At The Water's Edge:

Landscape-Based Adaptations for Sea-level Rise in Barnstable

Coastal Resiliency Studio - LA 609 Fall 2018
Department of Landscape Architecture and Regional Planning
University of Massachusetts, Amherst

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Professor Jack Ahern, Ph. D., FASLA
Report Editors: Josiah Simpson, Jessica Schoendorf, Ben Breger

Studio Sponsor:
Barnstable Clean Water Coalition
Zenas Crocker, Executive Director
864 Main Street, Osterville, MA

Collaborators:
Mark Ells | Town Manager, Barnstable, Masssachusetts
Elizabeth Jenkins | Director of Planning and Development, Barnstable, Massachusetts
James Benoit | GIS Manager, Barnstable, Massachusetts
Daniel Santos | Department of Public Works, Barnstable Massachusetts
Dale Saad | Department of Public Works, Barnstable Massachusetts
Daniel Horn |Harbormaster, Barnstable, Massachusetts
Elizabeth Hamin | Professor, UMass Department of Landscape Architecture and Regional Planning

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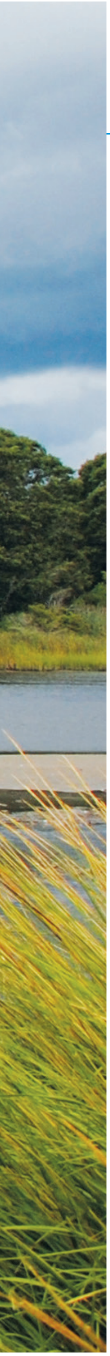


Overview

Barnstable, Massachusetts is Cape Cod's largest town located between Mashpee and Yarmouth. The town's two coastlines, abutting Cape Cod Bay to the north and Nantucket Sound to the south, comprise 170 miles of coastline, and make Barnstable especially, and profoundly, vulnerable to coastal hazards.

Barnstable's bi-coastal geography increases its risks and vulnerabilities from coastal processes and events including flooding and storm surges. These hazards are not a problem to be solved, but a reality that all coastal communities must accept. During the winter of 2018, Barnstable was inundated by flooding and storm surge by three 100 year storms- also known as a storm with a 1% chance of occuring in any given year. Houses and businesses along coastlines and harbors throughout Barnstable remain highly exposed to these events and make the town vulnerable to future damage and destruction. Coastal communities can no longer fight climate change; they must adapt to its realty.

This report resulted from a collaboration Among the UMass studio, the Barnstable Clean Water Coalition and the Town of Barnstable to propose design alternatives to build coastal resilience capacity. Resiliency refers to the capacity of a community to adapt to and "bounce-back" from the inevitable challenges and disturbances brought on by climate change, including sea level rise and the increased frequency and strength of coastal storm events. When designing for resiliency, exposure is determined by how open a location is to disturbances, while vulnerability is dependent upon what assets exist at an exposed coastal location. For instance, an undeveloped beach is highly exposed to coastal processes but not vulnerable. On the other hand, a beach developed with a residential neighborhood is highly exposed and highly vulnerable. Many parts of Barnstable have been developed on highly exposed areas making them vulnerable and further justifying the need for resilient design interventions in the near future.

This studio recommends strategies and goals that are necessary to build resilience capacity. These include working with nature (instead of fighting against it), understanding the difference between short- and long-term time-frames when discussing adaptation and sustainability, and designing for the uncertainty of the future. Although we cannot predict the exact nature of future events, we are certain that the nature of ocean processes and storms has and will continue to shape Barnstable now and in the future.

Working with nature means learning from nature and natural processes. Using bio-mimicry is an effective design tool that allows one to work with nature to build sustainable and resilient coastal solutions. It may be wise to employ bio-mimicry and other "nature-based" design strategies while thinking about future generations. Although the most severe effects of sea level rise may not be felt for many years or decades, resilient design strategies will take years or decades to establsh and thus should be introduced now to preserve the coast in the future. Our new reality includes sea level rise and increased frequency and strength of storms from climate change.

An "inconvenient " reality is that many of Barnstable's coastal neighnorhoods cannot practically, or feasibly, be protected from expected long-term coastal flooding risks. Strategic retreat is recommended as it allows for the community to consider its options, to develp plans that are fair, considerate and that have public understanding and support. The alternative to retreat is crisis and emergency response, with the very real risk of loss of property and life. A planned, strategic retreat also allows for time to coordinate infrastructure investments, to adapt plans and zoning policies and untimately to build a more resilient community.

The report describes processes that continue to shape Cape Cod and projections for the future as climate change continues to impact Barnstable's coastline. Conceptual plans are offered for focus areas that represent common, recurring conditions across Barnstable. We offer this work in the spirit of raising awareness of risks and vulnerabilities and informing public discussion, as well as providing examples of design interventions that can help to build coastal resilience in Barnstable.

(Figure - 1) Left: Near Osterville Grand Island along the Seapuit River.

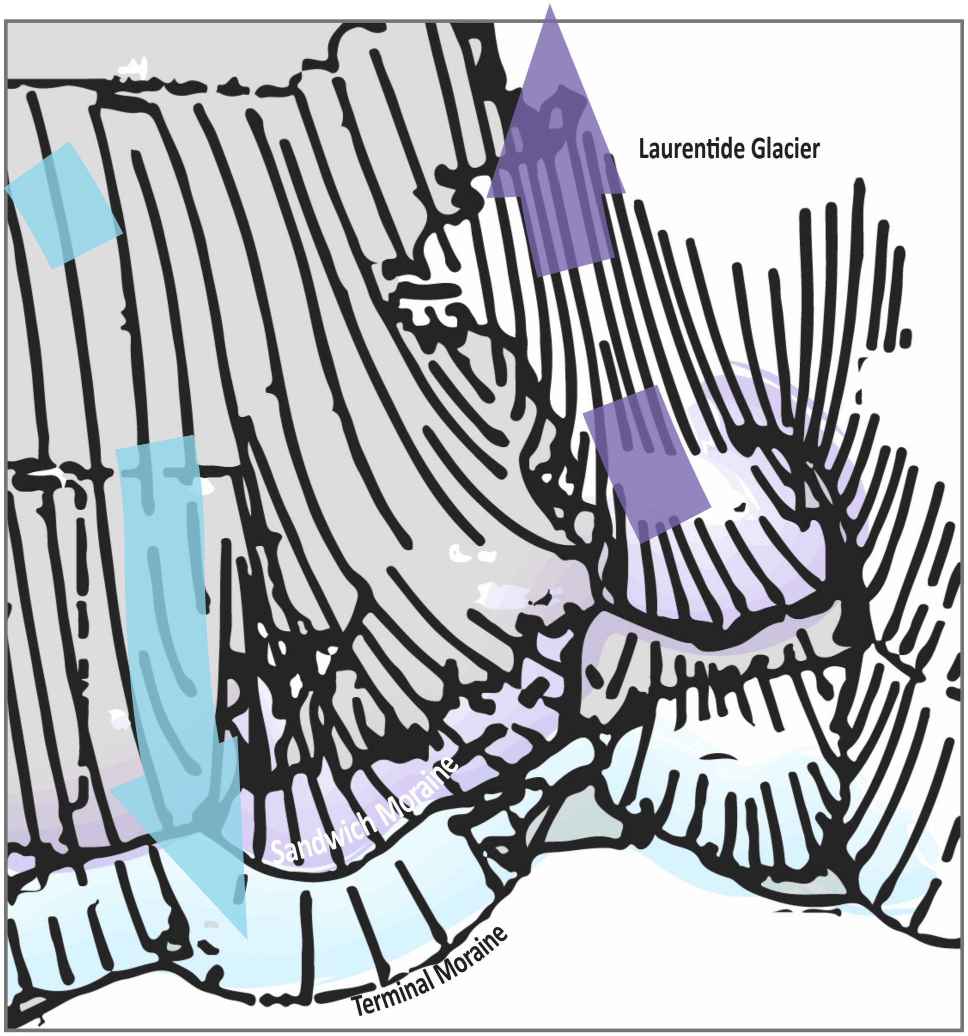
Shaping the Land

Geomorphological processes continuously shape the coastline of Cape Cod. These processes can be either engaged or interrupted to influence and change the level of resilience for a specific coastal area. Geomorphological processes are particularly important for planning "Living Shoreline" systems that can increase the durability and resilience of coastal areas within the context of global climate change and sea level rise. As sea level rises, the forces of the ocean will increasingly impact the coast and change the landform more dramatically than in recent history. This section defines key characteristics of coastal geomorphology and their relevance to coastal resilience planning.

Geomorphology is the study of the origin and evolution of landscapes created by physical forces, biological activity, and chemical processes operating at the earth's surface (Giese et al., 2015). Coastal geomorphology focuses on coastal environments like the Cape Cod peninsula, where the forces of the ocean are constantly at work shaping and reshaping the coastline. The glacial history of the Cape and coastal geomorphic processes that have occurred there for the last 10,000 years are responsible for creating the unique and beautiful mix of beaches, bluffs, sand dunes, and tidal marshes that both residents and visitors enjoy today (Strahler, 1966).

(Figure - 2) Houses overlook Cape Cod Bay near the Sandy Neck Gate House.

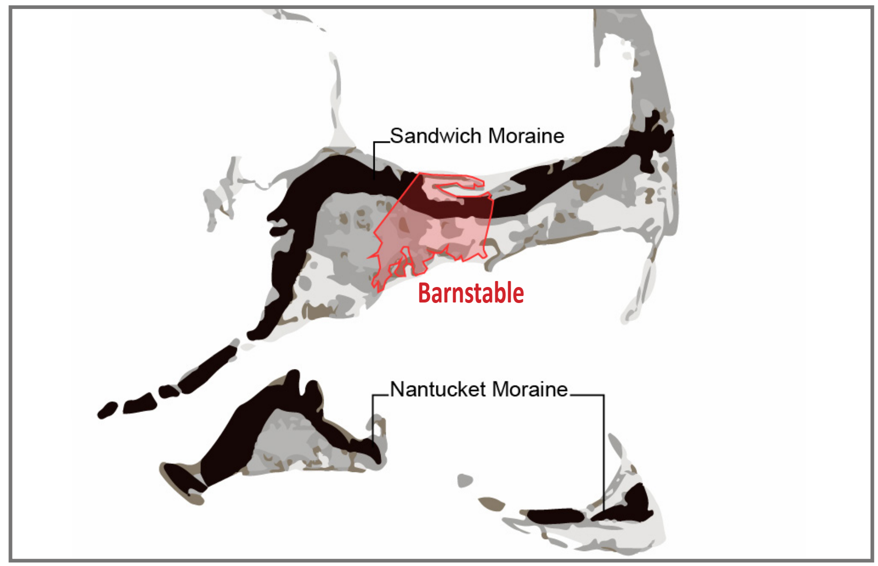
Advance + Retreat



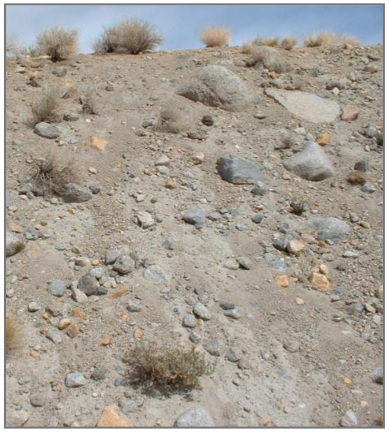
(Figure - 3) Advance and retreat of the Laurentide Glacier (light blue). Retreat started around 24,000 years ago but paused for several thousand years over present-day Cape Cod leaving behind the Sandwich Moraine when the glacier retreated 16,000 years ago (purple).

Glacial History

Cape Cod's coastal geomorphology cannot be understood without first referencing the last period of glaciation. Around 100,000 years ago, the earth experienced a period of cooling that caused glacial ice to extend from the Arctic Circle south and east (Strahler, 1966). The ice sheet pushed a voluminous amount of aggregate and sediment, known as glacial till, south by plucking bedrock material and thrusting it up into the ice and conveying materials by melt-water at the base. Glacial till is an unconsolidated mix of fine sediment, such as clay and silt, granular aggregate, such as sand and gravel, and a cornucopia of stones, rocks, and boulders. This material collected at the southernmost reaches of the ice sheet creating a terminal moraine that rose hundreds of feet (USGS, 1976). This deposited material made the present-day islands of Nantucket and Martha's Vineyard. The earth began a period of warming 24,000 years ago exposing the Nantucket Moraine.



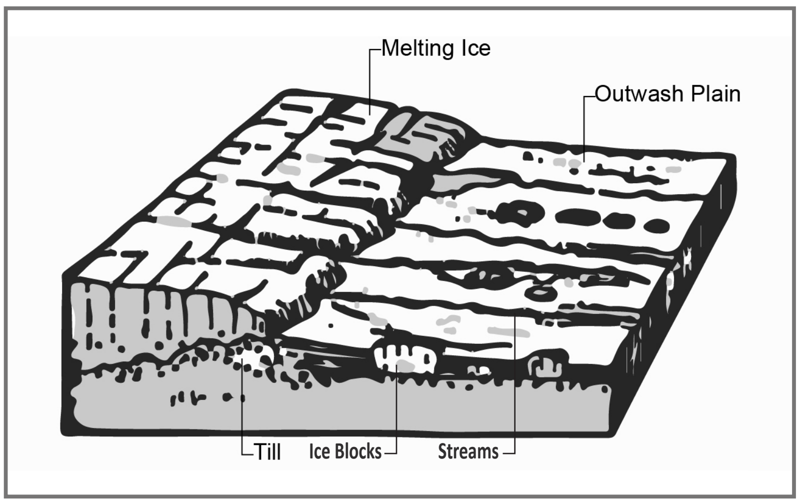
(Figure - 4) The glacier's terminus left behind moraines of deposited material. These "piles" were the post-glacial origin of today's Martha's Vineyard, Nantucket Island, and a ridges making the Elizabeth Islands and Cape Cod.



(Figure - 5) Typical till from terminal moraine.

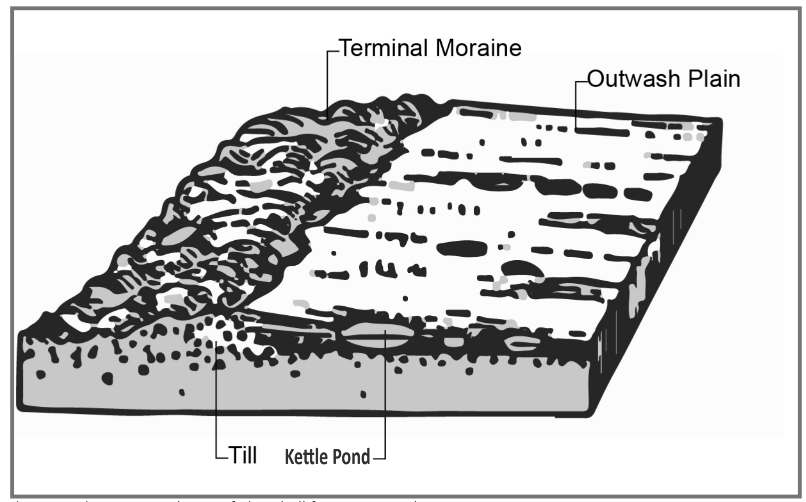
The glacier retreated and for several thousand years paused over present-day Cape Cod and the Elizabeth Islands. The glacier's melt-water created an outwash plain of fine aggregate and sediment creating a flat gentle land form. When the glacier retreated 12,000 years ago it left behind the Sandwich Moraine, a rough and jagged landscape composed of an unconsolidated mix of glacial till hundreds of feet high (Strahler, 1966). Cape Cod's present day landscape is either former moraine or outwash plain. Sea levels have risen an estimated 400 feet since the glacier retreated, the physical forces of the ocean eroded much of what the glacier left behind, washing that material out to the continental shelf. The geologically rapid rate of erosion is due to the composition of till as unconsolidated material. Oceanic and other geomorphological forces have sculpted this unique and fragile land form for the last 12,000 years. Some of these forces include currents, tides, waves, and weather explained over the following pages. Each has influenced the character of the Cape's landform over long-term, slow processes, and shorter term cataclysmic events. Over that time, plants have colonized what was once a barren post-glacial landscape. Niche ecosystems evolved to tolerate inhospitable soil, unique landforms, and dynamic cycles of disturbance and rapid change.

Glacial Advance Landscape

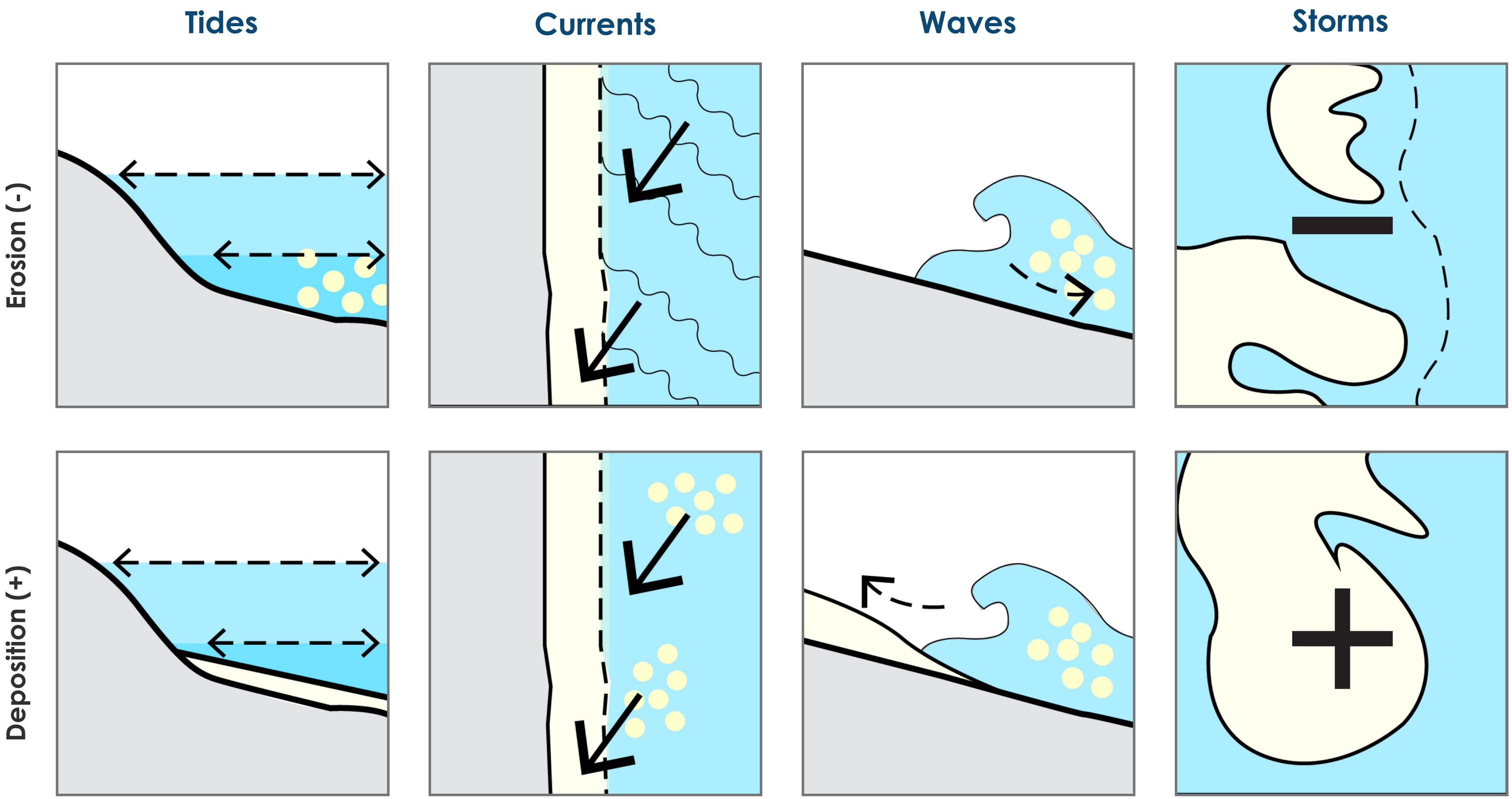


(Figure - 6) Retreating glacier and glacial till from Laurentide advance 24,000 years ago.

Glacial Retreat Landscape



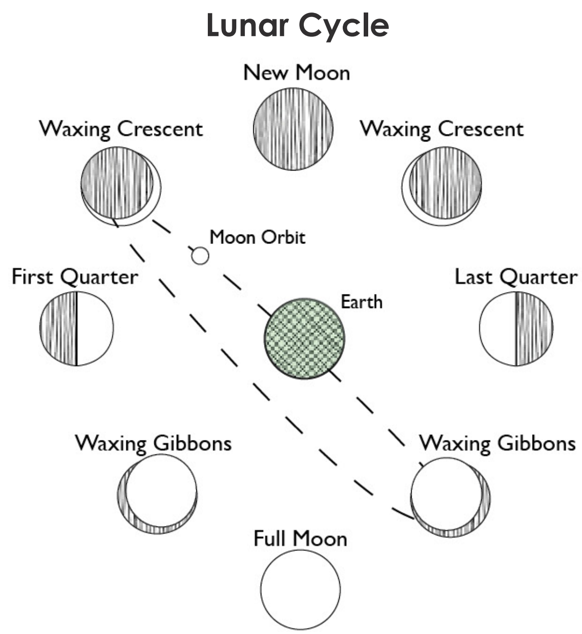
(Figure - 7) Conceptual area of glacial till from Laurentide retreat 5,000-8,000 years ago.



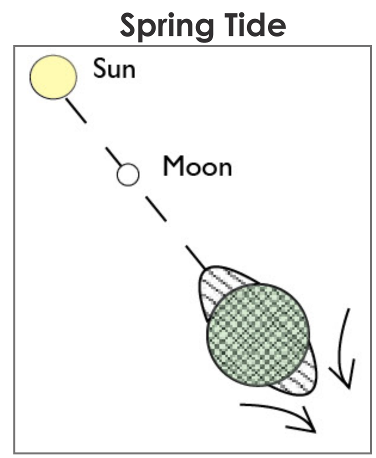
(Figure - 8) Currents, tides, waves, and storms are forces that cause erosion. Currents transport material along a prevailing direction. Tides push and pull material off the beaches and dunes. Waves are destructive, breaking away material and pulling them to sea. Storms happen occasionally but can cause much erosion in a short period.

Tides

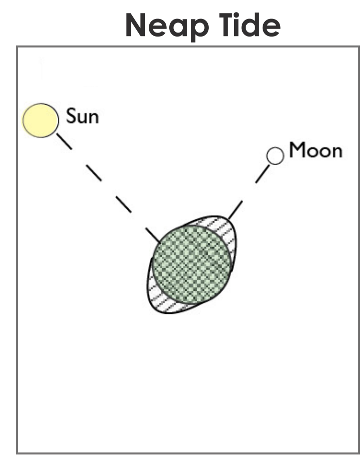
The changing tides are a constant geomorphological process. Tide is influenced mainly by the gravitational pull from the Moon during its lunar cycle and by its rotation around the Earth (Figure-9), and secondarily by the orbit of Earth around the Sun. The Moon is key to tidal cycles because its azimuth and distance above Earth, seen as a new moon, half, or full moon, affects the amount of gravitational pull that influences the movement of ocean water known as tide. The highest tides, Spring Tides, occur at the new and full moon when the Earth, Moon and Sun are aligned (Figure-10). Neap Tides cause the lowest low tides (Figure-11).



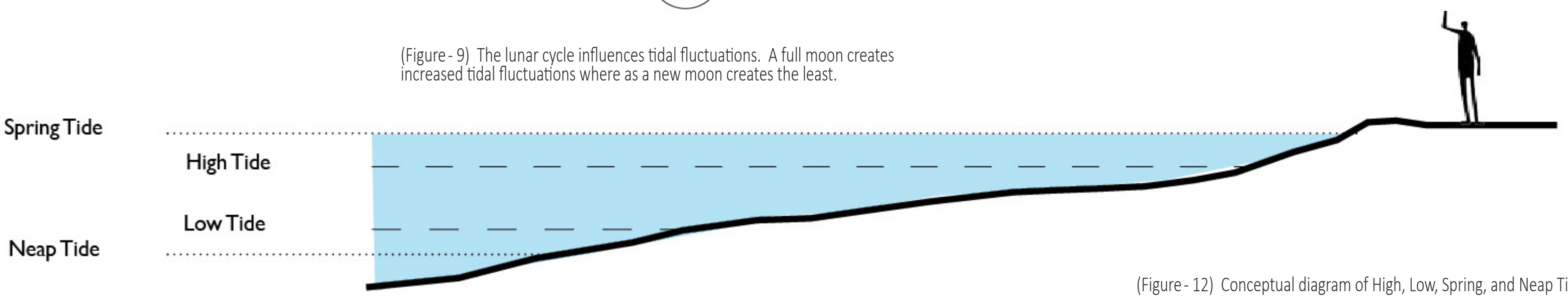
(Figure - 9) The lunar cycle influences tidal fluctuations. A full moon creates increased tidal fluctuations where as a new moon creates the least.



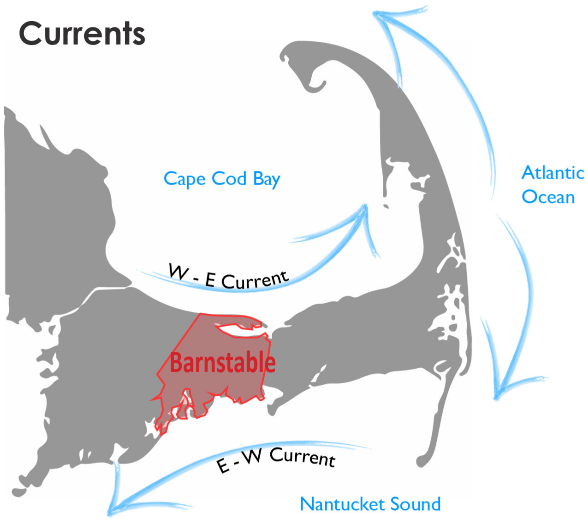
(Figure - 10) Spring Tide occurs when the Earth, Sun, and Moon are aligned. This causes The highest of high tides.



(Figure - 11) Neap Tide occurs when the Moon and Sun are at a ninety degree angle to each other. This causes the lowest low tide.



(Figure - 12) Conceptual diagram of High, Low, Spring, and Neap Tides.



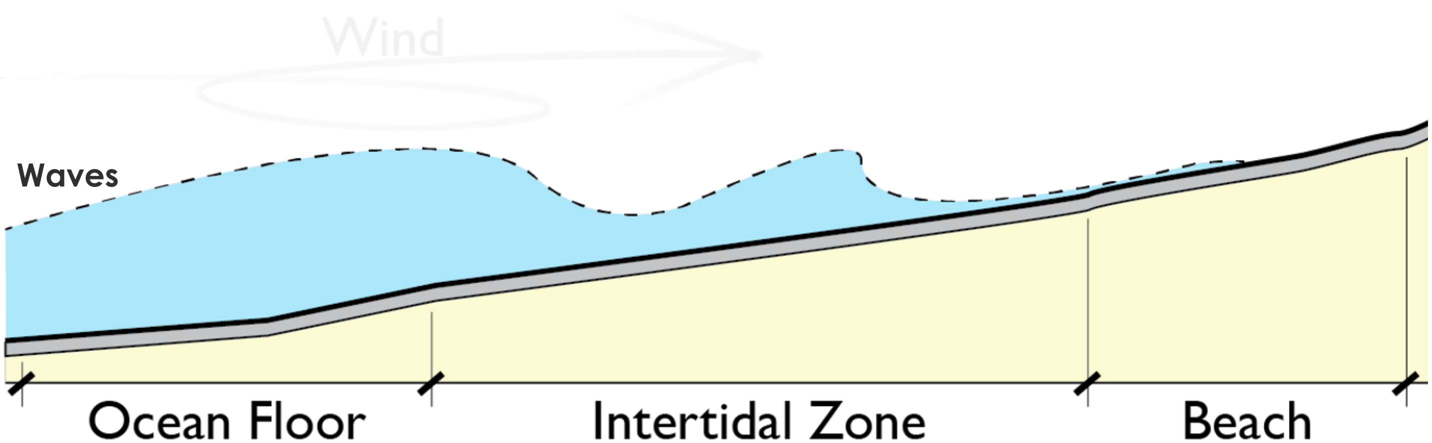
(Figure - 13) Movement of currents around Cape Cod

Currents

Ocean currents are generally constant, with west-to-east currents flowing across Cape Cod Bay and east-to-west currents flowing across Nantucket Sound (Figure-13). Local currents are influenced by oceanic currents, such as the Gulf Stream, local landforms, the temperature of the ocean, and prevailing winds. Variations in season and water temperature can change currents, however, the currents are nearly constant.

Waves

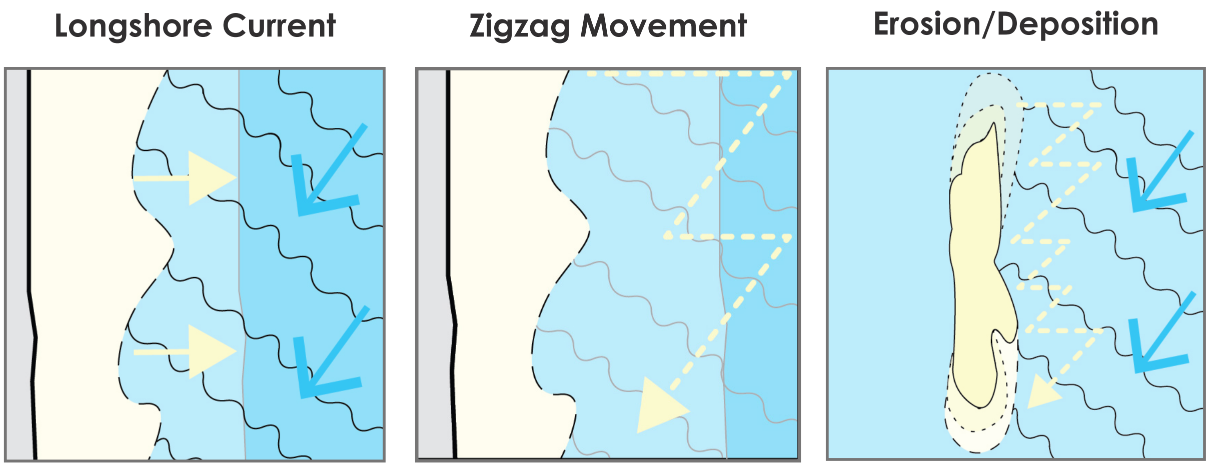
Waves, which are affiliated with currents and tides, are caused by the friction of wind over water, globally and locally (Figure-14). Light wind creates little waves, strong wind creates big waves. The greater the distance the water is exposed to wind, known as fetch, causes larger waves. If the ocean floor is constant and smooth there is less interruption to the wave swell as it moves across the ocean. Changes in coastal underwater elevation, such as sandbars, disrupt waves and reduce their size and force. As waves crash onto the shore, the force of the water erodes the shore pulling the soil materials into the ocean. Wave action is constant and relentless. On a calm day, wave erosion is minimal while on a stormy day erosion can be very substantial.



(Figure - 14) Wind over the water, called "fetch", creates friction over the ocean that forms waves.

Littoral Drift

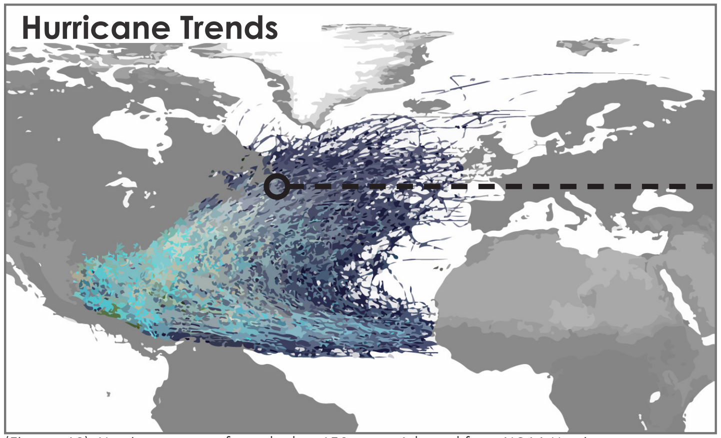
Littoral drift (also called longshore drift) is a geological process that combines the energy of the wind, waves, and current to transport sediments (sand and silt) along the coast parallel to its shoreline. The energy fueling the drift comes from the prevailing current and wind direction usually striking at an oblique angle to the coast. Incoming wind often strikes the coast at an oblique angle- squeezing water along the coast, and generating a water current that moves parallel to the coast. The wind fetches waves that break on the beach and beach sand is moved by the swash and backwash of water on the beach. Breaking surf sends water up the beach (swash) at an oblique angle and gravity then drains the water straight downslope (backwash) perpendicular to the shoreline. The combination of swash and backwash moves sediment incrementally along the prevailing current in a zigzag fashion within the surf zone. Littoral drift is simply the sediment moved by the current by the combination of these factors.



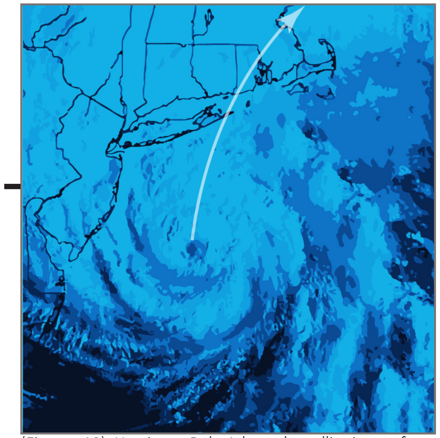
(Figure - 15) Littoral drift is oblique wave action against the beach, that moves up the beach at the wave angle, then swashes back perpendicularly to the water. That force causes sand and other particles to zig-zag in the direction of the prevailing current.

(Figure - 16) Showing the deposition area off the western tip of Dead Neck /Sampson's Island. Littoral drift has moved thousands of yards of sand hundreds of feet in approximately ten years.

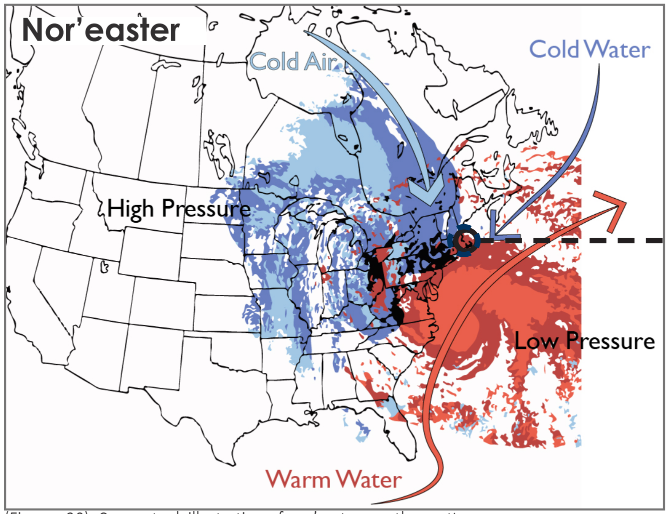
(Figure - 17) The eastern end of Dead Neck/Sampson's Island is eroding. It has lost thousands of cubic yards of sand from the erosion caused by littoral drift.



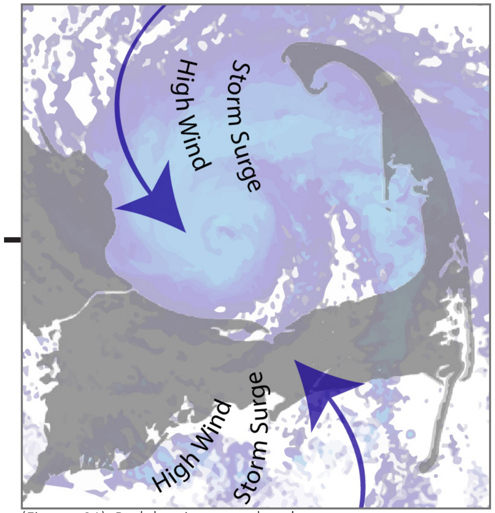
(Figure - 18) Hurricanes tracts from the last 150 years. Adapted from NOAA Hurricane History, https://oceanservice.noaa.gov/news/historical-hurricanes/.



(Figure - 19) Hurricane Bob. Adapted satellite image from NOAA-10 of Hurricane Bob from August 19, 1991.



(Figure - 20) Conceptual illustration of nor'easter weather pattern.



(Figure - 21) Both hurricanes and nor'easters rotate counter clockwise.

Weather and Storms

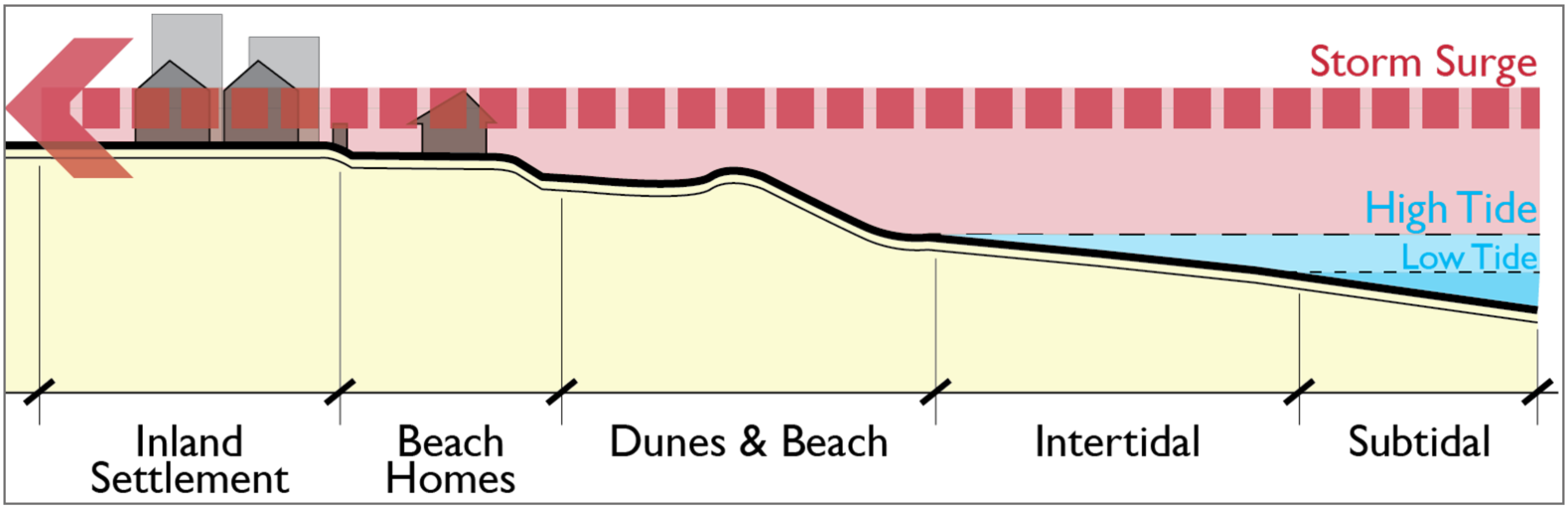
Weather changes cause wind by the differential movement of pressure systems. On the Cape, prevailing winds are relatively constant depending on the time of year. Storm events are less predictable. Major storms on the Cape include hurricanes that occur in the late summer and fall following the Gulf Stream's warm water north from the Caribbean, potentially straight into the Cape (Figures-18 and 19). Nor'easters usually occur in the winter and are caused by the collision of north-moving, wet, low pressure from the south with south-moving cold, high pressure from the north (Figure-20). Both hurricanes and nor'easters cause strong winds, lots of precipitation, and create storm surges. The Cape is vulnerable to these storm events because it is surrounded on three sides by water. Coastal resilience on Cape Cod primarily concerns the impacts of hurricanes and nor'easters from high winds, large waves and storm surges that can cause flooding and coastal erosion.

A "Perfect" Storm

A perfect storm is a cataclysmic event where a combination of factors combine that can cause record-breaking storm surges and flood events. When a high tide coincides with a spring tide (highest high tide) and a storm event such as a nor'easter or hurricane these ingredients together can create a "perfect" storm. An event like this creates a storm surge by water being pushed inland into higher elevations well beyond the inter-tidal zone.

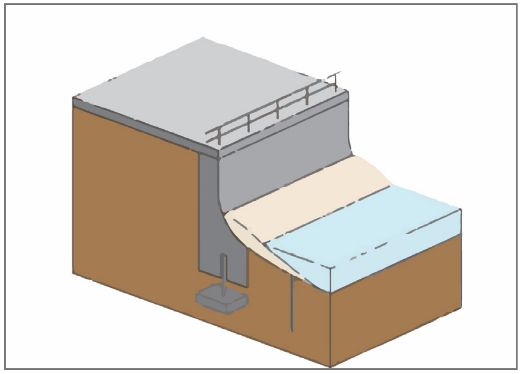
Spring High Tide + Storm Event = Perfect Storm


(Figure - 22) Storm flooding at Blish Point 2018.

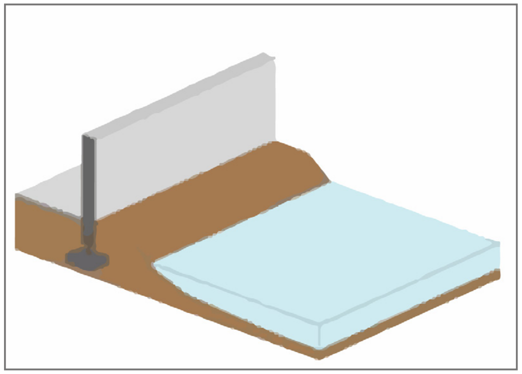


(Figure - 23) A diagram showing the relative flood level of a storm surge effect compared to mean annual high and low tides.

Gray Engineering

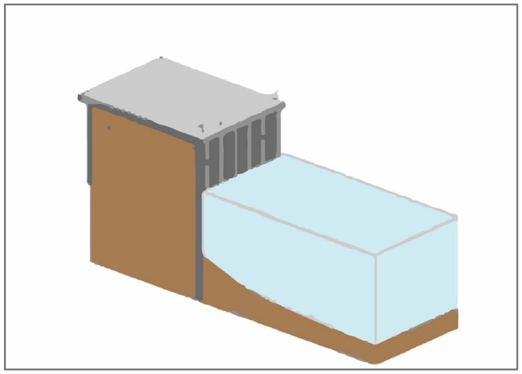


(Figure - 24) Sea Wall

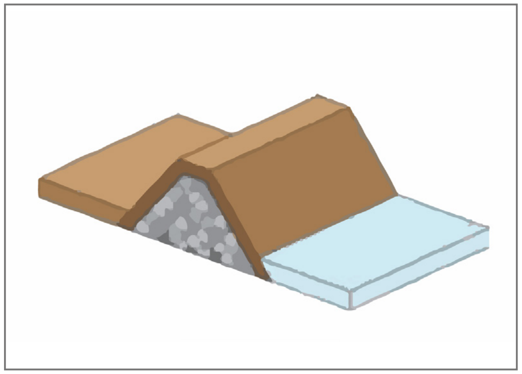


(Figure - 25) Flood Wall

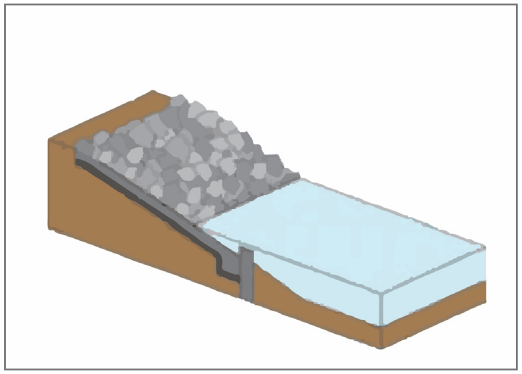
Humans have designed various interventions to protect vulnerable developed areas from constant geomorphological processes. Examples of "gray" or "hard" engineered solutions include seawalls, flood walls, bulkheads, and levees or dikes. These forms of protection have a lifespan and require on going maintenance. Continuous geomorphological processes wear against the man-made gray infrastructure and cause deterioration because they are inflexible to the natural conditions they are meant to provide protection from and they degrade continuously over time. (NYC Climate Adaptation Plan)



(Figure - 26) Bulkhead



(Figure - 27) Levee

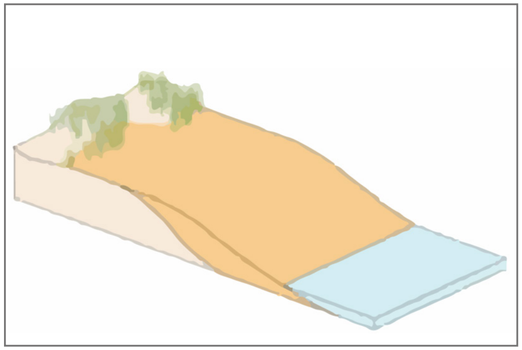


(Figure - 28) Revetment

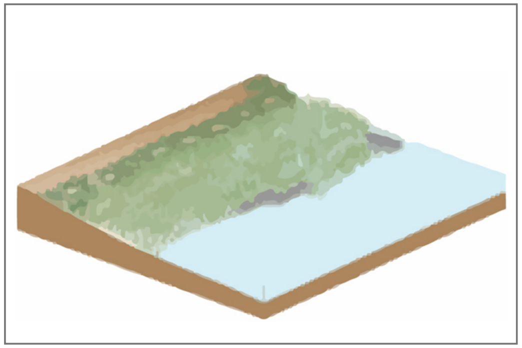
* All diagrams adapted from New York & Connecticut Sustainable Communities Coastal Climate Resilience report.

Green Engineering

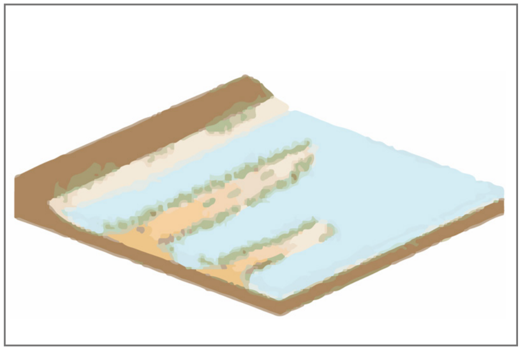
More recent human interventions have focused on working with nature to protect developed areas of coastal communities. These include: constructed breakwaters and wetlands, beaches and dunes, and living shorelines. They follow the idea of bio-mimicry, or applying characteristics of natural systems to designed systems. Green engineering is resilient because it is "living" and adapts to the geomorphological processes that are constantly changing the coastline. Constructed breakwaters use living systems to absorb wave energy similar to the effect coral reefs have on tides. Beaches and dunes are stabilized through the dune grass that grows in the sandy soil. This grass also replenishes the dunes by catching and retaining sand through wind movement. Living shorelines stabilize coastal beaches in a similar way by forming new living habitats (e.g.: oysters) and plants such as eel grass that help attenuate wave energy and replenish the landscape by retaining sediments. (NYC Climate Adaptation)



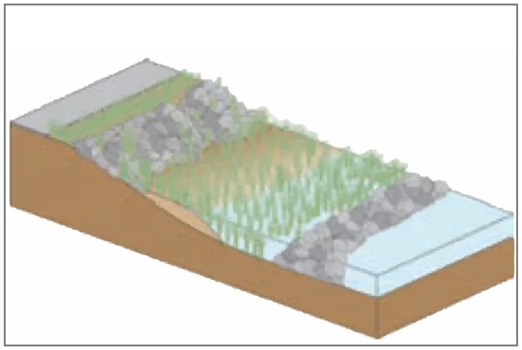
(Figure - 29) Dune and Beach



(Figure - 30) Coastal Wetland



(Figure - 31) Barrier Islands



(Figure - 32) Living Shoreline

Overview

There are many different coastal conditions that intersect and overlap along the Barnstable coastline. Coastal conditions are created by geomorphological processes that occur where the land meets the sea. Barnstable has approximately 170 miles of combined coastline on the town's north and south shore. These two extensive coastlines make Barnstable extremely vulnerable to event-based and gradual coastal hazards.

The interactions of these coastal conditions lead to different levels of resiliency. Understanding coastal conditions is critical when designing in the face of climate change, because understanding coastal types and their levels of resiliency allows town managers, planners, and policy makers to make informed decisions about the allocation of finite resources. Coastal conditions must be considered when creating resilient communities for short-term and long-term planning.

(Figure - 33) Dunes at Sandy Neck, Town of Barnstable Public Lands.

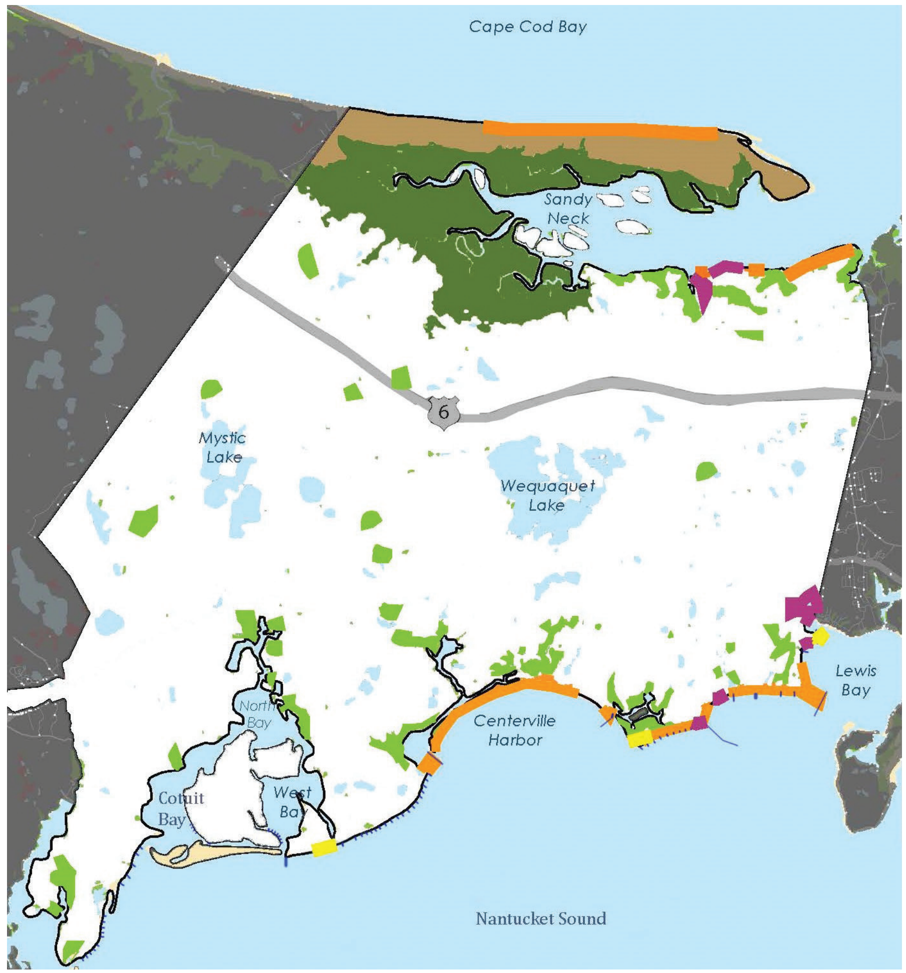
Coastal Landscapes of Barnstable

In order to understand the diverse coastal conditions of Barnstable, the coasts have been classified into seven different types. By breaking down coastal conditions into typologies, similar design strategies can be applied to the same typologies occurring in different areas in the town.

The map to the right is a summary inventory of different coastal typologies found in Barnstable. The occurrences of these seven coastal typologies are shown along both coastlines.

Key : Coastal Typolgoies

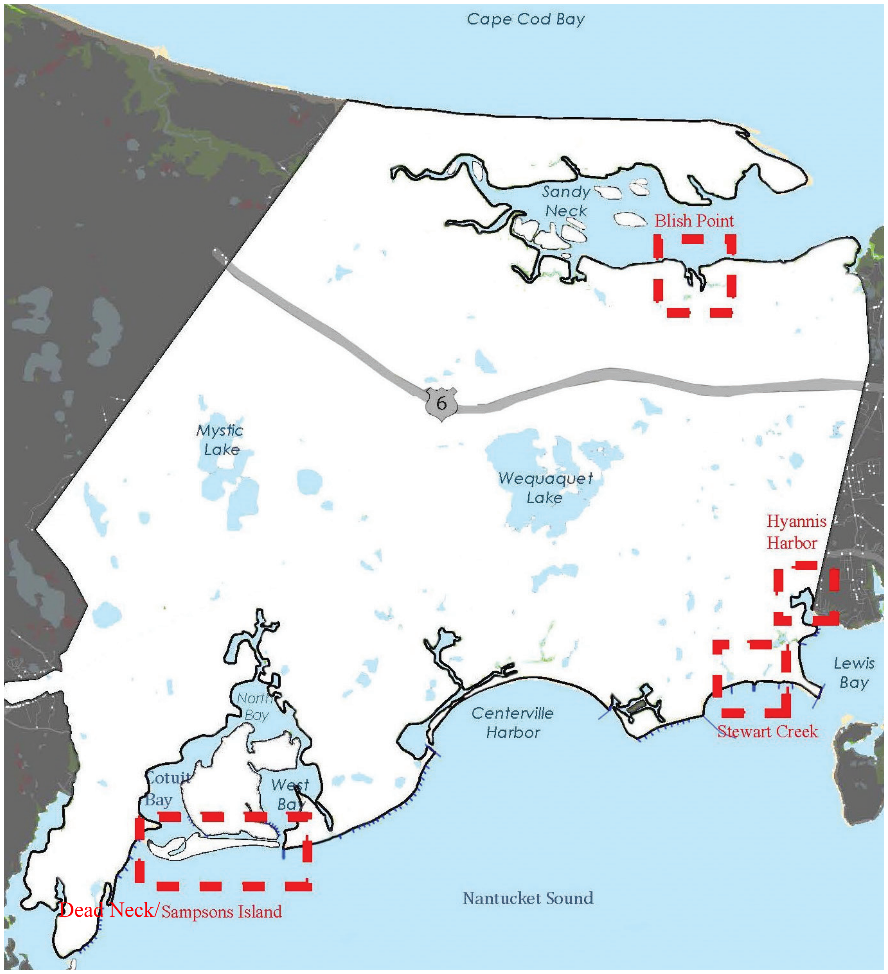
- Saltmarsh
- Developed Saltmarsh
- Barrier Island/Dune
- Bulkhead
- Beach
- Developed Beach
- Bluff



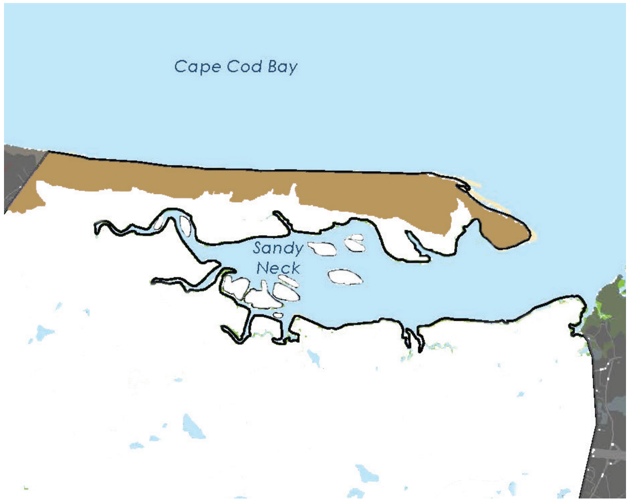
(Figure - 34) All the seven different coastal typologies in Barnstable. Source of base-map: New England Climate Adaptation project- MIT Science Impact Collaborative

Studio Focus Areas

1. Blish Point
2. Dead Neck/Sampson's Island
3. Stewart's Creek
4. Hyannis Harbor



(Figure - 35) Focus areas of the Barnstable studio.



(Figure - 36) A map showing an example of a beach, at Sandy Neck. Source: New England Climate Adaptation project- MIT Science Impact Collaborative

(Figure - 37) A beach at Blish Point.

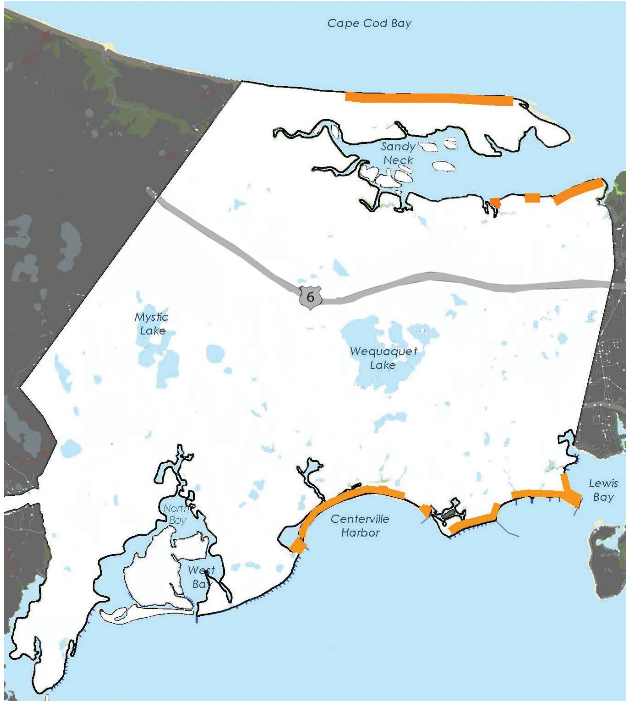
Beach

A beach is a narrow, gently sloping strip of land that lies along the edge of a bay, sound, or ocean. Beaches are formed from sand, pebbles, rocks, and seashell fragments.

Beaches are constantly being weathered and eroded since they are exposed to the full force of wind and waves. The coastal dunes and beach grasses along the beach can absorb the wave and wind action along the beach making it a highly resilient landscape - one that has the inherent capacity to recover from disturbances, such as coastal storms and flooding.

Coastal Hazards of Beach	
Storm Surge	High
Sea-level Rise	High
Exposure	High
Vulnerability	Low

(Figure - 38) Section showing a beach with its typical American beach grass vegetation cover.



(Figure - 39) Areas of developed beach at Barnstable. Source: New England Climate Adaptation project- MIT Science Impact Collaborative

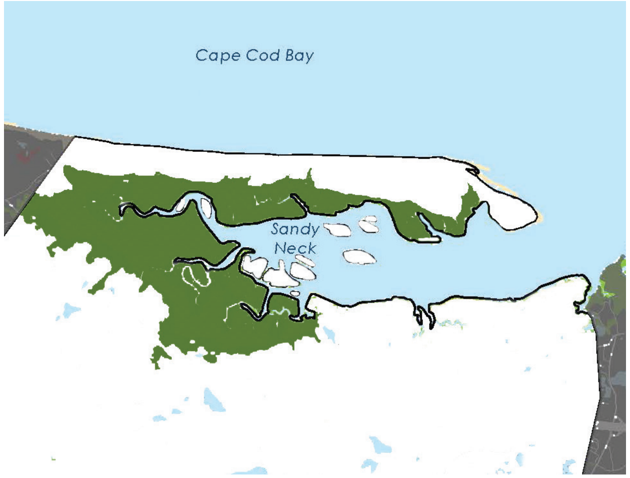

(Figure - 40) A beach and the development right behind the primary dune.

Coastal Hazards of Developed Beach	
Storm Surge	High
Sea-level Rise	High
Exposure	High
Vulnerability	High

Developed Beach

A developed beach replaces coastal dunes with waterfront development of homes and infrastructure. With the same exposures to erosion and weathering but no dunes and vegetation, the developed beach is now fully exposed to the full force of wind and waves, making it an unsuitable location for development. Developed beaches are highly vulnerable to coastal flooding and have very low resilience capacity.


(Figure - 41) Section showing a developed beach.



(Figure - 42) Salt Marshes at the Great Marshes. Source: New England Climate Adaptation project- MIT Science Impact Collaborative

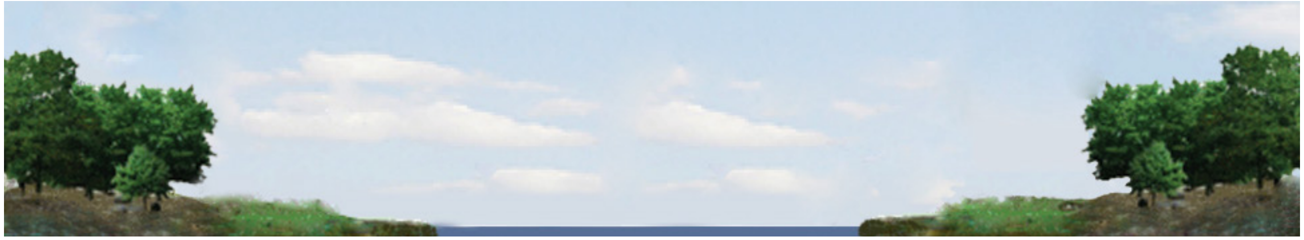

(Figure - 43) A salt marsh in Barnstable

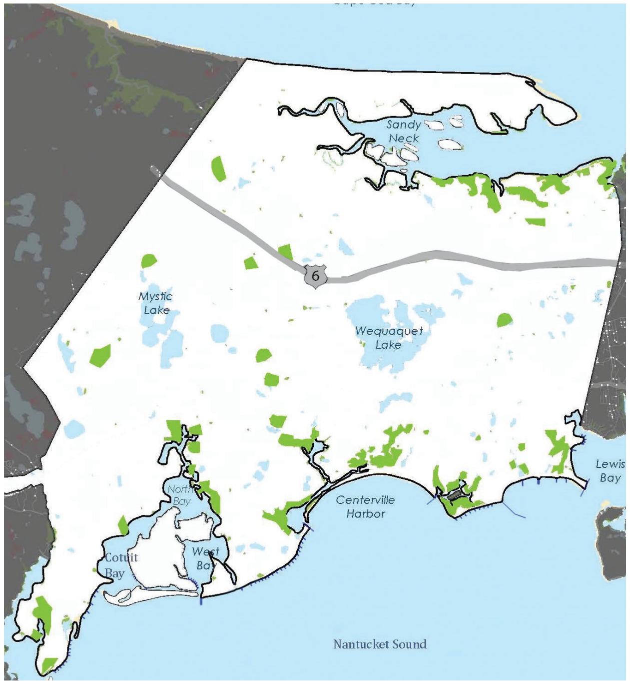
Coastal Hazards of Salt Marsh	
Storm Surge	Medium
Sea-level Rise	Low
Exposure	Medium
Vulnerability	Low

Salt marsh

A salt marsh is a type of wetland located in the inter-tidal zone of sheltered marine and estuarine coastlines. The inter-tidal zone is the seashore area which is covered by water at high tide but exposed at low tide. Salt marshes are dominated by salt tolerant grasses (e.g. ***Spartina alterniflora, Juncus gerardii, and Spartina patens***) that stabilize the substrate and attenuate wave energy. When these grasses decompose in the anaerobic environment of marsh, peat is formed and carbon is stored. Salt marshes not only store carbon, but they also filter water and improve water quality. Salt marshes, like most estuarine environments, are nurseries for many fish and shellfish. Preserving salt marshes are essential to protect human health and the health of the oceans.

Salt marshes tend to grow in areas exposed to relatively low energy waves and are highly resilient because the plant species that grow in salt marshes have evolved with changing tide levels for thousands of years. As the sea level rises, grasses migrate upland and the marsh migrates inland. Salt marshes are examples of naturally resiliant ecosystems and are important models for coastal resilience planning.


(Figure - 44) Section showing a salt marsh with its typical vegetation cover.



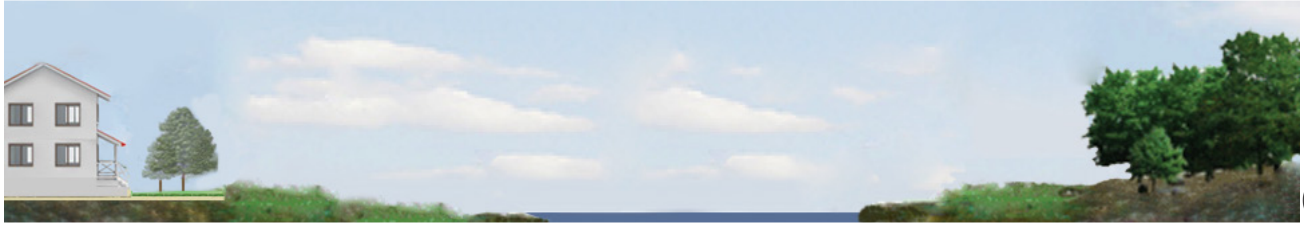
(Figure - 45) Developed Salt Marshes in Barnstable. Source: New England Climate Adaptation project- MIT Science Impact Collaborative

(Figure - 46) A salt marsh and the development along it

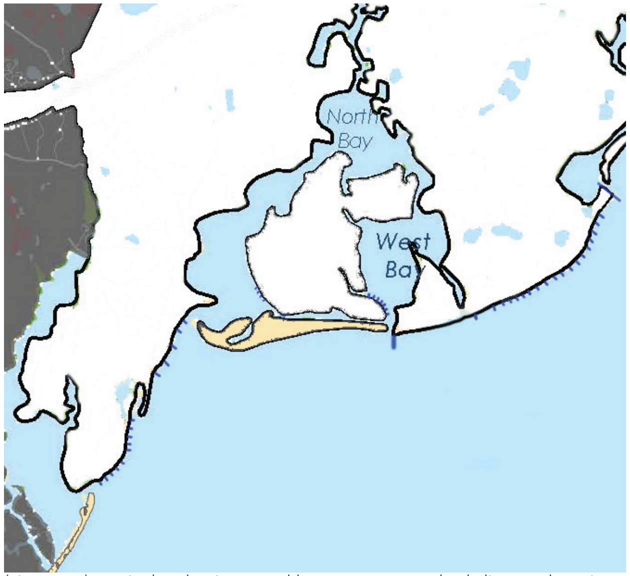
Developed salt marsh

Salt marshes are typically developed adjacent to the marsh, but lax wetlands regulations have allowed marshes to be filled and developed. Due to this development, marshes have no space to migrate inland, reducing their natural resiliency. A developed marsh is a flat lowland made more vulnerable to flooding and sea level rise—their capacity to migrate landward is now restricted by infrastructure, embankments or topography. Developed salt marshes have very low resilience capacity.

Coastal Hazards of Developed Salt Marsh	
Storm Surge	High
Sea-level Rise	High
Exposure	Medium
Vulnerability	High



(Figure - 47) Section showing a developed salt marsh.



(Figure - 48) Barrier beaches in Barnstable. Source: New England Climate Adaptation project- MIT Science Impact Collaborative


(Figure - 49) A barrier beach at Dead Neck/Sampson's Island.

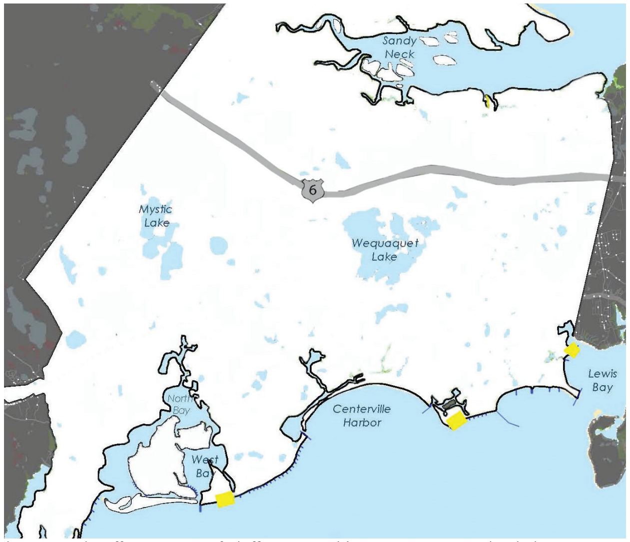
Barrier Island

A barrier island is a low-lying strip of beach and dunes roughly parallel to a coastline. They are dynamic systems that migrate down-current which can cause issues for any infrastructure associated with these shifting islands. Barrier islands protect the coast by mitigating and buffeting wave forces. Barrier islands are highly exposed, but also are extremely resilient.

A barrier island is impacted by erosion processes, but can adapt because it is a living system. They can be breached, but because of the dune ecosystems they support, primarily American beach grass, they demonstrate resilience to high levels of exposure, sea-level rise, and storm surge.

Coastal Hazards of Barrier Beach	
Storm Surge	High
Sea-level Rise	High
Exposure	High
Vulnerability	Low


(Figure - 50) Section showing a barrier beach with typical vegetation.



(Figure - 51) Different areas of Bluff in Barnstable. Source: New England Climate Adaptation project - MIT Science Impact Collaborative

(Figure - 52) A bluff with development abutting it

Coastal Hazards of Bluff	
Storm Surge	Medium
Sea-level Rise	Medium
Exposure	Medium
Vulnerability	Low

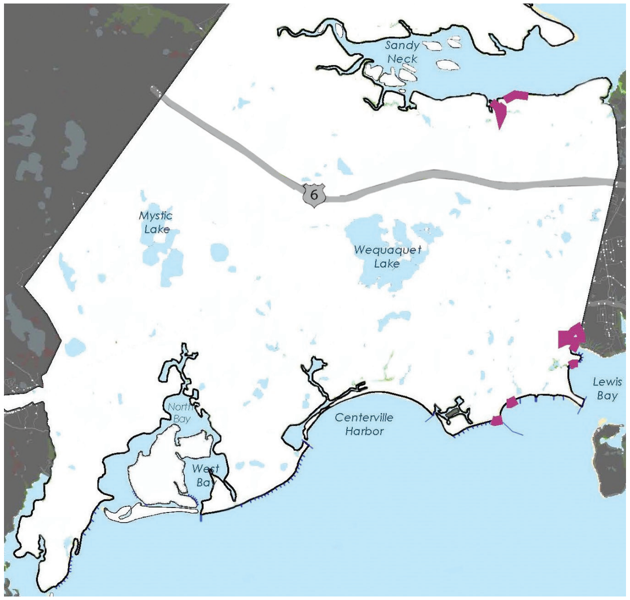
Bluff

A bluff is a coastal hill or a ridge of high elevation formed from glacial till. Developed bluffs can be hardened with concrete to prevent erosion to unstable and unvegetated faces of bluffs caused by wind and wave energy.

A bluff naturally reduces exposure because of its steep elevation. But over the long term , it is affected by storm surges, sea-level rise, and exposure.

Development close to bluffs is resilient because it is less exposed. Developing too close to bluffs puts infrastructure at risk to erosion. Across the Cape, many bluffs are actively eroding, placing coastal properties at great risk. Many properties have been moved back away from eroding bluffs and many more will need to be moved in the future. The more a bluff is developed, the higher the level of vulnerability because there is a greater amount of infrastructure at risk to erosion. If a bluff is stabilized with vegetation, bluffs can become resilient systems despite a high level of exposure.

(Figure - 53) Section showing a bluff alongside its vegetation cover



(Figure - 54) Bulkheads/Seawalls in Barnstable. Source: New England Climate Adaptation project- MIT Science Impact Collaborative

(Figure - 55) A seawall along the beach at Blish Point in Barnstable.

Coastal Hazards of Seawall/Bulkhead	
Storm Surge	Medium
Sea-level Rise	Medium
Exposure	High
Vulnerability	Medium

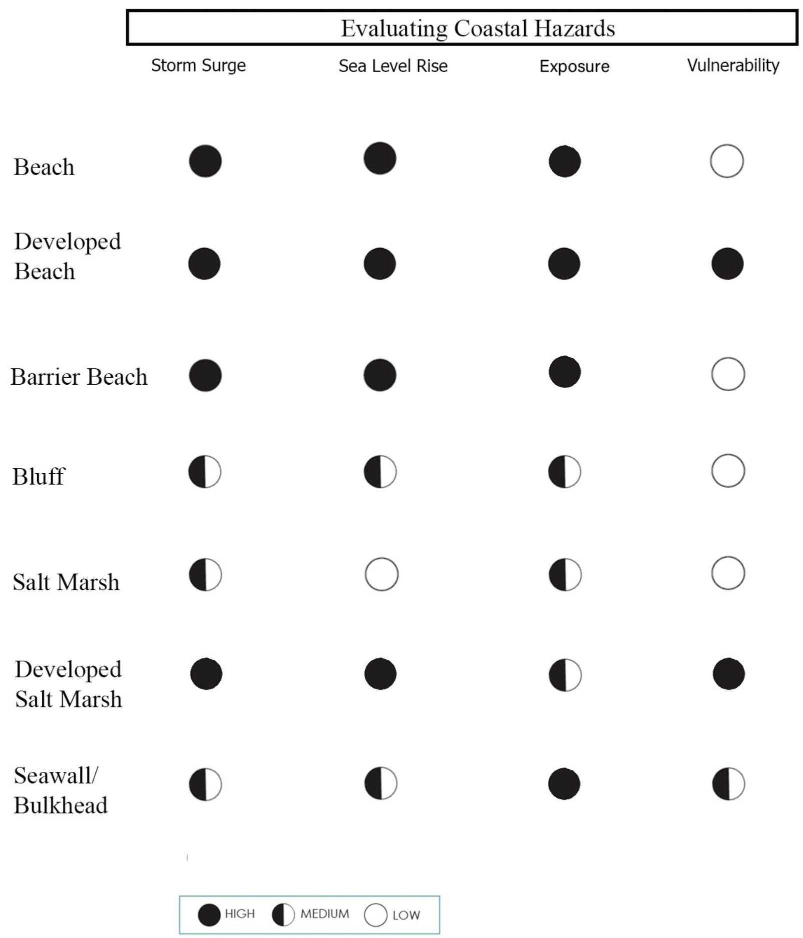
Bulkhead/Seawall

Bulkheads are structured walls of steel, stone, wood and concrete. They are designed to resist erosion, and absorb storm and wave action. Unfortunately, bulkheads actually deflect wave energy, causing turbulence and erosion at the base of the bulkhead/seawall. However, they may break and must be replaced overtime. They also cannot adapt to sea-level rise and cannot recover overtime, as they are non-living systems.

Revetments are also structured, slopig walls of boulders, and have similar coastal conditions as bulkheads.

Bulkheads and seawalls both have a high level of exposure to coastal hazards, but a medium level of storm surge resistance and sea-level rise. They have a medium level of vulnerability and a low level of resilience.

(Figure - 56) A section showing a bulkhead facing the harbor.



Having understood the different coastal conditions and typologies, the studio design groups were able to make informed decisions to build coastal resilience capacity across all of the main coastal typologies in Barnstable

(Figure - 57) Matrix showing all the different coastal typologies in Barnstable, comparing and evaluating their level of resiliency to different coastal hazards.

Overview

Climate change will continue to drive sea level rise (SLR) and cause extreme weather events to occur more frequently and strike with increased severity, resulting in a wide range of impacts to communities, natural resources, and infrastructure in coastal areas around the world (IPCC 2018; Northeast Climate Science Center 2018). In any given area, there is a specific degree of exposure and level of asset vulnerability to the impacts of climate change. Exposure is simply an inventory of the elements in an area where a hazard may occur, while vulnerability refers to the likelihood of exposed elements (buildings and infrastructure) to suffer adverse effects when impacted by a hazard event (IPCC 2014). The most vulnerable areas are low-lying coastal developments and communities prone to erosion, subsidence, and coastal flooding from large storms. The magnitude and speed of sea level rise and the frequency of increased coastal flooding are variable, and this study relied on recognized expert advice to make these predictions (IPCC 2018; Northeast Climate Science Center 2018).

Sea level rise is a continuous, ongoing process, occurring on a global scale, over a time period of decades and centuries – extending well into the future. Sea level rise is influenced by many factors. Thus, there is variability among SLR projections for the future. Causes of variability include the rate at which humans continue to release

(Figure - 58) A visualization of Hyannis Harbor under roughly 6 to 8 feet of water. This is the current level of a 100-year (1%) flood and could be the level of a 10-year (10%) flood in 2100.

WOODS HOLE		Median (50th percentile) 50% probability SLR exceeds	Likely Range (17th-83rd percentiles) 66% probability that SLR is between...	99.9th Percentile Value Exceptionally unlikely that SLR will exceed
Emissions Scenarios: Medium (RCP 4.5); High (RCP 8.5)		Feet (relative to Mean Sea Level in 2000)		
2030	Med	0.7	0.5-0.8	1.2
	High	0.7	0.4-0.9	1.5
2050	Med	1.1	0.8-1.5	2.5
	High	1.2	0.9-1.6	2.7
2070	Med	1.7	1.2-2.2	4.6
	High	1.9	1.4-2.5	5.2
2100	Med	$\boxed{2.4}$	1.6-3.2	8.3
	High	$\boxed{3.1}$	2.1-4.1	9.9

average: 2.75'

(Figure - 59) Sea level rise projections produced by the Northeast Climate Adaptation Science Center at UMass-Amherst localized to the Woods Hole Tide Gauge. These are the official projections used for planning purposes, by the Commonwealth of Massachusetts. Projections are given for the medium (RCP 4.5) and high (RCP 6.5) emissions scenarios, at multiple levels of likelihood, in feet relative to the mean sea level in 2000.

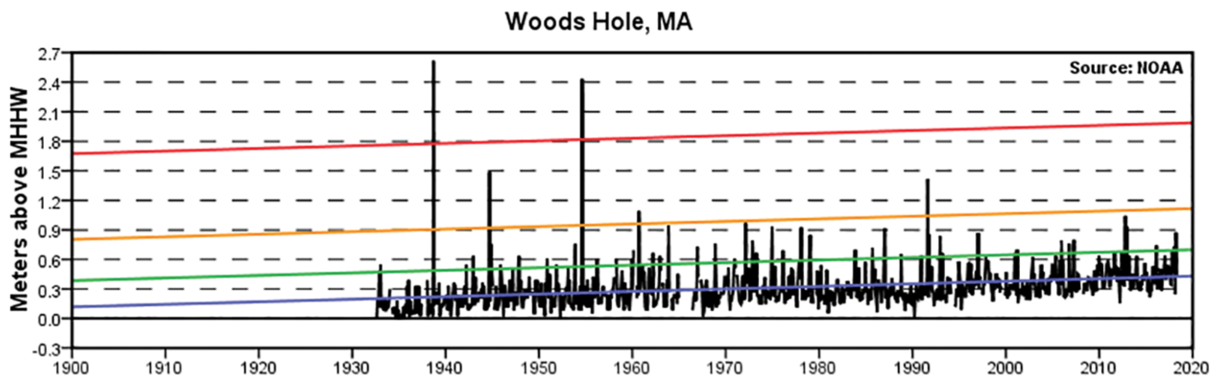
greenhouse gases (carbon dioxide, methane) into the atmosphere, the rate at which glaciers and polar ice sheets melt as a result of warming temperatures, and the extent to which ocean waters expand as the ocean temperature warms. Furthermore, there are localized factors on Cape Cod which exacerbate sea level rise, such as land subsidence, a unique problem due to the depletion of groundwater resources in the underlying sandy soil.

Sea Level Rise and Flooding Projections

The Northeast Climate Adaptation Science Center (NCASC) at UMass-Amherst has produced official sea level rise (SLR) projections, adopted by the Commonwealth of MA, with localized data for Woods Hole, which we use as a proxy for Barnstable (Figure-59). These projections incorporate two future greenhouse gas emissions scenarios and present variability in the form of probability percentiles (50th percentile means there will be a 50% chance SLR is above or below that point). Using the 50th percentile and an average of the medium and high emissions scenarios (2.4 and 3.1), Barnstable could see 2.75 ft of SLR by 2100. This is the number we will explore in vulnerability assessments in this report.

More frequent and severe storms and SLR will work together in the future to result in coastal flooding events with sea levels well above the current sea level – referred to as “storm tide,” or the total observed seawater level during a storm event (Figure-59). For annual flooding levels, we rely on the National Oceanic and Atmospheric Administration’s (NOAA)

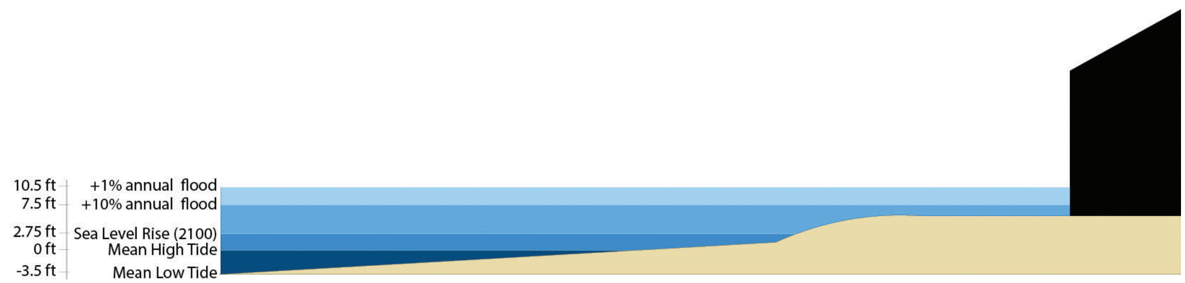
Tide Gauge data, which has recorded sea levels since 1932. Based on the event-based extreme sea levels in the past (Figure-60), NOAA has derived the flood levels which have a 10% and 1% chance of occurring in a given year. Localized to Barnstable, the current 10% flood level is 4.8 ft and the 1% flood level is 7.6 ft. We were unable to find information about the flood levels and frequency projected for 2100. However, by adding SLR to the current flood levels, we can estimate a 10% annual flood in 2100 to have a storm tide of 7.5 feet and a 1% annual flood to result in 10.5 feet of flooding, both levels measured above 2018 mean high tide. While these numbers may appear drastic, they represent a relatively conservative estimate of SLR and storm surge scenarios because they are based on 2018 flood levels which are highly likely to be affected by climate change by the year 2100.



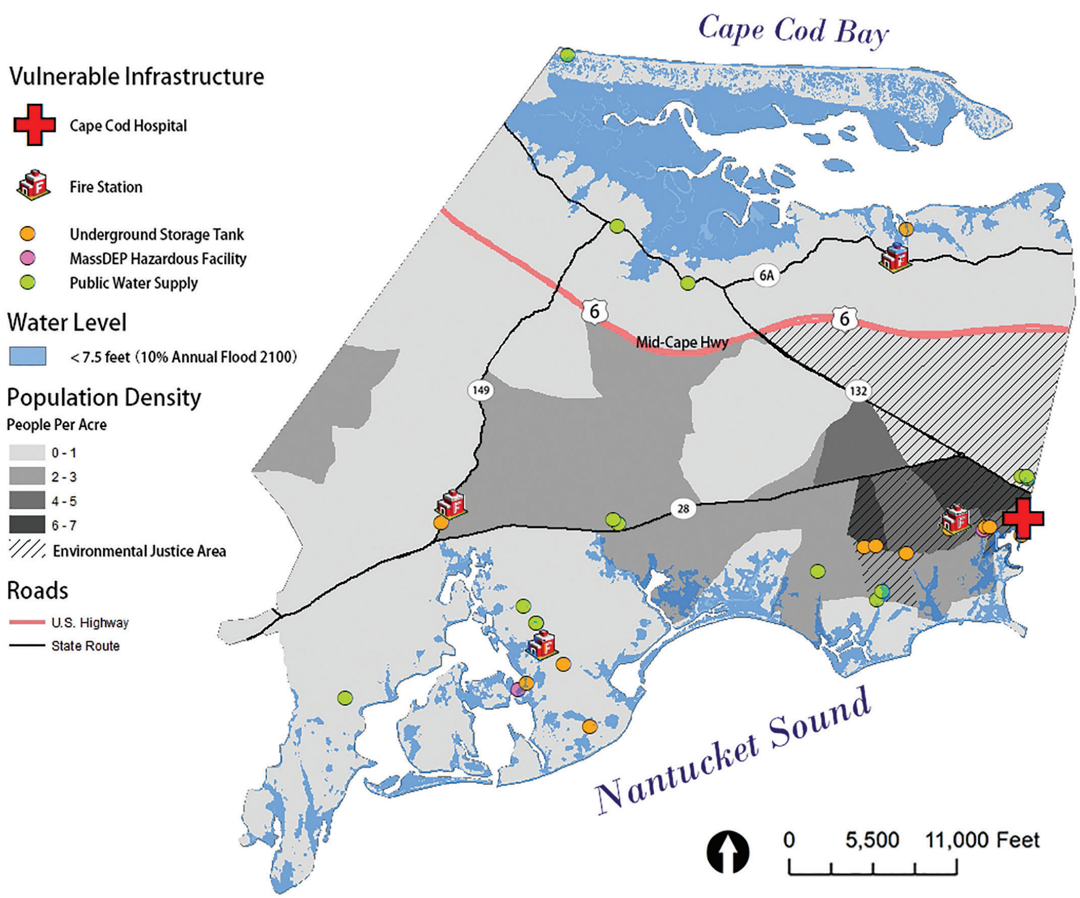
(Figure - 60) NOAA Tide Gauge information showing historical monthly extreme water levels since 1932 for Woods Hole, MA. This data is used to produce flood frequency projections and historical sea level. In this graph, there is sea rise of 2.61 millimeters/year (95% confidence interval of +/- 0.2 millimeters/year), or about 10 inches of sea level rise since 1932. A 1% annual flood has roughly 7.5' feet of flooding and a 10% flood has roughly 4.5' flooding.

Barnstable Vulnerability

The location and underlying geology of Barnstable make this community especially exposed to the impacts of sea level rise and extreme weather. A raised glacial moraine runs across the northern section of the town from east to west, however, the topography slopes away from this moraine towards both coasts, such that the coastal areas are predominantly low-lying. There are few coastal bluffs in Barnstable and the coast is predominantly composed of low-lying dune and marsh systems. Underground, the dynamics



(Figure - 61) Sea water levels projected for 2100 combining SLR of 2.75 feet and flood levels for a 10% and 1% storm.



(Figure - 62) Social and physical vulnerabilities for Barnstable with 7.5 feet of flooding, which is the flood level of a 1% storm in 2018 and could be a 10% storm in 2100. Environmental justice neighborhoods are concentrated areas of poverty and non-English speaking populations, making the people in these areas more vulnerable to the impacts of climate change. Physical infrastructure, such as Cape Cod Hospital and the urban area of Hyannis are assets vulnerable to the impacts of SLR and flooding.

between salt and fresh water have important implications for drinking water quality and supply in Barnstable. As the level of salt water rises so does the risk of salt-water intrusion and groundwater well contamination.

As a low-lying and coastal community, Barnstable has a high degree of exposure to the impacts of climate change in the future. Furthermore, as a highly developed town, which serves as the regional hub for governmental, medical and social services on Cape Cod, there is also a high degree of asset vulnerability to these impacts. Hyannis Harbor is the urban center for much of the Cape and includes Cape Cod Hospital, two ferry terminals, many businesses and restaurants, homes, and public parks. Vulnerability includes both physical features, such as infrastructure and buildings, as well as social components, such as areas of high population density, economically disadvantaged and non-English speaking populations, and other critical infrastructure, such as commercial and transportation hubs.

Figure-62 shows the vulnerability of critical infrastructure in Barnstable to rising sea levels, such as medical and emergency services, roads, hazardous chemical sites, the water supply, and both air and sea travel terminals. While the north coast of Barnstable is more exposed to rising seas, as it is largely a low-lying salt marsh, vulnerability is decreased in this area because there is less infrastructure and resident population. As noted in Figure-62, the most densely populated areas of Barnstable are in the southeast corner, in Hyannis, and along the southern coast and highlands. Cape Cod Hospital, located in Hyannis, serves as the regional trauma center for all of Cape Cod and the roads and infrastructure which serve the hospital are highly vulnerable and the hospital itself could be flooded during heavy storm events in the future. The southeast "quadrant" of Barnstable also contains concentrations of low-income, minority, and non-English speaking populations, deemed "environmental justice" neighborhoods by the State (Commonwealth of MA, 2018). Thus, these areas are more vulnerable to SLR and flooding due to the high population density, lack of resources to deal with disasters, and communication issues due to a language barrier. As Barnstable begins planning for climate change, these areas should be prioritized for proactive interventions which build both social and physical resiliency. Interventions to build coastal resiliency in Hyannis Harbor will be explored as a focus area of this report.

Conclusion

Efforts to enhance coastal resilience and reduce vulnerability in Barnstable will need to grapple with the uncertainty in projecting sea level rise (SLR) and flood levels. The estimate used here for SLR and flood levels for 2100 provide a glimpse into the impacts and vulnerabilities in an intermediate scenario. However, this could be a major over-estimate or under-estimate of the impacts of climate change depending on a variety of global and local phenomenon and society's ability to reduce greenhouse gas emissions. The most recent IPCC (2018) report paints a bleak picture for the future, concluding that the effects of climate change will occur sooner and be more severe than previously predicted. The IPCC report finds little cause for hope that society will be able to avoid catastrophic impacts of climate change through reductions in greenhouse gas emissions. Planning for an uncertain future will involve trade-offs such as the need to limit development or relocate residents in vulnerable areas and losing tax revenue or expending money on protection mechanisms which may never be utilized. There is also the social justice component where the most vulnerable populations are often the most under-resourced, making it difficult for them to move or spend on protection measures. This uncertainty may be reduced as science advances, but it will always be present. Redesigning an area to enhance coastal resilience involves incorporating this uncertainty and deploying systems which can adapt to the changing world.

Assessing vulnerabilities is a crucial first step in adapting to the impacts of climate change. The research we have compiled indicates that there is critical infrastructure vulnerable to flooding now and this problem will only get worse in the future. Moving forward, the Town of Barnstable can apply for grants from NOAA or the Commonwealth of Massachusetts to further study the magnitude of vulnerability. With this information in hand, the Town can then develop a resilience plan, which addresses adaptation techniques specific to each vulnerable area. The techniques recommended will need to take into account the underlying ecology and geomorphological processes impacting a given area. Certain ecosystems, such as dunes and salt marshes, are inherently resilient to storm surge and sea level rise and those areas should be restored and strengthened.

Planning for coastal resilience will also necessitate difficult and unprecedented conversations about relocating residents away from the shoreline. "Retreat" is a strategy that works in conjunction with protection, as the space vacated by the homes can be used to provide protection for the remaining community. This is a complex multi-dimensional problem that will require new ways of thinking and a coordinated strategy amongst all levels of government, federal to local, residents and other stakeholders. Coastal properties are not only beloved homes for residents but also important tax assets for the Town. Maintaining the housing stock is in the best interest of all stakeholders but sea level rise is inevitable and will most likely require relocation. As the Town begins planning a retreat strategy, public engagement and community participation is crucial to success. It wil be important for residents and Town officials to understand and trust one another and for the process to be participatory and inclusive. Furthermore, in many areas, the existence and magnitude of climate change is still being debated, so any public engagement regarding retreat must begin with an understanding that climate change is real and a certain amount of sea level rise is inevitable.

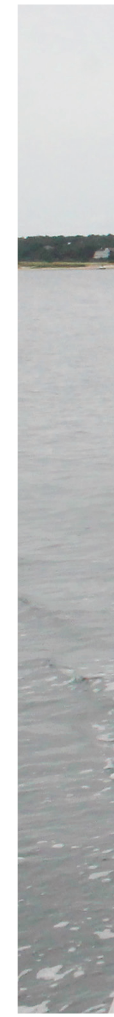
We outline a few strategies which can be explored to address the issue of relocation. An important first step could be limiting further (re)development or expansion in vulnerable locations. There could also be a policy set in place before natural disasters destroy homes, that the owners receive an insurance buy-out but are prohibited from re-building in the same location. Transfer of development rights (TDR) involves incentivizing coastal residents to relocate to a less vulnerable area by being granted the right to sell their development rights to a "bank" that can offer these rights to developers to increase density in town-approved, less vulnerable locations (for example in town centers or along public transportation routes). Rolling easements (Titus 2011) prohibit coastal residents from armoring the shoreline and compensates them for an easement which can "roll" landward as sea level rises, eventually inundating their home- in other words, a delayed, but inevitable retreat policy. All of these strategies will involve compensation for homeowners and will likely require new sources of funding, which can't be provided solely by the Town of Barnstable. Retreat is a difficult and complex problem to solve but is a pro-active approach, rather than waiting for the inevitable crisis. Doing so will allow the overall resilience of the community to increase by providing space for new adaptive infrastructure which protects the homes that remain. Our proposals take this approach of "retreat and protect" and while we focus on 4 sites, many of our ideas are transferable and adaptable and can be applied elsewhere, throughout the Town and the Cape Cod region. The adaptation recommendations, conceived primarily to build coastal resilience capacity, all hold the important potential to provide a suite of co-lateral benefits including: recreation, pedestrian circulation, environmental education, habitat conservation, fisheries, tourism, and shell-fisheries support, which add further value to our proposals and should be factored into the town's decision-making process.

In conclusion, climate change is an unprecedented and complex problem. Increasing resilience will require novel and adaptable solutions. Our proposals engage and adapt the inherent resilience found in many of the coastal ecosystems on Cape Cod and work with the geomorphological processes which have shaped the coast. By using 'living systems' as opposed to hard infrastructure, our proposals allow the infrastructure to adapt to an uncertain future of sea level rise and increased flooding frequency and intensity. While there is a high degree of vulnerability in Barnstable, there are also examples of resilient ecosystems throughout the town which we look to restore and strengthen in order to protect the residents and infrastructure of the town. We now invite you to explore our vision for a resilient Barnstable.

"We can plan now and retreat in a strategic and calculated fashion, or we can worry about it later and retreat in tactical disarray in response to devastating storms. In other words, we can walk away methodically, or we can flee in panic."

- Pilkey et al (2017)

(Figure - 63) Opposite: The report authors, Professor Jack Ahern, and the study sponsor, Barnstable Clean Water Coalition Executive Director, Zenas Crocker, touring Dead Neck/Sampson's Island to understand the processes that are shaping the island.

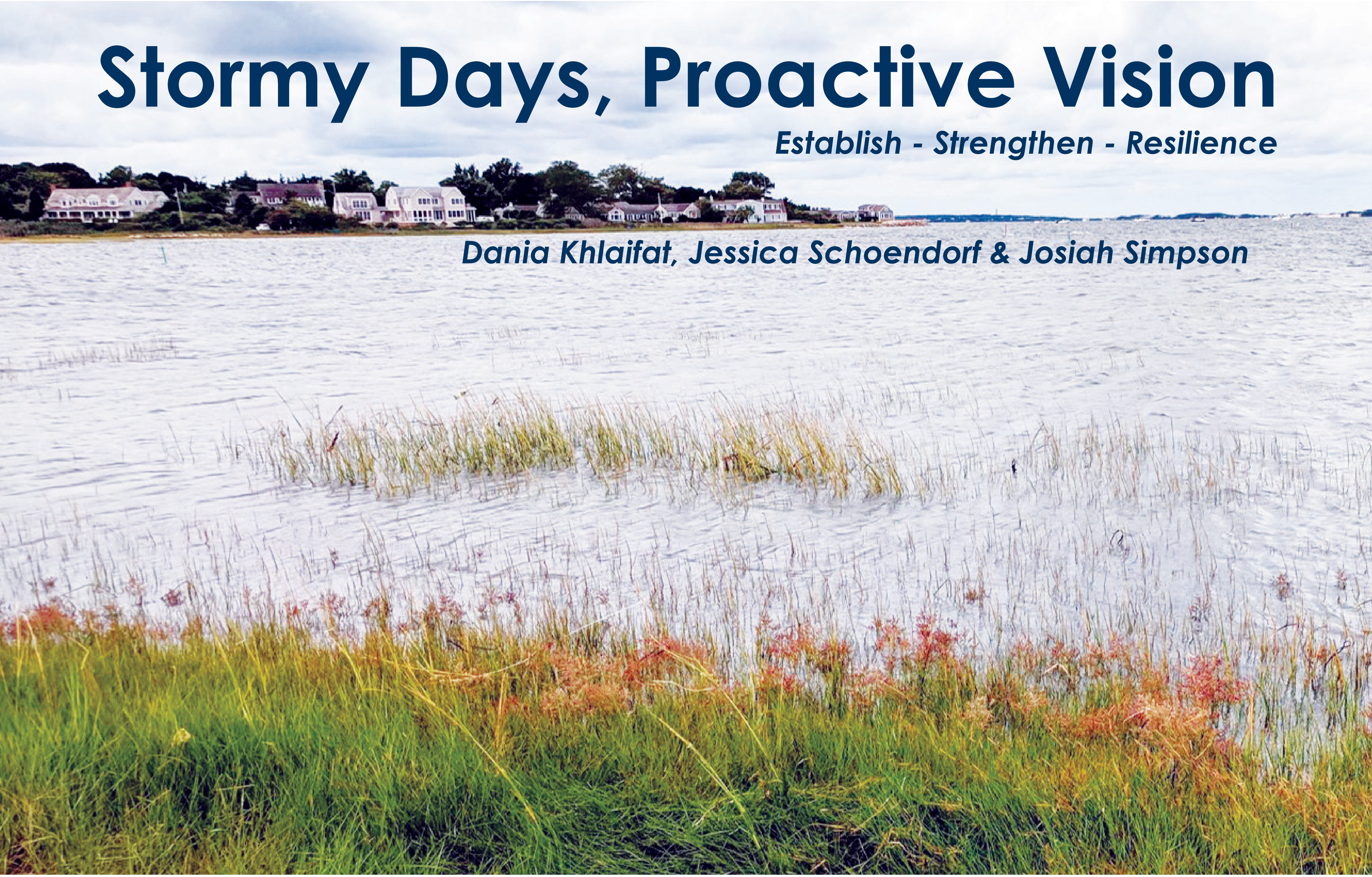



BOSTON
CROOKED

Stormy Days, Proactive Vision

Establish - Strengthen - Resilience

Dania Khlaifat, Jessica Schoendorf & Josiah Simpson



Overview

The residents of the village of Barnstable at Blish Point face an enormous and ever-present and unprecedented challenge: how to adapt the neighborhoods, commercial enterprises, and infrastructure under the threat of rising sea levels and worsening and extensive damage from storms. One thing is for certain, time is of the essence! Blish Point is on the front line of climate change impacts. It has recently experienced flooding and damage across large areas from storm events and sea level rise. In January and March 2018 two 100-year storms swamped the harbor, the neighborhood along Commerce Road and developed areas around the tidal marshes, up to the back doorsteps of the village center.

Climate predictions show that 1% storms are increasing in severity and frequency making them statistically more common. This means that today's 100-year storm will likely qualify as tomorrow's 10-year storm. Additionally, a recently released IPCC report shows that major effects of climate change will affect most people in their lifetime (IPCC 2018). The new report underscores that climate-related changes will be highly impactful as soon as 2040.

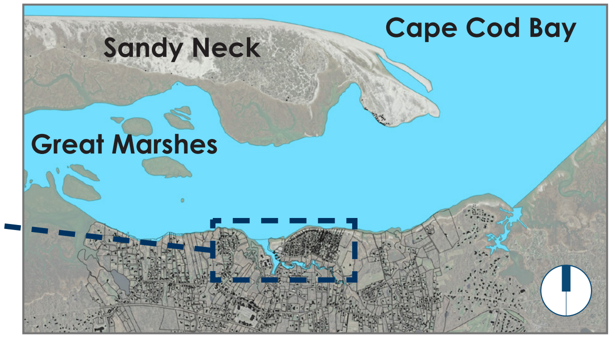
As waters rise, these developed areas are at risk of storm-related flooding events and even daily tidal inundation, making them increasingly vulnerable. On the ground, a pragmatic approach is to adapt the landscape and its infrastructure for these inevitable changes.

Adaptation is a proactive strategy, it makes interventions that mitigate and attenuate the impacts of climate change.

Our design exploration involved the assessment of the vulnerability, risk, opportunities, and challenges of key areas at Blish Point. We offer these proposals as ideas to stimulate and inform discussion rather than as *"fait accompli"* recommendations. These include the neighborhood off Commerce Road, the Harbor, and the commercial village area along Route 6A. These areas contain vulnerable residential neighborhoods and the commercial harbor that is an integral part of the fabric of Barnstable. One certainty is that the situation today will be different and more extreme in twenty years, forty years, eighty years, and beyond. This requires bold design and planning decisions that are phased over the next eighty years to maximize the protection of life, property, and the cultural heritage of Barnstable, while taking a "big-picture", long-term view of the extraordinary changes that must take place. Our team has explored various areas for phased retreat and resilient coastal defenses with these specific goals: establish a resiliency strategy for the community in the near and long-term future; initiate dynamic living-shoreline interventions that use the town's resources effectively and efficiently; look for new opportunities for enhancing the recreational, cultural, and economic conditions to make the best of an inevitably difficult situation; and create a positive proactive vision for the future instead of a risky reactive response like we've seen in other national emergency situations (Hurricanes Katrina 2008, Sandy 2013, and Florence and Michael 2018).

(Figure - 64) View across Barnstable Harbor from Blish Point.

(Figure - 65) Map of Cape Cod, showing Barnstable and Blish Point (Google Earth).



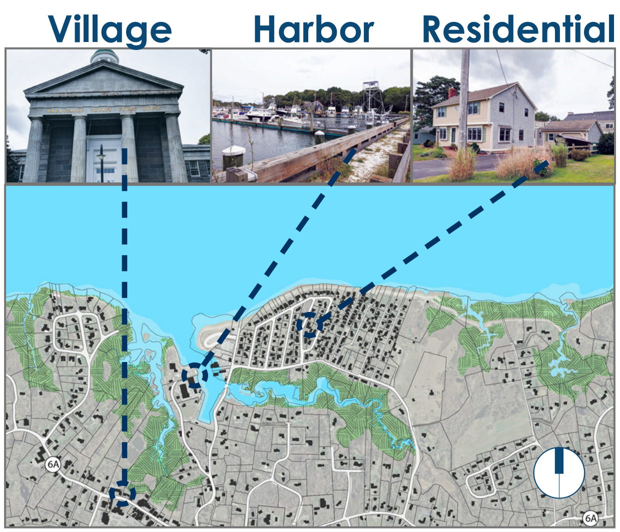
(Figure - 66) Map of the surrounding Blish Point context.

Location, Location, Location

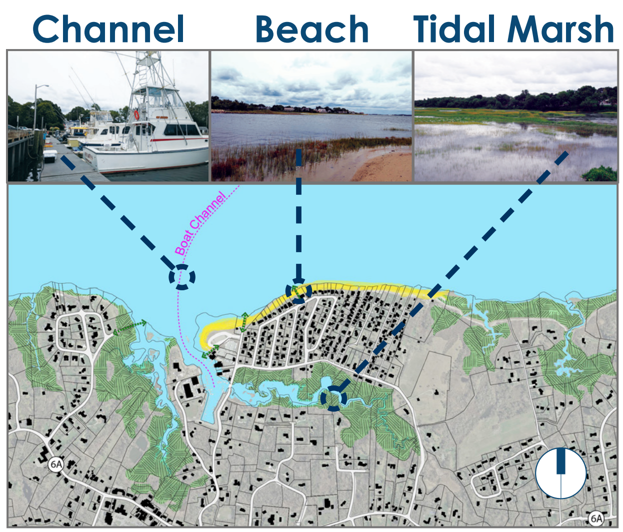
Blish Point and Barnstable Harbor are located on the northern coast of Barnstable (Figure-65), where daily low and high tides from Cape Cod Bay fluctuate between nine and eleven feet. At high tide , this water inundation feeds the resilient ecology of the Great Marshes, while testing the inevitable adaptability of Sandy Neck's natural dune systems, and in contrast, breaching the developed and inflexible landscape of Blish Point and Barnstable Harbor (Figure-66) (Town of Barnstable).

The developed landscape in and around Blish Point is one of the main reasons that preparing for extreme disturbances resulting from climate change is an uphill battle. Between 1940 and 2018, Blish Point's residential and commercial developments and infrastructure were built on an exposed area along Barnstable's coast on previous dune systems and filled tidal marsh (Figure-67). Developing on and destroying these natural systems has left this residential neighborhood along Commerce Road extremely vulnerable when storm surge and flooding inundation occurs.

Our team has analyzed and assessed the Commerce Road residential neighborhood, Barnstable Harbor, and Barnstable Village to understand what assets are most important to the greater community. We found Blish Point (similar to the rest of Cape Cod) to value their unique coastal landscape that offers numerous recreation and tourist opportunities for continued economic stability.



(Figure - 67) Map showing the main community zones within the Blish Point area.

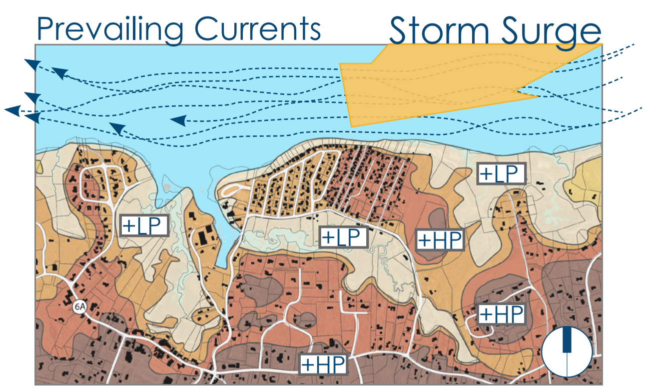


(Figure - 68) Map showing the main environmental zones within the Blish Point area.

Experiencing Disturbance Now

In order to protect Blish Point's unique coastal landscape, recreation and tourist opportunities, Barnstable Harbor, the coastline, and Barnstable Village must remain intact and able to flourish for years to come. Doing nothing to defend these assets will leave the town and Blish Point community vulnerable to the slow moving yet inevitable disaster that will affect many residents of Barnstable over the coming years. The all too-common "wait and see" mentality will cause the greatest level of loss and is, arguably, the town's worst option.

Blish Point must be proactive when preparing for the impacts of climate change, not just because it may occur in the future in another's lifetime. Blish Point must be proactive because it has already been greatly impacted (Figures-69, 70, 71, 72, 73, 74, and 75).



(Figure - 69) Elevation Map showing high points, low points, and the direction of prevailing currents and storm surge around Blish Point

(Figure - 70) 2018 1% Storm Simulation (NOAA): Two of these "1 every 100 year" storms occurred twice in 2018. This will become the 10% storm in 2100, making it ten times more likely to occur.

(Figure - 71) 2100 1% Storm Simulation (NOAA)

(Figure - 72) Near Main Street January 2018.

(Figure - 73) Blish Point flooding 2018.

(Figure - 74) Blish Point flooding 2018.

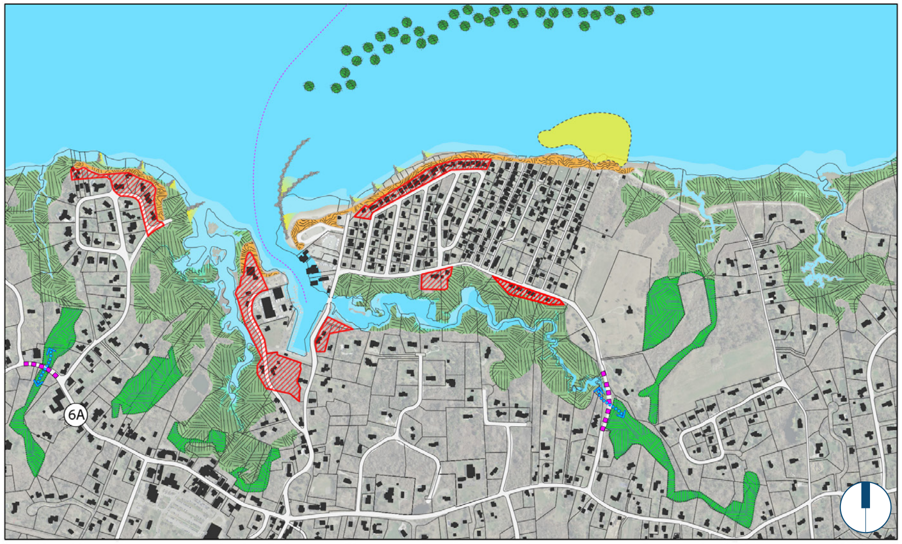
(Figure - 75) Blish Point flooding 2018.

Strategic Phasing: Overview

Creating a combined strategy to retreat from and defend Blish Point will take a phased approach. Phasing these two strategies will spread out the pain and hardship felt across the community over time, and more evenly distribute the costs and benefits within the larger community. Defensive strategies utilize living-shoreline systems. These systems mimic nature's form, processes, and resilience making them a promising option for the community to build resilience capacity to flourish within a context of an uncertain future with rising sea levels. Furthermore, the opportunities for living-shoreline systems to create secondary benefits and values such as recreation, wildlife habitat, shellfish cultivation, and commercial enterprises, beyond their primary function are invaluable to the future of Barnstable's coastline.

Deciding which strategy and defensive tactics to employ and where to deploy them require considerable evaluation, which is beyond the scope of this report. However, our design exploration involved the assessment of the vulnerability, risk, opportunities, and challenges of key areas at Blish Point. One certainty is that the situation today will be different and more extreme in the future. This requires bold design and planning decisions that are phased over the next eighty years to maximize the protection of life and the cultural heritage of Barnstable, while taking a " big-picture", long-term view of the extraordinary changes that must take place.

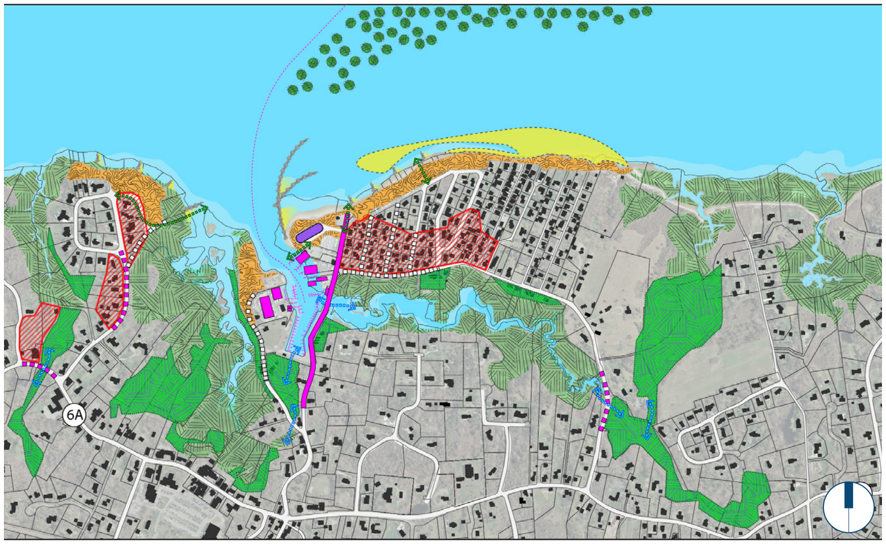
Establish: 2030



(Figure - 76) "Establish" is about introducing the groundwork for a resilient future for Blish Point and Barnstable Harbor. This strategy includes a balance of retreat and protection measures. Retreat during this phase aims to relocate the most exposed and at-risk residences and convert that space into natural defenses to protect the remaining interior neighborhood.

- Sand Motor- Dredge sediment from boat channel and deposit into feeder beach area extending the beach and providing sand that "feeds" the beach and dunes systems.
- Dune System and Living Shoreline- Deposit sediment for primary dune, establish supportive habitat for eel grass growth and estuarine species
- Tidal Marsh- establish beginning of tidal marsh expansion through managed growth resulting from strategic retreat.

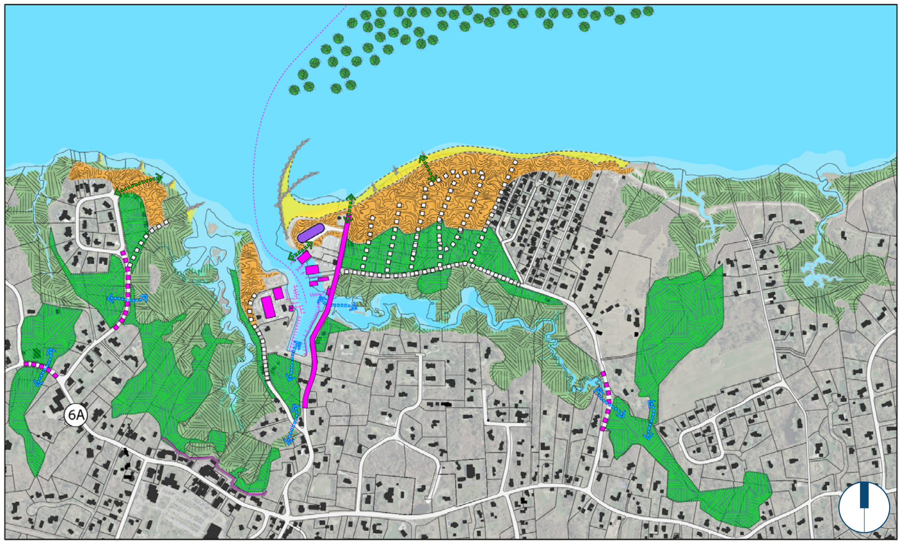
Strengthen: 2060



(Figure - 77) By 2060 the ecological tactics and interventions initiated in 2030 will have begun to mature. Early pilot programs for expanding dunes, tidal marshes, and decommissioning vulnerable neighborhoods are evaluated to determine what is working and what needs to be improved or strengthened. Continuing the process of retreat of vulnerable neighborhood homes will continue. As retreat areas open up more living protection tactics will be introduced there to strengthen the present and future resiliency of Blish Point and Barnstable Harbor.

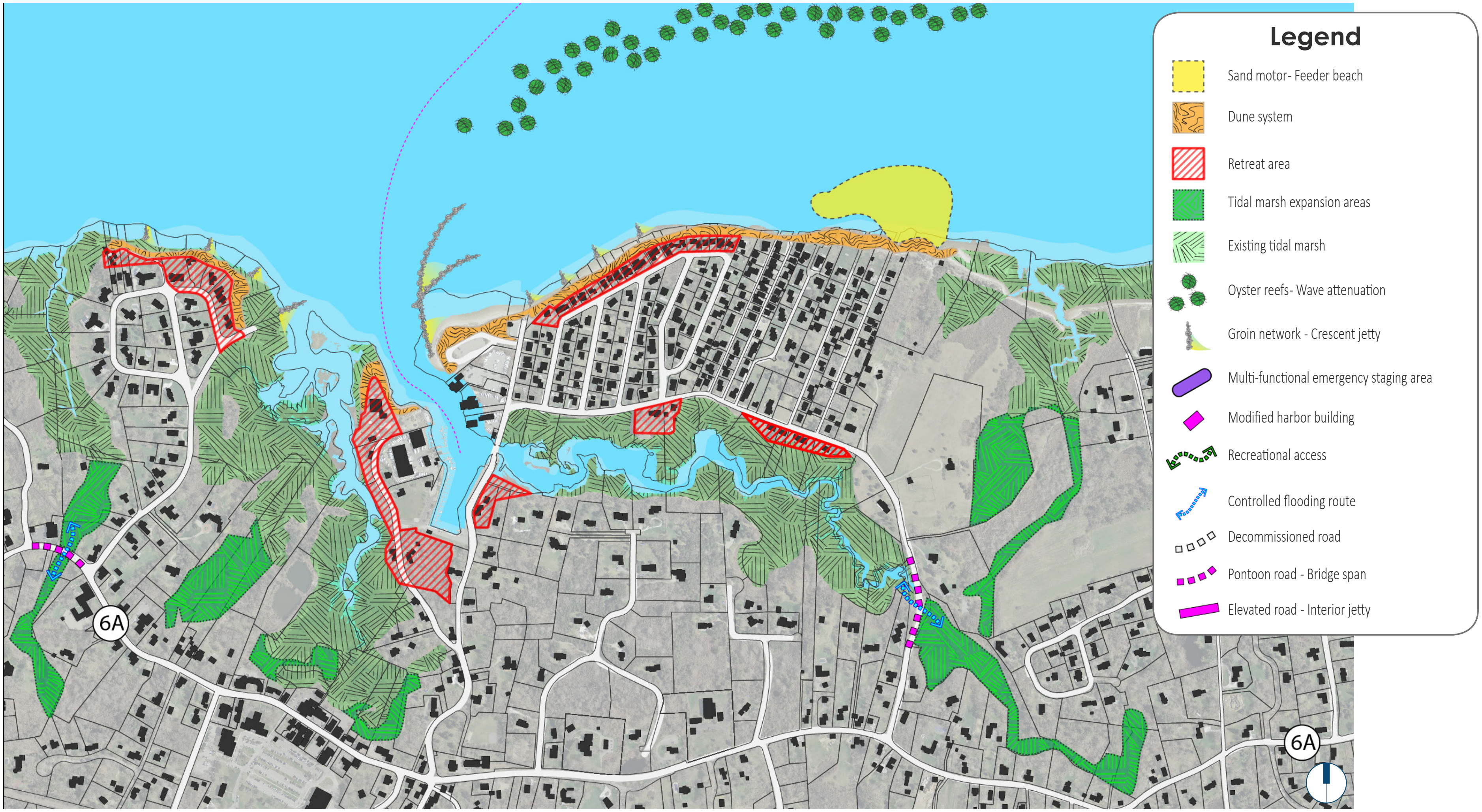
- Millway Road transformed into an Elevated Road that also provides an inland jetty mitigating the force of storm surge.
- A multi-functional dune-structure provides an emergency staging facility that also provides recreational access and cultural event space.
- Adapt the harbor for higher sea level and stronger storm surges.
- Ongoing expansion of dune and tidal marsh areas.
- Retreat from developed areas that are increasingly vulnerable to sea level rise.

Resilience: 2100

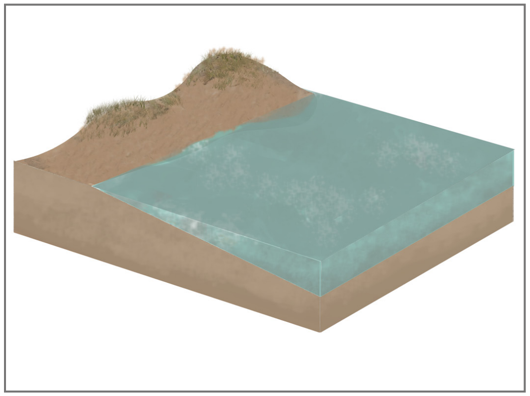


(Figure - 78) The overarching direction for Blish Point at 2100 and beyond is a robust integrated suite of restored natural systems and artificial interventions that mimic and employ natural processes to create a massive defensive system for the harbor and interior areas of Barnstable.

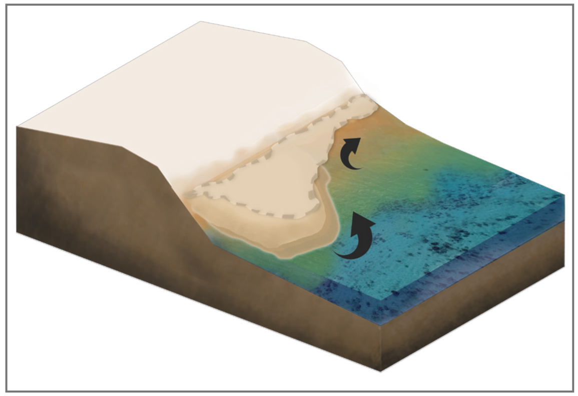
- The dune network, integrated with a multi-functional Dune-Structure has matured to create a "living" buffer from higher sea levels and storm surges.
- The Millway Road, now an elevated access way, reinforced with living retaining walls, functions as both vehicle access to the beach and an inland jetty.
- Vulnerable areas within the Commerce Road neighborhood have been transformed to either restored dunes or tidal marsh activated with recreational public boardwalks, water access points, and overlooks.



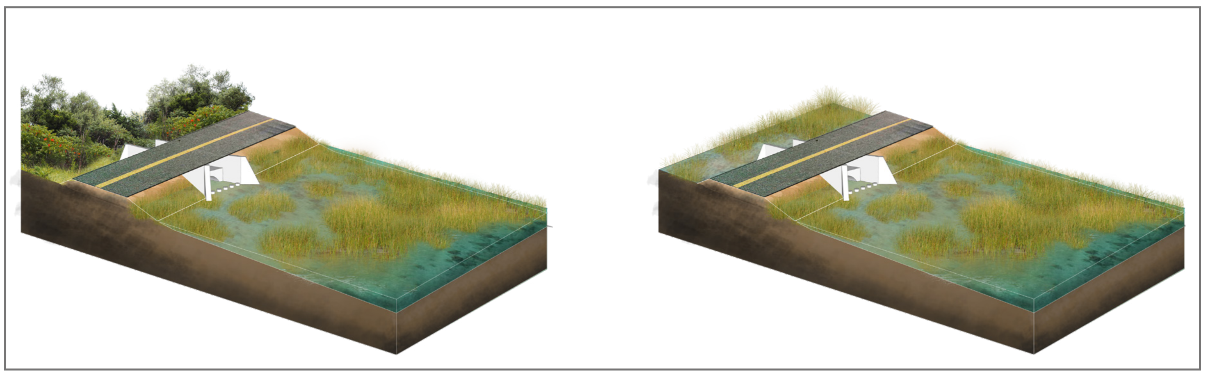
(Figure - 79) Establish: 2030



(Figure - 80) Dune System: Restoration of dunes by both rapid construction and more gradually by trapping drifting sand allowing dunes to build up naturally over time.



(Figure - 81) Sand-Motor: Dredged material from the boat channel is deposited up-current as a feeder beach.

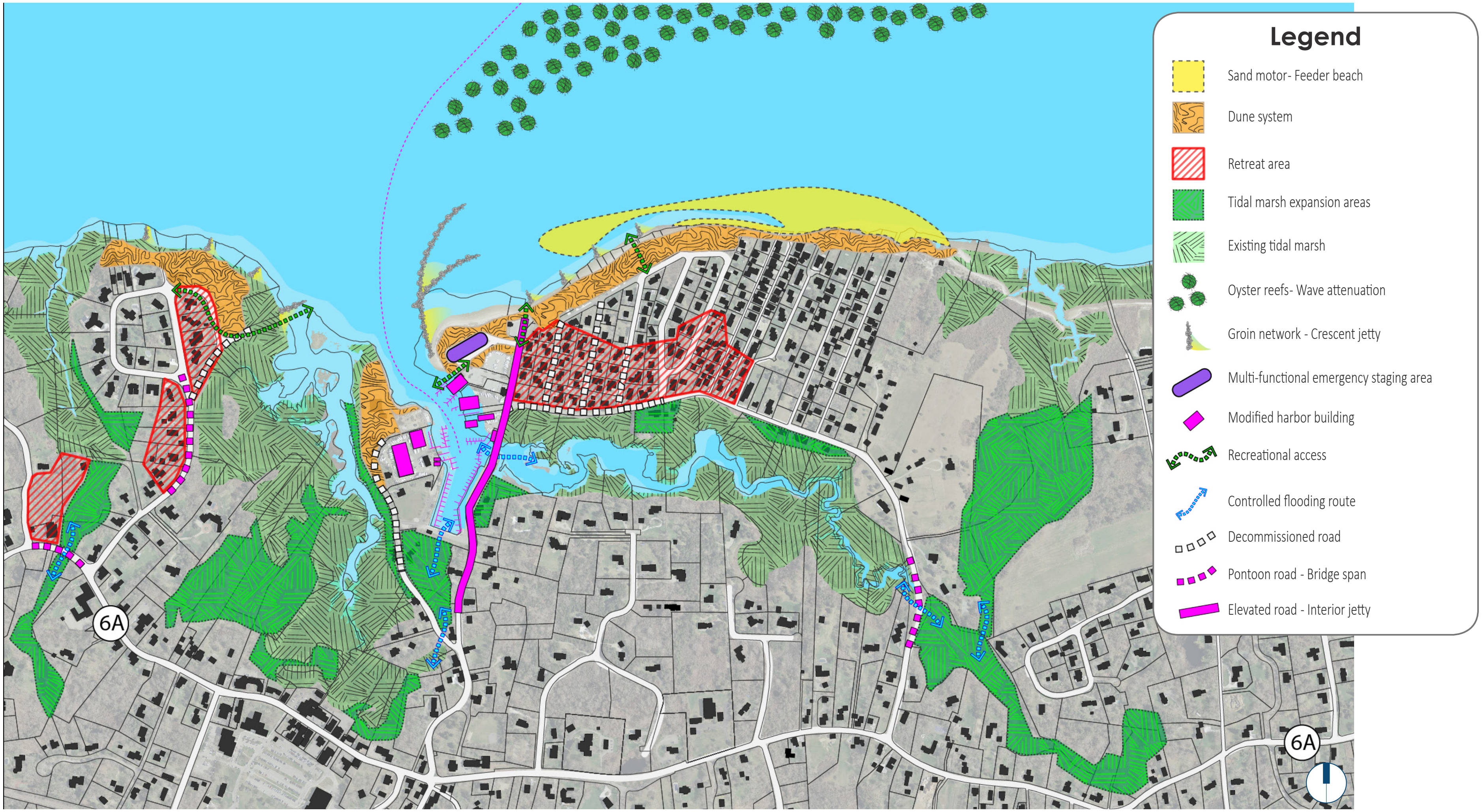


(Figure - 82) Tidal marsh expansion: Upland areas are prepared for inundation regulated by controlled flooding through flow-regulating culverts. Restoration facilitates the expansion of marsh systems over time. Restored and expanded marsh areas store flood water during storm events.

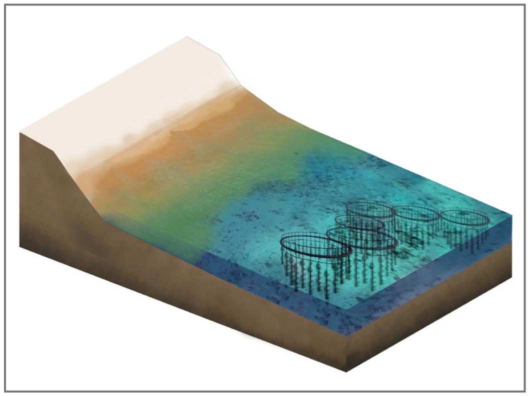
Establish: 2030

"Establish" is about introducing the groundwork for a resilient future for Blish Point and Barnstable Harbor. This includes a balance of retreat and protection measures. Retreat during this phase aims to relocate the most exposed and at-risk residences and convert that space into natural defenses to protect the interior neighborhood. During this phase, retreat is used as a necessary tool to decrease loss of life, money, property, and infrastructure in the future. Establishing protection tactics includes using a hybrid of bio-mimicry and engineered solutions to design dynamic systems that will address current issues as well as to plan for the uncertainty of climate change. The tactics proposed for 2030 will evolve over time to create valuable community resources for a new Blish Point:

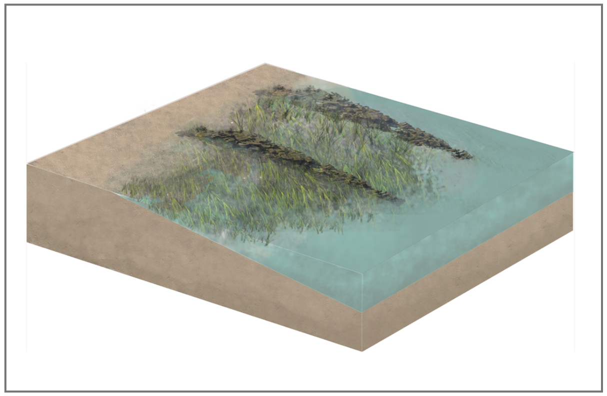
- Sand Motor- Dredge sediment from boat channel and deposit into feeder beach area extending the beach and providing sand that "feeds" the beach and dune system.
- Dune System and Living Shoreline- Deposit sediment for primary dune, establish supportive habitat for eel grass growth and estuarine species.
- Tidal Marsh- managed expansion of tidal marsh systems inland to harness the ecological service of flood storage. These areas are managed to become estuarine habitat for plants and animals. Estuarine regeneration occurs in tandem with strategic retreat from low lying and filled areas.



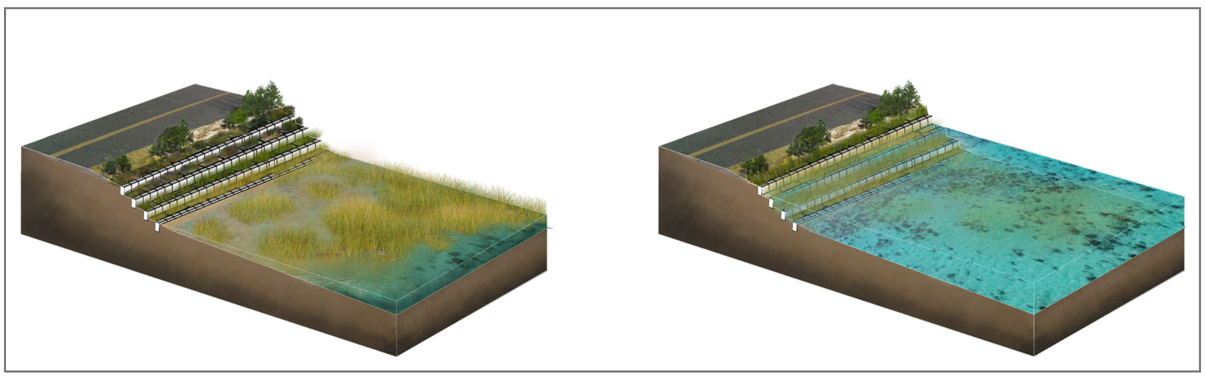
(Figure- 83) Strengthen: 2060



(Figure - 84) Wave attenuation: Wave energy is reduced by a floating oyster farm. The shellfish grow on a rope medium tethered outside the boat channel. The mass of these structures dissipates wave energy reducing the erosive forces of everyday waves on the shore.



(Figure - 85) Groin Network: A series of groins that intercept sediment carried by the longshore current to expand the beach outward and raise its elevation.

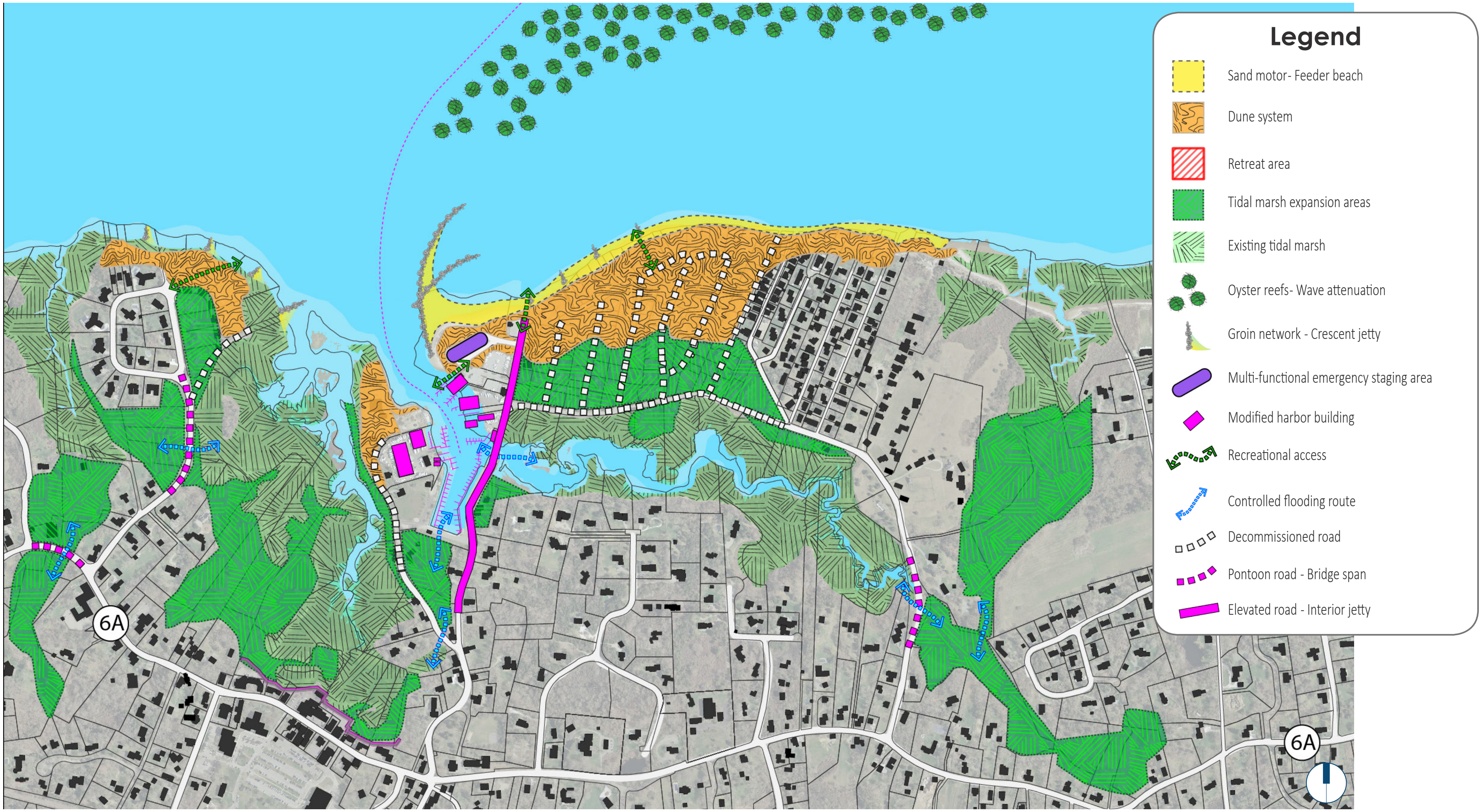


(Figure - 86) Elevated Road and Living Retaining Wall: An elevated road extends down Millway Road to maintain road access to the harbor and Blish Point beach. The elevated road also functions as an inland jetty to buffer the harbor from direct force of a storm surge. Living retaining walls reinforce and provide structure to the elevated road, the porous structure, such as gabions allows water in and out. Gabions are modular steel baskets that can be filled with large crushed stone, providing stability and porosity. The plants in the planted walls start as upland species that transition to tidal marsh species as sea level rises and the conditions change over time.

Strengthen: 2060

By 2060 the ecological tactics and interventions initiated in 2030 will have begun to mature. Early pilot programs for expanding dunes, tidal marshes, and decommissioning vulnerable neighborhoods are evaluated to determine what is working and what needs to be improved or strengthened. Continuing the process of retreat of vulnerable neighborhoods will continue. As retreat areas open up, more living protection tactics will be introduced there to strengthen the present and future resiliency of Blish Point and Barnstable Harbor.

- Millway Road transformed into an elevated road that also provides an inland jetty quelling the force of storm surge.
- A multi-functional Dune-Structure provides an emergency staging facility that also functions as a cultural event space with recreational access and infrastructure.
- Adapt the harbor for higher sea level and stronger storm surges.
- Ongoing expansion of dune and tidal marsh areas.
- Retreat from developed areas that are increasingly vulnerable to sea level rise.

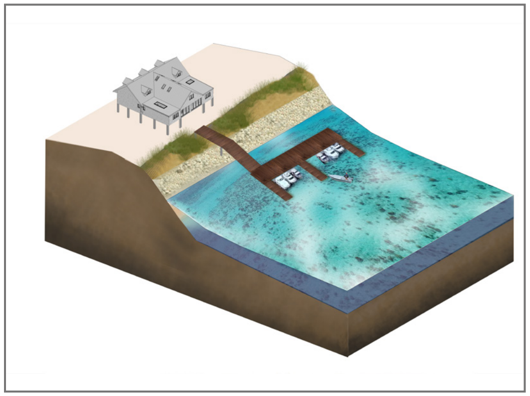


(Figure - 87) Resilience: 2100

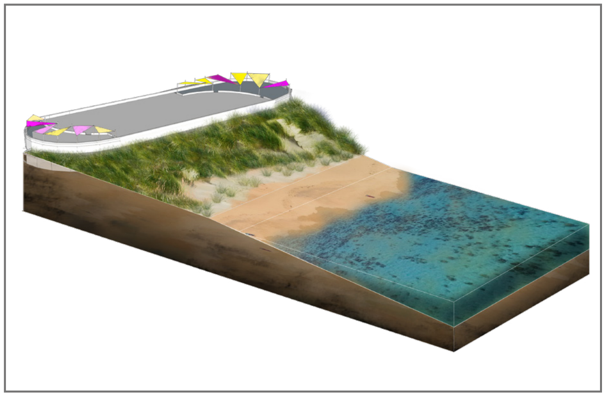
Resilience: 2100

The overarching direction for Blish Point by 2100 and beyond is a robust integrated suite of restored natural systems and artificial interventions that mimic and employ natural processes to create a massive defensive system for the harbor and interior areas of Barnstable.

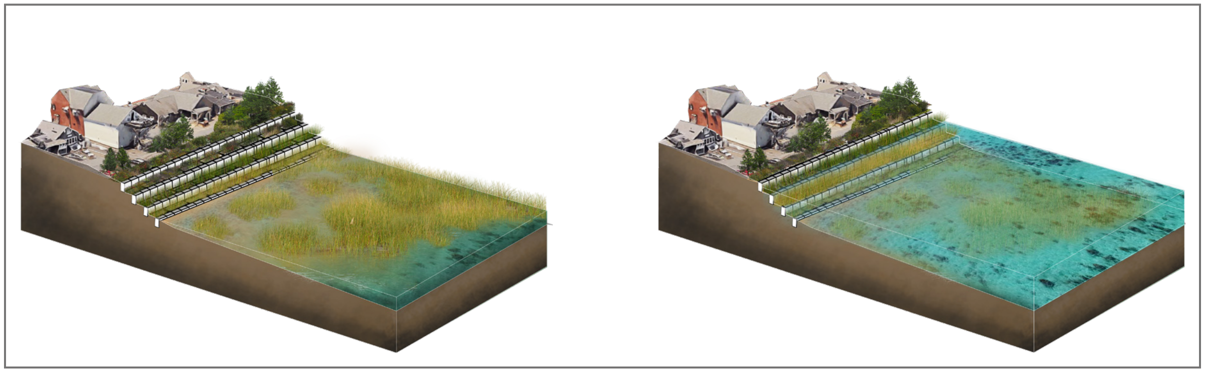
- Millway Road transformed into an elevated road that also provides an inland jetty quelling the force of storm surge.
- A multi-functional dune-structure provides an emergency staging facility that also functions as a cultural event space with recreational access and infrastructure.
- Adapt the harbor for higher sea level and stronger storm surges.
- Ongoing expansion of dune and tidal marsh areas.
- Retreat from developed areas that are increasingly vulnerable to sea level rise.



(Figure - 88) Harbor Modifications: Millway Road raised, harbor street parking converted to a float-ready structure, piers and docks adapted for rising sea level.



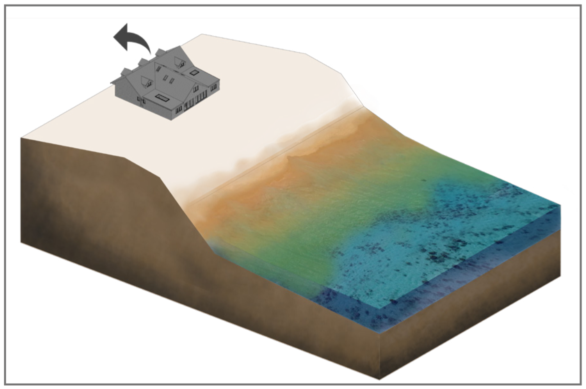
(Figure - 89) Dune-Structure: A multi-functional emergency staging area with sea, air, and mainland access. It is a flood ready-structure, built within the dune system at Blish Point that hides its mass. The structure allows for boat trailer parking on the ground floor, overflow parking on the second, and open space on the top floor that can host cultural events with sweeping views of the bay.



(Figure - 90) Living Retaining Wall: A living retaining wall is constructed along the marsh side of the Village Center to protect the village from flooding and allow the tidal marsh to expand as sea level rises. The wall structure and plants buffer the village from floodwaters. The structure is porous, similar to gabions that allow water in and out. The plants in the planted walls start as upland species that transition to tidal marsh species as sea level rises and the conditions change over time.

Strategic Rationale for Retreat

Decommissioning neighborhoods and infrastructure is controversial, requiring in-depth studies and a robust public process. Retreating from the ocean should be done strategically, focusing on the most vulnerable areas and those that can make room for living shoreline protection systems. We explored the costs and benefits of "stay in place"- not retreating, and compared them with the negative and positive implications of phased "retreat". We attempted to balance the realities of both options to create a framework for coastal resilience planning for Barnstable going forward (Stanford, 2018).



(Figure - 91) Retreat: the retreat tactic is chosen as part of the "Make Room" strategy. A strategic phasing of this tactic will ensure that this will gradually take place from 2030 to 2100 and beyond, giving due notice to residents to plan and prepare.

Retreat

- **Benefits of "Retreat"**- proactively decommission areas prone to flooding:
  - Ability to manage the strategic retreat process proactively, and develop planning tools and a comprehensive plan
  - A phased process gives due notice to affected properties to plan and prepare
  - Town can apply for state and federal funding to partially offset retreat and living shoreline costs
  - Living shoreline and other adaptations will protect other neighborhoods and villages
  - Town can phase-out infrastructure intentionally and efficiently
  - Barnstable will gain a new public shoreline
  - Ecological benefits of the living shoreline/dune system

- **Costs of "Retreat"**- proactively decommission areas prone to flooding:
  - Very substantial costs for vacating 30+- homes per phase
  - Short term emotional/financial cost for the affected properties

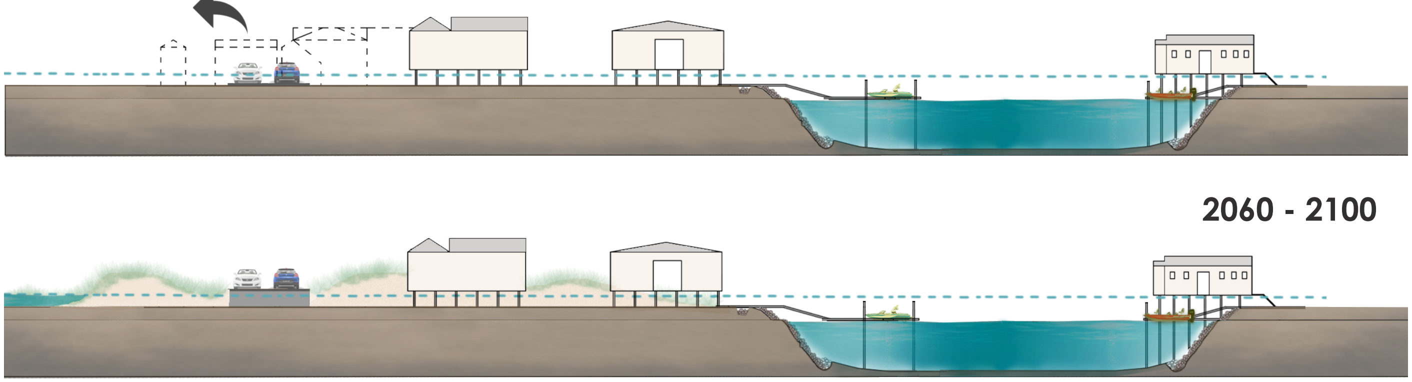
Stay in Place

- **Benefit of "Stay in Place"**- no planned/phased retreat:
  - Short-term emotional/financial relief for affected properties
  - Delay of the inevitable moving of houses (years to decades?)

- **Cost of "Stay in Place"**- no planned/phased retreat:
  - All homes eventually will be lost or moved
  - Crisis situation after major storms, potential loss of life
  - Response(s) will be in reactive, emergency mode
  - Town-managed infrastructure will ultimately be abandoned
  - Living shoreline strategy can't be implemented until space is made via strategic retreat
  - Can't apply for state/federal funding to subsidize retreat and living shoreline costs

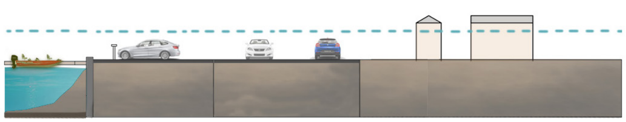
Based within the context of climate change and sea level rise, our observation is that the benefits of planned retreat outweigh the costs of "stay in place". Starting the process of "retreat" will involve a multi-pronged effort including governmental partnerships, assistance and compensation programs, and professional teams providing technical support.

Harbor Adaptation



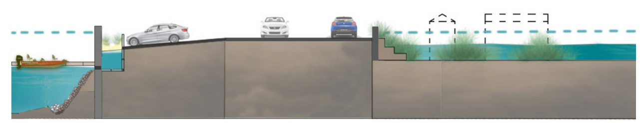
(Figure - 92) Through phases, the harbor will incorporate a set of strategies. In 2030, the "Establish" plan begins implementing strategic retreat to relocate from vulnerable areas in the harbor area. By 2060, structures that must stay in the harbor will be raised on piers to protect them from sea-level rise and storm surge. In place of the retreated structures, a dune system will be established to create a more resilient harbor area to protect not only itself but the inlands. Tidal marshes will also extend to reach the dunes of the harbor, creating yet another layer of protection. The harbor itself will have a stronger base, seawalls that are tucked into its edges, mitigating the force of storm surge.

2030



(Figure - 93) This diagram cuts from the bulkhead through Millway Street, showing the projected 1% storm elevation in 2030. Homes, the street and the parking lot are vulnerable to inundation. The area along the parking lot of the harbor will have to be adapted.

2060-2100

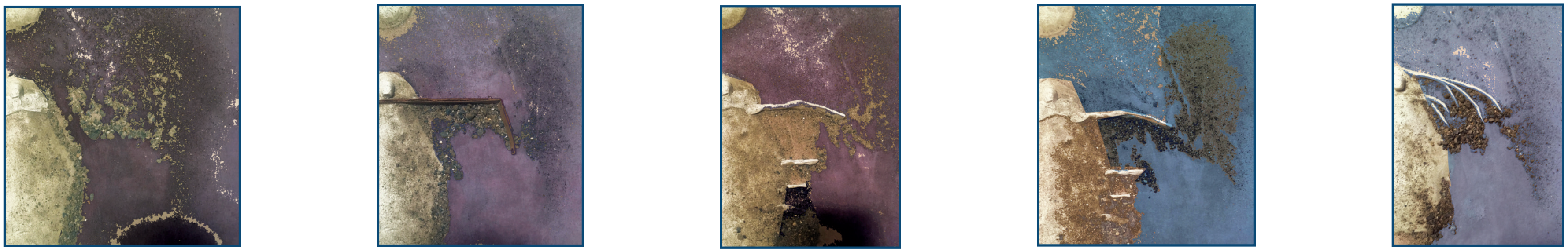


(Figure - 94) By 2060, the street and parking lot along the harbor will be raised, incorporating a living retaining wall that allows the salt marshes to expand and grow along it as shown. As well as that, the parking lot will allow the collection of storm water. The bulkhead will also be raised to ensure that storm water cannot surpass it.

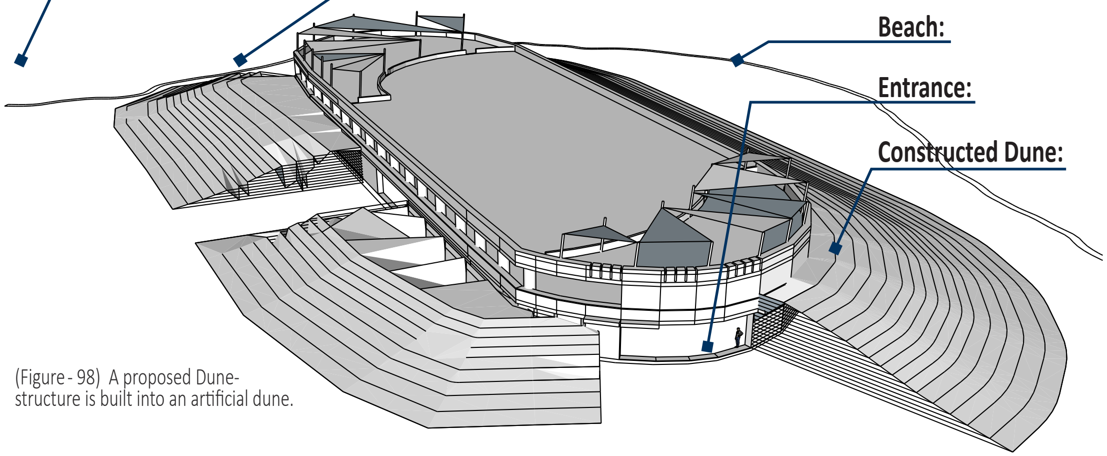
Crescent Jetty

(Figure - 95) A rendering showing what the crescent jetty will look like. Not only will it serve its functional purpose to trap fleeting sand from the sand motor (feeder beach) and deflecting storm surge from inundating the harbor, but it will also have hbitat and recreational functions.

(Figure - 96) On a stormy, rainy day, the crescent jetty will protect the harbor and the inlands by being itself exposed to the shore, by being flood resistant, and by absorbing the forces of the waves.



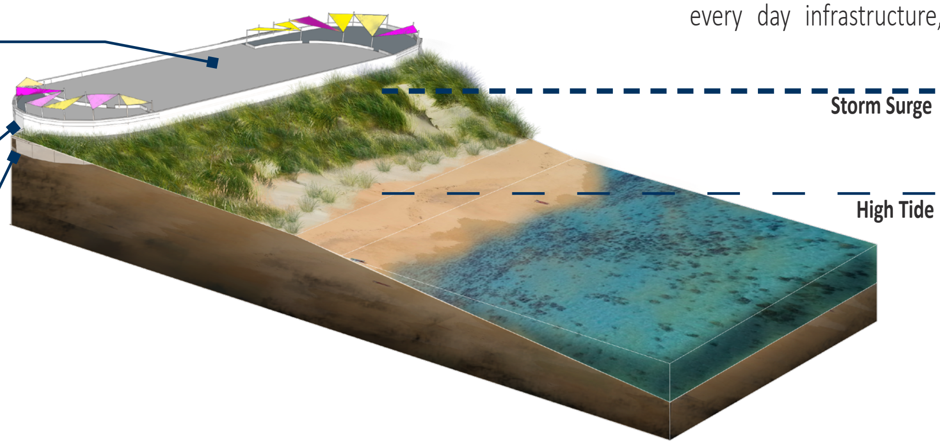
(Figure - 97) Experiments performed by this study with sand and clay helped to explore different shapes of jetties and how they would create the shape of the land and the recreational experience in the future. Although a straight linear jetty serves the function of keeping sediment out of the active harbor way just as the crescent shape does, it doesn't maintain a natural-appearing coastline and is a less interesting walking experience (De Zan Motor).



(Figure - 98) A proposed Dune-structure is built into an artificial dune.

Multi-functional Dune-Structure

The proposed dune-structure is built into a artificially constructed dune that obscures the ground floor and part of the second floor. The structure supports the aeolian accumulation of sand that forms and moves dunes over time. The purpose is to be more attractive but also integrate with a critical natural system- the dune. It offers a multi-functional amenity providing recreational access and a commercial asset to the harbor on sunny days, while also creating an emergency facility during storms. This facility's operation and purpose is fully integrated with Barnstable's emergency management plan. When necessary it can receive and deploy material and help by air, sea, and land. During the summer season, most people will enjoy the dune-structure as their access to the boat ramp or the location of an open-air concert. The Dune-structure provides cultural event space, every day infrastructure, and emergency preparedness.



(Figure - 99) Designed to withstand powerful storms, combining 'grey-infractructure' with dune restoration.

Simulated 1% Storm event 2100

(Figure - 100) Above: By 2100, we envision a more resilient Blish Point and Barnstable Harbor Area, one that when flooded, is able to absorb the shock from a cataclysmic event, and that can bounce back from future anticipated coastal disasters.

(Figure - 101) Opposite: On typical summer days the adaptations for Blish Point enhance recreational assets and allow Barnstable residents and visitors to continue to enjoy the area. The application of the "living shoreline" strategy protects the Point, and also promotes and enhances the beach, the ocean view, access to recreation areas including the Crescent Jetty extending into the bay.

Moving Forward

Throughout our study, we acknowledged that hard engineering solutions such as flood walls that may protect Blish Point will not only be costly, Summer Season 2100

but will also possibly take away the one thing people at Blish Point enjoy the most, the beach. Our vision for Barnstable is a resilient yet a dynamic one. By using natural systems to provide the best balance of cost to benefit, we create an ecosystem that can adapt to climate change and coastal hazards, in the present and in the future. While sometimes hard infrastructure is the solution, we chose to incorporate multi-functional infrastructure that promotes ecological functions and provides new opportunities and values. While the prediction models from the IPCC and others propose an increasingly grim future, we believe proactive planning is better than "wait and see" - and could result in an environmental healthy, sustainable and resilient future for Blish Point.

Resilient Hyannis Harbor:
A Museum Without Walls

Yincheng Zhang & Mitch Johnson

(Figure - 102) Hyannis Harbor Waterfront.

Site Introduction

Hyannis Harbor is one of the region's most important assets with great historic, cultural, economic and transportation importance, not only for the Town of Barnstable but for the entire Cape Cod region. These important assets contribute to the viability and visibility of Hyannis as a distinctive place on Cape Cod, which are highly vulnerable to coastal flooding. Here we explore a suite of strategies to build resilience capacity for Hyannis Harbor.

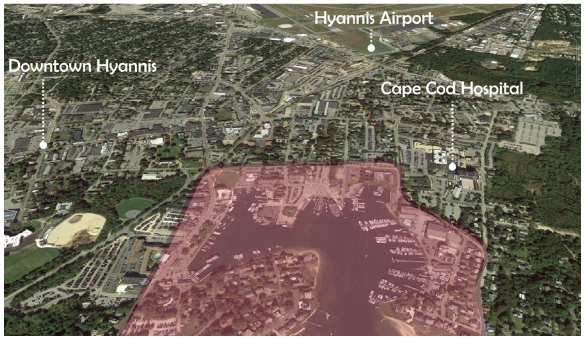
Existing Conditions

Hyannis Harbor is home to two ferry terminals which provide service to Nantucket and Martha's Vineyard. Other land uses around the harbor include commercial, residential, cultural and public parks. Commercial uses include hotels, restaurants, and private marinas. There are also several residential neighborhoods in the harbor area. Public, cultural and institutional uses include the Cape Cod Maritime Museum, Bismore Park and Aselton Park. In Bismore Park there are seasonal artist sheds that function as affordable studio and gallery space for local artists next to the Hy-Line ferry terminal. Two ferry terminals, one operated by the public Steamship Authority and another by the private Hy-Line Cruises, are located on the waterfront.

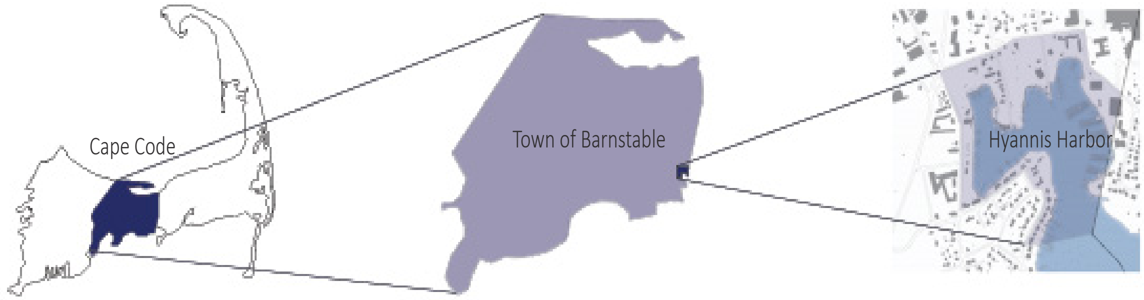
A significant amount of land around the harbor is currently dedicated to parking to accommodate seasonal demand, but then is largely empty during the rest of the year. A large proportion of the harbor edge features man-made structures such as bulkheads and seawalls.

Hyannis Harbor is set back and sheltered from Nantucket Sound. However, the harbor faces significant flooding and water quality challenges. The substantial amounts of impervious surfaces that surround the harbor cause large amounts of sediments and nutrients such as fertilizers and oil to run off directly into the Harbor.

There are a number of storm drainage pipes from the airport and the surrounding areas that discharge directly into the harbor. With a large amount of development along the harbor, flooding has already become a concern with seasonal storms waters often rising above the bulkheads and flooding key parts of the harbor. Coastal and stormwater-related flooding are expected to become more severe and frequent as a result of expected climate change.



(Figure - 104) Surroundings of Hyannis Harbor.



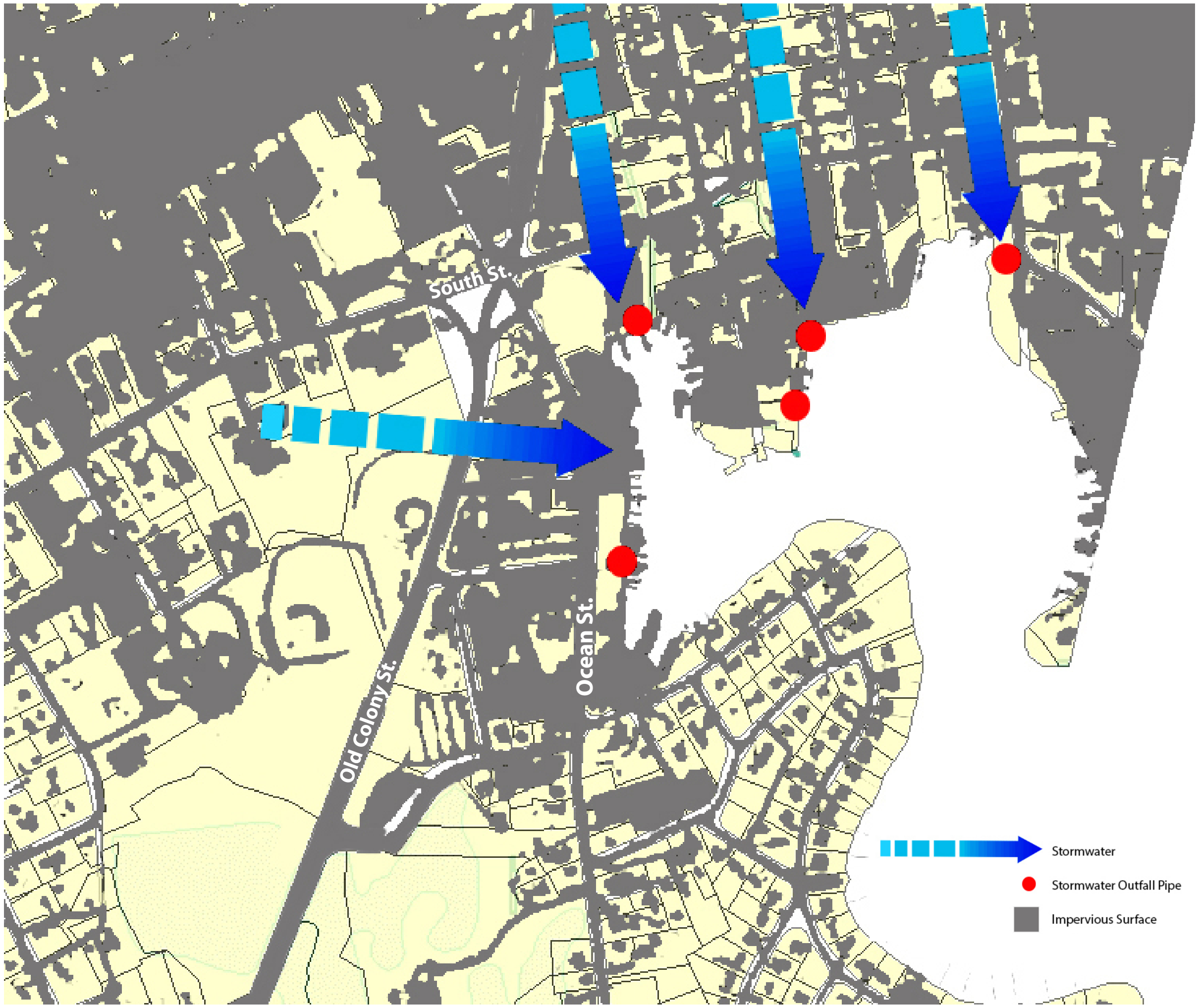
(Figure - 103) Location of Hyannis Harbor.

Problem 1: Water Quality

Water quality is one of the major issues in Hyannis Harbor. There are large areas of impervious surface including the downtown urban area and parking lot that drain into the harbor from outfall pipes scattered around the harbor, In addition to the underground pipe system, the runoff flow from adjacent and nearby impervious surfaces also bring pollution and debris from upland which includes oil from downtown Hyannis and Barnstable Municipal Airport.

(Figure - 105) Large pavement areas are found around harbor.

(Figure - 106) Stormwater outfall pipe in harbor.



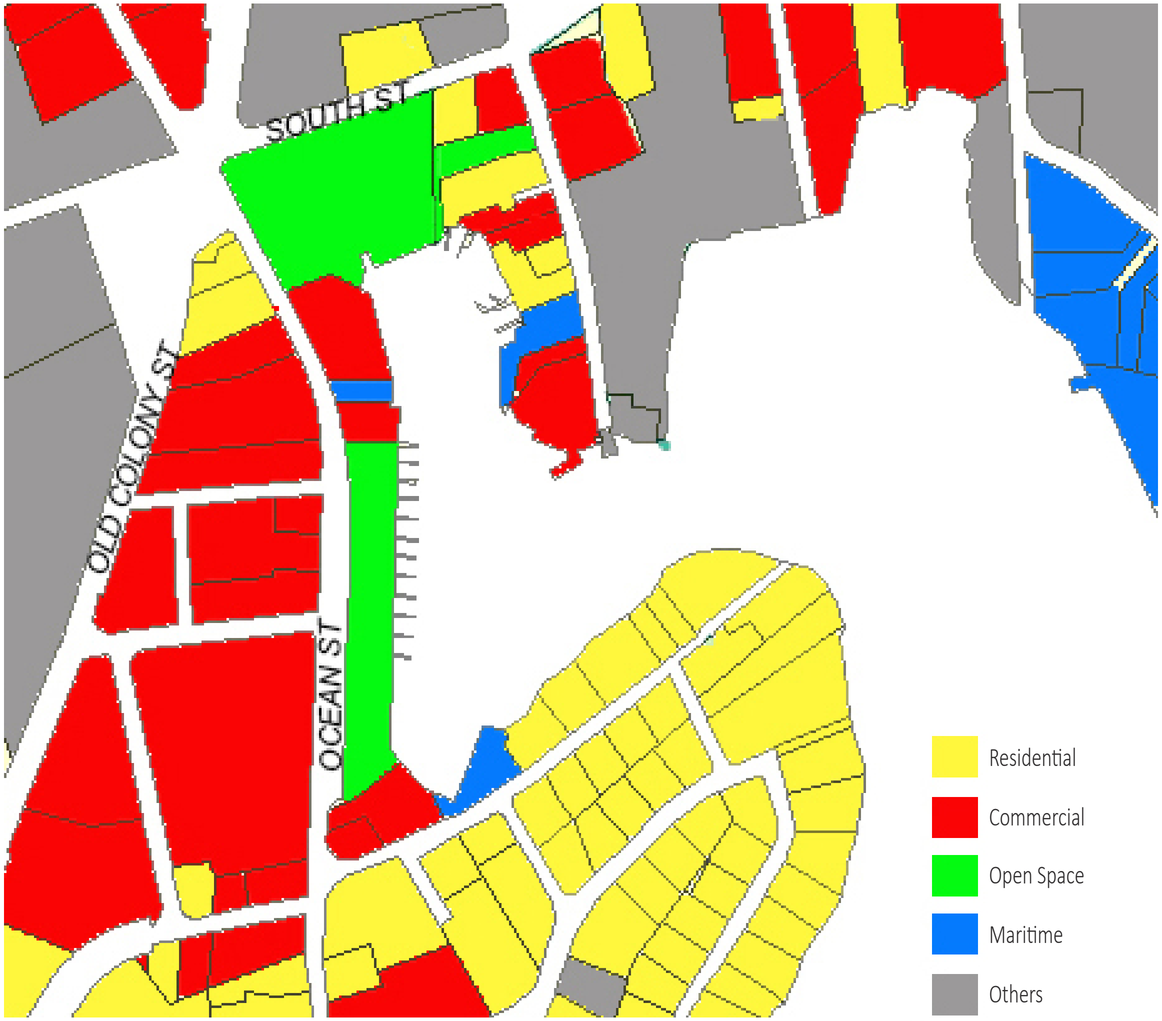
(Figure - 107) Impervious Surface and Stormwater Outfall Pipe Distribution Map.

Problem 2:
Maintaining a Working Harbor

Hyannis Harbor is a major and busy harbor on Cape Cod. Economic and maritime uses include commercial boats, private boats, pleasure boats, and fishing boats. The harbor is also the center of tourism in Cape Cod. Residents and tourists enjoy taking a walk here. The challenge is to redesign the harbor to be resilient while maintaining a dynamic, working harbor.

(Figure - 108) Bismore Park.

(Figure - 109) Hyannis Hy-Line Ferry.



(Figure - 110) Land Use Map in Hyannis Harbor. Source: MassGIS

Problem 3: Flooding

The 3rd issue facing Hyannis Harbor is flooding. Most public spaces are only slightly above mean sea level which makes it highly exposed to future sea level rise and flooding. Figure 113 shows the future sea level rise inundation area in the year 2100. The 1st below image shows the 1% possibility of flooding in 2100. Most areas of the harbor will be submerged. In 2007, the Bismore Park was flooded by a storm surge, seriously impact the functioning of the harbor.

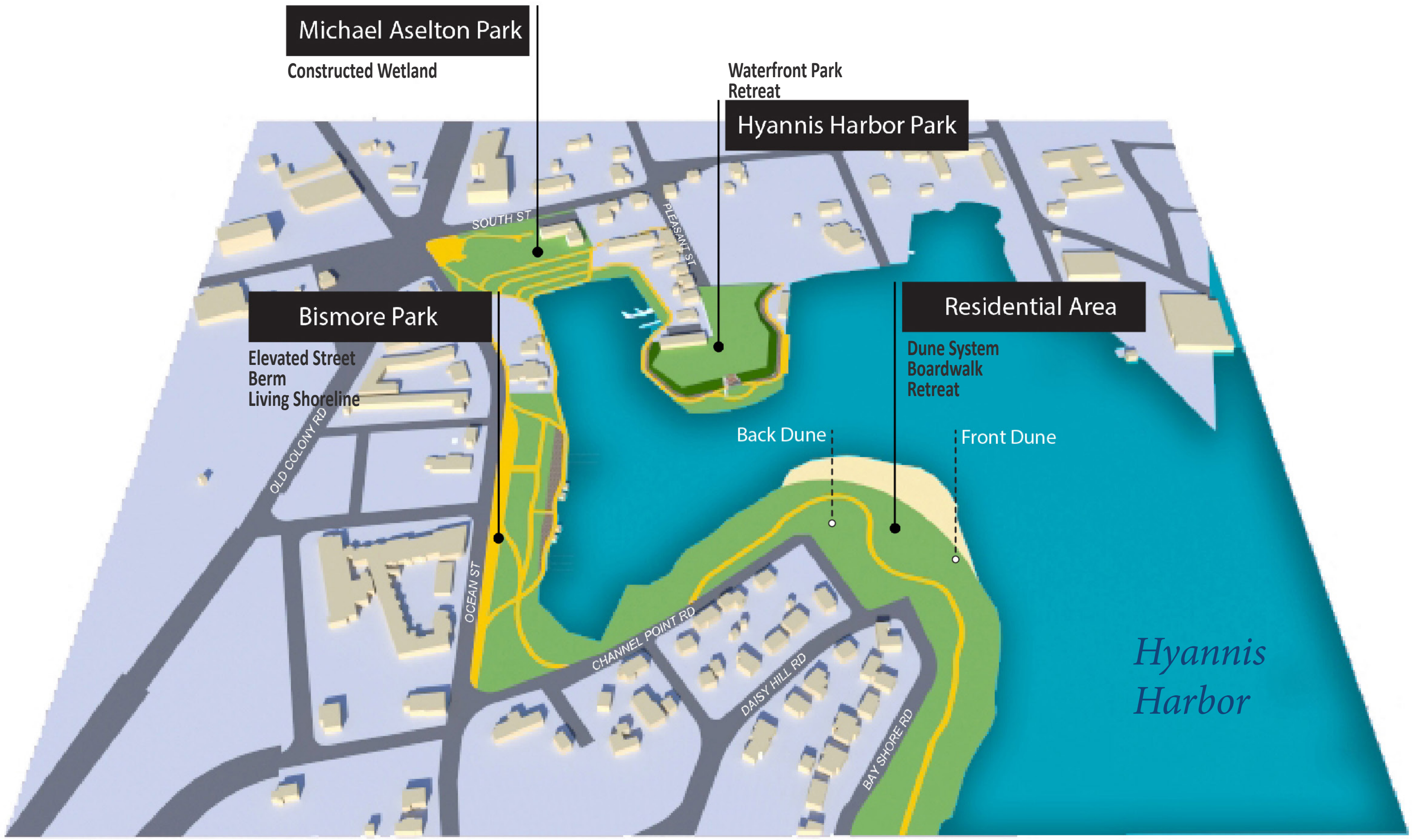
(Figure - 111) 1% Storm in 2100.
Source: National Oceanic and Atmospheric Administration (NOAA)

(Figure - 112) Storm Surge in 2017.

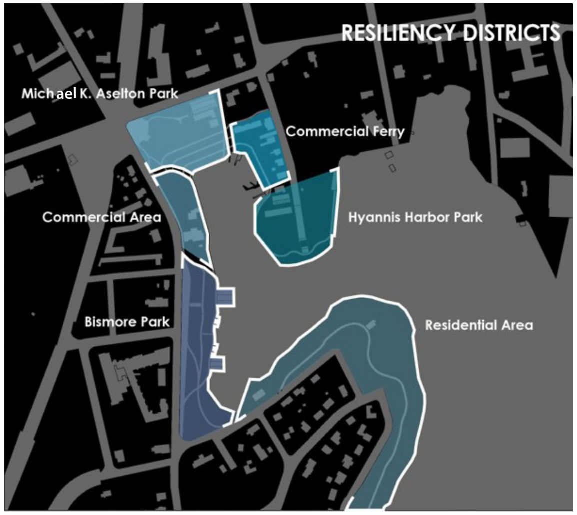
(Figure - 113) Sea Level Rise and year 2100 Flood Scenarios.

Hyannis Harbor

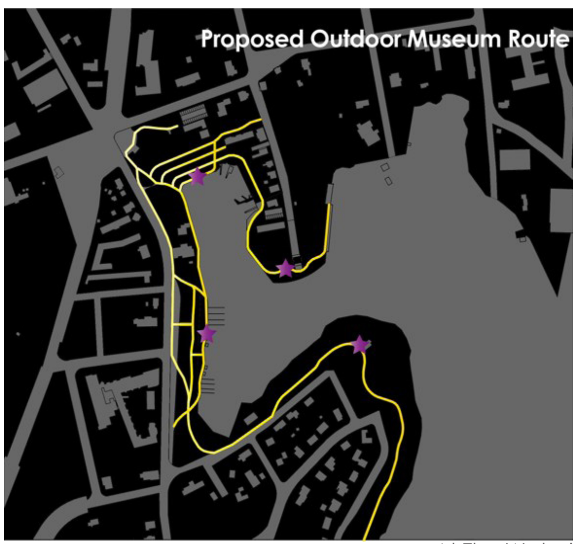
Proposed Hyannis Harbor and Adaptation Strategy



(Figure - 114) Proposed Hyannis Harbor and Adaptation Strategy Map.



(Figure - 115) Resilliency Districts.



(Figure - 116) Proposed Outdoor Museum Route.

Proposed Design Concept

Our proposal "Resilient Hyannis Harbor" addresses the issues discussed above and creates an interpretive "museum without walls", a model for integrating: education, social activity, and resilient infrastructure into the urban harbor front in Barnstable. The existing edges made of bulkheads and concrete give access to the harbor but creates a lifeless edge. The waterfront is highly exposed to flooding and water quality issues. Our proposal introduces new resilient infrastructure that brings the health of the water and surrounding landscape into balance with the working harbor and introduces a new collection of outdoor destinations. These outdoor destinations include exhibition space that feature "gates" and signage interpreting the history of the maritime harbor as well as the resilient landscapes that support it.

Bismore Park

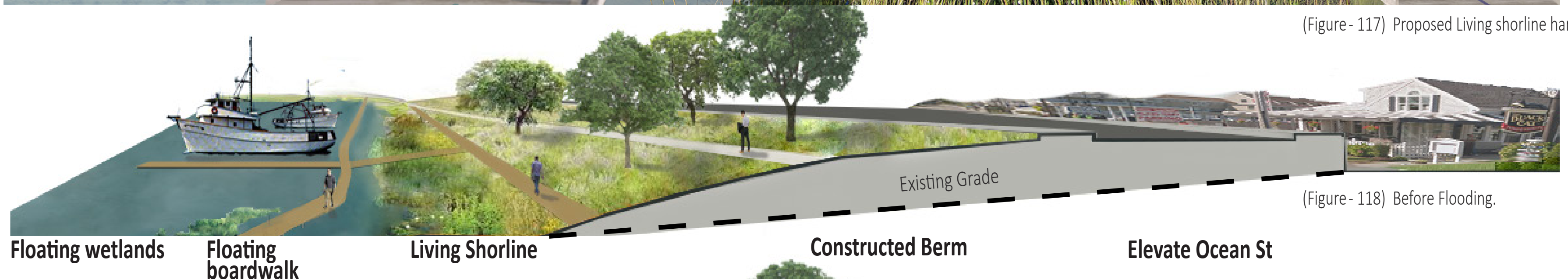
In a 10 % annual chance flood in 2100, flooding at Bismore Park could flow over Ocean Street and into the adjacent businesses. Our proposal creates a berm that elevates the waterfront edge of Bismore Park and Ocean Street by 11 feet to offer a longer-term solution for sea level rise and flooding in the harbor area. During a coastal storm, the park can flood, adding storage capacity to the harbor and acting as protection for nearby homes and businesses. The design of such improvements also enhances Bismore Park's recreational, aesthetic, and ecological value. Ocean Street would be raised to contain the 1% annual flood level in 2100. This elevation would be met with pathways along a terraced landscape leading down to the water's edge. The existing bulkheads at the water's edge would be replaced with a living shoreline featuring native plants . This living shoreline would be able to adapt and adjust to sea level rise and flooding. A floating boardwalk along the harbor edge adjusts to sea level rise while allowing free access to the harbor front for the majority of the time when water levels are "normal". Floating wetlands around the boardwalk will provide habitat for microorganisms to help clean and filter the harbor waters.

Hybrid boardwalk

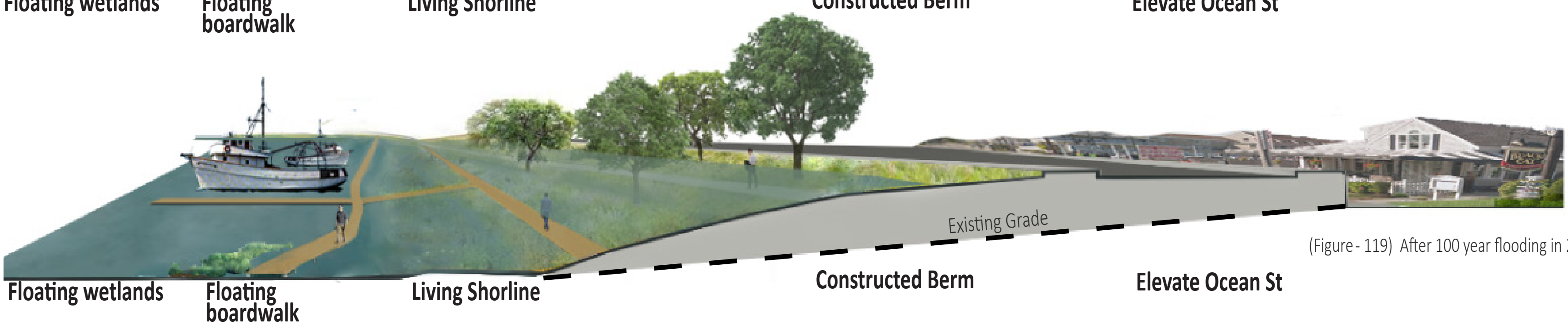
The residential neighborhood on Bar Harbor Street to the south is presently one of the most exposed areas of Hyannis harbor. With a 2.75' sea level rise in 2100, a 10% flood would impact most of the neighborhood. The most vulnerable properties are directly on the shoreline. We recommend moving these properties with some form of compensation to enable these residents to relocate to safe locations. We propose replacing those houses with a hybrid dune-boardwalk structure. The new boardwalk provides an infrastructure that creates protection from future flooding while also serving as a habitat area for beach wildlife and an attraction for residents and visitors. The design is a combination of manmade and natural systems with a concrete bulkhead built into the dune and covered with native grasses that are protected by dune fences. A fringe marsh is proposed along the beach to better stabilize the dune edge and shoreline.

Bismore Park

(Figure - 117) Proposed Living shorline harbor walk.



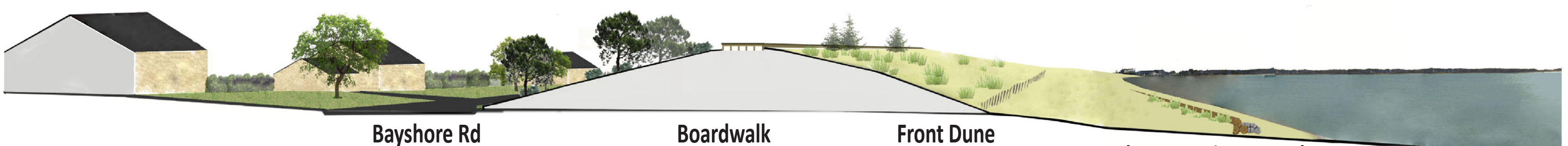
(Figure - 118) Before Flooding.



(Figure - 119) After 100 year flooding in 2100.

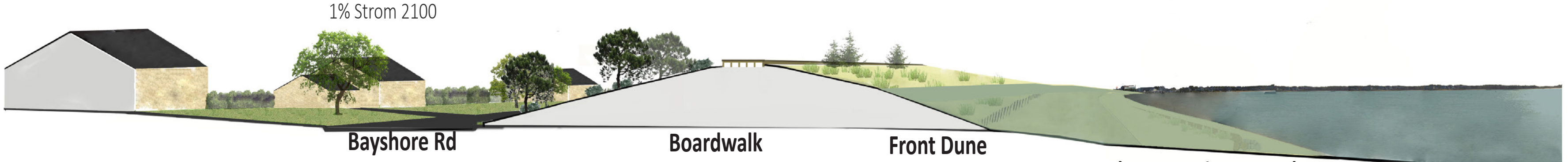
Hybrid Boardwalk

(Figure - 120) Proposed Hybrid Boardwalk



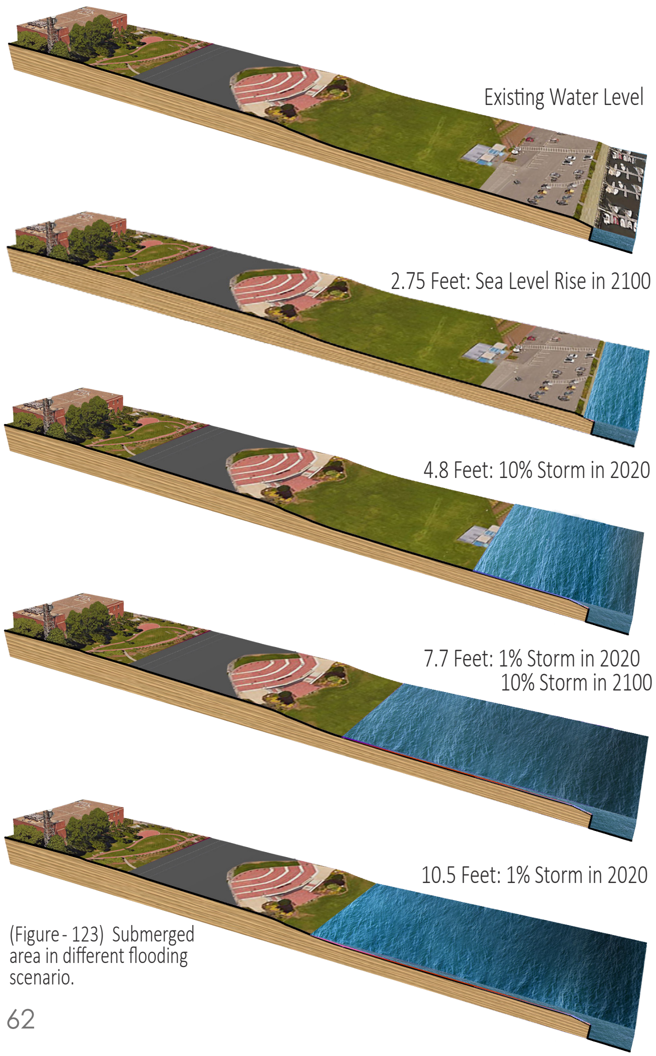
(Figure - 121) Proposed Hybrid Boardwalk section

1% Strom 2100



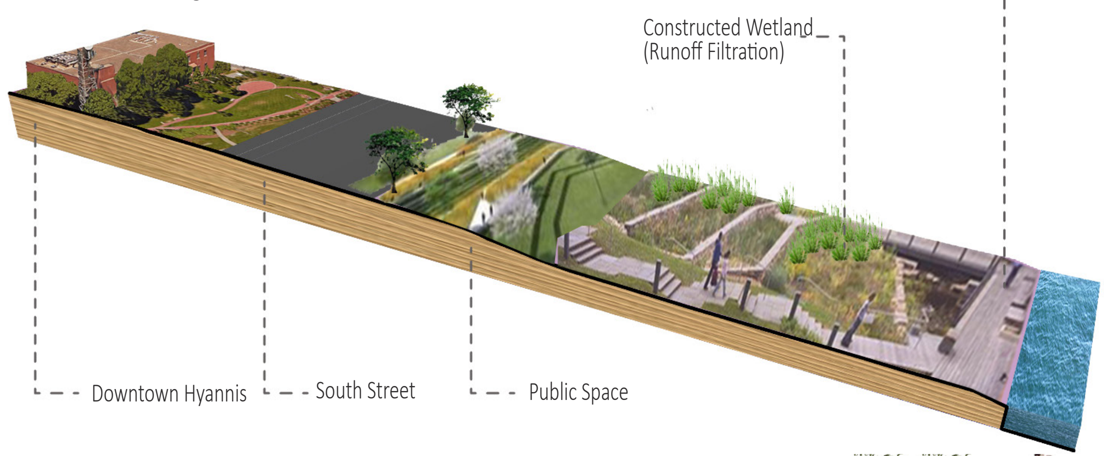
(Figure - 122) After 100 year flooding in 2100

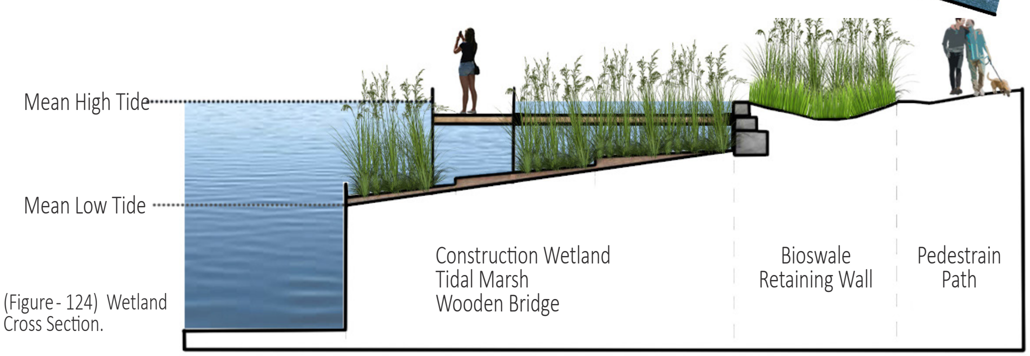
Michael Aselton Park



(Figure - 123) Submerged area in different flooding scenario.

Hyannis Harbor is called the "Gateway to the Sea". One of the nicest areas along the harbor is a small park named after Michael Aselton, a police officer that died in the line of duty in 1983. The park was officially dedicated in 1996 and includes walking trails, benches and some lovely views of the harbor. Importantly, the park has the steepest topography along the harbor. The steep topography brings concentrated stormwater from downtown Hyannis directly emptying into the harbor at the park's edge. The town has already implemented a subsurface wetland system at the maritime museum to mitigate and infiltrate the stormwater before discharging into the harbor. The redesign of the park proposes additional stormwater treatment facilities by removing parking and lawns to create treatment wetlands comprised of native plant species. These treatment wetlands will improve water quality in the harbor and add visual interest. These wetlands will be another "station" of the museum without walls – here interpreting and demonstrating how green infrastructure can improve water quality in the harbor.



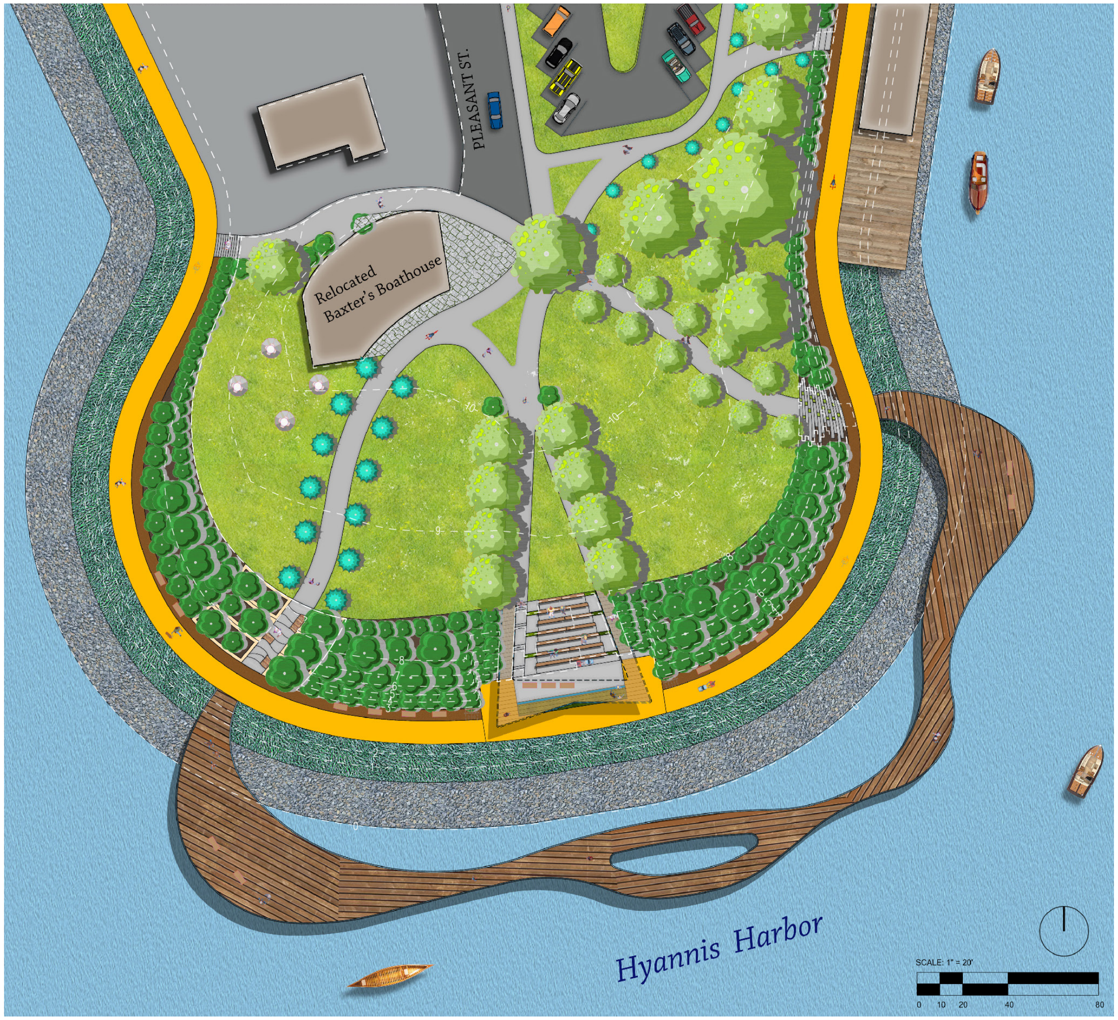


(Figure - 124) Wetland Cross Section.

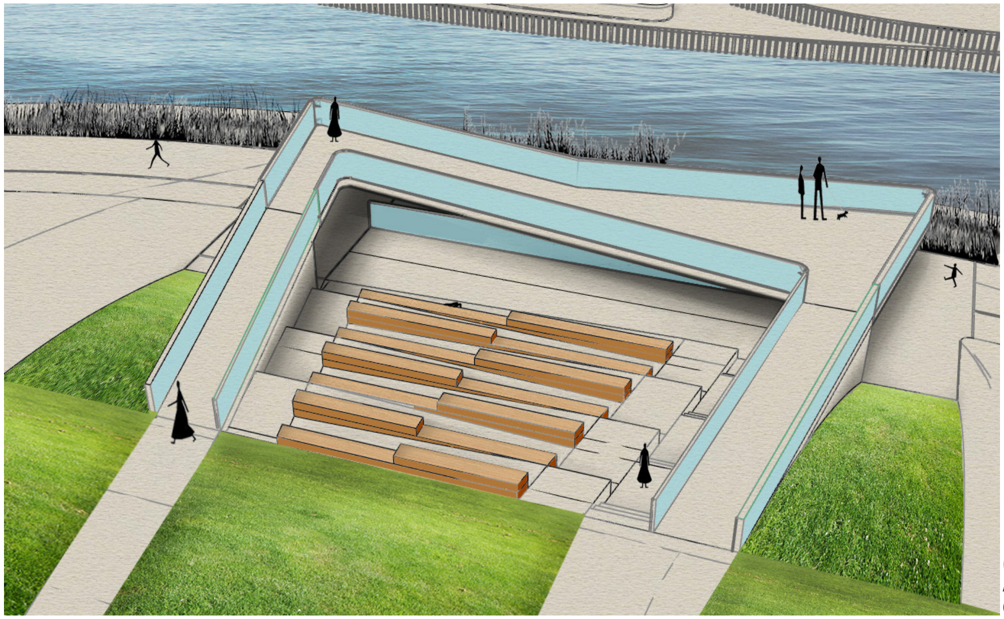
Hyannis Harbor Park

Hyannis Harbor Park is presently a small green space at the end of Pleasant Street, surrounded by two large parking lots. The land is a peninsula that extends into the harbor that provides superb views of the waterfront. This area is under five feet elevation above sea level, with high exposure to future flooding. Our recommendation is to move the Baxter's Boathouse restaurant to a higher elevation,further uphill on Pleasant Street. The proposal is to expand the Hyannis Harbor Park and remove the two parking lots. It's the proper place to build a park with a living shoreline,tidal wetland plant species, bike and walking trails and a fishing spot for both tourists and residents to fully enjoy the waterfront.

(Figure - 125) Existing Hyannis Harbor Park



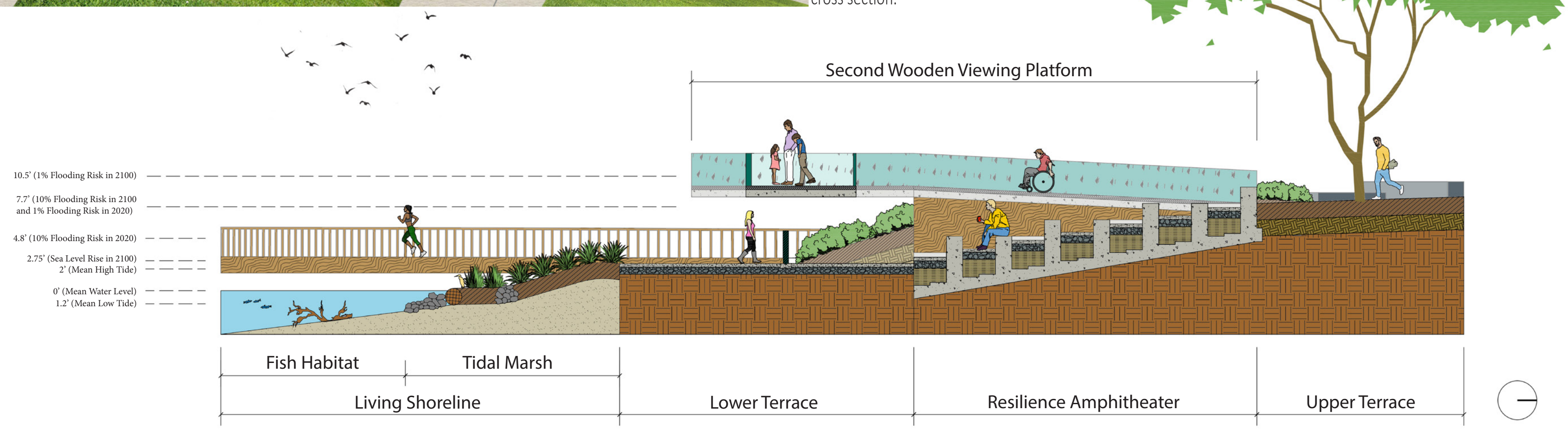
(Figure - 126) Proposed Hyannis Harbor Park



The proposed amphitheater and 2rd floor wooden platform together demonstrate the different water level heights on the front of the amphitheater. The benchmarks are 2.75 feet, 5 feet, 7.7 feet, 10.5 feet from the existing sea level elevation. The amphitheater is also a berm that creates two terraces with different elevations. Giving people direct experience of future flood senarios. Waterfront park is resilient because evacuation is not and issue and the structures will not be damaged by floods. The amphitheater can hold a variety of town events as a public and tourist space and as a focal point where people can gather and enjoy the spectacular views of the harbor.

(Figure - 127) Left:Proposed Amphitheater.

(Figure - 128) Below: Amphitheater and platform cross section.



Conclusion

This proposal creates a new resilient landscape for Hyannis Harbor front addresses the issues of water quality and flooding while keep the harbor functioning. It also makes an outdoor museum that integrates education, social activity and resilient infrastructure. This proposal balances the ecology of the harbor with the working harbor while also creating a collection of outdoor destinations. These outdoor destinations provide the framework to show and explain how resilient landscapes can support an urban, working harbor and make the town of Barnstable a leader in coastal resilience against climate change.

(Figure - 129) Proposed Hyannis Harbor Park

Grow with the flow:

Creating a resilient coast at Stewart's Creek

Ben Breger and Tia Novak

Stewart's Creek

Stewart's Creek is a salt marsh on the southern coast of Barnstable, Massachusetts. Until 2013 Stewart's Creek was practically disconnected from Nantucket Sound. A three-foot diameter culvert permitted highly restricted tidal flow in and out of Stewart's Creek. This disconnect from natural coastal processes allowed the creek to become highly developed, lowered water quality, and led to an infestation of common reed, *Phragmites australis*. The problems that resulted from a lack of tidal flow in Stewart's Creek disrupted the natural salt marsh community, and associated land filling along the marsh borders has diminished the natural resiliency of this salt marsh.

The former culvert was replaced with a six-by-four-foot culvert under Ocean Avenue in 2013, reconnecting Stewart's Creek with Nantucket Sound. This culvert successfully expanded the upper and lower limits of the tide range within the creek. The culvert can also be closed ocean-side during storms to limit flooding to the upland areas of the marsh, and has log stops that can be used as weirs to maintain salinity in the pond (Army Corps of Engineers, 2016).

Although this new culvert restored significant tidal flow into Stewart's Creek and improved water quality, the Phragmites infestation was not resolved. The salt marsh remains compromised - surrounded by dense stands of Phragmites. Re-establishment of the salt marsh and estuarine ecosystem was further disrupted by the culvert intended to restore the habitat. While the culvert is a helpful tool to control flooding and maintain water levels in the marsh (a potentially helpful

(Figure - 130) Aerial view of Stewart's Creek looking south towards Ocean Avenue and the Nantucket Sound. Source: Island Reality, March 2016.

(Figure - 131) By using LIDAR elevation data produced by MassGIS, we estimated the areas flooded by a 10% and 1% annual storm. The most vulnerable areas in Stewart's Creek are the homes adjacent to the marsh to the southeast and Ocean Avenue.

tool in eliminating Phragmites), the area directly upstream of the culvert traps sediment by design. This sedimentation basin captures sediment traveling from the beach to the marsh and can be accessed by machinery for maintenance. Trapping sediment in a contained space interrupts the natural sedimentation processes necessary for salt marsh species like smooth cordgrass (Spartina alterniflora) to become established, thrive, and to adapt to rising sea levels incrementally. The current state of the salt marsh—infested with Phragmites – with associated disruption of essential sedimentation processes—make community engagement difficult both physically and visually, and prevents opportunities for recreation and environmental education the Stewart's Creek.

Although Stewart's Creek is sheltered from most event-based coastal hazards, residents in this area are increasingly vulnerable from the impacts of sea-level rise and coastal flooding because homes and infrastructure are located along the water's edge, at low elevations within the FEMA flood zone. Ocean Avenue, which runs between Stewart's Creek and Keyes Memorial Beach, has been flooded in the past – notably in 1991 during Hurricane Bob, at 5.5 feet. The road's proximity to the ocean makes Ocean Avenue extremely vulnerable to storm surge and sea level rise. The only buffer to Ocean Avenue is a narrow dune and Keyes Memorial Beach, a soft-sediment habitat that is prone to sudden erosion events and offers little protection from major coastal storms.

Stewart's Creek and the surrounding area remains vulnerable to many coastal hazards that will only worsen with climate change, including storm surge, sudden erosion events, and flooding. The effects of climate change will damage the millions of dollars in assets and infrastructure at Stewart's Creek and places the residents that live there at great risk.

Conventional approaches to flood control—dikes, armored coastlines, and sea walls—are becoming increasingly unsustainable approaches due to their continual cost and maintenance (Temmerman et al., 2013). Fortunately, there are many opportunities to create a resilient coastline at Stewart's Creek by employing innovative and hybrid approaches. The existing coastal conditions—the shallow shoreline, the coastal dunes, the salt marsh, and the plant and animal communities that live in these environments—make Stewart's Creek uniquely positioned to become a model coastal resilient community. Our approach for increasing coastal resiliency for the Stewart's Creek community is for a phased retreat of housing from the flood zone to allow space to create new living systems which provide protection, can adapt to changing conditions, and support recreation and economic opportunities for the community.

A Layered, Living Systems Approach to Coastal Resiliency

A phased plan focused on a layered, living systems approach will allow new resilient infrastructure to grow and adapt to changing conditions. Redundancy in resilient design reduces risk and creates a safe-to-fail strategic approach to protecting vulnerable coasts. If one component of the living system fails, the remaining two strategies continue to protect the coastline. The layered living systems approach proposes three modular strategies which act independently but work synergistically to reinforce one another, offshore, on the coast, and along the marsh edge.

Offshore, the creation of a submerged living breakwaters system will mitigate storm surge and build on the already existing shell-fishing economy in Barnstable. On the coastline, a reinforced dune system will protect Ocean Avenue, and create another buffer from storm surge and sea level rise. In the salt marsh at Stewart's Creek, a strategy to relocate homes in low-lying areas around the marsh will provide space for the salt marsh to adapt to rising sea levels by migrating landward.

A naturally resilient and dynamic salt marsh system with a protective berm that runs along the eastern side of the marsh will add a final level of protection for the homes that remain adjacent to the salt marsh.

These three living systems strategies are all naturally-occurring ecosystems where many species provide valuable ecosystem services. Through restoration and enhancement of existing ecosystems and coastal conditions at Stewart's Creek, resilient design can provide protection for humans, habitat for marine species, and build on and support the existing tourism and marine-based economy and recreational opportunities in Barnstable.

(Figure - 132) Overview of Stewart's Creek master plan focus areas.

(Figure - 133) By restoring the salt marsh and allowing it to expand with sea level rise, it will increase the resilience of the community by mitigating storm surge and absorbing flood waters. A perimeter boardwalk through the marsh allows residents to engage with the natural beauty and ecology of the area. Though this proposal will require the removal of roughly 14 homes, there are benefits to the broader community, including storm protection, recreation, and education.

Salty, Stable, and Sustainable: Restoring the Salt Marsh

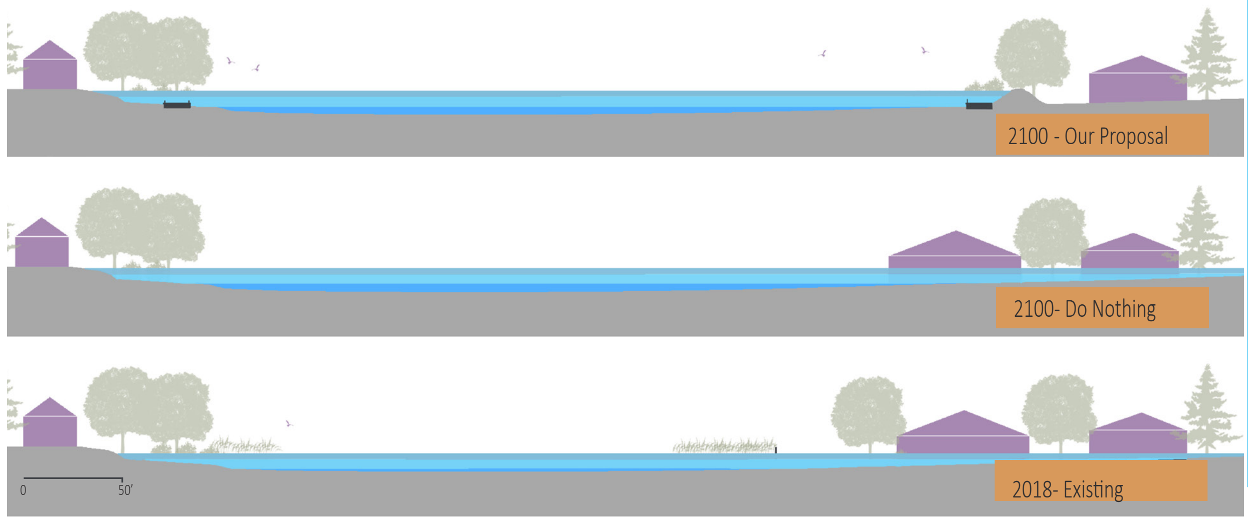
Salt marshes are inherently resilient ecosystems due to their ability to migrate landward with sea level rise. Marsh grasses like smooth cordgrass (Spartina alterniflora) (as opposed to unvegetated mud flats) spread via thick mats of rhizomes, and are able to trap sediments and stabilize substrate. The stability provided by marsh vegetation and the rhizome mat mitigates the detrimental effects of tidal currents, wave action and reduces erosion (Best et al., 2018). Marshes also reduce flooding by absorbing excess water, and are able to store large amounts of carbon through trapping and quickly decomposing organic matter. These characteristics make salt marshes an important ecosystem for increasing coastal resilience.

Salt marshes are able to adapt to changing coastal conditions, and the species that live in these dynamic ecosystems are able to quickly recover from disturbance due to the reasons listed above and the biodiversity found in these marshes. However, the ability of marshes to be resilient is dependent on their ability to migrate landward and accrete sediment to support salt marsh grass species. Expansion of marshes is impeded by filled land, hardened coastlines, and built infrastructure. The accretion of sediment is dependent on wave energy, which is impeded by the limited size of the existing culvert.

The 2013 culvert replacement project opened up Stewart's Creek to the tides, having the effect of increasing the salinity of the water, raising the high water level, and enabling fish migration between the marsh and ocean. However, the salt marsh remains heavily infested with the invasive Phragmites a competitively dominant reed to all marsh vegetation with the exception of Spartina alterniflora, that reduces overall biodiversity. The mean high and low tide levels are not reaching the expected levels or having the effect of eliminating the Phragmites.

Understanding the exact reasons why the desired effects are not being achieved will require extensive data collection, especially studies that examine the pore salinity of the substrate of the marsh. In the meantime, the implementation of a long term plan that involves strategic removal of the Phragmites along the terrestrial border of the marsh and restoration of native salt marsh vegetation is proposed.

Achieving resiliency of the salt marsh to sea level rise will require room to grow. Fourteen homes in Stewart's Creek will either be flooded or highly vulnerable to storm damage well-before 2100. To protect the remaining community and the infrastructure that supports it, a strategic retreat of the most vulnerable homes on the edge of Stewart's Creek is proposed.



(Figure - 134) Current flooding risk for low-lying homes to the east of Stewart's Creek will only worsen with climate change. By doing nothing, many homes will flooded regularly. We propose to remove the most vulnerable homes and use the vacated space to put in place a berm which protects the many remaining homes and boardwalk to allow people to engage with the salt marsh.

- 1% Annual Flood
- 10% Annual Flood
- Mean High Tide

A Strategic Retreat

Managed retreat is a difficult but necessary action that will protect the Barnstable community and the town's investment in new infrastructure. Restored tidal flow makes for a healthier and more resilient salt marsh which protects more homes than it harms. By removing homes which are already highly vulnerable, space can be made available for the salt marsh to expand, for a public boardwalk, and for a protective berm which protects the roughly 70 homes which remain directly uphill of the salt marsh and the removed homes.

Our proposal calls for the removal of 14 homes to make this possible. The criteria for selecting these 14 homes is that they sit at or below 11 feet elevation and all or some of the house is within the 10% annual flood elevation in 2100. Three homes northward were excluded because despite meeting the above criteria, they are likely far enough landward in the salt marsh that they would be well-protected from storms.

Further analysis of parcel data shows that 8 of the homes proposed for relocation are the second-home of the owner. The average year built for the 14 homes is 1973 and the average assessed value is $425,000. If a sale price of roughly $500,000 - $750,000 is assumed, than the total value lost from relocating these homes is $7 – 10.5 million.

However, for the roughly 70 homes which remain, using the same sales price estimate, that sacrifice could enable the protection of $35 – 52.5 million worth of real estate. Residents can either be directly compensated for the value of their home or offered development rights for a parcel of land which is out of harm's way.

This process will require a great deal of community engagement and strategic planning, which we do not address in our proposal. However, we offer evidence of vulnerable homes and a vision for what can be done with those vacated parcels, should the town decide to pursue this strategy.

(Figure - 135) Stewart's Creek is a salt marsh surrounded by a suburban residential community.

Making Room for Recreation and Education

Although restoring the marsh will require calculated and carefully implemented interventions, using the existing salt marsh ecology will prove more sustainable (and cost effective) than conventional approaches to coastal resiliency. Restoration of the marsh will reconnect the community with this unique, beautiful, healthy, and resilient ecosystem, and create opportunities for recreation and education.

A perimeter boardwalk trail with interpretative signage will connect with the existing boardwalk found at Keyes Memorial Beach with a spur trail to Main Street, making navigating the marsh and surrounding amenities intuitive for both locals and tourists. The boardwalk plan includes viewing platforms for viewing birds and wildlife, as well as areas to rest. A boat launch close to Ocean Avenue, off Keating Road, will allow easy access for kayaks and paddle boards. A new trail system will facilitate recreation and education opportunities within Stewart's Creek, enriching the community.

(Figure - 136) Our proposal includes recreation opportunities, such as a looping boardwalk and a boat launch, to allow people to engage with Stewart's Creek. The restored salt marsh also will support an abundance of biodiversity, which increases the overall resiliency of the marsh and the community.

Restoring the Dune

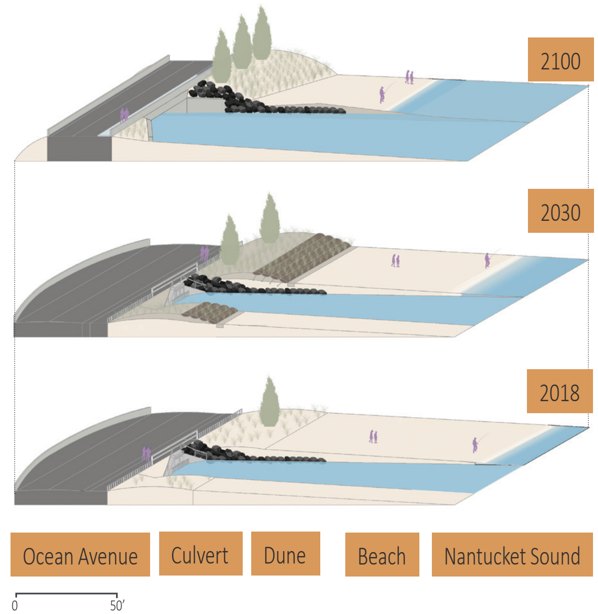
Ocean Avenue runs perpendicular to Stewart's Creek and is an important thoroughfare both for the neighborhood and for the town. However, the road sits on a narrow dune between the Nantucket Sound and Stewart's Creek, making the road highly vulnerable to erosion and flooding during a heavy storm. Despite this vulnerability, Ocean Avenue and the adjacent dune does provide important protection for residents around Stewart's Creek by serving as a breakwater. To maintain the use of Ocean Avenue, it will be important to protect, reinforce, and raise the road.

A raised, reinforced dune between Nantucket Sound and Ocean Avenue can serve as a barrier to mitigate storm surge, wave energy, and flooding while also protecting the road.

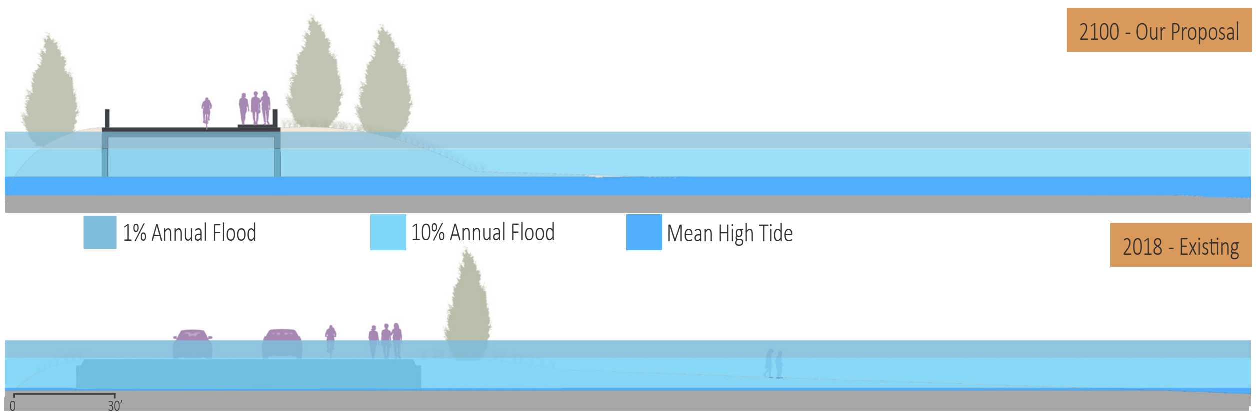
A vegetated dune planted with native vegetation, including American beach grass (Ammophila breviligulata), seaside goldenrod (Solidago sempervirens), bayberry (Myrica gale, Myrica pensylvanica) and eastern red cedar trees (Juniperus virginiana), will maintain the integrity of the dune through providing stabilization and mitigating the erosion associated with wave energy and storm surge. Raising the road and widening the opening beneath it will allow more sediment accretion in the marsh and provide more tidal flushing to expedite the elimination of Phragmites.

A boardwalk along the dunes will connect to the boardwalk system in Stewart's Creek and Keyes Memorial Beach, with ample parking and a small park, allowing the existing recreation area to be enhanced, while simultaneously increasing coastal resilience.

(Figure - 138) Stewart's Creek is located in the southeast corner of Barnstable

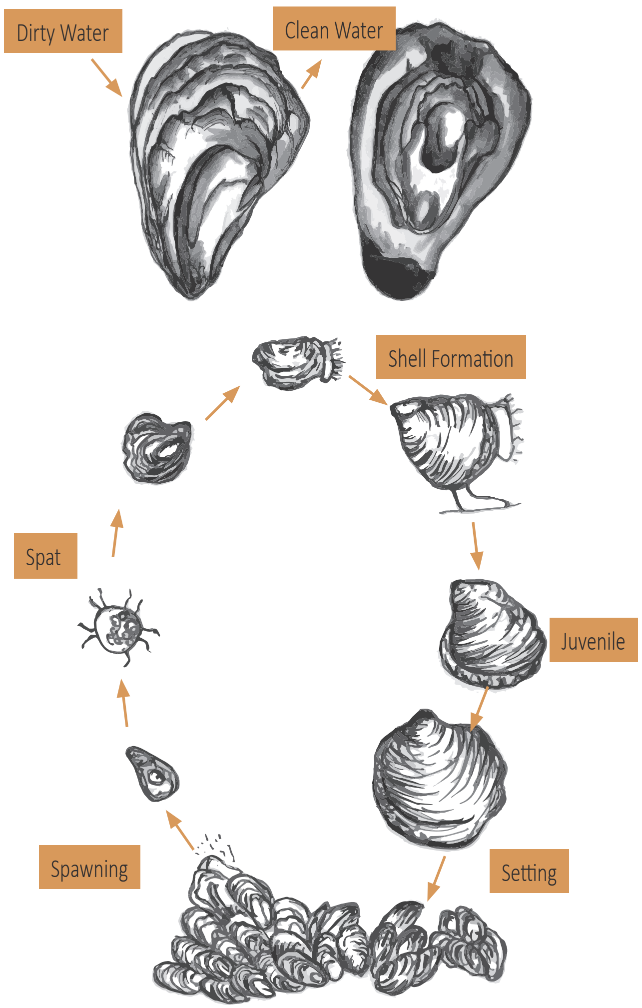


(Figure - 139) We propose to restore and raise the dunes adjacent to Ocean Avenue and to widen and raise the culvert that travels under Ocean Avenue. This will protect Ocean Avenue from sea level rise and allow more sediment to travel into Stewart's Creek.



(Figure - 137) Ocean Avenue is currently vulnerable to both 10% and 1% flooding events and is a main thoroughfare for vehicular and pedestrian traffic. We propose to raise the road and also restore the dunes on the seaward side in order to protect against the impacts of storm surge and flooding.

(Figure - 140) By raising Ocean Avenue, restoring the dunes, and widening the culvert, the overall resiliency of the community is increased. Ocean Avenue is currently susceptible to flooding and the culvert restricts sediment deposition into the salt marsh, which is necessary for it to expand with sea level rise.



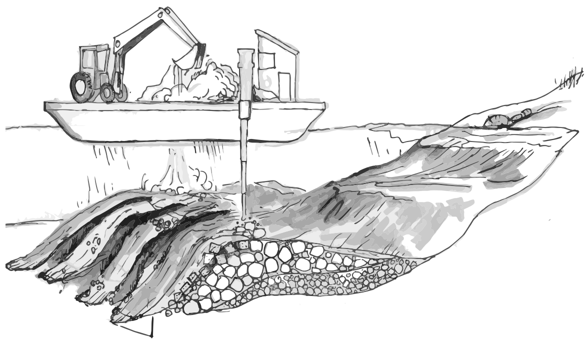
(Figure - 141) Oysters are able to filter water as it passes through their shells. Furthermore, they have the ability to self-construct upon one another, making them well equipped to serve as a breakwater, because they can grow with time.

A Submerged Living Breakwater: Re-establishing the Oyster Reef

The creation of a submerged living breakwater system will serve as the first line of defense against incoming storms and re-establish habitat for the native shellfish population. The breakwater will run parallel to the direction of incoming waves and be sited close to shore to provide more direct protection for the Stewart's Creek community.

The breakwater will use an ECOcrete framework that imitates the spur and groove structure of coastal coral reefs (Orff, 2016). This structure integrates surge channels thought to play an important role as an offshore breakwater in areas where these reef habitats are found (Duce et al., 2014). The spur-and-groove structure also prevents erosion to the reef and provides micro-habitats for reef species to become established.

Although coral reefs are not native to New England, oyster reefs were once common along the Atlantic Coast. Oysters accrete calcium carbonate and establish themselves on existing oysters during the sessile stage of their life-cycle, building reefs naturally as part of their life strategy. By creating an oyster reef that serves as a submerged breakwater, the living submerged breakwater can build over time and become self-sustaining.



(Figure - 142) This submerged, living breakwater would provide a first line of defense against incoming storms.

Barnstable has a rich history of shellfishing and the town promotes this activity by stocking coastal areas with shellfish and encouraging children to learn how to harvest and prepare oysters, mussels, clams, and scallops for consumption (BARS,2018). We propose that the living breakwater can be incorporated into the town's existing shellfish programs, and serve an important recreation and economic resource for the town.

Conclusion

With the uncertainty that remains in forecasting future climate conditions, traditional gray infrastructure is no longer the best choice to protect our coastlines. Conventional approaches lack the necessary dynamism to adapt to changing conditions, and often deflect wave energy causing erosion, degrade over time, and are expensive to rebuild. Restoring the salt marsh will restore the inherent resiliency found in this ecosystem. A phased, strategic retreat moves the most vulnerable homes out of harm's way, creates the space for the salt marsh to expand and protect the hundreds of remaining homes. Removing the most vulnerable fourteen homes also creates space to build a protective berm along the eastern edge of the marsh, and allows for the construction of a boardwalk system that makes recreation and education at the salt marsh possible. A reinforced dune will protect a raised Ocean Avenue, adding another layer of protection that shelters an important route for the local community and town. Finally, an oyster reef that serves as a submerged breakwater will act as the first line of defense to protect Stewart's Creek from coastal hazards like storm surge and sea level rise.

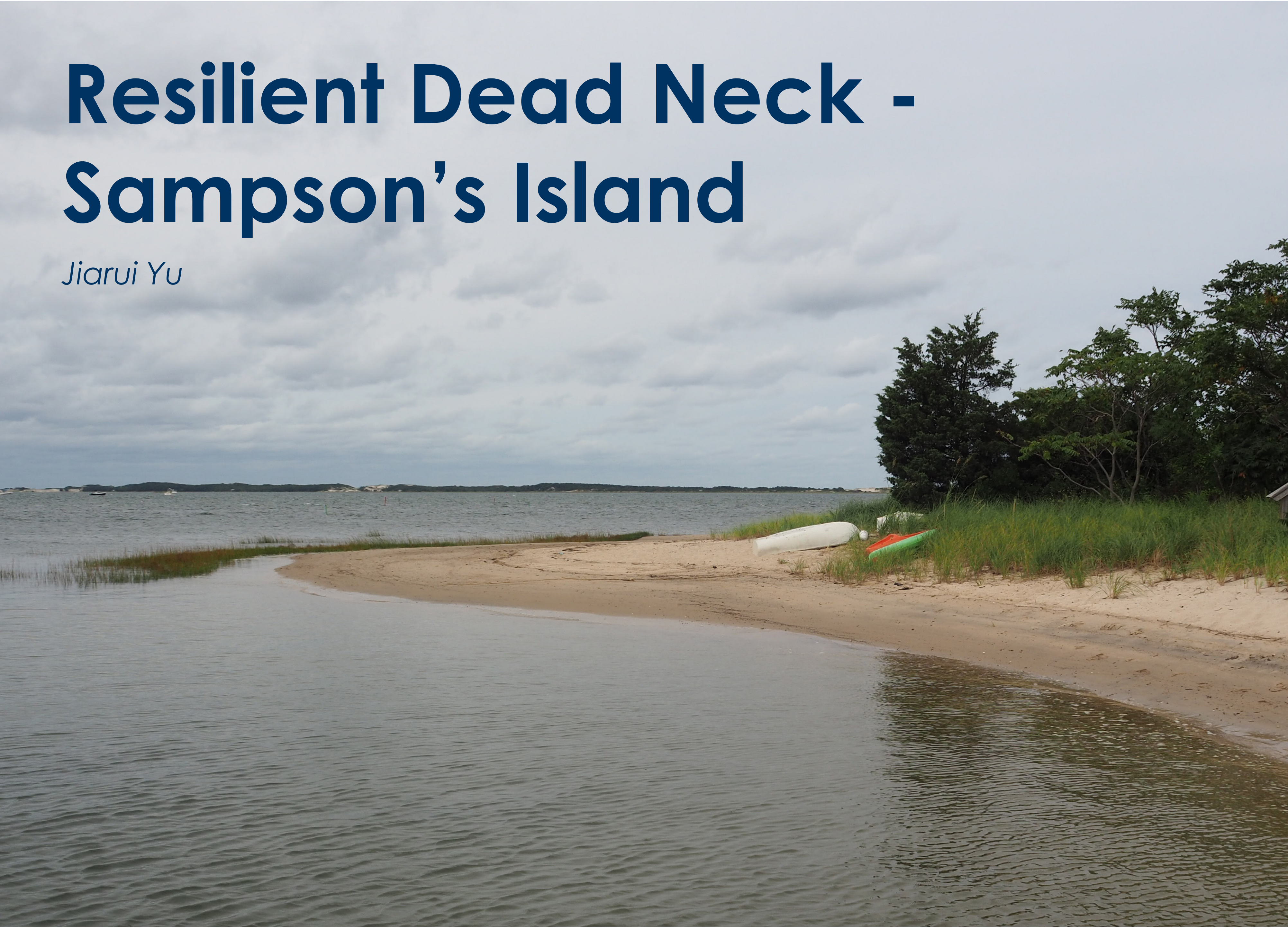
A living systems approach using a restored salt marsh, a reinforced dune, and the re-establishment of a native oyster reef, has an inherent ability to adapt to dynamic conditions, and will enhance the quality of life for residents now and in the future. In a layered systems approach with redundant, modular infrastructure, resilience is built into the design. Arguably equally important, all of these strategies feature coastal conditions native to Cape Cod and are intrinsically of the place.

Salt marshes, dunes, and oyster reefs, are all coastal conditions found across Cape Cod. Stewart's Creek is uniquely positioned to become naturally resilient because these coastal conditions are all present at the site and reduce risk through redundancy. For this reason, these strategies could be safely tested at Stewart's Creek and applied elsewhere in Barnstable and on Cape Cod.

We know that climate change is not a problem that we can avoid, but a reality to which we must adapt. Stewart's Creek is a perfect pilot site to test these adaptive strategies to make a resilient Cape Cod, while retaining the ecosystems and cultural identity that makes the Cape such a special place.

Resilient Dead Neck - Sampson's Island

Jiarui Yu



Site Introduction

Dead Neck/Sampson's Island (DNSI) is a classic example of a coastal barrier island, located on the Nantucket Sound-side of Barnstable. Barrier islands once existed across much of the southern coast of Cape Cod along Nantucket Sound. These barrier beaches have been developed and modified to keep navigation channels open into many of the Cape's bays – including the Three Bays of Osterville. The west end of DNSI is adjacent to the "cut" into Cotuit Bay. The east end (Dead Neck) is adjacent to the "cut" into West Bay. DNSI provides a great deal of protection for Grand Island/Oyster Harbors that lies across the Seapuit River – a small channel behind the barrier island.

Barrier islands in the Cape region can vary from a few hundred feet wide to a few thousand feet wide. Islands support important wildlife species, particularly shorebirds, including the endangered Piping Plover. Barrier islands provide a naturally-resilient "barrier" protecting coastal dunes, bluffs and marshes from coastal storms and storm surges. They are typically structured by a primary and secondary dune system, with the primary dune covered by a dense stand of American beach grass and native herbaceous plants (seaside goldenrod, beach pea, beach heather, dusty miller) along with salt-tolerant shrubs and small trees in the inter-dune and back dune areas (bayberry, eastern red cedar, scrub oak). Intact barrier islands support important wildlife species, particularly shorebirds, including the endangered Piping Plover.

(Figure - 147) Sampson's Island Shoreline

Under "normal" weather conditions, barrier island plants grow very deep roots that can reach groundwater in the very dry sandy soil. These same roots are key to the island's resilience because they can survive strong waves and even "overwashing" during storms – while retaining much of the vegetation – stabilizing the dunes. When the islands get washed-out, they recover quickly starting with natural colonization of American beach grass. During storms, barrier islands attenuate much of the energy of waves and storm surges. As a result, the mainland can be protected from coastal flooding by the islands- hence the name "barrier" island.

Dead Neck/Sampson's Island is bounded by the human-made "cuts" to Cotuit Bay to the west, and West Bay on the east, in the Osterville and Cotuit villages of Barnstable (Figure 144 and 145- DNSI location and photo of the island). The island is affected by east-to-west longshore currents – causing continuous erosion on the east end, and deposition at the west end. After a lengthy permitting process, a multi-year dredging project has recently commenced (2018-2020). The dredging will move approximately 50,000 CY of dredged sand from the west end to the east end of the island. This dredging operation presents a rare opportunity to restore a more robust dune system to the east end of the island.

(Figure - 145) Dead Neck/Sampson's Island

(Figure - 143) Cape Cod (Google Earth()

(Figure - 144) Dead Neck- Sampson's Island (Google Earth)

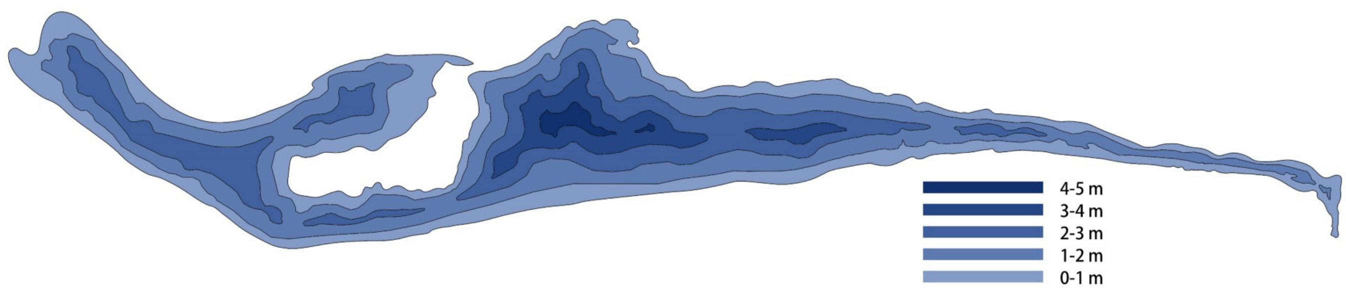
Existing Wetlands

Dead Neck/Sampson's Island supports a substantial area of wetlands that provide important ecological functions. There are three types of wetlands on the island; fresh marsh (in light green); salt marsh (in dark green); and developing salt marsh (medium green). The salt marshes, in particular, are important for coastal resilience.

(Figure - 148) Existing Wetland Conditions

Existing Elevation

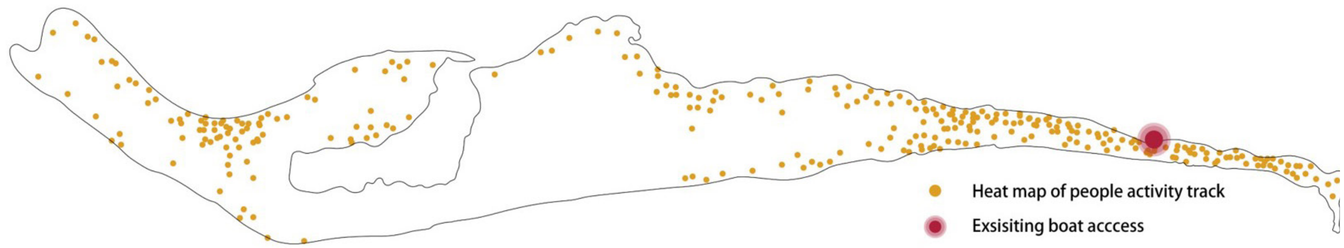
The existing topography of the island shows a trend of higher elevations in the west and lower elevations in the east. The high point on the west side of the island is about 3.5 m above sea level, and the commanding high point of the whole island lies in the middle of the island, which is about 5.5 meters above sea level. To the east of the island is the currently eroding dunes, with a high point of about 2m above sea level.



(Figure - 149) Existing Elevation

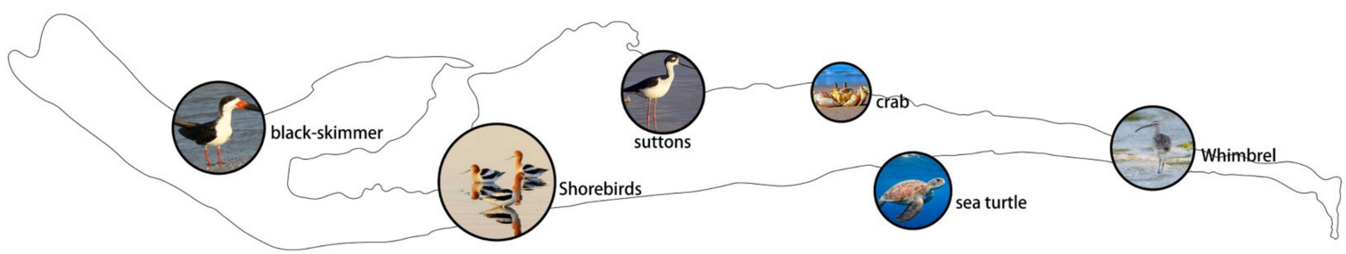
Existing Public Access for Recreation + Birdwatching

Presently, there is a moderate amount of seasonal "informal" public access to the east end of the Island on the Seapuit River side. Most access is by small motorboats and paddle-craft. The west end of DNSI are visited by recreational boaters. This project proposes a moderate increase in recreational and environmental education visitors – limited to specific areas to avoid disturbance to the nesting shorebirds and other wildlife.



(Figure - 150) Existing Public Access

Intact barrier islands, such as DNSI, support a diversity of wildlife species, particularly shorebirds, including the endangered Piping Plover. Barrier islands can provide protected habitat for sensitive species. If properly managed, DNSI could provide limited access to selected areas on the island where visitors could see, and learn about, native flora and fauna.



(Figure - 151) Existing Birdwatching

Master Plan Of Dead Neck Sampson's Island

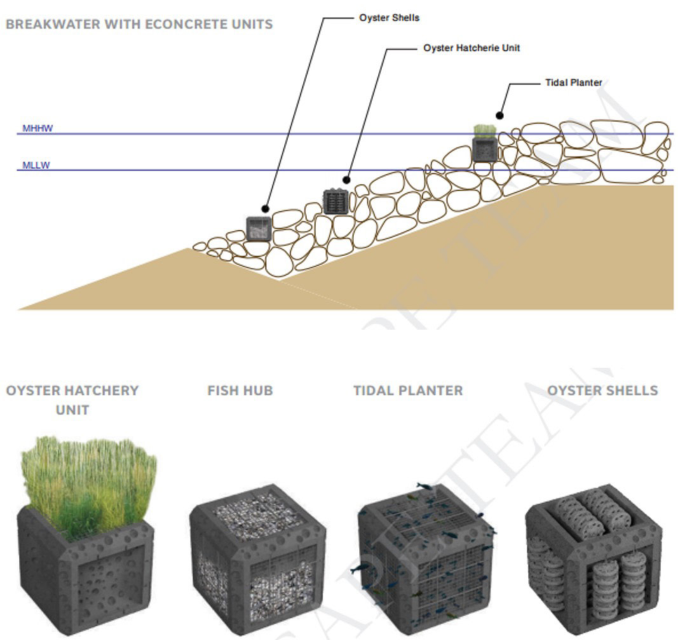
The current and near-future dredging operation (2018-2020) provide a unique opportunity to re-design the island for ecological stability and resilience. The middle of the island is partially forested with characteristic back-dune vegetation (eastern red cedar, bayberry, scrub oak) and will not be changed by the dredging operation. Here, an ecologically-sensitive system of wildlife trails and raised viewing platforms is proposed. Each viewing platform is located to provide different landscape experiences. The bulk of the dredged materials will be deposited at the eastern end of DNSI. Here a restored "dune-system" is proposed – with a primary dune, secondary dune and interdune "trough". A single movable wooden walkway is proposed for the eastern end of the island to allow limited pedestrian access across the island without disruption of the sensitive nesting shorebirds.

During storms, the restored island will attenuate much of the energy of waves and storm surges. DNSI provides a great deal of protection for Oyster Harbors that lies across the Seapuit River behind the island.

(Figure - 152) Proposed Master Plan

(Figure - 155) Section 1

(Figure - 156) Section 2

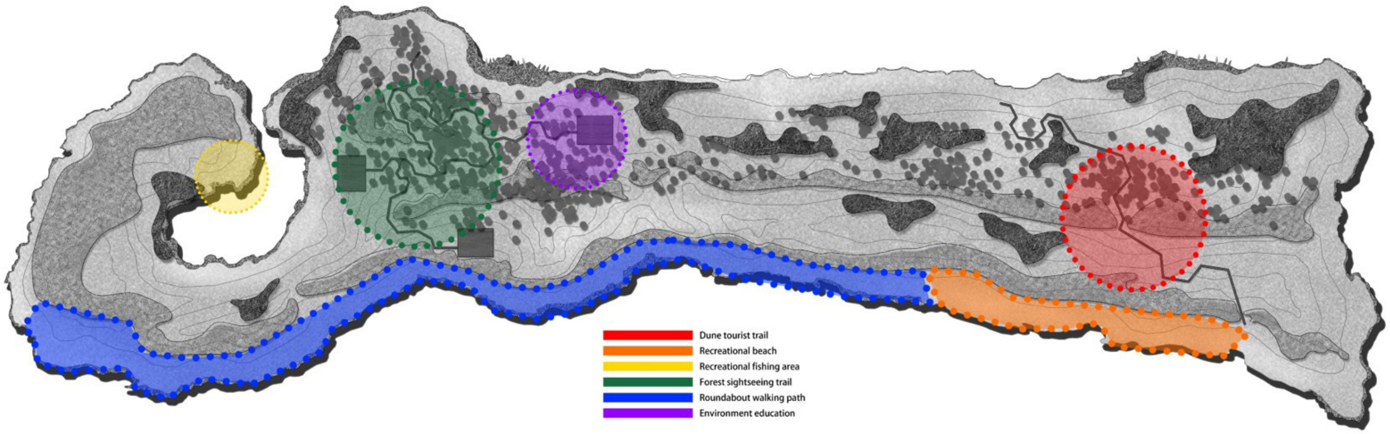


(Figure - 153) EConcrete Units (econcretetech.com/scapestudio.com)

(Figure - 154) Fish Hub (econcretetech.com/scapestudio.com)

ECONCRETE UNITS STRATEGY

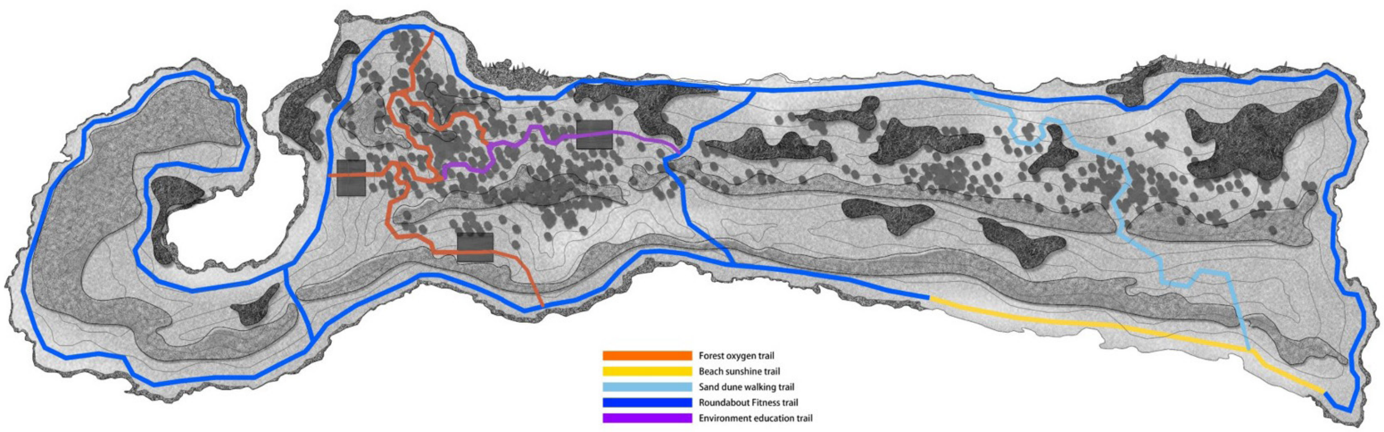
Off shore from Dead Neck Sampson's Island ,a living breakwater is proposed. The breakwater would be 15-20 meters wide, divided into four layers, the bottom layer is the concrete base, then a rock matrix, a silt gravel layer, and the top layer is the econcrete modules, providing a habitat for shellfish. Here, four different "cement boxes" in different layers are organized for; oyster hatchery, fish hub, tidal planter, and oyster shells. Oysters not only clean water, but also help form a living breakwater and reduce the impact of coastal floods on Grand Island. The various boxes in the living breakwater carry different functions, and overall they have the function of improving water quality, providing food for local fish, fixing aquatic plants to prevent eutrophication. However, the most important function is to make the breakwater flexible and resilient to coastal processes and storm impacts.



(Figure - 157) Proposed wildlife viewing areas

Proposed Trail Analysis

The master plan proposes a trail system for moderate, seasonal use: the outermost beach is a leisure trail around the entire island; in the middle of the island, which is the most abundant in unique landscape resources, a trail and 3-4 viewing platforms are linked with wooden trestle roads. This route in the middle of the island can also be used as an educational tour of barrier beach functions, and wildlife/habitat interactions.



(Figure - 158) Proposed trail system


(Figure - 159) Photo showing erosion on DNSI

Looking to the Future

The recommendations made in this report are intended to provide the the Town of Barnstable with ideas, visions, and strategies for enhancing coastal resilience in the face of climate change. Sea level rise and increased storm intensity and frequency will combine to drastically alter the shoreline of Barnstable and the homes and infrastructure located along the coast. Our landscape-based solutions employ natural coastal ecosystems found on Cape Cod, rather than exclusively engineered, 'hard' solutions. In doing so, our proposals support a "sense of place" and have inherent resilience because the natural systems can adapt and grow over time with changing conditions. As co-benefits, outdoor recreation, tourism, habitat, and environmental education opportunities are all increased.

Enhancing coastal resilience using some or all the strategies outlined in this report will require a long-term planning and community engagement process for the town of Barnstable. There are grants available from the Commonwealth of Massachusetts, such as the Municipal Vulnerability Preparedness Program (MVP) which provides funding for resiliency planning and project implementation. Engaging in these discussions may be difficult in the short term but will help avoid disastrous consequences in the future, as the sea level continues to rise. Climate change is an unprecedented problem and there is no established guidebook on how to best adapt communities to the coming changes. Novel solutions will be required to grapple with this complex problem. The proposals outlined in this report represent a vision of what is possible and include a suite of potential strategies for enhancing coastal resilience in Barnstable, which also increase recreation, environmental education, and habitat. Our hope is that these ideas can spark a sustained public conversation which is needed to advance Barnstable towards a more resilient future.

(Figure - 160) American beach grass at Craigville Beach stabilizes the underlying sand dune which can protect homes from coastal flooding and build resilience capacity along Barnstable's coast.

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