Managing Flooding in Nantucket

IQP Project Report

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Authors:
Robert Blythe
James Casella
Kaija Gisolfi-McCready
Maura Walsh

Advisor:
Dominic Golding

Sponsors:
Peter Morrison
Vincent Murphy

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by
Robert Blythe
James Casella
Kaija Gisolfi-McCready
Maura Walsh

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Report Submitted to:

Vincent Murphy
Nantucket Natural Resources Department

Peter Morrison
Nantucket Civic League

Dominic Golding
Worcester Polytechnic Institute

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Abstract

Nantucket is particularly susceptible to flooding and is increasingly concerned about the exacerbating effects of climate change as sea levels rise and storms become more frequent and intense. Unfortunately, little of the local data on flooding has been systematically analyzed. To address this problem, we built a database comprising 703 flooding events and 856 storm and non-storm flood instances. We found that 88% of the events were minor, nuisance flood events from high tide flooding and winter storms account for the major of major flood events. We identified the causes and effects of flooding at three location (Polpis Road near Sesachacha Pond, Polpis Road near Fulling Mill Creek, and Children's Beach) and recommended several potential mitigation strategies.

Executive Summary

As an island 30 miles south of Cape Cod, Nantucket is particularly susceptible to tropical storms, hurricanes, and Nor'easters, and the flooding that ensues across the island. Looking toward the future, climate change could increase flood damage and coastal erosion as sea levels rise and storms become more intense and frequent.

Distinct parts of the island flood in different ways. Nantucket Harbor, the largest harbor on the island, undergoes 'tidal stacking' when northerly winds push water into the harbor and inundate downtown. Affected areas overlooking the harbor are home to many historic buildings, commercial establishments, as well as critical infrastructure. These assets are frequently inundated by flood waters; some may be severely damaged by wave and wind action during storms. Other areas, such as Brant Point, Long Pond, Polpis, and Madaket, also frequently experience flooding.

Mitigating local flooding requires understanding the local hydrodynamics that produce periodic flooding and assembling robust strategies to mitigate what nature delivers. The objectives of our study are to (1) assemble and analyze a database of local flooding events, gathered from varied historical and other sources; (2) evaluate three locales that experience frequent and unique flooding; (3) build a knowledge base of research on urban flooding whose mitigation strategies are applicable to selected locales; and (4) recommend specific mitigation strategies for each of our selected case study areas. Our focus is on public infrastructure.

To satisfy objective one we formulated a robust database containing 856 flooding instances that occurred across the island. Each event's general location, latitude and longitude, type of flooding, date, verified highest mean higher high water and causes are included. Analysis of our database indicates areas that flood most frequently, causes of both major and minor flooding on the island and maximum and minimum heights for flood water per area. Data from the database also serves in understanding the complexities of flooding in our three case study locations.

We recommended three locales for expansive research: Polpis Road near Sesachacha Pond, Polpis road by Fulling Mill Creek and Children's Beach. Polpis Road near Sesachacha

Pond suffers from wave action from the pond during high winds and overflow from surrounding wetlands. Flowing water inundates and erodes the roadway making it inaccessible to residents. This section of Polpis road is part of an evacuation route for residents and needs to remain passable during storms. We recommended two major mitigation strategies; building a causeway underneath Polpis Road by Sesachacha Pond to protect against erosion and reduce the buildup of water on the roadway and building a pipe from the pond to the Atlantic Ocean to drain the pond more effectively twice a year. Additionally, our recommendations include planting vegetation along the barrier between the pond and ocean and building a Rip Rap wall along the barrier between the pond and road.

Polpis Road near Fulling Mill creek floods due to coastal flooding, run off from Fulling Mill Creek and when the wetland becomes overwhelmed. This section of Polpis Road is part of a separate evacuation route so its access must be maintained during storms. To address the three types of flooding in this area of road we developed two mitigation strategies; replacing the existing culvert with a larger, higher culvert and building a bridge in the central part of the road to connect the wetlands on either side and to raise the roadway to protect against sea level rise. Part of the culvert replacement strategy includes raising the height of the roadway which protects against future sea level rise. Our final location, Children's Beach, floods from coastal flooding. As our lowest lying area closest to the water our mitigation strategies include raising the beachfront to protect against sea level rise, installing a padlock and bollards at the boat ramp, implementing a municipal fine for opening the ramp's tidal gate and repairing the pump station on Children's Beach. We suggest part of the pump station repairs also includes increasing the size and capacity of its associated tank. Elevating the waterfront could increase the burden on the pump station and a larger tank would increase the quantity of water the pump could manage at once reducing chances of backflow and upstream flooding.

Authorship

Section	Primary Author	Secondary Author	Editor
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Introduction

As an island 30 miles south of Cape Cod, Nantucket is particularly susceptible to tropical storms, hurricanes, and Nor'easters. These storms cause frequent and severe flooding in many parts of the island. Nantucket is increasingly concerned about climate change, which is expected to increase flood damages and coastal erosion as sea levels rise and storms become more intense and frequent.

Distinct parts of the island flood in different ways. Nantucket Harbor, the largest harbor on the island, undergoes 'tidal stacking' when northerly winds push water into the harbor and inundate downtown. Affected areas overlooking the harbor are home to historic buildings, commercial establishments, as well as critical infrastructure. These assets are frequently inundated by flood waters and may be severely damaged by wave and wind action during storms. Other parts of the island, such as Brant Point, Long Pond, Polpis, and Madaket, frequently experience flooding.

The Town of Nantucket is dedicated to addressing these flood and erosion problems. It has developed policy and planning documents, including the Natural Hazards Mitigation Plan and the Coastal Management Plan. The Natural Resources Department (NRD) and Coastal Resiliency Advisory Committee (CRAC) are in the process of developing a coastal resiliency plan. These efforts will need basic data on flooding such as frequency, depth, areal extent, and damages, that is collated, systematically mapped, and analyzed. The goal of this project is to collate these data and illustrate how they might be used to develop and enhance flood mitigation strategies tailored to Nantucket's distinctive vulnerabilities. To achieve this goal, we identified four objectives:

- Assemble and analyze a database of local flooding events, gathered from varied historical and other sources (such as newspapers, town records, rainfall data, etc.).
- Select one or more areas on the island for case studies
- Build a knowledge base of urban flood mitigation strategies
- Evaluated mitigation methods suitable for subareas where flooding frequently occurs

To accomplish these goals, we researched Nantucket's existing flooding infrastructure, reviewed solutions to flooding implemented that communities like Nantucket have implemented, case studies and town records. We also interviewed key stakeholders and experts to better understand how to best modify and adjust Nantucket flooding infrastructure. Using gathered data and analysis, we evaluated and proposed a flooding prevention plan that more effectively mitigates flooding on the island.

Literature Review

Nantucket has historically suffered from chronic flooding caused by heavy rains, high tides, and storms. In recent decades, the island's battle with surrounding bodies of water has become more difficult. Climate change and sea-level rise have exacerbated flood conditions. While Nantucket has implemented flooding mitigation plans and infrastructure, much more can be done to improve its effectiveness and protect Nantucket's historical infrastructure.

Section 1: Flooding on Nantucket

Nantucket Island situated miles south of Cape Cod near the Gulf Stream. The island experiences frequent and severe flooding from heavy rains, high tides, and storms. It has been in the path of notable hurricanes and tropical storms that move up the East Coast and is also prone to Nor'easters, large scale winter storms that cause excessive flooding (Figure 1) (Brace, P. R., 2018). The island's low-lying topography exacerbates the extent and severity of flooding, which can lead to significant damage of island infrastructure. Surface water runoff floods downtown streets when excessive rainfall exceeds the capacity of the storm drain system. Even in good weather, extreme high tides and king tides lead to "nuisance flooding," sometimes called sunny day flooding in downtown (Figure 2). Sunny day flooding will increase in frequency and severity with sea level rise. Northeast winds pushing water into the north facing harbor entrance exacerbate flooding in the harbor by driving tidal surge inland and inhibiting its release in a process known as "tidal stacking." Table 1 lists the eight most severe storms to hit Nantucket in the past 30 years and indicates associated flooding.

Table 1: Table displaying recent and severe storms that caused flooding on Nantucket (Hazard Mitigation Plan, 2019).

Date	Name	Flooding/Damages
December 1992	"Perfect Storm" or "No Name Storm"	Severe and widespread coastal flooding. Downtown and Brant Point were affected.
October 2005	Tropical Storm Wilma and Nor'easter	Coastal flooding across the island.
November 3, 2005	Tropical Storm Noel	Coastal flooding and five roads on Brant Point were closed.
October 18, 2009	Strong but unnamed low-pressure system	Washington Street and Lafayette Street both flooded. Children's and Jetty's beach parking lots both flooded.
October 29, 2012	Hurricane Sandy	Storm surges of 2.5ft to 4.5ft along with coastal flooding. Broadway Street flooded and was considered impassible, Straight Wharf also flooded.
February 9, 2013	Blizzard of 2013	Coastal flooding and a storm surge of 3ft to 4ft. Easy Street, Washington Street, and Beach Street all flooded
January 3-5, 2018	Winter Storm Grayson	Easy Street and Washington Street both flooded. Numerous houses on Washington Street were shifted on their foundation.
March 2-4, 2018	Winter Storm Riley	Brant Point was cut off from Easton Street due to flooding, Brant Point during this storm was considered inaccessible. Sesachacha Pond was breached and flooded Polpis Road.

Tidal stacking contributed to flooding during the renowned 1992 "Perfect Storm" (Beegel, 2019), one of the worst Nor'easters to strike New England. That storm was accompanied by waves of thirty feet, storm tides exceeding three feet and 80-mph winds (Figure 3). The flood inundation from this storm reached all the way to Sea Street (Hazard Mitigation

Plan, 2019, p.131). A more recent example of extreme flooding in Madaket and the downtown area occurred early in March of 2018 (Figure 4). "Winter Storm Riley" brought several feet of flooding, at its worst during high tide. Tidal stacking caused flood waters to rise further, although it did not match the 1992 "Perfect Storm" record (Sutters & Balling, 2018).

Figure 1: Winter Storm Riley affecting the Washington Street area on Nantucket (Sutters & Balling, 2018).

Figure 2: Photograph of flooding on Easy Street occurring from a tidal flood in September 2020 (Murphy, Vincent)

Figure 3: Image shows the severity and size of the waves in the 1992 "Perfect Storm" along the coast of Hull, MA (Tom Herde, Boston Globe).

Figure 4: Flooding on Commercial street in Downtown Nantucket from Winter Storm Riley, 2018 (Sutters & Balling, 2018).

Many areas on Nantucket experience frequent flooding as highlighted in blue on Figure 5, especially the downtown area around the harbor. Specific areas subject to flooding in the downtown area include Easton Street, South Beach Street, Children's Beach, Easy Street. (Figure 6). Other areas located downtown that also experience frequent flooding include Washington Street, Broad Street, Francis Street, and the White Elephant Hotel (Hazard Mitigation Plan, 2019). Tidal inundation and storm surges cause most of the flooding in these areas. Bulkheads and wave attenuation barriers in several locations downtown help reduce the severity, and impacts of flooding, but cannot prevent it entirely. These structures can be seen at Children's Beach, Easy Street, and Francis Street Beach. The storm drainage system exits at the Easy Street bulkhead on Easy street through duckbill check-valves (V. Murphy, personal communication, Sept. 25, 2020). Unfortunately, while the check-valves were installed recently in 2017, they no longer function as designed and allow water to flow back through the storm drain system and pool on the street.

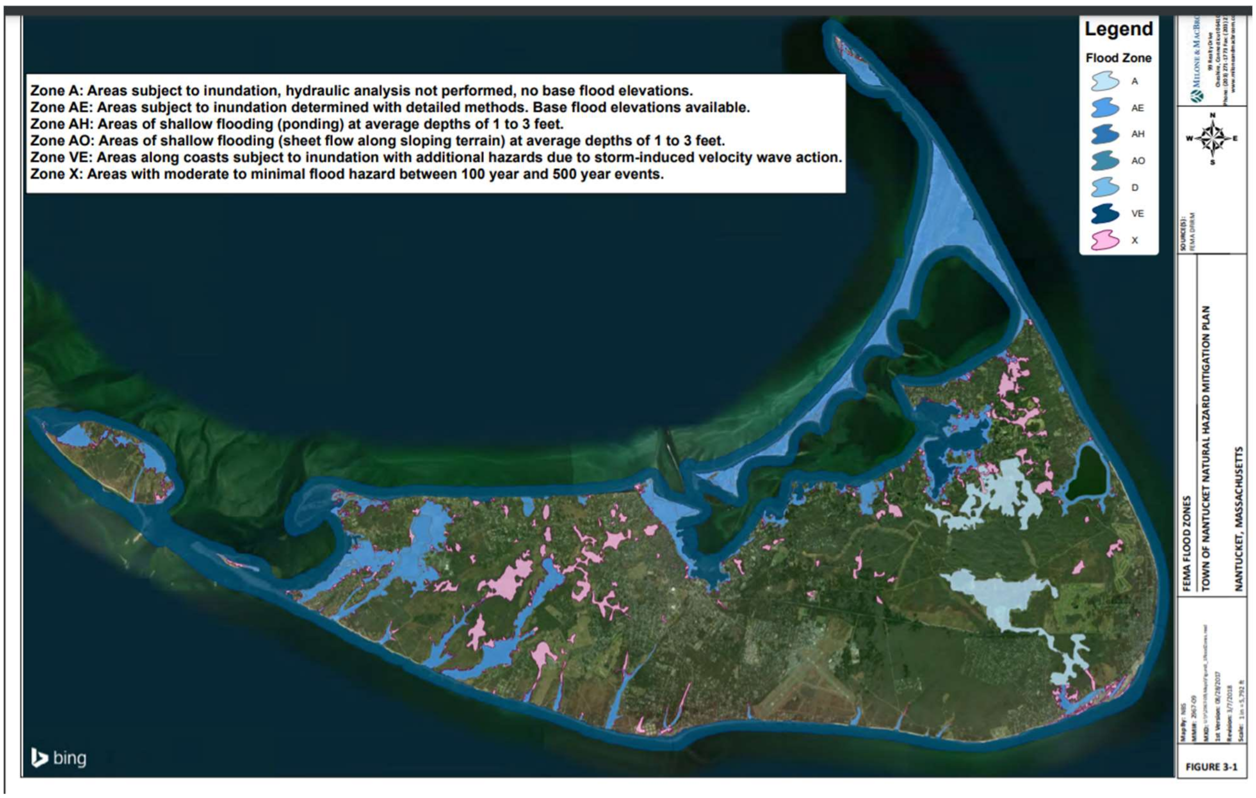

Figure 5: Map that shows predicted flooding areas for certain flood events, much of the downtown area according to this map is expected to flood (Hazard Mitigation Plan, 2019)

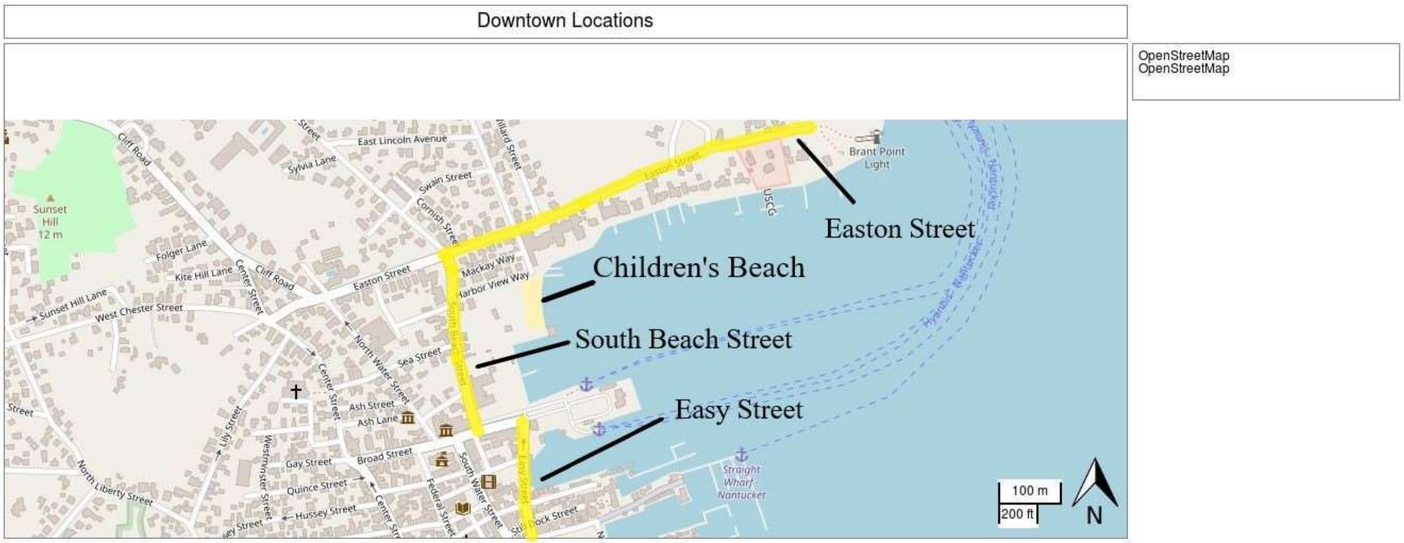

Figure 6: Downtown locations susceptible to flooding. Map generated using MORIS, highlighted and annotated post render (MORIS).

Areas outside of downtown that flood frequently include Brant Point neighborhood, Madaket Harbor area, Polpis Road, and Polpis Harbor area. On Brant Point, Easton Street tends to flood first and can experience a few inches to several feet of flooding. Brant Point primarily floods due to tidal inundation and heavy rains, which back up through the storm drain system. Madaket Harbor experiences flooding from storm surges and excessive rain (Sutters & Balling, 2018). Multiple areas of Polpis Road, which extends from the western end of Milestone Road to Siasconset, experience flooding.

One of the areas that floods most frequently is the section that borders Sesachacha Pond (Figure 7). It experiences such high flood waters that it renders the road impassable by car (Hazard Mitigation Plan, 2019, p.133). Polpis Road by Sesachacha Pond would require a category 3 or 4 hurricane to occur to flood due to hurricane surge inundation (Figure 7). Other areas along Polpis Road like Fulling Mill Creek suffer from flooding due to tidal inundation and especially storm surges during hurricanes and other storms and these floods often compromise access to the Polpis Road (Hazard Mitigation Plan, 2019, p.140. Polpis Road near Fulling Mill Creek could be inundated by a storm surge from a hurricane as small as a category two (Figure 8).

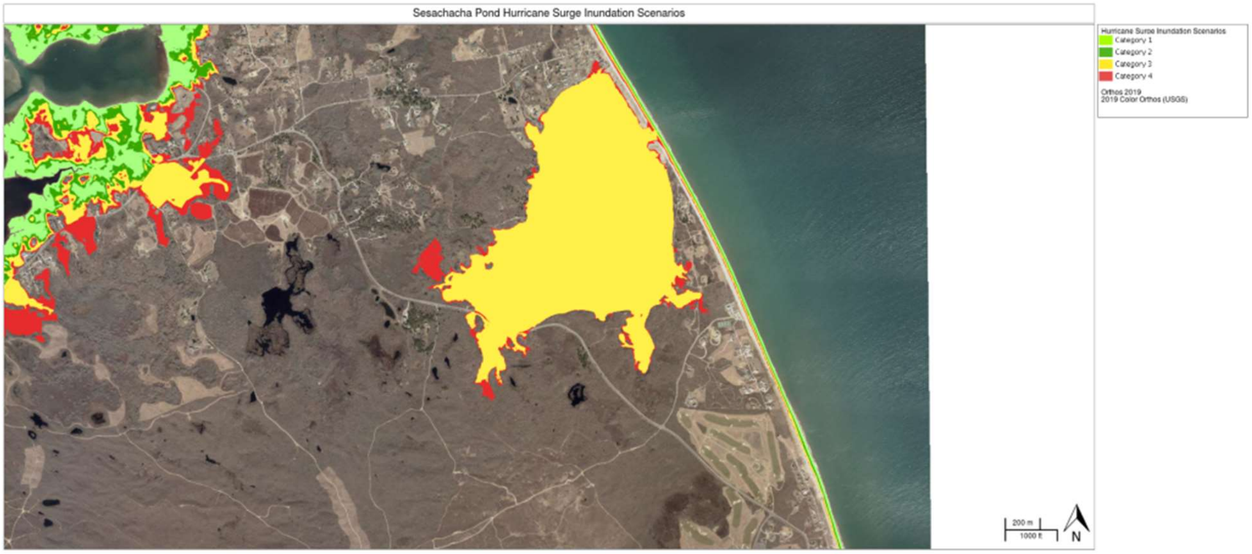

Figure 7: Polpis Road by Sesachacha Pond Hurricane Surge Inundation Scenarios (MORIS).

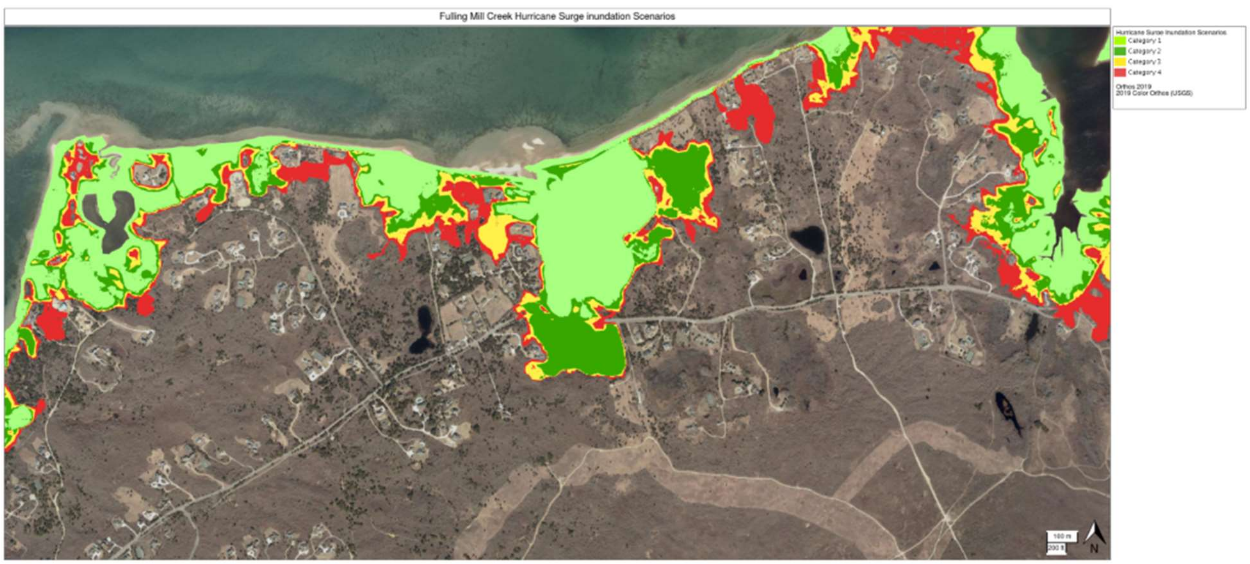

Figure 8: Polpis Road by Fulling Mill Creek Hurricane Surge Inundation Scenarios (MORIS)

Section 2: Concerns about Sea Level Rise

Sea level rise because of climate change will exacerbate the frequency, extent, and severity of all types of flooding on Nantucket and globally. As sea-levels continue to rise, a substantial portion of Nantucket's existing coastal wetlands could disappear. Inundation will create new saltmarshes in some low-lying areas negatively effecting houses, septic systems wells and roads in those areas. Saltwater will advance up Madaket Ditch into Long Pond and storm surges from hurricanes and nor'easters will penetrate further inland. In 80 years, Category 1 hurricanes will have adverse impacts comparable to Category 3 hurricanes at present (Hazard

Mitigation Plan, 2019). As sea levels rise on Nantucket, areas that are now seldom affected will begin to flood with more frequency. Figure 9 shows that sea level has been rising an average of 3.75 mm/year since 1965 in Nantucket, which is among the highest rates observed in the North East (Figure 10), experiencing 8 inches of sea level rise from 1965 to 2019.

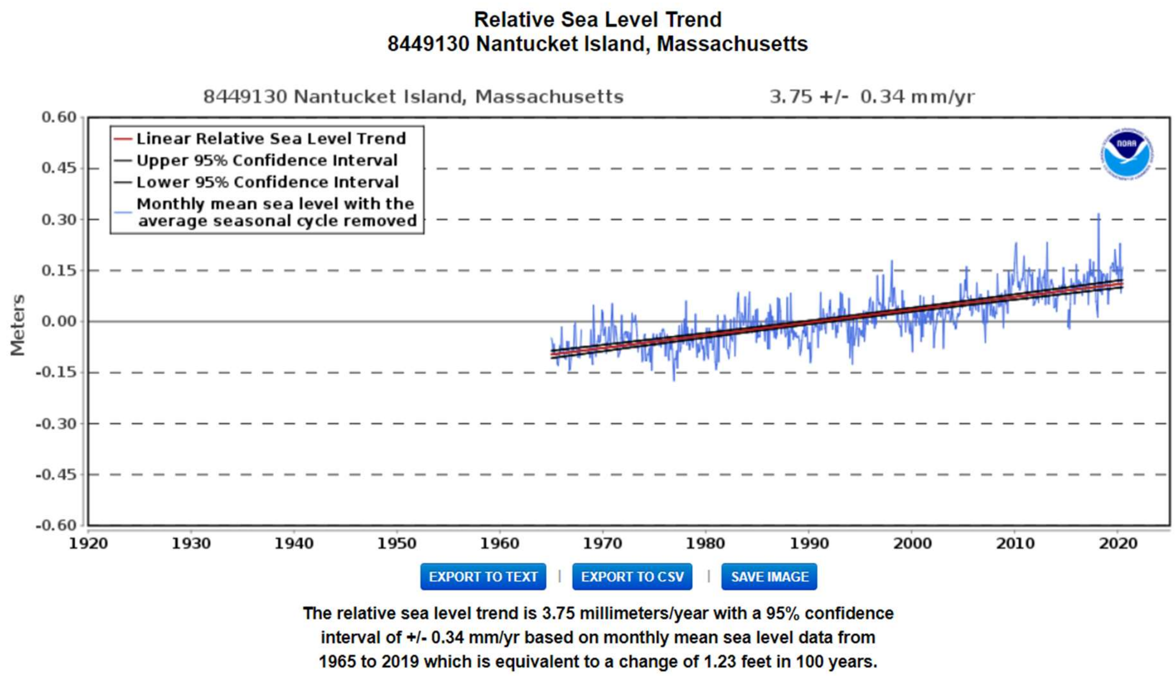

Figure 9: The Relative Sea Level Trends on Nantucket (Sea Level Trends - NOAA Tides & Currents)

Relative Sea Level Trends for Northern Atlantic

The graphs compare the 95% confidence intervals of relative sea level trends. Trends with the narrowest confidence intervals are based on the longest data sets. Trends with the widest confidence intervals are based on only 30-40 years of data. The graphs give an indication of the differing rates of vertical land motion, given that the absolute global sea level rise is believed to be 1.7 +/- 0.3 millimeters/year.during the 20th century. The calculated trends for all stations are available as a table in millimeters/year and in feet/century

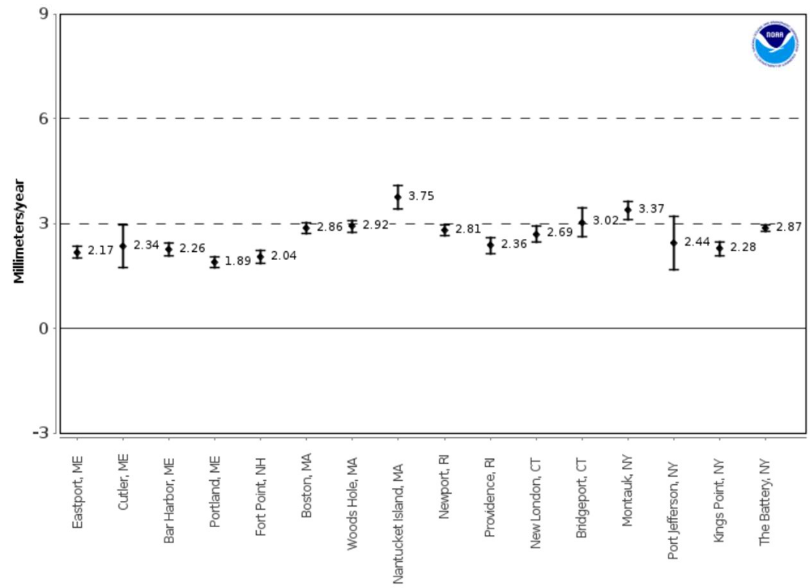

Figure 10: A graph showing the relative sea level trends in the Northern Atlantic at a sampling of stations (Sea Level Trends - NOAA Tides & Currents)

While Figure 9 portrays a gradual increase in sea level rise, future projections by NOAA suggest increases may be exponential (Figure 11). As a result, Nantucket may see a much more rapid increase in sea level rise within the next few decades. Areas on Nantucket that may be most heavily impacted by such changes are (from west to east) Madaket Harbor, Eel Point Marsh, North Pond, Long Pond, Hummock Pond, Children's Beach, Brant Point, The Creeks, Polpis area, Nantucket Harbor, and Sesachacha Pond (Figure 12).

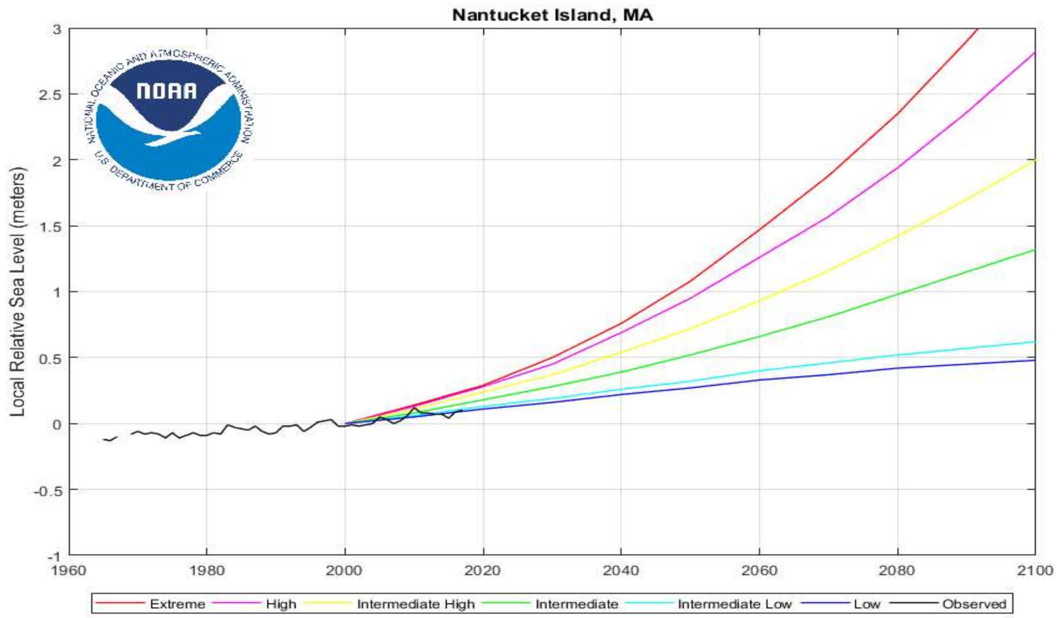

Figure 11: "Annual Mean Relative Sea Level Rise Since 1960 and Regional Scenarios 8849130 Nantucket Island, Massachusetts" (Sea Level Trends – NOAA Tides & Currents)

Figure 12: Areas prone to high tide flooding (NOAA's Sea Level Rise viewing tool). Callouts added after retrieving the figure (October 13, 2020) (NOAA Logo Sea Level Rise Viewer).

The Hazard Mitigation Plan predicts sea level rise increase areas affected by inundation, result in more frequent storm surge flooding, cause further erosion of beaches and bluffs, and threaten Nantucket's coastal wetlands, unless they can migrate inland faster than the sea rises. Higher ocean levels will force storm surges from hurricanes and nor'easters further inland. By the end of this century "FEMA coastal base flood elevations, which are currently at 8 to 9 feet (NGVD) depending on the location, will progressively rise" (Hazard Mitigation Plan, 2019, p.178), impacting areas that are currently unaffected due to their elevation. As sea levels rise, drainage systems will become less effective. Areas like Brant Point and downtown will be at a heightened risk of flooding as "Nantucket already experiences problems with inadequate storm drainage in areas such as Brant Point and downtown" (Hazard Mitigation Plan, 2019, p.178). Flooding mitigation practices need to be proactive in protecting the lands that are not just in immediate danger, but also those with elevations that could be impacted in the coming years.

Section 3: Flood Damage

Flowing water is one of the most powerful natural workhorses on Earth, able to uproot trees or carve paths through the earth. Along with immense force comes the ability to damage and destroy buildings and other infrastructure. The primary factors which cause damage are depth, velocity, rate of water rise, and debris impacts (FEMA 2014, p.27)

3.1: Depth

The depth of a flood and flood inundation, where waters are not moving fast but rise to significant depths can cause considerable damage. The buildup of water on the exterior of a waterproof building exerts hydrostatic pressure (Figure 13). When enough water builds up outside of a building the force created can cave in walls, bring underground structures like septic tanks to the surface or in extreme cases lift the building out of the ground (FEMA 2014, p.29). The depth of flooding can also disrupt the daily routine of area residents or force evacuation. Deep flood waters may render vehicles inoperable and isolate people in their homes for the duration of the flood. Deep floods can damage internal features of buildings when waters infiltrate the building through windows, doors, or other openings. If buildings are designed to allow flow in and through a building it will suffer less structural damage. Buildings need to be specifically adapted for this type of wet flood proofing.

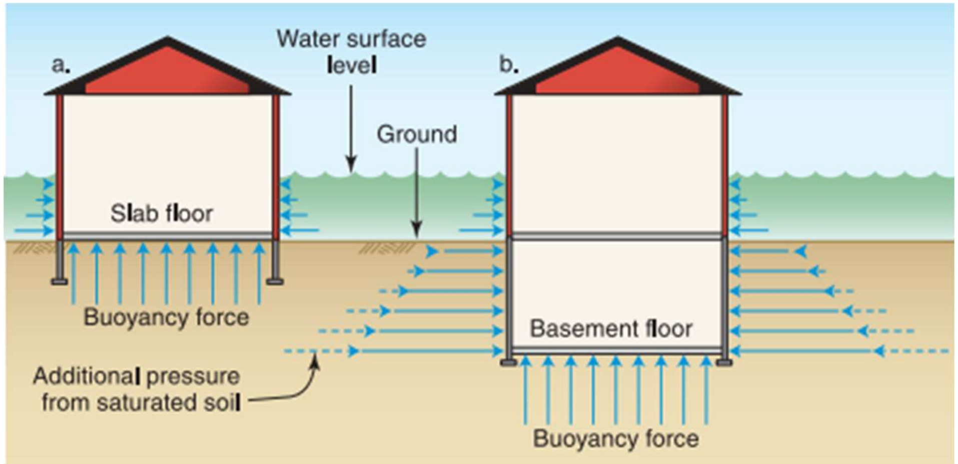

Figure 13: Hydrostatic pressures exerted on a building during flooding (FEMA, p. 29)

3.2: Velocity

Water velocity is one of the most dangerous parts of a flood. Water weighs 63 pounds per cubic foot. Even slow-moving water can impart a significant force on anything in its path. To resist the water objects in its path must expert an equal and opposite force or be swept up and carried with the flood (Pistrika et Jonkman 2009, p.426). Water can move cars, mailboxes, and trees. If a person is caught in flowing water, they will be swept away if the flow is fast and deep enough. Water velocity adds to the force of hydrostatic pressure and the force generated by water flow compounds on the force applied from water weight causing structural failure. The flow imparts additional force on the building as water flows past. This force can damage home paneling or remove molding (Figure 14) (FEMA 2014, p.30).

Figure 14: A home which had the wall ripped off due to flood water velocity (FEMA, p.31)

3.3: Rate of water rise

Equally as harmful as depth and velocity, the rate at which the flood rises causes significant problems. Rapidly rising waters give homeowners little time to prepare. They may not have set up flood proofing measures to protect themselves or to evacuate areas at risk (Garrett AO, n.d., p.8). This can lead to inadequate protection for the home or the residents. If they are not able to evacuate before the flood starts, deep or fast-moving waters may prevent them from evacuating for the duration of the flood.

3.4: Debris Impacts

With a combination of deep water and fast flow velocity, lots of debris can be carried with the water. Anything from natural materials such as bushes, rocks, or trees to manmade objects like trash cans and cars can be moved by flood waters. Debris slams into houses and can easily shatter windows or break walls. In the wintertime, Nor'easter flooding can bring inland large chunks of ice which serve as additional debris to impact structures and damage property (FEMA 2014, p.33). Wind and waves associated with coastal storms can exacerbate the damage caused by debris.

Section 4: Flood Mitigation

Flooding itself is a complex issue requiring a multi-step approach to reduce its effects. Most flooding strategies aim to prevent the target structure from being damaged. These approaches fit in to one of three categories: avoidance, dry proofing, and wet proofing (Proverbs & Lamond 2017, p.6). Additionally, flood insurance is an important aspect of flood protection.

4.1: Avoidance

The aptly named avoidance method prevents damage to structures by preventing floodwaters from encountering the structure. If the water can be stopped before it reaches the target or the target can be moved out of the path of the water, then no damage can be done. There are three major avoidance methods: relocation, elevation, and barriers (FEMA 2014, p.93).

4.1.1: Relocation

The most logical of these strategies, relocating a structure out of flood zones provides clear benefits to minimize damage. The process involves raising the structure out of the ground and transporting it to another location, where it is re installed on new property. Relocation is a highly effective way of protecting a home that is commonly practiced on the island. Organizations on Nantucket have shipped houses to new locations and the town frequently relocates old and historic structures. Even large brick structures have been moved, for example, in 2010 the Sankaty Lighthouse was moved to preserve its historical value and it as a working lighthouse because the cliff it sat on was eroding (Atlantic East 2010). A historic structures' age contributes to its ability to move, older homes tend to align with FEMA descriptions of easy homes to move because they are rectangular and one to two stories high (FEMA 2014, p.104). While costly and potentially harmful to a structure, relocation is a strong candidate for flood mitigation, though likely as a last resort if no other measures can effectively preserve the structure.

4.1.2: Elevation

Elevation effectively reduces the risk of flooding by raising the structure in danger. Elevating the structure prevents flood waters from reaching the inhabited part of the building or the building’s utilities. Elevation is done by using jacks to progressively lift the structure and build supports underneath. The goal of elevation is to allow the flood waters to pass under the house or around a raised foundation, preventing water from entering the home. Elevating a building is theoretically simple for many timber-framed buildings on Nantucket although it may be expensive (FEMA 2014, p.104). Many houses around the harbor are built on pilings (Figure 15) and elevated on stilts (Figure 16), and many houses in flood prone areas have already been elevated on stilts or floodproof foundations. Elevation presents a viable solution to flooding without extreme change to the layout or location of the buildings on the island.

Figure 15: Houses on stilts in the North Wharf area (V. Murphy, personal communications, Sept. 25, 2020)

Figure 16: Former Stilt house built near Millie's Bridge (Nicole Harnishfeger. (Mar 2018). "Stilt House." Inquirer & Mirror)

4.1.3: Barriers

If modifications to a structure are not feasible or desirable to the owner, barriers also act as part of the avoidance method. Barriers come in many forms such as floodwalls (Figure 17), a sea wall, or ditches placed to redirect water around a structure (FEMA 2014, p.155). Geographic features such as wetlands also act as natural barriers. Wetlands provide an interesting alternative approach to constructing a barrier. They act as both a natural reservoir, retaining flood waters that enter, and an attenuator as the flora provide friction to the flowing flood waters, slowing flow and consequently reducing the force of waves (Smolders, Plancke, Ides, Meire, et Temmerman, p.6). Salt marshes provide a natural alternative, as seen in Figure 18 they are already present across the island and on the harbor. Restoring and creating new coastal wetlands could provide a natural buffer between the harbor and inland that would both reduce the quantity of water able to pass and attenuate the force of the water that does. When constructed barriers like sea walls are tall enough to withstand high flood levels, they are effective at preventing damage to structures. Sea walls may not be an effective mitigation system for Nantucket. The density of private beachfront housing on flood prone areas would require independent homeowners to forfeit a portion of their property to construct an effective seawall (V. Murphy, personal communication, Sept. 25, 2020). Currently, many town wave attenuation walls stop at private property, allowing for waters to flow around the wall rendering them ineffective (Figure 19). Additionally, building new barriers including seawalls, bulkheads, and other structures is currently prohibited on the island without a waiver indicating a special need for installation (Nantucket Coastal Conservancy, n.d.).

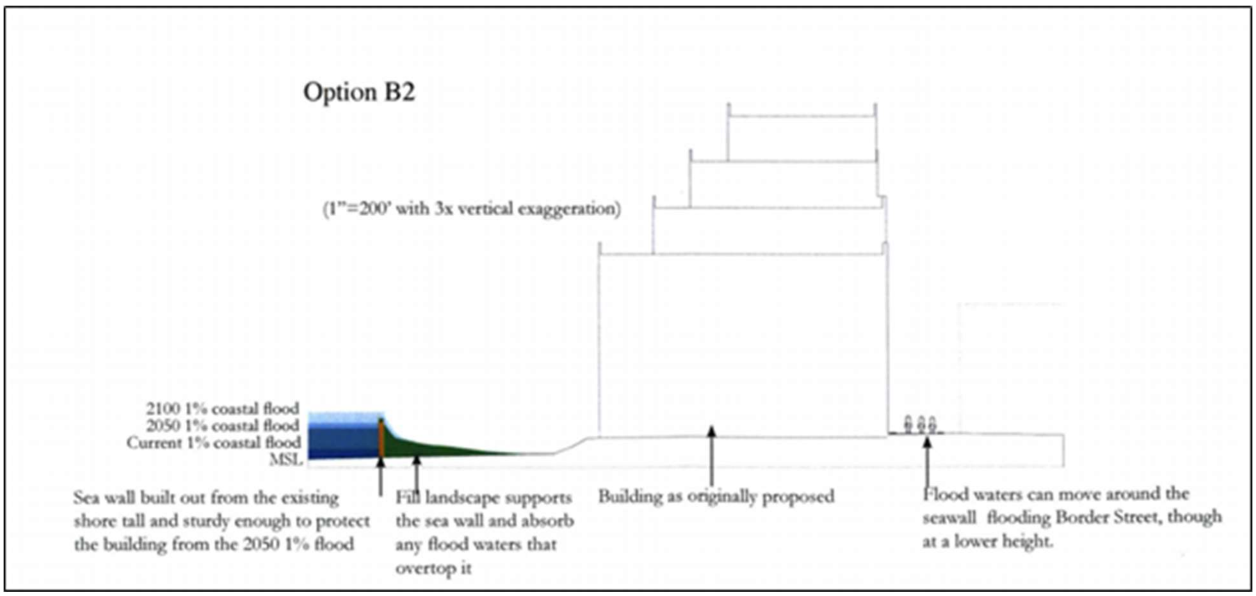

Figure 17: A diagram of a Boston building using a proposed sea wall as flood protection (Wolff. Option B2. (2009). MIT).

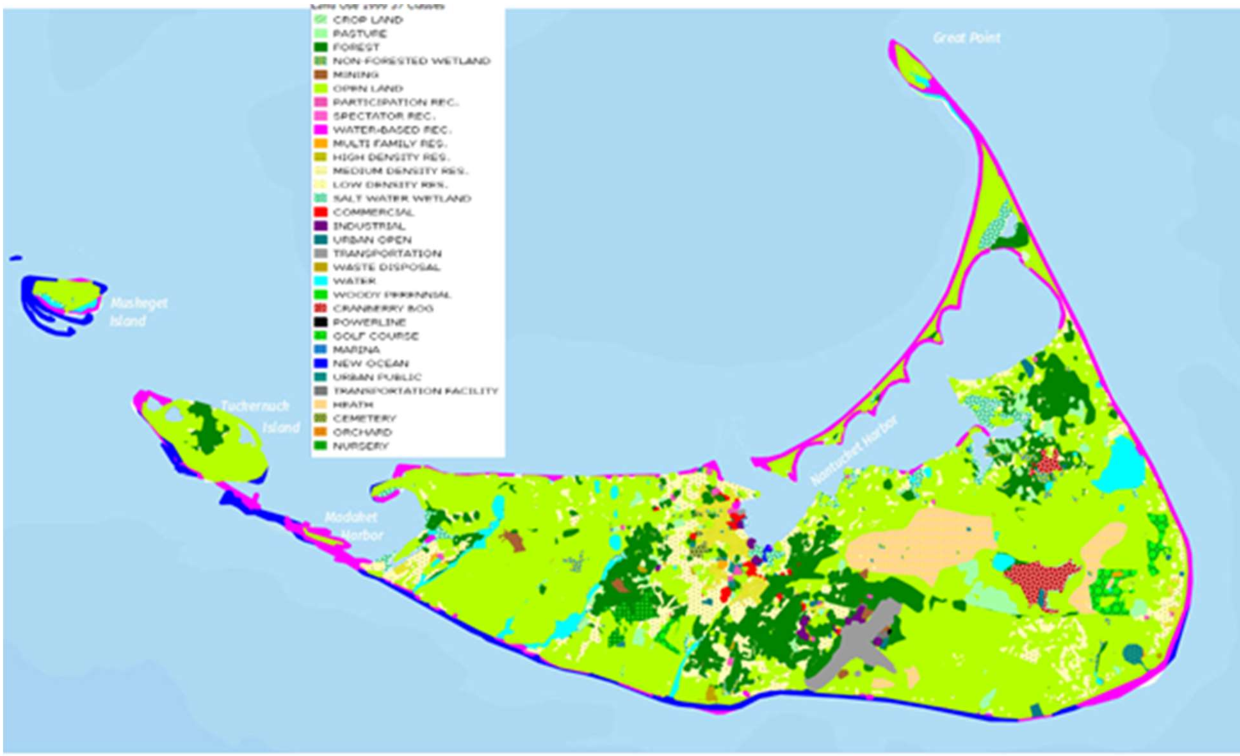

Figure 18: GIS map of the land use of Nantucket (Resource Mapping Project).

Figure 19: A wave attenuation wall near the intersection of Easy and Oak St. (V. Murphy, personal communications, Sept. 25, 2020)

4.2: Dry Proofing

Dry proofing a structure mitigates flooding damage by keeping water out. Instead of stopping the water before it can reach the structure, the water will be by the structure. Dry proofing is done through various methods. Some choose to board up windows and doors or covering openings with blockades (Proverbs & Lamond 2017, p.7). It is also possible to create seals inside buildings such that the normal function of the building remains intact and the interior becomes waterproof (Figure 20) (Corps of Engineers 1995, p.75). When employed as a last-minute solution dry proofing such as stacking sandbags in front of doors and boarding windows may not be effective. Most temporary measures are not able to withstand serious flood pressures and are often washed away by the force of the flood. When implemented in permanent fashions such as the door shields (Figure 20) or door skirts and sealants for concrete, dry proofing can hold up well against flooding. Dry flooding increases the hydrostatic pressure a building experiences posing a major risk to structures that cannot withstand the additional force. Thus, dry proofing is only a safe method of prevention when structures are strong enough to withstand high forces. Conversely, dry proofing has the benefit of subtle modification. Historic buildings could adapt dry proofing without significant changes to their aesthetic. Sealing basement walls and adding rubber seals to the bottom of doors would be sufficient in prevent major waterflow.

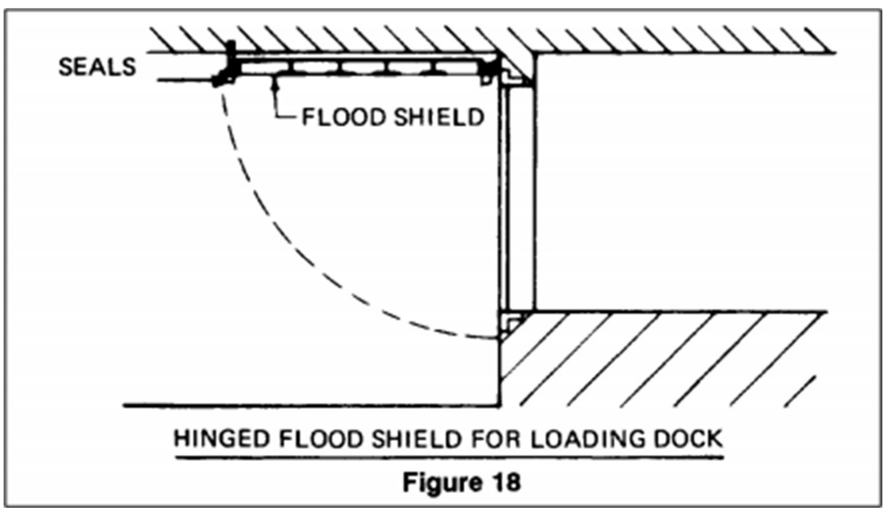

Figure 20: An example of a dry proofed loading dock, using a deployable seal to cover the entrance during floods (Corps of Engineers 1995)

4.3: Wet Proofing

Wet proofing a structure provides a different approach to preventing damage when compared to avoidance or dry proofing. Wet proofing focuses on minimizing resistance to flood waters. Instead of keeping water out, a wet proofed structure will allow water to enter and flow through, while controlling the path of waterflow inside the structure (Proverbs & Lamond 2017, p.8). The main benefit of wet proofing over dry proofing is the reduction or elimination of hydrostatic pressure to the structure. Wet proofing equalizes the pressure of the flood water outside and inside (Figure 21). Floodproofing a building is a multi-step process. Typically, the basement of the houses flood, so holes must be added to the basement walls or foundation to allow water to enter. The basement should be cleared of any items that are not water resistant and could be damaged by a flood, any remaining items should be waterproofed, and any loose items should be secured in watertight containers. The greatest challenge is relocating furnaces, electrical panels, and other house utilities out of the flood zone, which often requires significant change to the original structure (FEMA 2014, p.67). Water-proofing modifications occur in the interior a building preserving the historic exterior. That said, any changes made to a historical building requires a permit from the island's Historic Development Commission because the process may involve the removal of historic material (Nantucket Code, § A301-4). Wetproofing provides a subtle way to preserve historic structures without the risk of hydrostatic pressure damage from flood waters.

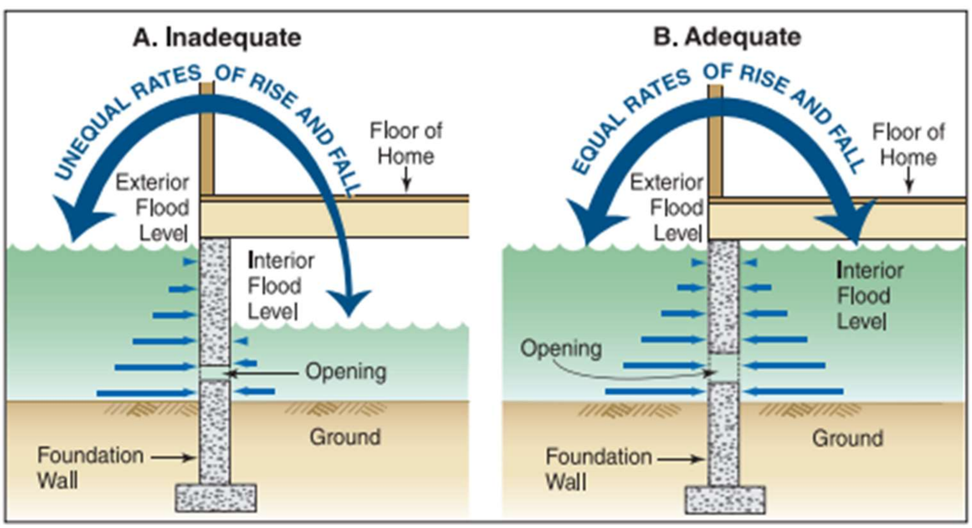

Figure 21: A diagram showing the pressure difference flood water inflicts on a home and a home with adequate wet proofing (FEMA 2014, p.140)

4.4 Flood Insurance

No floodproofing or mitigation method is perfect, faults can occur in many ways, from rodents chewing through dry proofing to a flood wall collapsing. Regardless of the cause, unexpected property damage will occur, and costs can quickly add up to financially harmful levels; as FEMA estimates, $25,000 in damage can be caused by only 1 inch of flooding (FEMA 2020, November 23). Nantucket as a community participates in the National Flood Insurance Program, or NFIP, meaning island homeowners and businessowners can enroll in and benefit from FEMA flood insurance. As outlined by FEMA, NFIP flood insurance policies can offer coverage limits of up to $250,000 for homeowners and $500,000 for businesses, which offers significant peace of mind knowing should your home or business be damaged by floods, lots of the cost may be covered (FEMA n.d. Types of flood insurance). An equally viable option is to enroll in private flood insurance, although coverage will vary by provider. Even if a building is not in a high-risk flood zone, flood insurance is strongly encouraged, considering the downtown area alone, as shown in Figure 22, most residential areas of the island are at some risk of flooding per the FEMA flood zone maps. Buildings which merely had flooding as an afterthought were affected along with ones bordering the harbor front, flood insurance would be able to help all the buildings affected more rapidly recover and help the island return to normal.

Figure 22: Map that shows predicted flooding areas for certain flood events, much of the downtown area according to this map is expected to flood (Hazard Mitigation Plan, 2019)

Section 5: Nantucket's Current Approach

The town of Nantucket has extensive strategies for flooding mitigation as outlined by the 2019 Hazard Mitigation Plan (HMP), the Coastal Management Plan (CMP), the Coastal Risk Assessment and Resiliency Strategies Report (CRARSR) and the mission and activities of CRAC. As of March 2019, the Hazard Mitigation Plan outlines the functions of various town departments in Nantucket and their responsibilities in managing flooding. The HMP also defines town legislation for managing flooding, gaps in regulation and priorities for action. The most crucial areas to address are those with deep and or repeated flooding (Figure 22). The Coastal Management Plan outlines policies and procedures for protecting town infrastructure, public access points and roads adjacent to the island's coastline. The plan divides the island into ten sectors to address the unique challenges and risks posed in each area. The Coastal Risk Assessment and Resiliency Strategies Report assesses the vulnerability of different areas on the island using GIS mapping and projection reports. It outlines resiliency tools that the town can use to protect infrastructure and identifies areas where changes in policy are necessary to allow for the implementation of tools. The Costal Resiliency Advisory Committee serves to implement a Coastal Resiliency Plan for the town and address the impacts of sea-level rise and climate change on the island.

Coastal Erosion

The HMP defines plans to help mitigate flooding while also protecting the ecology of Nantucket. Regulations in zoning are designed to limit development in flood areas to encourage balance of development and natural space (Hazard Mitigation Plan, 2019, p.121). The Wetland Protection Act restricts construction within 100 feet of the edge of a wetland. Construction within 100 feet of eroding bluffs is also prohibited because the bluffs are borders of wetlands. Regulations are intended to limit damages and losses when erosion occurs (V. Murphy, Personal Communications, Dec 3, 2020). Figure 23 shows that extensive areas of the Nantucket shoreline, especially on the south, west, and northwest parts of the island. Coastal erosion equally contributes to inland flooding by destroying barrier beaches and sandbars which act as a natural buffer to the ocean.

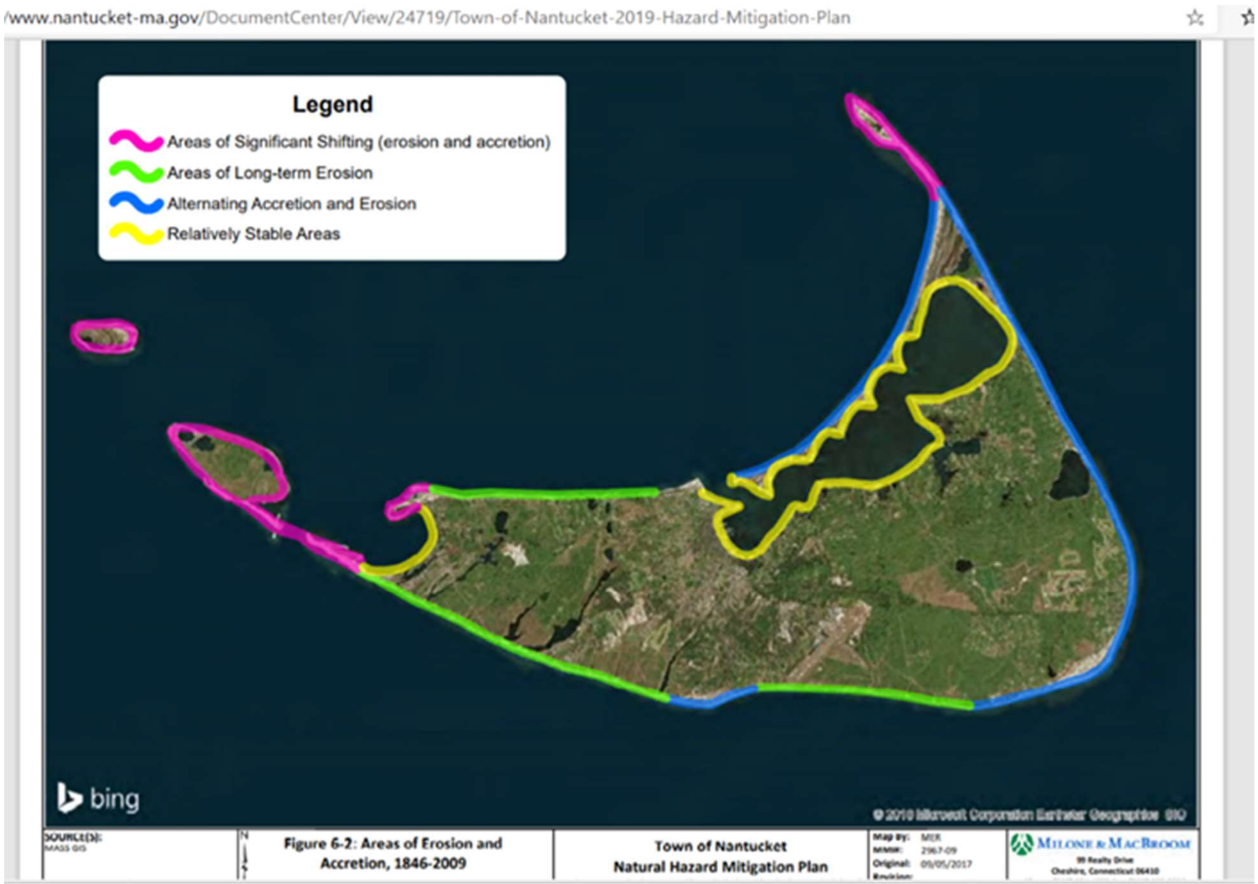

Figure 23: Areas of concern for erosion on the island (Hazard Mitigation Plan)

Flooding Mitigation Regulations

The HMP outlines specific laws and regulations aimed at reducing flooding. Building in areas where there is frequent coastal storm flooding that could cause structural damage is banned and projects cannot undermine the ability of wetlands to reduce the rate of waterflow. Building codes require structure's foundations to withstand the force of floods and that any part of the building "subject to damage be above or otherwise protected from flooding (Hazard Mitigation Plan, 2019, p.121). Any development or redevelopment policies need to include effective storm water management policies. The HMP advises that developers build detention and retention facilities for water when necessary. Possible suggested strategies to reduce runoff volume include the use of "swales, infiltration trenches, vegetative filter strips, and permeable paving blocks" (Hazard Mitigation Plan, 2019, p.121). The goal is for post-development storm water to leave a site at a rate slower than pre-development conditions (Hazard Mitigation Plan, 2019, p.121). Each of these policies is designed to reduce different flooding effects.

Ground Infrastructure

The Hazard Mitigation Plan outlines requirements for a Storm Water Management Plan (SWMP) that guides the DPW aimed at both preventing and managing flooding. The plan uses the Wastewater Capacity, Management Operations and Maintenance (CMOM) program to identify connections to the sewer and water system that would allow for better water flow. Poor drainage occurs in some areas that are so low lying that there is no slope to drain water well. Low lying areas cannot have pumps to drain water because ground water levels are so high. The CMOM works to modify and rebuild the town's century old sewer system to better operate and maintain collections systems, identify constrained areas, and respond to sewer overflow events. Increased runoff from newly developed areas, climate change and an increase in basement sump pumps has contributed to capacity issues in the town drainage system (Hazard Mitigation Plan, 2019). Pipe capacity can be increased by increasing outflow points with backflow prevention mechanisms. The addition of sediment traps and hydrocarbon interceptors can help maintain water quality. In conjunction with the CMOM the SWMP can drain stormwater from the surface more efficiently.

Flood Water Management Plans

The Department of Public Works (DPW) is responsible for preparing for and responding to flood events on public property. Their responsibilities include preparing town roads and infrastructure for flood events including sewer pumping and waste management systems. The DPW puts up barriers on flooded streets, in coordination with the Police department and removes them after floods have subsided. They also close and open the Children's Beach wave attenuation gates and maintain the stormwater network. An activity undertaken during flood events to remove blockages. The DPW maintains town owned culverts, catch basins, leaching systems and other drainage facilities and manage the repair and restoration of flooded areas.

The DPW is often overwhelmed by the quantity and scale of flood events that occur on the island and frequent storms drain their resources (Hazard Mitigation Plan, 2019, p. 68). For example, in 2019 they did not have enough material to barricade all roadways that could potentially flood. Nantucket is limited by its location and cannot make the mutual-aid agreements that benefit its mainland counterparts. Usually, a mutual-aid agreement would provide a town relief from carrying the whole burden of disaster preparation and clean up. Unfortunately, as an island with no near neighbors, Nantucket cannot depend on mutual aid and relies instead of on-call local contractors and emergency contracts with private companies (Hazard Mitigation Plan, 2019, p.68).

Areas for Infrastructure Improvement

Despite the extensive efforts of the town to combat flooding there are parts of the system that fail. For example, the Children's Beach pump station was intended to improve the water quality of stormwater discharged into the harbor and drainage in South Beach Street and Brant Point. (V. Murphy, personal communication, Sept. 25, 2020). The gate operation is not consistent because residents interfere and leave the gate open. The Children's Beach pump station was intended to improve storm water drainage in south beach street and Brant point but fails in high-water events (Hazard Mitigation Plan, 2019). The wave attenuation gate at the Children's Beach boat ramp operation is not consistent in flood events because boat owners wishing to use the ramp interfere and leave the gate open. This is an occasional to regular occurrence when the gate is closed during storm events, with no predictability.

The Coastal Management Plan (2014) identifies key issues whose improvement could help mitigate flooding and coastal erosion. They identified sixteen issue points including coastal hazards, erosion control, water quality and harbors (Table 2). The island is divided into ten sectors and the plan outline specific action steps that protect each specific sector of coast. (Figure 24). Section 1A/B is identified as an area for tidal wave energy exploration and contains an important habitat for shellfish. The Easy Street bulkhead is recognized as infrastructure that needs to be replaced to protect the properties and infrastructure on the waterfront and in downtown and mitigate flooding. It was upgraded in 2017 based on the recommendation in the CMP. For each section of the island the plan identifies issues and potential actions to mitigate flood problems.

Table 2: Issue descriptions for CMP (Coastal Management Plan, 2014)

Issue	Status	Recommend
Water Quality	Town Water Quality Initiative underway	Reference WQI in CMP to satisfy this issue
Habitat	Covered by Town of Nantucket Wetlands Protection Bylaw Chapter 136	Reference Bylaw in CMP to satisfy this issue
Coastal Hazards	Policy developed by CMP	
Erosion Control	Policy developed by CMP	
Harbors	Harbor Plan covers pertinent issues	Reference Harbor Plans in CMP to satisfy this issue
Public Access Policy	Policy developed by CMP	CMP developed in consideration of One Big Beach, Roads and Right of Way Committees
Beach Access Policy	Beach Management Plan completed	Reference WQI in CMP to satisfy this issue
Off Shore Resources	Covered by Commonwealth of Massachusetts Oceans Management Plan	Reference Ocean Management Plan in CMP to satisfy this issue
Homeland Security	Policy developed by CMP	
Alternative Energy	Policy being developed by NP&EDC	Considered in CMP, additional input to be given by NP&EDC
Fisheries	Covered by Town of Nantucket Wetlands Protection Bylaw Chapter 136, Harbor Plan and Shellfish Management Plan	Reference Bylaw and both plans in CMP to satisfy this issue
Data Accessibility	Website construction underway	Make drafts, updates and final principals available through town website
Consistency	See preparation and review	Existing plans and initiatives considered by CMP
Recreation	Covered by Town of Nantucket Wetlands Protection Bylaw Chapter 136 and Beach Management Plan	Reference Bylaw and BMP in CMP to satisfy this issue
Aesthetics	Covered by Town of Nantucket Wetlands Protection Bylaw Chapter 136	Reference Bylaw in CMP to satisfy this issue
Integration with Municipal Harbor Plan	Issues covered by CMP outside of scope of Harbor Plan	Reference Harbor Plans in CMP to satisfy this issue

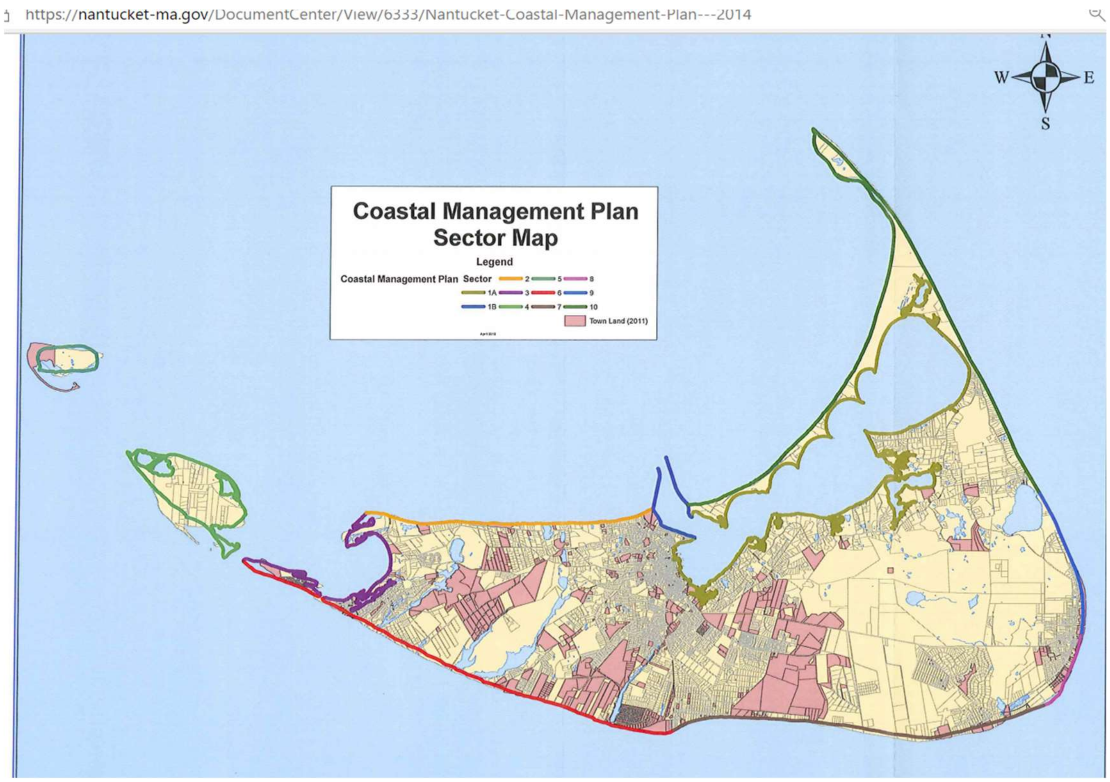

Figure 24: Coastal Management Plan Sector Map (Coastal Management Plan, 2014)

The Town of Nantucket Coastal Risk Assessment and Resiliency Strategies report outlines proposed strategies for mitigating flooding and coastal erosion for the island. It includes both property protection tools, such as structure elevation, wet proofing, dry proofing, and relocation as discussed above, as well as other approaches, including regulatory tools, education, and outreach (Table 3). Increasing the standards for structures in risk zones and preventing hazardous development patterns are crucial supportive function to proposed mitigation strategies (Table 3).

Table 3: An outline of flooding and coastal erosion mitigation tools proposed by the RARSR (Town of Nantucket Coastal Risk Assessment and Resiliency Strategies Report, 2020)

Measure	Summary	Benefits	Barriers to Implementation
Property Protection			
Elevation	Raise structure above flood level	Reduce insurance premium Open to residences Permitted in V zones	Harder to access "Dead space" under structure Difficult for some buildings
Wet Floodproofing	Retrofit lowest floor to allow flooding	Relatively inexpensive	Extensive post-flood cleanup Inappropriate for most residential
Dry Floodproofing	Waterproof structure Barriers at openings	Relatively inexpensive Doesn't require extra space	Manual barrier installation Subject to storm predictions Vulnerable to flow & waves Inappropriate for most residential
Site-Scale Floodwalls	Install concrete or earth barriers on property	Prevent water contact with structure & need for retrofits	May require large area Obstructs views
Temporary Flood Barriers	Deployable & removable barriers	Prevent water contact with structure & need for retrofits Relatively inexpensive	Manual installation Subject to storm predictions Short-term only
Relocation	Move structure to safer location	All vulnerability removed Open to residences	Cost, decreased value of new site Loss of Neighborhood Cohesion
Adaptive Re-use	Maintain structure, change to floodable use	Low disruption, low cost	Limited applicable uses Risk persists
Acquisition & Demolition	Sell property & convert to public open space	Landowner compensated All vulnerability removed Public & habitat benefit	Municipal Cost Loss of Neighborhood Cohesion Requires landowner interest
Regulatory Tools			
Floodplain Management	Increase standards for structures in risk zones	Protect new & improved construction	Older structures often exempt Doesn't address climate change
Zoning Regulations	Prevent hazardous development patterns, allow inland migration	Control level of risk in hazard areas, plan for future changes, integrate multiple priorities	Balance with economic pressures Public pushback possible
Rolling Easements	Legal & property-right measures encourage gradual inland migration	Work with landowners for mutual benefit	Private landowner may not be willing partners
Public and Institutional Education			
Education and Outreach	Keep municipal staff and the public informed	Public & institutional support for other policies & programs	None

From the research gathered it is clear Nantucket and Massachusetts have an in-depth set of laws designed to regulate building in flood risk areas. That said, there are gaps in infrastructure and strategies. Our team should focus our efforts on how to adapt existing structures and historical locations to withstand flooding events. The Hazard Mitigation Plan designated downtown Nantucket as an important center of growth. This is also the area with the highest concentration of historical buildings. Salvaging as much historical infrastructure as possible is crucial to the town identity and growth prospects.

Methods

Our goal of developing and enhancing flood mitigation strategies on Nantucket has four primary objectives: (1) Assembling a database of local flooding events, (2) recommending one or more locales for pilot testing, (3) building a knowledge base of urban flood mitigation strategies that could be effective on selected locales (4) evaluating mitigation methods appropriate for each selected locale. Each objective was divided into the tasks necessary to complete them (Figure 25). Each objective and their designated tasks were completed based on a seven-week timeline (Appendix B).

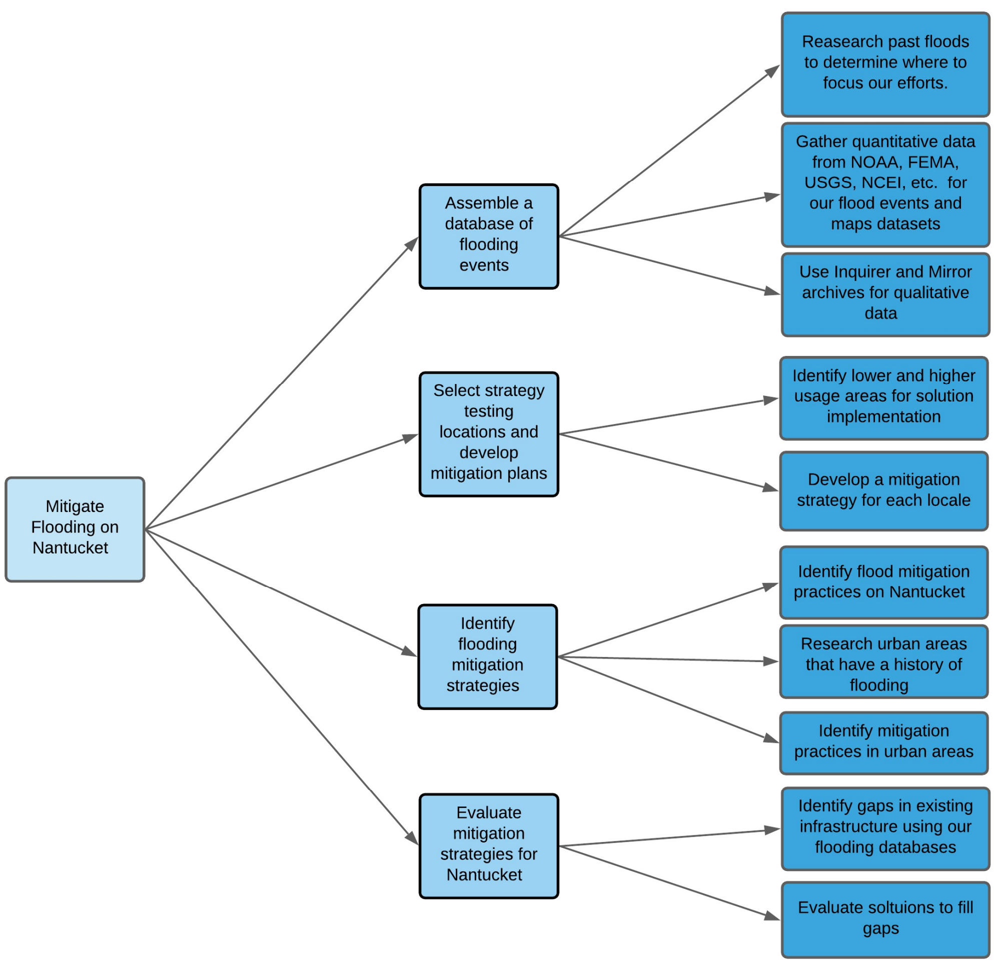

Figure 25: Breakdown of objects and their related tasks.

Objective 1: Assemble Flood Data

We collected data from flood events, flood maps and photos of past flooding events to create a database of flooding in Nantucket. The database includes flood dates, depths, extent using the NOAA water depths, and locations based on the Inquirer and Mirror (I & M) reports. We indicate the immediate cause of the flooding, such as high tide flooding, storm surge, rainfall, wind, etc. Some estimates on the type and severity of related damages were provided by the NOAA NCEI database. Our gathered data evolved as we conducted additional background research and become more familiar with the types of data that are available. For example, we included both NOAA water level and meteorological data for some dates. Our database includes a total of 703 unique instances of flooding including 111 storm driven flooding events and 592 high tide (non-storm) flooding instances collected from data from the NOAA station information for Nantucket including but not limited to "tides/water levels" and "meteorological obs." (Station Home Page - NOAA Tides & Currents). We also gathered information from FEMA maps, the Inquirer and Mirror and Chuck Larson's Easy Street report (High-Tides and Flooding on Easy Street, 2020). Our database records both flooding events and instances. A flooding event is a day where flooding occurred, and a flooding instance is an area which was affected by flooding. There are 57 instances of flooding not included on our GIS maps because those instances lack specific locational data.

We developed maps of flood locations based on our database. We consulted Nathan Porter, Nantucket GIS Coordinator, to help supplement our understanding of ArcMap, the software used to generate our GIS layers for this report. Fortunately, both Vincent Murphy, Coastal Resiliency Coordinator, and Nathan Porter, were able to provide us with useful layers and information to develop our GIS layers. We needed specific coordinates for each flooding instance in the database to place the event on the GIS layer. Unfortunately, we had very limited locational data for 57 flood locations so we could not include these locations in the GIS layers.

The GIS allows a user to click on any data point on the map (using the "identify" tool) and see all the information that is available in the database for that datapoint. We created multiple symbology scenarios including one where the size of the dot on the map is scaled to represent the NOAA water levels (i.e., a larger dot indicates deeper flooding). We also created a symbology based on the storm type where each storm type is represented by a different color.

Our different methods of symbology allow users to analyze the database's information in different ways.

Finally, we collected images from the Inquirer and Mirror, and other reports (detailed in Reference section) associated with flood events that are both integrated in the flood database and included in their own dataset.

The Inquirer and Mirror keeps a good record of major storms and flood events that have affected the island, so it became a key source of information for significant flood events. The Inquirer and Mirror includes information about the nature of the event such as flood heights, extent and properties affected, as well as photographs and interviews with officials and affected residents. The I&M provided most of our qualitative information including description of flooding instances, the type of event, areas affected, informal reports of the depth at some flooding locations and more.

The "Storm Events Database" from the National Center for Environmental Information (NCEI), a branch of the National Oceanic and Atmospheric Administration (NOAA), helped us identify past flood events due to coastal flooding, flash flooding, and storm surge/tide. It also provided the events' date, time, and a property damage estimate. The NCEI database provided us with a strong quantitative basis for our database.

The FEMA Flood Map Service Center shows areas prone to flooding and high-risk zones for damage. We used the FEMA layers to identify the types of flood zones impacting each of our case studies. The NOAA website "Tides & Currents" provided us with tidal data, speed of waterflow for the north facing harbor and metrological data. The technical report produced by NOAA titled: "2019 State of U.S. High Tide Flooding with a 2020 Outlook" provided us with a threshold of 1.77 feet MHHW above for high tide flooding on Nantucket. However, Chuck Larson's Easy Street report identified high tide flooding to occur at 1.1 above feet MHHW (High-Tides and Flooding on Easy Street, 2020). We opted to use 1.1 feet above MHHW as a more conservative metric for high tide flooding and Larson supported his claim with images showing water beginning to flood Easy Street at 1.1 feet MHHW. Easy Street has one of the lowest road elevations. We also consulted the Massachusetts Ocean Resource Information System (MORIS) which provided us with multiple GIS layers including Storm Tide Pathways, Impervious Surface, Coastal Inundation Uncertainty – Current Mean Higher High Water, Coastal

Inundation Scenarios, and Hurricane Surge Inundation Scenarios. The Town and County of Nantucket online GIS System provided us with Storm Tide Pathways, and ArcMap provided us with Nantucket Probability of Inundation layers for 2030, 2050, and 2070. The storm tide pathway layer was based on the maps from the Center for Coastal Studies based in Provincetown, MA. We also obtained data on sea-level rise on Nantucket from NOAA Tide Buoy Number 8449130 attached to Steamship Warf, approx. 100 meters (325 feet) from Easy Street.

Our findings were categorized and recorded based off type of flooding, date, storm name, location, and severity (Table 4).

Table 4: An example on how we organized the information gathered.

Name of Event	**Type of Flooding Event**	**EVENT_ID**	**BEGIN_DATE**	**Corresponding Predicted MHHW (ft) (NOAA Tidal Buoy)**	**Verified Highest MHHW (ft.) (NOAA Tidal Buoy)**	**Wind Gust(kn.) (NOAA Tide Buoy)**	**Sustained Wind(kn.) (NOAA Tide Buoy)**	**Lowest Barometric Pressure(mb) (NOAA Tide Buoy)**	**Highest Barometric Pressure (mb) (NOAA Tide Buoy)**	**Causes**	**Depth**	**Impassable? Y/N**	**Area**	**Affected Areas**
Winter Storm Riley	Nor' Easter	744233	3/3/2018	-0.228	3.26	---	---	---	---	Nor' Easter, Storm Surge		---		Brandt Point, Sesachacha Pond, Polpis Rd.
Winter Storm Juno	Blizzard	557916	1/27/2015	-0.02	3.69	51.51	39.07	989.9	1011	Storm surge, high winds, snow	Deep enough to hamper power utility crews	---	Eel Point / downtown waterfront streets	

Objective 2: Select Initial Locales for Implementation

Through conversations with our sponsor and use of our database to identify areas which are subject to frequent flooding, we selected three locales for case studies: Children's Beach, Polpis Road by the Lifesaving Museum, and Polpis Road by Sesachacha Pond. We selected Children's Beach because it serves as breach point for floodwater to move further into downtown and contains significant infrastructure in the surrounding area which are dependent on the area's resistance to flood events. Children's Beach also serves as the only boat access point in the downtown part of Nantucket. Polpis Road by the lifesaving museum was selected for its proximity to a wetland divided by the road, main access to the northeast area of the island, role as an evacuation route, year-round resident population, and frequency of flooding events. Polpis Road by Sesachacha Pond was selected for its unique positioning near Sesachacha pond and importance as the evacuation route for Wauwinet, Polpis, and 'Sconset residents. Using our information gathered from objectives 3 and 4 we developed mitigation options for each area.

Objective 3: Identify Flood Mitigation Strategies

The third objective of this project was to identify possible mitigation strategies for our selected locales on the island from strategies used on Nantucket and other urban areas. The four comparable areas we researched include Falmouth, MA, Duxbury, MA, Essex, MA, and South Boston, MA. Falmouth was chosen for its proximity to Nantucket and for its similar sea-level rise and coastal flooding issues. Duxbury, MA was chosen because it has a small historic waterfront area known as Snug Harbor whose downtown contains working, recreation, and residential functions like those at Children's Beach. Snug Harbor is also home to the town pier including the towns boat launch (Snug Harbor Resiliency, Duxbury, MA, 2019). Like Children's Beach, Snug Harbor has a low-lying waterfront with a boat ramp and floods frequently during storms. Essex, MA was chosen as another research location due to its similarities to the Polpis Road by Sesachacha Pond area. Essex installed a causeway with tidal flaps to resolve the flooding issues on their sister road. Finally, we researched South Boston, MA for an example of a well-developed mitigation plan and as a model of how to present and format the case studies. South Boston also provided an example area with working waterfront areas and significant historic character like the situation on Nantucket.

Objective 4: Evaluate Mitigation Options for Nantucket

With an understanding of flooding on the island and specific solutions, we evaluated various methods for mitigating flooding in our selected case study sites on Nantucket. We analyzed the data collected from objectives one and two to evaluate the viability of different approaches to address the diverse kinds of flooding at the various locations on Nantucket.

Using the data in our database from objective 1, we determined what type of storms and flooding occurred as well as the vulnerabilities at each location. We also drew from GIS maps developed to each location's flooding. We used the mitigation strategies collected in objective 2 to suggest strategies for Nantucket.

Each strategy was evaluated against factors such as cost, feasibility, justifiability, and acceptability. Cost was estimated when possible if data was available from the other towns that we researched. We compared the cost to the value of structures at risk. For each location, we provided both a short term and long-term solution. We also evaluated each solution from a cultural standpoint to ensure it does not compromise Nantucket's values of historic nature the island's buildings, the island's natural beauty or have severe environmental effects such as increasing erosion.

Preliminary Findings

Flooding Database

We identified a total of 703 flooding instances and 856 flooding events including 111 storm driven flooding instances and 592 high tide (non-storm) flooding instances collected from the NOAA NCEI database, the Nantucket NOAA station data, FEMA maps, the Inquirer and Mirror and Chuck Larson's Easy Street report (Table 5) (High-Tides and Flooding on Easy Street, 2020). Using multiple datasets and storm categories allowed us to evaluate the island's flooding issues through different metrics. The information gathered from the database provides us with a breakdown of flooding occurring on the island based on MHHW. The database allows us to analyze the primary causes of flooding and understand which events lead to distinct levels of flood waters. This information can be used by the DPW and town representatives to better prepare themselves for storms and prevent excessive damage from higher flood levels.

Table 5: An excerpt from the flood event database

	Name of Even	Type of Flo	EVENT_ID	BEGIN_DATE	Verified Highes	Causes	Depth	Impass	Latitude	Longitud	Area	Affected Area	Notes
174	---	High Tide		7/2/1992	1.14	0							---
175	---	High Tide		10/25/1992	1.11	0							---
176	---	High Tide		11/24/1992	1.21	0							---
177		High Tide Flooding		12/11/1992	1.91	High Tide Flooding			41.285016	-70.09745	Easy St		
178	"The No Name S	Nor'Easter		12/12/1992	2.35	---	2 feet	Yes	---	---	A&P (now Stop & Shop) Parking		---
179	"The No Name S	Nor'Easter		12/12/1992	2.35	---	Up to 4 feet	Yes	---	---	Folger Hotel		---
180	"The No Name S	Nor'Easter		12/12/1992	2.35	---	Waves overtoppe	Yes	41.260847	-69.96237	Codfish park		---
181	"The No Name S	Nor'Easter		12/12/1992	2.35	---	Filled almost all tl	0	41.295086	-69.98045	Sesachacha Pond		---
182	"The No Name S	Nor'Easter		12/12/1992	2.35	---	3.12 feet MHHW	0	41.285313	-70.09633	NOAA Station		Harbor swe
183	"The No Name S	Nor'Easter		12/12/1992	2.35	---	up to 5 feet	Yes	41.288462	-70.0969	White Elephant		---
184	"The No Name S	Nor'Easter		12/12/1992	2.35	---	---	Yes	41.285016	-70.09745	Easy St.		---
185	"The No Name S	Nor'Easter		12/12/1992	2.35	---	---	Yes	41.285456	-70.09895	Broad St		All the way
186	"The No Name S	Nor'Easter		12/12/1992	2.35	---	---	Yes	41.286627	-70.09948	Sea St		---
187	"The No Name S	Nor'Easter		12/12/1992	2.35	---	---	Yes	41.290513	-70.10336	Brandt Point		---
188	"The No Name S	Nor'Easter		12/12/1992	2.35	Storm Surge, High Wind						Town, Madaket,	Winds wer
189	---	High Tide		1/14/1993	1.34	0							---
190	---	Winter Storm		2/2/1993	1.31	0							---
191	---	High Tide		2/13/1993	1.15	0							---
192		High Tide Flooding		3/5/1993	1.23	High Tide Flooding			41.285016	-70.09745	Easy St		
193	---	High Tide		3/6/1993	1.49	0							---
194	Super Storm '93	Storm		3/14/1993	1.88	0							Not a lot w
195	---	High Tide		12/5/1993	1.14	0							---
196		High Tide Flooding		12/11/1993	1.6	High Tide Flooding			41.285016	-70.09745	Easy St		
197		High Tide Flooding		12/12/1993	1.47	High Tide Flooding			41.285016	-70.09745	Easy St		
198	---	High Tide, storm surge		12/13/1993	2.08	0							Brandt Poi
199		High Tide Flooding		12/14/1993	1.46	High Tide Flooding			41.285016	-70.09745	Easy St		
200	---	Nor'Easter		12/16/1993	2.11	0							Cliffside Be
201	---	High Tide		1/8/1994	1.1	0							---
202	---	High Tide		3/4/1994	1.32	0							---
203		High Tide Flooding		5/26/1994	1.19	High Tide Flooding			41.285016	-70.09745	Easy St		
204	---	High Tide		5/27/1994	1.26	0							---
205	---	Nor'Easter		9/5/1994	1.26	0							---
206	---	Nor'Easter		12/24/1994	1.09	0							Easy St Bas
207	---	High Tide		1/2/1995	1.12	0							---
208	---	High Tide		10/28/1995	1.14	0							---

After assembling our database, we looked at the cause of flooding on Nantucket. We found that 88% of the events were minor, nuisance flood events from high tide flooding while winter storms account for the majority storm driven (non-high tide) flooding (Figure 26).

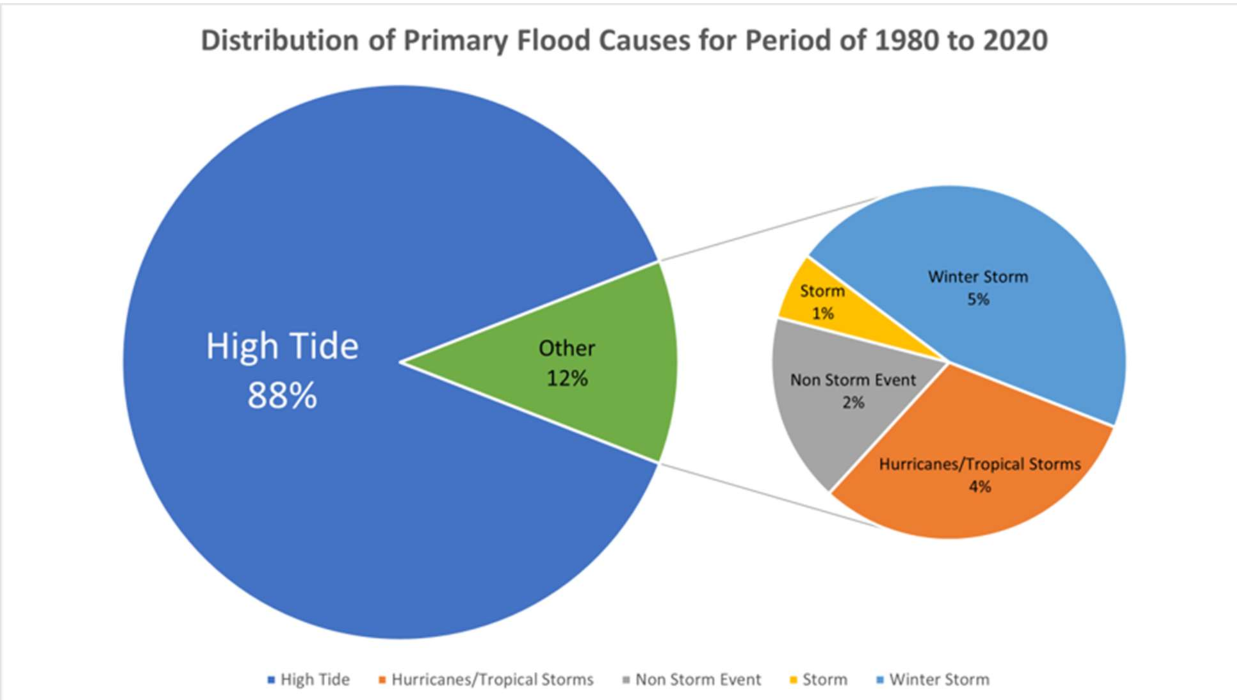

Figure 26: Distribution of Primary Flood Causes for Period of 1980 to 2020

In addition, we created histograms which show the counts of flood events by month for 1980 to 2020 (Figure 27). Flood height is determined by the NOAA tidal gauge using the MHHW (Mean Higher High Water) tidal datum where zero feet MHHW is the average of the highest high tide from every day for the period of 1983 to 2001. These graphs show an interesting pattern. Routine nuisance and high tide flooding occur consistently throughout the year, as shown by graphs A and B. More severe flooding occurs during the winter as shown by graphs C and D.

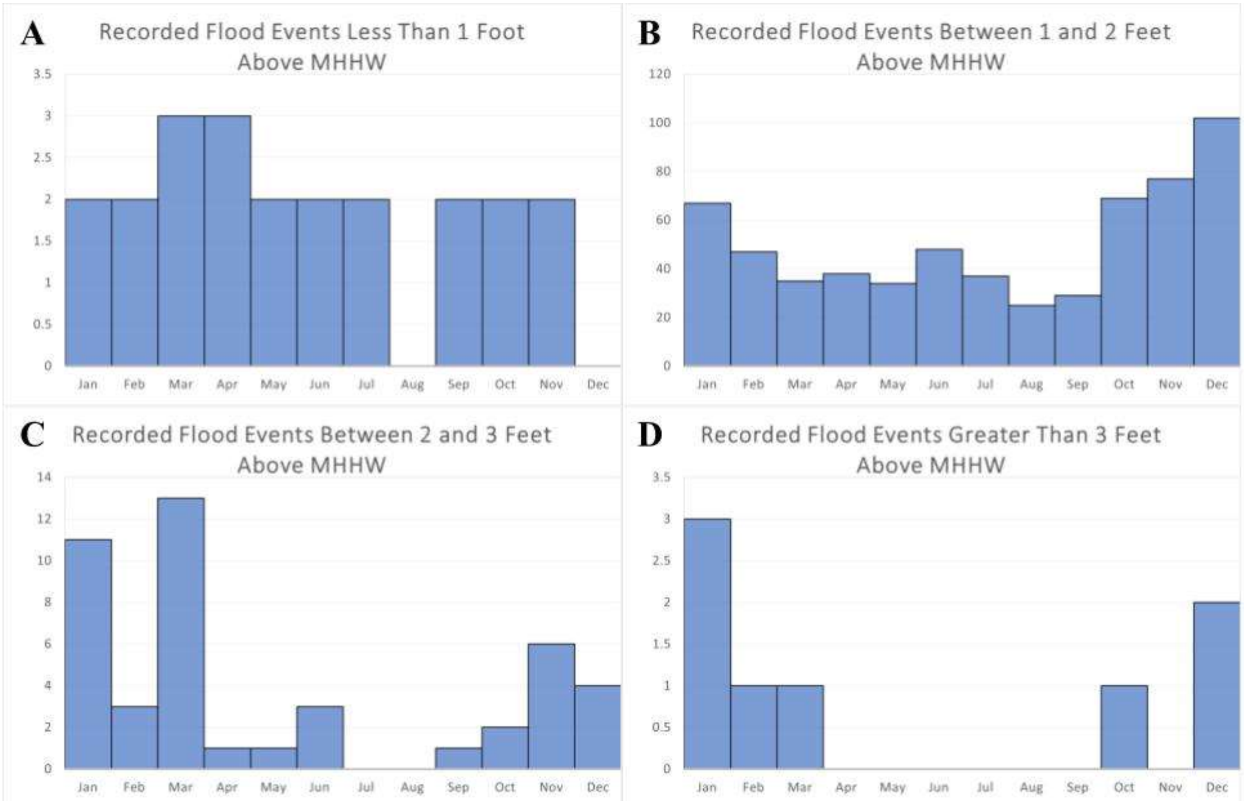

Figure 27: Histograms showing the counts of food events by month for 1980 to 2020.

In addition to the graphs above, we were also able to spatially analyze our data. We imported the data into the GIS software ArcMap for specific locations that were noted in the I&M. These specific locations were translated into coordinates. Occasionally, we would have to use our best judgement on coordinate locations which lead to the location in Madaket and Nantucket Harbors. These points are the most accurate we can make them, without taking too many liberties. In the layer shown in Figure 28, we explored the idea of mapping the water level information from the NOAA tidal buoy. We see that the Northeast corner of the island is impacted at higher water levels while unsurprisingly, the low-lying downtown area is impacted at every water level

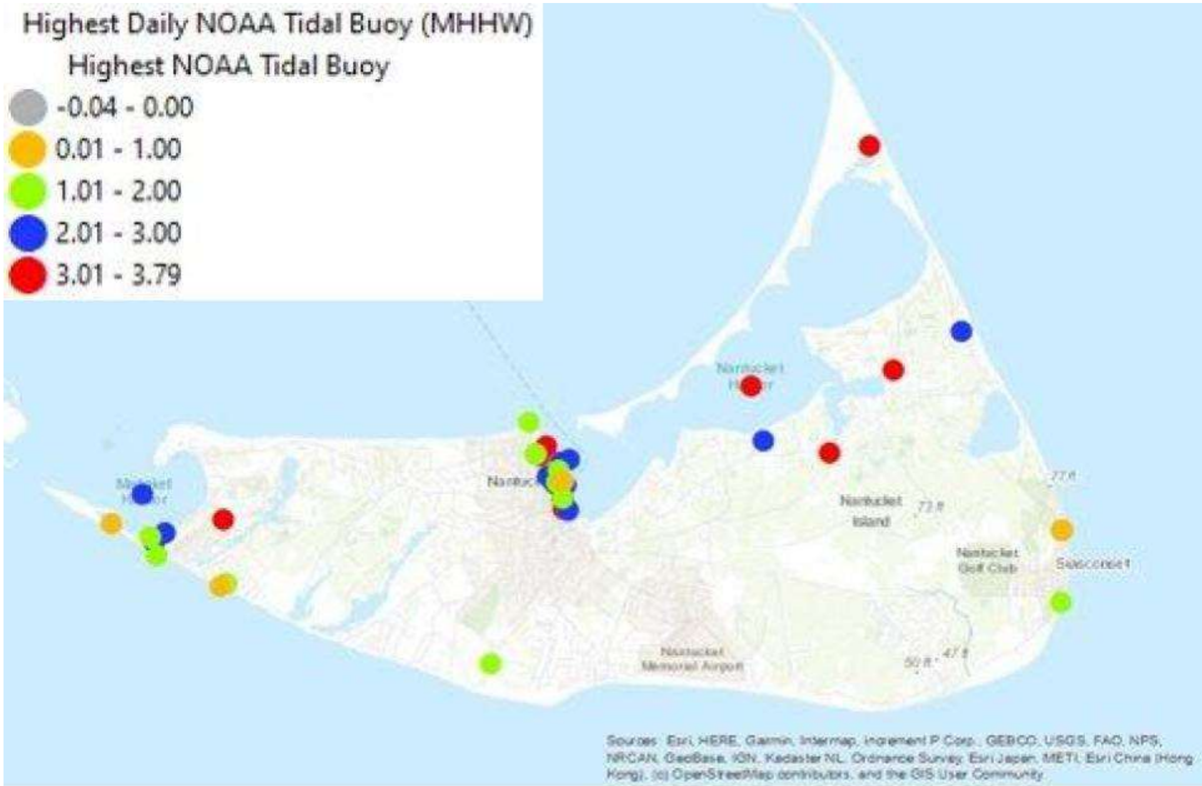

Figure 28: NOAA Tidal Gauge data from our database presented on a map of Nantucket created using ArcMap.

Using the information from our database and ArcMap, we grouped the instances of flooding by cause (Figure 29). The coral color includes instances that involved "Rain, Wind, Storm Surge, Very high winds, Storm surge, etc." as proximate causes. The wide dispersion of flood instances shaded in the coral color show that the effects of wind driven waves and storm surge can be felt all over Nantucket. By contrast, high tide flooding (HTF) is concentrated in low lying areas such as downtown and Madaket. The dark green dots represent flood instances caused by hurricanes or strong Atlantic storms. These are distributed widely across the island and not confined to low lying areas. This is not to say only these areas are the only areas effected during flooding, simply the I&M reported flood impacts at these locations.

Figure 29: Map depicting the cause of flooding across the island, grouped into larger categories, and generated using ArcMap.

Another benefit of using ArcMap is the ability to easily read all the database information for each point (Figure 30). Figure 30 shows that the event was a coastal flood caused by storm surge and wind where water washed over what is assumed to be the marshland. This impacted the Folgers Marsh area which is one of our case study locations.

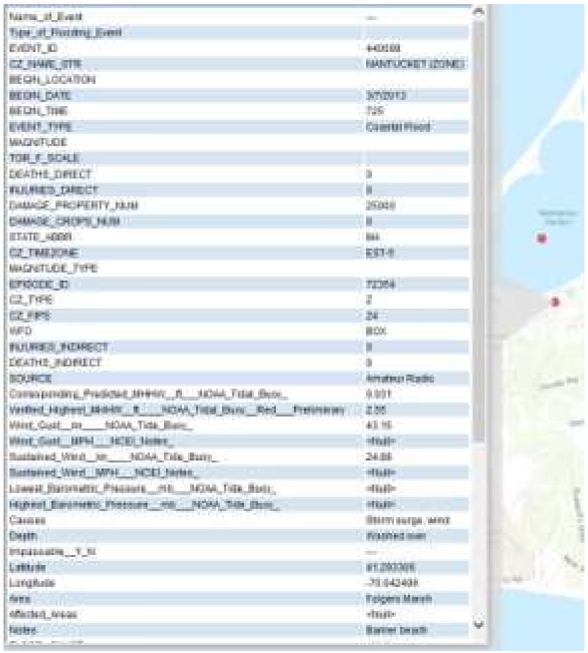

Figure 30: Database information for a point from ArcMap

Overall, the graphs above and the screenshots from the GIS layer generated by ArcMap shows the capability our database will provide those on the island with crucial data on flooding, their causes, and what causes of floods generate damage based on the NOAA tidal buoy data and NCEI database.

Case Studies

We selected three locations as case studies to serve as examples for possible mitigation strategies on the island. We identified locations based off interviews with project sponsors Vincent Murphy and Peter Morrison as well as utilizing our database from objective one to identify areas with frequent flooding (Figure 31).

Figure 31: A map of Nantucket showing the case study locations. Base layer is from ArcMap.

Children's Beach

We selected Children's Beach and surrounding area for its drainage issues and wave attenuation problems. During high tide flooding and storms the water from the downtown area drains to a single point which can periodically overload the drainage system, particularly during storm events preventing water from flowing out of the area. Children's Beach also poses a political problem; it has a tidal gate intended to attenuate waves that has been opened by residents when it should be closed. With the wave attenuation gate open, waves come from the harbor, through the open gate and increase the potential for damage to buildings, vehicles etc.

Children's Beach is a low-lying sandy beach on Nantucket Harbor, accessed by Harbor View Way. The beach has a maximum elevation of around 6 feet NAVD88 (Fuss & O'Neil, 2019). The beach's elevation and boat ramp make the area prone to flooding from wave action and storm inundation. The houses along Harbor View Way and the parking lot are in the path of flooding and are vulnerable both to damage from inundation and impacts from wave action. Behind the beach, the greenspace, Children's Beach playground, and band stand are at risk of flood damages. A very widely used portion of the beach is the Children's Beach boat ramp, which is both vulnerable to damage from floods and serves as an entry point for flood waters to progress further into downtown. Homes, public infrastructure, and businesses such as The White

Elephant Hotel and Children's Café have sustained damages from storm flooding in the past. Many stakeholders are affected by Children's Beach flooding which makes mitigation in this area critical for the island. Flooding mitigation infrastructure in the area consist of the Children's Beach Pumping Station and the tidal gate spanning the boat ramp.

The pumping station's purpose is to drain water from Children's Beach and other low-lying areas like Brant Point. The station itself sits behind the beach while the control house for the pumping station is located off the beach. The pumping station drains into the harbor behind the Nantucket Yacht Club parking lot on South Beach Street. The DPW performs routine maintenance and is responsible for operating the pumping system. The pumping station functions as expected under normal conditions. Under extreme conditions including exceptionally high tide levels and floodwater inundation, the pumping station can get bogged down and loses efficiency. In 2017 and 2018 the pump station had two pump failures and "a complete loss of pumping capability during flooding events in early 2018" (Hazard Mitigation Plan, 2019, p.30). There have been instances where water flowed back up the storm drainage system through the pumping station into the road "questioning the effectiveness of the tide gate and check valves" (Hazard Mitigation Plan, 2019, p.30). Back flow also inhibits drainage from Brant Point causing water to collect in the surrounding wetlands.

The Children's Beach boat ramp is the only public boat ramp in the downtown area. The boat ramp is bordered by a retaining wall and the pier. Access to the ramp is controlled by a tidal gate managed by the DPW (Figure 32). During storms, the gate is shut by the DPW to block access to the ramp, break waves rising to shore and reduce the force of floodwaters in the area. When shut, the gate is reinforced through sandbagging and the placement of concrete jersey barriers which help the gate avoid damage from wave action. The jersey barriers also keep residents from opening the gates during a storm. The tidal gate is not meant to nor does it prevent inundation, but rather it serves as a wave attenuation device to reduce damages related to wave action. During most storm events on the island the gate is closed and reinforced however, "on several occasions private individuals have opened the gate during a storm's low tide to more rapidly drain the area and have not returned to close the gate before the next high tide cycle" (Hazard Mitigation Plan, 2019, p.30). When opened during a storm or even a king tide more water is brought inland via the boat ramp and increased water force can damage homes and buildings.

Figure 32: Children's Beach Tidal Gate (Fuss & O'Neil 2019)

To develop mitigation strategies for flooding caused by the boat ramp and low-lying waterfront on Children's Beach we researched Duxbury, MA. Duxbury Mass sits on the coast South of Boston, bordering Kingston north of Plymouth. Duxbury has a small historic waterfront area known as Snug Harbor which includes working, recreation, and residential infrastructure. The town pier is also located in Snug Harbor, which contains the towns boat launch (Snug Harbor Resiliency, Duxbury, MA, 2019). Sung Harbor's low-lying waterfront with a boat ramp frequent flooding during storms and vulnerability to sea level rise it a suitable candidate with potential mitigation strategies that could benefit Children's Beach. Flooding is one of the many factors discussed in Snug Harbor's Resiliency report. To mitigate flooding on their beach front Snug Harbor proposed including an oyster reef breakwater on the beachfront, changing the boat ramp, lifting the coastal edge, improving beach nourishment, and improving stormwater management (Snug Harbor Resiliency, Duxbury, MA, 2019). Nantucket harbor is an entryway for boats and an oyster reef breakwater would damage boat traffic. Proposed changes to the boat ramp in Snug Harbor include a deployable gate or barrier to the ramp to help attenuate waves and decrease water force. Nantucket has already installed an attenuation gate on their boat ramp.

That said Duxbury's proposals to lift the coastal edge, improve beach nourishment and improve stormwater management are all applicable to Children's Beach. Raising the elevation of the harbor front will decrease its vulnerability to flooding events and protect against future sea level rise (Snug Harbor Resiliency, Duxbury, MA, 2019). Duxbury identified many strategies, for a full revision their report is linked in our references. Nantucket could also benefit from raising the elevation of Children's Beach. That said, raising the elevation of an entire area would involve significant construction and prove costly. To improve beach nourishment Duxbury aims to maintain healthy, erosion resistant beaches and dunes which will protect the areas behind them from flooding (Snug Harbor Resiliency, Duxbury, MA, 2019). Adding additional vegetation and dunes to Children's Beach in lower traffic areas could help prevent erosion and contribute to wave attenuation. Duxbury's stormwater proposal acknowledges that any changes to the harbor such as raising structures or elevating the coastline will require additional stormwater infrastructure to make sure areas can accommodate and drain water properly (Snug Harbor Resiliency, Duxbury, MA,2019). The existing stormwater infrastructure on Children's Beach is not functioning properly. Improvement of this infrastructure could significantly improve the beach's drainage issues. Any capital infrastructure we may propose should acknowledge the increased burden on the stormwater management systems.

Another area we focused on for information and inspiration was South Boston. In 2018, a comprehensive document titled "Coastal Resilience Solutions for South Boston" was published and was a basis for our research in the South Boston area. Appropriately, early in the document, the author analyzes sea level rise projections for South Boston area. The importance of sea-level rise is a trend across all the locations we looked at and only emphasizes the need for Nantucket to examine their own sea-level rise projections, and how they can be utilized to protect their assets in the future.

The report identified some strategies which could be considered for Nantucket. Elevating the existing waterfront areas is one key strategy to resist sea level rise and future storms, as stated by the report (“Elevated waterfront parks and plazas block critical flood entry points by raising the minimum elevation within the park. They also provide public open spaces,” page 20). Raising the waterfront does not require the implementation of further permanent structures along the Children’s Beach coastline preserving its aesthetic and functionality. On Nantucket raising the beach front and roads bordering the harbor could prove effective. It would improve the protection already present in the Harbor front and add resiliency against sea level rise by maintaining an elevation buffer above the sea level.

Polpis Road by Sesachacha Pond

We selected the section of Polpis Road near Sesachacha pond for its unique location and run off issues. It is also a primary evacuation route for residents of Polpis and Wauwinet. When both the Polpis road by Sesachacha Pond and Milestone Road are blocked, residents who live in ‘Sconset are also isolated. Milestone road is outside of flood zones but can be rendered undrivable by snowdrifts. Under these circumstances, residents of Polpis, Wauwinet and ‘Sconset are all isolated. Sesachacha Pond is a large, shallow, brackish pond bordered by Polpis Road on the south and separated from the ocean by a barrier beach on the northwest. It is an “unconnected low-lying area” whose low elevation puts it at risk of breach from the Atlantic Ocean via Sesachacha barrier beach (Figure 33, MORIS - Coastal Inundation Uncertainty). Powerful nor’easters can breach the barrier beach and wind driven waves can flood the road and undermine its foundation (Figure 34) (Hazard Mitigation Plan, 2019, p.188).

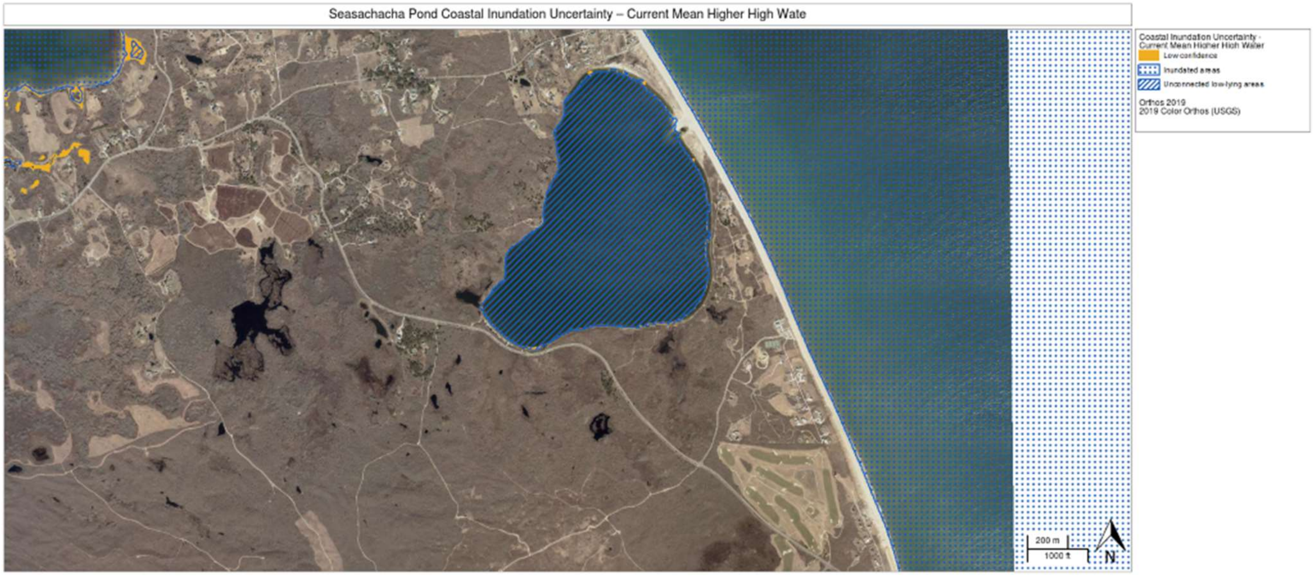

Figure 33: Polpis Road by Sesachacha Pond Coastal Inundation Uncertainty – Current Mean Higher High Water (MORIS)

Breached Sesachacha Pond
Photo: Susan Turer

Figure 34: From the HMP page 35: "Sesachacha Pond was breached by the Atlantic Ocean, causing inundation to extend inland and overtop Polpis Road, which was subsequently washed out." (HMP page 135)

Sesachacha Pond is bordered by wetlands. While wetlands are effective in retaining water, they do not drain rapidly. During high intensity or frequent storms, the wetlands become overburdened causing overflow onto the road. Water runoff collects on the surface of the road and any backflow from wetlands accumulates as well. Flooding may also compromise the structural support of the roadway. This section of road was recently repaired because the foundation beneath the it had eroded away causing collapse. The foundation for the road is made of non-porous materials allowing wind driven wave action to corrode its foundation (Rob McNeil Interview 12/3/2020) (Figure 35). In fact, wave action during a higher-than-normal pond elevation caused the original collapse. Polpis Road near Sesachacha Pond is well constructed but, the interface between the pond and road is subject to impacts from the weather (Rob McNeil, Interview 12/3/2020) (Figure 36). Currently, cement blocks support the road's foundation while the DPW works to design, permit, and construct a more permanent solution (Rob McNeil Interview 12/3/2020). Until then, McNeil is working with the NRD to improve the existing concrete wall following the Wetlands Protection Act.

Figure 35: Polpis Road by Sesachacha Pond Impervious Surface Map (MORIS)

Figure 36: Image of Sesachacha Pond and Roadway. Image and description provided by Vincent Murphy.

Polpis Road runs along the southwest edge of Sesachacha Pond through areas designated as 100- and 500-year flood zones (Figure 37). Despite the 100- and 500-year flood designations, flooding on Polpis road near Sesachacha pond is more frequent than numbers suggest. Especially if there has been significant rain, the pond is full and high winds are blowing from the east.

Figure 37: Polpis Road by Sesachacha Pond FEMA National Flood Hazard Layer (MORIS)

This section of road becomes inundated in a 10-12-foot storm surge (Figure 38) and will flood from a category 3 or higher storm (Figure 39). Currently, Sesachacha Pond is drained down twice a year in April and October under permit issued by the U.S Army Corp of Engineers. Drainage aids the herring run and serves the added benefit of reducing water height in the area to prevent excess flooding. If the pond were not reduced regularly, Polpis Road would flood during lower-level storm events. However, not every pond opening event is successful in reducing water height as proper water flow requires wind with a western component and an outgoing tide. The channel must remain open for a few days to allow the pond the drain down.

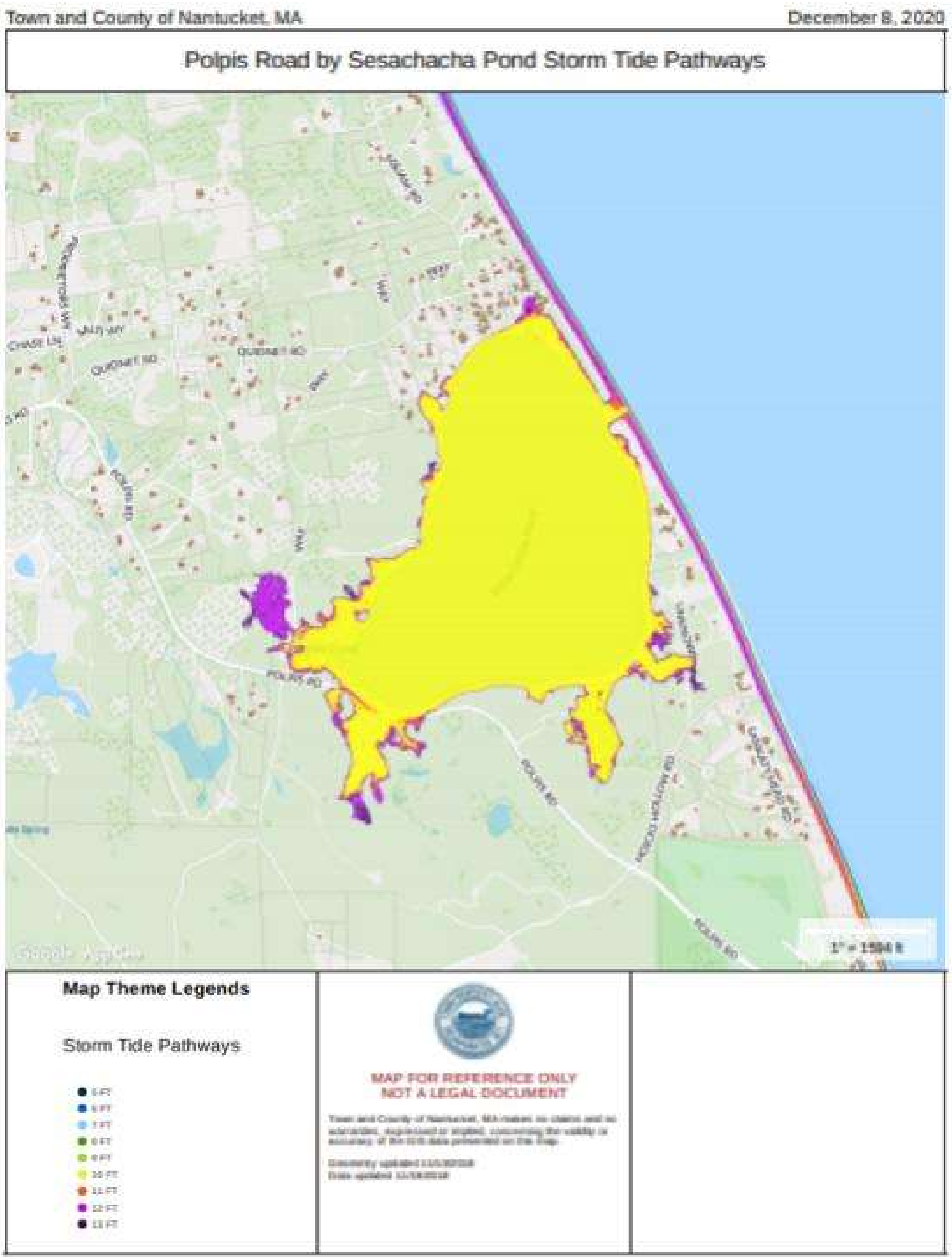

Figure 38: Polpis Road by Sesachacha Pond Storm Tide Pathways (Town and County of Nantucket, MA, MapGeo)

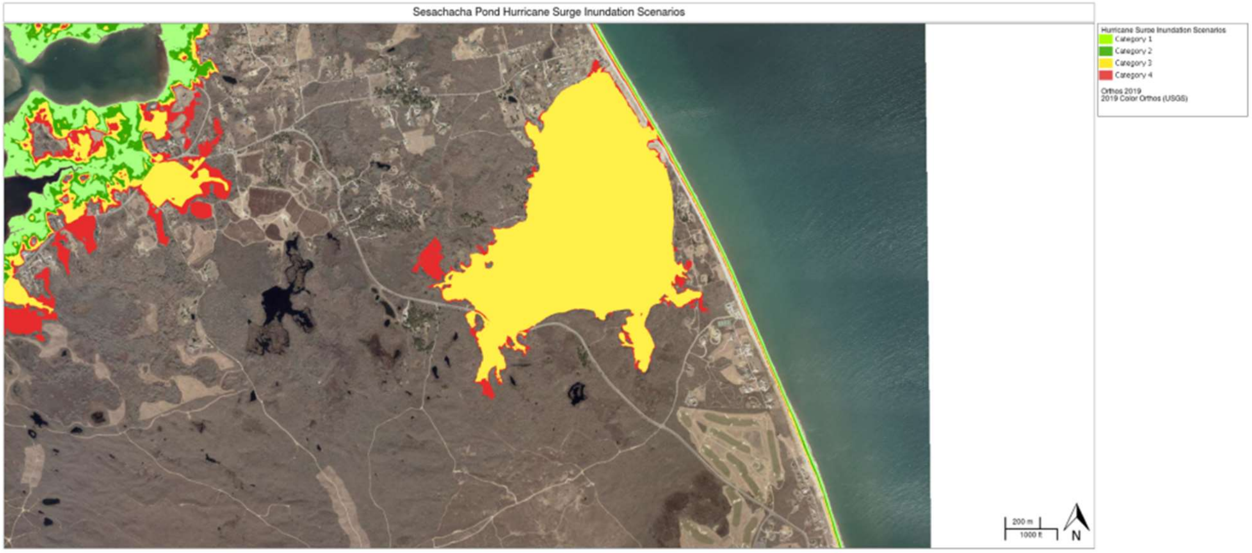

Figure 39: Polpis Road by Sesachacha Pond Hurricane Surge Inundation Scenarios (MORIS)

Polpis Road by Sesachacha Pond will be at increased risk of flooding as water levels of Sesachacha Pond increase due to sea level rise (Figure 40Figure 40: Polpis Road by Sesachacha Pond Coastal Inundation Scenarios) (Figure 41, Figure 42, Figure 43: Nantucket Probability Inundation 2030, 2050, 2070). The higher the water in the pond the harder it will be to reduce water heights that do not cause wave action on the bordering road. Effective flooding mitigation strategies are necessary for preserving constant functionality of the road.

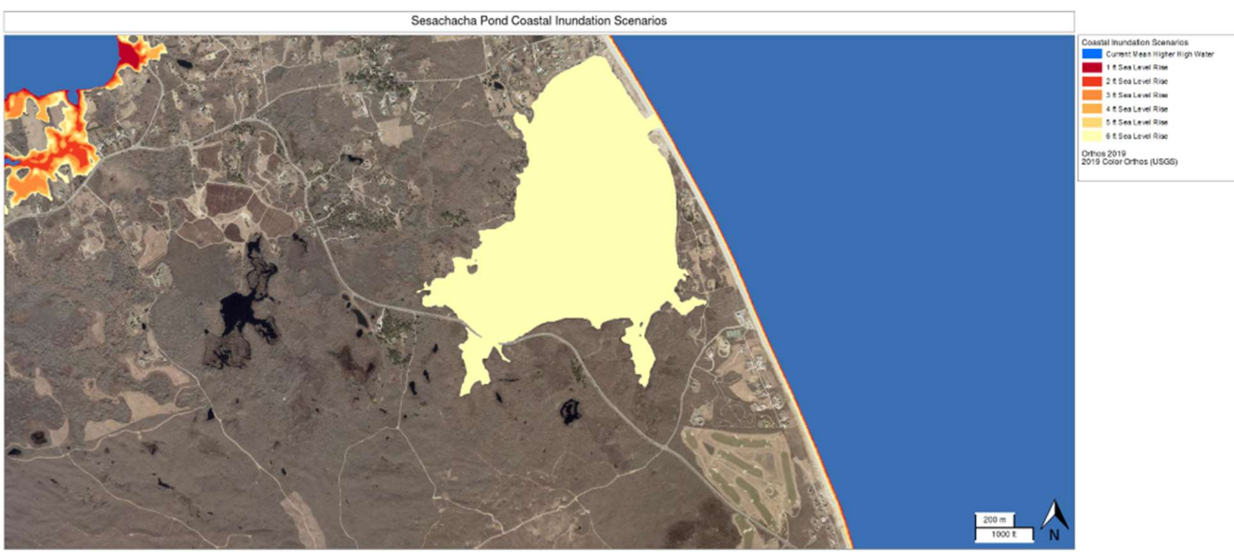

Figure 40: Polpis Road by Sesachacha Pond Coastal Inundation Scenarios (MORIS)

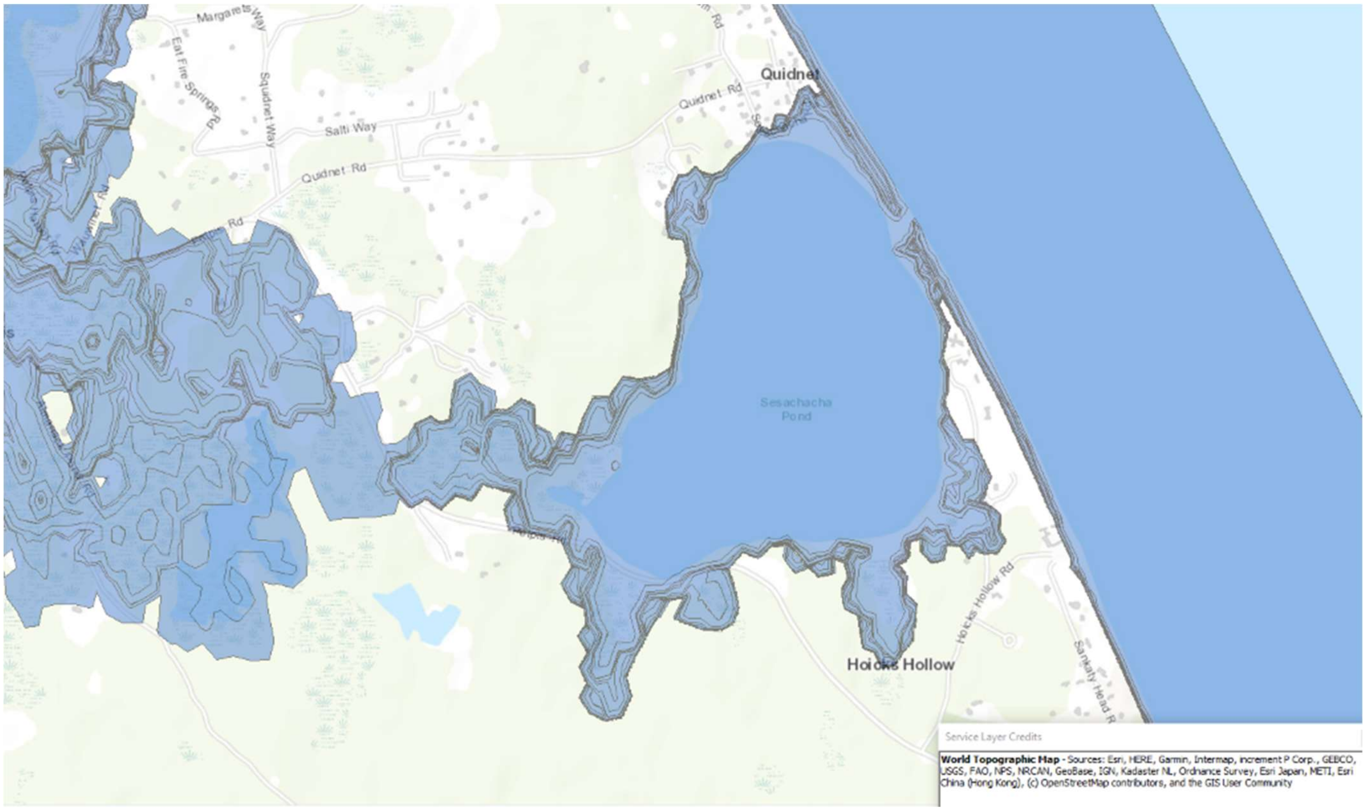

Figure 41: Nantucket Probability of Inundation 2070 edited to 50% transparency (Retrieved on ArcMap, owned by bhoffnagle_WHF, published 6/21/2020)

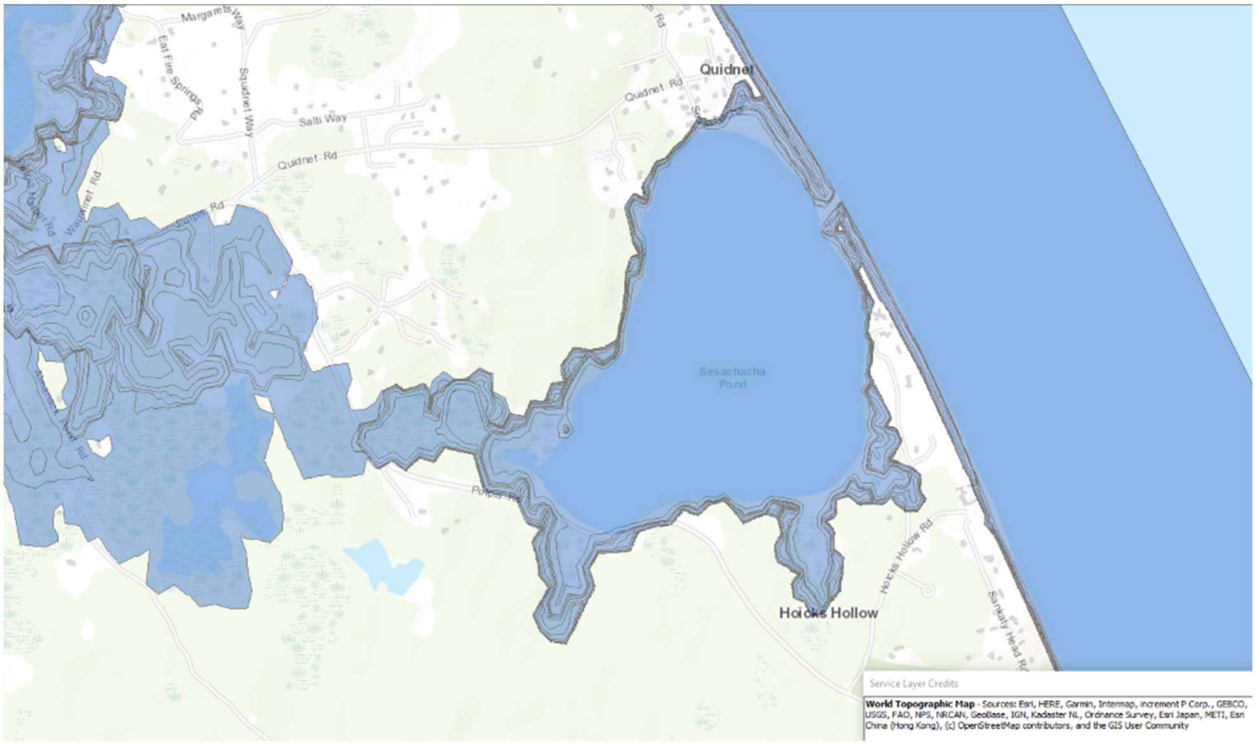

Figure 42: Nantucket Probability of Inundation 2050 edited to 50% transparency (Retrieved on ArcMap, owned by bhoffnagle_WHF, published 6/21/2020)

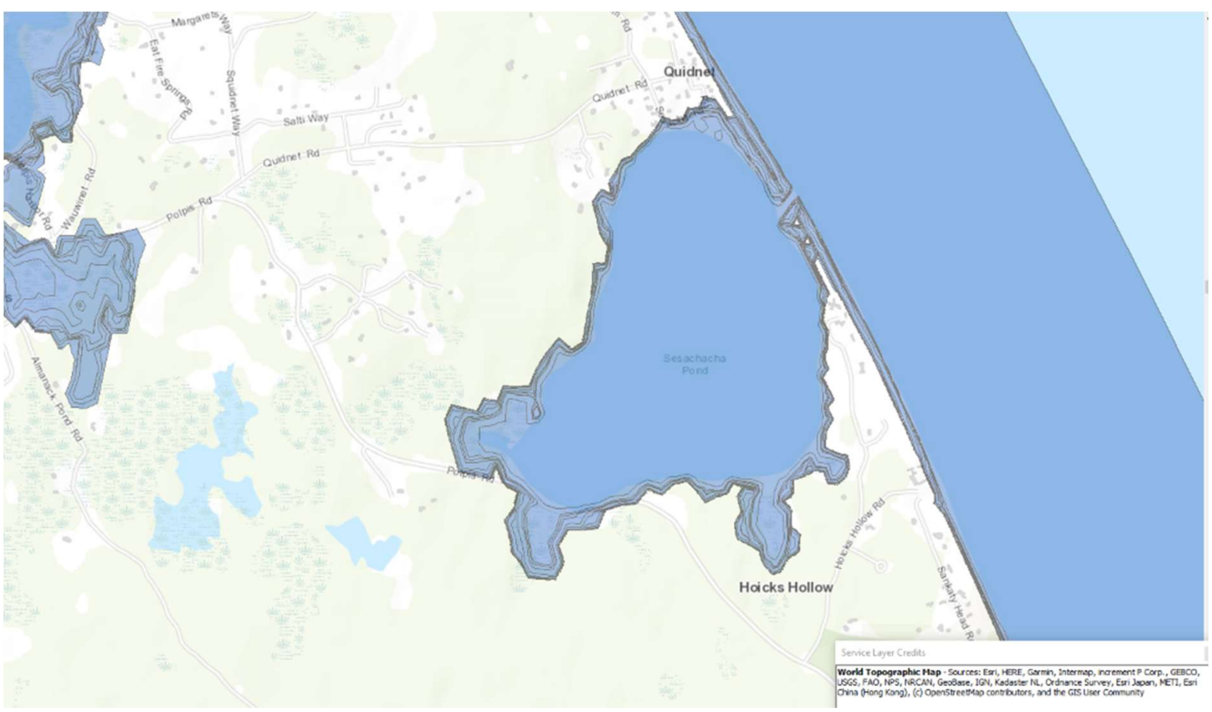

Figure 43: Nantucket Probability of Inundation 2030 edited to 50% transparency (Retrieved on ArcMap, owned by bhoffnagle_WHF, published 6/21/2020)

To find mitigation strategies for the types of flooding Polpis Road experiences we researched Essex, MA and Falmouth, MA. The Causeway in Essex, MA faces a winter flooding issue. The Route 133 causeway floods regularly due to tidal inundation and impacts significant town infrastructure which "stretches for 0.8 miles and spans both salt marshes and the Essex River" (Essex HMP, 2019, pg. 72) (Figure 44). In 2012 Essex raised the road 8 inches to the maximum height allowed and installed tidal flaps on the causeway to further reduce flooding (Great Marsh Regional Coastal Adaptation Plan, 2017 seen in the Essex HMP, 2019, pg. 28). Their efforts reduced the severity and frequency of flooding at the causeway although it still floods multiple times per year (Essex HMP, 2019, pg. 28).

Figure 44: Image from the Essex HMP page 35 showing the "Essex Causeway" flooding. (Essex HMP, 2019, page 35)

To address the remaining causeway flooding, Essex plans to create live video feed of the causeway so residents and travelers can go online and evaluate its useability. They also propose tracking and monitoring flow beneath the causeway to evaluate its effectiveness (Essex HMP, 2019, pg. 116 Table 29). The implementation of these solutions is estimated to cost around 10,000 (Table 6, Essex HMP, 2019, pg. 125, Table 30). A causeway would be a viable and effective mitigation strategy for Polpis road near Sesachacha Pond and an elevated causeway is being considered by the DPW (Rob McNeil, Interview 12/3/2020). The only impervious surfaces in the area are the roadway and the adjacent bike path with a vegetated strip between them that acts as a soak way area. The causeway could include both the road and the bike path diverting flood waters to the more absorptive surrounding area.

In the short term, live video feeds of the road would inform residents of the road's current conditions, signal to residents when the road is inundated and facilitate quicker evacuations for residents at risk for isolation.

Table 6: Potential Mitigation Measures (Essex Hazard Mitigation Plan, 2019, pg. 125, Table 30)

TOWN OF ESSEX HAZARD MITIGATION PLAN
2019 UPDATE

Table 30 – Potential Mitigation Measures

Mitigation Measure	Priority	Lead Dept./Group	Time Frame	Estimated Cost	Potential Funding Sources
Main Street/ Causeway/Bridge Woodman's Beach- Short term actions to 2030: *Create live video feed showing the Causeway so residents and travelers can go online and see in real-time if it's flooded/impassable. *Track and monitor flow beneath Causeway. *Convene Essex Causeway working-group.	High	Town Administrator /Conservation Commission/ Chamber of Commerce	Short term 2019-2020	Low $10,000	Essex/ Donations/ MVP

Our research of Falmouth also resulted in possible mitigation strategies that are applicable to Polpis road by Sesachacha Pond. Falmouth Massachusetts is located on Cape Cod and faces a coastal flooding issue. Due to their proximity to Nantucket, they see similar sea-level rise issues. Nantucket and Falmouth share vulnerabilities to costal erosion, sea level rise and coastal flooding (Figure 45). Additionally, both Falmouth and Nantucket participate in the state-funding Municipal Vulnerability Preparedness (MVP) Program workshop opening them up to comparable grant opportunities. Surf Drive is one of the main roads in Falmouth that sits on an eroding beach that floods frequently (Figure 46). Oyster Pond and Salt Pond border the west side of the road. Surf Drive is also a key emergency route that links Woods Hole to the rest of Falmouth. The similarities between Surf Drive by Oyster Pond and Salt Pond and Polpis Road by Sesachacha Pond make Falmouth a strong candidate for possible mitigation strategies for the Sesachacha Pond area.

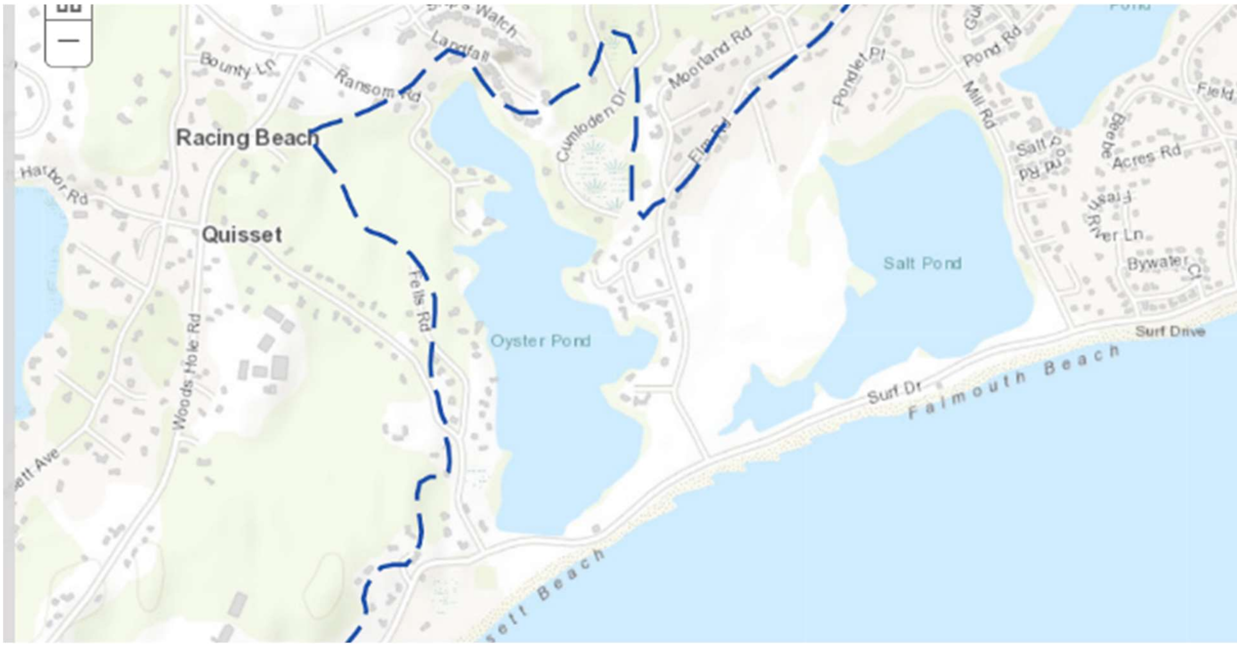

Figure 45: Coastal Resiliency Planning for the Surf Drive Area by the Woods Hole Group (whg.maps.arcgis.com)

Figure 3-3. Flooding on Surf Drive during Hurricane Sandy.

Figure 46: Falmouth's Multi Hazard Mitigation Plan Final Report March 2017 by the Woods Hole Group

To address flooding along Surf Drive, Falmouth proposed protecting vulnerable sections of roadway with beach/dune nourishment, elevating the road, and adding a revetment or sheet pile wall for protection and constructing a tall flood barrier (i.e., seawall) seaward of at-grade roadway (Coastal Resiliency Planning for the Surf Drive Area Executive Summary (Draft), August 2020). Each of these solutions could be applies to Polpis road by Sesachacha pond. Adding vegetation and nourishment to Sesachacha barrier beach would provide wave attenuation and decrease the likelihood that the Atlantic Ocean breaches the barrier. To install a causeway under the section of Polpis road by Sesachacha Pond the road would need to be elevated. Raising the height of the road would protect against future inundation caused by sea level rise. Lastly, a revetment or sheet pile wall or tall flood barrier between the pond and roadway would protect against wave action and flooding. Table seven shows the estimated cost, target effects, and adverse impact of each of these solutions.

Table 7: Falmouth proposed Potential Actions, Estimated Cost, Target Effects, and Adverse Impacts (Coastal Resiliency Planning for the Surf Drive Area Executive Summary (Draft), August 2020)

Potential Actions	Estimated Cost	Target Effects	Adverse Impacts
Protect vulnerable sections of roadway with beach/dune nourishment	$7.2 mil	Enhances coastal ecosystem function	Not a long-term solution
Research and develop policies for phasing out Town services to private homes and roads in vulnerable areas	N/A	Balances present use w/future cost; abandon road	Loss of homes; no connection along Surf Drive
Engage in public outreach to prepare residents for future changes (e.g., ending road maintenance)	N/A	Builds public awareness of risk and need for change	Potential push back from residents
Cease maintenance of Surf Drive along the barrier beach	N/A	Avoids continued maintenance cost of high-risk asset	Potential push back from residents
Remove existing Surf Drive pavement along barrier beach and construct extended Surf Drive bridge	$143 mil	Maintains access and utility connections	Loss of homes; no connection to beach
Elevate road and add revetment or sheet pile wall for protection	$29-60 mil	Protects existing infrastructure	Loss of accessible beach; aesthetics
Construct tall flood barrier (i.e., seawall) seaward of at-grade roadway	$31-50 mil	Protects existing infrastructure	Loss of accessible beach; aesthetics
Abandon Surf Drive (remove any remaining pavement)	$845k	Avoids continued maintenance cost of high-risk asset	Potential push back from residents

Like Falmouth's vegetation efforts, Nantucket could plant dense vegetation along the edge of Sesachacha between the pond and the ocean. Currently there are about 1.1 acres of sand, untouched by plant life (Figure 47). Additionally, there is a 108-to-126-foot gap where the bi-annual drainage efforts occur (Figure 47). To improve the efficiency of these efforts, a one-way pipe with a check valve flowing from Sesachacha Pond into the ocean could be installed in this area and backfilled as needed. Backfilling the 108-126-foot gap will also fortify the barrier beach by increasing the surface area both for wave attenuation and dense plant vegetation.

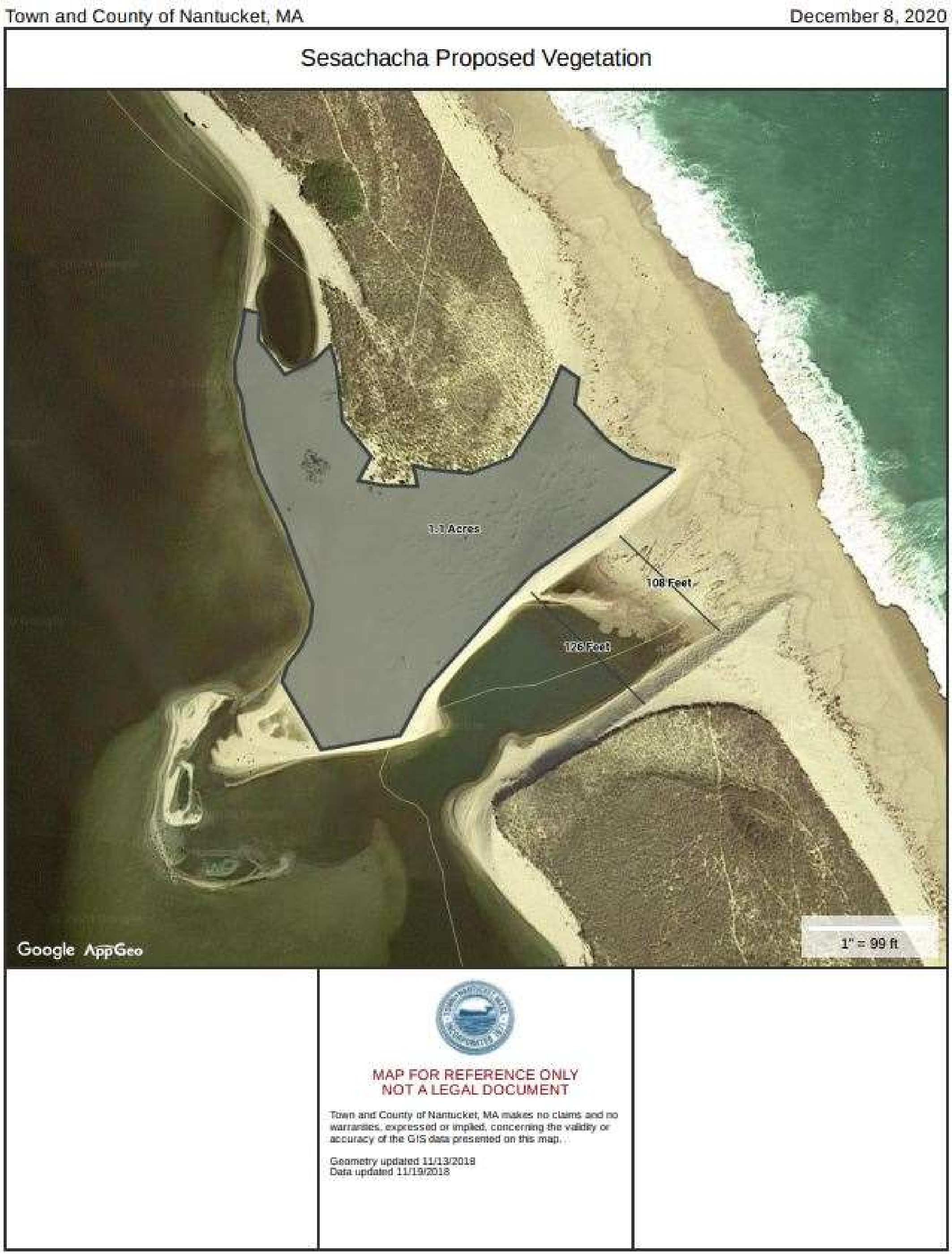

Figure 47: Area of proposed pipe and vegetation. Town and County of Nantucket, MapGeo. Edits measurements added by the flooding team using mapgeo.

Polpis Road by Fulling Mill Creek

The third location we selected is the area known as Folger's Marsh on Polpis Road near the Shipwreck and Lifesaving Museum. We selected this location because it is part of an evacuation route and because of its unique flooding challenges. When Polpis Road near Fulling Mill Creek floods, Polpis and 'Sconset residents are isolated and cannot be accessed by emergency vehicles (Hazard Mitigation Plan, 2019, pg. 140). Fulling Mill Creek is comprised of an upstream wetland system with a large tributary/watershed (Rob McNeil, Interview, 12/3/2020). The marsh, wetland, and intertidal area on the north side of road bordering the harbor are about 30 acres in area. About 10 acres of wetland sit behind the section of road where the culvert is located. The placement of the roadway has effectively divided the single wetland into two wetlands north and south of the road joined by a culvert. The wetland on the southern side of the road is now a degraded saltmarsh wetland. Along with the area of Polpis Road by Sesachacha Pond, this section of road also suffers from flooding when the wetland becomes overwhelmed with water.

Along Polpis Road at Fulling Mill Creek is a culvert and tidal creek which conveys water out to the harbor (Rob McNeil, Interview, 12/3/2020). The culvert in is old and undersized for the quantity of water that needs to flow through it (Personal Communication Vincent Murphy, 12/9/2020). On days with repeated rain or during larger storm events the road is particularly susceptible to flooding because the culvert's size limits drainage. Additionally, the existing culvert disrupts waterflow between the bisected wetland altering salinity and damaging ecology. After the culvert was constructed, a bike path was added along Polpis Road and the culvert was extended to accommodate the bike path. The culvert still needs to expand to accommodate an increase in waterflow. A new culvert design will account for sea level rise, critter passage, and the new standards and regulations put in place after the initial culvert was installed (Rob McNeil, Interview, 12/3/2020).

Folger's Marsh experiences coastal flooding during lower-level storms and the road faces inundation from category 2 storms and above (Hazard Mitigation Plan, 2019 and Figure 48). Severe storms such as Winter Storm Riley, cause "scouring and wash over at the culvert" and require "concrete roadblock protection" (Hazard Mitigation Plan, 2019, p.188).

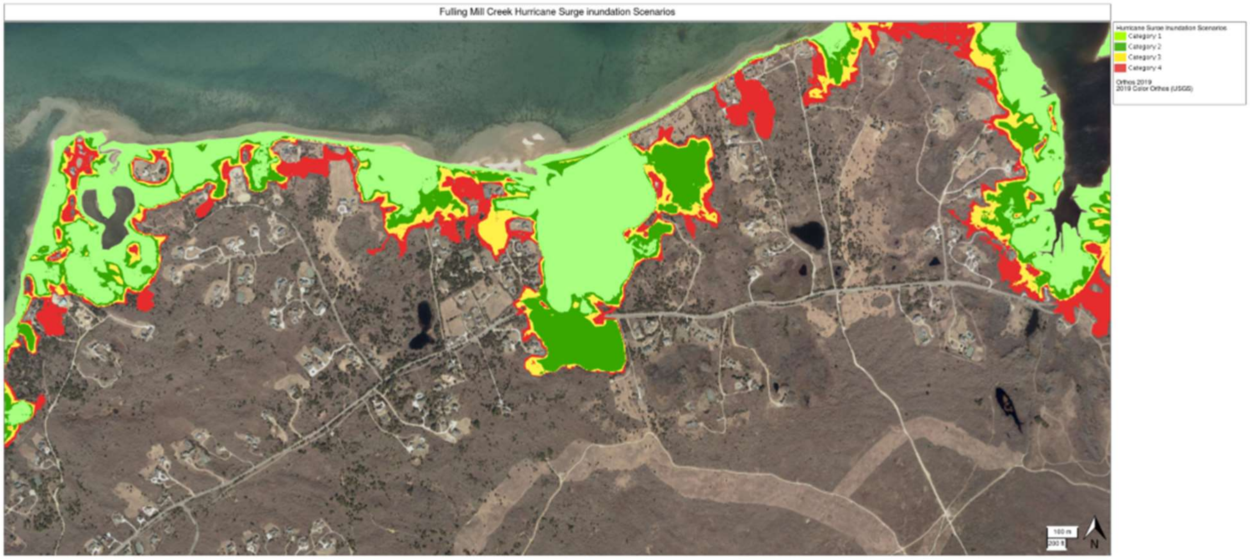

Figure 48: Polpis Road by Fulling Mill Creek Hurricane Surge Inundation Scenarios (MORIS)

Polpis Road by Fulling Mill Creek is in the 100-year flood category and has a base flood elevation of 8 feet based on Mean Lower Low Water (Hazard Mitigation Plan, 2019, p.101). MLLW is a unit of measure that uses the average lowest low tide per day from 1983 to 2001 (NOAA Tides & Currents). This means Fulling Mill Creek can be inundated with as little as a seven to eight-foot storm surge based on these zero points, which leads to frequent flooding of the area even from minor storm events (Figure 49).

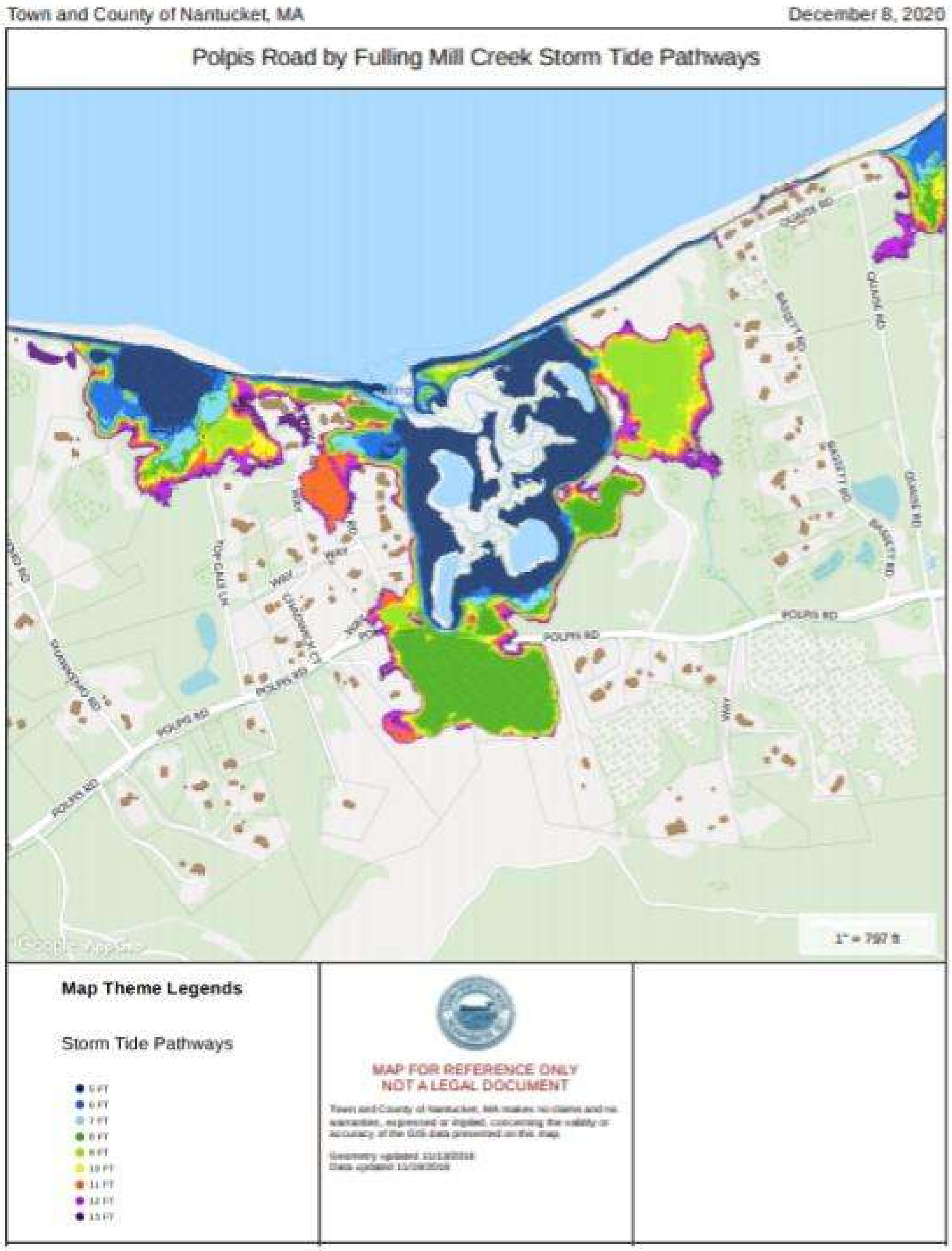

Figure 49: Polpis Road by Fulling Mill Creek Storm Tide Pathways (Town and County of Nantucket, MA, MapGeo)

To address concerns around flooding on Polpis road by Fulling Mill Creek, Nantucket entered a limited public-private partnership with Nantucket Engineering & Survey to complete a study of the Fulling Mill Brook watershed and hydrologic conditions at Polpis Road to identify improvements that could mitigate flooding in the area (Figure 50). Rob McNeil hopes the partnership leads to a full hydrological model of watershed with a design for a new culvert under Polpis Road and the bike path able to withstand sea level rise, and flush from behind roadway (Rob McNeil, Interview, 12/3/2020). There are also efforts to design the culvert to allow animals to pass through, so they do not have to cross the road which requires special design considerations to ensure it is accessible to different species (Rob McNeil, Interview 12/3/2020). Elevating the roadway to accommodate a larger culvert and raise the road surface out of expected sea level rise elevations is also under consideration (Rob McNeil, Interview, 12/3/2020). A new policy from the Coastal Resilience Advisory Committee (CRAC) to analyze the NOAA Sea Level Rise expectation from 2000-2100 will determine the new height of the road and ideally construction would be completed sometime in the next five years (Rob McNeil, Interview, 12/3/2020).

Strategy #F10

Participate in a limited public-private partnership with Nantucket Engineering & Survey to complete a study of the Fulling Mill Brook watershed, in particular the hydrologic conditions at Polpis Road, to identify alternatives for improvements to this area.	
Total STAPLEE Score	Flooding
Primary Hazard	8
Status	New
Responsible Department	Public Works
Timeframe	7/2018-6/2020
Estimated Cost	$50,000 - $100,000
Potential Funding Sources	Operating Budget / Capital Improvement Budget

Figure 50: Strategy #F10 from the Hazard Mitigation Plan, page 272.

Additionally, the Hazard Mitigation Plan proposed increasing the elevation of Polpis Road at Fulling Mill Brook to the base flood (8') plus one foot, repairing the culvert and hardening the embankment to account for wave action (Hazard Mitigation Plan, 2019). It is expected that the DPW makes these adjustments withing a three-year timeframe from 7/2020 to 6/2023 and that they will cost more than $100,000 with funding potentially coming from the Capital Improvement Budget (Figure 51). Appropriately, the final elevation of increase should be examined and analyzed due to sea-level rise. (Hazard Mitigation Plan, 2019, p.147, 270).

Strategy #F16

Increase the elevation of Polpis Road at Fulling Mill Brook and harden the embankment for wave action. Final elevation to be examined and analyzed considering sea-level rise.	
Total STAPLEE Score	Flooding
Primary Hazard	5
Status	New
Responsible Department	Public Works
Timeframe	7/2020-6/2023
Estimated Cost	More than $100,000
Potential Funding Sources	Capital Improvement Budget

Figure 51: Strategy #F16 from the Hazard Mitigation Plan, page 280.

To gather additional mitigation strategies for Polpis road by Fulling Mill Creek we included strategies from Falmouth and South Boston, MA. Specifically, we used strategies from the report on Coastal Resilience Planning for the Surf Drive Area because of the similarities between Surf Drive and Polpis Road by Fulling Mill Creek. Both roadways are primary means of travel for emergency response and they both face severe inundation from storm events (Woods Hole Group, Coastal Resiliency Planning for the Surf Drive Area, 2020, p. 11,23). Each roadway also has aquatic areas lying on both sides of the road. The main strategy we identified in the Surf Drive report was to elevate Surf Drive road, upon further investigation it was discovered that the DPW had already planned to elevate the Polpis Road Fulling Mill Creek (Coastal Resiliency Planning for the Surf Drive Area: Executive Summary, 2020, p. 7). The Surf Drive report also discussed vegetating the beach in front of the road to reduce the erosion and inundation levels in the area (Coastal Resiliency Planning for the Surf Drive Area: Executive Summary, 2020, p. 7). Increasing vegetation on the Fulling Mill Creek wetland is not feasible due to how densely vegetated the wetland currently is. However, increasing the size of the wetland and vegetating the expanded area could prove beneficial in slowing the flow of water inwards towards Polpis Road. Our research of South Boston also provided us a helpful guideline for presenting the information from our case studies. In areas identified for improvement in the report, the information was laid out providing a general overview of the area, listing options, providing costs of options, as well as more specific locations where each strategy may be built.

Recommendations and Conclusions

Database

From the outset of this project one of our goals for the database was to build numerical figures which reinforce undocumented but common knowledge amongst islanders such as which areas flood and when flooding occurs. Upon analyzing our results, we found that our conclusions do support common knowledge of flooding, such as Madaket and Downtown suffering as low-lying harbor fronts, and roads such as Easy Street, Easton Street and Washington Street are common places to flood during storms. Additionally, as seen in the flood histograms from our preliminary findings section, we were able to provide numerical proof to a common claim on the island that the worst flooding occurs during winter, as well as rarely during the summer months if hurricanes strike the island. Further, having flooding events documented allows for future island projects and mitigation strategies to have a better idea of how they will be affected by and can adapt to flooding. Our database could be used in this light to identify areas of the island subject to repeated flooding, like how we identified our case studies, showing how they flood. Having a record of and knowing how areas flood is of great benefit as if causes of flooding are known for an area, plans can be better tailored to mitigate certain causes of floods while avoiding unnecessary infrastructure.

Upon completion of this project the database will fall under the purview of the Natural Resources Department, we advise that the database continue to be updated as flooding occurs on the island. This may be incorporated into currently existing flood reporting work done by the town as well as through community involvement. One of the responsibilities of Coastal Resilience Coordinator Vince Murphy is as the Town Storm Reporter for Massachusetts Coastal Zone Management, adding updating the database to storm reporting is one way we believe the database can be further updated. Additionally, Nantucket residents may be of great aid in contributing to the database, having citizens report flooding in their area will provide a much larger set of information helping to capture more areas affected by floods and the extent of floods. We believe citizen reporting can be achieved through a variety of methods, from setting up an email open to the public for flood reporting or using forms. We believe that a form such as a Google Form or one hosted on the Nantucket town website would be the easiest way to allow citizen reporting, a mock form can be seen in Appendix D.

For each location we selected we researched flood mitigation strategies unique to the problems those locations face.

Children's Beach

The current pathways for floodwater to enter the downtown area through Children's beach are the boat ramp and pumping station. Resolving the issues outlined in the Findings Section will begin to bolster the beach's resistance to future storms. We have identified multiple actions for the area's stakeholders to consider:

1. Conclusion: The tidal gate is a critical piece of infrastructure that minimizes wave damage to the properties and infrastructure behind Children's Beach. Members of the public regularly open the gate to access the boat ramp but fail to close the gate afterwards leaving the area behind the beach vulnerable to flood damage. We recommend the town consider several options to address the problem:

    1.1. Install a padlock and chain to prevent the public from opening the gate. It is a quick, low-cost solution to prevent the tidal gate from being opened by unauthorized individuals. While a lock is no obstacle for those who have the capability to move concrete jersey barriers, it will act as a deterrent to opening the gate.

    1.2. Install bollards. Made of metal or other materials bollards are rods placed vertically in the ground to block vehicular access or direct traffic while allowing people through. Installing bollards along the top of the boat ramp will prevent vehicles from accessing the area. Bollards are significantly more challenging to move than jersey barriers and access to the boat ramp will be under full control of the DPW, deterring people from opening the tidal gate through preventing access to the ramp. We recommend Internal Locking Removable Bollards, which are attached to the ground by permanent sockets installed in the pavement that are flush with the road when not in use. They are held in place with a key that locks the bollard to the socket.

1.3. Install security camera and fine those opening the gate and/or failing to close it. Right now, there are no legal consequences for members of the public for opening the tidal without permission. Instead of adding physical barriers to prevent it opening, legal penalties might serve as an effective deterrent to opening the gate. We recommend instituting municipal fines for opening the tidal gate in the range of $50 to $300 and they will require enforcement from the Nantucket Police Department. A security camera would lessen the burden of the police department to physically inspect the gate at intervals and act as an additional deterrent and if publicly viewable through live streaming would provide citizens a way to see if the ramp is closed.

1.4. Additional suggestions to better accommodate boats in the harbor during storms when the boat ramp is sealed include:

1.4.1. Install emergency moorings. We advise the town install emergency moorings for use during storms in sheltered areas such as Polpis Harbor. This will provide boat owners an additional option to keep their boat protected if they are unable to remove their boat from the harbor before a storm.

1.4.2. Install alternate boat ramp. While suitable land is very tricky to find, we have identified two locations where the town owns land suitable for a secondary boat ramp: The town land next to the Great Harbor Yacht Club and Cathcart Road. A second boat ramp presents a unique opportunity for the town to build a ramp with a much higher elevation, which could be storm and sea level rise resistant without the need for a tidal gate. Cathcart is in an area of a high elevation, which combined with a matching boat ramp could be resistant to sea level rise and wave runup (V. Murphy. Personal Communications. 1, Dec 2020). This would by no means be an easy undertaking, these areas do not currently have the infrastructure in place to allow boats to reach shore or necessarily road space to allow access to large boat trailers, and channels to the ramp may have to be dredged. A study on current use of the Children's Beach boat ramp could indicate how busy it is, especially during the time before storms, having a second boat ramp could alleviate some of the congestion on the Children's Beach ramp.

2. Conclusion: The Children's Beach Pumping Station serves to reduce flood waters in downtown and surrounding areas and is a critical part of Downtown's stormwater drainage system. We recommend the town considers repairing the pump to improve its effectivity.

   2.1. Follow through with pump repairs. In response to the malfunctions of the pumping station under extreme circumstances, the town brought in an engineering firm to find problems and identify ways to improve the system (Hazard Mitigation Plan, 2019). The engineering firm produced a report outlining problems with the pumping station including missing check valves inside the pump allowing backflow, inadequate sizing of pump components which contributed to the pump overloading, and underpowered pump motors reducing the effectiveness of the pump (Fuss and O'Neil 2019, page 5). Full analysis of the pumping station is available in the Fuss and O'Neil report, linked in the References section. Our recommendation for the pumping station is to resolve all identified issues in the Fuss and O'Neil report. Resolving the issues should prevent the pumping station from backflowing and causing upstream flooding as well as allow it to operate at full capacity under extreme conditions.

   2.2. Upgrade the size and storage capacity of the tank associated with the pumping station. Increasing the size of the tank will allow for the pump station to take in more water and reduce the chances of backflow into Downtown and Brant Point.

3. Conclusion: The flood gate and pumping station together currently provide sufficient protection to the Children's Beach area in all but extraordinary storms. This may not be true in the future unfortunately, as sea level rise and climate change increase the heigh of tides and magnitude of storms. To combat this in the long term, Nantucket may seek to take more intensive mitigation strategies. This includes the following:

   3.1. Elevate Children's Beach waterfront. Elevating the waterfront would consist of the gradual increase in elevation of all bulkheads and harbor walls around Children's Beach, as well as increasing the grade of the boat ramp and increasing the height of the beach. This option is incredibly resource intensive, but offers strong protection, as the elevation of the waterfront is gradually increased with time, it will continue to provide a height buffer to withstand storm surge and inundation from the harbor with protection which increases with the sea level instead of remaining stagnant and being overcome by future storms.

Polpis Road by Sesachacha Pond

Polpis road by Sesachacha Pond is a crucial part of the evacuation route for residents of Wauwinet and Polpis. The wave action and resulting inundation on the road need to be mitigated to reduce the frequency residents are isolated.

1. Conclusion: Wave action on Polpis road by Sesachacha Pond is a significant source of flooding and causes irreparable damage to the roadway. To combat wave action, we have the following recommendations:
   1.1. Elevate the roadway and install a causeway. A causeway would allow water to flow through the road and would help mitigate inundation on the surface. Elevating the roadway would protect against future sea level rise in the area and decrease the risk of future inundation as sea-level rise raises pond levels.
   1.2. Install a pipe from Sesachacha Pond to the Atlantic Ocean. A pipe with a check valve would allow the pond to be drained more effectively without having to dig channels from the pond to the ocean twice a year. The check valve would remain closed for most of the year and could be opened during the Fall and Spring when the pond is regularly drained. The pipe would also allow for the strengthening of the barrier between the pond and ocean as it would remain untouched all year. That said the pipe would require special design considerations to maintain herring populations in the pond.
   1.3. Fortify the barrier between Sesachacha Pond and the Atlantic Ocean. Planting dense vegetation around the pond barrier could increase the absorption rate of water attempting to enter the pond and attenuate waves that overwhelm the barrier decreasing wave action in the pond. A stronger barrier will prevent Sesachacha pond from connecting to the Atlantic Ocean as frequently and will reduce the risk of flooding on the bordering section of Polpis Road.
   1.4. Install a retaining wall along the roadway. We recommend adding a rip-rap style wall along the roadway between Sesachacha Pond and Polpis road. A Rip-Rap wall consists of a layered stone base that allow vegetation and ecology to flourish between gaps. A Rip Rap wall would preserve the natural appearance of Sesachacha Pond and protect its ecology while contributing to wave attenuation and protecting the roadway.

2. Conclusion: Inundation at Polpis road by Sesachacha Pond isolates residents in the area and block access from emergency vehicles. We recommend the following steps be taken to improve residents' knowledge of flooding circumstances:
   2.1. Install live stream cameras that monitor flood levels in the area. Live stream cameras are a cost-effective way to communicate to residents what flood conditions are in the area. They will have better warning when road conditions worsen and have a greater chance of evacuating safety.

Polpis Road by Fulling Mill Creek

Polpis Road by Fulling Mill Creek is part of the evacuation route for 'Sconset and Polpis residents. Mitigating the frequent flooding caused by the culvert and low road elevation are important to both residents in the area and the town.

1. Conclusion: The culvert at Polpis Road by Fulling Mill Creek is undersized and aged causing frequent inundation. We recommend making the following adjustments:
   1.1. Design a new culvert that spans both the road and adjacent bike path. A new culvert will allow a greater quantity of water to flow between either side of the wetland. It will also balance the salinity between the northern and southern half of the wetland boosting ecology. Increased waterflow will reduce the frequency in which Polpis Road by Fulling Mill Creek floods.
   1.2. Increase the size and density of the wetland in the area bordering the harbor. An increase in vegetation could help to slow the movement of water toward the road and alleviate some of the stress placed on the culvert. While an ideal solution it is difficult to achieve.
2. Conclusion: The low elevation of this section of road and rising sea levels will cause this area to become inundated more frequently. We recommend taking the following steps to protect the road from current and worsening inundation:
   2.1. Elevate the road to one foot above flood water levels. Elevating the road will reduce the frequency in which this section of road floods and protect against inundation as sea levels rise.
   2.2. Build a bridge spanning the central section of Polpis road at Fulling Mill Creek. If the road is going to be elevated as suggested in HMP plan F16, we suggest making it a bridge at 5 ft above current elevation. A bridge would allow water to flow freely

between the two wetlands which would restore the ecology and would be beneficial to the environment in this area. The increased elevation of a bridge would allow the roadway to be passable in most conditions preventing isolation in the area caused by the flooding of the road which satisfies the 30-, 50-, and 100-year plan.

Funding

While our recommendations are all feasible, we acknowledge that they will require considerable funding. For this reason, we explored the funding methods that Scituate Massachusetts used for their coastal resiliency projects. Seen in Building a Resilient Scituate Climate Vulnerability and Action Plan, some funding options for our recommendations include FEMA Hazard Mitigation Assistance, Massachusetts Community Preservation Act (specifically at Children's Beach to preserve and maintain the park), Massachusetts office of Coastal Zone Management grant program "Recipients receive up to $500k and are required to provide at least 25% of the total project cost. The program is open to the 78 municipalities located within the MA coastal zone", Municipal Vulnerability Preparedness Program (Building a Resilient Scituate Climate Vulnerability and Action Plan, March 2018, pg. 100). It is important to note when addressing climate change, the grant opportunities increase. If we approach the issue from a sea-level rise due to climate change, Nantucket may qualify for other grant programs seen in Appendix C of Building a Resilient Scituate Climate Vulnerability and Action Plan.

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Figure 9

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Appendices

Appendix A: Sponsor Description

Nantucket Natural Resources Department Overview

Brief History and Background

The island of Nantucket also known as the "Faraway Island" is thirty miles off the south coast of Cape Cod (Figure 52). It is a 105 square mile island accessible from both Hyannis and Oak Bluffs. The town is governed by an elected board and officials and serves to meet the historical environmental and social needs of the island. The select board sits adjacent to multiple committees and commissions designed to meet unique community needs such as the Nantucket water committee, Historic District Commission, and Nantucket housing Authority. The Natural Resource Department sits under the preview of the select board and the town manager and staff (Figure 53). They are concerned with the wellbeing and upkeep and of the natural resources and wildlife of the island.

Figure 52: Present day Birdseye view of Nantucket island

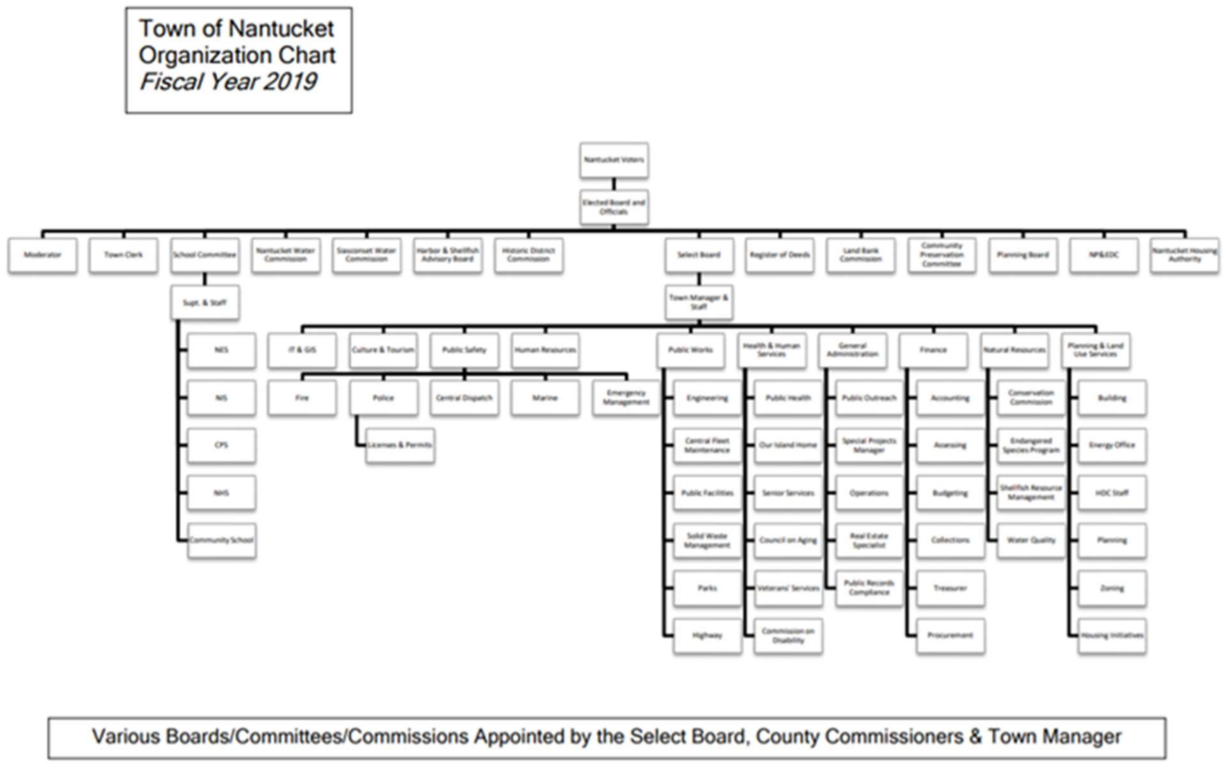


Figure 53: Organizational chart of Nantucket town government.

Department Purpose and Mission

The mission statement of the Nantucket Natural Resources Department is "to preserve, protect or restore Nantucket's natural resources through responsible active management, research, education and outreach to the citizens of Nantucket" (Natural Resources, n.d). Roughly half of the land on island is conservation land protected by numerous groups within town government including the NRD (Figure 54). Their main concerns are protecting the numerous estuaries on the island (light blue spaces on Figure 54), regulating fishing, and preventing and managing flooding that inevitably occurs. Nantucket's topography combined with its geographical location puts it at considerable risk for flooding. The lowest points of the island like Madaket, are at sea level (Figure 55) allowing them to flood both frequently and with great quantities of water (Figure 56). Its geography exposes it to Nor'easters that cause extensive damage and flooding. Additionally, Nantucket harbor, the main harbor on the island faces to the north creating the perfect environment for siloed storms and storm surge in that pocket. Downtown historical Nantucket sits right on the harbor shore. To combat flooding and protect the history of the town the NRD takes on numerous projects a year to address pertinent issues (Natural Resources, n.d).

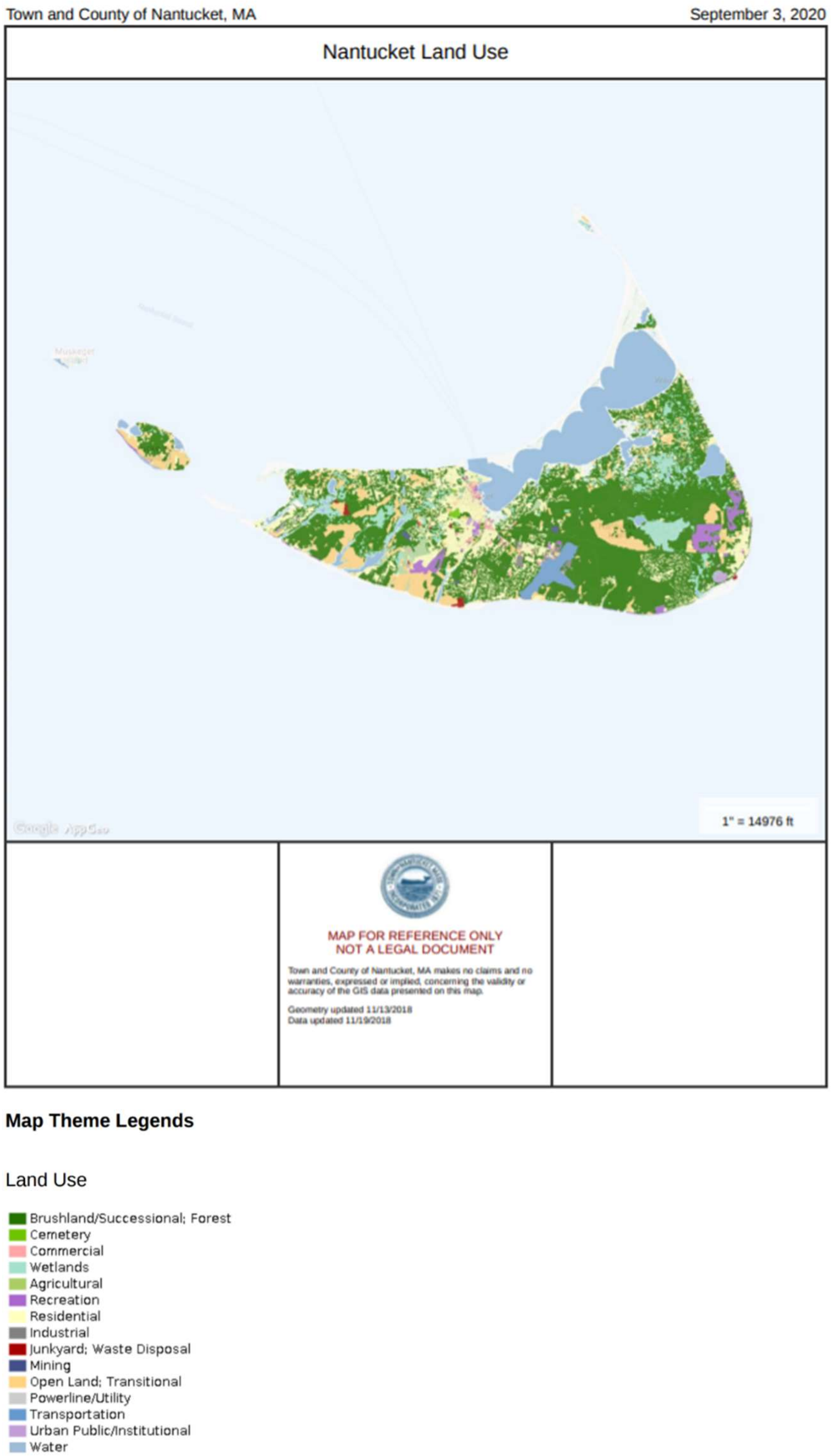


Figure 54: A GIS map of Nantucket showing land use and the numerous ways to utilize the land with a large body of brushland/successional, forest.

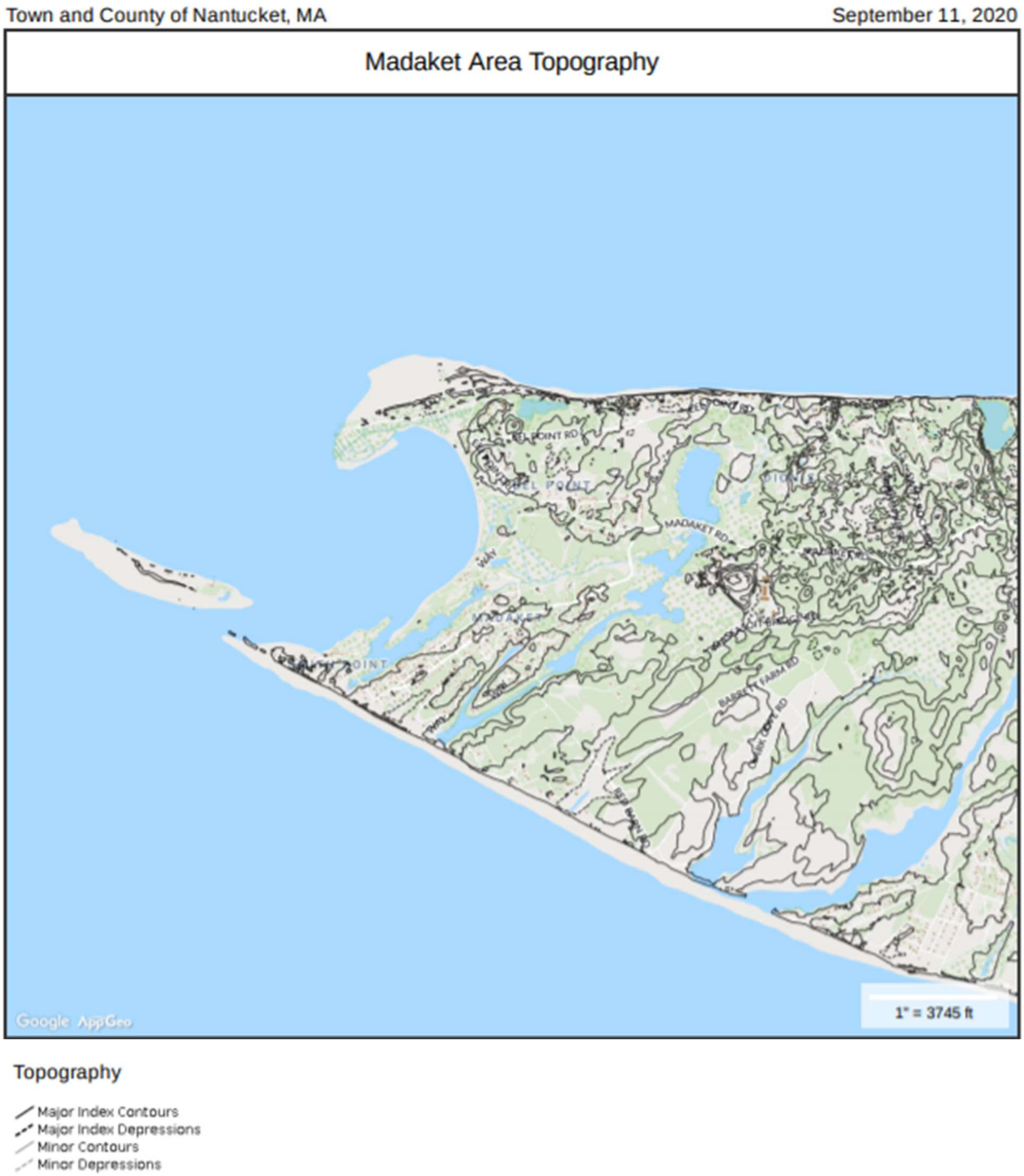


Figure 55: A topographic map of the Madaket area showing the low elevation of Madaket.

Figure 56: A map of Nantucket showing the FEMA National Flood Hazard Layer. The northwest end of the island known as Madaket is shown in light blue, and an area of concern. Generated using MORIS

Department Projects and Activities

The Natural Resources Departments leads various projects to preserve and improve the health of the island's flora and fauna. Implementing regulations in addition to community education and involvement help to facilitate the NRD programs.

Best Management Practices for Nantucket

One project to protect the health of the islands water supply is the Best Management Practices for Nantucket program or BMP. The purpose of BMP is to limit fertilizer use and encourage more responsible fertilizer use. It is centered on science-based guidelines of fertilizer product usage on the island (Young 2012). Excessive fertilizer in soil is a major concern for the community as runoff is toxic to humans and marine life, such as the large eelgrass beds and shellfish hatcheries around the island as seen in Figure 57. The NRD runs program to educate landscapers and islanders about how to safely use fertilizer and requires landscapers to obtain licenses proving they completed the training. The BMP information on fertilizer use contains many guidelines on not just various methods to apply fertilizer but ways to clean it up after application. They also provide resources to make smarter fertilizer decisions on a site-to-site basis including information on soil testing and proper lawn-care through alternatives such as composting (Young 2012).

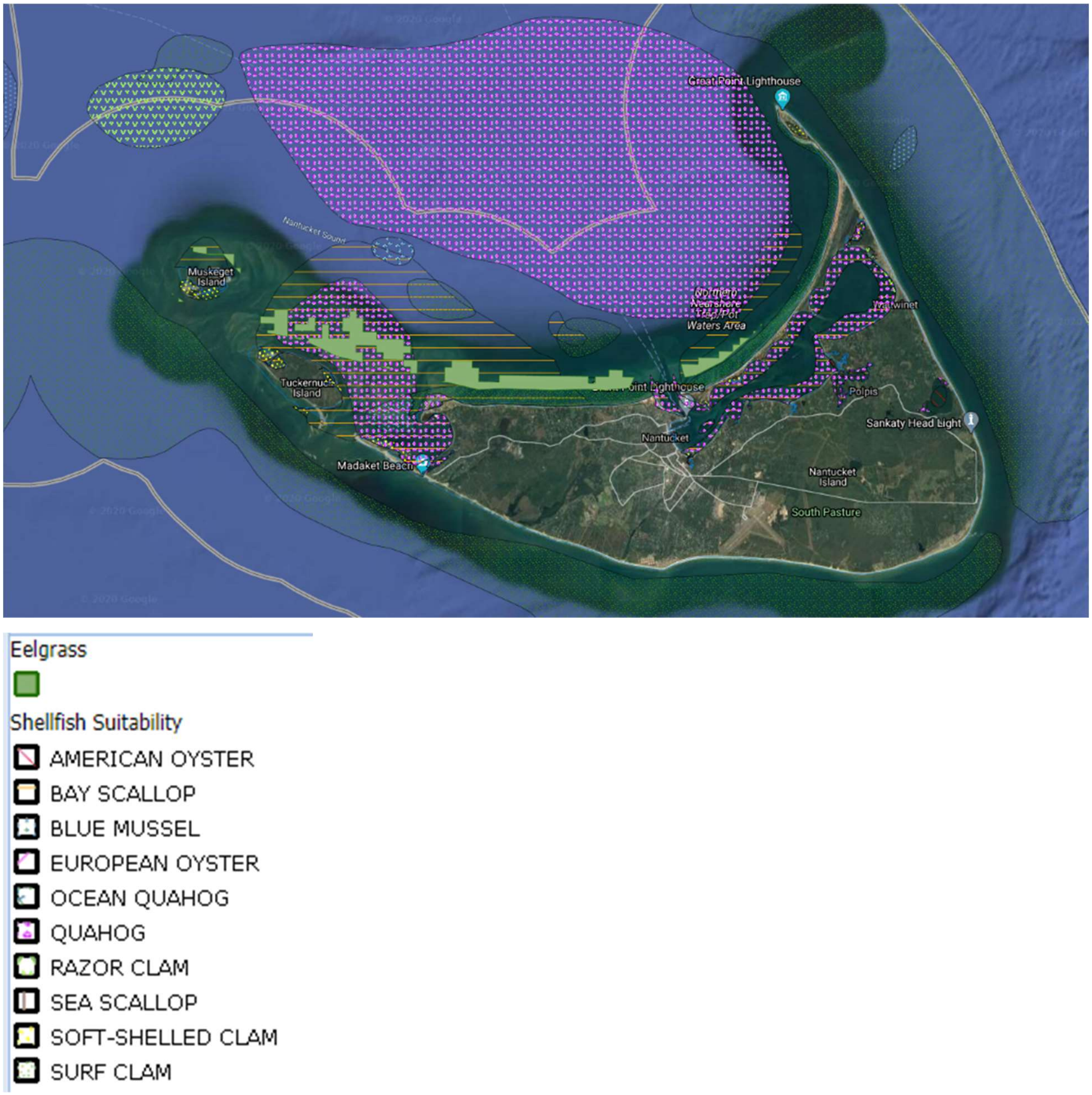


Figure 57: An overlay of all the eelgrass beds and shellfish fisheries around the island.

Shellfish Programs

Another effort run by the NRD is the Shell Recycling Program. The Shell Recycling Program aims to nurture a self-sustaining colony of shellfish on the island. Over farming of shellfish such as oysters and scallops have led to a lack of sustainable populations across the world (Figure 58), Nantucket is one of the few places with a sustainable hatchery. The Shellfish Propagation Program aims to “Develop and implement a shellfish management plan … to protect and enhance the island’s shellfish resources, employing either community-based management or co-management” (Herr 2012). The NRD collects waste shells from surrounding restaurants and uses them to create new sections of reef on which juvenile shellfish can grow. The shellfish program is one of the most demanding activities for the NRD. They must continuously monitor the shellfish populations and actively develop the fishery.

Figure 58: A map showing where oyster reefs are currently or where they used to be and their condition

Costal Resilience Advisory Committee (CRAC)

The Coastal Resilience Advisory Committee (CRAC) is overseen by the NRD in consort with other departments such as the DPW and PLUS. It is 9-member committee created by the Select Board. The CRAC’s mission statement is to implement a “Coastal Resiliency plan for the town of Nantucket to address the impact of climate change and sea level rise” (Murphy 2020). The plan’s goal is to address the social, cultural, economic, and infrastructural needs of Nantucket while simultaneously protecting the natural environment. This includes the historical preservation of town landmarks.

Vincent Murphy, the Coastal Resilience Coordinator has been addressing rising water levels due to global warming and coastal erosion leading to flooding. As stated in Mr. Murphy's Coastal Resilience Methods, Nantucket needs to adapt to these issues through planning resiliency and structural resiliency. Shoreline management is also a concern along with protecting community infrastructure, private property, and water management. An array of tools and methods have already been proposed by Mr. Murphy in his Coastal Resilience Methods document.

Appendix B: Project Timeline

Table 8: Project Schedule

Objectives/Tasks	10/19	10/20	10/21	10/22	10/23	10/24	10/25	10/26	10/27	10/28	10/29	10/30	10/31	11/1	11/2	11/3	11/4	11/5	11/6	11/7	11/8	11/9	11/10	11/11	11/12	11/13	11/14	11/15	11/16	11/17	11/18	11/19	11/20	11/21	11/22	11/23	11/24	11/25	11/26	11/27	11/28	11/29	11/30	12/1	12/2	12/3	12/4	12/5	12/6	12/7	12/8	12/9	12/10	12/11	12/12	12/13
Assemble Database of Flooding																																																								
Research past floods to decide where to focus our efforts																																																								
Gather quantitative data from NOAA, FEMA, USGS, etc.																																																								
Interview long time residents and historians																																																								
Identify Flood Mitigation Strategies																																																								
Identify Nantucket mitigation strategies																																																								
Research urban areas																																																								
Identify urban mitigation strategies																																																								
Evalute Strategies for Nantucket																																																								
Identify gaps in existing infrastructure																																																								
Analyse infrastructure for Nantucket																																																								
Recommend Area for Testing																																																								
Identify low and high usage areas																																																								
Prepare strategies for each area																																																								
Present strategies to stakeholders																																																								
Prepare report & recommendations																																																								

Appendix C: Interview Preamble and Questions

Preamble to be read to interviewee before interview:

We are a group of students from Worcester Polytechnic Institute working with Nantucket's Natural Resources Department to investigate flooding on the island. We are hoping to learn about Nantucket's history of flooding and what the island is currently doing to reduce the damages of flooding to propose new ways the island can mitigate flooding. You may stop this interview at any time for any reason, and you will be able to review any information we use from this interview before it is published to request it not be used. We would like to be able to quote you, by name if you will allow us. Do you object to us recording the interview?

List of questions and topics for various interviewees:

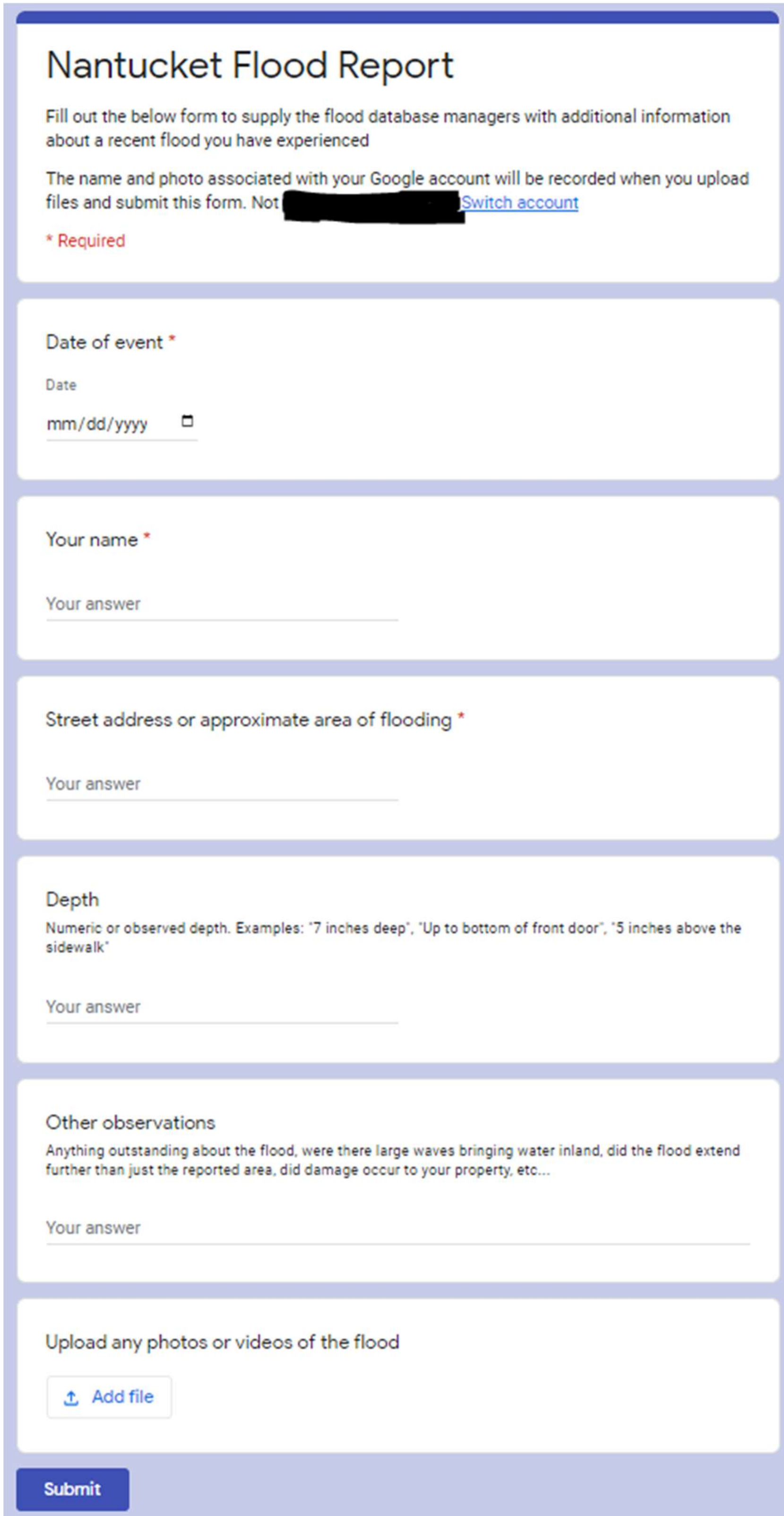
Knowledgeable Islanders:

- What storms were the worst that you remember?
  - For each storm,
  - When did it occur?
  - Where were the most significant damages done by the storm?
  - Where was the flooding worst during the storm?
  - Is there anyone else we could speak to about this storm?

Town Officials and Flooding Experts

- How long has flooding been an issue, is it getting worse?
- Severity of flooding in the area, certain coastal areas worse than others?
- What types of infrastructure have been implemented to mitigate flooding?
  - How effective is each piece of infrastructure?
- How effective are our identified flood mitigation strategies?
- What permits or permissions would be needed to implement a given strategy?
- Does a given strategy fit with your ideas of Nantucket's values?
- Do you think a given strategy will negatively impact any communities?
- Is the implementation of a given strategy feasible for the town budget?

Appendix D: Mock Public Flooding Form



Nantucket Flood Report

Fill out the below form to supply the flood database managers with additional information about a recent flood you have experienced

The name and photo associated with your Google account will be recorded when you upload files and submit this form. Not [redacted] Switch account

* Required

Date of event *

Date

mm/dd/yyyy

Your name *

Your answer

Street address or approximate area of flooding *

Your answer

Depth

Numeric or observed depth. Examples: "7 inches deep", "Up to bottom of front door", "5 inches above the sidewalk"

Your answer

Other observations

Anything outstanding about the flood, were there large waves bringing water inland, did the flood extend further than just the reported area, did damage occur to your property, etc...

Your answer

Upload any photos or videos of the flood

Add file

Submit

Figure 59: Mock Public Flooding Form generated using Google Forms