasibility study that examines the costs of benefits and alternatives. If study finds there is sufficient reason to move forward, Congress then must authorize funding the eventual construction.
- A suitable "borrow source" needs to be identified for clean sand. Options include terrestrial (coastal sand deposits), backbarrier (sediment deposits in marsh, tidal creek, bay, estuary, lagoon), dredged material (from harbor/navigation/waterway projects), and offshore (ocean) sources. For dredged material, potential contamination is an issue. Sand sources vary greatly in quality (ebb and flood tidal delta sand classified as best, harbor dredging as worst); and cost (flood and ebb tidal least expensive, continental shelf most expensive).

10. LEVEES OR DIKES

Levees (also called dikes) are earthen embankments located at the shoreline that provide protection from flooding.



Levees are commonly used throughout the country along riverbanks to direct the flow of the river and protect communities from flooding. Concrete floodwalls on top of levees are used to increase the height of surge protection (see Floodwalls, page 68). Ring levees, which completely encircle an area, are found in the Midwest. Levees are also found along the Atlantic Ocean in the Northeast to protect areas from coastal flooding. Levees are used extensively in the Netherlands along rivers and coastlines in combination with surge barriers. In New York City, there is a levee in Staten Island at Oakwood Beach that was completed by the U.S. Army Corps of Engineers in 2000. As with other structural options, failure is a possibility, and in the case of levees, it can be particularly damaging when large developed areas are completely behind a levee on all sides, as evidenced by Hurricane Katrina in New Orleans. The most common reasons for a levee to fail are overtopping, erosion, internal erosion, and slides within the levee embankment or the foundation soils.



New Orleans, LA

Hazards Addressed

- Levees can offer protection from low to high surge events.
- While they are not typically used to protect from wave forces or from erosion, when combined with armored rip-rap, levees can resist heavy storm waves.

Applicability

- Levees are more suitable for low-lying areas that could require high elevation structures to protect from storm surge. They are less suitable for oceanfronts where wave forces typically require a seawall or armored dune.
- New levee construction and modification of existing levees depends on the availability of materials, suitability of foundation materials, and availability of land. An existing public right of way makes the creation of a levee easier.

Costs

- Costs of new levees vary based on the height of the levee, but typically range between $2,000 to $10,000 per linear foot with annual maintenance costs of approximately 2% of construction. An armored levee can significantly increase costs to approximately $10,000 per linear foot. Additional pumping systems are typically also required.
- Because of the slopes on either side, levees require an extensive amount of land and can block views and access to the water.
- Since levees must be continuous, often across multiple property lines, they potentially raise land condemnation issues.
- Levees can cause significant environmental disturbance of shoreline and near shore areas
- Like other structural measures, they often require an extensive permitting process.
- Levees require permits from NYS Department of Environmental Conservation and the U.S. Army Corps of Engineers. The environmental consequences are largely site-specific and therefore require extensive research and investigation before levee projects can proceed. FEMA also runs a levee accreditation program for levees that are designed to provide protection from at least the 1 percent annual chance flood for NFIP purposes.

Potential for Co-benefits

- Land area on top of the levee can sometimes be used for other functions, like paths or roadways (see Multi-purpose levees, page 86).

Additional Considerations

- Levees are typically spearheaded by local government, but depending on scale and urgency of the project, they can be funded completely by the federal government, or a combination of city, state and federal funds.
- Picking an appropriate design flood elevation for levees is a challenge, given the uncertainty associated with even the best sea level rise projections and the costs associated with increasing design. When the design level is exceeded, the results can be catastrophic. Decisions about the design elevation and other complementary strategies must consider the potential for overtopping or failure.
- Protective coastal infrastructure, such as seawalls, levees and surge barriers, may encourage development in areas vulnerable to coastal flooding. This can inadvertently increase a community's vulnerability, as it may lead to an increase in population, and give a false sense of protection from coastal hazards, resulting in complacency about taking mitigation actions.

Ability to Address Coastal Hazards

EVENT-BASED	Storm Surge (High)	●
	Storm Surge (Low)	●
	Wave Force	◐
	Sudden Erosion	◐
GRADUAL	Frequent Flooding due to Sea Level Rise	●
	Gradual Erosion	◐

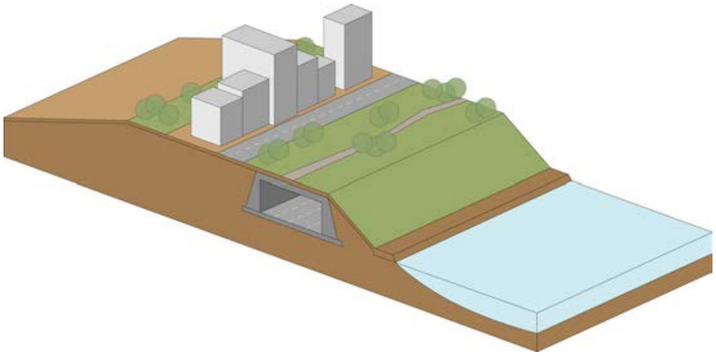
Applicability to Geomorphology Type

1	Oceanfront Beaches	○
2	Hardened Oceanfront Plains	○
3	Coastal Marshes	●
4	Hardened Sheltered Bay Plains	●
5	Oceanfront Slopes	○
6	Sheltered Bay Slopes	◐
7	Hardened Sheltered Bay Slopes	◐
8	Sheltered Bluffs	○
9	Hardened Sheltered Bluffs	○

● HIGH ◐ MEDIUM ○ LOW

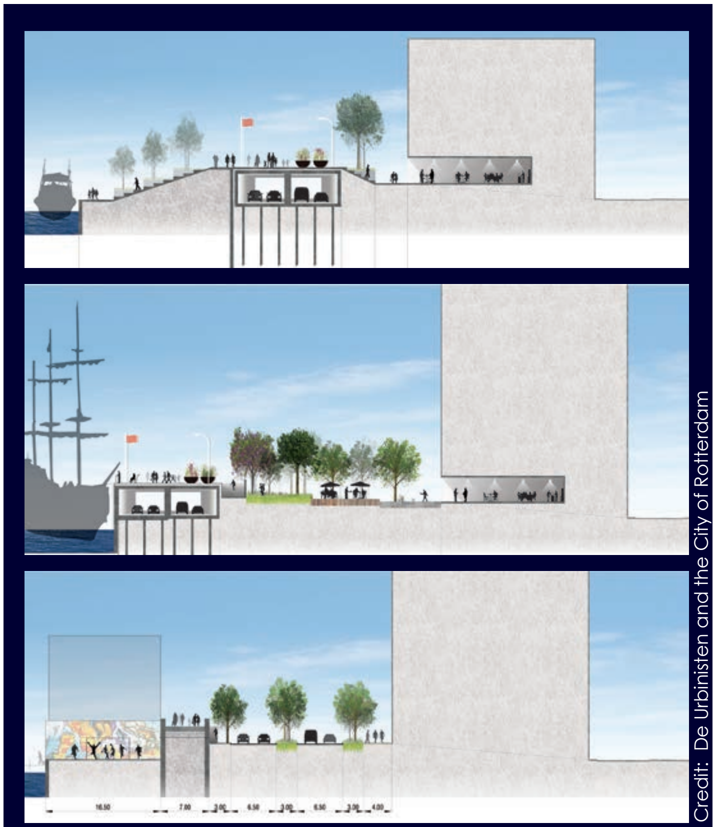
11. MULTI-PURPOSE LEVEES

Multi-purpose levees are levees that combine other functions, such as transit, highways, buildings, or parks, either on top or within a levee structure.



In dense waterfront cities, a traditional levee can impose unwanted negative consequences for urban life by cutting off public access and views to the waterfront. Rather than conceiving of levees as stand-alone pieces of infrastructure, there is growing interest in multifunctional design to integrate levees with other urban uses, such as waterfront parks, transportation networks and even development. From the Netherlands to Japan, cities are discovering new ways to seamlessly incorporate flood protection into low-lying urban areas. In Tokyo, for example, "super levees" are being developed that are extremely wide—in this case 1,000 feet wide and 30 feet high—in conjunction with redevelopment plans. Even when these levees are overtopped, the width of the levee means they are resistant to overflow, seepage, and earthquakes. However, given that existing neighborhoods must be temporary relocated in order to construct and the resulting character of the redeveloped communities is different than what existed previously, they raise many social, design, environmental, and feasibility issues.

There are also designs for multi-purpose levees that involve land fill into the waterways at higher elevations than the existing shoreline, creating a new raised ring of land that could be utilized for a variety of land use purposes. Such schemes would require environmental analysis as to the impacts on hydrology, water quality, and ecosystems.



Credit: De Urbinisten and the City of Rotterdam

CASE STUDY: RIVERDIKE ROTTERDAM

With centuries of experience designing dikes to keep water out of their cities, Dutch designers and planners have begun experimenting with ways that these utilitarian structures can combine with other urban objectives to create new urban forms and spaces. Often referred to as "super dikes," Tracy Metz, author of *Sweet and Salt: Water and the Dutch*, notes that these are "the theme du jour in the world of hydraulic engineering and water defenses." One recent example from the Dutch urban design firm De Urbanisten is a series of planning proposals called Riverdike Rotterdam. The firm has proposed a series of upgrades to Rotterdam's existing dike system that would both strengthen their level of safety and improve their quality as urban spaces. The design strategies range in complexity and include widening dikes to form the foundation for new waterfront public spaces, integrating dikes with roadways and bike paths, and incorporating dikes into buildings. By combining these programs into a single spatial planning process, the hope is that additional value—through economic development, public-private partnership, and/or improvements to the public realm—can be achieved.

Hazards Addressed

- Multi-purpose levees address the same hazards as levees.
- While they are not typically used to protect from wave forces or from erosion, when combined with armored rip-rap, levees can resist heavy storm waves.
- When wide enough, levees are less likely to fail even if they are overtopped by flooding.

Applicability

- Like levees, multipurpose levees are more suitable for low-lying areas that could require high elevation structures to protect from storm surge. They are less suitable for oceanfronts where wave forces typically require a seawall.
- Large amounts of land are required for multi-purpose levees. Areas with an existing public right of way for a park, road, highway, or railway are often most suitable. There are additional hurdles when private development is in close proximity to the shoreline.

Costs

- The cost of multi-purpose levees is highly dependent on the height of the levee and the types of other features incorporated into the design, such as parkland, development, roadways, or other infrastructure. However, various forms of private-public partnerships may be able to help finance such projects, particularly in high value areas.
- In developed areas, displacement of existing populations would often be required while the levees are under construction. The social implications for neighborhoods could be high.
- In many areas a multi-purpose levee would require fill into the water, which can create environmental impacts and necessitates an extensive permitting process.
- Levees require permits from NYS Department of Environmental Conservation and the U.S. Army Corps of Engineers. The environmental consequences are largely site-specific and therefore require extensive research and investigation before levee projects can proceed. Multi-purpose levees with development may raise additional concerns if levees are seeking accreditation through FEMA's levee accreditation program.
- For existing properties, construction of a multi-purpose levee may lead to the loss of waterfront frontage, which could impact real estate values and the ability to have water-dependent uses.

Potential for Co-benefits

- Multi-purpose levees can provide additional benefits through infrastructure improvements, new public space, and development opportunities.
- By combining other uses, flood protection is integrated into the fabric of an urban area and other sources of funding, such as transportation funding or private-public partnerships, may be available.

Additional Considerations

- Picking an appropriate design flood elevation for levees is a challenge, given the uncertainty associated with even the best sea level rise projections and the costs associated with increasing design. When the design level is exceeded, the results can be catastrophic. Decisions about the design elevation and other complementary strategies must consider the potential for overtopping or failure.
- Protective coastal infrastructure, such as seawalls, levees and surge barriers, may encourage development in areas vulnerable to coastal flooding. This can inadvertently increase a community's vulnerability, as it may lead to an increase in population, and give a false sense of protection from coastal hazards, resulting in complacency about taking mitigation actions.

Ability to Address Coastal Hazards

EVENT-BASED	Storm Surge (High)	●
	Storm Surge (Low)	●
	Wave Force	◐
	Sudden Erosion	◐
GRADUAL	Frequent Flooding due to Sea Level Rise	●
	Gradual Erosion	◐

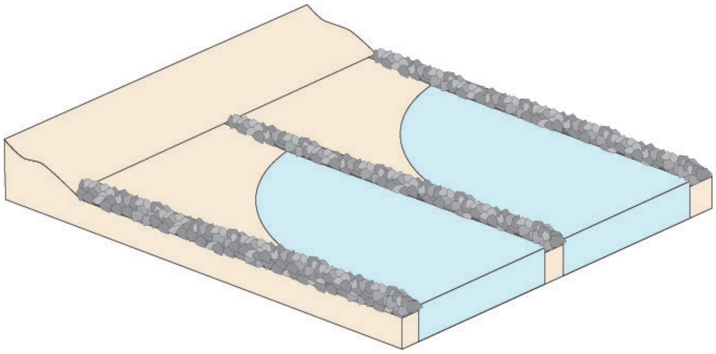
Applicability to Geomorphology Type

1	Oceanfront Beaches	○
2	Hardened Oceanfront Plains	○
3	Coastal Marshes	●
4	Hardened Sheltered Bay Plains	●
5	Oceanfront Slopes	○
6	Sheltered Bay Slopes	◐
7	Hardened Sheltered Bay Slopes	◐
8	Sheltered Bluffs	○
9	Hardened Sheltered Bluffs	○

● HIGH ◐ MEDIUM ○ LOW

12. GROINS

Groins are structures that extend perpendicularly outward from the shore to trap sand, prevent beach erosion, and break waves.



Groins are a prevalent strategy in conjunction with beach nourishment projects. They are constructed to maintain a beach wide enough to protect from storms through controlling the amount of sand moving alongshore. Groins are typically constructed out of concrete or stone rubble, timber, or metal sheet piles and are usually constructed in a series down a beach, called a groin field. They are often built perpendicular to the shoreline, though sometimes at a slight angle. They can be notched to help anchor sand, or permeable, to allow sediment to pass through and allow for littoral drift. Some groins are built with attachments at the seaward end in a T, L, or Y formation to better trap sand.

Over time, the shoreline adjusts due to the presence of the groin disrupting the sediment transport, and often results in an increase in beach width updrift of the groin and erosion and decrease of the beach width downdrift of the groin. Poorly designed and improperly sited groins have led to a discouragement of the use of groins for shore protection in coastal policy in the United States and elsewhere. By allowing a certain amount of sand to pass through groins, coastal engineers can design or retrofit existing groins to improve for sediment transport.

In New York, groins are commonly found along the south shore of Long Island, the Rockaway peninsula, Brooklyn and Staten Island, including the Rockaways, Coney Island and Midland Beach.

Rockaway Beach, Queens

Hazards Addressed

- The primary function of groins is to prevent the erosion of beaches. They may also offer some protection from wave forces.
- They are most effective when combined with beach nourishment, as they can extend the lifespan of beach nourishment projects. On their own, groins lead to increased erosion on adjacent beaches.

Applicability

- Groins are most suitable for areas with extensive oceanfront beaches or in concert with a beach nourishment project.
- In general, choice of materials and construction method will depend on wave conditions. For sheet pile groin construction, soil conditions must permit pile driving.

Costs

- Groins are estimated to cost $1,500 - $3,000 per linear foot, depending on materials, and the site. They require maintenance every year and have a lifespan of 50-100 years.
- Groins can exacerbate erosion of adjacent "downdrift" beaches by preventing littoral sediment transport. The design of permeable groins can prevent this, as can placing a sufficient amount of sand on the beach before the construction of groins.
- A permit is required from NYS Department of Environmental Conservation and the Army Corps for constructing, modifying or restoring a groin, but not for routine maintenance.

Potential for Co-benefits

- Groins complement the protective abilities of beach nourishment by reducing erosion and extending the lifespan of a nourishment project.
- Construction methods and materials are adaptable to a wide range of site conditions and budgetary constraints.

Additional Considerations

- Groins are often considered to be detrimental to shoreline environments and are heavily regulated in beachfront communities; they are banned in some parts of the country.

Ability to Address Coastal Hazards

EVENT-BASED	Storm Surge (High)	○
	Storm Surge (Low)	○
	Wave Force	◐
	Sudden Erosion	◐
GRADUAL	Frequent Flooding due to Sea Level Rise	○
	Gradual Erosion	●

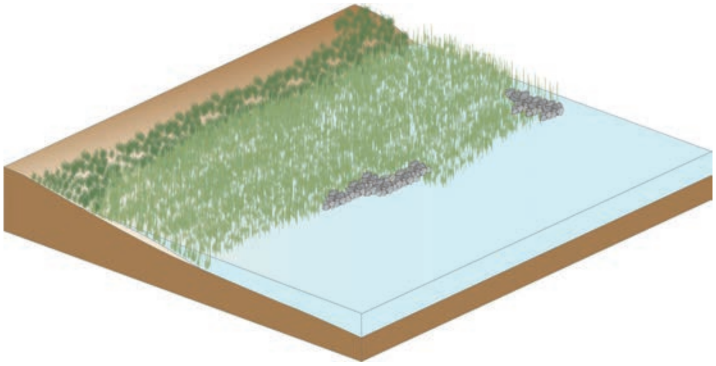
Applicability to Geomorphology Type

1	Oceanfront Beaches	●
2	Hardened Oceanfront Plains	○
3	Coastal Marshes	○
4	Hardened Sheltered Bay Plains	○
5	Oceanfront Slopes	○
6	Sheltered Bay Slopes	○
7	Hardened Sheltered Bay Slopes	○
8	Sheltered Bluffs	○
9	Hardened Sheltered Bluffs	○

● HIGH ◐ MEDIUM ○ LOW

13. CONSTRUCTED WETLANDS

A constructed wetland is a new or restored tidal wetland that uses plants and soils to retain and filter water while creating wildlife habitat.



In addition to the many ecological functions that tidal wetlands provide, they can help reduce risks from coastal hazards. Over the years, over 80 percent of the wetlands in the New York estuary system have been filled and destroyed, and salt marsh extent continues to decline, making it all the more important to protect and restore these wetlands where possible. Large wetland areas may be able to slow down the rate of surge through friction, and if large enough, may provide some reduction in flood heights depending on the speed and intensity of a storm.

Additionally, the construction of fringe wetlands—smaller size wetlands along the coast—can dissipate wave energy and provide erosion control to stabilize shorelines, though are unlikely to reduce the height or extent of coastal flooding. High attenuation across relatively small traverse distances suggests that even narrow wetlands offer relatively high shoreline erosion protection value (Barbier et al. 2008; Morgan et al, 2009). Furthermore, according to a study by Gedan and colleagues (2011) combining manmade structures with wetlands in ways that mimic nature is likely to increase coastal protection. However, the success of constructed wetlands is closely tied to specific site conditions. In order for vegetation to take hold, wave frequency and heights and currents must be low, or structures must be installed to protect the wetlands from waves. Furthermore, the flattening of topography that may be required to create wetlands, as well as the placement of fill into open waters to create shallower areas for wetland vegetation to take hold, may have unintended environmental and flood impacts that should be examined.

The numerous co-benefits of constructed wetlands, such as intertidal habitat protection and creation, long-term sustainability, carbon reduction, water quality improvement, and recreational benefits, make this strategy increasingly attractive and worthy of further study.

Jamaica Bay, Queens

Hazards Addressed

- Extensive areas of coastal wetlands can mitigate wave forces and can provide some reduction in lower levels of storm surge. By protecting inland areas from wave forces, smaller wetlands areas can provide moderate protection from shoreline erosion.
- Wetlands may have some ability to reduce risk from frequent inundation and periodic low surge flooding.

Applicability

- Wetland restoration is most viable in the same areas where they were once found, which is typically low-lying areas within sheltered water bodies or along extensive outwash plans or stream deltas, though there may be some scattered opportunities for wetland construction elsewhere.
- Constructed wetlands are feasible in areas with light to moderate fetch of less than one mile, small waves, and low to medium currents. The viability of wetlands in high energy environments is enhanced when combined with other strategies, such as a breakwaters (see Breakwaters, page 92, Artificial Reefs, page 94, Floating Islands, page 96, and Constructed Breakwater Islands, page 98)
- Wetlands thrive on relatively flat areas where there are fine grain sediments. Coastal wetlands are not sustainable on steep slopes.

Costs

- Constructed wetlands are comparatively low cost. On average, a new constructed wetland costs $700,000 to $1,000,000 per acre. Restoring degraded wetlands and shoreline planting is generally less expensive.
- Unlike other strategies, established wetlands have little to no recovery costs following a storm event. However, on-going maintenance is required and should be factored into the cost.

Potential for Co-Benefits

- Constructed or restored wetlands protect natural resources, create or restore important declining intertidal habitat, and contribute to long-term sustainability in the form of carbon sequestration.
- Wetlands improve water quality by filtering storm water before it enters the waterways and by processing nutrients and pollutants in the receiving waters.
- Wetlands can improve neighborhood drainage following a flood event.
- Recreational benefits associated with wetlands include fishing, bird watching, and kayaking.
- Wetlands help trap large and small floatable debris dispersed during storms.

Additional Considerations

- Storm surge protection is very site-specific, and may be unreliable . More research in needed to better understand the impact of discreet fringe wetlands on storm surge.
- Wetlands limit certain forms of public access to the water and other construction opportunities.
- Sea level rise may change the locations of coastal wetlands and make it difficult to maintain constructed wetlands near the shore.

Ability to Address Coastal Hazards

EVENT-BASED	Storm Surge (High)	○
	Storm Surge (Low)	◐
	Wave Force	◐
	Sudden Erosion	◐
GRADUAL	Frequent Flooding due to Sea Level Rise	○
	Gradual Erosion	●

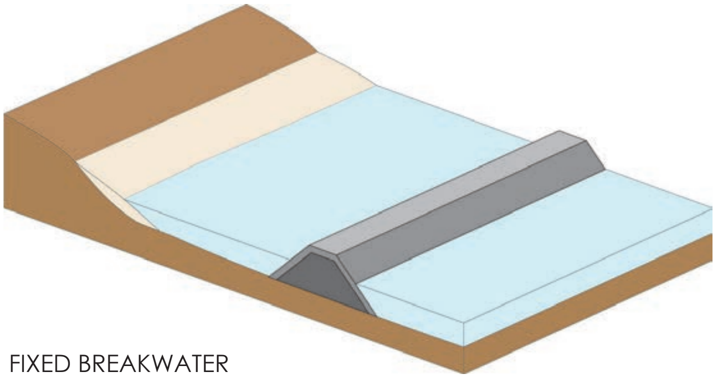
Applicability to Geomorphology Type

1	Oceanfront Beaches	○
2	Hardened Oceanfront Plains	○
3	Coastal Marshes	●
4	Hardened Sheltered Bay Plains	●
5	Oceanfront Slopes	○
6	Sheltered Bay Slopes	◐
7	Hardened Sheltered Bay Slopes	◐
8	Sheltered Bluffs	○
9	Hardened Sheltered Bluffs	○

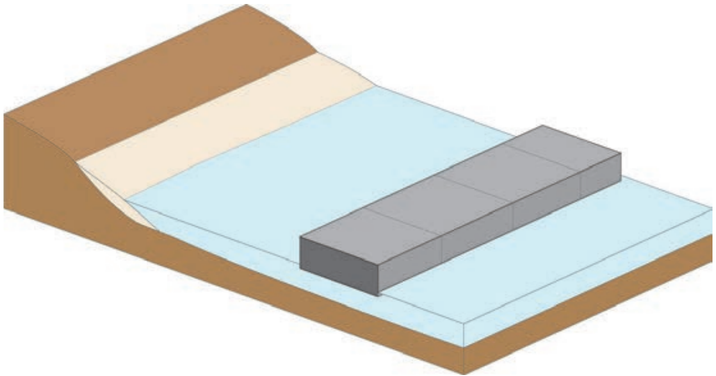
● HIGH ◐ MEDIUM ○ LOW

14. BREAKWATERS

Breakwaters are offshore structures typically made of rock or stone intended to break waves, reducing the force of wave action. Breakwaters can be either floating or fixed to the ocean floor.



FIXED BREAKWATER



FLOATING BREAKWATER

Breakwaters are offshore structures intended to reduce wave heights and protect against shoreline erosion. While large breakwaters have historically served harbor protection and navigational functions, shore-parallel breakwaters have more recently been employed to protect longer stretches of coastline by attenuating or dissipating wave energy. By breaking down large waves, breakwaters allow sediments and materials carried by water to accumulate at the shore, extending the beach, nourishing a wetland, or protecting shoreline structures.

There are many variations in breakwater design depending on site-specific wave forces. Breakwaters may be either fixed or floating. The choice depends on the water depth and the tidal range. Fixed breakwaters may be either submerged (or "low-crested") or above water ("emerged"). They are sometimes constructed attached to a shoreline, or completely detached. In high wave energy environments, fixed breakwaters are typically built with large armorstone, or pre-cast concrete units or blocks. In lower wave-energy environments, grout-filled fabric bags, wood, scrap tires, gabions and other materials may be suitable.

Floating breakwaters can tolerate higher water levels than fixed breakwaters, but only waves shorter in length, and are commonly used to protect against boats and marinas from waves and wakes. Materials for construction vary according to the scale of the structure and local conditions, but can include wood, scrap tires, logs, barges, reinforced concrete, and steel drums. The breakwater must be anchored to the sea bottom; piles are the most reliable and long-lasting type of anchor.

Beacon, NY

Hazards Addressed

- Breakwaters are used to reduce the force of waves and are well-suited to protect shorelines from erosion. They may also contribute to some reduction in total flood levels for surge events.
- They can increase the longevity of a beach nourishment project and stabilize wetland areas.
- Fixed breakwaters are typically better suited to address significant wave forces found along the oceanfront.

Applicability

- Breakwaters can protect oceanfront areas from wave forces. They may also provide some protection from lower wave heights, as well as wakes, in sheltered water bodies.
- Fixed breakwaters are most economical in areas of shallow water. They become very expensive in deep water.
- Conditions that favor floating instead of fixed breakwaters include: poor foundation soils, deep water where fixed breakwaters would be expensive, water quality concerns, ice concerns, visual impact, and need for flexibility in layout or arrangement.
- Floating breakwaters require anchoring, so strong foundation soils that can support piles are necessary.
- Where tidal range is large and fixed breakwaters would be subjected to widely carrying degree of submergence, floating breakwaters can tolerate higher tidal fluctuations. However, they are only effective against shore-period waves, most commonly present in sheltered locations.

Costs

- Breakwater designs vary widely based on site specific conditions and materials used, and costs are therefore difficult to generalize. Breakwaters can cost anywhere between $1,000 per linear foot to tens of thousands of dollars per linear foot. The lifespan of a breakwater can be 50-100 years, with regular maintenance. Maintenance costs approximately $1,000 to $10,000 per linear foot.
- Breakwaters can cause erosion of adjacent, unreinforced shorelines if not designed properly.
- Fixed, emerged breakwaters can reduce water circulation leading to water quality problems.
- Permits are required from the U.S. Army Corps of Engineers and the NYS Department of Environmental Conservation for constructing, modifying or restoring a breakwater, but not for routine maintenance.

Potential for Co-benefits

- Breakwaters can create calm water areas suitable for recreational purposes.
- In the right conditions, submerged breakwaters can function similar to reefs, creating areas of lower wave energy to support the colonization of submerged aquatic vegetation and provide attractive fish and shellfish habitat (see Artificial Reefs, page 94). Crests of breakwaters can also provide habitat enhancement opportunities (See Constructed Breakwater Islands, page 98). Floating breakwaters can integrate vegetation (see Floating Islands, page 96).

Additional Considerations

- Submerged breakwaters can create a navigational hazard for small crafts.
- Breakwaters are often spearheaded by local government, but depending on scale and urgency of the project can be funded completely by Army Corps or a combination of city and federal funds.

Ability to Address Coastal Hazards

EVENT-BASED	Storm Surge (High)	○
	Storm Surge (Low)	◐
	Wave Force	●
	Sudden Erosion	●
GRADUAL	Frequent Flooding due to Sea Level Rise	○
	Gradual Erosion	●

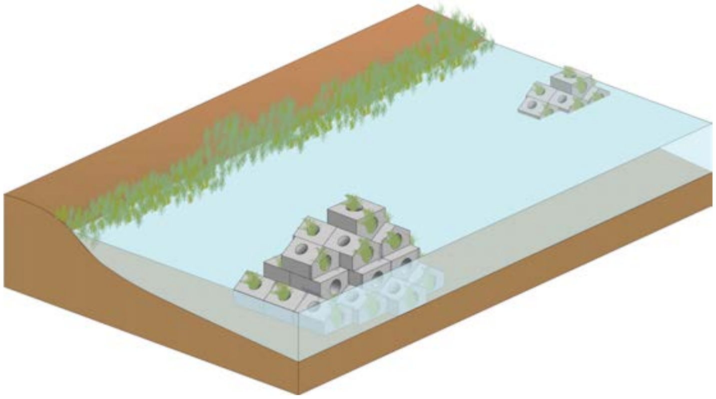
Applicability to Geomorphology Type

1	Oceanfront Beaches	●
2	Hardened Oceanfront Plains	●
3	Coastal Marshes	◐
4	Hardened Sheltered Bay Plains	◐
5	Oceanfront Slopes	●
6	Sheltered Bay Slopes	◐
7	Hardened Sheltered Bay Slopes	◐
8	Sheltered Bluffs	○
9	Hardened Sheltered Bluffs	○

● HIGH ◐ MEDIUM ○ LOW

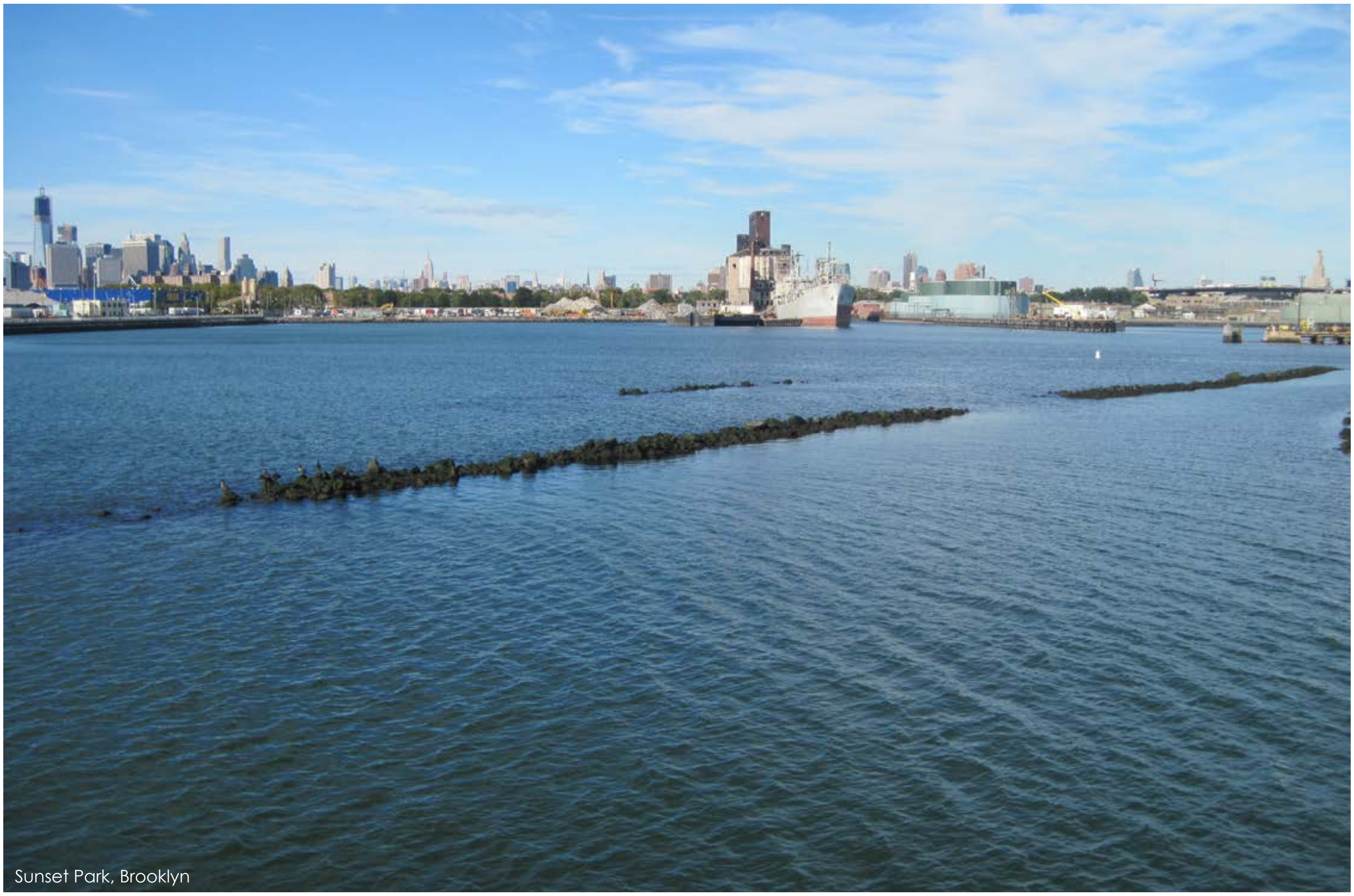
15. ARTIFICIAL REEFS

Artificial reefs are submerged, or partially submerged, structures made of rock, concrete, or other materials, that are designed to provide marine habitat for plants, invertebrates, fish, and birds, while also attenuating waves.



Artificial reefs are often created as a way to enhance fish communities, create sport diving opportunities, and restore marine environments in coastal waters by increasing the amount of habitat for marine life. Recent research, however, has begun exploring the use of artificial reefs as a type of off-shore “living breakwater” that mimic naturally occurring oyster reefs. Vertical shoreline structures can reflect erosive wave energy back into the water body, thereby impacting natural habitat in the littoral zone. Reefs, both naturally occurring and artificial, provide a complex, three-dimensional biogenic structure that can attenuate erosive wave energy, stabilize sediments, and reduce marsh retreat (Scyphers, 2011). While this approach holds much promise for creating a more sustainable shoreline, there is still much research needed to better understand how it can best function as a an erosion control strategy, although artificial reefs have been installed for this purpose in the Gulf Coast, Florida, and New Jersey, among other places.

Like fixed breakwaters (see Breakwaters, page 90), artificial reefs can be submerged or emergent. Artificial reefs can be constructed from a variety of materials, provided that they are made of durable, stable, and environmentally safe materials, such as mounds from rubble or shells and prefabricated concrete units with holes, as well as recycled materials, such as scrap metal, rocky dredged material, and train and subway cars that are cleaned before deployed onto reef sites. Once the material is placed and secured on the ocean floor, it acts similarly to naturally-occurring rock outcroppings by providing hard substrate for the formation of a life-bottom reef community. Marine life quickly takes over, encrusting the substrate with organisms such as barnacles, mussels, and oysters.



Sunset Park, Brooklyn

Credit: Scape Studio

Hazards Addressed

- As with breakwaters, artificial reefs dissipate wave energy, protect shorelines from erosion and minimize sediment movement. They may also contribute to some reduction in overall flood levels for surge events.
- In beach locations, off-shore reefs can minimize the frequency that beach renourishment needs to occur.

Applicability

- As with breakwaters, artificial reefs protect areas from wave forces, even ocean areas with large waves. They may also provide some protection from lower wave heights, as well as wakes, in sheltered water bodies. They are most effective in shallow water bodies.

Costs

- Costs range depending on the type of material used. By way of example, in an installation on Dauphin Island, AL, it cost $400/unit for precast concrete “Coastal Havens,” which are triangular units with a 2.4 m base width and 1.7 m height. While the costs associated with artificial reef materials are relatively low, installation can be challenging and increase the costs.
- Typically they require on-going monitoring, which should be factored into the cost.
- Like with breakwaters, artificial reefs require permits from NYS Department of Environmental Conservation and the U.S. Army Corps of Engineers. The environmental consequences are largely site-specific and therefore require extensive research and investigation before a reef project can proceed.
- Oyster and mussel reefs may raise concerns about poaching of shellfish in waters that may not be safe for human consumption.

Potential for Co-benefits

- Artificial reefs tend to have a low visual impact, since the reefs are typically submerged.
- Depending on the type of artificial reef, they are potentially flexible to adaptation. If the design configuration has unforeseen consequences, for example on sediment movement, it is relatively easy to readjust the location, spacing, and configuration of reef units.
- Artificial reefs create and/or restore habitats. Much of New York Harbor was once filled with oyster reefs, which have disappeared due to dredging and changes in water quality.
- Artificial reefs provide educational opportunities to engage students in learning about marine science, biology, and ecology.
- They also provide recreational benefits for fishing and deep sea diving.

Additional Considerations

- Due to the dynamic nature of the ocean, unforeseen coastal issues may arise. For example, settlement of the reef structures over time may reduce the elevation of the crest, thereby reducing its ability to reduce waves. Scour and unforeseen sediment movement may also occur.
- This is a relatively new strategy for coastal hazard mitigation. Additional research is needed on the feasibility of this strategy in New York.

Credit: NY/NJ Baykeeper

Oyster Reef Ball

Ability to Address Coastal Hazards

EVENT-BASED	Storm Surge (High)	○
	Storm Surge (Low)	◐
	Wave Force	●
	Sudden Erosion	●
GRADUAL	Frequent Flooding due to Sea Level Rise	○
	Gradual Erosion	●

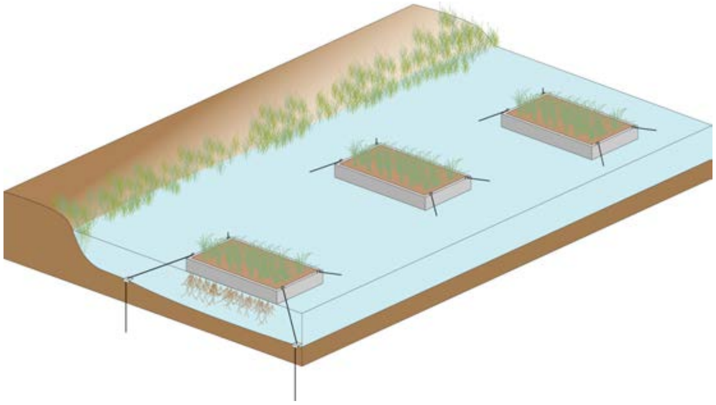
Applicability to Geomorphology Type

1	Oceanfront Beaches	●
2	Hardened Oceanfront Plains	●
3	Coastal Marshes	◐
4	Hardened Sheltered Bay Plains	◐
5	Oceanfront Slopes	●
6	Sheltered Bay Slopes	◐
7	Hardened Sheltered Bay Slopes	◐
8	Sheltered Bluffs	○
9	Hardened Sheltered Bluffs	○

● HIGH ◐ MEDIUM ○ LOW

16. FLOATING ISLANDS

Floating Islands are planted mats or structures that can attenuate waves while providing ecological benefits, such as habitat restoration and improved water quality.



Floating islands planted with vegetation can provide many of the benefits of a traditional floating breakwater with added ecological benefit. Vegetated floating islands can dampen wave energy to reduce erosion on sandy or marshy shorelines, but are not designed to provide protection from storm surge or significant wave action. Today, floating islands are sometimes used as water treatment wetlands that can improve water quality through the microbial break-down of pollutants. However, research is underway on their effectiveness as an erosion reduction technology that may have cost saving and efficiency benefits. Several manufacturers produce floating islands, and while they come in various specifications, they generally consist of a buoyant substrate that is anchored to the seabed. Holes in the substrate support and anchor vegetative plant materials, allowing root structures to pass through into the water. While relatively untested at a large scale, pilot projects are underway in the Gulf Coast, Maryland, and Jamaica Bay.

® Biohaven Floating Island, Isle de Jean Charles, Louisiana

Credit: Martin Ecosystems

Hazards Addressed

- Floating islands can act as breakwaters to protect shorelines from erosion and low to moderate wave forces.

Applicability

- Floating islands are most successful in sheltered water bodies with low wave energy and in shallower waters.
- They are inappropriate for high wave energy environments, where they cannot withstand forces.

Costs

- Costs for floating wetland islands are estimated at $80/sq. ft., according to a project in Terrebone, LA using Biohaven Floating Island technology.
- Like with breakwaters, floating islands require permits from NYS Department of Environmental Conservation and the U.S. Army Corps of Engineers. The environmental consequences are largely site-specific and therefore require extensive research and investigation before a reef projects can proceed.

Potential for Co- benefits

- Installation of floating islands is relatively simply and flexible. They are low cost and effective on a localized scale.
- Floating vegetated islands share many of the ecosystem benefits of wetlands, such as habitat creation, nutrients, carbon sequestration, and water quality improvement.
- Volunteer installation and monitoring of vegetated floating islands can provide educational opportunities on ecology, climate change, and coastal construction.

Additional Considerations

- To date, this is a relatively untested strategy for coastal resiliency. Further research is needed to better understand the overall effectiveness of vegetative floating breakwaters in coastal hazard reduction compared to traditional breakwater technologies. The environmental permitting for floating islands would require project applicants to demonstrate that the habitat and water quality benefits surpass potential shading or other negative environmental impacts.

Ability to Address Coastal Hazards

EVENT-BASED	Storm Surge (High)	○
	Storm Surge (Low)	○
	Wave Force	◐
	Sudden Erosion	◐
GRADUAL	Frequent Flooding due to Sea Level Rise	○
	Gradual Erosion	●

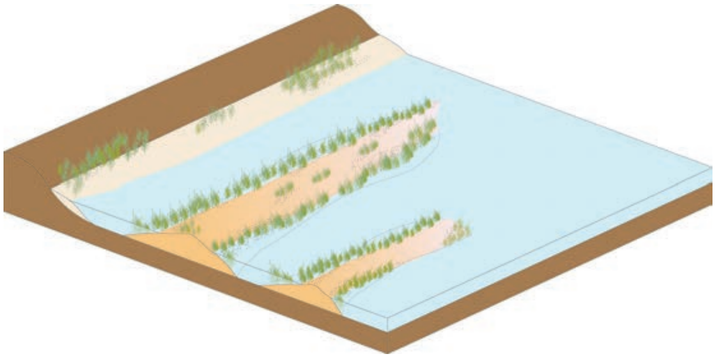
Applicability to Geomorphology Type

1	Oceanfront Beaches	○
2	Hardened Oceanfront Plains	○
3	Coastal Marshes	●
4	Hardened Sheltered Bay Plains	●
5	Oceanfront Slopes	◐
6	Sheltered Bay Slopes	◐
7	Hardened Sheltered Bay Slopes	◐
8	Sheltered Bluffs	○
9	Hardened Sheltered Bluffs	○

● HIGH ◐ MEDIUM ○ LOW

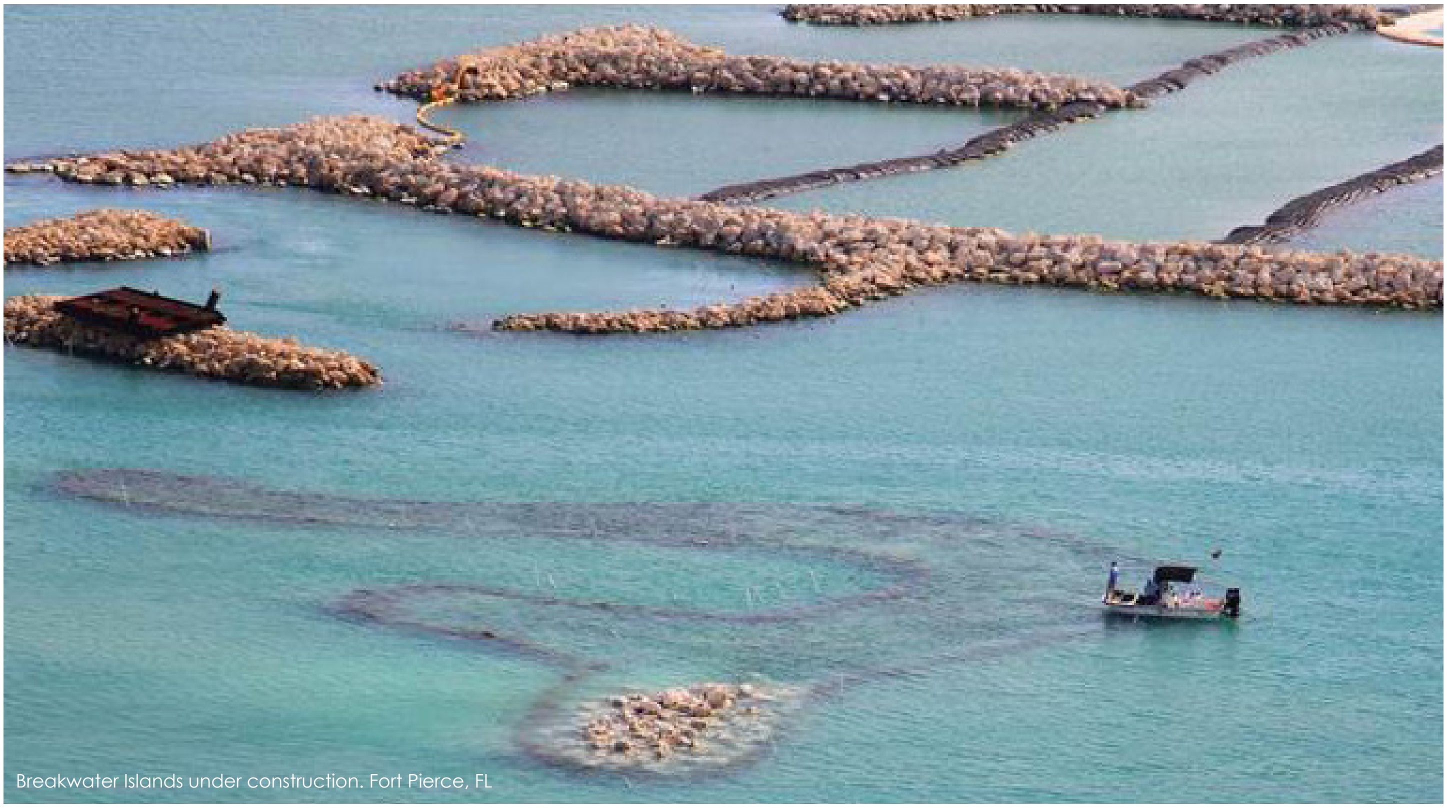
17. CONSTRUCTED BREAKWATER ISLANDS

Constructed breakwater islands are off-shore islands constructed through fill of sand and rock.



Off-shore constructed breakwater islands are artificial islands that function as breakwaters while also doubling as habitat-enhancing islands. By emulating nature, artificial islands employ naturalistic elements to function as a permanent breakwater. These structures can mimic sand bars or wetland islands. They can be created through off-shore nourishment, or by using geotextile tubes filled with dredged material to create a base, then filled with rock or sand. Unlike a traditional breakwater, the island's dunes can then be planted with beach grasses and other native plants. Other features which provide ecosystem value, such as oyster reefs and near shore subaquatic vegetation, can be integrated. Constructed breakwater islands require shallow water conditions, can be costly, and require extensive environmental permitting.

In response to Hurricane Frances, the 2004 storm that destroyed the Fort Pierce Marina in Florida, the city received FEMA funding to construct a permanent natural-appearing, artificial breakwater island. The project, which is to be completed in 2013, consists of 12 islands and one peninsular structure that form a storm protection system to protect the marina and adjacent public waterfront areas. The 14.66 acre islands also provide habitat and improve water quality by incorporating mangrove planting, oyster recruitment, shorebird habitat, and natural limestone artificial reef areas.



Breakwater Islands under construction. Fort Pierce, FL

Credit: BiMaccaFerri, Inc.

Hazards Addressed

- As with breakwaters, constructed breakwater islands can reduce the force of waves and are well-suited to protect shorelines from erosion. They may also contribute to some reduction in overall storm surge levels for some surge events.

Applicability

- As with breakwaters, artificial reefs protect areas from wave forces, even ocean areas with large waves. They may also provide some protection from lower wave heights, as well as wakes, in sheltered water bodies.
- Like breakwaters, constructed breakwater islands are most effective in shallow water bodies where less fill is necessary.
- Best suited for specific waterfront land uses that require protection from waves where waterfront space is highly valued, such as central business areas.

Costs

- Costs vary based on site-specific conditions, but upfront capital costs can be significant. Water depth can significantly increase the cost and viability of constructed breakwater islands. In Fort Pierce, Florida, the construction of a 12-island, 14.66 acre breakwater island cost $18.9 million.
- On-going monitoring of ecological elements is necessary and should be factored into the project cost.
- As large in-water structures, projects would face an extensive permitting process. Like breakwaters, permits are required from the U.S. Army Corps of Engineers and the NYS Department of Environmental Conservation for constructing, modifying, or restoring a breakwater.

Potential for Co-benefits

- Vegetated breakwater islands provide many opportunities for ecological enhancement and creation of intertidal habitat. This may contribute towards mitigation of environmental impacts caused by the placing of fill.
- Vegetated breakwater islands offer aesthetic value and potential recreational opportunities that would not be provided by a traditional breakwater structure.

Additional Considerations

- Extensive hydrological studies are necessary to determine the appropriate configuration of constructed breakwater islands, as they may have potential impacts on hydrology, water quality, navigation, and ecology.

Ability to Address Coastal Hazards

EVENT-BASED	Storm Surge (High)	○
	Storm Surge (Low)	○
	Wave Force	●
	Sudden Erosion	●
GRADUAL	Frequent Flooding due to Sea Level Rise	○
	Gradual Erosion	●

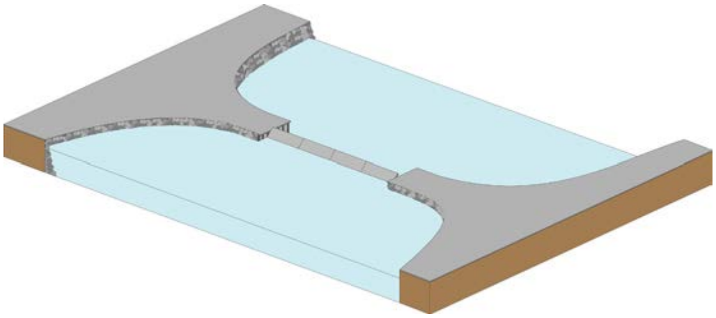
Applicability to Geomorphology Type

1	Oceanfront Beaches	●
2	Hardened Oceanfront Plains	●
3	Coastal Marshes	●
4	Hardened Sheltered Bay Plains	●
5	Oceanfront Slopes	●
6	Sheltered Bay Slopes	◐
7	Hardened Sheltered Bay Slopes	◐
8	Sheltered Bluffs	○
9	Hardened Sheltered Bluffs	○

● HIGH ◐ MEDIUM ○ LOW

18. SURGE BARRIERS

Surge barriers consist of fixed dam structures and operable gates that can be closed to stop water in order to prevent storm surge from flooding coastal areas.



Surge barriers provide a high level of protection from storm surge, and are typically integrated into a larger flood protection system that includes shoreline levees, seawalls, and pumps. Under normal conditions, surge barriers remain open to allow water and vessels to pass, but can be closed when water levels rise due to storm surge. All surge barriers require extensive maintenance and monitoring. The design of surge barriers varies widely, and is largely a product of local conditions. Various types of gates—sector gates, vertical lifting gates—are possible, as well as various design options for pumping stations, navigational locks, and adjacent levees and seawalls. On a smaller scale, tide gates, which close during incoming tides, can be placed at the mouth of streams, small rivers, or culverts, to prevent waters from entering.

Domestically, the Army Corps of Engineers has been responsible for leading the design and construction of various barrier systems. In the northeast, they have constructed six storm surge barriers. Nearly three decades after the first disastrous hurricane in 1938, several New England barriers, including ones in Providence, RI, New Bedford, MA and Stamford, CT, were constructed. Following Hurricane Katrina, between 2005-2011 the Inner Harbor Navigation Canal-Lake Borgne Storm Surge Barrier, which is part of the Greater New Orleans Hurricane and Storm Damage Risk Reduction System, was constructed at a cost of $1.3 billion. It spans 1.8 miles and includes a 26 foot-tall barrier with three movable gates and connects into a system of levees, seawalls, and pump stations.

Throughout the world, large-scale barriers have been erected to reduce the risk of flooding in major cities. The Thames Barrier in London, completed in 1982, is 0.3 miles wide and includes 8 rotating sector gates. Maeslant Barrier in Rotterdam, completed in 1997, is part of the larger Delta Works system, and is 0.2 miles wide and includes two floating sector gates. Currently under construction, the MOSE project consists of a series of mobiles gates to block the Venice Lagoon from high water levels in the Adriatic Sea. The gates are designed to lie at the bottom of the sea and are raised by pumping compressed air into an underwater chamber. In New York, as part of a 2009 conference for the American Society of Civil Engineers, engineering firms made conceptual designs for a two-barrier and three-barrier system in the New York City area.

Credit: CH2M HILL

CASE STUDY: ST. PETERSBURG, RUSSIA

To protect St. Petersburg, the flood-prone Russian city located only a few meters above sea level, from increasingly frequent flooding caused by storm surge from the Gulf of Finland, a 16-mile long barrier system was recently completed that separates the Neva Bay from the Gulf. The project, which began in 1978 and experienced several halts in the 1990s and early 2000s, resumed in 2005 and was finally completed in 2011. The barrier system is designed for 1-in-1000 year flood (or 16-foot storm surge) and consists of 11 rock and earth embankment dams separated by two channel openings and six sluice complexes, each with up to 12 steel radial gates 24 meters wide, for a total of 64 gates. According the Halcrow, the engineering consultant for Stage 2 of the project, the sluices allow for water flow during normal conditions but can be closed in times of flood. The two navigational channels—one at 200 meters wide and the other at 130 meters wide—allow for both cargo and recreational marine traffic to pass through to the St. Petersburg port. Additionally, the barrier doubles as part of St. Petersburg's ring road highway, with a 6-lane road extending across the main hydraulic structures, a tunnel at the 200m opening, and a viaduct and vertically-lifted steel bridge at the 100m opening. The barrier also incorporates water management controls that aim to improve water quality and environmental conditions on the bayside of the barrier.

Ability to Address Coastal Hazards

EVENT-BASED	Storm Surge (High)	●
	Storm Surge (Low)	●
	Wave Force	●
	Sudden Erosion	●
GRADUAL	Frequent Flooding due to Sea Level Rise	○
	Gradual Erosion	○

Applicability to Geomorphology Type

1	Oceanfront Beaches	◐
2	Hardened Oceanfront Plains	◐
3	Coastal Marshes	●
4	Hardened Sheltered Bay Plains	●
5	Oceanfront Slopes	◐
6	Sheltered Bay Slopes	●
7	Hardened Sheltered Bay Slopes	●
8	Sheltered Bluffs	●
9	Hardened Sheltered Bluffs	●

● HIGH ◐ MEDIUM ○ LOW

Hazards Addressed

- Surge barriers can be designed to protect from low and high surge events, depending on the design elevation, and from wave action and erosion.
- Because they require closing in the event of a storm, they do not protect from gradual hazards of sea level rise and erosion.
- They can protect very large areas from coastal flooding by shortening the exposed shoreline.

Applicability

- Surge barriers are most appropriate for waterways that require use of navigational channels. They require connections from adjacent shorelines with high elevations which is more likely to be feasible in sheltered water bodies such as where a narrow river mouth or inlet can be closed off, as this reduces expenses.
- Depending on a given geography and the construction of adjacent dams, as in the St. Petersburg case study, other opportunities may exist to cross larger bodies of water.

Costs

- Costs vary widely depending on types and components, particularly the number and size of movable parts. Fixed components are estimated at $16,000 per linear foot, and movable components can range from $40 million to $400 million. Based on costs associated with built projects, construction costs for barriers range widely from $1 million (IHNC barrier) to $6.125 billion (Venice MOSE), and annual maintenance costs range from $ 0.5 million (Providence, RI) to $20 million (Eastern Scheldt Barrier). Tide gates for small streams and rivers cost an estimated $20,000 per linear foot (All figures in 2013 dollars).
- The modifications to water flow that result from barriers change the chemical, physical, and biological properties of the estuarine system by altering the temperature, salinity, suspended matter, and nutrients in the water. Use of movable rather than fixed barriers can reduce these impacts.
- Storm surge barriers have very high upfront capital and maintenance costs, determined by a variety of factors such as design type, local soil characteristics, desired height and hydraulic head over the barrier, single vs. multi-stage construction (single is less expensive), and availability of raw construction materials.
- In New York City, the construction of in-water infrastructure requires permits from NYS Department of Environmental Conservation and the U.S. Army Corps of Engineers. The environmental consequences are largely site-specific and therefore require extensive research and investigation before they can be built. Because of the complexity of the project, the funding requirements, and the environmental impacts of storm surge barriers, they are likely to experience an extensive permitting process and may take a long time to build.
- There is the potential for increased river flooding from backed-up water on the landward side of the barrier, although this may be preventable with proper monitoring and design. Storm surge barriers may increase storm surge in areas outside the barrier in the event of a storm.

Potential for Co-benefits

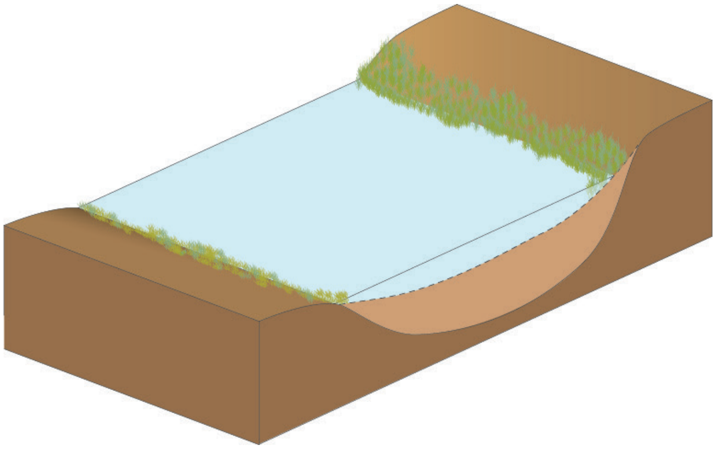
- Barriers can enhance in-water recreational opportunities by blocking waves and creating calmer waters.
- In some instances, such as in Venice, the barriers can also function to improve water quality by dispersing pollutants.

Additional Considerations

- Picking an appropriate design flood elevation for surge barriers is a challenge, given the uncertainty associated with even the best sea level rise projections and the costs associated with increasing design. When the design level is exceeded, the results can be catastrophic. Decisions about the design elevation and other complementary strategies must consider the potential for overtopping or failure.
- Protective coastal infrastructure, such as seawalls, levees and surge barriers, may encourage development in areas vulnerable to coastal flooding. This can inadvertently increase a community's vulnerability, as it may lead to an increase in population, and give a false sense of protection from coastal hazards, resulting in complacency about taking mitigation actions.
- Strong political will is necessary to construct barriers, due to extremely high direct and indirect costs associated.
- Storm surge barriers are typically constructed by the U.S. Army Corps of Engineers as part of a larger flood control project, with a mix of federal, state, and local funding. In order for the Army Corps to build such a project, the U.S. Congress must authorize the funding of a feasibility study that examines the costs of benefits and alternatives. If the study finds there is sufficient reason to move forward, Congress then must authorize funding the eventual construction.
- The potential combination of other shoreline and in-water strategies in conjunction with barriers is an area of growing research and study.

19. COASTAL MORPHOLOGY ALTERATION

Altering the bathymetry of a water body to allow for shallow waters can reduce the extent of storm surge.



New York's waterways were historically much shallower than they are today, with most of the waters less than 20 feet deep, according to the *Hudson-Raritan Estuary Comprehensive Restoration Plan*. Today, over hundreds of miles of established navigational channels and associated berthing areas are routinely dredged to meet shipping needs. In Jamaica Bay, which was once filled with wetlands and is experiencing a wetland loss rate at somewhere between 33 and 44 acres per year, a study has shown that tidal ranges are much greater in dredged areas than at shallower depths (Swanson and Wilson, 2007). If large scale dredging has had an impact on increasing tides, might the inverse—the restoration of coastal morphology—be able to reduce a storm surge? Researchers have recently shown that shallowing these deep channels can slow the propagation of a storm surge and reduce flood levels inside the bay (Orton et al. 2012). Similarly, lateral narrowing of tidal inlets might be an effective means for reducing flood levels.

Jamaica Bay, Queens

Hazards Addressed

- Coastal morphology alteration of strategic areas within a waterbody may be able to reduce overall surge heights for moderate storm surge events and provide some protection from waves in the event of a storm.

Applicability

- Coastal morphology alteration is most promising as a potential strategy in inlets leading to sheltered water bodies and in relatively narrow or shallow bottleneck areas for a propagating storm surge.

Costs

- Costs are unknown, as this strategy is relatively untested. Costs would be dependent on availability of clean fill.
- Costs associated with permitting and monitoring must be considered.
- Hydrodynamic modeling would be required to understand the impacts on oxygen levels, sediment transport, wetlands, and ecosystems. This approach could provide environmental gains by restoring a waterbody to its naturally occurring depth. However, it could also cause potential negative environmental impacts on water quality, particularly if pollutant flushing (e.g. nitrogen) is reduced, or oxygen levels are reduced.
- If this strategy were implemented through the placement of large amounts of fill on benthic habitat, it would have to undergo an extensive permitting process with the NYS Department of Environmental Conservation and the U.S. Army Corps of Engineers.
- It may result in loss of navigational channels which would have negative economic impacts, disrupt the movement of waterborne freight, and possibly prevent some forms of recreational boating.

Potential for Co-benefits

- Coastal morphology alteration could be used in combination with restoration to enhance biodiversity, an approach recommended by the *Hudson-Raritan Estuary Comprehensive Restoration Plan*. Shallows restoration is a restoration approach that can enhance littoral zones. These zones support high densities of organisms and biodiversity, particularly when vegetated.
- Halting dredging of an inlet and letting it fill from natural sedimentation can save costs associated with maintenance dredging.

Additional Considerations

- This strategy is relatively untested. The overall impacts on flooding and sea level rise are uncertain and detailed hydrodynamic modeling is required to better understand at what scale shallows restoration could have an impact on storm surge.
- Shallowing would limit navigability of waterways that are currently used for recreational and commercial maritime activities.

Ability to Address Coastal Hazards

EVENT-BASED	Storm Surge (High)	○
	Storm Surge (Low)	◐
	Wave Force	◐
	Sudden Erosion	◐
GRADUAL	Frequent Flooding due to Sea Level Rise	○
	Gradual Erosion	○

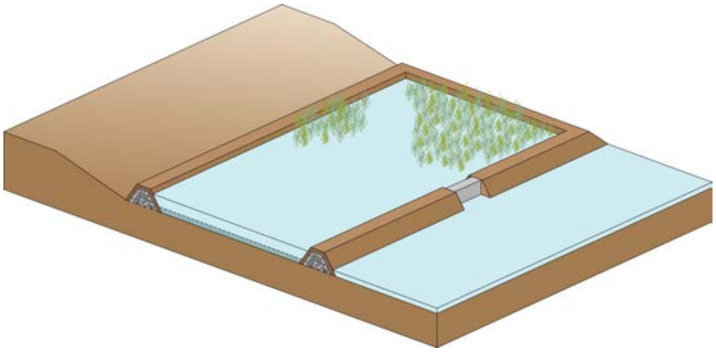
Applicability to Geomorphology Type

1	Oceanfront Beaches	○
2	Hardened Oceanfront Plains	○
3	Coastal Marshes	●
4	Hardened Sheltered Bay Plains	●
5	Oceanfront Slopes	○
6	Sheltered Bay Slopes	○
7	Hardened Sheltered Bay Slopes	○
8	Sheltered Bluffs	○
9	Hardened Sheltered Bluffs	○

● HIGH ◐ MEDIUM ○ LOW

20. POLDERS

A polder is a low-lying tract of land enclosed by levees that form an artificial hydrological entity. It could be used to divert and temporarily detain flood waters.



Poldering is a traditional Dutch technique that involves reclaiming land by enclosing an area of water with eathern dikes and then mechanically pumping out the water. More recently, with Dutch policy evolving from a strategy of keeping water out to accepting periodic flooding, polder systems are being rethought and re-envisioned. As various design proposals have explored, by inverting polders and the dike rings that surround them and allowing the water in, large quantities of floodwaters can be diverted and retained. In Noordwaard, Netherlands, a sparely populated 7.9 square mile polder used mainly for agricultural use, the polder is being opened up to make room for the Merwede River. By lowering a portion of the dike, water can flow over when necessary and discharge into the Hollands Diep estuary, thereby lowering the level of the river upstream. Could this strategy inspire coastal interventions that could help divert water in the event of storm surge? While reclaiming land may not be feasible in densely developed areas, could new in-water structures or waterfront parks be designed to act as a giant retaining basin, diverting flood waters to keep critical areas dry until the surge subsides? The size of such a polder would have to be massive and the environmental impacts would need to be investigated, but new research on polder technology may be able to show how this historic land reclamation technique can be transformed into a storm surge protection strategy.

Credit: Guy Nordenson and Associates/ Catherine Seavitt Landscape/ ARO

CASE STUDY: ON THE WATER/PALISADE BAY

On the Water/Palisade Bay is a 2007 research and design initiative that imagines the transformation of the New York–New Jersey Upper Bay in the face of sea level rise. Rather than relying solely on traditional coastal engineering solutions, the study explores the Upper Harbor's underlying dynamic systems as a basis to synthesize strategies for both storm defense and environmental enrichment along the region's highly urbanized coast. According to the researchers, the goal is "to layer these priorities throughout the harbor zones to not only create a comprehensive storm defense system but to also provide new places for recreation, agriculture, ecologies, and urban development." The proposal suggests a series of inventive "soft" infrastructure strategies to buffer and absorb flooding while layering new destinations, housing, and urban farms on the water. These strategies include in-water components, such as reefs created from sunken subway cars, wave and wind turbines, oyster racks and archipelago islands. Shoreline edge design ideas include piers, pile fields, slipways, mounds, basins and mat vegetation, blurring the artificial line between water and land currently present in the harbor. The project is also notable for its widespread influence in climate resilience and coastal planning, including Rising Currents, a provocative 2010 exhibition at the Museum of Modern Art in which the curators challenged design teams to develop outside-of-the-box solutions to address rising seas in New York Harbor.

Hazards Addressed

- Polders can be used to divert and detain waters in the event of significant riverine flooding. Although their applicability to storm surge is largely conceptual, at a large enough scale they may allow for the reduction of moderate levels of storm surge. This strategy is relatively untested and requires additional modeling and research.

Applicability

- While the applicability of this strategy is as of yet uncertain, there is some promise in sheltered water bodies and within coastal parklands.

Costs

- Costs are unknown, as this strategy is relatively untested.
- Associated environmental impacts have the potential to be high. Like with other in-water strategies, projects would face an extensive permitting process involving the U.S. Army Corps of Engineers and the NYS Department of Environmental Conservation. Given that this strategy is untested in the region, regulatory hurdles would be significant.
- Large areas of unused or underused land or water would be required. In dense areas, it may be cost prohibitive to acquire sufficient parcels.

Potential for Co-benefits

- While not retaining water, polders could provide additional space for a range of uses, such as ballfields, farmland, or other temporary recreational uses.

Additional Considerations

- As a large engineered structure, it has the potential to disrupt natural hydrology and ecosystems. In-depth hydrological studies would be required to determine how such a system could be effective without disrupting other man-made and natural systems.
- High dike walls associated with polders may limit waterfront access and visibility.

Ability to Address Coastal Hazards

EVENT-BASED	Storm Surge (High)	○
	Storm Surge (Low)	◐
	Wave Force	○
	Sudden Erosion	○
GRADUAL	Frequent Flooding due to Sea Level Rise	○
	Gradual Erosion	○

Applicability to Geomorphology Type

1	Oceanfront Beaches	○
2	Hardened Oceanfront Plains	○
3	Coastal Marshes	◐
4	Hardened Sheltered Bay Plains	◐
5	Oceanfront Slopes	○
6	Sheltered Bay Slopes	◐
7	Hardened Sheltered Bay Slopes	◐
8	Sheltered Bluffs	◐
9	Hardened Sheltered Bluffs	◐

● HIGH ◐ MEDIUM ○ LOW

REACH STRATEGIES SUMMARY

ABILITY TO ADDRESS COASTAL HAZARDS

● HIGH ◐ MEDIUM ○ LOW

	EVENT BASED				GRADUAL	
	Storm Surge (HIGH)	Storm Surge (LOW)	Wave Action	Sudden Erosion	Frequent Flooding due to Sea Level Rise	Gradual Erosion
UPLAND						
01. Elevation of land and streets	◐	●	◐		●	
02a. Deployable Floodwalls	○	●	○		○	
02b. Permanent Floodwalls	●	●	◐		○	
03. Waterfront Parks	◐	●	◐	◐	●	●
04. Strategic Retreat	●	●	●	●	●	●
SHORELINE						
05. Bulkheads	○	◐	◐	◐	●	●
06. Revetments	○	◐	●	●	●	●
07. Living Shorelines	○	◐	◐	●	●	●
08. Seawalls	●	●	●	●	●	●
09. Beaches / Dunes	●	●	●	◐	●	◐
10. Levees (or Dikes)	●	●	◐	◐	●	◐
11. Multi-purpose Levees	●	●	◐	◐	●	◐
IN-WATER						
12. Groins	○	○	◐	◐	○	●
13. Constructed Wetlands	○	◐	◐	◐	○	●
14. Breakwaters	○	◐	●	●	○	●
15. Artificial Reefs	○	○	●	●	○	●
16. Floating Islands	○	○	◐	◐	○	●
17. Constructed Breakwater Islands	○	◐	●	●	○	●
18. Surge Barriers	●	●	●	●	○	○
19. Coastal Morphology Alteration	○	◐	◐	◐	○	○
20. Polders	○	◐	○	○	○	○

UPLAND

Elevation of streets and land can reduces vulnerability to frequent inundation and surge events by elevating land to above a design flood elevation. It is probably not feasible for very high surge elevations.	01. Elevation of land and streets
Deployable floodwalls are most suitable for low to moderate surge events and in areas that experience low to moderate wave action in the event of a storm. Since they must be installed prior to an event, they are not suitable to protect from daily tidal inundation.	02a. Deployable Floodwalls
Permanent floodwalls can be designed to address high and low surge events in moderate to high wave action environments. Since they are in place all the time, they could protect from frequent flooding due to sea level rise, but aren't designed to be permanently at the	02b. Permanent Floodwalls
Parks can be designed to withstand and recover from a variety of coastal hazards and can offer some protection to adjacent inland areas from moderate surge levels, wave action, erosion, and frequent flooding.	03. Waterfront Parks
By relocating vulnerable uses away from the areas at risk, they are protected from all coastal hazards, though the land itself may still be susceptible to impacts from coastal hazards.	04. Strategic Retreat

SHORELINE

Bulkheads protect sites from erosion and moderate wave action. They are not designed to protect from major flood events but do manage daily and monthly fluctuations in tide levels.	05. Bulkheads
Revetments are used to stabilize shorelines to prevent erosion but do not provide protection from high water levels. They are often used in concert with seawalls, bulkheads, or levees to add additional armoring protection from waves and wakes.	06. Revetments
Designs vary greatly, though generally living shorelines are designed to stabilize a shoreline, absorb wave energy, and prevent erosion. They are most successful in low and moderate wave energy environments.	07. Living Shorelines
Seawalls are designed to prevent storm surge from flooding inland areas and to resist strong wave forces and erosion.	08. Seawalls
Beaches and dunes in combination can protect inland areas from flooding, waves, and erosion, though the beach itself is a sacrificial element and may be lost to erosion in a storm or gradually over time if not replenished.	09. Beaches / Dunes
Levees are used to protect areas from low to high surge events, when combined with armored rip-rap, levees can resist heavy storm waves.	10. Levees (or Dikes)
Like levees, multi-purpose levees are used to protect areas from low to high surge events. They are not typically used to protect from wave forces or against erosion, but provide some benefits from these hazards.	11. Multi-purpose Levees

IN-WATER

The primary function of groins is to prevent the erosion of beaches. They may also offer some protection from wave forces.	12. Groins
Extensive areas of coastal wetlands can mitigate wave forces and can provide some reduction of total flood levels. By protecting inland areas from wave forces, they can provide some protection from erosion.	13.Constructed Wetlands
Breakwaters are used to reduce the force of waves and are well-suited to protect shorelines from erosion. They may also contribute to some reduction in total flood levels for some surge events.	14. Breakwaters
As with breakwaters, artificial reefs are used to reduce the force of waves and are well-suited to protect shorelines from erosion. They may also contribute to some reduction in overall flood levels for some surge events.	15. Artificial Reefs
Floating islands can act as breakwaters to protect shorelines from erosion and moderate wave forces.	16. Floating Islands
As with breakwaters, constructed islands can reduce the force of waves and are well-suited to protect shorelines from erosion. They may also contribute to a reduction in overall flood levels for some surge events.	17. Constructed Breakwater Islands
Surge barriers can be designed to protect from low and high surge events and from wave action and erosion. Because they require closing in the event of a storm, they do not protect from gradual hazards.	18. Surge Barrier
Shallowing of strategic areas within a water body can reduce overall surge heights for moderate storm surge events and provide some protection from waves in the event of a storm. This strategy is relatively untested and requires additional modeling and research.	19. Coastal Morphology Alteration
Polders are used to divert waters in the event of significant riverine flooding. Their applicability to storm surge is largely conceptual though at a large enough scale, they may allow for the moderate reduction of storm surge. This strategy is relatively untested and requires additional modeling and research.	20. Polders

LIKELY APPLICABILITY TO COASTAL AREA TYPOLOGIES

● HIGH ◐ MEDIUM ○ LOW

	GEOMORPHOLOGY								
	Oceanfront beaches	Hardened Oceanfront Plains	Coastal Marshes	Hardened Sheltered Bay Plains	Oceanfront Slopes	Sheltered Bay Slopes	Hardened Sheltered Bay Slopes	Sheltered Bluffs	Hardened Sheltered Bluffs
UPLAND									
01. Elevation of land and streets	●	●	●	●	◐	◐	◐	○	○
02a. Deployable Floodwalls	○	○	●	●	○	●	●	●	●
02b. Permanent Floodwalls	◐	◐	●	●	◐	●	●	●	●
03. Waterfront Parks	●	●	●	●	●	●	●	●	●
04. Strategic Retreat	●	●	●	●	◐	◐	◐	○	○
SHORELINE									
05. Bulkheads	○	◐	○	●	○	○	●	○	●
06. Revetments	○	●	○	●	◐	●	●	◐	●
07. Living Shorelines	○	○	●	●	○	●	●	●	●
08. Seawalls	●	●	◐	●	●	◐	◐	○	○
09. Beaches / Dunes	●	◐	○	○	◐	○	○	○	○
10. Levees (or Dikes)	○	○	●	●	○	◐	◐	○	○
11. Multi-purpose Levees	○	○	●	●	○	◐	◐	○	○
IN-WATER									
12. Groins	●	○	○	○	○	○	○	○	○
13. Constructed Wetlands	○	○	●	●	○	◐	◐	○	○
14. Breakwaters	●	●	◐	◐	●	◐	◐	○	○
15. Artificial Reefs	●	●	●	●	●	◐	◐	○	○
16. Floating Islands	○	○	●	●	◐	◐	◐	○	○
17. Constructed Breakwater Islands	●	●	●	●	●	◐	◐	○	○
18. Surge Barriers	◐	◐	●	●	◐	●	●	●	●
19. Coastal Morphology Alteration	○	○	●	●	○	○	○	○	○
20. Polders	○	○	◐	◐	○	◐	◐	◐	◐

UPLAND

Elevation of land is most suitable for low-lying areas that are vulnerable to surge. In medium elevation areas, there may be some opportunities to increase elevations to provide protection.	01. Elevation of land and streets
Deployable floodwalls are not suitable for areas along the oceanfront which experience high wave action in the event of storm.	02a. Deployable Floodwalls
Permanent floodwalls are most suitable for sheltered areas which experience less wave action, but may be engineered for oceanfront areas.	02b. Permanent Floodwalls
The improvement or creation of a waterfront park to serve as a flood buffer is suitable for nearly any geomorphology, though it requires the presence of a substantial amount of open space.	03. Waterfront Parks
Strategic retreat is most suitable on a large scale for areas most exposed to storm surge and wave forces, and as part of an overall plan.	04. Strategic Retreat

SHORELINE

Bulkheads are most suitable for sites with pre-existing hardened shoreline structures. On unreinforced sites, particularly low-lying marshes, they may lead to loss of intertidal habitat. On unreinforced, soft shorelines, bulkheads may accelerate erosion of adjacent, unreinforced sites. For oceanfront areas, bulkheads may be damaged from storm waves and lead to additional damage.	05. Bulkheads
Revetments are most suitable for sites with pre-existing hardened shoreline structures. On unreinforced sites, particularly low-lying marshes, they may lead to loss of intertidal habitat. On sandy shorelines revetments revetments may accelerate erosion of adjacent, unreinforced sites. They well-suited to mitigate wave action on ocean-fronting shorelines and provide erosion protection on steeper	06. Revetments
Living shorelines are suitable for most types of areas except high wave energy environments where wave action and fast currents are typically too strong.	07. Living Shorelines
Seawalls are most suitable for areas highly vulnerable to storm surge and wave forces. They may disrupt sediment transport and lead to the erosion of beaches.	08. Seawalls
Beaches and dunes are most suitable for low-lying oceanfront areas with existing sources of sand and sediment transport systems to provide ongoing replenishment.	09. Beaches / Dunes
Levees are less suitable for oceanfronts where wave forces typically require a seawall. They are more suitable for low-lying areas that could require high elevation structures to protect from storm surge.	10. Levees (or Dikes)
Like levees, multi-purpose levees are less suitable for oceanfronts where wave forces typically require a seawall. They are more suitable for low-lying areas which require high elevation to protect from storm surge.	11. Multi-purpose Levees

IN-WATER

Groins are most suitable in coordination with beach nourishment	12. Groins
Wetland restoration is most viable in the same areas where they were once found, which is typically low-lying areas within sheltered water bodies, though there may be some scattered opportunities for wetland creation elsewhere.	13. Constructed Wetlands
Breakwaters can protect oceanfront areas from wave forces. They may also provide some protection from lower wave heights, as well as wakes, in sheltered water bodies. They are most effective in shallow water bodies.	14. Breakwaters
As with breakwaters, artificial reefs can protect oceanfront areas from wave forces. They may also provide some protection from lower wave heights, as well as wakes, in sheltered water bodies. They are most effective in shallow water bodies.	15. Artificial Reefs
Floating islands are most successful in sheltered water bodies with low wave energy and in shallower waters.	16. Floating Islands
As with breakwaters, constructed islands are best-suited to protect oceanfront areas from wave forces. They may also provide some protection from lower wave heights, as well as wakes, in sheltered water bodies. They are most effective in shallow water bodies.	17. Constructed Breakwater Islands
Surge barriers require connections from adjacent shorelines with high elevations which is more likely to be feasible in sheltered water bodies, but depending on a given geography, there may be opportunities elsewhere.	18. Surge Barriers
Coastal morphology alteration is most promising as a potential strategy in inlets leading to shallow or bottleneck areas and sheltered water bodies.	19. Coastal Morphology Alteration
While the applicability of this strategy is untested, there is the most promise in sheltered water bodies and within coastal parkland.	20. Polders

OTHER STRATEGIES

01. EMERGENCY MANAGEMENT

Emergency management refers to coordinated efforts of resources and responsibilities to address hazards in a comprehensive and systematic manner before, during, and after a disaster to create sustainable and resilient communities.

There are four key phases in emergency management planning:

- Mitigation – efforts to reduce disaster risk exposure and impact before they occur
- Preparedness – efforts to prepare for a likely hazard by increasing coping capacity
- Response – actions taken to respond to an emergency or disaster and provide relief
- Recovery – actions taken to restore the community to pre-disaster conditions (can include mitigation against future events)

The mitigation concept of emergency management often gets the least attention, yet it is one of the most critical steps in breaking the cycle of disaster damage, reconstruction, and repeated damage. The starting point is the risk assessment, which includes profiling hazards, evaluating assets, and identifying vulnerabilities (both physical and social). These actions often provide the greatest value for the public by creating safer more resilient communities in the medium and long-term. Using site strategies, such as designing buildings with new flood protection standards, is an example of mitigation to a coastal hazard event.

Preparedness focuses on ensuring effective coordination during a disaster response. It consists of a continuous cycle of planning, organizing, training, equipping, evaluating, and taking corrective action in order to increase coping capacity during and after a disaster. Scheduled test deployment of temporary barriers could serve as an example of preparedness in coastal hazard protection.

Response to a disaster is centered on immediate actions to save lives and protect property. It is focused on short-term, direct protection against hazard impact and incidences. In New York City, the Office of Emergency Management coordinates the response to disasters through incident monitoring, field response, urban search and rescue, and logistics through the centralized Emergency Operations Center.

Recovery actions are phased into the short, medium, and long term, and include the development, coordination, and execution of service and site restoration plans; reconstitution of government operations and services; and assistance to affected persons. It also includes regulatory and policy measures that improve the economic recovery of devastated neighborhoods, evaluation and lessons learned, and development of initiatives to mitigate the effects of future incidents. Post-storm clean up and rebuilding is an example of the recovery phase of emergency management.

Lower East Side following Hurricane Sandy

Rockaways, Queens following Hurricane Sandy

02. INSURANCE

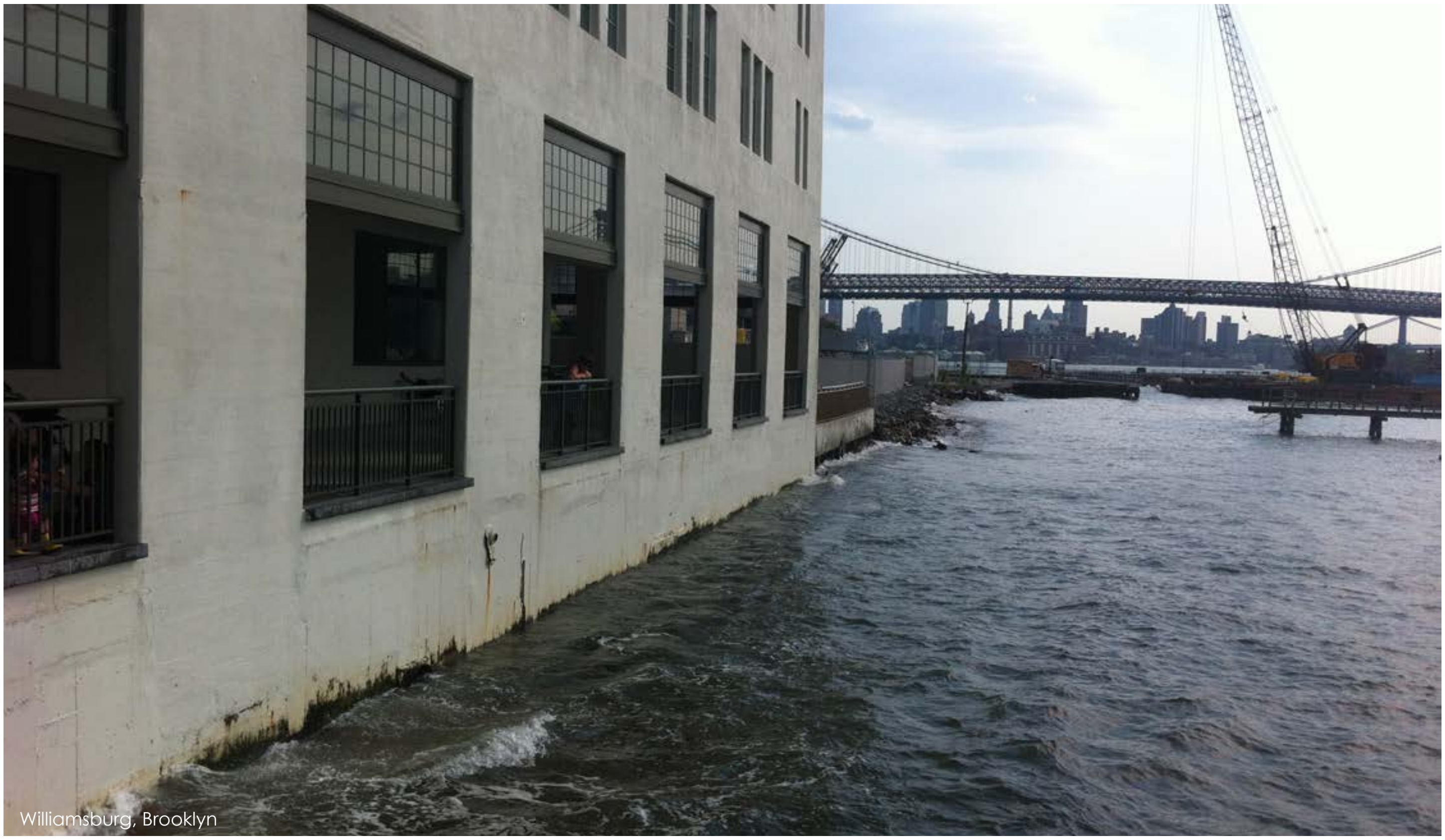
Insurance against losses from flood damage is not covered by most home insurance policies but is available through the National Flood Insurance Program.

Insurance is another strategy in the flood protection and coastal hazard adaptation tool box. The National Flood Insurance Program (NFIP) is an insurance program administered by the Federal Emergency Management Agency (FEMA) to reduce loss of life and damage caused by flooding, to help flood recovery, and promote equitable distribution of costs. Coverage is required of all homes with federally-regulated mortgages within the FEMA-designated Special Flood Hazard Area.

To participate in the NFIP, communities must adopt local building codes that enforce FEMA's standards for flood protection for new construction, substantially improved buildings, and substantially damaged buildings. Damage to a building is considered "substantial" if the cost of restoring the building to its previous condition would equal or exceed 50 percent of the market value of the structure before the damage occurred. The NFIP covers direct physical losses resulting from coastal storms and related hazards.

Unlike other strategies that seek to prevent flood damage, insurance provides a means for recovering financial damage after an event. The insurance system is based on the concept of transferring risk from an individual policyholder (home or business) to a larger risk-sharing pool. For instance, the NFIP pools risk broadly across the entire country. Another core insurance concept is the principle of risk-based premiums, where those with greater risk (i.e. those most likely to suffer flood damage and require a claims payment from insurance providers) pay higher premiums than those with less risk. Thus, property owners in flood prone areas pay more for insurance than those who own property in areas with less risk. The risk-based rate system is necessary to ensure financial solvency and payment to policyholder in the event of a loss. If the rates are too low, the insurance provider is not financially sustainable.

Insurance may in some instances incentivize mitigation measures, such as retrofitting an existing building, by offering discounts on flood insurance premiums, if the construction meets NFIP standards. However, these standards were developed with low-density, rural and suburban communities in mind and are difficult to meet for much of the building stock within New York City, as with other urban waterfront communities. For instance, older, attached buildings on narrow lots are hard, if not impossible, to elevate. Recent changes to the NFIP that end the practice of "grandfathering" older buildings (i.e. offering reduced insurance rates that are not based on flood risk) present substantial issues for communities, such as New York City, where retrofitting to national standards is difficult and expensive.


Williamsburg, Brooklyn

03. LAND USE MANAGEMENT

Land use planning shapes and manages growth and development to achieve a community's vision.

Planning for any area involves the development of an overall vision that considers the livability, growth, and sustainability of the area in a way that achieves community objectives within the context of a regional framework. When undertaking long term land use planning for coastal communities, coastal hazard risk should be considered together with other key criteria. Some neighborhoods may be well-suited for future growth and development, based on infrastructure and other area characteristics, while others may not.

Planning objectives may be implemented through a variety of planning tools, including for instance, the creation of economic development or strategic retreat programs that seek to address specific socioeconomic or geographic issues, capital investments in public infrastructure and facilities, and regulatory mechanisms such as zoning or building codes. The implementation of land use management objectives, however, is often incremental; While some projects and programs can shape near-term development patterns, most regulatory measures, such as zoning, are long-term strategies.

Zoning is a tool used by governments that influences the use, bulk, and density of development in an area in order to achieve local planning objectives. Zoning amendments can facilitate investment in flood-resilient buildings by removing zoning disincentives to meeting or exceeding floodproofing standards in building codes. For instance, targeted relief from height limits can reduce disincentives for property owners to elevate their structures to reduce flood risks. Removing zoning impediments to resilient building design also requires consideration of other purposes of the zoning limits, such as the preservation of community character and the quality of the public realm. (For more on this subject, see the report, *Designing for Flood Risk*, recently released by the Department of City Planning.) Where consistent with other planning objectives, zoning can also, perhaps less intuitively, promote a more resilient waterfront through increases in permitted densities or height limits that incentivize new, resilient buildings that replace older, non-resilient buildings. In all cases, zoning should be consistent with a plan that considers a broad range of planning objectives.

Regulatory tools can also be used in accordance with a land use plan to promote the long-term reduction of a community's exposure to coastal hazards by reducing the permitted scale or density of new development or placing limitations on redevelopment, such as rebuilding restrictions set forth in building codes or zoning that enforce limitations on the ability to rebuild once a structure has been substantially damaged. Regulators can also implement restrictions on development of undeveloped land vulnerable to current or future coastal hazards in order to limit increasing a community's risk. However, reducing the extent of permitted development may have the unintended effect of encouraging existing, non-resilient buildings to remain.

Other regulatory measures may serve to restrict the location of buildings, structures, or uses in order to manage risks in coastal areas. For instance, buffers and setback regulations limit the proximity of new construction to vulnerable shorelines, wetlands, or other natural features. The distance of a setback or buffer can be a fixed distance, or can be based on sea level and erosion rates, which is sometimes called a "rolling easement." For instance, the State of Maine has instituted a rule that within its the coastal dune system, buildings of greater than 35 feet in height or covering a ground area greater than 2,500 square feet must be set back further inland to allow room for a two foot rise in sea level. While setbacks based on rates of sea level rise are more flexible and can

Credit: Jeff Shumaker

Rendering from the Coney Island Comprehensive Rezoning Plan, NYC Department of City Planning adequately take into account variations in slopes and other site-specific factors, the uncertainty of sea level rise projections makes it difficult to establish a fixed setback distance. In addition, setbacks may be difficult to implement in a space-constrained, urban environment.

Another mechanism is the issuance of permits or approvals for development conditioned upon imposing certain requirements or restrictions upon private property that serve the land use management policies of the coastal area. Such conditions could restrict the use of hard shoreline armoring, require land to be set aside for natural buffers, or require other measures to mitigate impacts associated with a development.

When considering restrictions or conditions upon development of private property, regulators are subject to the limitations of constitutional regulatory taking standards. For instance, when placing conditions upon private property in relation to a development permit or land use approval, there must be an "essential nexus" between the legitimate state interest and the conditions, and the nature and extent of the conditions must be "roughly proportional" to the impact they seek to address. Unlike regulatory tools, buyout programs are not subject to limitations of regulatory takings because the land owner voluntary accepts buyout compensation.

Other planning tools include the incorporation of climate resilience into policies, such as through a state or local Coastal Zone Management program.

INCORPORATING RESILIENCE INTO NEW YORK CITY'S LAND USE MANAGEMENT

New York City has taken many steps, both preceding and following Hurricane Sandy, to integrate climate resilience into its land use and waterfront management policies.

Vision 2020, the New York City Comprehensive Waterfront Plan is a 10-year plan for the use and development of the city's waterfront and waterways that was released by Mayor Bloomberg and the Department of City Planning in March 2011. The 10-year plan was developed through an extensive public outreach process and in consultation with many other city agencies. The report lays out a vision for the future with new citywide policies for a broad range of goals including identifying and pursuing strategies to increase coastal climate resilience.

Following the release of *Vision 2020*, the Department of City Planning began work on updating the *New York City Waterfront Revitalization Program* (WRP) to incorporate the plan's goals, recommendations, and priorities. The WRP is New York City's principal coastal zone management tool. It establishes the city's policies for development and use of the waterfront and provides the framework for evaluating the consistency of discretionary actions in the Coastal Zone. The proposed revisions would require projects to consider the vulnerabilities and consequences associated with coastal flooding based on climate change projections, and encourage applicants to minimize these consequences through design strategies that will enhance their ability to withstand and quickly recover from weather-related events.

Following Hurricane Sandy, Mayor Bloomberg issued an Executive Order to temporarily suspend certain provisions of the Zoning Resolution to enable rebuilding to the advisory flood elevations released by FEMA after the storm, which represented the best currently available information on flood risks. In May 2013, City Planning began public review of a zoning text amendment that will enable new and existing buildings throughout designated flood zones to meet the latest standards for flood-resistant construction, while mitigating potential negative effects of flood-resistant construction on the streetscape and public realm. This proposal was strongly shaped by the City Planning study *Designing for Flood Risk,* initiated in 2011, which articulates principles for good building design within flood zones. In June 2013, Mayor Bloomberg issued *A Stronger, More Resilient New York*, the final report of his Special Initiative for Rebuilding and Resiliency, which identified over 250 specific recommendations to make the city more resilient to climate events including coastal flooding.

04. INFRASTRUCTURE PROTECTION

The protection of an individual infrastructure asset, such as subway entrances, electricity generators, wastewater treatment plants, and communications towers, through site-scale or component-scale protection.

Infrastructure systems are critical to the ongoing functionality of the city and its ability to deliver essential goods and services to its population. They include our roads and highways, energy, waste management, water supply and wastewater systems, communication networks, and public transit. Because infrastructure is typically a system made up of various nodes and networks, interruptions at any one of many points can cause ricocheting impacts throughout the entire system, potentially impacting the health and safety of large populations and areas. Furthermore, infrastructure is as operationally complex as it is physically. Infrastructure is controlled by a combination of private and public entities at various levels of government with different jurisdictions and funding sources. Investment in infrastructure, particularly with older systems such as those in place in New York, is extremely costly and requires on-going maintenance.

Potential strategies vary widely depending on the type of infrastructure, and range from floodproofing or elevating individual buildings or mechanical components, to larger operational and design changes in how systems withstand climate events.


DUMBO, Brooklyn

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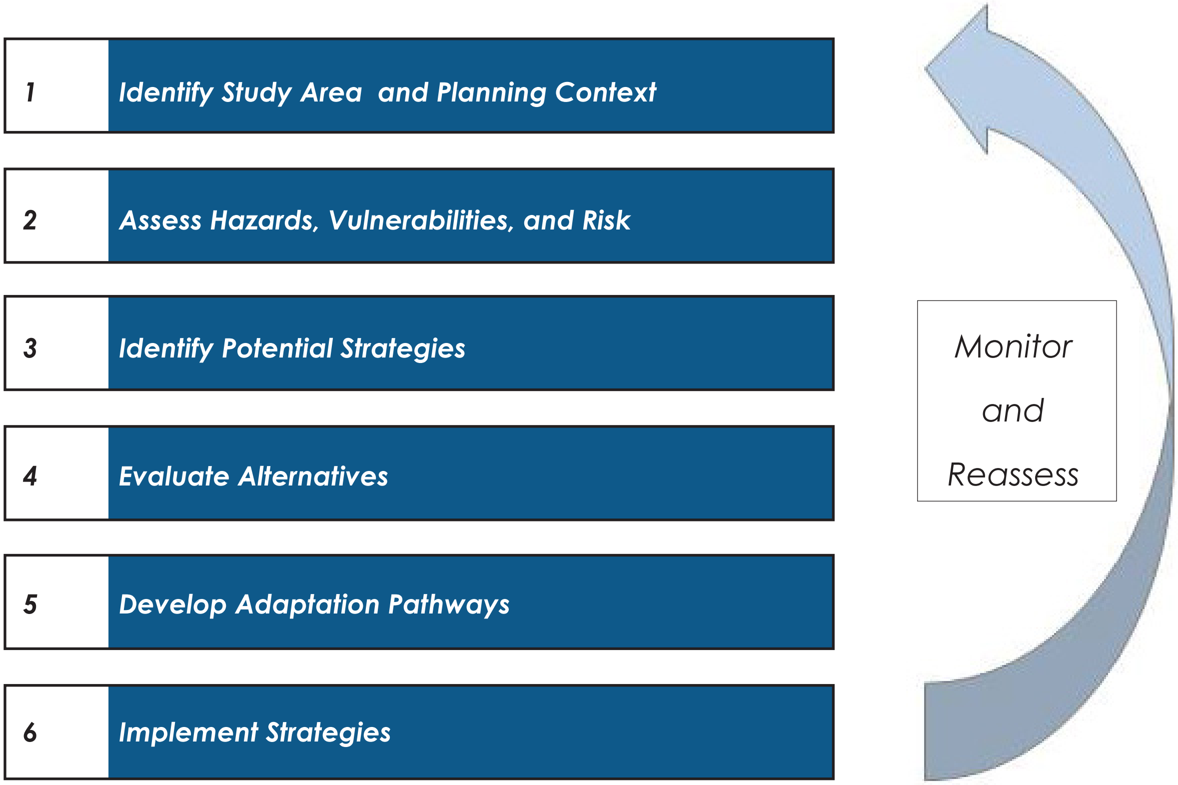


PART IV

FRAMEWORK FOR EVALUATION

Creating a more resilient city is a long-term, on-going process of assessing risks, developing and evaluating alternatives, and implementing flexible and adaptive strategies.

With many potential strategies to pursue, one of the greatest challenges lies in deciding what actions to pursue, and where and when to implement them, given limited resources. This is a complex decision-making process that can straddle geographic and temporal scales. The intent of this section is to establish a framework and process to guide plans and projects related to climate resilience within New York City and beyond.

While many considerations are integral to this process, the overarching goal is to create a resilient city. Resilience is commonly defined as the ability to withstand and recover quickly from disturbance. In relation to coastal hazards, resilience is the ability of a building, site, neighborhood, community, ecosystem, or city to avoid significant damage and recover from a coastal storm. Resilience is also the ability of a system or community to adapt over time to changing climate hazards. Resilience also includes the recognition that risk cannot be avoided altogether and that the most resilient strategies are robust enough to provide some protection even if one or more of their components fail. Despite a community's best attempts to protect itself, there is always the possibility that multiple lines of protection could fail or that a more extreme or unexpected event could happen.

In terms of urban planning, resilience also encompasses a broader notion about ensuring a city's vibrancy, livability, and equity in the near and long term. While planning to withstand climate events is very important, a community's other goals, including economic prosperity and job opportunity, sustainability, quality of the public realm, and affordability and livability for its residents, are also important to ensure that the community can meet the needs and values of its residents in ordinary circumstances, as well as when climate events occur.

The preceding chapters identified types of resilience strategies that are most likely to be suited to various coastal neighborhoods and sites. The following steps are intended to provide a flexible, replicable process for selecting strategies for implementation across various physical and time scales. This process is not meant to outline the entire planning process, but rather to describe the discrete portion of this process for identifying and evaluating strategies for climate resilience. Every specific planning project or initiative will have its own goals and limits, but these general steps and concepts can aid in the complex process of planning for coastal climate resilience.

Evaluation Process

1 Identify Study Area and Planning Context

The goal of this step is to identify the geographic scope of the analysis and to begin to divide it into more manageable sub-areas, if necessary. Throughout this process, the analysis will address the scale of the entire study area and of individual sub-areas. Boundaries of sub-areas can be based on water bodies and geographic features with common characteristics and common hazard exposure, as well as regulatory or political boundaries. Also, at this point, it is necessary to understand the planning context for this study. This means identifying stakeholders, other relevant plans or projects, and examining existing conditions, trends, and objectives for the area beyond climate adaptation through public engagement.

2 Assess Hazards, Vulnerabilities, and Risk

The goal of this step is to understand the vulnerabilities and risk of the entire study area and individual sub-areas. These will vary from place to place, and have the potential to change over time. See following section, "Assessing risks."

3 Identify Potential Strategies

In this step, potential strategies are identified for various sub-areas based on the analysis of step two and the area's geomorphology and land use characteristics. At the end of this step, alternatives are developed for the entire study area. Alternatives may include multiple combinations of different strategies at different scales, acting in concert to address multiple hazards and as redundant elements of an overall system. See following section, "Developing Alternatives."

4 Evaluate Alternatives

These alternatives are then evaluated for their overall costs and benefits, including risk reduction benefits and financial costs, in addition to other considerations such as environmental quality, urban design, and consistency with other community goals, as indicated by relevant plans and stakeholder engagement. The evaluation should identify those strategies that maximize potential benefits with respect to potential costs, in terms of both the cost-effective use of present-day resources and long-term outcomes with climate change and other trends. However, strategies that may be cost-beneficial may not be feasible if they require large sums of money beyond realistic budget constraints. In the end, this evaluation should result in an understanding of which alternatives are most cost-effective, realistic, and desirable, for which areas, and over the short, medium, and long term. See following section, "Evaluating Costs and Benefits."

5 Develop Adaptation Pathways

Adaptation pathways are flexible plans for how to combine a series of actions that can be taken in the short-term, with periodic decision points over time, to address longer term objectives. Once alternatives have been evaluated for their cost-effectiveness based on a wide range of potential costs and benefits and consideration of multiple future time frames, they can be narrowed down to a set of alternatives that are cost-effective for a given sub-area and given time frame. The challenge then is to identify adaptation pathways that chart a course from the short term (next 10 years), through the medium term (next 20-50 years), to the long term (beyond 50 years). Such a pathway should include those actions that are a cost effective means to meet short-term needs, but include steps to transition eventually toward an approach that is likely to be cost-effective for the long term. A pathway should also include pre-determined steps to re-evaluate progress towards implementation and changes in climate projections and other risk factors. One example may be to design a bulkhead to a design height that is suitable for the short term, but in a way that can be increased in the future if necessary.

6 Implement Strategies

At most scales, resilience strategies are unlikely to be implemented by one single person or entity with a single project. Rather, it will take the coordinated action of many individuals and many organizations. At each scale there are multiple actors involved, all of whom play an important role. For instance, decisions about floodproofing individual buildings involve not just the building owner, but federal agencies that set standards, local agencies that enforce them, and public programs and private companies that insure properties based on them. In the instance of shoreline or in-water strategies, the U.S. Army Corps of Engineers and various other local, state, and federal agencies participate in the design, review, and construction of projects, following an extensive permitting process and using public funding from a variety of sources. In addition, infrastructure systems, such as transit networks, energy systems, communication networks, and water supply systems are owned and maintained by a variety of local, state, and private entities. Implementation includes not just identifying what needs to be done but who needs to do what at various scales of action.

Assessing Risks

Risk is generally defined as a product of the likelihood of an event occurring (typically expressed as a probability) and the magnitude of consequences should that event occur. This means that events with the greatest consequences and highest probabilities present a higher risk than those with lower consequences and probabilities. Risk can be managed through mitigation actions that reduce the likelihood of an impact or the magnitude of consequences, but risk cannot be fully eliminated. For the purposes of coastal climate adaptation, "events" are understood as coastal storms and their associated impacts as well as gradual changes in conditions arising from sea level rise. "Consequences" include the loss of life, damage to property, and impacts on society, public health, natural systems, and the economy.

Coastal climate risk can be understood as the interaction between coastal hazards and the populations, built environment, infrastructure, and natural resources that are vulnerable to the hazards. Mapping coastal hazards is important to understand what geographic areas and communities are vulnerable. This interaction should also be analyzed over time through the development of maps that reflect climate projections and analysis of land use and population trends. Risk varies from one neighborhood to another depending on the nature of the area's exposure to coastal hazards and what vulnerabilities exist. For example, a high density area with greater population and assets and moderate exposure to coastal hazards may face greater risk, in absolute terms, than a low density area with fewer people and more open space with high exposure to coastal hazards.

The first element of this analysis is to identify different geographies exposed to coastal hazards and the differences in the nature and degree of their exposure. Coastal hazards include events like hurricanes, which as evidenced by Hurricane Sandy are not just a future risk from climate change but also a very current threat as well, to gradually increasing risks due to climate change such as flooding at high tide due to sea level rise. One readily available measure of probabilistic risks for storm surge is FEMA's Flood Insurance Rate Maps, which indicate the geography and height of flooding that has a 1 percent annual chance of occurring as well as that of the 0.2 percent annual chance storm. Areas identified on FEMA's Flood Insurance Rate Maps as either Coastal A or V zones are likely to experience moderate wave action from a 1 percent annual chance coastal storm. Areas with non-stabilized, soft shorelines and high fetch are likely to face erosion hazards, both gradually over time and suddenly in the event of a storm. Some areas today experience flooding at monthly high tides. These areas are generally the ones most vulnerable to further inundation through gradual sea level rise. To identify areas vulnerable in the future, sea level rise projections can be added to the elevation of today's mean higher high water or highest astronomical tide. To account for sea level rise, future flood heights over multiple time periods can be estimated either using a simplified "bathtub" approach of adding sea level rise projections to the height of the base flood elevations for the 1 percent or 0.2 percent storm and extending the flood zone geography to the resulting elevation contour, or through more involved flood modeling software using sea level rise projections. These projections can be highly technical and resource intensive, but their availability is of great value to governments and other actors in the planning process.

To understand more fully the risks that these hazards pose, the vulnerability of populations, the built environment, infrastructure, and natural resources that are exposed to those hazards must also be examined. This involves taking an inventory of who and what is located within the areas exposed to various coastal hazards, and analyzing current vulnerabilities and future trends that could impact the nature and degree of their vulnerability. Within each area exposed to coastal hazards this inventory should consider the presence of:

- Vulnerable populations
- Types of buildings, both in terms of their use and structural characteristics
- Critical facilities and infrastructure
- Parks and open spaces
- Ecological systems
- Potentially hazardous materials and uses

For each of these categories, factors that make them more or less vulnerable to coastal hazards should be examined, such as the ability of a building type to withstand flooding or the ability

PHOTO: Michael Pilgrim

St. George Ferry Terminal, Staten Island

of a population to evacuate. In addition, the consequences of being affected by a coastal hazard should be considered. For instance, the functions that a critical infrastructure system performs should be considered, along with how coastal hazards may interrupt these services, and what the consequences of this interruption would be on the immediate neighborhood and broader area. Finally, socioeconomic and land use trends, as well as changes in natural systems and infrastructure aging, should be explored to identify how vulnerabilities and risk may change in the future.

There is substantial uncertainty in examining both how climate hazards may evolve over time and how the elements of vulnerability may change. While know sea level rise is happening, projections for the New York area come with substantial uncertainty ranges. The degree of our uncertainty increases over time, particularly as we begin to look 25, 50, or even 100 years into the future. Likewise, population and socioeconomic trends are very difficult to project. One way to manage this uncertainty is to explore future scenarios that represent different ranges in climate projections and different future trends in vulnerabilities. These scenarios can provide a helpful lens to identify and evaluate potential decisions, making it possible to identify robust approaches that can be effective in multiple sets of possible future circumstances.

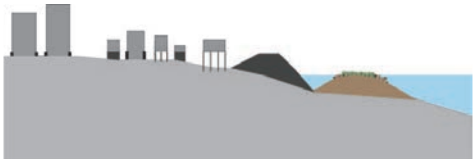
Do Nothing

Site-scale protection

Site-scale protection
+ Reduce surge heights

Strategically Retreat

Site-scale protection
+ Mitigate wave action



Site-scale protection
+ Reduce surge heights
+ Mitigate wave action

Mitigate flooding at high tide.

Illustrative examples of potential objectives and approaches

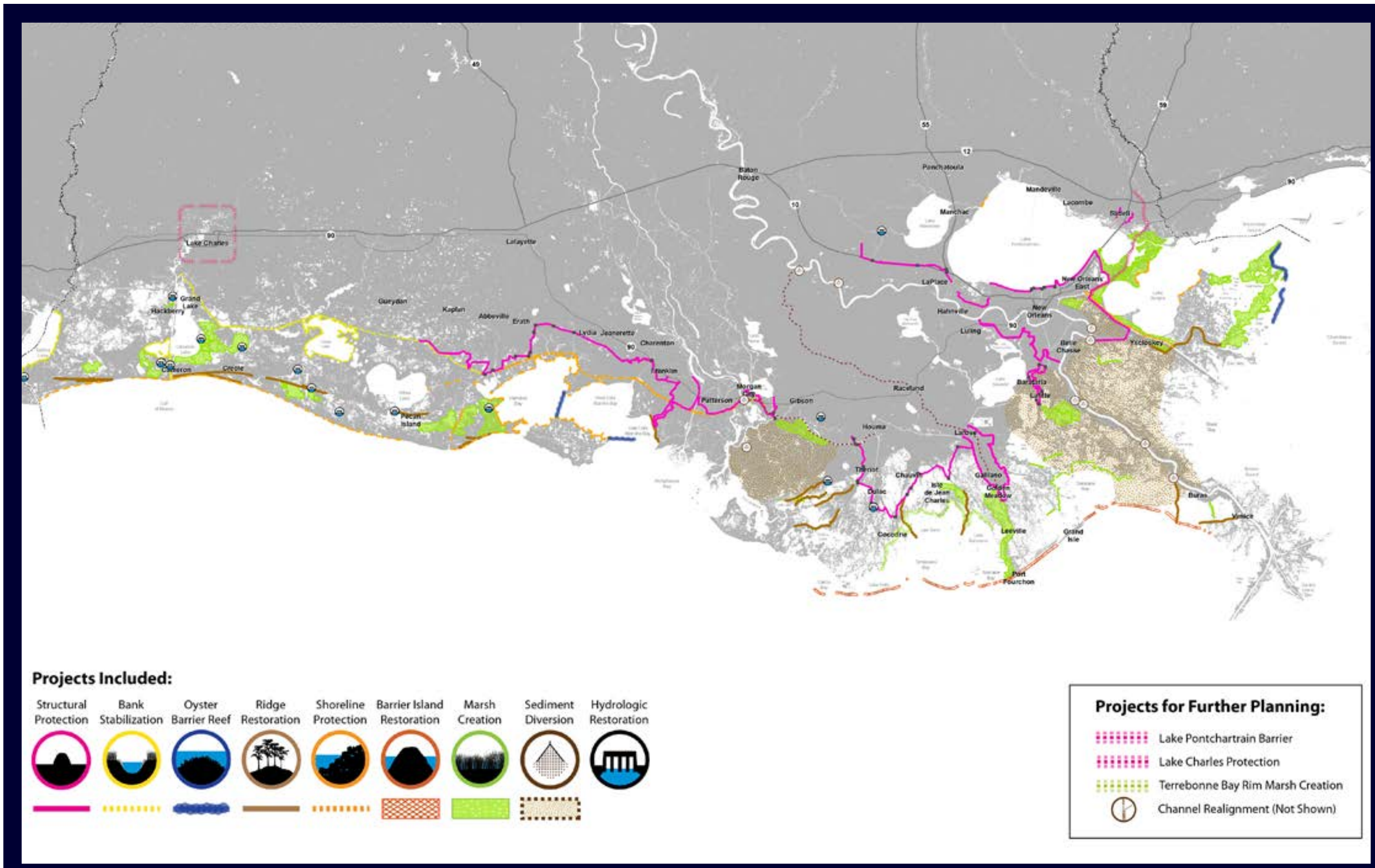
Developing Alternatives

There are many potential strategies to increase resilience at various scales, as described in Part 3 of this report. The first step toward developing alternatives is to identify objectives for coastal resilience for each sub-area. In some areas, breaking waves in the event of a storm may be the objective because of the vulnerability to wave action, while in other areas the objective may be reducing surge heights or mitigating flooding at high tide. In addition, the degree of risk in a given sub-area should be a consideration. For instance, in areas with greater risk the objective may be to prevent inundation from even very low probability events, because there are great consequences if the area were to flood.

To conduct an initial screening analysis to identify which strategies may be appropriate for different sub-areas, examine the ability of a strategy to address coastal hazards and its applicability to different building and geomorphology types. The charts on page 62-63 and 106-109 can be used to guide this analysis. It is important to understand the applicability of different strategies geographically to understand what strategies may work within individual sub-areas, and where regional opportunities for larger-scale reach strategies may exist. In addition, factors within each sub-area should be identified that may drive the feasibility, costs, and benefits of a given strategy, such as density of population and the built environment, socioeconomic factors, presence of infrastructure, elevation, and soil characteristics.

Based on this examination, as well as the assessment of risk, it may be necessary to refine the study area boundaries by grouping areas with common regional opportunities and common risk profiles. Similarly, study areas may need to be divided into multiple sub-areas to address differences between neighborhood characteristics and needs. In order to evaluate a regional strategy, such as a surge barrier, the entire area it would affect should be analyzed both as a whole and broken into smaller geographies, to identify and evaluate a range of alternatives.

Strategies can be used in combination, as part of a “multi-layered approach” to resilience. Strategies may be supplementary to one another (redundancy), such as retrofitting buildings in addition to building a levee. Redundancy reduces the amount of residual risk by providing back-up in case one element fails. Strategies may also be complementary, addressing different types or



Credit: Louisiana Coastal Protection and Restoration Authority

CASE STUDY: 2012 LOUISIANA'S COMPREHENSIVE PLAN FOR A SUSTAINABLE COAST

Louisiana's coast faces unique vulnerabilities to hurricanes and coastal flooding due to its location on the Gulf of Mexico. This is compounded by the fact that the coastal area is predicted to lose an estimated 1,750 square miles to subsidence and sea level rise – more than one and a half times the size of Rhode Island—in the next 50 years if no action is taken. In 2006, the State Legislature required the submission of a Louisiana Coastal Master Plan every 5 years and subsequently, a single, unified authority was established – the Coastal Protection and Restoration Authority (CPRA) – to develop, implement, and enforce it. The 2012 Coastal Master Plan, an update to the plan presented in 2007, presents a 50-year plan that interweaves coastal protection and wetland restoration. It is based on a two-year planning effort that evaluated hundreds of candidate project ideas and employed innovative analytical tools to model scenarios, balance restoration and protection goals, and identify projects that most effectively use limited funds. and resources.

In order to evaluate the hundreds of potential projects, CPRA used an intricate evaluation process to understand the practical implications of the various project options and their tradeoffs, the consequences of the projects to land loss, as well as damages to communities if no actions were taken. To address the complex interplay of factors affecting coastal systems over time, seven interrelated predictive models were employed to evaluate the following: eco-hydrology, wetland morphology, barrier shoreline morphology, vegetation, ecosystem services, storm surge/waves, and risk assessment. Over 60 scientists and engineers contributed to create the models and analyze the data. Outputs from each predictive model inform the inputs for other models, simulating the interplay between different factors such as changes in estuary water characteristics, wetland morphology, and storm surge, for instance. This "systems" approach allowed for projects to be evaluated based on current knowledge about coastal processes and made it easier to identify projects that best achieve the plan's objectives. The projects were also measured against a set of environmental and climate change scenarios.

To sort and understand these results, a computer-based planning tool helped systematically consider the many variables, such as costs, funding, environment and stakeholder preferences, as well as groups of projects that worked well together. Then, using decision drivers, the planning tool was used to sort through the hundreds of projects by answering questions first and foremost about flood risk reduction and land building, as well as funding availability, and near and long-term benefits. CPRA found that other decision criteria, such as cultural heritage, socioeconomic distribution, navigation, use of natural processes, often reconfirmed the preferred scientific outcomes, and when there was significant overlap, it helped hone in on projects that reflected the main preferences and needs of coastal users. Finally, as the project options narrowed, they were checked against real world constraints, such as implementation challenges, and local knowledge and preferences.

The outcome of the analysis is a coast-wide plan consisting of 109 projects that include structural protection, bank and ridge stabilization, oyster barrier reefs, barrier island restoration, marsh creation, sediment diversion, hydrological restoration and a coastwide nonstructural program. Eighty-five percent of the projects performed well under one or both future scenarios and satisfy multiple stakeholder preferences. Given the uncertainty of future environmental conditions, an adaptive management framework is being developed to maintain the objectives of the plan through adjustments to planning, policy and implementation over the next 50 years.

Examples of Types of Benefits	*Examples of Types of Costs*
Risk Reduction	Residual risk
Avoided costs	Construction, maintenance and operation costs
Environmental benefits	Environmental degradation
Socioeconomic and equity benefits	Socioeconomic and equity impacts
Improvements to the public realm/urban design	Negative impacts on public realm/urban design
Climate mitigation benefits	Contributions to climate change
Furthering local goals, plans	Inconsistency with local goals and plans

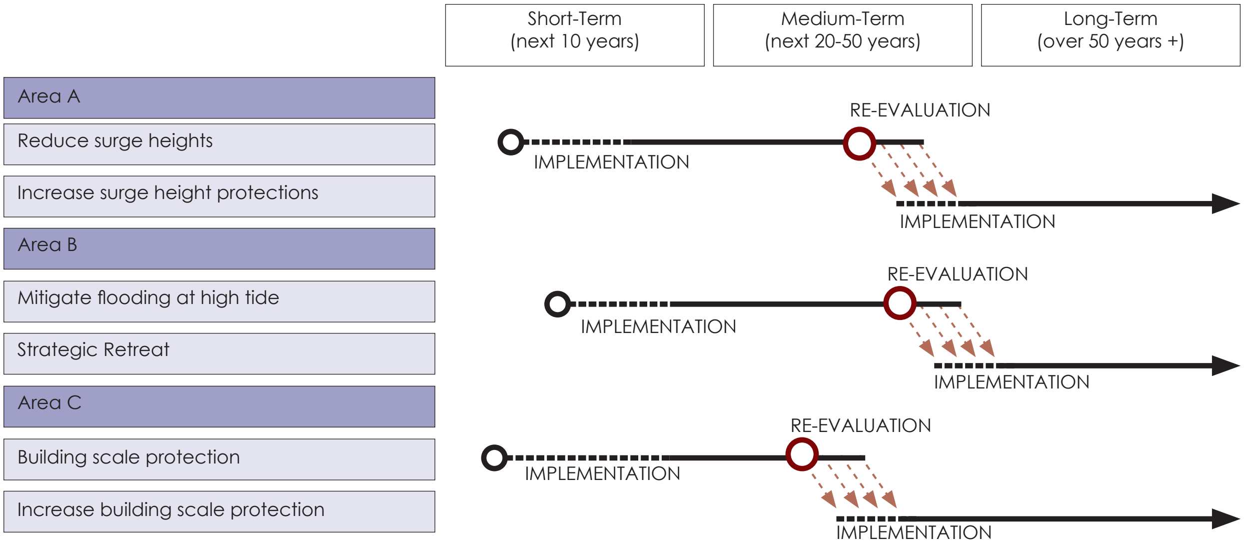
degrees of risk, such as using an off-shore wave break to reduce wave action in combination with building-scale strategies to protect from stillwater flooding. An approach may include multiple individual strategies at various scales, by, for instance, combining site-scale protection with reach strategies. See the image on page 120 for examples of different approaches. Specific strategies within an overall approach will vary depending on the land use and geomorphology characteristics present within a study area. For instance, beach nourishment may be part of an approach to reduce surge heights within a sandy oceanfront beach area, while in a sheltered, hardened outwash plain area, levees, seawalls, and floodwalls would be more appropriate.

Approaches for various sub-areas can then be combined into alternatives that cover the entire study area. These alternatives can include strategies at various scales. For example: Alternative "1" may include site-scale protection throughout the entire study area in combination with an offshore breakwater to mitigate waves in sub-area "A" and a seawall to reduce surge heights in sub-area "B." Alternative "2" may include site-scale protection throughout the entire study area in combination with a seawall that reduces surge heights in both sub-area "A" and sub-area "B."

Evaluating Costs and Benefits

Alternatives should be evaluated for the benefits they offer, both in terms of risk reduction as well as co-benefits to the environment, social and economic development, and the quality of the public realm. The costs of an alternative include financial considerations, such as the cost of construction and maintenance and operation over its lifespan, as well as indirect environmental, economic, or social costs. In addition, alternatives should be evaluated for their consistency with local plans and goals, including those identified through stakeholder engagement. These plans may include, for instance, goals for reducing greenhouse gas emissions through encouraging smart growth around existing transit hubs. As shown in the following chart, for each potential benefit, there is a corresponding potential cost.

Some of these costs and benefits can be quantified. When they cannot, the analysis can be supplemented with qualitative analysis, with a scoring system to weight qualitative and quantitative considerations appropriately. Risk reduction in terms of the projected likely damages from coastal hazards that would be avoided and the projected financial costs of construction and maintenance over the lifespan of an alternative can both be quantified. To identify the level of protection afforded by various interventions, appropriate analytical tools should be used wherever possible. For instance, hydrodynamic modeling of proposed coastal interventions would be used to identify the level of protection created by off-shore wave attenuation features, and to understand how they would interact with each other. The likely impacts of an alternative on either promoting or hindering the ability of natural systems to perform ecological services and provide biodiversity can be evaluated through a mix of quantitative and qualitative analysis. Equity can be considered by identifying disparities in how the benefits and external costs of an alternative are shared among population groups. Impacts on the public realm and urban design can be examined through a mix of qualitative information (such as a rendering) and quantitative data (such as estimates on the amount of public space lost). Other elements, such as consistency with local plans require qualitative analysis. It should be particularly noted when a project is able to further a local planning objective, such a providing access to the waterfront, improving drainage in a neighborhood or providing habitat restoration opportunities.



Illustrative example of a flexible adaptation pathway. Adaptation pathways are flexible plans for how to combine a series of actions that can be taken in the short-term, with periodic decision points over time, to address longer term objectives.

In addition to noting the costs and benefits of various alternatives, it is also necessary to look at who pays the costs and who benefits. In instances that involve the construction of new, significant pieces of infrastructure, the benefits are substantially to private entities while many of the costs are borne by the public sector (which is funded in large part through taxes). Financing mechanisms that balance the costs and benefits to the public and private entities should be considered.

Cost-benefit analysis is an important tool for identifying strategies and alternatives where benefits justify costs. Consideration should also be given to the timeframe of implementation. Costs and benefits of alternatives will change over time, as hazards and vulnerabilities change. A common method to assist in cost-benefit analysis is to calculate the net present value of the benefits of a project over its lifespan as compared to the costs incurred to implement the measure. As part of this analysis, a discount rate is selected based on the concept that various investments must compete for scarce present dollars, while future dollars are less valuable from a financial standpoint. The results of this analysis will of course be sensitive to the selection of the discount rate. In addition, to provide a perspective on long-term decisions that is not dependent on discounting future values, policy decisions about larger scale plans should consider the consistency of alternatives with objectives for the short, medium, and long term. Consideration should be given to how changes in conditions over the long term may affect the cost-effectiveness and overall desirability and feasibility of various alternatives.

For instance, there may be alternatives where the costs exceed the benefits given today's risks, but that, as risks increase, could eventually provide benefits that exceed the costs over time. A seawall built to a very high elevation is one such example. Building the seawall to such a high elevation may not make sense to pursue in the short term because the benefits are realized primarily in the future. It may, however, make sense to avoid actions in the short term that preclude such a seawall in the future, or to undertake lower-cost, preliminary steps that would make the project possible in the future. There could also be alternatives where the benefits outweigh the costs given today's circumstances, but in the future the costs may exceed the benefits. Elevating land to a height that will be overcome by sea level rise at some point in the foreseeable future is one such example. However, such an approach may be justifiable if the lifespan of the project is relatively short, the cost is relatively low, it will provide short term benefits, and does not prevent the realization of a longer term strategy.

Because projections of future risk are uncertain, the benefits of taking mitigating actions are also uncertain. Therefore alternatives that are the easiest to make actionable are those that have few costs and address significant near-term risks, or so-called "no regrets" strategies. Other alternatives are more likely to prove cost-beneficial are those that are robust and work for a wide range of possible future outcomes, or those that provide additional benefits that aren't as uncertain. Understanding the time it will take to implement a given alternative and the ways in which cost-effectiveness of an alternative changes over time are important to making these decisions. Keeping a broad view of costs and benefits is important throughout.

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Sand dunes in Cape Cod, MA

APPENDIX: COASTAL AREA TYPOLOGY MATRIX

This matrix shows how the land use/density types and geomorphology types developed through analysis of the New York City coastal zone were used to create coastal area typologies. Sample sections of the coastline were classified according to its general land use/density type and its geomorphology type. The boxes shown in yellow are those that were selected for deeper analysis. See Part 2 of this report for more information.

	LAND USE / DENSITY TYPES							
GEOMORPHOLOGY TYPES	A	B	C	D	E	F	G	H
1	Orchard Beach, BX; Breezy Point, QN; Great Kills Park, SI.	Kreisherville, SI; Gowanus Bay, BK; Flushing Creek, QN.			Midland Beach, SI; Belle Harbor South, QN; Sea Gate, BK; Manhattan Beach, BK.	Coney Island West, BK; Rockaway Beach, QN.		
2				Gravesend Bay, BK		Bath Beach, BK		
3	Pelham Bay Park, BX; Jamaica Bay, QN; portions of Staten Island West Shore.				Douglaston, QN; Broad Channel, QN; Far Rockaway, QN; Canarsie, BK.	Marine Park, BK; Starrett City; BK; Coop City, BX; Edgemere, QN.		
4		Bloomfield, SI; Bowery Bay, QN; Newtown Creek East, QN.		Gowanus East, BK; Gowanus West, BK; Red Hook, BK; Newtown Creek West, BK; Greenpoint North, BK; Long Island City, QN; Mott Haven, BX; Greenpoint West, BK; Sherman Creek, MN.	Gerritsen Beach, BK; Great Kills, SI; Howard Beach North, QN; Belle Harbor North, QN.	East Harlem South, MN; East Village, MN; East Harlem North, MN; North Corona, QN.	Chelsea, MN; Soho/Tribeca, MN.	Battery Park City, MN; Lower Manhattan, MN.
7	Butler Manor Woods, SI.				Prince's Bay, SI; Tottenville, SI.			
6			Westchester Creek, BX.	Lower Bronx River, BX.	Riverdale, BX.			
5		Flushing Bay, QN; Port Morris, BX; Sunset Park South, BK.	Mariner's Harbor, SI.	DUMBO, BK; Edgewater, SI.	Throggs Neck, BX; Whitestone, QN; Country Club, BX; City Island, BX; College Point, QN.	Bay Ridge, BK; Astoria, QN.	Brooklyn Heights, BK; Kips Bay, MN.	
8	Inwood Hill Park, MN.					Norwood, BX.		
9						West Harlem, MN; Morris Heights, BX.	Upper West Side, MN.	

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