STORY MAPPING SEA LEVEL RISE:
THE HISTORY AND FUTURE OF THE NANTUCKET WHALING MUSEUM

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

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14 December 2022

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Abstract

The goal of this project was to create a tool for the Nantucket Historical Association to use to communicate with staff and others about the effects of rising sea levels on the Nantucket Whaling Museum and possible adaptation strategies therein. We examined data and projections on sea level rise in Nantucket, delved into the history of the Whaling Museum, examined the building's vulnerabilities to flooding, and explored current and potential mitigation strategies. Working closely with NHA staff and town officials, we created an ArcGIS story map to assemble this research and present it in a compelling and visually appealing manner.

Acknowledgement

We would like to take this opportunity to extend our sincerest thanks and appreciation to everyone whose feedback and support has assisted this team in making this project a reality.

Thank you to our sponsor, the Nantucket Historical Association, for hosting us in the Whaling Museum, for educating us about the rich history of Nantucket, and for sharing its concerns regarding the Museum complex. We extend a very special thank you to the following individuals who candidly shared their extensive experiences and expertise as we navigated this project:

- Niles Parker, Gosnell Executive Director of the NHA
- Ed Rudd, Maintenance and Program Manager for the NHA
- Vince Murphy, Nantucket Resilience Coordinator
- Holly Backus, Preservation Planner & Local Hazard Mitigation Plan Coordinator
- Peter Morrison, Co-chair, Nantucket Civic League
- Mary Novissimo, Director of Visual and Immersive Experiences for the NHA
- The Staff at the NHA Research Library

A special thank you to the Nantucket Yacht Club for providing us with housing and to Young's Bicycle Shop for generously loaning us bicycles for our entire stay on Nantucket. We would also like to acknowledge ReMain Nantucket and the NHA for creating an enjoyable scavenger hunt upon our arrival which helped us learn about Nantucket's rich heritage.

Finally, we would like to express our gratitude for the guidance, support, and patience of our WPI advisors for this trip, Dominic Golding, PhD., and Bruce Bursten, PhD. This project has had a profound impact on each of us, and we truly appreciate your empathy and direction throughout this experience.

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Executive Summary

Sea level rise (SLR) and coastal flooding is a growing threat to Nantucket and its way of life. It can be difficult for Nantucketers to picture future effects of SLR and how the island may change. The Nantucket Historical Association gave us the task of creating a story map for use as a tool to aid the NHA in discussions of resilience in the face of SLR and its widespread impacts. While many are aware of the presence of SLR and flooding, the severity of SLR in the future is not as common knowledge. Using the Whaling Museum as a core case study, our goal was to create a prototype story map to communicate the effects of rising sea levels on the complex in an engaging, meaningful, and effective manner. We identified four objectives in accomplishing this:

1. Establish the design criteria for the story map on sea level rise.
2. Collect and collate the best available information (qualitative and quantitative) on the past and projected impacts of sea level rise on Nantucket's downtown.
3. Design, storyboard, test, and refine prototype story map designs through an iterative process guided by stakeholder and user feedback.
4. Provide the NHA with a final story map, ensure it is properly hosted, and send them a detailed package of data, assets, and supplemental info from the development process.

Methodology

Through extensive discussion with key members of the NHA, we solidified design criteria such as our target audience, learning outcomes, and geographic scope; these criteria informed our choices of which qualitative and quantitative data and accounts, gleaned from the Association's own archives and authoritative sources on SLR, were most prudent to include in our work. A rigorous storyboarding process guided us in deciding how to best present these and in what sequence, and by developing the resulting mockups into testable prototypes we were able to collect valuable feedback that would guide subsequent iterations of the interactive. Upon completion of our final map, we transferred ownership of it to the NHA alongside a detailed cache of all assets, records, and data which proved useful in its development in order to facilitate its final implementation and deployment at a later date.

Outcomes

Beginning with the history of the Whaling Museum, our story map shows how vastly the museum has changed over the past 150 years, and includes projections to show that even more change in the future will be warranted as a response to sea level rise. Alongside historic photos, we use a schematic that progresses with time to demonstrate past changes to the property. Additionally, we present options that the NHA can take to protect the museum moving forwards. These are separated into time-framed categories of short- (by 2030), medium- (2050-2070), and long-term (2100+) solutions and adaptation strategies. While these intervals are not contiguous, they are based on the time frames used by the Coastal Resilience Plan which we continued to use to maintain uniformity with the shared primary source data. The strategies presented in the story map were taken and adapted from documents such as *Floodproofing Non-Residential Buildings* (FEMA, 2013), *Nantucket Resilience Design Standards* (*Resilient Nantucket*, 2021), and the NPS *Guidelines on Flood Adaptation for Rehabilitating Historic Buildings* (NPS, 2021).

Short-term strategies reflect low-to-moderate cost wet and dry floodproofing measures that deal with moderate flooding such as the Whaling Museum has seen and will continue to see. Most of this flooding is from storm runoff, backup of water systems, and groundwater breaching through the floor. Medium-term strategies are generally more expensive and are designed with more extreme flooding in mind. More extreme flooding includes both height of the water and frequency as SLR continues to increase. Finally, long-term strategies are designed for the most extreme scenarios based on NOAA SLR projections. These are the most expensive and disruptive to the property, and are especially difficult to implement given their respective engineering challenges along with the historic significance of the Candle Factory. While these strategies would see implementation only far into the future, planning for them now is critical to assure that this historic property becomes more resilient.

Recommendations

The Nantucket Historical Association may implement our story map in any number of ways to present the history, the present state, and the future prospects of the Whaling Museum, and to inspire educated action toward preservation. In particular, we hope that the story map can serve the NHA as a tool to raise awareness in the following areas:

- It may serve NHA staff, volunteers, and members of the board by demonstrating how the properties of the Whaling Museum have had major changes over the course of its history and will continue to change in response to SLR. In doing so, it will teach that adaptation measures are not to be feared and will be key to the building's preservation.

- It may serve as a conversation starter for preservation planners, particularly those grappling with SLR: rising tides have already shown significant effects on Nantucket and these are only projected to get worse as time goes on. The Whaling Museum, being in a high-risk area will see the forefront of these threats in the future. Strategies for short, medium, and long term adaptations in response to increased flooding are topics of discussion for the NHA and may prompt similar discussion for sites across the island.

- It may serve as a brief case study on flooding and resilience for additional parties interested and affected by SLR, such as neighbors, town officials, residents, and visitors.

- It may serve as a shorthand reference for the NHA utilities team on present water vulnerabilities within the museum, particularly those affecting the Candle Factory, and bring attention to correcting or otherwise safeguarding them through future work.

- It may serve as a high-level overview to be used by planners and museum directors during future museum adaptation efforts, expansion, or renovations. As a reminder of hazards in the near and far future, this map can guide large-scale decisions about ways to modify the museum towards those which are sustainable and most effective at protecting the museum's valuable artifacts for posterity.

- It may serve, at the Association's discretion, as a publicly-available online resource or exhibit to educate broader audiences about the dangers of sea level rise using the museum as a real-world example and powerful focal point.

- It may serve as a strong primer for contractors and other workers making adjustments to the museum or performing regular maintenance going forwards. In this context, it can provide historical background and an overview of many specifics and vulnerabilities of the building in short order; this information would ensure that construction work proceeds in a resilience-conscious way, and, as an added benefit, that the historical intricacies of the building are respected when selecting building materials and construction techniques reducing the chance of damage to the building or its character.

As part of our research into potential mitigation strategies with the goal of stimulating discussion within the NHA, we identifited several resilience pathways the organization may consider investigating, all of which are derived from the standards of applicable flooding treatments outlined by the NPS. These include temporary protective measures, landscape adaptations, dry floodproofing, wet floodproofing, basement and foundation modifications, and elevation. As climate change volatility and SLR projections portray a grim future for Nantucket, the NHA is proactively gathering data on how to best protect the Whaling Museum complex on Nantucket. While the year intervals mirror those used in the Coastal Resiliency report and are in no way hard dates, the NHA may consider implementing any of these treatments if they see fit.

Short Term Strategies (by 2030)

- Green Infrastructure: Consider installing landscape adaptations
    - Ex: Rain gardens, planter boxes, bioswales, and vertical vegetation
- Wet Floodproofing: Inspection and evaluation of wall foundation strength of Candle Factory
- Wet Floodproofing: Wrapping adhesive waterproofing membrane along areas that collect water prior to storms
- Dry Floodproofing: Use flood gates and sump pumps within the Candle Factory
- Dry Floodproofing: Ensure downspouts are clear of debris and draining away from the foundation
- Consider the benefits of installing either backflow valves or installing flood gates in lower elevation toilets
- Evaluate the integrity of masonry work; repoint using appropriate grade hydraulic lime
- Elevate and rebuild the property on 4 Whalers Lane

Because most of the present-day flooding is a result of storm events and surface runoff from roofs, the short-term strategies will continue to be effective in mitigating water issues. These are presently urgent as they address flooding the NHA is already grappling with and will see more frequently in the future. Having mostly low to moderate costs, these options could be implemented with relatively little time spent planning.

Medium Term Strategies (2050-2070)

- Dry Floodproofing: Examine the structural integrity of the masonry
- Dry Floodproofing: Consider anchoring the Candle Factory to its foundation to prevent shifting or collapse
- Dry Floodproofing: Applying a waterproof coating on the foundations of each structure within the complex that is compatible with the historic masonry of the buildings
- Wet Floodproofing: Create an elevated floor by several inches in Candle Factory to allow water to run underneath
- Using a silicone-based brick sealant on the interior and exterior exposed masonry
- Elevation of the Discovery Center, making the first four feet waterproof

The implementation of medium-term solutions is when more significant changes to the museum infrastructure come into play. Based on NOAA projections, the museum will begin to exhibit severe effects from SLR and the exterior of the Whaling Museum will be at substantially higher risk than it will have been in the short-term phase. The NHA may want to consult with material scientists to develop pertinent solutions in addition to those presented here.

Long Term (2100+)

- Elevate the Candle Factory onto a new foundation and allow water to flow underneath
- Retrofit the Candle Factory on a buoyant foundation
- Relocation of the Candle Factory Building

Long term solutions can be the hardest to envision and accept. Not only are they very expensive to execute, but imagining the relocation of the Candle Factory and museum will be difficult for many people to contemplate; indeed, one of the challenges facing the NHA is a certain sense of denial among many of its stakeholders. While many current NHA staff may never see these types of strategies actually implemented, it is critical to begin conversations about these realities in the present in order to assure the ultimate preservation of the museum.

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Introduction

Sea level rise (SLR) remains one of the most widespread consequences of the Earth's changing climate, but many still fail to understand how severe its rate and impacts have become. Since 1965, the Island of Nantucket has experienced an 8-inch rise in sea level, and current data suggest that levels will rise between 2.4 feet and 5.5 feet more by 2070. The Nantucket Coastal Resilience Advisory Committee anticipates that as many as 2,373 buildings are at risk of coastal flooding and erosion due to sea level rise; around half of these are in the historic downtown and Siasconset districts. Damage to many meticulously-preserved buildings from the island's past may exceed $3.4 billion by 2070 (Coastal Resilience Advisory Committee, 2021).

The Nantucket Historical Association (NHA) maintains the Nantucket Whaling Museum in the downtown area, an important repository of the island's history and tourist attraction averaging over 90,000 visitors each year. As discussed in its Strategic Plan, the NHA is committed to raising public awareness about the impacts of sea level rise on Nantucket by developing exhibits that use technology to tell compelling stories (NHA.org). These exhibits use documents, artifacts, photos, and other media from the NHA collections and archives to provide powerful stories about the likely impacts of sea level rise on the people, historic buildings, and infrastructure that are most at risk in Nantucket. The Association wants to see this same strategy employed toward a new goal: a polished, interactive tool for educating staff and others about the Whaling Museum's history, its present and future vulnerabilities to flooding, and options for mitigation and adaptation.

Using Esri's ArcGIS and StoryMaps software, the goal of this project was to create a prototype story map for the NHA's to use as a tool to communicate the effects of rising sea levels on the Nantucket Whaling Museum and its immediate surrounding area in an engaging, meaningful, and effective manner. We identified four objectives to achieve this goal:

1. Establish the design criteria for the story map on sea level rise.
2. Collect and collate the best available information (qualitative and quantitative) on the past and projected impacts of sea level rise on Nantucket's downtown.
3. Design, storyboard, test, and refine prototype story map designs through an iterative process guided by stakeholder and user feedback.

4. Provide the NHA with a final story map, ensure it is properly hosted, and send them a detailed package of data, assets, and supplemental info from the development process.

Through our meetings and interviews with NHA staff we determined the initial design criteria of the story map (and continued to refine it over time). These criteria both informed our design process and determined what pieces of background information, gathered as part of our ongoing research, were most relevant to incorporate. After storyboarding the layout of its content, we developed a prototype matching the Association's specifications before soliciting feedback from the NHA, allowing the findings to guide our revision process.

Background

In this section, we draw on the recent *Nantucket Coastal Resilience Plan* (NCRAC, 2021) to review the basic data on sea level rise in Nantucket, the types of hazards that result, and the risks posed to buildings and other structures. We also discuss visualizations of projected sea level rise that have been created for Nantucket. The National Park Service's *Guidelines on Flood Adaptation Adaptation for Rehabilitating Historic Buildings* (Eggleston et al., 2021) are reviewed for possible application within the Whaling Museum complex. Additionally, case studies on climate change exhibits and examples of interactive educational tools on SLR helped further develop our awareness.

1. Sea Level Rise on Nantucket

For the island of Nantucket, the impacts of climate change are becoming increasingly apparent with rising sea levels and more severe coastal storms, erosion, and flooding. Sea level rise (SLR) is the most notable effect of climate change on Nantucket. Anthropogenic climate change resulting from increased greenhouse gas emissions causes global warming, and in turn the melting of glaciers, thermal expansion of the oceans, and SLR. According to the Woods Hole Oceanographic Institute (WHOI), "Since the turn of the 20th century, the seas have risen between six and eight inches globally" (WHOI 2019). SLR is not evenly distributed throughout the ocean, however, and varies from location to location (WHOI 2019). Figure 1 shows that sea levels have risen by 1.4" per decade on Nantucket or some 8" in total since 1965.

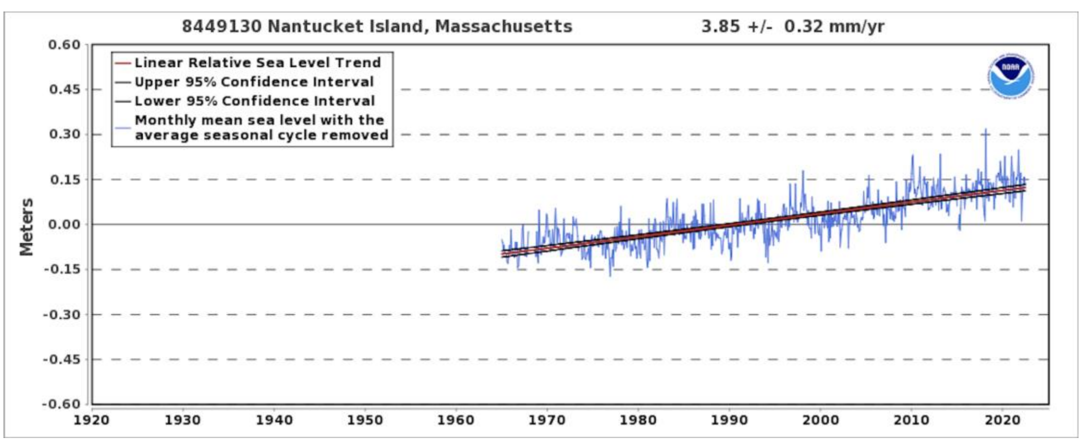


Figure 1: SLR trends for Nantucket Island (Sea Level Trends - NOAA Tides & Currents, n.d.).

Using scaled data from the International Panel on Climate Change (IPCC), the 2017 National Climate Assessment, and the Global and Regional Sea Level Rise Scenarios for the United States (NOAA), the Commonwealth of Massachusetts generated four scenarios for SLR projections in the state (Table 1). These scenarios make assumptions about future efforts by countries worldwide to curb GHG emissions and control climate change (NCRAC, 2021).

Table 1 shows mean sea level projections, taken from the Nantucket Coastal Resilience Plan, for four scenarios over four time periods. The 'intermediate' scenario projects a rise of 5.2 feet in mean sea level on Nantucket by 2100 compared with 10.5 feet under the 'extreme' scenario. The Nantucket Coastal Resiliency Advisory Committee (NCRAC) used the 'high' scenario to evaluate risks to Nantucket based on the assumption that while the scenario is unlikely, it is better to plan for the worst rather than be caught unprepared.

Relative Mean Sea Level for Nantucket, MA (feet NAVD88)

Scenario	Probabilistic Projections	2030	2050	2070	2100
Intermediate	Unlikely to exceed (83% probability) given a high emissions pathway	0.7	1.5	2.4	4.2
Intermediate-High	Extremely unlikely to exceed (95% probability) given a high emissions pathway	0.9	1.8	3.0	5.2
High	Extremely unlikely to exceed (99.5% probability) given a high emissions pathway	1.2	2.5	4.3	7.9
Extreme (Maximum physically plausible)	Exceptionally unlikely to exceed (99.9% probability) given a high emissions pathway	1.4	3.1	5.5	10.5

Sea level rise projections for Nantucket adopted by the Commonwealth of Massachusetts. Elevations given in feet NAVD88 relative to the year 2000.

Table 1: Scenarios of Sea Level Rise (NCRAC, 2022).

2. Coastal Hazards Associated with Sea Level Rise on Nantucket

SLR has many impacts on Nantucket. The *Nantucket Coastal Resilience Plan* (CRP) focuses on four coastal hazards: coastal flooding, high tide flooding, coastal erosion, and groundwater table rise. Coastal flooding is when an abundance of seawater – typically caused by strong winds during a storm – is pushed towards the coast, raising the water levels and draining into low-lying areas and floodplains (Figure 2). With SLR and other effects of climate change, coastal flooding is only expected to become more frequent as well as more severe. Coastal flooding causes serious damage to the interior and exterior of buildings as well as other infrastructure, such as roads and utilities (NCRAC, 2021).

Figure 2: Nantucket road being inundated by coastal flooding (Nantucket Magazine, 2020).

High tide flooding is when regular tidal forces overtake levees, floodwalls, and beaches enough to inundate low-lying areas. Commonly called 'nuisance' or 'sunny-day' flooding, these events cause public inconveniences like road closures, backed-up storm drains, and damaged infrastructure. According to a 2020 Town report on Easy Street flooding (NCRAC 2021), Nantucket is already seeing an increase in high tide flooding in the downtown area (Figure 3). As SLR increases, high tide flooding will become more frequent and inundate broader areas with a more forceful impact.

Figure 3: "Sunny day" flooding in downtown (NCRAC, 2021).

Coastal erosion is also threatening Nantucket and its infrastructure (Figure 4). "Erosion is a geological process in which earthen materials are worn away and transported by natural forces, such as wind and water." (NCRAC, 2021, p.45). Nantucket is especially susceptible to coastal erosion given that the island is composed almost entirely of sand and glacial debris. Nantucket can experience enormous erosion during severe storms that lead to substantial changes to the coastline. Sandy beaches and dunes tend to erode seasonally where they are replenished naturally; however, bluffs erode substantially during storms and do not replenish naturally. Unfortunately, erosion control structures on bluffs often exacerbate erosion at other locations by displacing wave and tidal energy.

Figure 4: Coastal erosion (NCRAC, 2021).

Groundwater table rise also poses a threat to parts of Nantucket. Groundwater table rise "is the increase of groundwater levels underneath a landmass, primarily driven by an increase in sea levels" (NCRAC, 2021, p.46). Near the shoreline, groundwater tends to rise and fall with the tides. Rising sea levels elevate the mean groundwater levels, with a general rule of thumb being that every foot of SLR causes about four inches of groundwater level increase. For low-lying areas, the groundwater could thus potentially pond on the surface, even if the area is not along the coast (Figure 5). This can cause the creation of new wetlands, changes in surface drainage, and saturated soil conditions. Rising groundwater could eventually affect building foundations, cause gradual subsidence, and infiltrate underground utilities (NCRAC, 2021).

Figure 5: Groundwater emergence on Brant Point, November 2020 (NCRAC, 2021).

3. Costs from Coastal Hazards

According to figures from the Nantucket Coastal Resilience Plan, around 2,373 structures on the island are at risk of flooding and erosion by the year 2070, which could result in more than $3.4 billion in damages (Figure 6). Cultural landmarks and irreplaceable historical buildings are among those risk, but eighty-four percent of the buildings that are at risk of flooding in the next fifty years are residential buildings (NCRAC, 2022). Figure 7 shows that the coastal flood and erosion risk to buildings is concentrated in the downtown area of Nantucket. The financial costs from these storm events and floods are extremely high, but the potential human cost is not to be understated all the same.

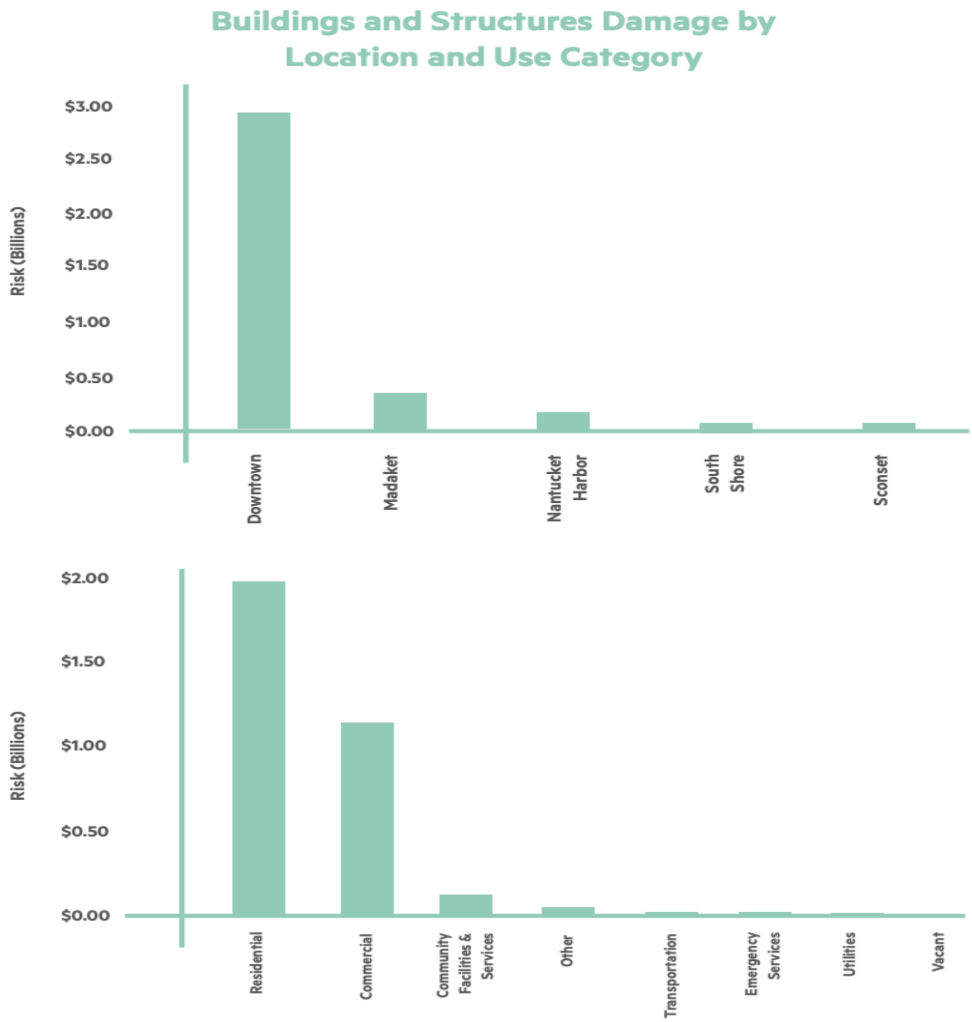


Figure 6: Risk (in billion $) of different locations on Nantucket (NCRAC, 2021).

The CRP finds that 34 essential community buildings could suffer more than $180 million in damages over the next 50 years. The report identifies five of the highest priority assets in need of protection as: the Steamship Authority Terminal on the Steamboat Wharf, the Coast Guard Station at Brant Point, the downtown Stop & Shop at 9 Salem Street, the Hy-Line Cruises Terminal on Straight Wharf, and National Grid Electrical Substation on Candle Street (NCRAC, 2021). These assets are crucial to the island's economy and well-being. Other assets in the downtown area that are of particular concern include properties of the Nantucket Historical Association: its offices and flagship attraction, the Whaling Museum complex.

Figure 7: Total coastal flood and erosion risk to buildings (NCRAC, 2021).

Storms hit Nantucket every year, costing taxpayers millions of dollars in direct damages to the island's infrastructure. The 2015 nor'easter storm 'Juno' cost Nantucket well over $1 million just in damages to the Town Pier in the downtown district alone. In 1991, the 'no name' storm cost the island upwards of $65 million in 2022 dollars (A. Jenness, 2016). Preparing for these disasters are costly, too: the National Flood Insurance Program asks for hefty annual premiums for flood insurance that are thousands of dollars a year per property (FEMA.gov). In addition to the hundreds of residential and commercial buildings at risk of coastal erosion and flooding, important infrastructure such as roads and utility lines will continue to be damaged.

4. Possible Protection and Adaptation Strategies for Downtown

The CRP identifies three general strategies via which Nantucket can respond to sea level rise: Adapt, Protect, and Relocate. Adaptation to flooding is already ongoing as home and business owners scramble to protect their property each time it occurs; for example, barriers are installed to keep water from getting into the main floor of buildings, and sealing methods can be implemented to help defend basements and foundations. Smaller outdoor appliances like airconditioning units and other utilities are often raised up on platforms to keep them dry. While physically raising wooden structures is an option that many homeowners pursue in Nantucket, elevating brick structures, such as the Whaling Museum's Candle Factory, NHA administrative offices, and several other buildings in the downtown, would prove complicated, time consuming, and expensive. Elevating some buildings also poses the risk of damage to the historic and architectural integrity of the structures. This means that elevation is unlikely as a short-term solution and may only be pursued in extremes (NCRAC, 2021, p. 132-133). Some additional near-term solutions for downtown include raising roads and creating access roads for when coastal and high-tide flooding obstruct low-elevation roads (as illustrated in Figure 8 below).

To protect as many buildings as possible, general coastline protection can be implemented. This may take the form of sea walls, bulkheads, or berms. Beaches and marshes can also be 'terraformed' (i.e., reshaped and vegetated) in order to shield large areas from water. One long-term solution outlined in the CRP involves building a large sea barrier around the harbor in the downtown area. While out of financial reach in the short-term, it may be financially and technically feasible in Nantucket's long-term strategy (NCRAC, 2021, p. 158-160).

When sea levels jeopardize buildings to the point that Adaptation and Protection are no longer feasible, Relocation (or retreat) may have to be considered. Nantucketers have been moving houses for centuries and moving houses has become commonplace in Nantucket as coastal erosion endangers increasing numbers of properties along the coastline (NCRAC, 2021, p. 133), but the feasibility of this strategy varies widely depending on the structure. Relocating a building's contents or "use", while leaving the original building behind, is a solution that often costs far less time and money, but may be unpalatable when the population wants to see buildings with sentimental or historical value maintained in their original form. In addition to these avenues, the Relocation strategy includes limiting future development in high-risk areas and moving resident communities from such areas to safer regions in order to keep people and future infrastructure out of unsafe zones (NCRAC, 2021, p. 80).

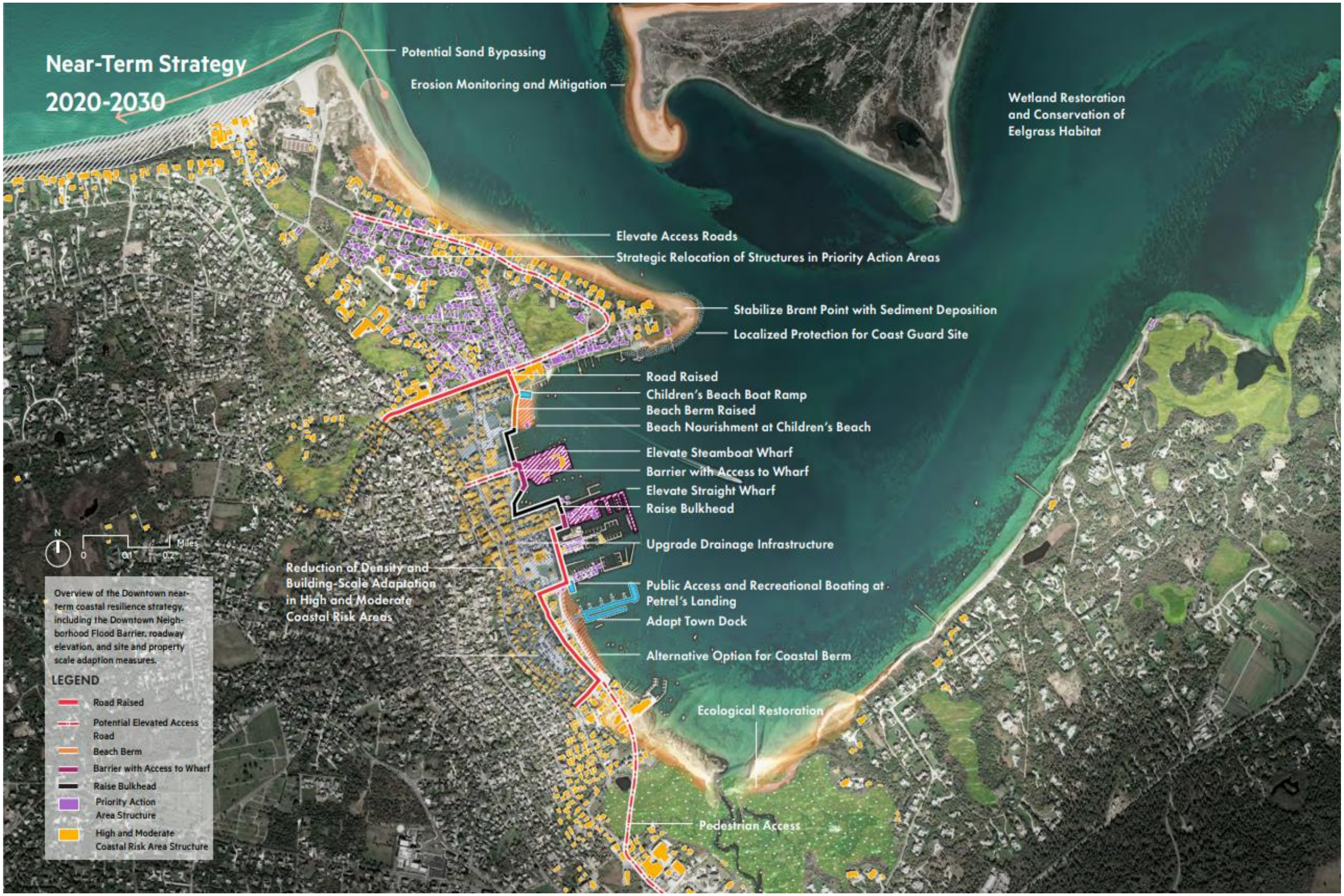


Figure 8: Downtown near-term coastal resilience strategy (NCRAC, 2021).

5. Visualizing Sea Level Rise in Nantucket

The Nantucket Historical Association is keenly aware of the threat of rising sea levels and is taking steps to engage the community regarding the need for historical preservation in light of it. From the many historically significant properties managed by the NHA, the Whaling Museum located on Broad Street close to Nantucket Harbor and near the entrance of Steamboat Wharf, is one of several vulnerable sites. As one can see in the University of Florida's rendering of Broad Street in Figure 9, an intermediate high sea level rise projection against the structures over several decades depicts a devastating outlook.

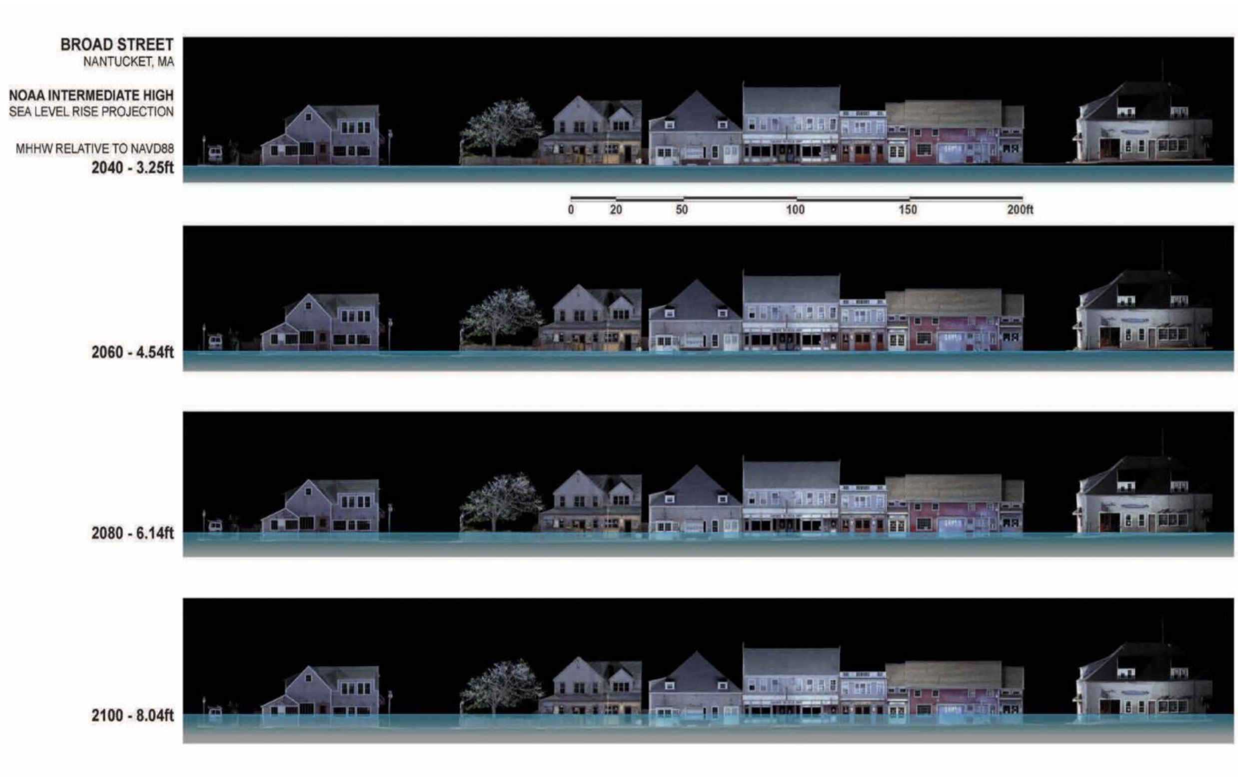


Figure 9: Visualization of broad street, sea level rise projections (University of Florida, Resilient Nantucket, 2019).

The computer-generated depictions in Figure 10 below provide a realistic outlook of an intersection of Broad Street over the course of several decades. It is important to bear in mind that the progression of rising waters is not gradual. Coastal flooding will become deeper, more frequent, and more extensive, as sea levels rise and storms become more frequent and intense.

These images indicate merely the ‘passive’ rise in sea level and do not account for the tremendous damage wrought by storms. Storms create tidal surges and waves over and above the levels indicated in these images. Winds, waves, and tidal scouring during storm events cause tremendous damage to buildings and other urban infrastructure. NOAA and others predict that the frequency and intensity of storms will increase in the future as the climate changes.

Figure 10: 3D visualizations of broad street, sea level rise projections (University of Florida, Resilient Nantucket, 2019).

Both Figure 9 and Figure 10 were created by the University of Florida Preservation Institute Nantucket (Resilient Nantucket, 2019) as part of an education and awareness project. The NHA would like to build on these visualizations and potentially use them as part of its effort to educate staff, volunteers, and the public about the implications of flooding for downtown in general and the NHA in particular.

6. Flood Adaptation and Rehabilitation of Historic Structures

Because many landmarked historic buildings fall under the purview of the National Park Service (NPS), owners do not have the ability to freely modify, repair or rehabilitate their structures and instead need to adhere to *The Secretary of the Interior's Standards for the Treatment of Historic Buildings* (Grimmer, 2017); they are required to pay close attention to the guidelines on allowable options and adaptation responses. Criteria relating specifically to flood treatments are detailed in *Guidelines on Flood Adaptation for Rehabilitating Historic Buildings* (Eggleston, et al., 2021). Some strategies as they relate to different neighborhoods within Nantucket have been previously addressed in "Resilient Nantucket: Flooding Adaptation & Building Elevation Design Guidelines" (Thomason, 2021). The NHA, like many other landmarked historic property owners in coastal areas, are grappling with the issue of how to preserve these historic buildings to ensure their resilience against the manifold consequences of climate change.

In its mission to develop strategies to best protect the Whaling Museum complex from flooding and the growing issue of sea level rise, the NHA has already begun taking, action as suggested within NPS recommendations, by assessing flooding vulnerabilities at the Whaling Museum complex based on the most current SLR data. The general reference for flood adaptation outlined by the NPS covers a comprehensive array of treatments, with approaches that range from low-cost, near-immediate actions to those at higher costs designed with long-term application in mind. These treatments, which can involve temporary protective measures such as landscape adaptations, dry floodproofing, wet floodproofing, filling the basement, elevation, abandonment, and relocation, can either be applied independently or in conjunction with other treatments to improve the fortitude of the structure. While there is no hierarchical order or objective 'right answer' for the application of these standards, as the circumstances and conditions of each structure are unique, the following discusses a number of options applicable for the Whaling Museum's consideration both now and into the future.

<u>Temporary Protective Measures</u>

According to the NPS guidelines, treatment measures should not change the distinctive materials and historical features of the structure. Temporary protective measures are the most affordable and least likely to have any damaging impact on the historical character of the structure. Some measures include improving lot grading to pitch water away from building foundations as illustrated in Figure 11; others require regular maintenance, like maintaining proper water run-off and drainage, as well as keeping gutters, downspouts, and sewer drains clean from debris. Some temporary measures include the installation of sump pumps and/or drain plugs to prevent sewer backup on lower levels. Impermanent measures include items like sandbags, portable floodgates, and inflatable flood walls. While the possibility of floodwaters breaching these temporary measures still exists, positioning them prior to a flood event decreases this risk. Utilizing a flood sensor may aid as an alert system in expediting the implementation of these temporary measures prior to any water damage occurring.

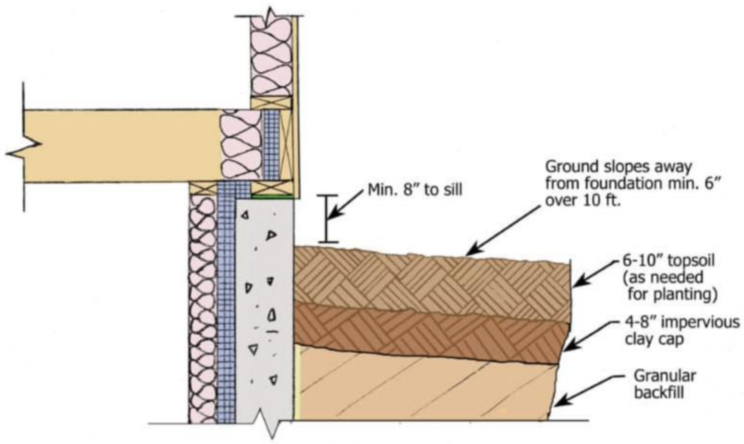


Figure 11: Illustration of lot grading around foundation (buildingadvisor.com).

<u>Landscape Mitigation</u>

Green infrastructure consists of natural systems that can divert, absorb, or capture water. In 2019, Congress enacted the Water Infrastructure Improvement Act, which defines green infrastructure as “the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters.” (EPA.gov). In keeping with NPS standards, the NHA can investigate the construction of rain gardens. Rain gardens, as illustrated in Figure 12, are sunken areas landscaped with plants that aid in absorbing floodwaters from roofs, streets, and sidewalks. Planter boxes are similar to rain gardens except they are constructed and designed to have vertical walls. They also can absorb runoff from roofs and sidewalks. Another green option is bioswales. Bioswales are a category of rain gardens positioned in the spaces between the sidewalk and the curb. NPS also recommends the use of permeable pavement provided the design and materials are in line with the aesthetics of the structure. Permeable pavement allows water to infiltrate into the substrate and soil below, which reduces surface runoff and helps keep trees healthy. The pavement can be made of porous concrete, asphalt, bricks, or other common materials (EPA.gov).

Figure 12: Illustration of rain garden on curb line (nyc.gov).

<u>Dry Floodproofing</u>

Dry floodproofing is synonymous with waterproofing or sealing the exterior of a structure from floodwaters, thereby preventing water from entering the structure. It is most appropriately applied in situations where anticipated flooding is less under 3 feet. To dry floodproof a historic structure, the NPS recommends that all openings that extend or are below the established flood level risk be designed to be temporarily or permanently sealed; the exterior foundation must be impervious to water, walls must be reinforced and anchored to withstand the hydrostatic pressure and imbalance forces of floodwater on the exterior walls and foundation as shown in Figure 13. Because dry floodproofing is usually completed below grade, the NPS maintains that the historic character of the affected structures are unlikely to be impacted (Eggleston, et al., 2021). Besides evaluating and anchoring the structure, the NPS encourages owners to quickly address any flooding issues, maintain an adequate drainage system, utilize sump pumps and connect backflow valves to sewer lines as additional floodproofing measures.

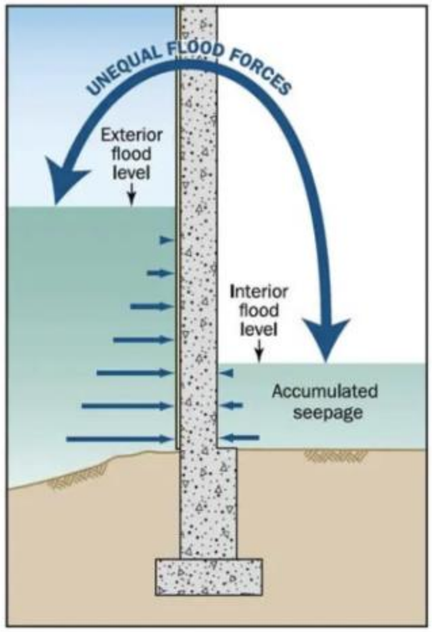


Figure 13: Illustration of hydrostatic pressure and water force imbalance in dry floodproofing (climatecheck.org).

Wet Floodproofing

Unlike dry floodproofing, wherein there exists an imbalance of pressure on the exterior walls and foundation of the structure, wet floodproofing allows water to freely enter and flow through the building. This method equalizes hydrostatic pressure on the foundation and in turn reduces the possibility of structural damage as depicted in Figure 14. Floodwater enters the building through vents in the foundation and passes through areas treated with flood resistant materials such as concrete, stone, masonry, ceramic tile, pressure treated lumber, epoxy paint and metals. These flood materials have added the benefit of being easy to clean. The NPS imposes limitations on utilizing wet floodproofing treatments if the historic building contains any features or finishes that are not flood damage resistant or if they are held at or below the established flood level risk. As long as any historic artifacts are elevated or removed prior to a flooding event, the NPS will approve this treatment for non-residential structures (Eggleston, et al., 2021).

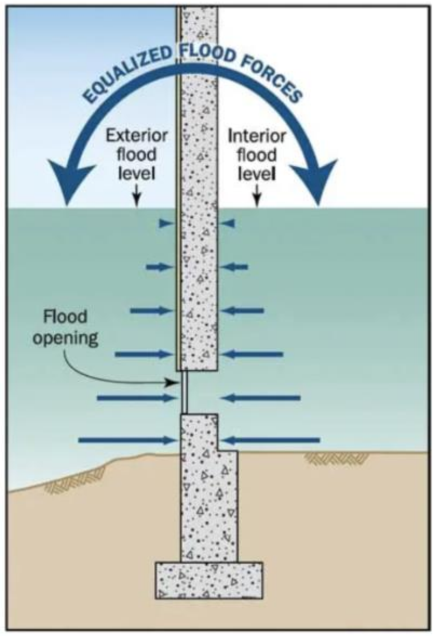


Figure 14: Example of equalized hydrostatic pressure on walls and foundation in wet floodproofing (climatecheck.com).

<u>Fill the Basement</u>

According to the NPS, filling the basement is another flood treatment option that generally will have minor impact on the historical character of the structure. Filling the basement protects against flood water entry via the basement. The caveat with this method is that the structure needs to be constructed with masonry, and the basement needs to be below ground level without a walkout option. Most importantly, there should be no features within the basement that contribute to the historical significance of the building. In utilizing this option, the owner must take care to ensure that the building is structurally sound and there is access to a pumping system if it becomes necessary to assist in draining the area. The owners will need to make sure that compacting equipment can be removed. To be successful, the basement should be filled and compacted with gravel, sand, or dirt up to the height of ground level as shown in Figure 15 (floodhelpny.org). The fill should be periodically inspected and replenished if necessary.

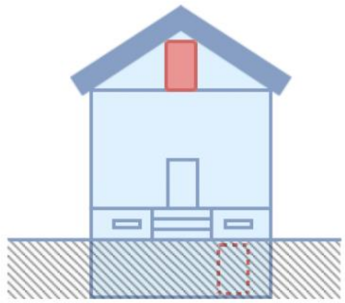


Figure 15: Filling the basement treatment option protects walls and foundation with equalized pressure from compacted fill (floodhelpny.org).

Elevate the Building on a New Foundation

Elevating a structure onto a new foundation, as exemplified in Figure 16 (njfloodalert), will drastically reduce the potential of structural flooding but doing so can greatly impact the appearance of historical buildings. While elevation will protect the structure, this modification requires consultation with professionals and floodplain officials to determine its feasibility. There are technical limitations to elevating a historical structure onto a new foundation, which are determined by flood risk and the composition of the structure. Frame built structures are easier to raise than masonry structures. Depending on the size, shape, and structural dimensions of the mason construction, it may be cost prohibitive or impractical to elevate, especially if the building is attached to another structure. Any elevation would also require that the new foundation be as harmonious as possible with the historical aesthetic of the structure.

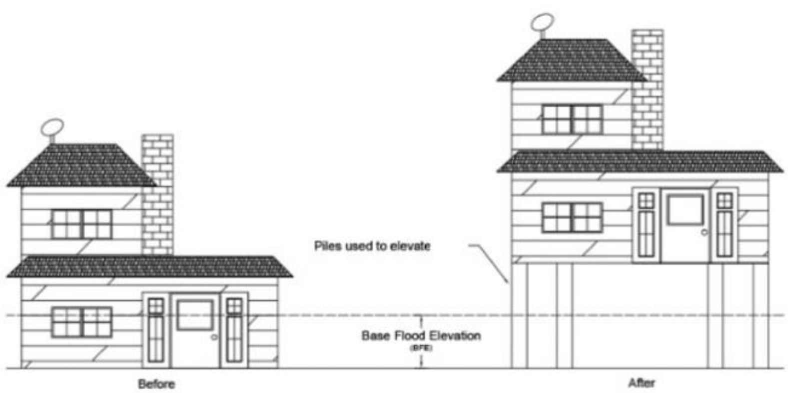


Figure 16: Before and after structure elevation depiction (njfloodalert.com).

Abandoning the Lower Level

For structures that are multi-floored, the NPS puts forth abandoning the lowest level of the structure as a floodproofing approach. In applying this treatment, the owners must be prepared to lose access to any space that is below the established flood risk level and the newly abandoned area must either dry floodproofed, wet floodproofed or filled. Additionally, items that were previously stored at this level need to be removed and relocated. While this approach is best suited for masonry buildings, the lower level needs to be inspected to ensure the walls are appropriately reinforced before pursuing any conversions (FEMA, 2015). Any feature modifications resulting from abandoning the lowest level need to be minimally damaging and compatible with the historic features and finishes on the structure. In Figure 17, the lowest level of the structure is abandoned and converted into a garage with newly installed flood vents to function as wet floodproofing.

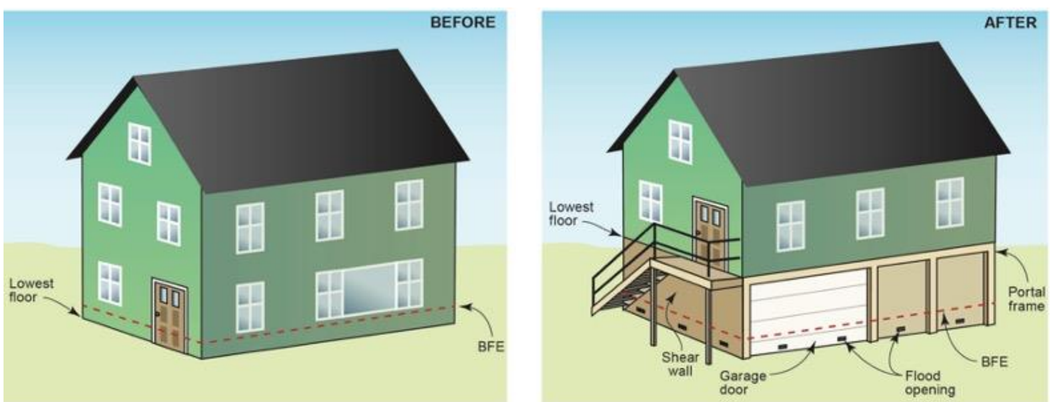


Figure 17: Illustration depicting abandoning the lowest level (FEMA, 2015).

Relocating the Structure

The act of physically removing a historic structure from its foundation and placing it onto a new foundation is not a new concept. Although not a recommended preservation practice, the NPS does allow for circumstances if the structure meets one or more of the following conditions: if it is subjected to frequent and significant flooding, if it is subjected to coastal erosion, or if it is subjected to the effects of sea level rise. There are many factors which need to be considered before relocation, the most important being that the new site is placed on a foundation of similar composition to the original and in as similar a locale as possible while remaining outside of any flood zones areas, thereby sparing the structure any further risk. Documenting the details about the structure for future generations is also an important aspect of the planning process. Other factors include ensuring the structural integrity of the historic building, securing professionals familiar with relocation, securing all necessary permits, and coordinating with law enforcement to avoid transport or roadway access issues. Figure 18 shows Schriber House in Oshkosh, Wisconsin, which was lifted six feet so fourteen dollies fitted with eight wheels each could relocate the 800,000-pound masonry building (Weston, 2016).

Figure 18: Relocation of the Schriber House, Oshkosh, Wisconsin (Weston, 2016).

7. Museum and Other Exhibits on Climate Change

Prior to commencing work on our story map, we sought inspiration from museums that have developed installations focusing on the effects of climate change and global sea rise. The installation at the Museum of Science in Boston entitled "Resilient Venice: Adapting to Climate Change" highlighted a system of gated flood barriers designed to mitigate flood damage (Figure 19). The International Institute for the Conservation of Historic and Artistic Sites (Iconem) was responsible for the realistic videos depicting projected sea level rise through the year 2100.

Figure 19: Interactive tables which allow users to implement different mitigation efforts in the Resilient Venice installation (Photo credit: Paige Colley).

Additionally, the Museum of Science recently hosted a temporary installation entitled "Change Climate Change" (Figure 20). This initiative made use of a 23-foot diameter inflatable globe which utilized high-definition imagery from NASA to exhibit the (literally) global impact of climate change on our environment (Gerber, 2022).


Figure 20: Planet Earth floating in 3D at the Boston Museum (mos.org & Bostonglobe.com).

Other examples of climate change exhibits that focus on rising sea levels include an exhibit at the Museum of the City of New York entitled "Rising Tide: Visualizing the Human Costs of the Climate Crisis." This exhibit offered the chance to witness consequences of climate change across the world with highlights of Miami and New York City through photographs, videos, drone images and audio (MCNY.org).

Although neither digitally accessible nor a physical exhibit in a museum, the National Park Service created an installation "Envisioning Sea Level Rise in Golden Gate National Recreation Area" utilizing the park as a living laboratory for climate change by installing two exhibits. Both exhibits use eye-catching sea level marker poles tagged with projected sea rise levels (Figure 21). Panels along the pathways serve as a guided tour on how expected future sea levels will impact the important natural and cultural aspects of a series of sites (Elder, 2020).

Figure 21: Permanent sea level rise exhibit including a panel-layered map of future sea levels (NPS.gov & W. Elder).

A series of recent efforts like these constitute a broad movement by museums to engage the public on the dangers of climate change. Such has grown vital with the passage of time: as put by Dan Yaeger, executive director of the New England Museum Association, a few years ago climate change “was abstract, theoretical, something for future generations to wrestle with. Now, climate change is undeniably upon us, with crazier-than-normal weather events, ever more urgent atmospheric predictions, and increasingly emotional political dialogue,” and with its change in priority museums have a responsibility to fulfill (nemanet.org).

Portsmouth, New Hampshire’s Strawbery Banke Museum offers a clear example of this idea, using its 10-acre area of preserved historic houses as the focus. Within an exhibit titled “Water Has a Memory: Preserving Strawbery Banke Museum & Portsmouth from Sea Level Rise” (Figures 22 and 23), the museum teaches visitors about the dangers posed to its homes by the waterfront of the Piscataqua River, showcasing the damage that rising groundwater has already had on four of its properties through a time-lapse video (strawberybanke.org).

Figure 22: Photos from within Strawbery Banke Museum's sea level rise exhibit (strawberybanke.org).

Figure 23: A time-lapse setup within the basement of Strawbery Banke's Shapley Drisco House (strawberybanke.org).

8. Interactive Mapping and Climate Change

The NOAA's Sea Level Rise Viewer utility is an excellent example of interactive mapping technology as it applies to SLR (Figure 24). It is available online for free and allows the visitor to explore an entire world map under different sea level conditions; to drive its impact home, it features edited photos visualizing flooding that could occur at local landmarks at every level (NOAA). While substantially larger in focus area than the NHA's project, this map serves as proof of the efficacy of interactive mapping in visualizing the impact of sea level rise. Maps are a strong, even essential, resource for conveying the severity of SLR in an instantly recognizable manner, so it comes as little surprise that *story maps*, which make use of map elements alongside structure, sequence, and additional multimedia assets, are so sought after to frame climate change and its effects in a way that is personal to the viewer.

Figure 24: The Sea Level Rise Viewer's overview of Nantucket, given a ten foot water level. Featured at right is a mockup of the sea alongside the NHA's Whaling Museum (NOAA).

The NHA is interested in exploring the use of Esri's ArcGIS, a family of professional geographic information system (or GIS) software, as a means of organizing geographic information and projections into an appealing interactive story map. The EPA defines ArcGIS's story maps as follows:

"ArcGIS StoryMaps are cloud-based, data presentation tools used by the U.S. Environmental Protection Agency (EPA) to communicate geospatial data in narrative format. Blending multi-media with map products, this tool leverages design features aimed at enhancing the access, understanding, and use of geographic information by Agency stakeholders. Developers can use the StoryMaps software to tell engaging stories with their data and tune their messaging for specific audiences" (EPA.gov).

Whether used as visualization utilities or an engaging public education tool, these displays integrate maps with text-based entries, audiovisual assets, and interactive elements to enhance the user’s understanding of the geographic information being presented; by way of connecting a database or similar living source of information to an ArcGIS project, one can easily make adjustments or additions to the data in question (pro.arcgis.com).

Using the ArcGIS StoryMaps software, the Nature Conservancy Maryland/DC created a story map entitled “Maryland’s Climate Revolution: Smart Solutions to Tackle Climate Change.” It begins with an animated visual of solar panels and a powerful opening statement: “...with more than 7,000 miles of tidal shorelines, Maryland is at ground zero for sea level rise. Our lands, our waters, our biodiversity, and our wellbeing are at risk” (ArcGIS.com). This is promptly followed by a tour in which the user is guided through a map with high-level overviews of the impacts climate change has had on Maryland, SLR included, and each area is accompanied by a photo demonstrating the point in question (Figure 25). By concluding with a call to action, the map tells visitors how they can do their part in practical terms rather than simply presenting numbers to them. Much like the NHA’s project, this story map discusses the impacts of climate change on just one central location rather than the world; the benefit of such a constrained scale is the ability to engage residents of the area on grounds supplemented by historical context and key, tangible outcomes to their actions rather than vague notions (EPA.gov).

Figure 25: A portion of the map and text content for the Conservancy’s story map (ArcGIS.com).

One of Esri’s own story maps is “Addressing the Climate Crisis: Why Geospatial Solutions are Key to Understanding and Responding to Climate Change,” and in addition to its engaging range of freely-explorable maps (ArcGIS.com), it presents a set of resources at the end for those who want to explore climate change data visualization further (Figure 26). Adding avenues such as these enable users to engage further with the subject matter if they so choose, allowing a better level of educational depth than a simple map could achieve on its own.

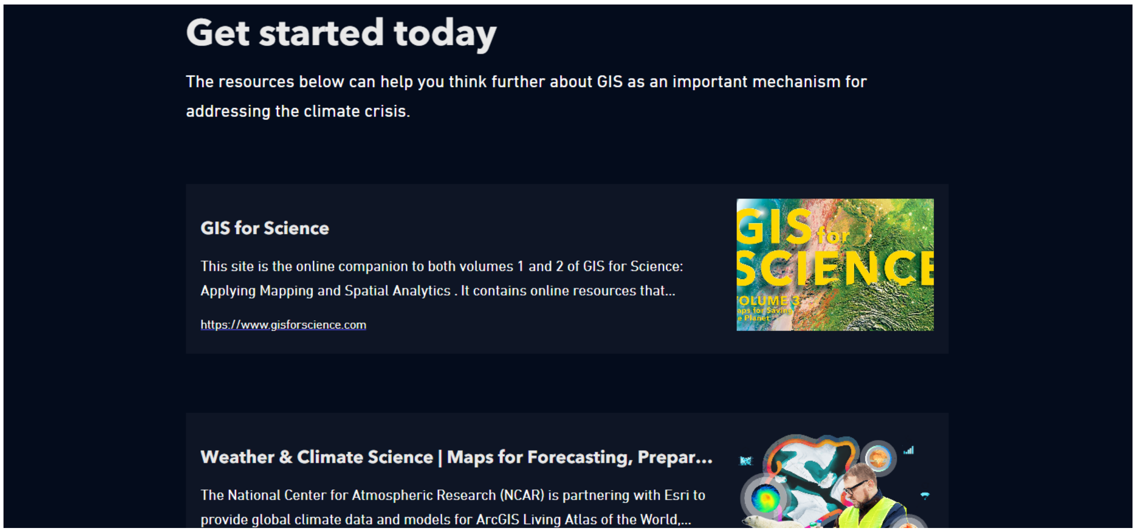


Figure 26: Extra resources on Esri's climate awareness story map (ArcGIS.com).

NOAA's story map "Coastal Flooding: How Coastal Communities are Being Impacted by Sea Level Rise and the Data that Can Help" was developed as an interactive tour of the same projections and data as the Sea Level Rise Viewer. Filled with intuitive visual breakdowns, it is particularly noteworthy for its progressive inundation data visualization of Norfolk, Virginia (Figure 27). As the user scrolls down the page, the water level in consideration continues increasing, mapping a sense of time (mere decades) to the user's navigation of the page so they internalize how significant the effects of SLR will become throughout the century (ArcGIS.com).

Figure 27: A progressive visual of inundation on NOAA's story map (ArcGIS.com).

9. Conclusion

While preserving the island for future generations is important to everyone, safeguarding these vulnerable historic locations is paramount to the NHA. However, facing a fierce opponent like global sea level rise presents an uphill battle. The NHA is committed to working with others on Nantucket to enhance public knowledge and awareness of climate change and the urgent implications for Nantucket.

Under Objective II of its Strategic Plan, the NHA seeks to "excel at exhibition presentation and storytelling…Nantucket has many distinguishing stories that provide insight into our shared American experience. Informed encounters with the past allow us to apply lessons in the present and better prepare us for the future." (NHA.org). To satisfy this objective, the NHA seeks to connect Nantucket's history to global issues by utilizing technology in exhibit presentation and storytelling. This strategic objective is the driving force behind this project relaying the narrative of climate change and its impact on Nantucket.

As such, the NHA has asked our team to develop an interactive story map to stress the destructive impact that projected sea level rise will have on the Whaling Museum complex, including the Hadwen and Barney Candle Factory, the Peter Folger Museum, and the Discovery Center. A digital multimedia tool for use by the NHA that is updatable, comprehensive, user-friendly, and informative will help the NHA meet this objective. Some museums, as discussed in the previous sections, have already developed visualization tools that raise awareness about rising sea levels. With precedents such as these in mind, an interactive mapping project will prove an effective and memorable way to educate the dangers of sea level rise, and how to navigate the future. Important considerations abound: be it efforts to mitigate damages to their own property, prepare financially, or to support larger efforts in the community to safeguard local infrastructure. Making use of the NHA's valuable historic resources and story maps as an educational medium, we aim to demonstrate just how this can be accomplished going forward.

Methods

Using Esri's ArcGIS and StoryMaps software, the goal of this project was to create a prototype story map for the NHA's internal use communicating the effects of rising sea levels on the Nantucket Whaling Museum in an engaging, meaningful, and effective manner. We identified four objectives to achieve this goal:

1. Establish the design criteria for the story map on sea level rise.
2. Collect and collate the best available information (qualitative and quantitative) on the past and projected impacts of sea level rise on Nantucket's downtown.
3. Design, storyboard, test, and refine prototype story map designs through an iterative process guided by stakeholder and user feedback.
4. Provide the NHA with a final story map, ensure it is properly hosted, and send them a detailed package of data, assets, and supplemental info from the development process.

Figure 28 shows the relationship between our research methods and objectives.

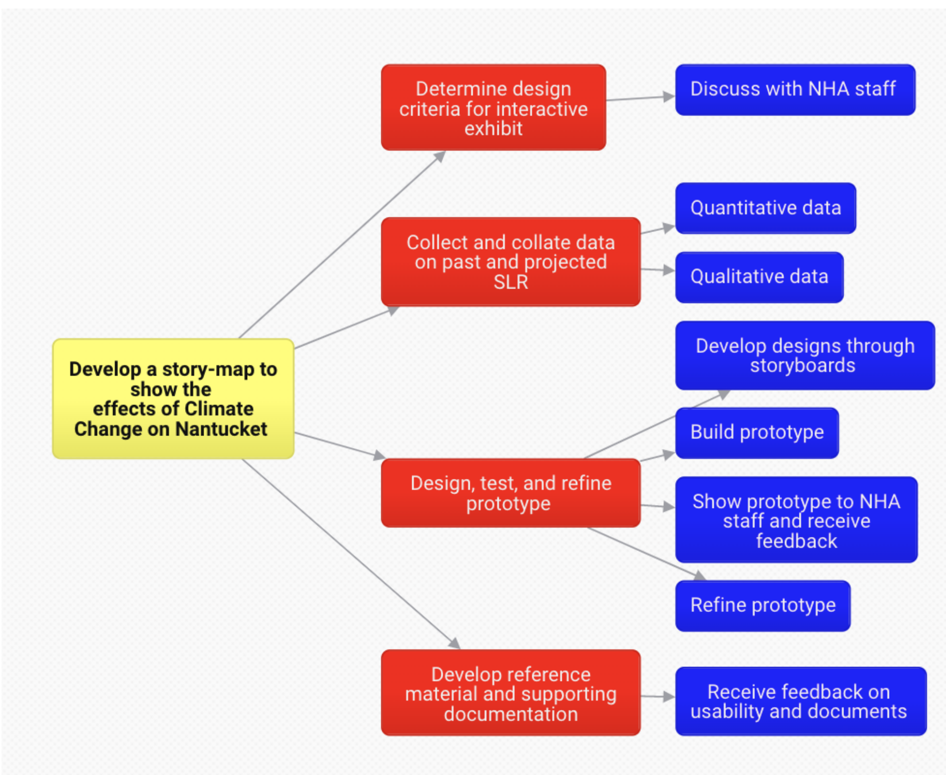


Figure 28: Project overview.

1. Establish Design Criteria

We identified the design criteria for the story map through consultation with staff at the NHA. The Association had indicated from the start that it preferred we use Esri's StoryMaps software to develop our prototypes, but otherwise the criteria were unspecified. Building on our background research and initial reviews of story maps depicting climate change, we met with staff soon after our arrival on the island to solidify the key goals and needs of this endeavor. We held regular meetings with the NHA in the weeks that followed to identify finer details of the design criteria as we began visualizing our map design.

The primary design criteria to define included:

- Intended audience(s);
- Learning outcomes;
- Software used (ArcGIS StoryMaps);
- Graphic design elements (e.g., font types, color palettes, etc.);
- Geographic and historical scope;
- Types of qualitative information (e.g., photos, stories, or newspaper articles reflecting the effect of storms, flooding, and damages to historic properties);
- Types of quantitative data (e.g., historical and projected SLR; types of coastal hazards to consider, such as coastal flooding, high tide flooding, coastal erosion, groundwater table rise; risk exposure data; etc.);
- Resilience efforts and response options (e.g. elevations, floodwalls, etc.);
- Choice of visual aids (i.e., maps, graphs, 3D imaging specific to Nantucket); and,
- Whether the NHA would like to solicit and incorporate design feedback from local merchants and infrastructure to expand the project's scope.

Upon our arrival on Nantucket, this project had been modified from the original deliverable of a story map of the downtown area to be utilized as an interactive SLR exhibit for a public audience, and was reframed to be a story map about the Whaling Museum complex and how to best protect it from SLR and flooding. The preliminary use case changed to a tool and presentation for NHA staff, volunteers, and board members rather than an exhibition.

2. Collect and Collate Data

Following the discussion about the design criteria in Objective #1, we determined what types of quantitative and qualitative data would be most effective in achieving the NHA's goal. We anticipated that visual data, such as flood zone maps, video footage, and photographs of floods and storm damage, as well as 3D visualizations of sea level rise, would be particularly impactful in conveying their message. In preparation for our time on the island, we had begun to collect and collate some of this data and had planned to commence implementation of them following arrival. Because the direction of this deliverable was shifted from an interactive educational instrument into an in-house utility, we focused on specific NHA sites in the downtown complex, which included the histories of the Whaling Museum, the Peter Folger Museum, the Hadwen & Barney Candle Factory and the Discovery Center. To properly capture this new vision, we revised our strategy and pivoted our efforts to adjust to the scope change.

2.1 Quantitative data

Prior to our on-island work, we collected and collated several sets of quantitative data on SLR and its current and potential impacts on Nantucket, as described in the background section above. Our data was drawn from local sources, including the Coastal Resilience Committee's highly comprehensive report. We met with Vincent Murphy, Coastal Resilience Coordinator, to identify data especially pertinent to our region of focus, and Holly Backus, Preservation Planner, to ensure any recommendations to the NHA were sensitive to Nantucket's overarching historical character. We also explored state sources, such as the Massachusetts Office of Coastal Zone Management (CZM), and federal sources, such as the NOAA, FEMA, and EPA.

2.2 Qualitative Data

While quantitative data supported the scientific premise of our map, we used qualitative data, such as historical photos, to add local character and context as a framing for the hard data. The qualitative elements that we selected both educate and bear sentimental or emotional weight to complement the information being presented. In doing so, we collected relevant assets, including both historical and recent files and artifacts, with a focus on those specific to the threatened locations designated by the NHA for inclusion in the story map. Our collection also includes photos and video clips we personally captured depicting flooding and storm surge damages to the downtown area, such as general flooding on Easy Street and the NHA's efforts to contend with water incursion within the Whaling Museum. Collating our own work with the archives of the NHA Research Library, the Nantucket Atheneum, and from The Inquirer and Mirror in consultation with NHA staff, we built an extensive qualitative dataset demonstrating how the museum has changed over time and what threats it will continue to contend with.

3. Design, Test, and Iterate

To meet the NHA's goals, the story map required an engaging narrative about sea level rise and the dangers posed to the Whaling Museum and the surrounding block in particular. To determine the best anecdotes, visual materials, and layouts to use in relaying critical information, we used detailed storyboards. Storyboards gave us both the opportunity to outline and to define the direction we wanted the project to move in and served as direct mockups of the form the final map was to take. We used these storyboards to develop our own ideas and before soliciting feedback from the NHA.

3.1 Visualizing Using Storyboards

In creating our storyboards, we used past story maps to determine design elements and technical aspects that we wanted to include in our own prototype. For example, Figure 29 shows a sample mockup of a common design pattern called a guided tour: as the user scrolls through the story, the map focuses on the locations being described in a set sequence. To add an interactive element, the user is able to click on specific locations on the map to automatically scroll the story back to sections referring to those locations. Having this option allows the user to focus on or revisit the locations they find most interesting, increasing engagement with the overall story map while maintaining a linear order. To balance this element, one can also include one or more *explorer* tours, where the user can study the map's sites at their own pace, affording a user full control over the pace of their experience and allowing the map to display numerous optional sites. Framing our story about SLR using maps like these involved a set of critical points around the museum marked with pinpoints and accompanied by text, photos, and audiovisual clips from the archive.

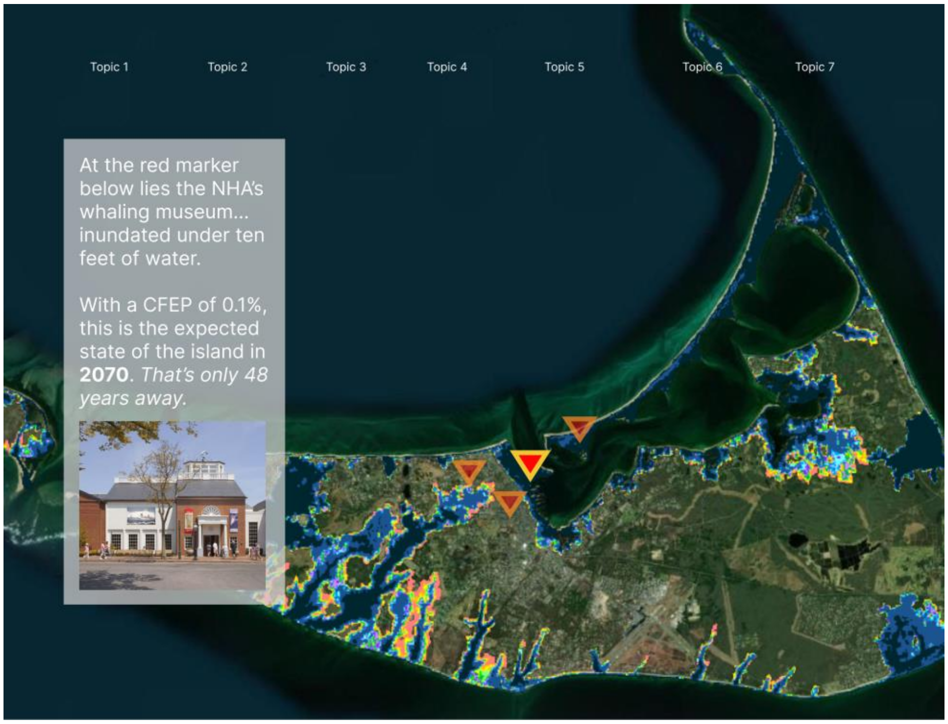


Figure 29: A mockup of a guided tour within a story map.

For data best expressed via a before-and-after format or when emphasizing a visual contrast, a swipe element is often used (Figure 30). A swipe gives the user a moveable horizontal bar that can be used to scrub between two different maps or images; left of the bar one image will be shown while the other displays to the right of it. This feature intuitively represents a comparison or a progression over time (left being "initial" and right being "final") and enables the user to view both states of a visual completely or side-by-side as they prefer. The use case for our group involved demonstrating how the museum changed over time using a swipe, though one as a comparison for conditions before/after flooding events was another idea discussed.

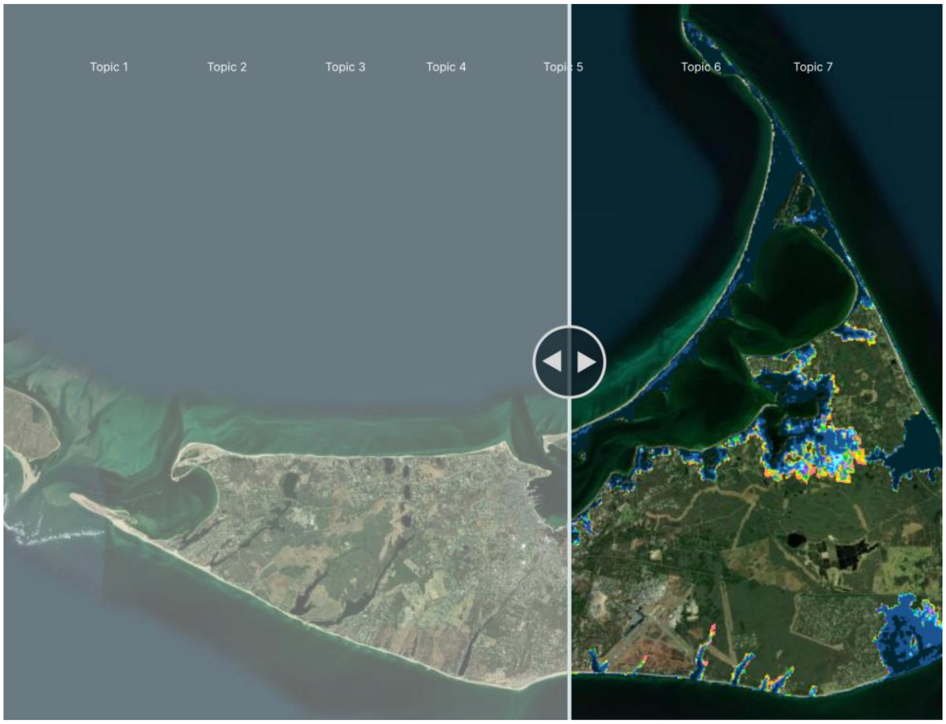


Figure 30: A mockup of a swipe map element showing coastline changes.

The main goal of the story map was not only for it to quickly express useful information, but also to offer research opportunities for users who want to dig deeper. With that in mind, we also embedded links and resources throughout the map (as detours and extra content at the end) giving the user optional avenues to continue learning (Figure 31). Between interactive elements such as these and other multimedia such as videos, galleries, and anecdotes, we created an experience that is predictable and user-friendly while allowing the user to immerse themself in the present and future of this complex issue.

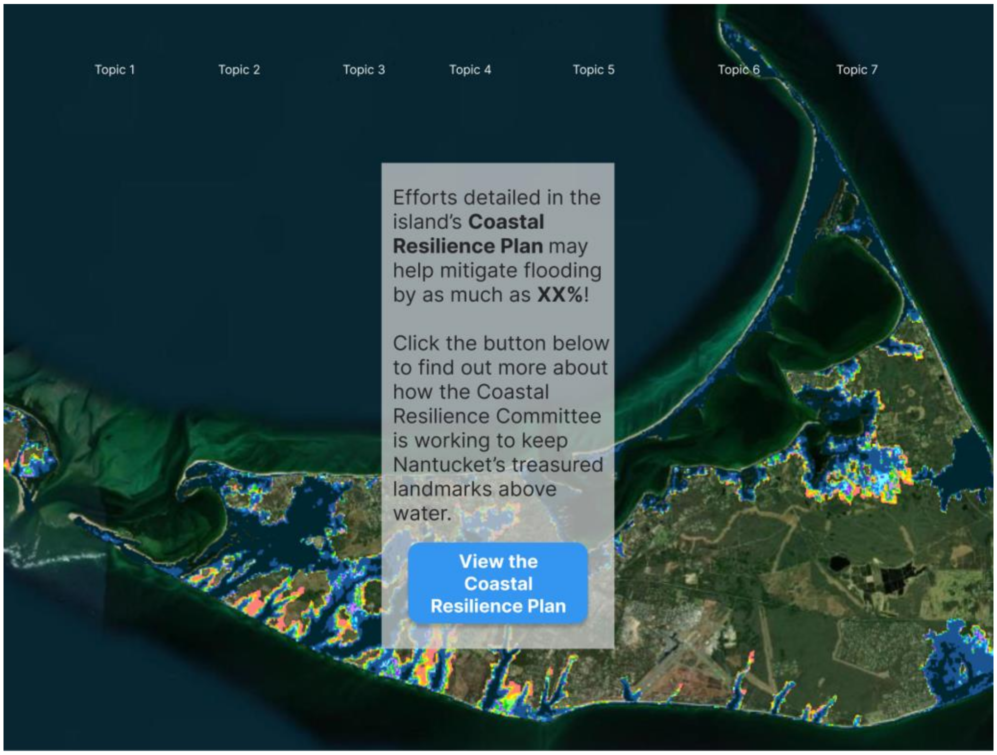


Figure 31: A mockup of how one might include an external link (button) in a map.

As part of drafting these storyboards, we identified and composed the data we wanted to present. Maps projecting the vulnerabilities to rising sea levels over time will be the main focus of the story. These maps, like the broader-scale examples in the above figures, give the user a powerful visual reference for the flooding and other effects sea level rise can have on Nantucket on their own. However, it was critical to tailor these data to one primary site: the downtown area's Whaling Museum and attached buildings, with its abundance of at-risk infrastructure within. To increase the impact at this point it became vital to frame numbers with illustrations of their real-world consequences. Using photos and historic stories to show how a landmark will be damaged in the years to come, we increased engagement by appealing to the sentiments of the user while still remaining informative.

The final form of any one of these storyboards was a series of mockups detailing, sequentially, what combination of these elements a user would see as they scroll through the story map. We presented these to the NHA to solicit feedback before rapidly processing our findings into fully-featured prototypes.

3.2 Building and Testing Prototypes

After developing each given storyboard we began to build a story map from it, implementing the aspects detailed in the previous section. While the limitations of the software meant certain advanced ideas were not feasible, the use of prior story maps for inspiration meant most concepts were well within the realm of possibility from creation.

We used Esri's ArcGIS StoryMaps web interface to produce all prototypes in the course of the project. Worth noting is the use of the word "prototypes" without mention of a final product; given the span of time we were working on our task, we had enough time to produce a well-refined draft as a proof-of-concept for an educational tool (and a strong foundation for future work), but the actual deployment of the map is, at their discretion, a task left to the NHA's own staff. As ArcGIS's story map editor is a menu-driven tool, all team members were able to collaborate readily on development. With this in mind, implementation proceeded rapidly and feedback was gathered in earnest from our key NHA stakeholders.

After taking note of this feedback, we repeated as many steps of our design process as needed to refine our prototype and address any issues. Most commonly we returned to the storyboard phase, drafting up one or more new ones (which we may have reviewed by the NHA prior to development via short discussions) before setting to work re-implementing based on the new mockup. Later in the process, when closer to a complete product, we added on to our latest prototype, and no sweeping changes were needed. Our feedback shaped the trajectory of our design process; upon the completion of each mockup, refined clarifications and criteria were implemented.

4. Deliver Map and Supplementals to the NHA

Our intention was always to deliver the final prototype for a cohesive, scientifically accurate, and personable story map meeting the NHA's specifications. Thus, as a last requirement, it was imperative that the project was as self-contained as possible to facilitate transfer to the NHA's staff and that we provided a useful point of reference to assist in any future deployment.

To this end, we assisted the Association in ensuring that the map and all dependencies were hosted and fully under their ownership. One or more of us will keep in contact as a technical reference for the Association and be ready to assist in answering queries that arise now that the final prototype is complete. This role may include addressing issues that appear during its implementation as a tool or exhibit, questions about future projects in a similar vein, or data-related miscellanea.

Part of the NHA's specifications includes the need to provide the sources used for sea level rise projections and visualization so that these sources can be accessed by museum staff to maintain the tool's timeliness and longevity by refining projections and accounting for new developments. Thus, we created a collection of reference material: sources and online resources to expedite future changes to the story map (such as guides and guidelines from Esri and the National Parks Service), and all assets used (such as photos taken, schematics drawn up, records found in the NHA archives, etc.), which we placed into an organized file to accompany our submission and enable easy access for revisions. We hope that in doing so we are facilitating the easiest pathway to have the NHA use the results of our project in the future; we hope that our proof-of-concept may one day serve as a visualization tool, a piece of educational media, or even a fully-developed exhibit helping unite Nantucketers' efforts towards resilience.

Findings: The Structure and Content of the Story Map

1. Story Mapping

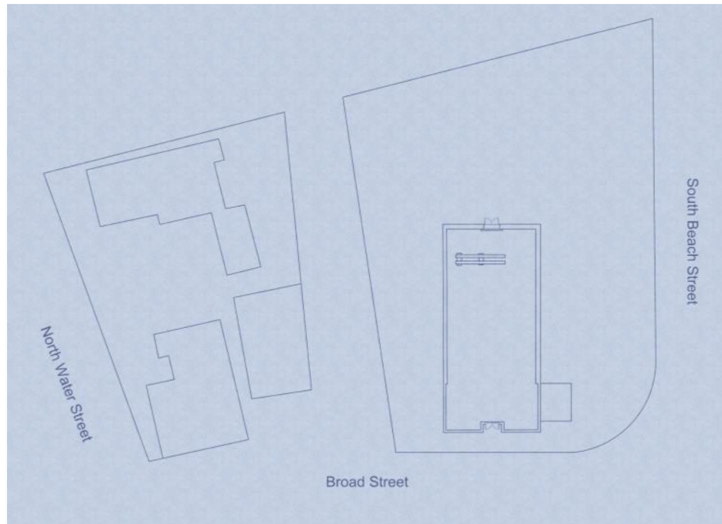
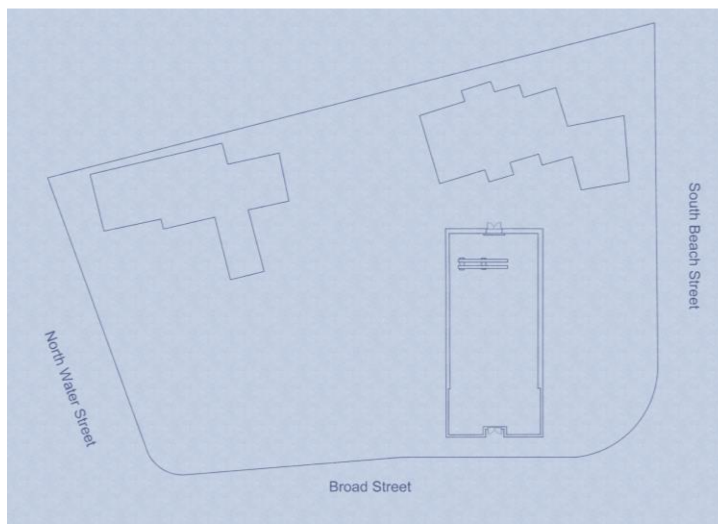
In consultation with Niles Parker, Ed Rudd, and other NHA staff, we developed a story map using Esri's ArcGIS StoryMap software. In this chapter we describe the structure, content, and purpose of the story map and the rationale behind our design choices. The story map is comprised of the following sections: History of the Museum, Looking Forwards, Hazards to the Complex, Protecting the Museum, and Resources. The introduction and conclusion summarize the key takeaways and encourage the reader to continue learning about SLR and resilience, especially as it applies to historic sites they wish to see preserved.

2. History of the Whaling Museum

Following a brief overview under the heading "Introduction", the first content section, "History of the Museum", outlines the evolution of the site on Broad Street as buildings have been constructed, modified, removed, and repurposed. By showing substantial alterations to the property and its surroundings over the last 175 years, we aimed to instill the notion that—despite the overall preservation of its character—the site at large has not stayed static in the past and will continue to change in the future. It is imperative that those trying to adapt the museum for flood resilience accept that they will need to make changes, but change is not to be feared and need not diminish or tarnish the character of the original structure.

We accomplish this by using a 'Sidecar' element in StoryMaps. Scrolling down the page presents a continuous feed of text and images on the left-hand side that discusses the history and changes to the complex over time, alongside independently created schematic maps to the right (Table 2). These schematics show outlines of past and present buildings that change while scrolling to illustrate changes to the layout of the block and some internal detailing.

While not dynamic, Table 2 provides a high-level overview of the phases of the museum detailed in the progressive timeline, with the schematic image and an exterior photo of the museum used in each stop along the way.

<table>
<tr><th>Date</th><th>Description and Photo</th><th>Schematic</th></tr>
<tr><td>1869-1930</td><td>Just after the abrupt decline of the whaling industry; the Candle Factory is no longer in operation and has a storage shed. The block is bisected by a short road.
</td><td>
</td></tr>
<tr><td>1930-1971</td><td>Following the NHA's acquisition of the factory. The shed had been taken off and the adjacent block was merged with the factory's block. Two buildings nearest the museum were demolished, but a new building was constructed behind it.
</td><td>
</td></tr>
</table>

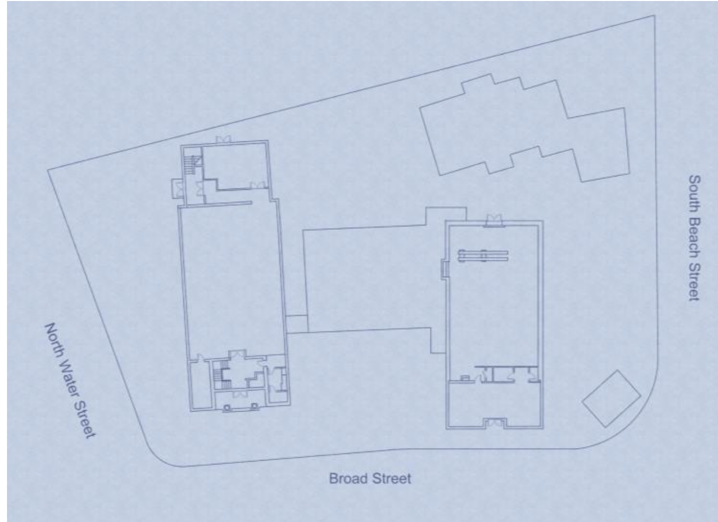
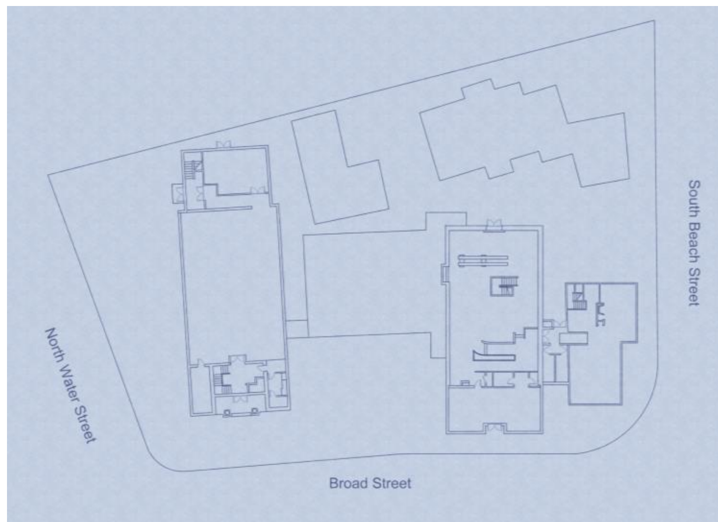
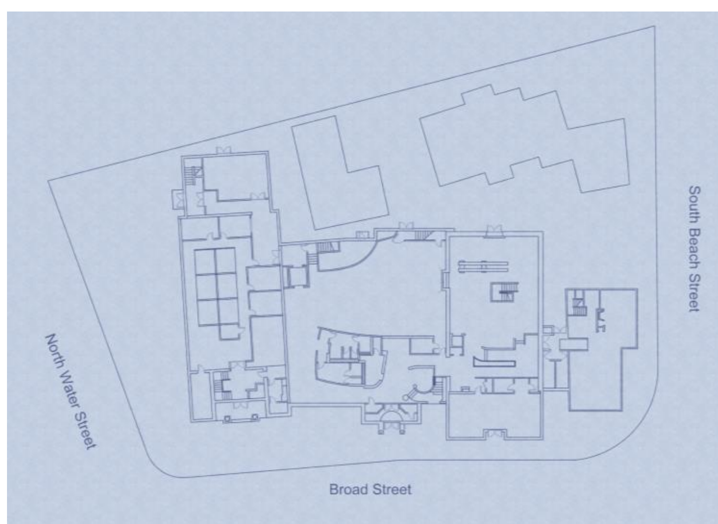
<table>
<tr>
<td>1971-1985</td>
<td>A third building was demolished to make way for the Peter Folger on the west side. An annex connected it to the factory. Around a decade prior, a Chamber of Commerce building was constructed to the southeast of the factory.
</td>
<td>
</td>
</tr>
<tr>
<td>1985-2000</td>
<td>The museum’s original gift shop, a space now occupied by the Discovery Center, was appended to the factory in place of the Chamber of Commerce building. The property now at 4 Whalers Lane was also built (just prior to 1975).
</td>
<td>
</td>
</tr>
<tr>
<td>2005-Now</td>
<td>After a period of construction, the museum reopened with an expanded central hub where the annex once was, including the new Gosnell Hall. The shop was moved into the factory, and the entrance and lobby were moved to the new structure.
</td>
<td>
</td>
</tr>
</table>

Table 2: Structure of the progressive schematic timeline with photos (nantuckethistory.org).

3. Looking Forwards: Sea Level Rise and Flooding Data

We present in-depth background on sea level rise and flooding to help users understand the need for mitigation strategies. SLR is not an easy concept to understand, so we begin by introducing some key terms in brief, such as mean higher high water, mean sea level, and NAVD88. We use visuals and simple explanations, such as those shown in Figure 32, to help 'lay audiences' better understand the data and basic concepts of relevance. We use this section to 'scare' the audience as well: graphs that show projections for the frequency of flooding events provide a strong sense of urgency. Figure 33 demonstrates this in our story map, where a graph, accompanied by a table summarizing its projections, is shown with text explaining the image to the user. This tells the user what to make of the data and what it precisely means for the Whaling Museum. This is an effective way of setting the scene without a need for excruciating detail.

Given many of our resources were connected to Easy Street projections, we calculated the difference in elevation from Easy Street to the Whaling Museum, using Chuck Larson's presentation and floor plans of the building showing elevation, to be around 2 to 3 feet. Having a reference point like Easy Street is helpful as many members of the on-island demographic are familiar with the location and are likely to have seen it flood.

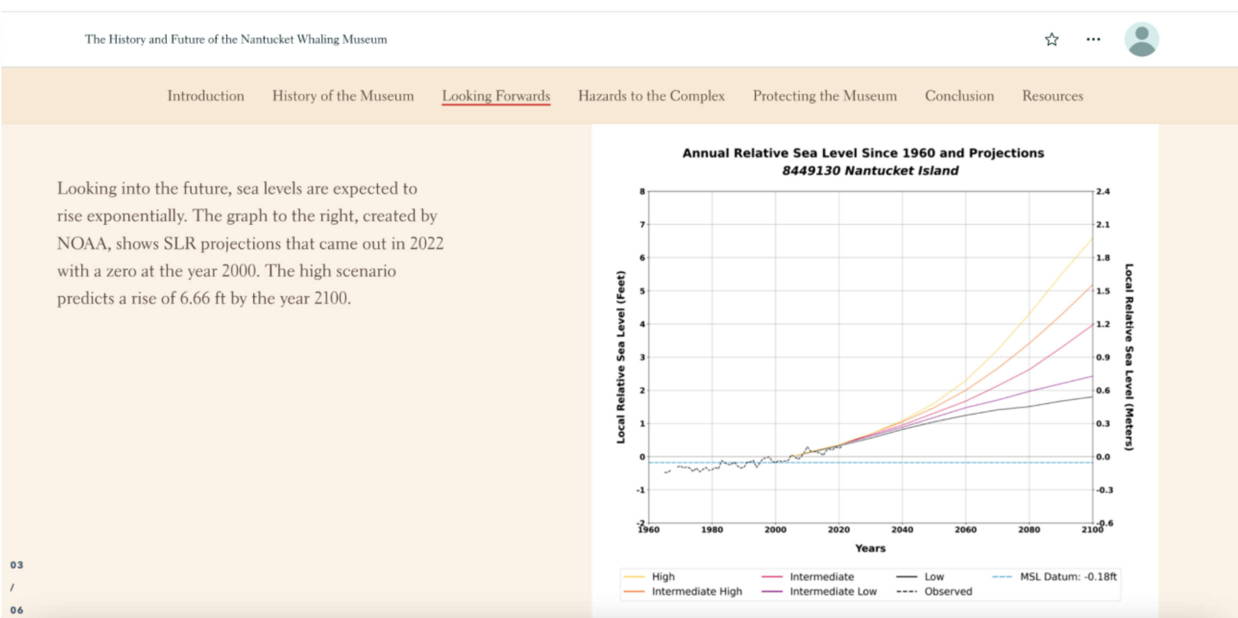


Figure 32: Screenshot of the SLR Section in the story map.

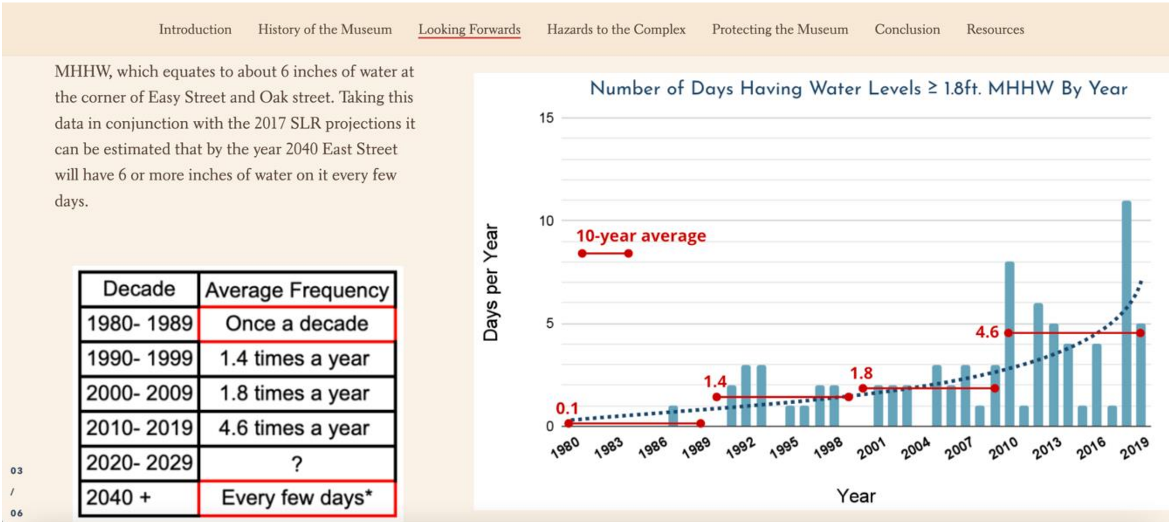


Figure 33: Screenshot of Easy Street flooding data in the Story Map

To emphasize the severity of future flooding, we use a NASA graph (Figure 34) that shows the number of days/year when flooding will be 39 inches above MHHW. We note that 39 inches above MHHW is about 4.7 ft. NAVD88. We include renderings from the University of Florida to illustrate that such flooding would reach Young’s Bicycle Shop on Broad Street (Figure 35). The combination of graphs, renderings, and simple explanations are intended to make seemingly abstract notions of sea level rise more real and the need for action more urgent.

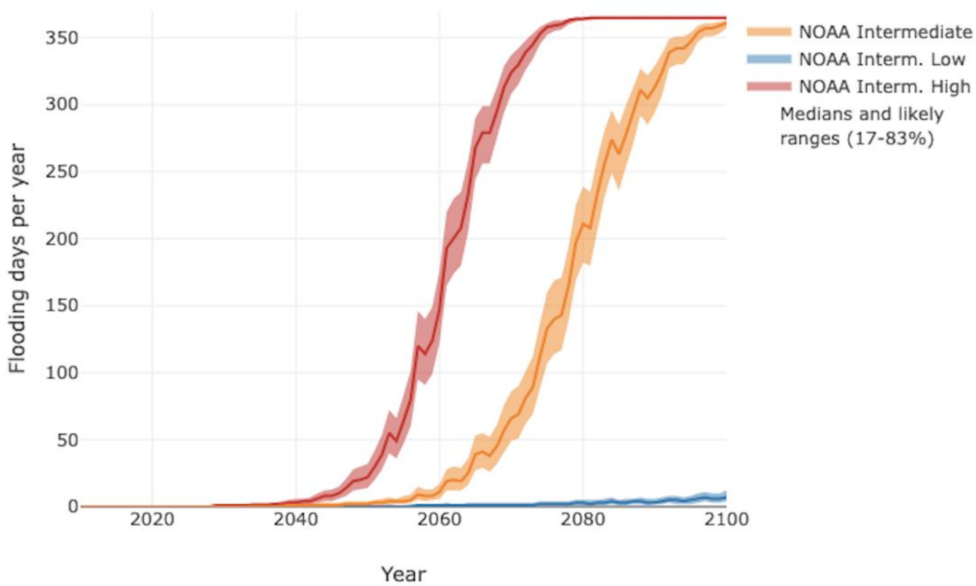


Figure 34: Number of days per year that sea level in Nantucket Island, MA is projected to exceed 39 in. above MHHW. (NASA)

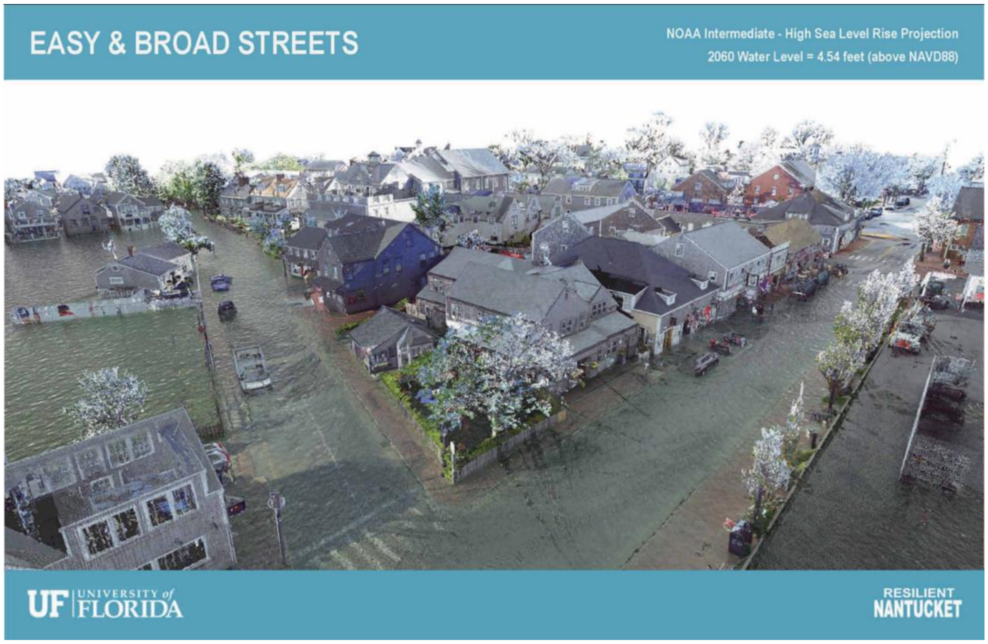


Figure 35: Rendering of Easy and Broad Streets (University of Florida, Resilient Nantucket, 2019).

4. Hazards to the Complex

The Candle Factory, a three-story brick and mortar structure, housed the Whaling Museum entirely within its walls between 1930 and 1978. As depicted in this 1968 rendering (Figure 36), the Candle Factory had open expanses to both the east and west.

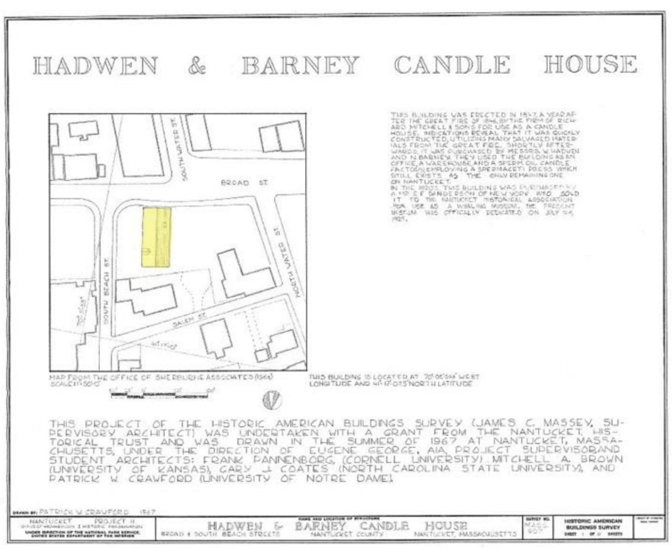


Figure 36: Top view rendering of the Candle Factory, 1968 (Library of Congress).

While the physical location of the complex is vulnerable to high tide flooding and storm surges in the future, most of the flooding at the Whaling Museum currently results from stormwater runoff from rooftops, driveways, lawns and streets during rain events. Stormwater runoff creates additional issues as it collects dirt, pollutants, bacteria, and pathogens before ponding in the lowest elevation points within the structure. Damp conditions pose hazards to the building and artifacts on display, including mold.

According to the *NHA Flood Resiliency Report and Capital Expenditure Forecast Plan* prepared in 2018 by McGrath Architecture, the area in front of the Hadwen & Barney Oil and Candle Factory is the most exposed location of the complex to both storm surge flooding and potential wind driven wave action (McGrath Architecture, 2018). The Candle Factory is already at risk for ponding as rainwater travels downhill on Broad Street towards the harbor. Fluctuations in groundwater can also affect flood water levels in this location, so there is an especially high risk of water infiltration in the building's lower level. Ground water levels are already very close to the surface in this location and sea level rise in the future is expected to exacerbate these problems as groundwater levels rise.

We created a schematic identifying the locations within the complex most jeopardized by pooling water and/or flooding as shown in Figure 37. On the story map, the user can click on or scroll to each waypoint to bring up a photo and description of the problems at that location as depicted in Figure 38. Table 3 provides a listing of the problems at these locations.

Figure 37: Locations within and around the Whaling Museum vulnerable to flooding.

Candle Factory	Discovery Center	Peter Foulger Museum
1. Elevator lift flooding 2. Groundwater intrusion through factory wall 3. Cold joint in theater 4. North elevation doorway flooding 5. Downspouts 11. Cracking due to Portland cement mixed with original lime	3. Toilets overflow due to overwhelmed sewer lines during storm events 7. Low drainage through pavement 9. Dated pipes 10. Foundation erosion	8. Cistern filling up 12. Electrical transformer box

Table 3: Story map hazard waypoints in/around the museum's three key structures.

Figure 38: Example of story map hazard description.

Ed Rudd guided our team on a walking tour and pointed out both the interior and exterior areas of the Candle Factory which are prone to flooding. The figures below aid in visualizing the areas exposed to damage. Figure 39 is the public elevator within the structure. This location frequently experiences flooding incidents with flood water pooling at the base of the elevator shaft, rendering the elevator inoperable. Figure 40 shows the damaged floor located on the base of the wall perpendicular to the elevator and Figure 41 provides a close-up view of the damage. For location reference on these areas, see Table 3.

Figure 39: Side view of elevator (Left: S. Turner) and base of elevator shaft (Right: E. Rudd).

Figure 40: Damaged wall adjacent to elevator door in Candle Factory (S. Turner).

Figure 41: Close-up of breaches in foundation behind current elevator shaft (E. Rudd)

In addition, because the exterior door located on the north elevation is often flooded, it remains protected by sandbags as a permanent installation as seen in Figure 42. From the interior view, one can see that if flood water were to breach this door, the water would flow down the steps to the lower elevation. While it appears that an internal flood gate might easily alleviate seeping water, it may be viewed as an obstruction and therefore a violation of fire codes.

Figure 42: North exterior and interior (respectively) of Candle Factory back door (S. Turner).

The toilets in the bathrooms located within the connection hallway between the Candle Factory and the Discovery Center typically overflow after a heavy rain event or storm surge when the township sewer lines get overwhelmed. These bathrooms are positioned at the top of a downward sloping ramp, and as a result when the toilets overflow water runs into the lower level of the Candle Factory. Figure 43 shows this downward sloping walkway.

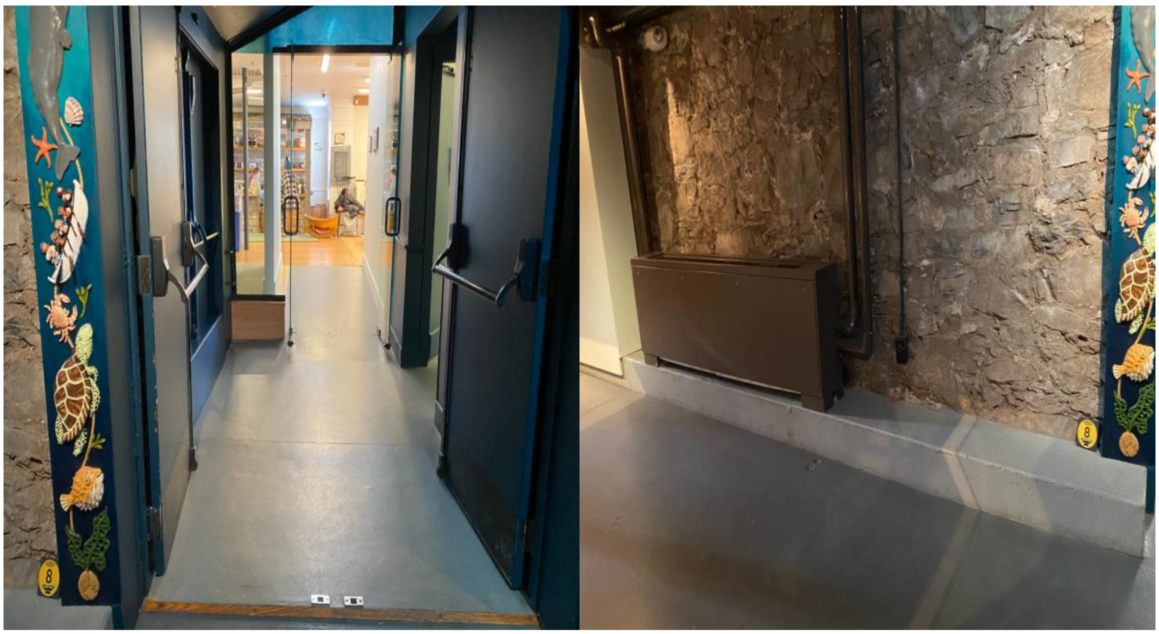


Figure 43: Connection hallway between Candle Factory and Discovery Center where toilet overflows from storm surge and travels downward slope. (S. Turner)

5. Current Measures Taken

According to information provided within the 2018 Flood Resiliency Report & Facilities Capital Expenditure Forecast Plan, flood barriers were positioned at the doors to the connecting structures, by the south facing gift shop entrance, as well as the south elevation doors (McGrath Architecture, 2018). Floodproofing strategies used within the Candle Factory include not only these barriers at connecting doorways, but also sandless sandbags, flood sacks, wet vacs, flood response kits, and employee training to ensure proper implementation of these tools in emergency situations. According to Ed Rudd, the NHA is still working on implementing the corrective measures suggested by McGrath Architecture in the 2018 *NHA Flood Resiliency Report & Facilities Capital Expenditure Forecast Plan* including a new shed roof installation at the Gift Shop connector, dry proofing the slab floor of the Candle Factory, and reconnecting the subterranean storm water drains along the perimeter of the building to the downspouts that empty directly onto the sidewalk of the Candle Factory (McGrath Architecture, 2018). A conservation measure currently benefiting the Nantucket Yacht Club dormitories includes cisterns to capture all the water from the roof, which is then used to irrigate the grounds. The NHA may opt to consider a similar system that could utilize captured water as gray water for toilets and irrigation.

6. Potential Mitigation Strategies

We separate potential mitigation strategies into categories of short- (by 2030), medium- (2050-2070), and long-term (2100+) solutions and adaptation strategies. While these intervals are not contiguous, they are based on the time frames used by the Coastal Resilience Plan which we continued to use to maintain uniformity with the shared primary source data. These suggestions are offered for the NHA's consideration, but they are not a comprehensive list of all available options. This team drew upon our research and the standards discussed within the NPS Guidelines for Flood Adaptation discussed in Section 7 of this report, which included resiliency, adaptations, and treatments ranging from temporary protective measures, landscape adaptations, dry floodproofing, wet floodproofing, filling the basement, and elevation. Interested parties are best advised that the choice, timing, and fine details of these strategies will require extensive engineering and architectural research that is beyond the scope of this project.

<u>Possible Short-Term Strategies (by 2030)</u>

The NHA, in its mission to preserve and protect the Whaling Museum from the effects of flooding and sea level rise, is controlling flooding events effectively with temporary protective measures. Within this short-range interval, most of the flooding issues are expected to be tied to surface water runoff from rainstorms. The continued utilization of temporary protective measures throughout the Whaling Museum complex, which currently includes wet vacs, sandbags, flood sacks, flood gates, and sump pumps can, while somewhat labor intensive, continue to regulate water issues for the immediate short term. Additionally, there are some possible landscape adaptations worth considering, including installing rain gardens, planter boxes, bioswales, and vertical vegetation to aid in absorption and may reduce the energy of water against the structures in the complex. One wet floodproofing strategy worth mentioning that may be pursued in the short term is the inspection and evaluation of the wall and foundation strength of the Candle Factory. Keeping informed on the integrity of the structure will allow the NHA to pursue proactive corrective measures as needed.

By consistently striving towards reducing its flood risk in the museum complex, the NHA may contemplate supplementing its current dry floodproofing measures of flood gates and sump pumps within the Candle Factory. One method would be to ensure that the downspouts are clear of debris and draining away from the foundation throughout the complex. The NHA may also consider deliberating the benefits of installing either backflow valves or installing flood gates in lower elevation toilets in Candle Factory. Additionally, wrapping the foundation in an adhesive waterproofing membrane along areas that collect water prior to a storm event is another dry floodproofing option to consider. The NHA may also want to investigate the use of temporary flood barrier systems. These are removable stop log-style barriers that act as a continuous floodwall. Such a system allows 10-foot sections to be easily deployed by one person, can be configured to any shape, and leaves a completely flat surface when disassembled (Figure 44).

Figure 44: Example of a multi-panel flood barrier system with modular components (floodbarrier.com).

While observing each of the elevations of the Candle Factory, we noticed a great deal of cracking, spalling, and possible efflorescence of brick along with some damaged mortar joints, all of which would greatly impact the preservation and resiliency of the structure in the face of SLR. After discussing this with Ed Rudd, we learned that the entire structure was repointed sometime during the 1980s, and the significantly damaged east elevation was repointed in spots around 2004. Upon further research, most of the construction through the early 20th century masonry used lime as the binding agent in the cement.

The most appropriate mortar to use in repointing historical structures is Type K lime mortar which is composed of 1 part Portland cement, 4 parts lime putty and 15 parts sand (gobrick.com). This type of mortar is softer, flexible, and permeable, allowing adequate moisture movement through the lime (evaporation of both water vapor and liquid water). Additionally, lime reacting with carbon dioxide in the atmosphere generates a self-healing, or autogenous, healing characteristic where limestone will seal cracks and fill voids in the mortar. Using an incorrect mortar type or one with a higher ratio of Portland cement to lime putty to sand ratio will be stronger in compressive strength than the bricks themselves and create stresses in the wall caused by expansion and contraction, and moisture will be trapped. Figure 45 below provides a visualization of the differences that lime and cement mortars have on moisture within a structure. Because mortars with a higher ratio of Portland cement trap moisture, the bricks become the most permeable part of the wall suffer the impacts of cyclical frosting and thawing actions that cause spalling and salt-induced decay that can cause efflorescence.

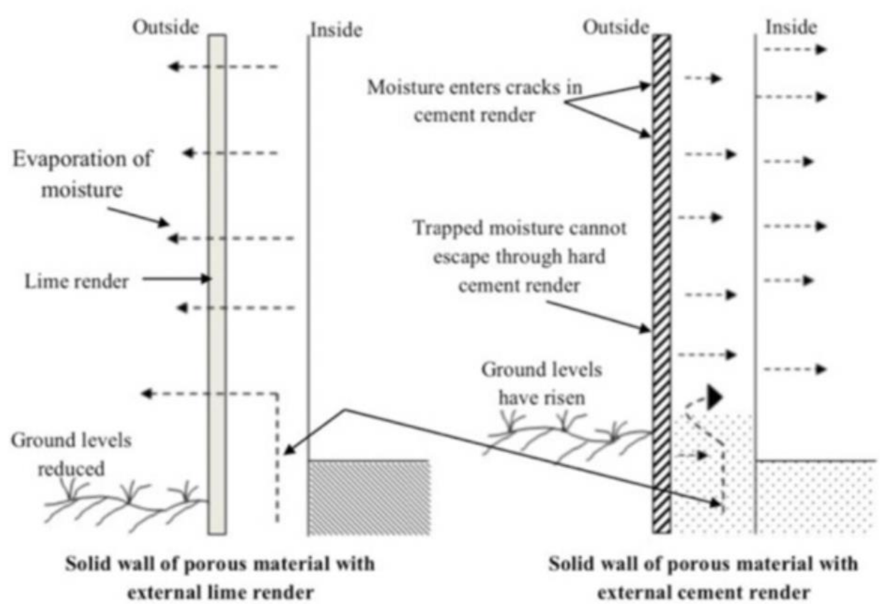


Figure 45: Visualization of the differences that lime and cement mortars have on moisture within a structure (roundtowerlime.com).

Upon inspection of the Candle Factory, it is likely that a mortar with a higher ratio of Portland cement may have been used for repair and restoration work based on the cracking, spalling and possible evidence of efflorescence of the bricks under the second level windows as depicted below in Figure 46. Another possibility is that an incorrect grade of Natural Hydraulic Lime (NHL) was used or that the NHL mortar was not cured properly. There are different grades of pre-mixed Natural Hydraulic Lime (NHL) mortars that can be used for historical restoration, but the curing process is different among the grades. While working with NHL mortars, it is important to allow the mortar to slow damp cure over a period of a few days of high humidity (or by misting the mortar with water over a period of a few days); the walls should be protected from high winds, direct sunlight, heat, and covered with damp burlap. Disregarding the proper steps in the NHL curing process will have a detrimental effect on the preservation of the masonry. As such, the NHA may wish to investigate having the mortar joints on the Candle Factory cleaned, repointed with the appropriate NHL grade based on the original mortar properties, and slow damp cured to minimize any potential for future water penetration through the masonry and to minimize irreversible brick damage. In keeping with the directives of the NPS and the Nantucket Historic District Commission (HDC), any repair and renovation of historic buildings should be sympathetic and compatible with other materials in the structure.

Figure 46: Possible efflorescence of bricks beneath the second story windows of the south elevation (left), and enlarged photo of cracked and spalled bricks (Right) (S. Turner).

Possible Mid-Term Strategies (2050-2070)

As time passes and the effects of climate change on the Whaling Museum become more apparent over the next 20 to 60 years, the NHA may look to the NPS recommendations for guidance in appropriate treatments. Mid-term timeline strategies may continue to include the previously mentioned temporary protective measures in some proportion. If landscape adaptation was previously employed, the vegetation should be mature enough during this interval to help protect the foundation from water and debris impact. Dry floodproofing windows and doorways below the base flood elevation with temporary closures may also be an option for the NHA to investigate during this time frame. Proactively monitoring and maintaining the integrity of the masonry can also be a treatment that the NHA might keep at the forefront of tasks. Alternately, given that there is extensive brickwork on the bottom of the building, the NHA may decide to investigate the use of a silicone-based brick sealant like a silane-siloxane hybrid to penetrate the bricks and still provide water repellency. A 2017 research study which tested silane-siloxane resins for use in the conservation of historical limestone concluded that "the higher hydrophobic and protection properties for silane-siloxane dilutable with organic solvents indicate it can be selected as a more suitable candidate for conservation and protection for cultural heritages" (Ershad-Langroudi et al., 2017). Depending upon actual sea level data trends toward the latter part of the mid-range interval, the NHA may also contemplate anchoring the buildings within the complex to their foundations to prevent movement and structural collapse.

In the first several years of this mid-term range, the NHA may explore implementing wet floodproofing of the Candle Factory floor. Via elevating the floor by several inches at the base of the structure, extra base height could be created to allow water to flow safely beneath the exhibit space and the water would then be removed via sump pumps. Another idea to consider is to implement modifications by removing everything from the floor and reconfiguring the displays as floating exhibits. In this way, the museum staff is afforded the capability to hoist them to higher levels if necessary. As these decades elapse and work under the premise that storms will be more frequent and intense within this time span, the NHA may decide to consult future SLR projections to determine if action needs to be accelerated and explore potential next steps.

The NHA has also acquired the property of 4 Whalers Lane located just behind the Whaling Museum. This building could give the NHA the opportunity to build a new raised structure in its place with SLR resilience in mind. In building a new structure, its aesthetic must still be in-line with the already existing museum and follow HDC guidelines. Having this space could give the NHA upwards of another 1,500 square feet to use. Within it, they could relocate much of what is in the basement of the Candle Factory to allow for wet floodproofing, though certain stipulations must be kept in mind. In areas where flooding events are likely to exceed 24 hours, caution must be taken that any components of the building below the flood risk level can withstand the resulting hydrostatic forces, and suitable ventilation for drying after a flood event exists (NPS, 2021). If the Candle Factory meets the requirements for wet floodproofing it could be cheaper and easier to execute than dry floodproofing.

Another possible mid-term strategy in reducing the risk of flood water damage to the Candle Factory involves the adaptation of another NHA property, the Discovery Center, which is connected to the Candle Factory but not a historical building. The Discovery Center is a frame structure and not constructed with brick and mortar; while it has not experienced any interior flooding, it has suffered damages against the exterior foundation as evident in Figure 47. Flood waters can also infiltrate the courtyard of the complex due to a dip in the block wall. Located on the corner of Broad Street and South Street, the building rests at the lowest part of the property.

Figure 47: Floodwater damage on the foundation of the Discovery Center (left) and dip in block wall rear yard (right) (S. Turner).

Ideally if the Discovery Center structure were to be elevated, the ground under the raised structure could be excavated and have a flood water collection cache installed. A new drainage infrastructure for the museum complex could then be designed. While the installation of a floodwater storage reservoir may prove useful, it is likely that this may violate the current

Wetland Protection Regulations from 2013 (nantucket-ma.gov, 2013) and would need to be approached carefully. This modification may also be disputed by the Conservation Commission as the location is subject to coastal storm flowage and may jeopardize the water quality of the area. As a more palatable alternative, a modified bio-infiltration basin could be excavated with the ability to capture and absorb flood water. In either scenario, the grounds of the Candle Factory could be re-graded and pitched toward the depressed area, with downspouts from the Candle Factory also draining towards the depression. The land behind the Discovery Center building could also be re-graded, reducing the ever-present moisture on the ground. Utilizing this in addition to a flood barrier system could eliminate flooding issues to the museum buildings.

<u>Possible Long-Term Strategies (2100+)</u>

One potential long-term adaptation that can be considered, although extremely cost prohibitive, would be to elevate the Candle Factory onto a new foundation and allow water to flow underneath. As per the NPS, there are several factors that require consultation with professionals to identify this feasibility. Factors such as the topography, shape, and size of the lot, placement, building footprint, massing and form with the existing width to height ratio, the number of floors, and construction type need to be evaluated (Eggleston et al., 2021). If it is determined to be a feasible project, this adaptation would legally require a ramp that does not exceed an 8.33% slope or an elevator to comply with the Americans with Disabilities Act. Another cost-prohibitive option that would be applicable only as a long-range strategy would be to retrofit the building on a buoyant foundation. A buoyant (or amphibious) foundation allows a building to rest on the ground until a flooding event occurs. As the water level rises, the building can float using vertical guide-posts and a buoyant structural subframe before lowering back down to the exact original foundation position when the flood waters recede. This adaptation would also require the evaluation of the factors previously discussed.

Under certain circumstances, the NHA of year 2100 may be tasked with considering the relocation of the building so that it may guarantee the preservation of the Candle Factory for future generations. While this is not a favored option at this time, it may become a necessary consideration contingent upon increased storm intensities, frequencies, and sea level rise. The NHA also has a long time horizon to plan and raise funds for such a contingency.

To elucidate the possible strategies that were previously discussed within the StoryMaps, we created an illustration utilizing the side car function for each of the time intervals as exemplified in Figure 48 below.

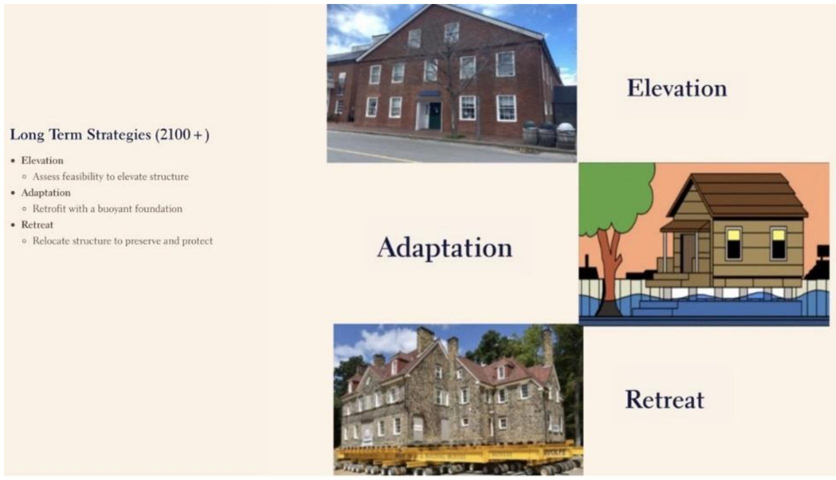


Figure 48: Example of StoryMaps 'Sidecar' component.

7. Unintended Consequences

As many private property owners in coastal communities begin to grapple with ways to protect their assets from flood damage in the face of sea level rise, it is critical that they are cognizant that local government and state agencies are doing the same. In Nantucket, one of the strategies proposed by the Coastal Resilience Community Planning for the downtown area is to raise many roadways. Given the fact that the curb line of the Candle Factory is already very low on the corner of the southwest elevation, the raised roadway might cause floodwater to flow directly toward the building. While the regrading of the pitch and slope of the roads may ease the burden on the storm sewer infrastructure, the NHA will need to keep the resilience plan of the local government in mind when determining any capital investment on its historic properties. The NHA may be hesitant to utilize a larger scale flood barrier method around the perimeter of its property so as to not overburden neighbors with additional water pooling, as this strategy and similar would require close cooperation between a number of stakeholders. While global efforts in slowing the rate of climate change are helping, they are far from a guaranteed solution. It is thus imperative that immediate steps are taken to safeguard Nantucket's history while policymakers and building owners have the time and foresight to do so.

Conclusions

Like other communities on the East Coast, Nantucket faces a growing threat from sea level rise and flooding. Downtown Nantucket is particularly vulnerable, as detailed in the Coastal Resilience Plan (NCRAC, 2021), given the density and historic value of many buildings. Historic buildings pose special problems for flood adaptation, which is why the NPS has developed detailed adaptation guidelines. The Whaling Museum and adjacent NHA buildings pose a particularly difficult problem regarding adaptation strategies. The Candle Factory is an iconic, historic brick building that cannot easily be protected by typical means of floodproofing, nor is the option of elevation or retreat especially feasible given the technical difficulties, extreme costs, and historic implications.

With the threat of sea level rise becoming more of a reality, businesses, town officials, and residents are struggling to come to terms with what that means for the future of Nantucket. The story map is a tool to help NHA staff, volunteers, and board members begin to think about short, medium, and long-term strategies. As per the Association’s specifications, the story map is designed as an educational tool with a depth of information; using the NHA’s archives and resources, we assembled a strong interactive map containing detailed schematics of the museum's infrastructure throughout its lifespan. In doing so, we established a sense of perspective on where the museum lies on the island relative to the sea, the vulnerabilities that have manifested in its historic Candle Factory, and the challenges the entire complex faces as a consequence of both.

Beginning with the history of the Whaling Museum, our story map shows how vastly the museum has changed over the past 150 years, and includes projections to show that even more change in the future will be warranted as a response to sea level rise. Alongside historic photos, we use a schematic that progresses with time to demonstrate past changes to the property. Additionally, we present options that the NHA can take to protect the museum moving forwards. These are separated into time-framed categories of short- (by 2030), medium- (2050-2070), and long-term (2100+) solutions and adaptation strategies. While these intervals are not contiguous, they are based on the time frames used by the Coastal Resilience Plan which we continued to use to maintain uniformity with the shared primary source data. The strategies presented in the story map were taken and adapted from documents such as *Floodproofing Non-Residential Buildings* (FEMA, 2013), *Nantucket Resilience Design Standards* (*Resilient Nantucket*, 2021), and the NPS *Guidelines on Flood Adaptation for Rehabilitating Historic Buildings* (Eggleston et al., 2021).

Short-term strategies reflect low-to-moderate cost wet and dry floodproofing measures that deal with moderate flooding such as the Whaling Museum has seen and will continue to see. Most of this flooding is from storm runoff, backup of water systems, and groundwater breaching through the floor. Medium-term strategies are generally more expensive and are designed with more extreme flooding in mind. More extreme flooding includes both height of the water and frequency as SLR continues to increase. Finally, long-term strategies are designed for the most extreme scenarios based on NOAA SLR projections. These are the most expensive and disruptive to the property, and are especially difficult to implement given their respective engineering challenges along with the historic significance of the Candle Factory. While these strategies would see implementation only far into the future, planning for them now is critical to assure that this historic property becomes more resilient.

Recommendations

Use of the ArcGIS Story Map

The Nantucket Historical Association may implement our ArcGIS story map in any number of ways to present the history, the present state, and the future prospects of the Whaling Museum, and to inspire educated action toward preservation. In particular, we hope that the story map can serve the NHA as a tool to raise awareness in the following areas:

- It may serve NHA staff, volunteers, and members of the board by demonstrating how the properties of the Whaling Museum have had major changes over the course of its history and will continue to change in response to SLR. In doing so, it will teach that adaptation measures are not to be feared and will be key to the building's preservation.

- It may serve as a conversation starter for preservation planners, particularly those grappling with SLR: rising tides have already shown significant effects on Nantucket and these are only projected to get worse as time goes on. The Whaling Museum, being in a high-risk area will see the forefront of these threats in the future. Strategies for short, medium, and long term adaptations in response to increased flooding are topics of discussion for the NHA and may prompt similar discussion for sites across the island.

- It may serve as a brief case study on flooding and resilience for additional parties interested and affected by SLR, such as neighbors, town officials, residents, and visitors.

- It may serve as a shorthand reference for the NHA utilities team on present water vulnerabilities within the museum, particularly those affecting the Candle Factory, and bring attention to correcting or otherwise safeguarding them through future work.

- It may serve as a high-level overview to be used by planners and museum directors during future museum adaptation efforts, expansion, or renovations. As a reminder of hazards in the near and far future, this map can guide large-scale decisions about ways to modify the museum towards those which are sustainable and most effective at protecting the museum's valuable artifacts for posterity.

- It may serve, at the Association's discretion, as a publicly-available online resource or exhibit to educate broader audiences about the dangers of sea level rise using the museum as a real-world example and powerful focal point.

- It may serve as a strong primer for contractors and other workers making adjustments to the museum or performing regular maintenance going forwards. In this context, it can provide historical background and an overview of many specifics and vulnerabilities of the building in short order; this information would ensure that construction work proceeds in a resilience-conscious way, and, as an added benefit, that the historical intricacies of the building are respected when selecting building materials and construction techniques reducing the chance of damage to the building or its character.

Possible Adaptation and Resiliency Options for the Whaling Museum

As part of our research into potential mitigation strategies with the goal of stimulating discussion within the NHA, we identifited several resilience pathways the organization may consider investigating, all of which are derived from the standards of applicable flooding treatments outlined by the NPS. These include temporary protective measures, landscape adaptations, dry floodproofing, wet floodproofing, basement and foundation modifications, and elevation. As climate change volatility and SLR projections portray a grim future for Nantucket, the NHA is proactively gathering data on how to best protect the Whaling Museum complex on Nantucket. While the year intervals mirror those used in the Coastal Resiliency report and are in no way hard dates, the NHA may consider implementing any of these treatments if they see fit.

Short Term Strategies (by 2030)

- Green Infrastructure: Consider installing landscape adaptations
    - Ex: Rain gardens, planter boxes, bioswales, and vertical vegetation
- Wet Floodproofing: Inspection and evaluation of wall foundation strength of Candle Factory
- Wet Floodproofing: Wrapping adhesive waterproofing membrane along areas that collect water prior to storms
- Dry Floodproofing: Use flood gates and sump pumps within the Candle Factory

- Dry Floodproofing: Ensure downspouts are clear of debris and draining away from the foundation
- Consider the benefits of installing either backflow valves or installing flood gates in lower elevation toilets
- Evaluate the integrity of masonry work; repoint using appropriate grade hydraulic lime
- Elevate and rebuild the property on 4 Whalers Lane

Because most of the present-day flooding is a result of storm events and surface runoff from roofs, the short-term strategies will continue to be effective in mitigating water issues. These are presently urgent as they address flooding the NHA is already grappling with and will see more frequently in the future. Having mostly low to moderate costs, these options could be implemented with relatively little time spent planning.

Medium Term Strategies (2050-2070)

- Dry Floodproofing: Examine the structural integrity of the masonry
- Dry Floodproofing: Consider anchoring the Candle Factory to its foundation to prevent shifting or collapse
- Dry Floodproofing: Applying a waterproof coating on the foundations of each structure within the complex that is compatible with the historic masonry of the buildings
- Wet Floodproofing: Create an elevated floor by several inches in Candle Factory to allow water to run underneath
- Using a silicone-based brick sealant on the interior and exterior exposed masonry
- Elevation of the Discovery Center, making the first four feet waterproof

The implementation of medium-term solutions is when more significant changes to the museum infrastructure come into play. Based on NOAA projections, the museum will begin to exhibit severe effects from SLR and the exterior of the Whaling Museum will be at substantially higher risk than it will have been in the short-term phase. The NHA may want to consult with material scientists to develop pertinent solutions in addition to those presented here.

Long Term (2100+)

- Elevate the Candle Factory onto a new foundation and allow water to flow underneath

- Retrofit the Candle Factory on a buoyant foundation
- Relocation of the Candle Factory Building

Long term solutions can be the hardest to envision and accept. Not only are they very expensive to execute, but imagining the relocation of the Candle Factory and museum will be difficult for many people to contemplate; indeed, one of the challenges facing the NHA is a certain sense of denial among many of its stakeholders. While many current NHA staff may never see these types of strategies actually implemented, it is critical to begin conversations about these realities in the present in order to assure the ultimate preservation of the museum.

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Appendix

<u>Ellis Island and Liberty Island- Heritage Case Study</u>

Many of our national historic treasures are at imminent risk of irreparable destruction due to the effects of climate change. Until 1954, immigrants arrived by boat to New York Harbor to be processed through Ellis Island, the port of freedom for millions looking for a better life in America. Liberty Island, located about one half mile away from Ellis Island, is home to America's 'beacon of promise', the Statue of Liberty (Figure 49). Home to iconic symbols and irreplaceable artifacts where the ancestors of countless millions first set roots in the United States, these islands are only accessible by ferry and both face the bleak possibility of being lost to flooding and rising sea levels. This became acutely evident in the wake of Superstorm Sandy.

Figure 49: Photo on left- satellite image of NY Harbor (NASA)
Top right photo - Ellis Island Main Hall on left (NTHP)
Bottom right photo - Liberty Island (NPS)

Normally, parts of Ellis Island experience chronic flooding, while the rest of the island is subjected to occasional flooding. On Ellis Island, the storm surge from Superstorm Sandy destroyed the electrical heating and cooling systems located in the basement that supported all the inhabited buildings on the island. Over 1 million temperature and humidity controlled artifacts needed to be relocated to a climate controlled facility (UNESCO). The National Park

Service repaired and stabilized approximately 6,000 feet of seawall that surrounds and protects Ellis Island. The work involved major repairs to the granite and concrete that comprise the walls. In addition to these repairs, the project added reinforcement on the land and water sides of portions of the island to further stabilize and strengthen the wall. Lastly, the project replaced the timber pile fender system and made other repairs to the ferry slips (NPS.gov).

Superstorm Sandy deluged Liberty Island and more than 75% of the land was flooded, although the pedestal and Statue of Liberty itself were not harmed. The facilities and infrastructure sustained extensive damage. The electrical systems were repaired and raised 20 feet above sea level. The lighting system was refitted and is now housed above the established flood risk level. A 300 foot dock was replaced, 54,000 paving blocks were replaced, 2000 feet of granite rock perimeter and 450 feet of railings were repaired (Figure 50) (NPS, 2013).

Figure 50: Ellis Island (left) and Liberty Island (right) post Superstorm Sandy (NPS 2013).

A 2015 vulnerability analysis carried out by the US National Park Service on its coastal properties concluded that 100% of the assets at Liberty National Monument are at “high exposure” risk from sea-level rise due to the extremely low elevation of the island and its vulnerability to storms. The assets at risk on Liberty and Ellis Islands, including the Statue, come out to more than US $1.5 billion (Peek et al. 2015). The National Park Service has estimated that repairs and restoration on both islands already exceeded $100 million.

The destruction inflicted by Superstorm Sandy upon these two heritage sites are alarming examples of the fate that awaits other historically significant sites like the Whaling Museum complex, due to flooding, storm surges, and sea level rise. The NPS handbook *Guidelines on Flooding Adaptation for Rehabilitating Historic Buildings* (Eggleston et al., 2021) outlines acceptable rehabilitative, protective, and adaptation methods.