Assessing Nantucket's Relationship with Coastal Erosion

by
Beauchesne, Sara R.
Eroshenko, Ivan O.
Govaert, Madison E.
Keable, Michael W.

Assessing Nantucket's Relationship with Coastal Erosion

An Interactive Qualifying Project
submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfilment of the requirements for the
degree of Bachelor of Science

by
Beauchesne, Sara R.
Eroshenko, Ivan O.
Govaert, Madison E.
Keable, Michael W.

Date:
11 December 2019

Report Submitted to:

Charles Stott
Nantucket Civic League

Peter Morrison
Nantucket Civic League

Professor Dominic Golding
Worcester Polytechnic Institute

Abstract

Erosion on Nantucket is an increasing threat to public and private property. In addition to observations in the field, we interviewed and surveyed stakeholders to identify erosion mitigation measures applicable to Nantucket in general and Madaket in particular. We recommend the town consider implementing a sand motion study, creating artificial reefs, dredging/beach nourishment, stabilizing dunes (by planting grasses, erecting fencing, and limiting beach access points), and installing shoal modules. Policies that restrict beach driving and establish property setbacks may also be effective. Finally, future success will require much greater coordination of erosion control efforts between the town, local organizations (such as the Civic League), and property owners.

Acknowledgments

We would like to extend our deepest gratitude to all of the following people and organizations that have helped us in our completion of our project:

- Our sponsors, Peter Morrison and Charlie Stott of the Nantucket Civic League, for all their support and connections that made this project successful.
- Our advisor, Dominic Golding, for always offering advice to help us mold our project.
- The Nantucket Yacht Club, for housing us.
- Vincent Murphy, the Coastal Resilience Coordinator, for his extensive knowledge and resources in aiding our project.
- Young's Bicycle Shop, for providing us with a mode of transportation around the island.
- ReMain Nantucket, for their warm welcome to the island.
- Nantucket Island Chamber of Commerce, for extending to us a space for work and interviews.
- All of our interviewees for taking their time to speak with us:
    - D. Anne Atherton
    - Rick Atherton
    - Holly Backus
    - Sarah Bois
    - Peter Brace
    - Jeff Carlson
    - Lindsay Dubbs
    - Bill Grieder
    - Jennifer Karberg
    - Rob McNeil
    - Emily Molden
    - Stephen A. Murphy
    - Vincent Murphy
    - Sarah Oktay
    - Eric Savetsky
    - Gregg Tivnan

    - Andrew Vorce
    - Judith Wegner
- All of the residents of Madaket that took the time to complete our survey and share their stories with us

Executive Summary

Coastal erosion is a major concern among coastal communities in the United States. In 2000, a report for the Federal Emergency Management Agency (FEMA) estimated that there were 350,000 structures within 500 feet of the U.S. shoreline (outside the major coastal cities), and that 25% (87,000 structures) would be lost to erosion over the next 60 years. Each year, approximately 1,500 homes are lost to erosion at the cost to homeowners of more than $530 million (Heinze Center 2000). Given predictions about the increased frequency and intensity of storms due to climate change, it is likely that erosion costs and losses will escalate in the future. As an island 30 miles off the coast of Massachusetts, Nantucket suffers from some of the highest rates of erosion in the state, ranging from 2-25 feet/year (CZM). The Nantucket shoreline has retreated hundreds of feet since the 1950s, especially along the south coast of the island and in particular locations, such as Madaket. Dozens of houses have been lost over the years, and many more are at risk in the future. Many property owners have taken steps to try to limit the damages from erosion, such as installing sandbags and groins. These efforts have been controversial, however, because they are often ineffective and cause unintended consequences, such as fouling fishing gear or creating excessive scouring on neighboring properties.

Given the ongoing and growing concerns, the Nantucket Civic League chose our team to characterize coastal erosion and its physical manifestations locally, trace the communitywide consequences of coastal erosion (physical, social, and institutional), distinguish the perspectives of various stakeholders on coastal erosion and potential actions for mitigating its effects, and delineate alternative mitigation strategies for public consideration and debate. Our team has focused on Madaket as a case study for the management of coastal erosion in other communities on the island.

The overarching goal of our project was to assist the Civic League in developing strategies and materials to help communities on Nantucket manage coastal erosion. The project objectives were to:

1. Evaluate best practices in the management of coastal erosion, and identify lessons learned from their application in selected communities in the U.S.

2. Assess the policies and plans currently in place on the island to mitigate the adverse effects of coastal erosion.
3. Develop a case study on the erosion problem and potential mitigation strategies in Madaket.

In order to accomplish these objectives and provide the Nantucket Civic League with appropriate guidance, we interviewed coastal erosion experts, town officials, local property owners, community activists, and other stakeholders. We reviewed existing policies and plans and conducted site observations. Lastly, we have developed a survey for the residents of Madaket to assess their understanding of erosion and the strategies they would like to see implemented to manage it.

It became evident that the issue of erosion impacts the island in broad ways. Several different organizations and committees are involved in protecting public and private properties and infrastructure from the threat of erosion. The topic of erosion on Nantucket is also very divisive. Some people believe 'erosion happens' and there is little that can or should be done, but many others are keen to explore innovative ways to stave off and limit losses. After compiling the information obtained in our interviews and survey results, we have developed a list of technologies, policies, and organizational tactics in order of priority that Madaket and the town can adapt to mitigate the effects of erosion. The goal in the end, is for the town to learn from this Madaket "case study", and apply the recommendation across the island.

In order to implement some of our recommended strategies, such as artificial reefs, beach dredging, and Joe Farrell's project, further research of the sand movement around the island must be conducted prior to executing the strategies laid out below.

In ranked order:

Rebuild Dunes

In general, the United States has shifted from the use of hard structures to control coastal erosion to the use of soft structures (National Research Council, 2014). Many states and local governments on the east coast are encouraging communities to protect and re-establish saltwater marshes and dune systems since they protect against storm surge, flooding and coastal erosion.

We recommend that Nantucket explore opportunities to protect and encourage the development of more extensive dune systems. Dunes can be maintained by erecting sand fences and planting dune grasses and other vegetation. Stabilizing existing dunes and encouraging dune growth and development are environmentally friendly solutions that have been shown to reduce coastal erosion in several areas on Nantucket. The structures are relatively easy and inexpensive to install, but may require periodic maintenance. They can also be damaged by beach driving and destroyed by severe storms.

To coincide with the efforts already being conducted by the town, individual private homeowners should apply for funds from the United States Department of Agriculture (USDA) for implementing dune fencing with dune grasses in front of their properties. In addition, the Madaket Conservation Association should facilitate group efforts to plant beach grasses and install dune fencing in areas that are vulnerable to coastal erosion in Madaket. The more vegetation incorporated into the dune systems, the more stabilized they will be. Finally, clearly marked beach access points in Madaket should be installed to reduce the number of people traversing the dunes and, ultimately, mitigating the rebuilding effort.

Guidance for Homeowners and "Erosion" Committee

Based on the interviews and survey results, the conclusion drawn is that homeowners want the town to take more action in regards to mitigating coastal erosion. Despite the town's initiatives to be more proactive by implementing the Hazard Mitigation Plan and establishing the Coastal Resilience Advisory Committee (CRAC). Which works directly with Coastal Resilience Coordinator, Vincent Murphy, on drafting the island's Coastal Resilience Plan. Although these plans are in place, more action must be taken to mitigate coastal erosion. In addition, better guidance must be disseminated to private homeowners from the government and large conservation associations.

After publication of Coastal Resilience Plan, the Coastal Resilience Advisory Committee, in collaboration with Vince Murphy, should refocus their roles. In the future, the committee should take on the role of an "erosion czar", overseeing the implementation of the erosion control efforts suggested as well as organizing a plan for future erosion efforts. The committee should also assess the long term vulnerability of the Millie's Bridge.

We also propose the committee to work with the town and large conservation organizations to provide a better guidance for homeowners by establishing a new web-portal or add new features to CRAC's current website. The website should include descriptions of the past, current, and future efforts completed or planned by both public and private entities to mitigate erosion. Ideally, the posted solutions would be inexpensive, innovative, and effective so that homeowners could learn from them and potentially apply the solutions to their properties. The Civic League and other smaller homeowner associations may use this solution to keep homeowners abreast of the most updated information on the website. Potentially, a system like this could help in organizing group efforts of homeowners in certain areas and neighborhoods.

In the short term, the inexpensive updating of the CRAC's website to include more pertinent information on erosion will be an asset to the residents of the island. Over the long term, establishing effective communication and collaboration between several committees will, over time, foster a communal effort to improve the current situation of coastal erosion. If all stakeholders are involved in a solution, the solution will be well received and, hopefully, cost effective.

Restrictions on Beach Driving

One of the popular policy-based strategies to mitigate coastal erosion effects is ban on beach driving in areas that are especially vulnerable to coastal erosion. As mentioned in section 4.3.2, driving too close to dune systems can uproot the vegetation and destroy the embryonic dunes, which collapses the dune system. The difficulty in implementing this recommendation is that beach driving is a big economic driver for Nantucket, because tourists have to purchase permits that allow them to legally drive on certain beaches. Sales of beach driving permits yield approximately 6% of annual town budget (V. Murphy, personal communication, October 24th, 2019).

A majority of Madaket residents support reducing the number of beach driving areas prone to coastal erosion and the recommendation to do so would protect the dune systems.

Reinstating Nantucket Conservation District

Reinstating the Nantucket Conservation District (NCD) could assist in channeling funding from the USDA to homeowners' non-profit group projects such as beach grass planting and culvert building. This strategy should encourage homeowners to undertake group effort projects rather than individual projects in addition to providing organizational aid for these projects outside of town-owned property. However, this initiative would also require electing a board of members to oversee the responsibilities of NCD.

It is a recommendation to reinstate Nantucket Conservation District and hold elections for the board of NCD members so that homeowners may have another option for information, demonstration, organization, and funding for their group non-profit projects.

Overlay Amendments (Setback laws, building restrictions, etc.)

Set-back ordinances are property laws governing lines and boundaries. A set-back law establishes a minimum distance from a property line that a building can be built. The distances are generally regulated by zoning laws. The zoning overlay laws cannot, unfortunately, protect any existing structures. In culmination establishing set-back laws is a good option for mitigating coastal erosion in the long term. To further support our conclusion, 90% of responses from the survey are in favor of the town implementing set-back laws to restrict structure building in these vulnerable areas (Figure 36).

With overwhelming support from the citizens, it is recommended that the town adjust the current overlay and/or introduce a set-back law to prohibit additional development on land within a certain distance (i.e. 100 ft) from the mean high water mark (HWM).

Farrell's Shoal Modules

Joseph Farrell's multi step project is worth implementing. The project consists of three stages: 1) collecting data on wave action and sand transport during a nor'easter in Madaket, 2) sinking temporary shoal modules off the beach in front of endangered houses and 3) replace the shoal modules with 100 to 140 feet of concrete units. The shoals could create artificial reefs and provide new habitats for sea creatures. The modules will be submerged deep enough so that they will not interfere with boat navigation. The project is currently on hold with permits needed to begin the second phase. As with implementing artificial reefs to sink temporary shoal modules

properly, there should be more data gathered on sand movement. Based on survey responses, this project has garnered the support and attention of several homeowners in Madaket (Coastal Recovery).

It is recommended that the town to conduct a sand study on the island to identify the most efficient place for Farrell's shoal modules to be installed. Then, it is recommend that the residents of south shore and the town proceed with implementing the temporary shoal modules off the shore and observing the results. If the results prove the temporary shoal modules to be efficient, it is recommended that Farrell proceed further into the phases of his project.

Stilting

Stilting houses is an additional way to mitigate the effects of coastal erosion. Elevating a house will protect it from flooding and storm damage. As stated in section 4.3.2, some homes in Madaket has started to implement this strategy. Outer Banks, NC is an example of a similar location with many stilted houses. Stilting houses, in some cases, can even be partially funded by FEMA.

Based on the federal funding available to lower the costs of this solution, it is recommended private homeowners in Madaket explore the option of stilting their houses and request funds from FEMA. The stilting may currently only be a few feet (three feet to five feet) in order to stay in compliance with home height restrictions of twenty five feet. It is also recommended that a an edit to local building codes be drafted to state that the height of the home begins at the first level mark and not at ground level.

Artificial Reefs in Madaket Harbor

Artificial reefs can make a positive impact in reducing the rate of erosion in certain coastal areas. As mentioned previously in section 4.3.1, artificial reefs, if implemented correctly, can reduce wave energy, thus reducing erosion impact on the coastline. Artificial reefs can also provide a new habitat for shellfish and are environmentally friendly. However, to implement artificial reefs properly and avoid any negative coastal impact more data should be gathered on sand movement around the island. Prior to implementation in the harbor and applicable areas, positive results from the Sesachacha project first need to be observed.

Following positive results from both the sand study that verifies an adequate ecosystem, as well as applications of it in Nantucket, it is recommend that artificial reefs be placed in Madaket Harbor. Though the area of Madaket Harbor does not necessarily receive high rates of erosion, it is a very crucial area, not just for Madaket, but for the whole island. Therefore, planning proactively could prove quite successful.

Beach Renourishment through Dredging

Proven to be successful in places such as Cape May, New Jersey, despite the various aspects such as determining material compatibility, long permitting process, high cost of implementation, and potential danger to the environment, beach renourishment through dredging can make a positive impact on reducing coastal erosion rates in Madaket. Dredging on Madaket's south shore would only be successful following specific findings in the proposed sand study. For example, if the sand study finds the ecosystem in Madaket Harbor to be too fragile, then dredging from father offshore may be the best solution.

It is recommended that the town to dredge material from Madaket harbor and deposit the material on the southern shore of Madaket as long as the dredged material and receiving material are compatible. Before beginning a dredging operation, local shell fishing needs to be considered in order to not disturb these areas.

Authorship

Section	Contributors
1. Introduction	Madison Govaert, Michael Keable
2. Background	Sara Beauchesne, Madison Govaert, Michael Keable
2.1 Defining Coastal Erosion	Madison Govaert
2.2 U.S. Coastal Erosion	Madison Govaert
2.3 Government Regulations and Policy	Michael Keable
2.4 Erosion on Nantucket Island	Sara Beauchesne
3. Methodology	All
3.1 Evaluate Best Practices	Sara Beauchesne
3.2 Assess the Policies	Madison Govaert
3.3 Develop a Case Study	Ivan Eroshenko
3.4 Recommendations	Michael Keable
4. Findings	All
4.1 Coastal Erosion on Nantucket	Sara Beauchesne, Michael Keable
4.2 Responding to Erosion in Madaket	Ivan Eroshenko, Madison Govaert
5. Conclusions and Recommendations	Ivan Eroshenko, Madison Govaert

Table of Contents

List of Figures

List of Tables

1. Introduction

Coastal erosion is a major concern among coastal communities in the United States. In 2000, a report for the Federal Emergency Management Agency (FEMA) estimated that there were 350,000 structures within 500 feet of the U.S. shoreline (outside the major coastal cities), and that 25% (87,000 structures) would be lost to erosion over the next 60 years. Each year, approximately 1,500 homes are lost to erosion at the cost to homeowners of more than $530 million (Heinze Center 2000). Given predictions about the increased frequency and intensity of storms due to climate change, it is likely that erosion costs and losses will escalate in the future. As an island 30 miles off the coast of Massachusetts, Nantucket suffers from some of the highest rates of erosion in the state, ranging from 2-25 feet/year (CZM). The Nantucket shoreline has retreated hundreds of feet since the 1950s, especially along the south coast of the island and in particular locations, such as Madaket. Dozens of houses have been lost over the years, and many more are at risk in the future. Many property owners have taken steps to try to limit the damages from erosion, such as installing sandbags and groins. These efforts have been controversial, however, because they are often ineffective and cause unintended consequences, such as fouling fishing gear or creating excessive scouring on neighboring properties.

Given the ongoing and growing concerns, the Nantucket Civic League chose our team to characterize coastal erosion and its physical manifestations locally, trace the communitywide consequences of coastal erosion (physical, social, and institutional), distinguish the perspectives of various stakeholders on coastal erosion and potential actions for mitigating its effects, and delineate alternative mitigation strategies for public consideration and debate. Our team has focused on Madaket as a case study for the management of coastal erosion in other communities on the island.

The overarching goal of our project was to assist the Civic League in developing strategies and materials to help communities on Nantucket manage coastal erosion. The project objectives were to:

4. Evaluate best practices in the management of coastal erosion, and identify lessons learned from their application in selected communities in the U.S.

5. Assess the policies and plans currently in place on the island to mitigate the adverse effects of coastal erosion.
6. Develop a case study on the erosion problem and potential mitigation strategies in Madaket.

In order to accomplish these objectives and provide the Nantucket Civic League with appropriate guidance, we interviewed coastal erosion experts, town officials, local property owners, community activists, and other stakeholders. We reviewed existing policies and plans and conducted site observations. Lastly, we have developed a survey for the residents of Madaket to assess their understanding of erosion and the strategies they would like to see implemented to manage it.

Throughout our time spent on the island, it became increasingly evident that the issue of erosion is a highly politicized topic. Approaching the residents with recommendations was a difficult task to keep everyone's interests in mind. Nevertheless, most people agree that there needs to be established an organized plan through both public and private efforts to counter the threats of erosion. In short, the most agreed upon actions include the following:

- Continue the effort of restoring dunes on beaches, stabilizing them with vegetation and fencing
- Conducting a study of the coast's erosion and accretion rates and long-shore drift to have a better understanding of where sand is moving, and what locations will need future actions taken place to protect them such as artificial reefs
- In the case that the stabilization project of the dunes in front of Millie's bridge in Madaket fails, and the bridge is compromised, we recommend perhaps redesigning it into a culvert as opposed to moving the bridge
- Establishing either a setback law, to restrict development within a certain distance to the mean high water line (MHW), and/or an overlay law, to prohibit structures within a defined area

2. Background

2.1 Defining Coastal Erosion

Coastal erosion issue is one of the most pressing problems for coastal communities in the U.S. and worldwide. Coastal erosion is the wearing away of beaches, bluffs and cliffs by natural processes such as storms and normal wave action, and runoff from the land. This natural process can be exacerbated by human activities, such as altering vegetation and drainage, and increasingly by our impact on climate.

All coastlines face erosion, but the rates of erosion and the associated costs and losses vary depending on the nature of the coastline and the type of land-use. Aside from loss of land, the major losses from erosion result from damages to buildings and infrastructure along the coast (Figure 1). The costs of erosion include the costs of preventive measures, repairing damage, and debris removal. "In the U.S., coastal erosion is responsible for roughly $500 million per year in coastal property loss, including damage to structures and loss of land" (U.S. Climate Resilience Toolkit).

Figure 1: Coastal Erosion (Drønen, 2018)

Experts predict that erosion will worsen with sea level rise and climate change. As the ocean temperatures increase, the hurricanes and other storms are expected to become both stronger and more frequent, causing the affected coastlines to erode faster. Moreover, "Since the start of the satellite sea level record in 1993, the average rate of sea level has been about one-eighth of an inch (3.1 mm) per year" (NOAA, 2019). Thus, low lying areas of the coastline may

be inundated more frequently and the destructive impacts of storm surge will increase (The Economist, 2019).

2.2 U.S. Coastal Erosion

The National Oceanic and Atmospheric Administration (NOAA) estimates that over 126 million people, about 40% of the country's population, live in coastal counties and face the threat of storms and erosion (NOAA, 2015). The Heinz Center report for the Federal Emergency Management Agency (FEMA) estimated losses in the value of properties within the coastal erosion zones of $3.3 to $4.8 billion already. The report projected that 87,000 structures along the coast would be lost to erosion over the course of 60 years, or about 1,500 homes lost a year. The Heinz Center estimated that annually erosion along the east coast of the U.S. costs homeowners approximately $530 million, communities about $410 million in loss of land, and the National Flood Insurance Fund nearly $200 million due to payouts for damaged structures and belongings (Heinz, 2000). Due to numerous factors that have changed over the past two decades, including increases in the frequency of intense storms, erosion rates, and urban development in coastal erosion zones, it is likely that these costs have only risen.

2.2.1 The Solutions Available

Many different approaches have been proposed to deal with coastal erosion and classifications of approaches vary. According to Neal, de Jonge, and Rangel-Buitrago (2019), current strategies can be broken into five types; Protection, Accommodation, Planned Retreat, Use of Ecosystems, and Sacrifice. Sacrifice remains fairly self-explanatory, being an acceptance of loss of property when no solution seems feasible. Use of ecosystems redirects attention to the basic environmental processes relating to erosion, "by means of the creation and restoration of coastal ecosystems, such as wetlands (e.g., mangroves), biogenic reef structures (e.g., corals, oysters, and mussels), seagrass beds and dune vegetation" (Neal et al, 2019, p. 292). Planned retreat is the process of extracting structures within the erosion risk zone and relocating businesses, people and associated infrastructure further inland. Accommodation is defined as adapting to the risk of the environment by using new construction techniques (e.g., elevating houses) and developing emergency plans to guide responses during the coastal disasters that will

inevitably happen. Protection focuses on active efforts to curb the effects of erosion on coastal communities through “hard” or “soft” structures (Neal et al, 2019, p. 292).

2.2.2 Hard and Soft Structures

“Hard structures” generally refer to physical, man-made structures, such as seawalls (Figure 2), groins, jetties (Figure 3), artificial reefs (Figure 4), and geotubes (Figure 5), while “soft structures” recreate natural systems, such as dunes (Figure 6) and wetlands (Rangel-Buitrago et al. 2019). Seawalls are large, typically stone or cement barriers that run parallel to a shoreline. Since they are enormously expensive to build and maintain, they are typically used to protect highly developed, dense urban areas directly from powerful storm waves and flooding from storm surge. Groins and jetties are solid structures running perpendicular or parallel to the shoreline. These structures are designed to trap sediment in order to prevent beach erosion and long-shore drift of sediment. Geotubes are giant pockets of geotextiles filled with a softer substance such as sand. They act like seawalls to block out direct erosion of cliffs and bluffs, but require constant replenishment with large amounts of sacrificial sand.

Figure 2: A Seawall on Quaise Road, Nantucket (Hunt, Sample, & Sullivan. 2014)

Figure 3: A Groin Field in Northwest Nantucket (Hunt et al. 2014)

Figure 4: An Artificial Florida Limestone Reef (Reefmaker. 2016)

Figure 5: Geotubes in Sconset, Nantucket (Hunt et al. 2014)

Figure 6: Sand Dune with Beach Grass and Fencing on Nantucket (Hunt et al. 2014)

Both hard and soft structured approaches to coastal management each have their own advantages and disadvantages (see Table 1). In the 1950s and 1960s, the most popular course of action in the U.S. was implementing hard structures. Hard structures appeared to offer the most obvious and most robust defense against coastal erosion, although it soon became apparent that they have many drawbacks. For example, seawalls may protect the immediate area behind them from direct wave action, but they tend to cause severe scouring where they end (Figure 7).

Figure 7: Scouring at End of Seawall on Nantucket (Hunt et al., 2014)

Seawalls may also lead to the depletion of beaches beneath them by blocking natural replenishment. Like other hard structures, seawalls are also expensive to install and repair. Alternatively, soft structures offer a more cost-efficient solution initially. Soft structures may not

cost as much to install, but may require more constant maintenance than their hard counterparts, depending on the structure. For example, planting dune vegetation may not require the same labor and materials costs as building a jetty, but the vegetation will require frequent observation and attention before it truly becomes established (Board, 2014). Additionally, though soft structures tend to be much better for the environment in the long run, they may take longer than hard structures to become fully effective. For instance, a geotube blocks erosion immediately following installation, whereas beach grass will take several years to become established and effective (Akson, 2012).

Table 1: Advantages and Disadvantages of Common Erosion Structures (modified from Hunt et al., 2014, Table 1)

Hard Structures	**Advantages**	**Disadvantages**
Seawalls	Direct barrier, firm, less frequent renovations required	Expensive to build and upkeep, disruptive to natural erosion patterns, directs energy elsewhere
Groins	Sediment and sand trap	Expensive to build and upkeep, disruptive to natural erosion patterns, directs energy elsewhere
Geotubes	Direct barrier blocking, softer than seawalls	Expensive to maintain (sacrificial sand washes away), disruptive to natural erosion patterns, redirects wave energy
Artificial reefs	No eyesore for land, decrease wave energy in the water	High cost installation, minimal options for locations

Soft Structures	Advantages	Disadvantages
Sand dunes	Natural deterrent to erosion	Constant attention and maintenance before established
Vegetation	Visually appealing and natural deterrent to erosion	Particular upkeep, out of hand growth could cause disruption to local ecosystems
Wetlands	Plants act as a natural barrier against waves, roots interlock soil in place	Overdone may disrupt local ecosystems, even more required upkeep

2.3 Government Regulations and Policies

Federal, states, and local governments oversee what property owners and local communities may do to control erosion through a complex set of policies and regulation (as shown in Table 2). The federal government focuses more on agency oversight of the issues through the FEMA, NOAA, and the United States Army Corps of Engineers (USACE). The states establish setback policies to limit development in the coastal zone and regulate the use of erosion control structures to minimize adverse impacts and unforeseen consequences. Local governments (i.e., towns and/or counties) enforce building codes and land use regulations, such as prohibitions on building in wetlands or on dunes. Individual property owners are required to comply with building codes to ensure structures can withstand storms and flooding.

Table 2: Summary of Approaches to Erosion Management (modified from Heinz 2000, Table S.5)

Federal Agencies	• Provide flood insurance coverage (FEMA-NFIP) • Prohibit federal expenditures in designated coastal barriers (U.S.FWS – Coastal Barrier Resources Act) • Provides disaster response and recovery assistance (FEMA) • Support state erosion management programs (NOAA – CZMA) • Participate in federal shore protection projects (USACE)
States	• Establish and enforce setback policies • Regulate the use of shoreline stabilization structures • Require disclosure of erosion hazards in real estate transactions • Participate in federal and nonfederal shore protection projects
Local Governments	• Establish and enforce building codes and land use regulations • Enforce NFIP building and floodplain management requirements • Participate in federal and nonfederal shore protection projects
Individuals	• Protect private property through structural and non-structural measures • Comply with building codes and land use regulations

2.3.1 Federal Regulations

The Army Corps of Engineers, under the power derived from the Clean Water Act of 1972, established the guidelines set forth in Nationwide Permit 13. In *Armoring Against Coastal Climate Adaptation in the US: A Massachusetts Perspective*, McGuire states, "The general permit [Permit 13] allows hard armoring with no application or review requirement so long as the armoring is no more than five-hundred feet in length and the fill material used to build the wall does not exceed one cubic yard per foot of length" (McGuire, 2017). In conjunction to the permitting process the Corps often works with local governments in developing coastal management projects that will reduce the risk of shoreline disasters like erosion or hurricanes. The USACE were granted rights to "conduct shore erosion control studies" via the Rivers and Harbors Act in 1930 (National Research Council, 2014).

The National Oceanic and Atmospheric Administration (NOAA) acts to "preserve, protect, develop, and where possible, to restore or enhance the resources of the nation's coastal zone" through the Coastal Zone Management Act of 1972 (CZMA) with the help of federal funding and planning (Neal 2018). The CZMA, "provides for the management of the nation's coastal resources...The goal is to 'preserve, protect, develop, and where possible, to restore or enhance the resources of the nation's coastal zone'"(NOAA, 2019). The Federal Emergency Management Agency deals with flood insurance for many coastal areas through the National Flood Insurance Act of 1968 and the National Flood Insurance Program (NFIP) (Neal 2018). The Stafford Disaster Relief and Emergency Assistance Act of 1988, "allows presidential disaster declarations to trigger financial and physical assistance through FEMA with 75% federal sharing of reconstruction costs" adding to the disaster support from FEMA (Neal 2018).

The Environmental Protection Agency is responsible for implementing the National Environmental Policy Act to ensure environmental protection in all large construction projects. NEPA requires federal agencies to submit project plans along with an Environmental Impact Statement (EIS) (Healy 2003 p 29). NEPA is designed to ensure the chosen project has the least negative impact on its surroundings. The NEPA process, however, only takes effect when a project is large or environmentally risky enough to trigger review (Healy 2003). For CWA Section 404 permitting categories I and II, no NEPA involvement is required.

2.3.2 State Regulations

The Commonwealth of Massachusetts currently supports the use of hard armoring over soft armoring as described in Chapter 91 of the permitting process (McGuire 2017). Chapter 91 of the Massachusetts Public Waterfront Act of 1866 provides for the "protection, management, and promotion of public use of tidelands and other waterways" while establishing a licensing program (Guercio, 2013, p. 370). Structures are prohibited in certain areas as Shipman notes, "Massachusetts coastal regulations, in part, prohibit armoring active coastal dunes, and prohibit armoring eroding coastal banks (coastal bluffs) when the proposed activity is intended to protect buildings constructed after the August 10, 1978, promulgation date of these regulations" (Shipman, 2009, p. 67). The main reason for not allowing hard structures on bluffs is to not disrupt the natural sediment flow that comes off the bluffs or dunes from waves or the wind. More recently, the Massachusetts Climate Change Adaptation Report of 2011 suggests not developing in areas prone to flooding from storm surges and coastal erosion. The report also suggests adding to the state building code to enhance materials and features to make storm resistant buildings (Guercio, 2013).

In conjunction with Chapter 91, the Massachusetts Department of Environmental Protection regulates the activities that may occur in or around defined wetlands according to the provisions of 310 CMR (Wetland Protections). Any project on a coastal dune or bank, as defined by 310 CMR 10.28 (2) and 10.30 (2) respectively, shall be subject to 310 CMR 10.27 Coastal Beaches, 10.28 Coastal Dunes and 10.30 Coastal Banks, and their respective subsections. These rules stipulate that any project should not cause more erosion or worsen the effects of flooding and should not affect the habitat of any rare species. All structures proposed must meet the requirements in these sections and seek approval from the Massachusetts Department of Environmental Protection.

Some have suggested the creation of artificial reefs to mitigate erosion. The Massachusetts Department of Environmental Protection, 310 CMR 10.25 sections 5, 6, and 7 could inhibit the creation of such artificial reefs. Section 5 states that the topography of the ocean floor shall not be altered to increase the effects of erosion. Section 6 stipulates that any structure should not adversely affect the water quality or the habitat of wildlife, while section 7 offers

protection for rare species. In order for a reef or any other erosion structure to be made they must accommodate these state regulations as well as any federal regulations that pertain as well.

The Massachusetts Office of Coastal Zone Management (CZM), through its StormSmart Coasts Program, “provides information, strategies, and tools to help communities and people working and living on the coast to address the challenges of erosion, flooding, storms, sea level rise, and other climate change impacts” (CZM n.d.). The program also provides checklists and guidance for local conservation committees to review before approving a project to implement an erosion structure.

2.3.3 Local Regulations

The town of Nantucket must adhere to the laws and regulations set forth in Chapter 91 and 310 CMR, but the town has promulgated its own set of laws to protect the coast and other environments. Nantucket Law Chapter 136 (Wetlands) states that no work shall be done to, “ remove, fill, dredge, alter or build upon or within 100 feet of any bank, freshwater wetland, coastal wetland, beach, dune, flat, marsh, meadow, bog, swamp” without receiving a permit from the Nantucket Conservation Commission (§ 136-3). The applicant must provide credible evidence that the work will not cause more severe flooding or erosion and not affect wildlife or any other interests set forth in the chapter.

In section one of Chapter 67 (Management of Coastal Properties Owned by Town), “a temporary moratorium on the use of Town properties located along the eastern coastline of Nantucket from Great Point south to and including the Siasconset sewer beds (hereinafter "Town-owned coastal land") for new coastal engineering structures, bluff armoring projects, hard or soft erosion control devices, bulkheads and the like, on Town-owned coastal land” (§ 67-1 (A)) with only permitting for project to be issued by the Board of Selectmen.

Chapter 99 of Nantucket Law relates specifically to Madaket Harbor stating that, “activities might include structural improvements (i.e., dredging…)” making any future projects available to have dredging incorporated. Any land involved in a project is still subject zoning regulations as set forth in Chapter 139.

With regard to soft structures, the Corps of Engineers states that, "Nonstructural measures are most often under the jurisdiction of state and local governments (and individuals) to develop, implement, and regulate, and they cannot be imposed by the Federal government" (USACE 2013). Soft structure projects, such as planting vegetation, must still comply with Massachusetts Chapter 91 and 310 CMR, as well as Chapter 136 of Nantucket Law in order to plant native vegetation as a means of erosion control. The StormSmart Coasts Program fact sheet *Introduction to No Adverse Impact (NAI) Land Management in the Coastal Zone* states, "public and private projects be designed and completed in such a way that they do not: 1) pose a threat to public safety, 2) increase flood or storm damage to public or private property, and/or 3) strain municipal budgets by raising community expenditures for storm-damage mitigation, stormwater management, emergency services, and disaster recovery efforts" adding to the complexity of implementing erosion structures (Shaw, 2008).

Beside town laws that directly impact the planning and building of an erosion structure the 2014 Coastal Management Plan (CMP) "establishes priorities and procedures for protecting and managing town owned infrastructure, public access points and roads around the island adjacent to the coastline" (CMP 2014, p. 3). In an attempt to protect particular parcels of town land and infrastructure that are suffering or at risk of coastal erosion the CMP evaluated, "water quality, coastal hazards, habitat, erosion control, harbors, public access policy, beach access policy, offshore resources, fisheries, alternative energy, homeland security, data accessibility, consistency with state and local laws, and integration with our municipal harbors plan" (CMP 2014, p. 3). The CMP also lays out the process for filing a coastal project with the Nantucket Conservation Commission. All necessary permits must be acquired before hand and a notice of intent must be sent to the commission that meets all state and town laws regarding wetlands. In addition to the CMP a new Community Resilience Building Workshops (CRB) final report came out in April of 2019, with the recommendation of creating a new municipal position of resilience coordinator who would be tasked with coordinating resilience efforts across the island and developing new resilience policies (CRB 2019).

The towns newly adopted Hazard Mitigation Plan (HMP) (see Appendix D) aims, "'To mitigate the detrimental impacts of natural hazards to Nantucket while maintaining and enhancing the Island's quality of life, historic essence, aesthetic beauty, and natural and habitat

resources'" (HMP 2019, p. ES-i). The report provides three mitigation strategies: retreat, accommodation, and protection with the goal of protecting town infrastructure while providing a limited plan for private property owners. The town has in the past taken on the tasks of, "beach and dune nourishment projects, bank stabilization projects, public education" as mitigation efforts against coastal erosion (HMP 2019, p. ES-vii). The HMP sets out a list of projects mainly pertaining to the town that they need to undertake in order to protect its infrastructure and mitigate the damage done in the future by all natural events.

2.4 Erosion on Nantucket Island

Erosion and sedimentation have been reshaping Nantucket for centuries. Figure 8 (MORIS excerpt below) shows how dramatically shorelines of Tuckernuck Island, Muskeget Island, and Smith Point have changed since the 1840s. In many places the shoreline has retreated several hundred feet in the past 150 years. Erosion rates vary dramatically around the coastline of Nantucket from less than two feet/year to more than twenty five feet/year. Erosion rates tend to be lower on the north coast and higher on the south coast, but vary due to a variety of factors, including ocean currents, wave energy, storm exposure, topography, and infrastructure. It's impossible to have a single strategy work for every coastal neighborhood of the island. While the area from Sankaty Lighthouse to Great Point may erode around three feet or less per year, Madaket loses an average of thirteen feet per year to erosion (Brown et al, 1979, p 15-19). Despite the fact that the erosion rates in Sconset may be lower than in Madaket, three feet of erosion at the base of a cliff can have dramatic impacts on bluffs above including any properties

on them. Thus, the areas of concern for Nantucket are a combination of erosion and the presence of key infrastructure (e.g., airport, sewer beds, Tom Nevers) and/or residential development.

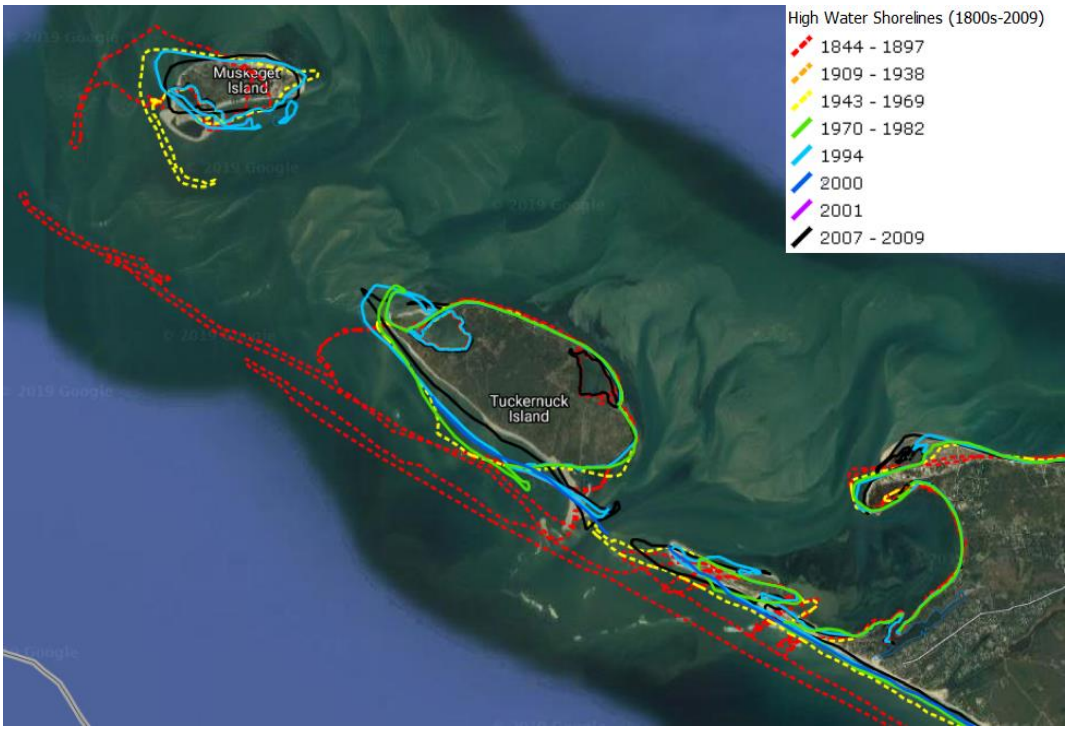


Figure 8: The Changing Shorelines of Islands Since the 1840s (MORIS)

Residents of Nantucket understand the threat of erosion very clearly. When asked to rate natural hazards on a scale of one to three, one being low risk, three being high risk, the average response rating of coastal erosion was 2.16 (HMP, 2019). Erosion was ranked as the fourth-highest hazard in terms of the number of respondents affected. The locations mentioned most frequently as being vulnerable to erosion included Madaket areas such as Ames Avenue, Smith's Point, and Millie's bridge (HMP, 2019).

There has been a number of previous actions taken both by individual homeowners and homeowner associations with a goal to mitigate coastal erosion. Unfortunately, most of the actions taken previously had very controversial and diverse results. For example, the ‘Geotube project’ implemented by Sconset Beach Preservation fund included installing geotubes, which are giant cylinders made of an extremely durable plastic mesh filled with sand. The tubes extend 900 ft along the beach to block the oncoming wave energy from further eroding the bluff.

The project proved to be working for Sconset; the houses at the top of the bluff above the tubes have experiences little if any property loss since their installation. However, it became a very controversial topic over time due to the sheer cost of the project and its constant maintenance. It also has left many residents here with negative opinions of action against erosion due to the legal battles of the town denying the expansion of the project several times over the past year.

Individual homeowners have also taken action against erosion in their own ways. Some residents believe nature will be nature and choose to retreat, whereas others may choose to build up their own defenses against the elements. The barricade in front of Eugene Ratner's house is an example of a controversial private project. Ratner surrounded his house with sandbags to decrease the impact of the waves on his property. However, the wave energy blocked by the bags got transferred to the neighboring properties, causing them to erode much faster than usual. Even so, Ratner believed he was successful in his actions, seeing as how his home lasted an extra few years after his neighbors had to relocate.

Currently, there's a lack of organization in terms of handling problems that arise from the effects of erosion. In the case of a private property such as a home becoming endangered by erosion, the town leaves the responsibility of relocating it, selling it, or demolishing it to the homeowners. This counts for all houses deemed uninhabitable, including when town utilities are compromised such as an exposed septic tank. The response of the town to erosion is very reactionary as opposed to proactive. In terms of infrastructure such as roadways being compromised, the town offers emergency solutions once a natural hazard has already damaged the roadway. However, in an attempt to be proactive and protect current infrastructure, soft structures have started being implemented such as a project to plant beach grasses along a dune in Madaket to stabilize the sand (courtesy of Vince Murphy, the town's Coastal Resilience Coordinator, and Jennifer Karberg, Nantucket Conservation Foundation's Research Program Supervisor). This project is being funded mainly by Madaket Conservation Association, a neighborhood organization of Madaket homeowners. Currently, the town does not have much set aside in terms of costs for erosion other than what may be in the Coastal Resiliency Plan, which is still in development.

3. Methods

The overarching goal of our project was to assist the Civic League in developing strategies and materials to help communities on Nantucket manage coastal erosion. We have outlined three major objectives that have helped us reach this goal, which were to:

1. Evaluate best practices in the management of coastal erosion, and identify lessons learned from their application in selected communities in the U.S.
2. Assess the policies and plans currently in place on the island to mitigate the adverse effects of coastal erosion.
3. Develop a case study on the erosion problem and potential mitigation strategies in Madaket.

We accomplished these goals through a combination of additional background research, personal observation, and interviews. Through these efforts, we are able to provide a set of recommendations with Madaket's situation in mind that may be applied to an island-wide effort to manage coastal erosion. Figure 9 presents an overview of the tasks associated with each objective and discussed in detail below.

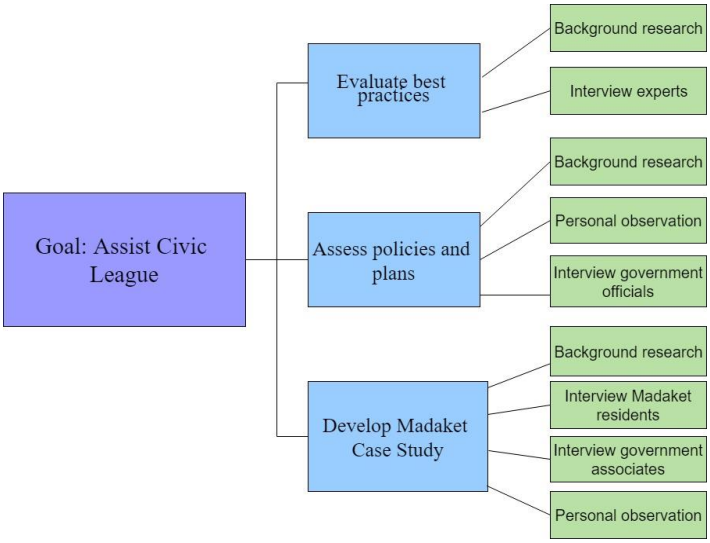


Figure 9: Project Objectives and Tasks

3.1: Objective 1: Evaluated best practices in the mitigation of coastal erosion and identified the lessons learned from their application in selected communities in the US

Building on the background research presented above, we conducted interviews with a variety of federal, state, and local government officials and other experts to determine best practices in the mitigation of coastal erosion in the U.S. We focused our attention on the east coast of the U.S., especially areas that face similar problems as Nantucket, such as the Outer Banks of North Carolina.

We conducted phone interviews with Sarah Oktay, Roberta Thuman, and Patricia Bowie. Dr. Sarah Oktay ran the University of Massachusetts Field Station on Nantucket for many years and served on several town committees that dealt with coastal erosion policies and plans. We quizzed Dr. Oktay about the nature of erosion on Nantucket, erosion control effort, and how Nantucket compares to other regions in the US. Patricia Bowie, Massachusetts Coastal Resiliency Specialist, gave us her perspective on how Nantucket's problems and strategies compare with other communities in Massachusetts. We also spoke to Roberta Thuman, Public Information Officer for Nags Head, NC.

The interviews lasted around an hour and began with a preamble that explained the nature of our research and the purpose of the interview. At each interview, almost all group members were present, and shared the responsibility of asking questions and taking notes. Following the interviews, we identified key themes and quotations to use in our findings. We solicited permission to quote the interviewees and explained that we will give each person we interview the right to review any materials we use prior to publication. See Appendix B and Appendix C for copies of the interview questions and preambles.

3.2 Objective 2: Assess the policies and plans currently in place on the island to mitigate the adverse effects of coastal erosion.

We supplemented our initial background research on Nantucket policies and plans to mitigate erosion by interviewing officials and other stakeholders and conducting site visits to key locations on the island.

In the background section above, we reviewed several key planning documents, including Nantucket's Beach Management Plan (BMP, 2005), Erisman's thesis on Nantucket's coastal resilience plan (Erisman, 2014), and the Nantucket Hazard Mitigation Plan (HMP, 2019).

We interviewed a variety of local officials and volunteers to clarify our understanding of the town plans and policies for mitigating coastal erosion. Table 3 indicates the name of the interviewee, the organization they represent, and the date of the interview.

Table 3: List of Interviews

Interviewee	**Represented Organization**	**Date Interviewed**
D. Anne Atherton	Nantucket Coastal Conservancy (NCC)	November 8th, 2019
Rick Atherton	NCC	November 1st, 2019
Holly Backus	Town of Nantucket Planning and Zoning	November 19th, 2019
Dr. Sarah Bois	Linda Loring Nature Foundation	November 21st, 2019
Peter Brace	NCC	November 6th, 2019
Jeff Carlson	Natural Resources Department	October 31st, 2019
Bill Grieder	Madaket Conservation Association	November 13th, 2019
Jennifer Karberg	Nantucket Conservation Foundation	November 13th, 2019
Rob McNeil	Department of Public Works	November 1st, 2019
Emily Molden	Nantucket Land Council	November 19th, 2019

Stephen Murphy	Town of Nantucket Fire Department	November 5th, 2019
Vince Murphy	Coastal Resiliency Advisory Committee (CRAC)	October 24th, 2019
Dr. Sarah Oktay	Former Vice Chair of Conservation Commission	October 29th, 2019
Gregg Tivnan	Town of Nantucket Planning Board	October 25th, 2019

We selected interviewees based on their official duties, their roles in developing plans and policies, and based on referrals.

In addition to that, we interviewed representatives of the SBPF (Sconset Beach Preservation Fund) to clarify their perspectives on erosion control efforts in Sconset and particularly learn about their insights from implementing the geotube project. We developed an initial set of Sconset related questions based on what we know about their efforts so far (see Interview questions).

We supplemented our understanding of the nature of the problems and previous erosion control efforts by conducting personal observations at key locations on the island, including Madaket, Sconset, the airport, and Tom Nevers. We took pictures to document the current conditions and erosion control measures at these sites with particular attention to the proximity of buildings and infrastructure as well as evidence of beach scouring, cliff collapse, and dune conditions.

3.3 Objective 3: Developed a case study on the erosion problem and potential mitigation strategies in Madaket.

Our third objective was to develop a case study on the erosion problem and come up with potential mitigation strategies in Madaket. To achieve the objective, we collected information on the extent and nature of the erosion problem, current and previous public and private attempts to control erosion or mitigate the adverse consequences in Madaket, and possible mitigation

strategies. We also obtained the opinions of homeowners in Madaket through an online survey distributed via the Civic League.

We reviewed newspaper articles, newsletters, blog postings and other local sources to gather information on the four topic areas, with a special emphasis on Madaket.

As described in section 3.2 we identified organizations and people, whom we interviewed both on Nantucket policies in general and some of the public or private projects to mitigate coastal erosion in Madaket.

In order to get public opinions on the problems and possible solutions, we conducted a survey of homeowners in Madaket. In order to do that, we developed an interview script alongside our sponsors that would give us an understanding of what solutions could work for Madaket homeowners from their standpoint, as well as identify any possible problems that we could address with our recommendations.

3.4: Recommendations

Based on the findings from our research, we developed several recommendations as to how the Town, the Madaket community, and the Civic League might move forward in developing strategies to mitigate the adverse impacts of erosion in Madaket.

4. Findings

4.1 Coastal Erosion on Nantucket

As an island 30 miles off the coast of Massachusetts, Nantucket registers some of the highest rates of erosion in the United States, ranging from two to twenty five feet/year (CZM, 2013). Since the 1950s, the shoreline has already retreated hundreds of feet in some places. The south coast of Nantucket, in particular the Madaket area, is “the fastest-eroding shoreline in the state of Massachusetts. To see this kind of rate of erosion is extraordinary” (Turer, 2016). Many homes have been lost over the years, with many more homes and substantial public infrastructure are at risk. Several private property owners acted on their own to try to limit the damages from erosion on their properties, including installing sandbags and fencing. The town has taken action to protect vulnerable areas such as downtown and is concerned about other high-risk areas such

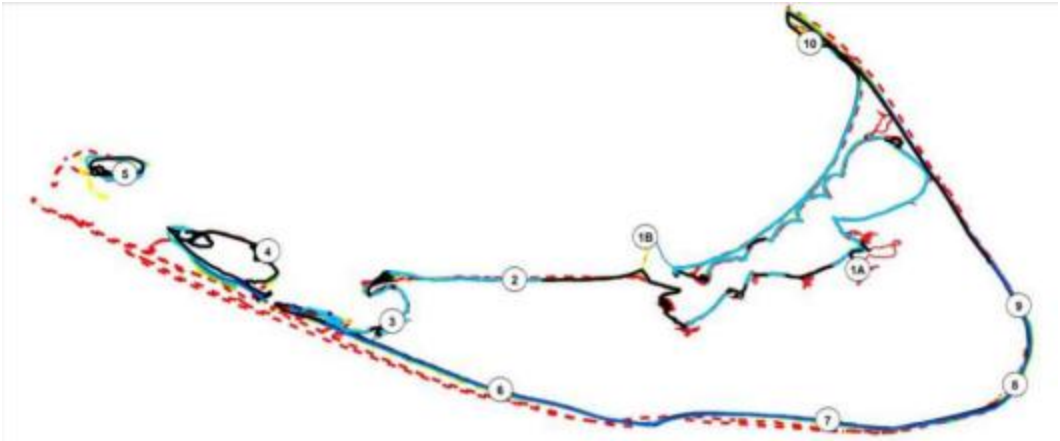
as Nobadeer Beach, Tom Nevers and Madaket where town infrastructure is at risk. After interviewing over a dozen town officials and other stakeholders, as well as surveying almost two hundred Madaket property owners, we developed a set of recommendations for mitigating the effects of erosion on the entire island of Nantucket, with a focus for Madaket. The following sections contain information about the research findings and describe how the results drove the decisions for the recommendations given to mitigate the effects of erosion.

4.1.1 Erosion Rates on Nantucket

Due to tidal movements, frequent storms, and the island's structure, the manifestation of coastal erosion vary widely across Nantucket. Nantucket is composed of sandy moraine deposits left behind by the retreating ice sheets several thousand years ago. This sandy material is especially susceptible to erosion and the shoreline of Nantucket has been continually changing by storms and tides for centuries. Madaket (southwest side) and Sconset (east side) exemplify the variations that trace to local topography. Figures 10 and 11 show the dramatic difference between the high bluffs at Sconset and low profile beach in Madaket. Figure 12 shows how erosion rates vary around the island. Erosion rates are generally lower on the north shore, where they are typically less than five feet/year. On the south shore they range from ten feet/year on Nobadeer Beach to twenty five feet/year around the islands of Muskeget and Tuckernuck. The islands and parts of Madaket are especially vulnerable to storms and tides, which continually reshape the shoreline. As seen in Figure 8, the shorelines in these areas have migrated several hundred feet since the end of the 19th century. Erosion averages about eight and a half feet annually in Madaket vs. only about 1.61 ft annually in Sconset (Knisel, 2013). The variability in erosion rates from place to place and over time complicates the responses taken by both town government and local property owners. The variation in erosion rates can be difficult to predict as, "some years Madaket loses thirteen feet due to erosion, other years it only loses two, it's very hard to plan around those rates" (S. Oktay, personal communication, October 29th, 2019). In Sconset, where a highly politicized and publicized erosion structure was installed, the rates may appear low on paper, but due to the structure of the coast and its steep cliffs, any horizontal erosion has a dramatic impact on the bluffs above. The erosion and retreating shorelines have destroyed numerous houses, disrupted infrastructure (e.g., roads, wells, and septic systems), and negated property boundaries across the island.

Figure 10: High Bluff and Beach in Sconset (Brace, 2010)

Figure 11: Low Profile Beach in Madaket (Lenhart, 2016).



Sector	1A	1B	2	3	4	5	6	7	8	9	10
Max. Erosion (ft/yr)	-4.82		-2.69	-8.50	-22.67	-23.46	-12.63	-9.22		-1.61	-7.94

Figure 12: Shoreline Change Around Nantucket (Knisel, 2013)

4.1.2 Impacts and Responses to Erosion in Nantucket

The visible effects of coastal erosion range from destroying homes during severe winter storms, exposing sewage piping, destroying roads, and slowly stealing properties one wave at a time. Damage can also come from any efforts taken to fight erosion. "Any sort of protection has costs associated with it. Sometimes they're social costs, economic costs, environmental costs" (J. Carlson, personal communication, October 31st, 2019). Erosion is more than a mere physical phenomenon. There are numerous heart-rending stories of places where grandchildren grew up, weddings took place, and memories were made, but unfortunately the properties no longer exist. The following story is from a Madaket homeowner who lost her home to coastal erosion (confidential, personal communication, December 5th).

> "I owned property on the ocean at the end of Rhode Island Avenue on Smith Point for 5 years. We as a community planted dune grass and dune fences to build up the beach and stall erosion. We had signs discouraging walking in the dunes.
>
> In 6 hours on October 8, 2002 we lost 60 feet of dune in front of our house and neighbors. The water took out the piers of the house in the front and

the deck in the front. The following week, the same situation reoccurred, removing more piers under the house. They were not even tropical storms that did this. I had two insurance companies at the time, hired two lawyers, a land-sea engineer, personal adjuster and a Nantucket mover of homes very familiar in these situations. I consulted numerous people to see if I could prevent future damage or replenish the beach. Sandbags were not an option. The house was condemned. The fire department got permission to burn the house down which was authorized by a town committee. I got a court injunction from a judge in Hyannis to prevent this from happening. The home was fully insured.

Eventually after six months, the insurance company paid a mover to buy the house and it was removed and sold and reassembled and put to good use. We are happy that someone was able to use the home.

Our final conclusion and advise from our numerous consultants is that 'you may win a battle but not the war'.

We agree wholeheartedly and have never regretted our decision. Mother nature cannot be beat and it is not worth the prolonged heart break nor receive ire from neighbors or town threats to try and delay the inevitable."

The worst part about this story is not the event, but the fact that this is one of many. Stories like these can be heard from dozens of homeowners past and present. The family, like many others on the island, realized that mother nature cannot be beat and the erosion will continue to be inevitable. Other, Nantucket residents acting through emotion, will do anything to save their homes. Some Madaket residents throughout the years have attempted to build defenses against nature's fury by installing steel walls and using piles of sandbags. Gene Ratner's efforts to save his home on Sheep Pond Road are known by many Nantucketers. Ratner built a defense of dozens of sandbags to prevent his property from eroding as shown in Figure 13. He was successful for a time, but while the sandbags protected the immediate area around his home, the sea scoured away his neighbor's properties on either side. After fifteen years, his home was left standing precarious and vulnerable on a peninsular and was eventually lost to the sea (Figure 14).

Figure 13: Sand Bags Protect Ratner's Home (Smith, 2008)

Figure 14: Ratner Loses the Battle (Powers, 2010)

It is apparent that erosion is destructive, unpredictable, and unforgiving. Peter Brace understood this concept as he stated, "You're not going to get away from erosion, you're not going to stop it" (P. Brace, personal communication, November 6th, 2019). Over time, the island has taken actions hoping to counter the impacts it has on the land. In 2007, the town took the preventative step of moving Sankaty Lighthouse away from the eroding Sconset bluff. Homeowners, are repositioning individual dwelling units in response to erosion rather than risking them being declared uninhabitable. The moves may be within their same lot, further back from the threat of the sea, or off the lot entirely.

Another area of Nantucket impacted by erosion are the many brackish ponds across the island. Some, such as Long Pond towards the southwest, are tidal and subject to severe flooding in storms. During a recent violent storm, Sesachacha Pond towards the east, breached to the

Atlantic, and strong easterly winds. Wave action eroded some of Polpis Road. As a short-term solution, the town used jersey barriers to make the road passable again. This spawned an idea for a project at Sesachacha Pond (discussed ahead in our findings). Damage to roads is an issue that Nantucket must confront, as "it always comes down to public health and utilities, and road access is a critical aspect of that" (G. Tivnan, personal communication, October 25th, 2019).

The public agrees that, "Something needs to be done, it's just a question of what, when, how, and who will pay for it" (B. Greider, personal communication, November 11th, 2013). In terms of funding, coastal erosion is a very costly problem to deal with. The island of Nantucket is small and the official estimated year-round population hovers around 11,000, which makes it difficult to find funding for mitigation structures, upkeep, and cleanup. Typically, homeowners are responsible for cleaning up and removing homes that are rendered uninhabitable by erosion and storm damage, but the town is responsible for repairing town infrastructure, such as roads, bridges, and sewer and water lines. Many properties in areas that are vulnerable to severe erosion, such as Madaket, do not have town sewer or water, but properties may be condemned if storms and erosion render their septic systems or wells inoperable.

Response to the erosion vary throughout the island in response to the severity of the issue. Most of the remaining erosion control structures (typically hard structures) have been in place for decades. A 2014 project, "Evaluating Coastal Erosion Structures", found that forty two out of the seventy two structures found were hard structures (Hunt et al., 2014). In order to make plans for the erosion effort, "The town of Nantucket put a moratorium [in 2008] on the installation of all seawalls and other hard structures until the town could approve a coastal management plan. Any seawall or hard structure built before 1978 was grandfathered in so the structure is allowed to be rebuilt or repaired in the same manner it was permitted" (Hunt et al., 2014). The main problem with these seawalls is their acceleration of erosion through redirection of wave energy known as scouring (Figure 15). Other hard structures such as those downtown, were grandfathered because soft structures, such as beach grasses or dunes, are not viable in the area. On the north side of Easy Street, the town recently installed bulkheads to protect downtown as shown in Figure 16. The bulkheads prevent erosion, but their primary purpose is to limit flooding in downtown.

Figure 15: Scouring at Southern End in Sconset (Kindflow Productions, 2018)

Figure 16: Easy Street Bulkhead Repairs (Pykosz, 2016)

The town's Natural Hazard Mitigation Plan (HMP) now in place does not deal directly with the issues of erosion, except for strategies #SC3 and #SC4. These strategies call for a sand study to be conducted to monitor island wide erosion and map harbor floors to gauge the sediment build up (HMP, 2019) To deal with erosion and coastal issues more specifically, the town has appointed a coastal resilience coordinator, and an advisory committee to develop and draft a Coastal Resilience Plan. This plan focuses on risks to town property and infrastructure but does not address land that is privately owned. Homeowners are left to act on their own, without town guidance. Unfortunately, unpermitted actions taken by homeowners may do more harm

than good (as in the case of the Ratner home). Thus, a coordinated effort amongst multiple homeowners with guidance from the town and large conservation organizations is likely the best strategy.

4.1.3 Action in Nantucket: Siasconset (Sconset)

Sconset faces a particularly severe erosion threat not because of high erosion rates per se, but because of its topography. Relatively little erosion of one to two feet at the base of the 100 foot bluff can dramatically affect the properties located on the cliff edge above. As a result, homeowners have tried various efforts to mitigate erosion through the years. The most recent effort entailed the installation of geotubes and has been controversial since its inception.

In 2013, the use of 900 feet of emergency geotubing was approved for an area off Baxter Road as seen in Figure 17. The Siasconset Beach Preservation Fund (SBPF) created a plan that "For every linear foot of protected bluff, SBPF is required to provide 22 cubic yards of sand for mitigation. Since the project area is 947 feet long, that is nearly 1,000 dump truck loads worth of sand" (Siasconset Beach Preservation Fund, 2013). To function as intended, this tubing must be covered with tons of "sacrificial sand", which serves to replenish sand swept away by storms that relentlessly uncover the geotubes and is needed to fulfill the state permit. With such ongoing maintenance after each storm, the geotubes proved effective in slowing erosion in the immediately affected area. However, such maintenance itself poses separate problems: the constant back and forth of trucks to replenish the sacrificial sand degrades the local roads. To add to these problems, the project has been controversial since the state overruled the ruling of the Conservation Commission allowed the project to proceed even though it is located on town property.

Figure 17: Exposed Geotubes in Sconset. (SBPF)

4.1.4 Impacts of Erosion in Madaket

The Madaket area faces a very different struggle with erosion. High and unpredictable erosion rates have reshaped the coastline and taken many homes over the years, including the infamous Stilt House at Millie's Bridge. Areas of special concern are Smith Point (Figures 18, 19), Millie's Bridge, Ames Avenue (Figures 20, 21), and the shore beyond Sheep Pond Road (Figure 22).

On Smith Point, erosion rates have taken out many houses including the family who lost their home (mentioned earlier on page 25). Compounding the threat to Smith Point is the prospect of Esters Island becoming an actual island due to a breakthrough in the land (Figure 18). Causing the three houses to only be accessible by boat, that would otherwise drive over the beach to access their homes. In figure 19, you can observe where the perpetual sand movement bridged the gap, making Ester's Island vehicle-accessible.

At Millie's Bridge and Ames Ave., a storm in 2017 took the Emery house (a.k.a. the Stilt House), and threatened the structural integrity of the bridge, forcing an emergency action of placing jersey barriers at the base. At the junction of Madaket Road and Ames Ave. is a new town project intended to protect the intersection leading up to the bridge. Were the road ever compromised, the bridge (along with all of Smith Point) would become inaccessible. On Sheep Pond Road homes are in danger of being lost (Figure 22), with homes like the Jordan's already

relocating back on their property (J. Jordan, personal communication, December 8, 2019). Smith Point has lost many feet of land, along with houses that were not moved.

Smith Point is an area of Madaket that has been most dramatically reshaped by erosion and sedimentation as a result of storms and tidal movements. Smith Point has approximately 50 homes that are seasonally occupied and accessible via Ames Avenue over Millie's Bridge (Figure 18). A further three homes are located further to the east on Esther's Island (Figure 19). Presently, a sand spit connects Smith Point and Esther's Island. Storms occasionally breach this spit, as happened most recently in 2007 (Figure 20), which means there is no land access to these properties.

Figure 18: Map of Smith Point Access through Millie's Bridge (Google Earth)

Figure 19: Smith Point After Sand Built Up Again (Google Earth)

Figure 20: Breakthrough Separating Esther Island and Smith Point in 2007 (Google Earth)

While a breach at Esther's Island is of concern, a far greater concern is the possible destruction of Millie's Bridge which would prevent access to more than fifty homes. This concern was heightened following a storm in 2017. Figure 21 shows the area around Millie's Bridge in 2015 when Hither Creek created a large lagoon on the south side of the bridge and the infamous Stilt House still stood on the bluff above the beach. Figure 22 shows the same area after a storm in October 2017 that filled the lagoon with sand. The Stilt House was rendered uninhabitable and was removed and the bridge was protected temporarily by the installation of Jersey barriers (Figure 23). The dune created during that storm has continued to grow with the

help of sand fencing, and the town is planning to plant beach grasses in 2020 in an effort to stabilize the dune system and afford additional protection to the bridge and Smith Point residents.

Figure 21: The Area of Millie's Bridge in May 2015 (Google Earth)

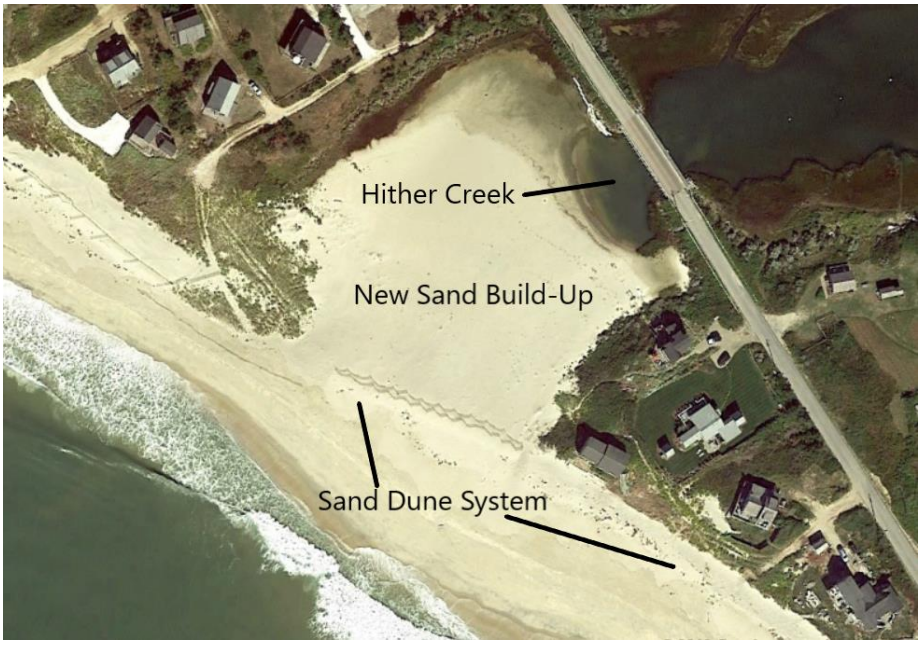


Figure 22: Millie's Bridge Area in 2018 (Google Earth)

Figure 23: Jersey Barrier Below Millie's Bridge (Keable, 2019)

While Millie's Bridge may appear to be better protected now than in the recent past due to the growth of the dune system, clearly another storm could just as dramatically alter the situation. Consequently, our interviewees suggested a variety of possible strategies to protect the bridge and maintain access to Smith Point. One option is merely to plant more grasses and install more fencing to promote dune growth and stabilization. Another option is to move Ames Avenue north onto existing town land, although this does little but gain some time. A more radical alternative might be to reconstruct Millie's Bridge as a causeway with culverts to allow the movement of water between the lagoon and Hither Creek proper. The most radical solution might be to move the bridge north and reconnect the road system. All of these possible solutions have significant financial and environmental implications as well as vocal proponents and detractors.

We conducted a survey, distributed to over 500 past and present members of the Madaket Conservation Association, and received 177 responses. The majority of respondents were unsure whether Millie's Bridge should be moved or recreated as a causeway or if Ames Avenue should be rerouted onto town property (Figure 24).

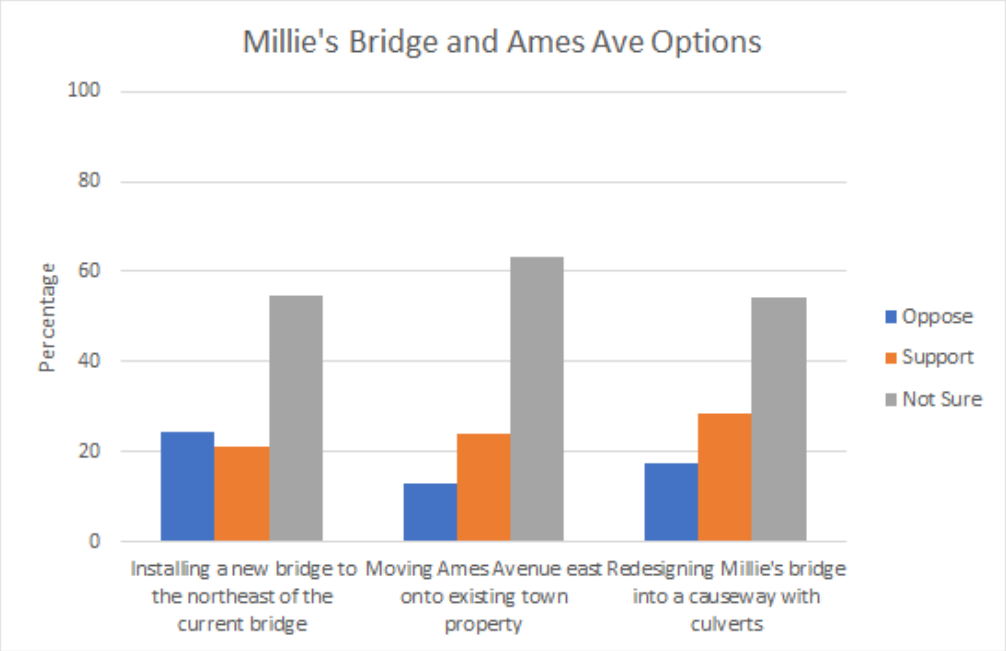


Figure 24: Madaket Resident Opinion for Millie's Bridge and Ames Ave.

A further area of particular concern in Madaket is Sheep Pond Road, facing the south shore. Figure 25 shows that the shoreline has retreated hundreds of feet in the last century. Many property parcels as well as actual homes and several portions of Sheep Pond Road have been lost to erosion during this time. Presently, 29 Sheep Pond Rd is just 200 ft from the high-water shoreline. Next to 29 Sheep Pond Rd. is 41 Sheep Pond Road, home to Jennifer Jordan, who since purchasing her property in 2000 has lost over two acres in land. In 2014 she had to move her house and since then has lost 70 ft (J. Jordan, personal communication, December 8, 2019). Figure 26 shows just how close the house now is to the edge of the embankment before the beach. Once the cement column is exposed (currently about 4 ft away), the town will deem the house uninhabitable and the homeowner will be left with the difficult decision of trying to move or sell the house or demolish it if necessary.

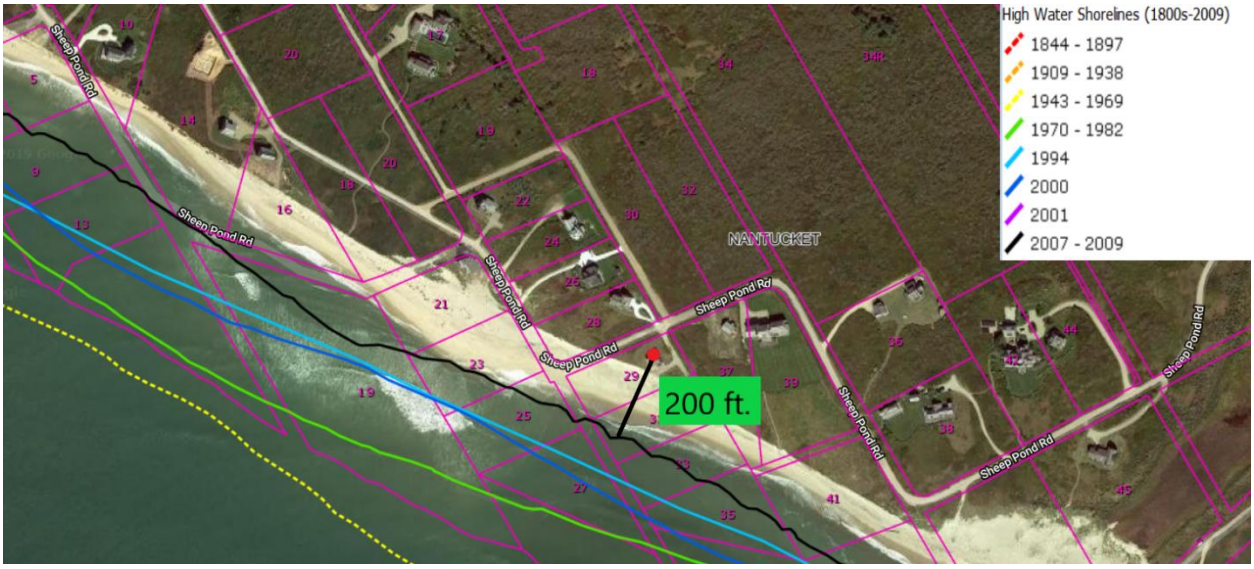


Figure 25: Loss of Shoreline on Sheep Pond Rd (MORIS)

Figure 26: 29 Sheep Pond Road (Keable, 2019)

4.2 Responding to Erosion in Madaket

Through our literature review, on-island interviews, and survey of homeowners' opinions, we have assembled a list of potential solutions that could minimize the damage done

by erosion, with special focus in mind on Madaket. There are no simple solutions to dealing with erosion. Each solution must be tailored to the particular situation, and each solution has advantages and disadvantages. “While I don’t believe you can stop mother nature, I do believe you can work with it and adapt” (B. Greider, personal communication, November 11th, 2019). However, the threat of erosion will only worsen with climate change and sea level rise, and the citizens of Nantucket are well aware of this impending danger: “Nantucket has limited time to figure out what we’re going to do to protect our citizens, our downtown area, our harbor” (P. Brace, personal communication, November 6th, 2019). In this section, we will introduce different erosion control strategies and assess their effectiveness in aiding the issue in Madaket.

Table 4: Alternative Strategies to Mitigate Erosion .

RESPONSES TO EROSION	**ADVANTAGES**	**DISADVANTAGES**
Research		
Sand Motion Study	• Better understand transport of sand around island • Beneficial to future projects such as artificial reefs and dredging	• Requires maintenance, • May be easily destroyed while developing from foot traffic and beach driving • Can also be destroyed if sea level/waves/storms wash away
Technologies		
Plant Beach/Dune Grasses*	• Proven effectiveness • Relatively inexpensive • Encourages dune build-up	• Requires maintenance, • May be easily destroyed while developing from foot traffic and beach driving • Can also be destroyed if sea level/waves/storms wash away

RESPONSES TO EROSION	**ADVANTAGES**	**DISADVANTAGES**
Install Beach/Dune Fencing*	• Reestablishes sand dunes, proven effective coastal protection	• Requires maintenance, • May be easily destroyed while developing from foot traffic and beach driving • Can also be destroyed if sea level/waves/storms wash away
Structuring Beach Access Points*	• Protects soft dune systems • Provides easier beach access for pedestrians	• Costly to enforce • Limits growth of plants
Beach Renourishment through dredging*	• Dredging keeps navigable channels clear • Provides sand for beach nourishment	• Matching grain size and composition may be difficult • Potential contamination or smothering of beaches and dunes • Ongoing process • Expensive • May disrupt scalloping • Requires baseline sand study
Artificial Reefs (Madaket Harbor)	• Absorb wave energy to reduce erosion at shore • Environmentally friendly • Promote habitat for aquatic species (e.g., oysters) • May improve water quality	• Limited to locations with relatively low wave energy • Long time period to establish • Susceptible to sea level rise • Experimental with limited data on effectiveness, durability, and adverse impacts

RESPONSES TO EROSION	**ADVANTAGES**	**DISADVANTAGES**
Joe Farrell's Shoal Modules	• Can act as a breakwater • Habitat for life • Replenish sand on beach	• Unexpected impacts with sand movement • Experimental with limited data of effectiveness, durability, and adverse impacts
Stilting of homes*	• Could possibly get funding from FEMA • Protects homes from property loss	• Funds from FEMA are not guaranteed • May need to make amendment to height restriction of homes • Expensive • Requires new building codes • Sewer & water connections
Policy		
Beach Driving Restrictions	• Protects embryonic and established dunes from damage • Conserves wildlife, especially bird nesting sites	• Potential loss of income for Town • Likely unpopular with tourists and some residents (e.g., recreational fishers) • Difficult and costly to enforce • Limits access (e.g., beaches and fishing)

RESPONSES TO EROSION	**ADVANTAGES**	**DISADVANTAGES**
Set-Back Laws (May be included in overlay amendment)	• Prevents structures from being built in erosion prone areas • Low cost implementation for town	• Does not protect existing structures • Opposition from developers • Opposition from owners of undeveloped land (i.e., 'uncompensated takings') • Long term to see any benefits • Implementation difficult with changing location of HWM
Zoning Overlay District Amendment*	• Prohibits building structures close to shoreline • Low cost implementation	• Too many overlays become cumbersome • Does not protect existing structures • Opposition from developers • Opposition from owners of undeveloped land (i.e., 'uncompensated takings') • Long term to see any benefits • Implementation difficult with changing location of HWM
Organizational		
Reinstate Nantucket Conservation District	• Provides funds for group projects of homeowners from USDA	• Funds are not guaranteed • Funds may only be used for private non-profit purposes • Requires reintroduction of committee

RESPONSES TO EROSION	**ADVANTAGES**	**DISADVANTAGES**
Coastal Erosion Czar and Implementation Committee	• Move CRAC from advisory to implementation role • Oversee implementation of erosion control efforts • Inexpensive	• Additional town committee • Requires town resources • Enforcement powers
Providing better guidance for homeowners	• Keep homeowners informed and encouraged • Can help organize group efforts • Inexpensive	• Requires close collaboration between Town and Conservation organizations

* See Appendix D

4.2.1 Research

One strategy to examine coastal erosion is an island-wide study of the motion of the sand in order to better understand the patterns of long-shore drift. We recommend the sand motion study not just for Madaket, but for the entire island. A sand motion study would not be fully effective for just one section of the island without taking into account the other coastlines. The study parallels the recommendations made in the town's Hazard Mitigation Plan (mentioned earlier on page 8). For options such as dredging or artificial reefs, a sand motion study would yield data on the littoral drift around the island, providing useful information to plan the best long-term erosion management strategies. When asked what more needs to be done, Jen Karberg states, "I think one of the pieces that we're missing is really understanding how sand moves around the island as a whole, because until you know, or can predict, where those erosion hotspots are going to be, where longshore drift is happening, where sand wants to deposit, it's hard to understand where a reef is going to be most effective" (J. Karberg, personal communication, November 11th, 2019). If a study prove that sand drifts to the east and west, away from the south shore. Erosion rates will increase in the years to come, making it wise to implement a more effective solution. Expressing great support for the sand motion study were ecologists Dr. Sarah Bois, Linda Loring Nature Foundation and Emily Molden, Nantucket Land Council. The outcome of this study will not be without a price, but will be vital in implementing the best long term erosion solutions. Ensuring proper success of the study, contracting the right

professionals will be vital, and could take between a year to several years to complete. Even so, the data obtained from sand study may provide a basis for effectiveness of projects to come, as well as potentially improve further effectiveness of more specific projects such as dredging, artificial reefs, and Joe Farrell's shoal modules.

4.2.2 Technologies

Dune Grass, Snow Fencing, and Beach Access

Previously mentioned in the background section, soft structures are more environmentally friendly substitutes for seawalls or other hard barriers. Many town official interviewed stressed the importance of rebuilding Madaket's dunes. These efforts will require installing snow fencing and/or planting dune grasses and vegetation to help stabilize sand dunes without significantly impacting the habitat. In our survey of Madaket residents, when asked about the effectiveness of dune grass and snow/sand fencing, 15% believed planting beach grass to be very effective with somewhat effective at 25% in mitigating erosion (Figure 27). In fact, the town of Nantucket is currently in the permitting process for one such plan to implement dune grasses. With the assistance of Vince Murphy, Coastal Resilience Coordinator and Dr. Jennifer Karberg, Research Program Supervisor for the Nantucket Conservation Foundation, beach vegetation will be planted along the sandy area where the Stilt House once stood south of Millie's Bridge as shown in Figure 28.

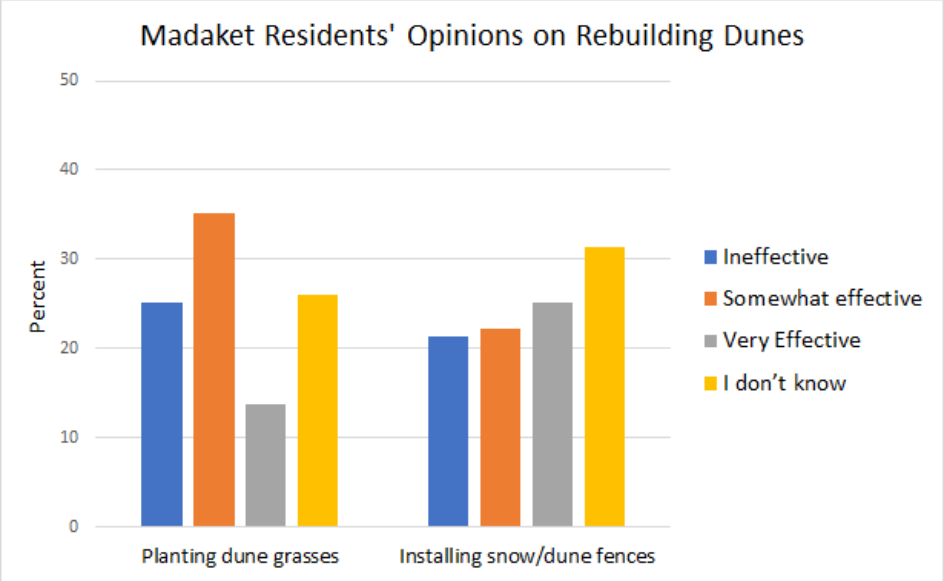


Figure 27: Residents' Opinions on the Effectiveness of Dune Grasses and Fencing

Figure 28: Property Ownership of the Dune at Millie's Bridge (Govaert, 2019)

[Note: The purple area is owned by Mass Audubon, the orange area n is privately owned, and the green area is town owned].

Planting beach grass and erecting sand fencing are much cheaper than some technologies mentioned below. In some cases, for a private non-profit property, the United States Department of Agriculture (USDA) may fund dune grass planting. However, dunes may require periodic maintenance (every one to five years) and take time to be established. These structures are much more vulnerable to severe storms and pedestrian or vehicular beach traffic. One such way to limit

damage from beach traffic is to include clearly marked beach access points and restrict driving (see discussion below). Without marked access, people may walk over the dune systems trampling vegetation while destabilizing the dunes. Evidence of this can be seen in Figure 29, which depicts a sign posted to keep people off the dunes, but the sand is covered in footprints and tire tracks. For more detailed information and guidance on dune fencing and other restoration practices, please refer to appendix D (CZM, 2019).

Figure 29: Dune in Madaket, with damage from footprints and tire tracks (Govaert, 2019)

Dredging and Re-nourishment

Another action to take in protecting beaches of Madaket against erosion is to re-nourish them through dredging, which was suggested by several stakeholders and received substantial public support in our survey. Dredging and beach nourishment is a common operation in many places such as New Jersey's Cape May (Figure 30).

Figure 30: Before (top) and After (bottom) Dredging Cape May, NJ (Kutner, n.d.)

Dredging and beach nourishment involves digging out navigational channels and other waterways to provide better access to ships navigating them, and relocating the sediment onto a shrinking beach. It may seem like a win-win situation, but there are many challenges when dredging. For one, it is a complicated permitting process especially considering that most dredging takes place within federal territory (over three miles off the coast). “If we had a dredging plan we could take sand from say, navigation channels, bring it out, store it for a year, let it become inert, and then find a correct recipient beach for the angularity of the sand that your after collecting and then spread it” (V. Murphy, personal communication, October 24th, 2019). The material would need to be thoroughly tested before disposing of it anywhere. Testing would including looking for contaminants to human life, to the environment, and checking if the grain size and composition of the material are suitable for where it would be deposited. Sara Oktay stated, “The beach isn’t just a parking lot, there are things that live in the beach at all times. If you bury them under 8 ft of sand you’re just going to kill them” (S. Oktay, personal communication, October 29th, 2019). Equipment from off island would require careful planning complicating an already expensive option that would need to be repeated approximately every five to ten years (CZM, 2013). Ideally, it would make the most sense to dredge material from Madaket harbor to nourish beaches on the southern shore of Madaket. However, thorough scientific assessments would be necessary to determine that the material from the harbor would be compatible with the material on the southern beach. In addition, an environmental study

would be necessary to confirm that dredging the harbor would not harm environmental resources such as the eel grass or scalloping beds. This is further evidence that a sand study would be highly recommended to precede dredging and beach renourishment. Our survey indicated that 52% of Madaket residents believe that beach renourishment through dredging would be very or somewhat effective (Figure 31).

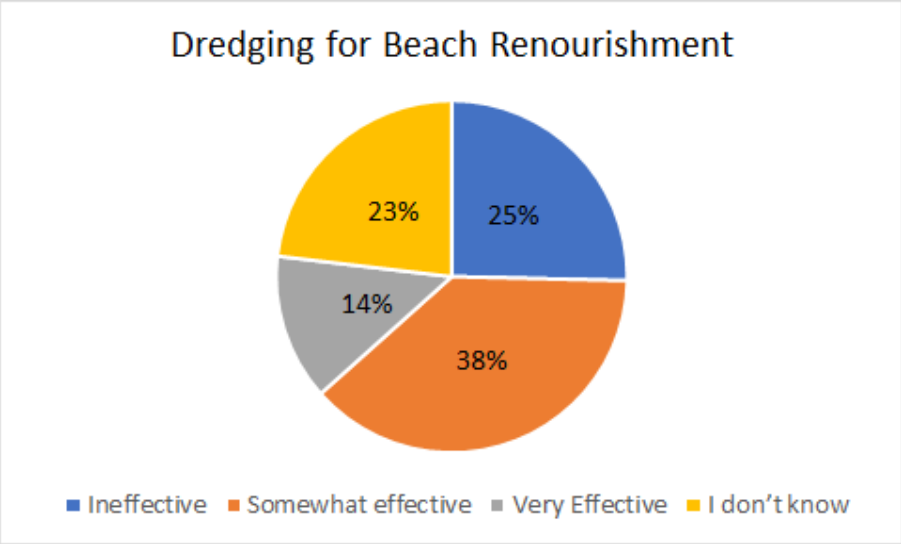


Figure 31: Residents' Opinions on Dredging and Renourishment

Artificial Reefs

Though not referred to as artificial reefs, a proposal was made in 1960 to sink old cars off the coast of Madaket. Over time, sand would fill the cars, creating a structure that would lessen the wave's impacts during storms. But when the town asked engineer Robert B. Mackinnon, he told them "the force of the sea is such that efforts like this would be puny in comparison and wouldn't work at all. The rate of erosion has moved so fast that about seven million tons of sand has moved out of the Smith Point area toward Tuckernuck" (Madaket Project Too Costly, Engineer Tells Selectmen. 1960). Nevertheless, there have been numerous successful efforts to create artificial reefs in other places around the globe. Survey responses show that the vast majority of Madaket residents (92%) think artificial reefs might be a somewhat to very effective mitigation strategy (Figure 32), although it is unclear how informed residents might be about the advantages and disadvantages of such approaches.

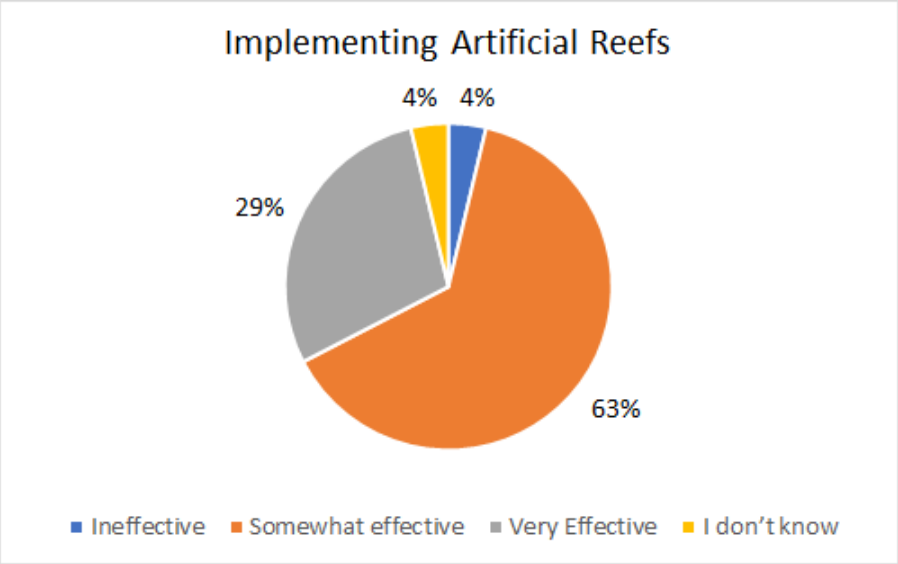


Figure 32: Madaket Residents' Perceived Effectiveness of Artificial Reefs

Artificial reefs have been constructed with a variety of materials to provide habitats for marine flora and fauna, while doubling also as a breakwater to minimize wave action in relatively low energy environments. As an environmentally friendly breakwater, artificial reefs lessen the intensity of erosion by decreasing wave energy. Reefs allow the development of a new home for aquatic life, such as oysters, which, in turn, may even improve the water quality (since oysters act as filters). In fact, according to Jeff Carlson of the Department of Natural Resources, artificial reefs have been proposed for another project on Nantucket. As mentioned earlier, a storm breached Sesachacha Pond and wave action undermined Polpis Road. As a result, the town is exploring the prospect of implemented artificial reefs like the ones shown in Figure 33 in the pond to both provide a habitat for oysters and dissipate future wave energy from eroding the foundation under the road.

Figure 33: Possible Artificial Reef to be Installed in Sesachacha Pond (LPBF, 2009)

Artificial reefs tend to be effective only in very specific locations. It is possible that they might be suitable in Madaket Harbor, where wave energy and tidal scouring are more limited. As for the Sesachacha Pond project, Carlson has full confidence that the project will be successful. It cannot significantly decrease the wave energy so it would be best placed in an area that experiences relatively low energy. The reef will also be affected by sea level rise, and being too deep beneath the water would not prove much more effective either. The reefs may take a long time to establish themselves in a new environment and they have not been tested extensively so there is little data on their durability and effectiveness. Other areas besides our focal point such as Hither Creek and various tidal edges within Nantucket may greatly benefit from structures such as these (J. Carlson, personal communication, October 31st, 2019).

Joe Farrell's Shoal Modules

Some of the Nantucket community have already proposed their own solution to the problem of erosion. One such gentleman, Joe Farrell, collected his own data on the wave action during a nor'easter in Madaket and proposed using what he dubs "shoal modules" to recover sand. These modules (as shown in Figure 34) are large 20 ft x 10 ft x 5 ft steel boxes that can be pumped or flooded that may be sunk off the shore in front of houses at risk of erosion. These modules would be sunk deep enough in the water as not to disrupt boat navigation, and possibly doubling as a fish habitat (like artificial reefs). The effect, sand will start accumulating behind

the location of the sunken module, which can be easily pumped clear of water and removed if need be. There is still concern as to how this might adversely impact the drift of the sand currently, as well as many other implications of the project that unknown of due to the lack of data and research on it. With that uncertainty in mind, many island residents support of this innovative idea. Several of our interviewees, including Bill Greider and Sarah Oktay, agree that this project might be successful for Madaket. Prefacing more scientific data on effectiveness and unintended consequences need to be explored, and that a pilot program should be established to study the effects with assurance that the modules can easily be removed. “This guy’s got a proven international success story and I don’t see why it wouldn’t work in Nantucket” (B. Greider, personal communication, November 11th, 2019). When Madaket homeowners were surveyed, several responses included references to Farrell’s project when asked about additional actions they would like to see. On the contrary, Vince Murphy, Coastal Resilience Coordinator, is opposed to this approach saying that “it doesn’t make sense to have those kinds of structures in the water, even temporarily” (V. Murphy, personal communication, October 24th, 2019).

Figure 34: The Shoal Modules as Part of Farrell’s Project (Coastal Recovery, 2006)

Stilting Houses

Another method to mitigate the effects of erosion on homes is through stilting more houses. Few homeowners of Madaket have already begun to implement this strategy. The Outer Banks, NC is an example of a location with many stilted homes. Elevating a house will protect it against damage caused by flooding and erosion, and FEMA may partially fund homeowners to undertake this type of project. Unfortunately, FEMA funding is not guaranteed for every homeowner. This method would also require amendments to building codes such as: the height restrictions in Madaket, incorporation of stilts as structural components of a house frame and additional extensions for piping for septic systems and water systems. The height restriction could be changed through amending the current overlay district so that the measurement starts at the first level of the house rather than ground level. The structural changes to houses may be more expensive, but are possible, as homes in Outer Banks, NC are also mostly on stilts and 80% of them use septic for wastewater treatment (L. Dubbs, personal communication, December 10th, 2019).

WhisprWave

One of the more recent ideas brought to the Conservation Commission was to install a mechanism called WhisprWave like the one in Figure 35. Proposed in 2003, the mechanism would cut the height of waves in half using big floating bricks that are anchored offshore. Residents were skeptical of its efficacy, as the invention had only been used in lakes, not the ocean. The town was also skeptical of the cost of $1.2 million to install and maintain the structures even with the possibility of applying for grants through the Army Corps of Engineers (Fiegl, 2003).

Figure 35: WhisprWave Mechanism (WhisprWave, 2011)

4.2.3 Policies

There are several policies that Nantucket should adopt to mitigate the impacts of coastal erosion. The two primary policies are prohibiting driving in protected dune areas and creating setback restrictions.

Beach driving is a popular tourist activity on Nantucket and provides substantial revenue to the town. As D. Anne Atherton noted, "Our beaches are not only such an integral part of our environment, but they drive our economy" (D. Atherton, personal communication, November 8th, 2019). However, beach driving may exacerbate erosion by destroying protective dunes. Driving too close to the visible dunes can uproot the vegetation and destroy the embryonic dunes, collapsing the dune system that takes many years to establish. Restrictions on beach driving would protect these dunes as well as the many wildlife sites along the shoreline like bird nesting sites. Figure 36 shows that there is overwhelming support from the Madaket homeowners for restrictions on beach driving. In an interview with Peter Brace he points out, "Driving on the beach, walking on the beach, is a privilege not a right. If you're told that you can't go on the beach because it's eroding, then respect that" (P. Brace, personal communication, November 6th, 2019). Nevertheless, others in town might be more resistant to restrictions. Beach driving permits

provide substantial revenue for the town and beach driving is especially popular among tourists and recreational fishers. It is possible to limit any ban on beach driving to particularly sensitive areas if needed. This might balance protection with beach access and still maintain much of the revenue stream. Since enforcement of the driving ban will require town staff time and resources, it is possible that some of the beach permit revenue could be set aside for those purposes.

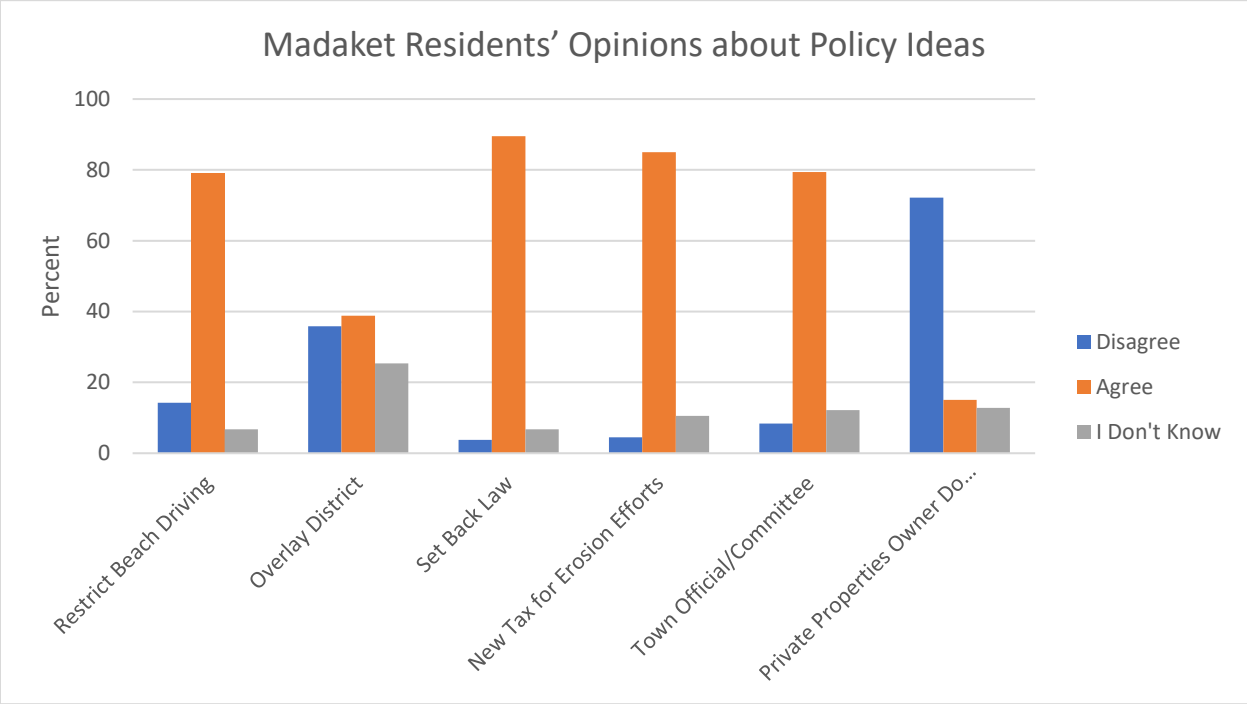


Figure 36: Residents' Opinions on Policies the Town Could Implement

Overlay zoning is a regulatory tool that establishes a special zoning district, placed over an existing base zone(s) (Miskowiak, 2006). In certain cases, overlay zoning also regulates the distance from a property line that a building can be constructed. Rather than suggest adding a whole new overlay district to Madaket, it would be more efficient to amend the current overlay and/or introduce a setback law to prohibit more development on land within a certain distance (i.e. 100 ft) from the mean high water mark (HWM). The trouble with this stems from the fact that this cannot protect any existing structures, and this type of setback law may upset developers and/or homeowners with undeveloped land. The HWM will change with sea level rise over the years, and benefits of this will take a while to become apparent.

4.2.4 Organizational Efforts

There are four primary organizational changes that might advance erosion planning and protection: having a town plan in place, reinstating the Nantucket Conservation District, establishing a committee to oversee implementation of erosion mitigation strategies, and providing better guidance from the town and large conservation organizations for private homeowners.

It is vital for the future of Nantucket residents that the town try to be more proactive in its approaches to erosion control. This is especially true for the situation in Madaket at Millie's Bridge. Currently, the bridge may be safer than it has in years with the sand build-up to the south of it and the upcoming plans to stabilize the area with plants and grasses. However, the town needs to be prepared with a comprehensive plan in case the dune system fails. It would be inconvenient for the bridge to be closed and for residents who live on Smith Point to have to dive on the beach in order to access their homes. If the bridge were closed, no emergency vehicles would be able to access these houses and the possible damage done to the dunes would reverse all the work of previous efforts. If the bridge, or Ames Ave, is compromised the town should have a plan in place to take action.

The Nantucket Conservation District is currently inactive, but reinstating it could provide its benefits for mitigating erosion effects. The purpose of a Conservation District is to address concerns over natural resources and organize public and private efforts to counteract coastal erosion. A Conservation District for Nantucket, an idea that Bill Greider is passionate about, could be the perfect committee for organizing erosion projects and funding resources. In addition to bridging the gap between public responsibility and private homeowners' involvement when it comes to erosion. Having an active Conservation District can also qualify Nantucket for USDA funding for projects such as replacing the culverts at Long Pond and group property dune grass planting. Funding is not guaranteed and must be used for a non-profit purpose like in some cases like restoring vegetation. If the Nantucket Conservation District is reinstated, a board must oversee the responsibilities of the organization.

One of the most evident issues on the island with regards towards coastal erosion is the organization and planning. Almost all of the people interviewed for this report agree that they

would like to see town taking a more responsible approach to the erosion problem. “If we wanted to make a change,” states D. Anne Atherton of Nantucket Coastal Conservancy, “we need to be involved in political action” (personal communication, November 8th, 2019). The town is beginning to develop a more proactive approach to the management of coastal erosion, as evident in the creation of the Coastal Management Plan, Hazard Mitigation Plan, and Coastal Resilience Advisory Committee with a Coastal Resilience Plan coming in the future. These efforts focus mainly on storm damage and flooding rather than erosion, and on town rather than private properties. Therefore, further actions should be undertaken to have a proactive approach. Thus, we believe having an “Erosion” committee could make a difference in organizing and planning erosion mitigation efforts as well as overseeing implementation of suggested strategies.

Based on our research, there is a clear need for more coordination between private and public erosion planning and protection. The town, in collaboration with large conservation organizations such as Nantucket Civic League and Coastal Resilience Advisory Committee, should provide a better guidance for private homeowners. To support this statement, in the recent survey of Madaket residents as seen in Figure 37, 57% of people replied that they are somewhat familiar with erosion control efforts and 10% reported that they were not familiar at all. The vast majority of responders, when asked what actions they would be in favor of the Civic League taking (in conjunction with the Madaket Conservation Association) as seen in Figure 38, said that they would support the league providing homeowners with information on local erosion control methods they could use as well as helping neighborhood homeowners coordinate erosion strategies. Providing strong guidance for homeowners on erosion will require teamwork and strong communication from all of the stakeholders. This attention to all voices and a common goal will take time, but the investment of this time will, hopefully, create a sustainable plan for mitigating erosion.

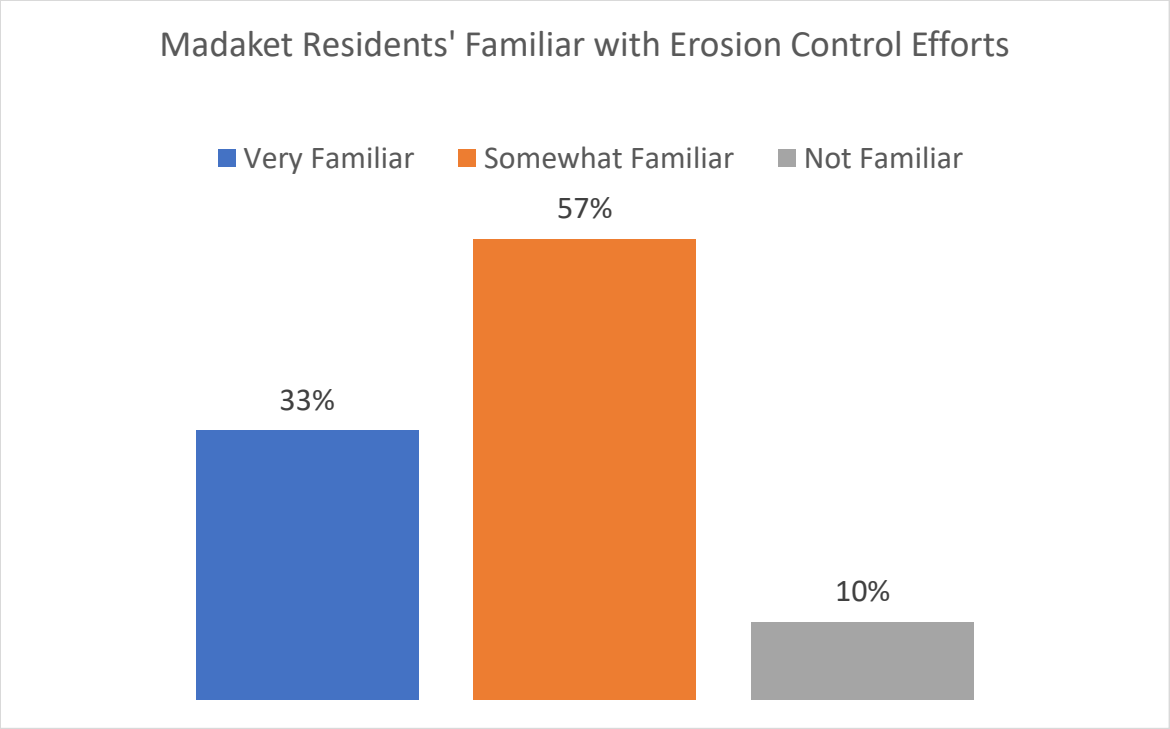


Figure 37: Familiarity of Madaket Residents with Erosion Control Efforts

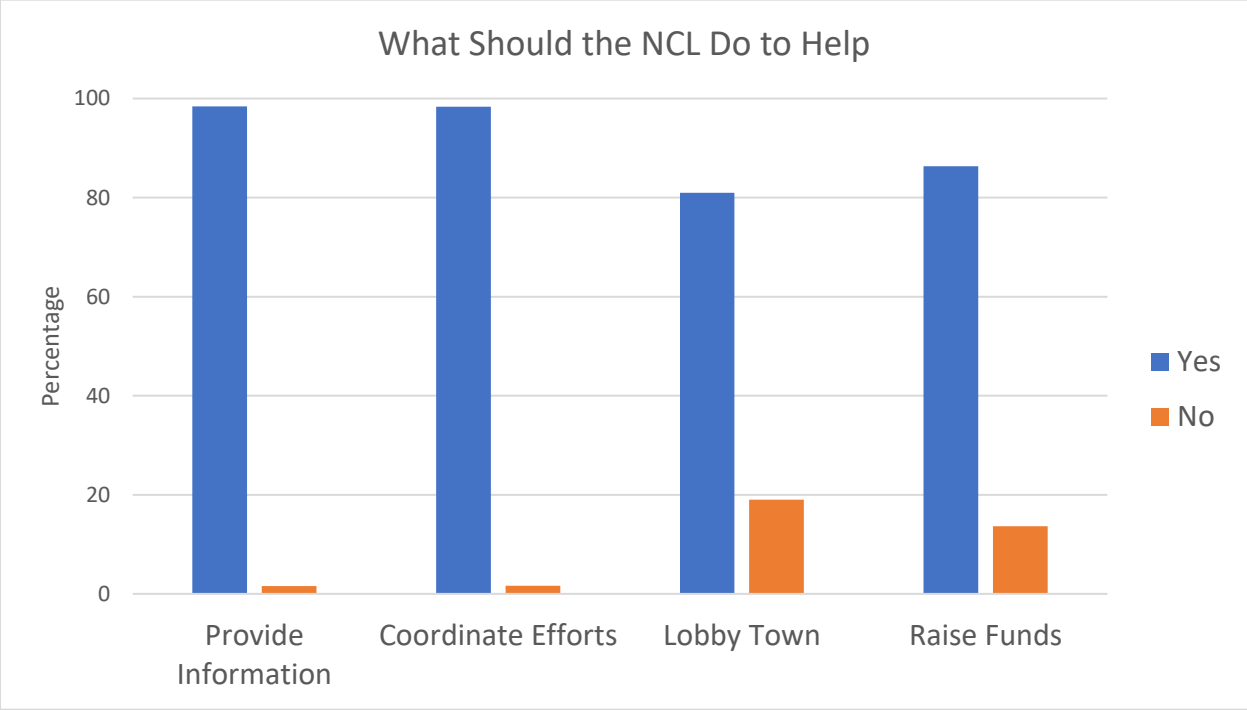


Figure 38: Residents' Opinions About Actions the Civic League Might Take

5. Conclusions and Recommendations

While conducting research it became apparent that the residents are fearful of what the future may bring because of the impact of erosion. Figure 39 depicts that the level of concern about erosion rises over time. Relatively few respondents are very concerned now, but more than 80% are concerned or very concerned about the situation in ten years. On the island, several different organizations and a committee are involved in the process of trying to promote the resiliency of its coastlines and are acting proactively to defend it island's property and infrastructure against the threat of erosion. After compiling the information obtained in the interviews and survey results, a list of technologies, policies, and organizational tactics that Madaket and the town can adapt to mitigate the effects of erosion have been created. The goal is for the town to learn from this Madaket case study and apply the recommendations, where appropriate, across the island.

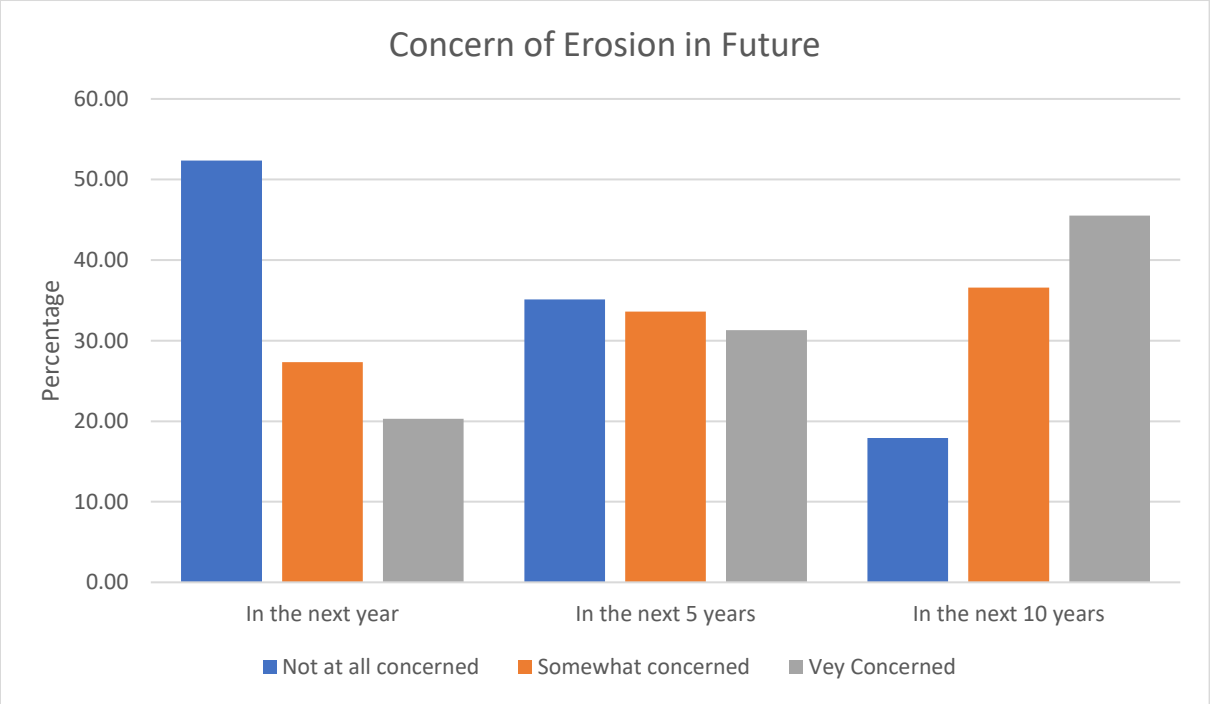


Figure 39: Shows the Concern of Citizens for Erosion

The general consensus among all of the recommendations is that in the end, nature will be nature. Jeff Carlson stated, "From a natural resources perspective, the biggest risks when implementing erosion structures is altering the natural environment in a way that we don't

anticipate and we can't mitigate. The easiest way to avoid the unknown environmental impacts is to let nature be nature" (J.Carlson, personal communication, October 31st). Nature is too unpredictable, the best we can do is work with it, adapt, and accept that this island is forever moving and changing around us.

Prior to implementing some of our recommended strategies: artificial reefs, beach dredging, and Joe Farrell's project, further research of sand movement must be conducted to monitor island-wide erosion and map harbor floors in order to determine the amount of sediment that has built up.

In ranked order:

Rebuild Dunes

In general, the United States has shifted from the use of hard structures to control coastal erosion to the use of soft structures (National Research Council, 2014). Many states and local governments on the east coast are encouraging communities to protect and re-establish saltwater marshes and dune systems since they protect against storm surge, flooding and coastal erosion. We recommend that Nantucket explore opportunities to protect and encourage the development of more extensive dune systems. Dunes can be maintained by erecting sand fences and planting dune grasses and other vegetation. Stabilizing existing dunes and encouraging dune growth and development are environmentally friendly solutions that have been shown to reduce coastal erosion in several areas on Nantucket. The structures are relatively easy and inexpensive to install, but may require periodic maintenance. They can also be damaged by beach driving and destroyed by severe storms.

To coincide with the efforts already being conducted by the town, individual private homeowners should apply for funds from the United States Department of Agriculture (USDA) for implementing dune fencing with dune grasses in front of their properties. In addition, the Madaket Conservation Association should facilitate group efforts to plant beach grasses and install dune fencing in areas that are vulnerable to coastal erosion in Madaket. The more vegetation incorporated into the dune systems, the more stabilized they will be. Finally, clearly

marked beach access points in Madaket should be installed to reduce the number of people traversing the dunes and, ultimately, mitigating the rebuilding effort.

Guidance for Homeowners and "Erosion" Committee

Based on the interviews and survey results, the conclusion drawn is that homeowners want the town to take more action in regards to mitigating coastal erosion. Despite the town's initiatives to be more proactive by implementing the Hazard Mitigation Plan and establishing the Coastal Resilience Advisory Committee (CRAC). Which works directly with Coastal Resilience Coordinator, Vincent Murphy, on drafting the island's Coastal Resilience Plan. Although these plans are in place, more action must be taken to mitigate coastal erosion. In addition, better guidance must be disseminated to private homeowners from the government and large conservation associations.

After publication of Coastal Resilience Plan, the Coastal Resilience Advisory Committee, in collaboration with Vince Murphy, should refocus their roles. In the future, the committee should take on the role of an "erosion czar", overseeing the implementation of the erosion control efforts suggested as well as organizing a plan for future erosion efforts. The committee should also assess the long term vulnerability of the Millie's Bridge.

We also propose the committee to work with the town and large conservation organizations to provide a better guidance for homeowners by establishing a new web-portal or add new features to CRAC's current website. The website should include descriptions of the past, current, and future efforts completed or planned by both public and private entities to mitigate erosion. Ideally, the posted solutions would be inexpensive, innovative, and effective so that homeowners could learn from them and potentially apply the solutions to their properties. The Civic League and other smaller homeowner associations may use this solution to keep homeowners abreast of the most updated information on the website. Potentially, a system like this could help in organizing group efforts of homeowners in certain areas and neighborhoods.

In the short term, the inexpensive updating of the CRAC's website to include more pertinent information on erosion will be an asset to the residents of the island. Over the long term, establishing effective communication and collaboration between several committees will, over time, foster a communal effort to improve the current situation of coastal erosion. If all

stakeholders are involved in a solution, the solution will be well received and, hopefully, cost effective.

Restrictions on Beach Driving

One of the popular policy-based strategies to mitigate coastal erosion effects is ban on beach driving in areas that are especially vulnerable to coastal erosion. As mentioned in section 4.3.2, driving too close to dune systems can uproot the vegetation and destroy the embryonic dunes, which collapses the dune system. The difficulty in implementing this recommendation is that beach driving is a big economic driver for Nantucket, because tourists have to purchase permits that allow them to legally drive on certain beaches. Sales of beach driving permits yield approximately 6% of annual town budget (V. Murphy, personal communication, October 24th, 2019).

A majority of Madaket residents support reducing the number of beach driving areas prone to coastal erosion and the recommendation to do so would protect the dune systems.

Reinstating Nantucket Conservation District

Reinstating the Nantucket Conservation District (NCD) could assist in channeling funding from the USDA to homeowners' non-profit group projects such as beach grass planting and culvert building. This strategy should encourage homeowners to undertake group effort projects rather than individual projects in addition to providing organizational aid for these projects outside of town-owned property. However, this initiative would also require electing a board of members to oversee the responsibilities of NCD.

It is a recommendation to reinstate Nantucket Conservation District and hold elections for the board of NCD members so that homeowners may have another option for information, demonstration, organization, and funding for their group non-profit projects.

Overlay Amendments (Setback laws, building restrictions, etc.)

Set-back ordinances are property laws governing lines and boundaries. A set-back law establishes a minimum distance from a property line that a building can be built. The distances are generally regulated by zoning laws. The zoning overlay laws cannot, unfortunately, protect

any existing structures. In culmination establishing set-back laws is a good option for mitigating coastal erosion in the long term. To further support our conclusion, 90% of responses from the survey are in favor of the town implementing set-back laws to restrict structure building in these vulnerable areas (Figure 36).

With overwhelming support from the citizens, it is recommended that the town adjust the current overlay and/or introduce a set-back law to prohibit additional development on land within a certain distance (i.e. 100 ft) from the mean high water mark (HWM).

Farrell's Shoal Modules

Joseph Farrell's multi step project is worth implementing. The project consists of three stages: 1) collecting data on wave action and sand transport during a nor'easter in Madaket, 2) sinking temporary shoal modules off the beach in front of endangered houses and 3) replace the shoal modules with 100 to 140 feet of concrete units. The shoals could create artificial reefs and provide new habitats for sea creatures. The modules will be submerged deep enough so that they will not interfere with boat navigation. The project is currently on hold with permits needed to begin the second phase. As with implementing artificial reefs to sink temporary shoal modules properly, there should be more data gathered on sand movement. Based on survey responses, this project has garnered the support and attention of several homeowners in Madaket (Coastal Recovery).

It is recommended that the town to conduct a sand study on the island to identify the most efficient place for Farrell's shoal modules to be installed. Then, it is recommend that the residents of south shore and the town proceed with implementing the temporary shoal modules off the shore and observing the results. If the results prove the temporary shoal modules to be efficient, it is recommended that Farrell proceed further into the phases of his project.

Stilting

Stilting houses is an additional way to mitigate the effects of coastal erosion. Elevating a house will protect it from flooding and storm damage. As stated in section 4.3.2, some homes in Madaket has started to implement this strategy. Outer Banks, NC is an example of a similar

location with many stilted houses. Stilting houses, in some cases, can even be partially funded by FEMA.

Based on the federal funding available to lower the costs of this solution, it is recommended private homeowners in Madaket explore the option of stilting their houses and request funds from FEMA. The stilting may currently only be a few feet (three feet to five feet) in order to stay in compliance with home height restrictions of twenty five feet. It is also recommended that a an edit to local building codes be drafted to state that the height of the home begins at the first level mark and not at ground level.

Artificial Reefs in Madaket Harbor

Artificial reefs can make a positive impact in reducing the rate of erosion in certain coastal areas. As mentioned previously in section 4.3.1, artificial reefs, if implemented correctly, can reduce wave energy, thus reducing erosion impact on the coastline. Artificial reefs can also provide a new habitat for shellfish and are environmentally friendly. However, to implement artificial reefs properly and avoid any negative coastal impact more data should be gathered on sand movement around the island. Prior to implementation in the harbor and applicable areas, positive results from the Sesachacha project first need to be observed.

Following positive results from both the sand study that verifies an adequate ecosystem, as well as applications of it in Nantucket, it is recommend that artificial reefs be placed in Madaket Harbor. Though the area of Madaket Harbor does not necessarily receive high rates of erosion, it is a very crucial area, not just for Madaket, but for the whole island. Therefore, planning proactively could prove quite successful.

Beach Renourishment through Dredging

Proven to be successful in places such as Cape May, New Jersey, despite the various aspects such as determining material compatibility, long permitting process, high cost of implementation, and potential danger to the environment, beach renourishment through dredging can make a positive impact on reducing coastal erosion rates in Madaket. Dredging on Madaket's south shore would only be successful following specific findings in the proposed sand

study. For example, if the sand study finds the ecosystem in Madaket Harbor to be too fragile, then dredging from father offshore may be the best solution.

It is recommended that the town to dredge material from Madaket harbor and deposit the material on the southern shore of Madaket as long as the dredged material and receiving material are compatible. Before beginning a dredging operation, local shell fishing needs to be considered in order to not disturb these areas.

References

Akson, B. (2012) Overview of Soft Coastal Protection Solutions. From http://ancorim.aquitaine.fr/IMG/pdf/2_Outil2_56P_EN.pdf

Aldrich, I. (2013, August 15). Nantucket Beach Erosion: A Disappearing Island. Retrieved October 3, 2019, from https://newengland.com/yankee-magazine/living/new-england-environment/nantucket-beach-erosion/.

Balling, J. (Ed.). (2002, December 5). Madaket home threatened by erosion called a hazard; town seeks permit to burn it down. *Inquirer and Mirror*. Retrieved from http://digital.olivesoftware.com/Olive/APA/Nantucket/SharedView.Article.aspx?href=NIM/2002/12/05&id=Ar00200&sk=ECF6B3AE

Board, O. S. (2014). Reducing Coastal Risk on the East and Gulf Coasts

Brown, F. D., Goetz, M. J., Gutman, A. L., Lentowski, J. F., & Tiffney, W. N. (1979). *Nantucket Shoreline Survey: An Analysis of Nantucket Shoreline Erosion and Accretion Trends Since 1846*. *Nantucket Shoreline Survey: An Analysis of Nantucket Shoreline Erosion and Accretion Trends Since 1846*. Nantucket, MA: Nantucket Conservation Foundation, Inc.

Climate change is a remorseless threat to the world's coasts. (2019, August 17). Retrieved from https://www.economist.com/briefing/2019/08/17/climate-change-is-a-remorseless-threat-to-the-worlds-coasts

Coastal Recovery, Farrell, Joe (2006)

Commonwealth of Massachusetts, Office of Coastal Zone Management (CZM), StormSmart Coasts Program, https://www.mass.gov/stormsmart-coasts-program

Commonwealth of Massachusetts, Office of Coastal Zone Management (CZM). (2013). StormSmart Properties Comparison Chart : Relative Costs of Shoreline Stabilization Options. CZM.

Commonwealth of Massachusetts,Office of Coastal Zone Management (CZM). (n.d.). CZ-Tip - Basics of Building Beach Access Structures that Protect Dunes and Banks. Retrieved from https://www.mass.gov/service-details/cz-tip-basics-of-building-beach-access-structures-that-protect-dunes-and-banks.

Community Resilience Building Workshop Summary of Findings FINAL REPORT, Community Resilience Building Workshop Summary of Findings FINAL REPORT (2019).

Dehring, C., & Halek, M. (2013). Coastal Building Codes and Hurricane Damage. Land Economics, 89(4), 597–613. Retrieved from https://muse.jhu.edu/article/523036

Drønen, N. (2018, January 22). How technology is helping professionals manage coastal erosion successfully. Retrieved November 15, 2019, from

https://blog.dhigroup.com/2018/01/22/technology-helping-professionals-manage-coastal-erosion-successfully/.

Dunk, D. R., & Epsilon Associates. (2019, May 16). Response to the April 22, 2019 Public Hearing Comments on the Expanded Baxter Road and Sconset Bluff Storm Damage Prevention Project (DEP File No. SE 48-3115). Retrieved September 5, 2019, from https://www.nantucket-ma.gov/DocumentCenter/View/24575/SBPF-Response-to-04_22_19-Public-Hearing-Comments

Erisman, A. (2014). Erosion Control, Sustainability, and Sea Level Rise: A critical Evaluation of Nantucket's Planning for Coastal Resilience. Master of Environmental Studies, University of Pennsylvania

Evans, B. L. (2004, November 16). Rising Sea Levels and Moving Shorelines. Retrieved from https://www.whoi.edu/oceanus/feature/rising-sea-levels-and-moving-shorelines/

Fiegl, C. (2003, August 21). New erosion control device touted for South Shore waters. *Inquirer and Mirror*. Retrieved from http://digital.olivesoftware.com/Olive/APA/Nantucket

/SharedView.Article.aspx?href=NIM/2003/08/21&id=Ar01600&sk=1FE52316

Graziadei, J. (2010, September 19). Mother Nature wins epic Nantucket erosion battle. *Cape Cod Times*. Retrieved from https://www.capecodtimes.com/article/20100919/News/9190323

Guercio, L., & Guercio, L. (2013). Climate change adaptation and coastal property rights: A Massachusetts case study. *Boston College Environmental Affairs Law Review, 40*(2), 349-349.

Healey, K., Romney, M., Roy Herzfelder, E. and Skinner, T. (2003). *Environmental Permitting in Massachusetts*. Boston: Massachusetts Office of Coastal Zone Management, pp.29-40. Retrieved from http://www.mass.gov/eea/docs/czm/fcr-regs/ma-env-permit-guide-2003.pdf.

Heinz Center. *Evaluation of Erosion Hazards, Report to the Federal Emergency Management Agency, Washington, DC* 203pp. (2000) https://www.fema.gov/pdf/library/erosion.pdf

Hunt, L. A., Sample, C. M., & Sullivan, K. M. (2014). Evaluating Coastal Erosion Structures. Retrieved from https://digitalcommons.wpi.edu/iqp-all/1645

Hunt, L., Sample, C., & Sullivan, K. (n.d.). *Geotextile Tubes, Siasconset Bluff Nantucket. Evaluating Coastal Erosion Structures* (pp. 12). photograph, Nantucket, MA, USA. Retrieved from https://digitalcommons.wpi.edu/iqp-all/1645

Hunt, L., Sample, C., & Sullivan, K. (n.d.). *Groin Field on the Northwest Shore of Nantucket. Evaluating Coastal Erosion Structures* (pp. 9). photograph, Nantucket, MA, USA. Retrieved from https://digitalcommons.wpi.edu/iqp-all/1645

Hunt, L., Sample, C., & Sullivan, K. (n.d.). *Seawall with Scouring on the Northwest Shore of Nantucket*. *Evaluating Coastal Erosion Structures* (pp. 8). photograph, Nantucket, MA, USA. Retrieved from https://digitalcommons.wpi.edu/iqp-all/1645

Hunt, L., Sample, C., & Sullivan, K. (n.d.). *Vertical Scouring at Seawall, Quaise Road. Evaluating Coastal Erosion Structures* (pp. 49). photograph, Nantucket, MA, USA. Retrieved from https://digitalcommons.wpi.edu/iqp-all/1645

Hunt, L., Sample, C., & Sullivan, K. (n.d.). *Zig-zag Fence, Beach Nourishment, Beach Grass, Pocomo Road Nantucket. Evaluating Coastal Erosion Structures* (pp. 46). photograph, Nantucket, MA, USA. Retrieved from https://digitalcommons.wpi.edu/iqp-all/1645

Knisel, J. (2013). *Shoreline Change Around Nantucket*. Retrieved from https://www.nantucket-ma.gov/DocumentCenter/View/938/Shoreline-Change-Around-Nantucket---2013

Lenhart, Cynthia. "New Listing in Madaket." *Compass Rose Real Estate*, 28 Mar. 2016, https://compassroserealestate.com/new-listing-madaket/.

Lindsey, R. (2019, November 19). Climate Change: Global Sea Level: NOAA Climate.gov. Retrieved November 15, 2019, from https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level.

Madaket Project Too Costly, Engineer Tells Selectmen. (1960, December 9). *Inquirer and Mirror*. Retrieved from http://digital.olivesoftware.com/Olive/APA/Nantucket/SharedView.Article.aspx?href=NIM/1960/12/09&id=Ar00113&sk=97E43E68

Management a reality. *Ocean and Coastal Management*, *156*, 290–299. https://doi.org/10.1016/j.ocecoaman.2018.01.027

McGuire, C. (2017). Armoring Against Coastal Climate Adaptation in the US: A Massachusetts Perspective. Coastal Management, 45(4), 271–276. https://doi.org/10.1080/08920753.2017.1327342

Nathanson, R. (2017, October 26). Slip Sliding Away on Nantucket. Retrieved from https://prospect.org/article/slip-sliding-away-nantucket

National Research Council. (2014). Reducing Coastal Risk on the East and Gulf Coasts. *National Academy of Sciences*. doi: 10.17226/18811

Neal, W., Pilkey, O., Cooper, J., & Longo, N. (2018). Why coastal regulations fail. Ocean and Coastal Management, 156, 21–34. https://doi.org/10.1016/j.ocecoaman.2017.05.003

Netco. (n.d.). *Siasconset Beach Preservation Fund (Sbpf) Nantucket, Ma*. Retrieved from http://netcomanage.com/siasconset-beach-preservation-fund-sbpf-nantucket-ma/

NOAA Office for Coastal Management. (2015). Economics and Demographics. Retrieved from https://coast.noaa.gov/states/fast-facts/economics-and-demographics.html

NOAA Office for Coastal Management. (2019), Coastal Zone Management Act. Retrieved from https://coast.noaa.gov/czm/act/

Oktay, S. D. (2013, June 20). Coastal Beach Processes & Erosion. *Yesterday's Island, Today's Nantucket*. Retrieved from https://yesterdaysisland.com/coastal-beach-processes-erosion/

Powers, Jim. "Workers Were Set up to Demolish Gene Ratner's Four-Bedroom House off Sheep Pond Road on Nantucket Wednesday." *Boston.com*, 17 Sept. 2010, http://archive.boston.com/news/local/massachusetts/articles/2010/09/17/hurricane_earl_deals_fatal_blow_to_nantucket_home/.

Proposals on Madaket's shifting sands made at ConCom meeting - snow fence, plantings, tires. (1977, September 15). *Inquirer and Mirror*. Retrieved from http://digital.olivesoftware.com/Olive/APA/Nantucket/SharedView.Article.aspx?href=NIM/1977/09/15&id=Ar01404&sk=A8ABA155

Pykosz, L. (2016, October 23). Easy Street Bulkhead Repairs Begin. *The Inquirer and Mirror*. Retrieved from https://www.ack.net/news/20161023/easy-street-bulkhead-repairs-begin

Rangel-Buitrago, N., de Jonge, V., & Neal, W. (2018). How to make Integrated Coastal Erosion

Reefmaker. (2016). *Artificial Reef*. photograph, Mexico Beach, FL, USA. Retrieved from https://commons.wikimedia.org/wiki/File:Artificial_Reef_by_Reefmaker1.jpg

Riethof, G. (2017). *West end of the island last Tuesday showing sand filling in the head of Hither Creek.* Retrieved from https://www.ack.net/photogallery/CC/20171030/PHOTOGALLERY/103009998/PH/1

Shaw, W. (2008) Massachusetts Office of Coastal Zone Management (CZM), *Introduction to No Adverse Impact (NAI)Land Management in the Coastal Zone*: *A legally sound way for municipalities to protect people and property*, Massachusetts Office of Coastal Zone Management (CZM).

Shipman, H., Dethier, M.N., Gelfenbaum, G., Fresh, K.L., and Dinicola, R.S., eds., 2010, Puget Sound Shorelines and the Impacts of Armoring—Proceedings of a State of the Science Workshop, May 2009: U.S. Geological Survey Scientific Investigations Report 2010–5254, 262 p. https://pubs.usgs.gov/sir/2010/5254/

Smith, Dana. "Sand-Filled Bags Protect Eugene Ratner's Home against the Sea." *Yankee*, 15 Aug. 2013, https://newengland.com/yankee-magazine/living/new-england-environment/nantucket-beach-erosion/.

Sutters, P. (2019). *The bluff along Baxter Road in Sconset following a winter storm in March 2018 that exposed the geotubes on the beach below*. Retrieved from https://www.ack.net/news/20190711/sbpf-files-appeal-in-superior-court-and-to-dep

Think Defence. (2019). Increment 2 - Wave Attenuation. Retrieved from https://www.thinkdefence.co.uk/ship-to-shore-logistics/increment-2-wave-attenuation/.

Town of Nantucket Beach Management Plan (BMP), Town of Nantucket Beach Management Plan (2005)

Town of Nantucket Coastal Management Plan (CMP), Town of Nantucket Coastal Management Plan (2014)

Town of Nantucket Natural Hazard Mitigation Plan (HMP), Town of Nantucket Natural Hazard Mitigation Plan (2019)

Turer, M. (2016, February 18). Madaket shoreline eroding at alarming rate. *The Inquirer and Mirror*. Retrieved from http://digital.olivesoftware.com/Olive/APA/Nantucket/SharedView.Article.aspx?href=NIM/2016/02/18&id=Ar00400&sk=1F650464

U.S. Climate Resilience Toolkit. (2019, September 13). Retrieved from https://toolkit.climate.gov/topics/coastal-flood-risk/coastal-erosion.

US Army Corps of Engineers (2013) *Coastal Risk Reduction and Resilience*. CWTS 2013-3. Washington, DC: Directorate of Civil Works, US Army Corps of Engineers.
Wilson, M. (2007). *The Sankaty Head Lighthouse will begin its move to a new site (foreground) tomorrow because of the threat of an eroding bluff*. Retrieved from http://archive.boston.com/news/local/articles/2007/09/30/traveling_light_on_nantucket/

Appendix A

The Nantucket Civic League is a non-profit volunteer organization that was founded in 1903 and grew out of the Nantucket Improvement Association. The Improvement Association was made up of mostly clergy whose mission it was to promote a higher moral standard across the island. Over time, the group expanded to include more local citizens, especially women, and became a very gender-equal association. Despite enthusiastic beginnings, the league went through several ups and downs of losing members and money, until it underwent a reorganization in 1973, which transformed the group into an umbrella consortium for all the varying neighborhood organizations seen in Figure 40 (Todd 2016).

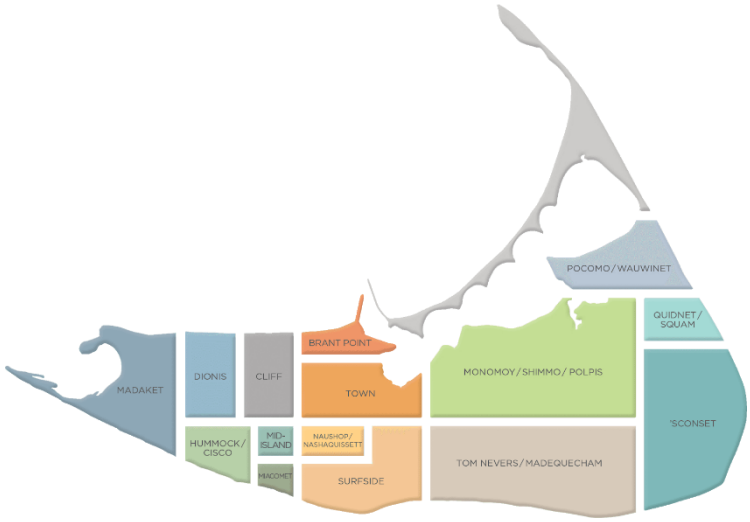


Figure 40: A Map of Nantucket Island's Neighborhoods (Fisher Real Estate).

Table 5: A Regionally Divided Table of All 25 Neighborhood Associations

Direct Civic League Associations	Austin Farms Homeowners Association	Brant Point Association
	Cisco Association	Fisher Landing Association
	Harbor South Civic Association	Hinckley Lane Association
	Hummock Pond Association	Hussey Farm Homeowners Association
	Madaket Conservation Association	Monomoy Civic Association
	Miacomet Conservation Association	
Nantucket Town Association	Naushop Homeowners Trust Association	Pine Valley Association
	Pocomo Area Association	Polpis Association
	Quidnet Squam Association	Shimmo Area
Siasconset Civic Association	Smith Point Association	Surfside Association
	Tom Nevers Civic Association	
Wauwinet Land Owners' Association	West Miacomet Association	

Nowadays, they are an organization with members representing each of these 25 neighborhood association, as well as over 2,000 families from these neighborhoods. Most of the Civic League's funding comes from dues paid by members. With approximately $5 from each

family, they operate on an annual budget of $8,000-$10,000. The Civic League is mainly a non-political group, except for issues concerning their overall mission for Nantucket. (Morrison, Stott, personal communication, 2019).

The purpose of Nantucket Civic League is to advance continuous improvement in the quality of life on Nantucket by identifying important and emerging issues, informing the community about them, and helping to build consensus on solutions. In the past, the League has been involved in a variety of issues, such as protesting the lack of clothing on beachgoers in the 1960s. More recently, issues of most concern have been affordable housing, land preservation, and coastal erosion (Re: Getting to Know Our Sponsors, 2019). Currently, the League has four priorities, which are: preserving the island's resources, educating and informing the public on island issues, improving the quality of living, and encouraging participation in local government. The League achieves its mission and priorities through a variety of programs and activities, including a newsletter, informational meetings, and lobbying local and state politicians and outreach to other organizations.

The Nantucket Civil League is involved in various programs on the island ranging from forums, to land preservation, and environmental work. The league's most popular program is its forums which are taped and available through a variety of ways including locally broadcasted and re-broadcasted as well as available "on demand" from NCTV18. The forums are meant to educate the people of the island, with a focus on issues that currently present or will present them as well as acquiring the opinion of the people. A direct action of preservation is the acquired ownership of Mill Hill Park, the NCL prides itself on the preservation of the land to ensure the natural landscape remains. Most recently, land at "Camp Richard" was preserved when the Boy Scouts tried to sell a portion of the land to a developer, the NCL and the Nantucket Land Council stepped in, and battled in court to preserve the land. One of the leagues many goals is to provide affordable living especially for the employees of local businesses. In order to help stem this issue the NCL launching a program with support from the Nantucket Cottage Hospital Community Health Improvement grant, for employees of local businesses in need of housing to receive affordable housing through an application. Under the guidance of the NCL, the Environmental Working Group, a subcommittee of people whose task it is to evaluate problem areas on the island in more detail. More specifically the Environmental Working Group's purpose is to help improve the

environmental quality on Nantucket, the NCL has identified a number of areas of concern on the island. These include trash and litter on the island, water quality, the human impact on the environment, and coastal erosion.

Figure 41: A Section of Erosion in Madaket

Due to its location, the island of Nantucket has been experiencing aggressive coastal erosion for many years. Not surprisingly, over time more and more residents densely built their homes along the scenic coast. As time went by, the threat of losing those homes became a fact of life all residents had to face to live on the island. Since the overall mission of the Nantucket Civic League is to improve the quality of life for all on the island, one of their tasks is to deal with the ever growing threat of coastal erosion. Several of the organizations partnered with the Nantucket Civic League, including the Madaket Conservation Association and the Siasconset Civic Association, deal with the problem more directly. During a storm, the island can lose up to 25' of land, which in turn destroys whichever homes are close enough to the edge. Just in 2017, 4 homes were destroyed. One of the reasons why there have only been temporarily effective solutions to this problem, is because depending on where you are on the island, the erosion behaves differently. Another reason why there has not been one true cure-all, is because the people of the island (both summer residents and year-round residents), are hesitant due to solutions failing in the past. All of these problems combine to answer our biggest question: why hasn't this problem been fixed yet?

Appendix B

Interview Questions (National Perspective): Keeley Belva (NOAA)

How long have you been working on coastal erosion issues and what is your role at NOAA?

Do you believe that the U.S. has proper control over coastal erosion?

Are some states more in control than others?

Do you believe the country is properly approaching the issue?

Do you believe that the U.S. has more control over erosion compared to other countries?

What were the most effective actions? What were the least effective?

What do you think are the biggest risks when implementing coastal erosion structures?

Are there any strategies you have heard of and wish the U.S. could implement?

Is there anyone you suggest we talk to learn more about action in the U.S.?

Interview Questions (East Coast (NC) Perspective): Roberta Thuman

Contact found at: http://www.nagsheadnc.gov/883/Beach-Nourishment---Complete

Do you believe that the outer banks have proper control over coastal erosion?

Do you believe that the outer banks has more control over erosion compared to other regions in the U.S.?

What were the most effective actions? What were the least effective?

What do you think are the biggest risks when implementing coastal erosion structures?

What is the general public opinion on the threats of coastal erosion? (Do they fear they will lose their homes, do they believe officials are doing enough in terms of action?)

What sort of policies do the outer banks have to follow when proposing solutions?

Are there any strategies you have heard of and wish NC could implement?

Is there anyone you suggest we talk to learn more about action or policy in the outer banks?

Is there anyone you suggest we talk to learn more about action in the U.S.?

Interview Questions (Massachusetts Perspective): Patricia Bowie

Contact found at: https://www.mass.gov/service-details/czm-staff-directory

What is your job title? How does it relate to coastal erosion?

Do you believe that Massachusetts has proper control over coastal erosion?

Do you believe that Massachusetts has more control over erosion compared to other regions in the U.S.?

Do certain coastal regions have more control than others?

What were the most effective actions? What were the least effective?

Are there any actions in process in Massachusetts/the U.S. that you think we should know about?

What do you think are the biggest risks when implementing coastal erosion structures?

Are there any strategies you have heard of and wish the state could implement?

Where/why do you think these strategies would be most effective?

Is there anyone you suggest we talk to learn more about action in Massachusetts or the U.S.?

Interview Questions (National compared to Nantucket Perspective): Sarah Oktay

Contact found at: https://naturalreserves.ucdavis.edu/people/sarah-oktay

What is your job title?

What is your relationship with coastal erosion? With erosion on Nantucket?

What is the number one thing you learned back when you were researching Nantucket?

Do you believe that the country has proper control over coastal erosion?

What were the most effective actions? What were the least effective? (Country wide or specifically Nantucket)

What do you think are the biggest risks when implementing coastal erosion structures?

Are there any strategies you have heard of and wish the U.S./Nantucket could implement?

Is there anyone you suggest we talk to learn more about action in Nantucket?

Is there anyone you suggest we talk to learn more about action in the U.S.?

Interview Questions (Nantucket Related):

What has been your involvement on the island in regards to coastal erosion?

What are your thoughts on the topic?

What do you think are the biggest risks when implementing coastal erosion structures?

What is your opinion on what the island has done so far to prevent coastal erosion? Are there any projects that you think we should take a closer look at on the island?

How do you view the town's role in approving coastal erosion projects?

What do you think needs to be done in the future in order to help protect Nantucket's coastline?

Is there anyone else you recommend we interview?

Interview Questions (Objective 2):

What is your job title?

What is your relationship with coastal erosion? With erosion on Madaket?

In your opinion, what is the extent of coastal erosion on Madaket?

What is the nature of coastal erosion on Madaket?

What factors make the erosion on Madaket more severe?

Do you know about any public or private attempts to prevent coastal erosion? If yes, what are the solutions / attempts and what do you think about them? What did the public think about the attempts?

What are some of the official policies in place for handling erosion? And local regulations about the problem specifically in Madaket?

Interviews of Homeowners in Madaket / Sconset (Objective 3)

How close to the coastal line is your house located?

What do you think about the extent of coastal erosion?

In your opinion, which factors make the erosion on Madaket more severe?

Do you know about any public or private attempts with a goal to prevent coastal erosion? If yes, describe them.

What do you think about the undertaken attempts to mitigate coastal erosion? Did they work?

How do you protect or will protect your house from being impacted by coastal erosion?

What issues should we consider when coming up with our recommendations?

Appendix C

On-Island Interview Preamble: (In person/phone/video)

Hello, my name is _____ and I'm part of a team of Worcester Polytechnic Institute students researching the effects of and possible solutions to coastal erosion here on Nantucket in collaboration with the Civic League. We would be grateful for your input to help our project. Would you be willing to lend more or less 30 minutes of your time for questions? Your participation is completely voluntary and you may rescind your answers at any point. Will it be okay to record the interview, or would you prefer we take notes? We will also like to use your answers eventually in our report, but will provide you a copy of any quotations before publication. You may also choose to remain anonymous. Thank you for your assistance. Are there any questions you have before we begin? If you realize you may have concerns afterwards, you may contact us at gr-ACK19NCL@wpi.edu or our advisor, Dominic Golding, at golding@wpi.edu.

Off-Island Interview Preamble: (Over the phone/video call)

Hello, my name is _____ and I'm part of a team of Worcester Polytechnic Institute students researching the effects of and possible solutions to coastal erosion on Nantucket in collaboration with the Nantucket Civic League. We would be grateful for your input to help our project. Would you be willing to lend more or less 30 minutes of your time for questions? Your participation is completely voluntary and you may rescind your answers at any point. Will it be okay to record the interview, or would you prefer we take notes? We will also like to use your answers eventually in our report, but will provide you a copy of any quotations before publication. You may also choose to remain anonymous. Thank you for your assistance. Are there any questions you have before we begin? If you realize you may have concerns afterwards, you may contact us at gr-ACK19NCL@wpi.edu or our advisor, Dominic Golding, at golding@wpi.edu.

On/Off Island Interview Preamble: (Email)

Hello, my name is _____ and I'm part of a team of Worcester Polytechnic Institute students researching the effects of and possible solutions to coastal erosion on Nantucket in collaboration with the Nantucket Civic League. We would be grateful for your input to help our project. Would you be willing to lend more or less 30 minutes of your time for questions? Your participation is completely voluntary and you may skip over any questions you like. If you answer any questions, we may like to use your answers eventually in our report. If we do, we will provide a copy of any quotations before publication for approval. You also have the option for your answers to remain confidential. Thank you in advance for your assistance. Are there any questions you have before you begin? If you realize you may have concerns afterwards, you may contact us at gr-ACK19NCL@wpi.edu or our advisor, Dominic Golding, at golding@wpi.edu.

Appendix D

Hazard Mitigation Plan (HMP)

https://www.nantucket-ma.gov/documentcenter/view/24719

Stilting

https://www.mass.gov/files/documents/2016/08/um/ssc4-quincy.pdf

Dunes

PDF Version of Fact Sheet 1

Dune Grass

CZ-Tip - Dune Building with Beachgrass

Fencing

PDF Version of Fact Sheet 6

Beach Access Points

CZ-Tip - Basics of Building Beach Access Structures that Protect Dunes and Banks

Costs Table

Cost Comparison Chart

Beach Nourishment

Beach Nourishment: MassDEP's Guide to Best Management Practices for Projects in Massachusetts

Zoning Overlay

https://www.uwsp.edu/cnr-ap/clue/Documents/PlanImplementation/Overlay_Zoning.pdf