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CLIMATE CAFE

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Saturday, April 10, 2021
3 PM

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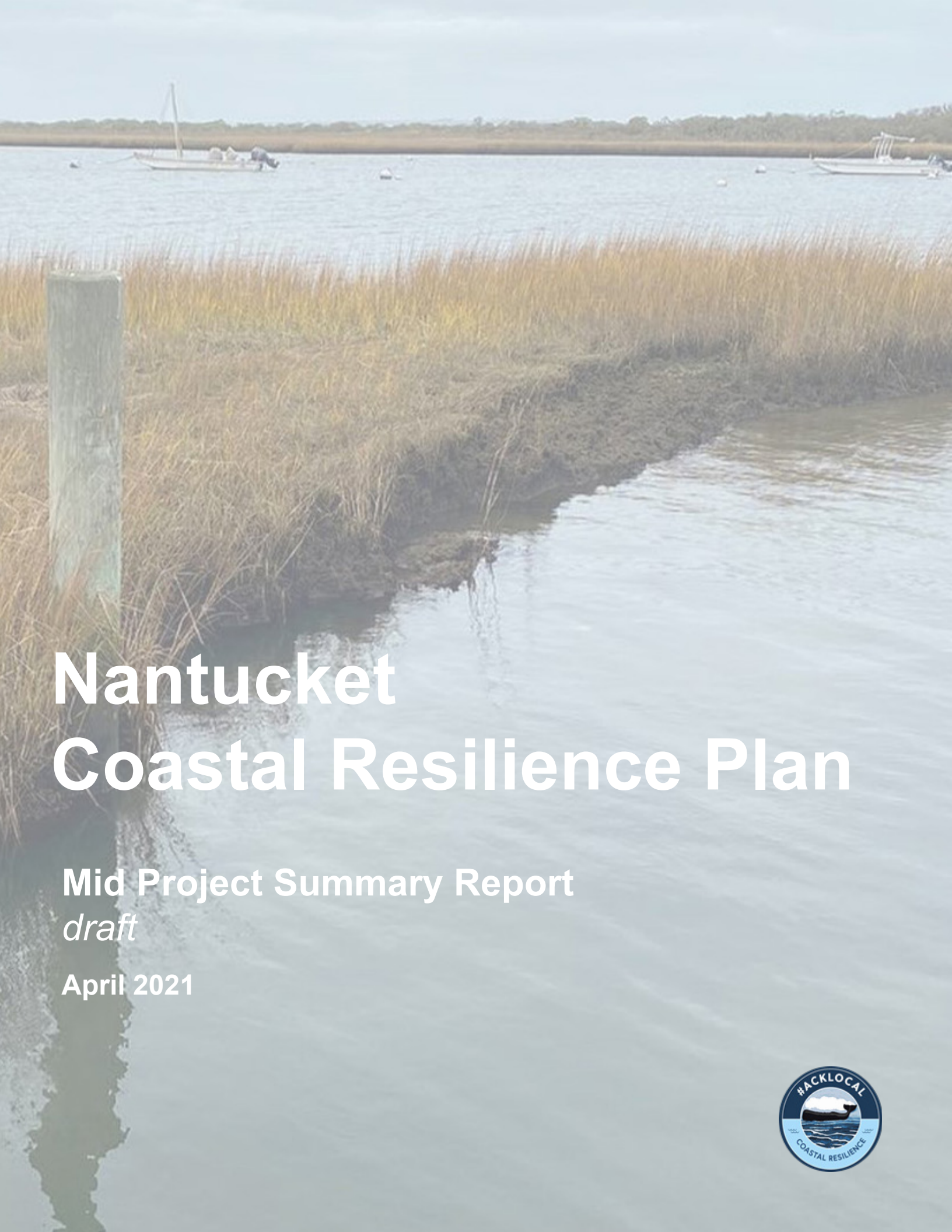

Nantucket Coastal Resilience Plan

Mid Project Summary Report

draft

April 2021

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DRAFT

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Acronyms and Abbreviations

ACS – American Community Survey

ADCIRC – Advanced Circulation Model

AEP – Annual Exceedance Probability. The probability of a flood event occurring in any year. The probability is expressed as a percentage. For example, a large flood which may be calculated to have a 1% chance to occur in any one year, is described as 1% annual chance or commonly the 100-year flood event.

ASCE – American Society of Civil Engineers

BLS – Below Land Surface

CRB – Community Resilience Building

CRP – Nantucket Coastal Resilience Plan

Exposure – Situation of populations, property, ecological resources, infrastructure, or other assets within hazard-prone areas.

FAA – Federal Aviation Administration

FDC – Flood Design Class

FEMA – Federal Emergency Management Agency, primarily responsible for disaster response and recovery following Federal declared state of emergency.

FIRMS – Flood Insurance Rate Maps. The official map of a community on which FEMA has delineated both the special hazard areas and the risk premium zones applicable to the community.

FIS – Flood Insurance Study. A compilation and presentation of flood risk data for specific watercourses, lakes, and coastal flood hazard areas within a community. When a flood study is completed for the National Flood Insurance Program, the information and maps are assembled into an FIS

GIS – Geographic Information System

HDC – Historic District Commission

HMP – Hazard Mitigation Plan

HVRI – Hazards & Vulnerability Research Institute

MC-FRM – Massachusetts Coastal Flood Risk Model, a dataset developed for the Massachusetts Department of Transportation to assess coastal flood risk to transportation systems at risk to future sea levels and coastal storms. Considered Best Available Flood Hazard Data for coastal Massachusetts.

MHC – Massachusetts Historical Commission

MHHW - Mean Higher High Water, or the average of the higher high-water height of each tidal day observed over the National Tidal Datum Epoch.

MMHW – Mean Monthly High Water, or the average of all monthly maximum tidal high-water heights in predicted astronomical tide levels.

MVP – Municipal Vulnerability Plan

NACCS – North Atlantic Coast Comprehensive Study

NHESP – Natural Heritage & Endangered Species Program

NOAA – National Oceanic and Atmospheric Administration

NRTA – Nantucket Regional Transit Authority

PIN – Preservation Institute Nantucket

Projection and Scenario - According to the International Panel on Climate Change (IPCC), in general usage, a projection can be regarded as any description of the future and the pathway leading to it. However, a more specific definition for the term "climate projection" is used by the IPCC when referring to model-derived estimates of future climate. A “scenario” is a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold. A projection may serve as the raw material for a scenario, but scenarios often require additional information (e.g., about baseline conditions). A set of scenarios is often adopted to reflect the range of uncertainty in projections. (IPCC)

RCP – Representative Concentration Pathway, or scenario estimating future concentrations of greenhouse gases used by the Intergovernmental Panel on Climate Change (IPCC).

SLR – Sea Level Rise

SOP – Standard Operating Procedure

SoVI – Social Vulnerability Index

Subsidence – Gradual settling or sudden sinking of vertical land surface elevation, exacerbating the effects of sea level rise.

UNSWAN – Unstructured Simulated Waves Nearshore

USACE – United States Army Corps of Engineers

USC – University of South Carolina

USGS – United States Geological Survey

WWC – Wannacomet Water Company

1 Introduction and Executive Summary

1.1 The Nantucket Coastal Resilience Plan

Launched in Fall 2020, the Nantucket Coastal Resilience Plan (the “Nantucket CRP” or “CRP”) is a crucial step in the Town and County of Nantucket’s process of preparing for and adapting to the combined threats posed by sea level rise, coastal flooding, and coastal erosion. The CRP will provide a comprehensive plan for building resilience to and reducing risk from flooding and erosion along Nantucket’s coastline. The process will involve analysis of risk and vulnerability across the island, examination of a range of coastal protection options, and recommendations for new policies and investments in nature-based and grey infrastructure. The CRP will provide detailed implementation guidance for projects recommended for the coming 10 years, as well as details on longer-term adaptation pathways. Throughout the process, the Project Team, led by the Town of Nantucket Natural Resources Department and Coastal Resilience Advisory Committee, will work in close partnership with the Nantucket community and other groups committed to advancing coastal resilience on Nantucket.

Scope of this Document

This report, delivered in April 2021, documents the status of the project at its mid-point. Specifically, the report provides an overview of existing built, social, and environmental conditions of the island; the findings of the community engagement process undertaken to this point for the CRP; and the island-wide coastal risk assessment. The report draws on a range of prior Town-led plans and studies, data from Town departments and State agencies, significant input from the Nantucket community, and comprehensive analysis of the risks that coastal hazards will pose to Nantucket over the coming decades.

Project Area

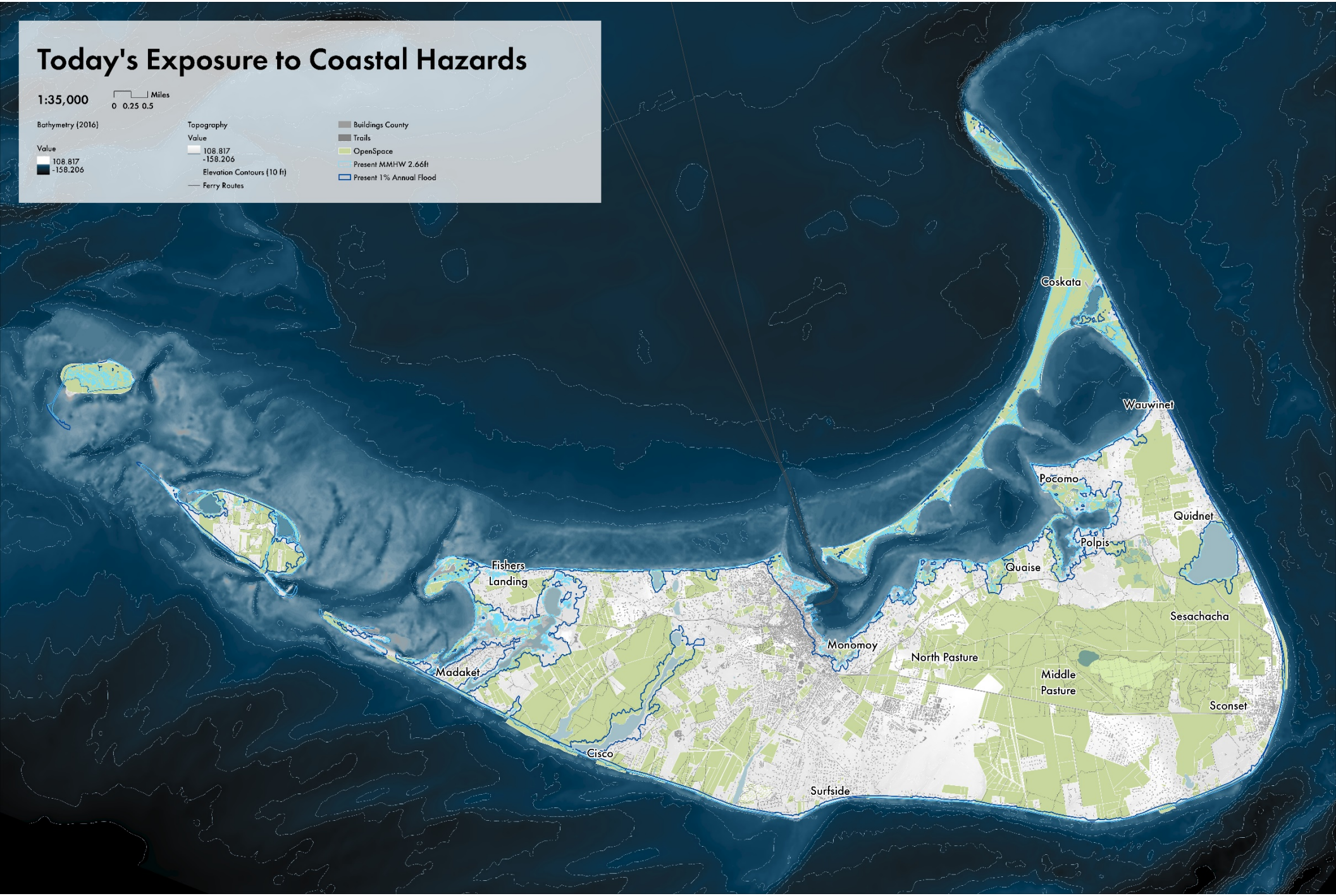
Nantucket County consists of Nantucket Island and its sister islands of Tuckernuck and Muskeget. Together, Nantucket comprises roughly 48 square miles located in Nantucket Sound approximately 30 miles from the mainland on Cape Cod, Massachusetts. Elevations range from sea level to 111 feet above sea level.

The CRP is an all-island, all-county plan focusing on the entire 88 miles of coastline. The project area encompasses an array of built and natural conditions, from the historic town centers in downtown and Siasconset (also referred to as “Sconset” and “‘Sconset”), to bays and tidal estuaries, to natural coastal bluffs along the South Shore, to the sparsely populated islands of Tuckernuck and Muskeget. **Figure 1 and Figure 2** on the following pages show the project study as well as overview of the coastal hazards facing Nantucket today and in the future.

Figure 1 and Figure 2. (next two pages) Maps showing the project study area and exposure to coastal hazards, including flooding from monthly high tides (MMHW), coastal storms, and coastal erosion today and in 2070.

The Project Mission Statement

*The **Coastal Resilience Plan** draws on the cherished built and natural heritage of Nantucket to create a community-supported roadmap to implementation for a series of layered flood control and adaptation approaches that lessen the loss from storm surges and help the community adapt to rising seas and eroding coastlines. In coordination with other ongoing adaptation and sustainability initiatives, the plan addresses the whole island and county while respecting the unique characteristics of each neighborhood. Driven by the inclusive and equitable engagement of all, the plan aspires to create social, environmental, and economic benefits and value to everyone who will share in Nantucket’s future.*


Today's Exposure to Coastal Hazards
1:35,000
Miles
0 0.25 0.5
Bathymetry (2016)
Value
108.817
-158.206
Topography
Value
108.817
-158.206
Elevation Contours (10 ft)
Ferry Routes
Buildings County
Trails
OpenSpace
Present MMHW 2.66ft
Present 1% Annual Flood
Coskata
Wauwinet
Pocomo
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Middle Pasture
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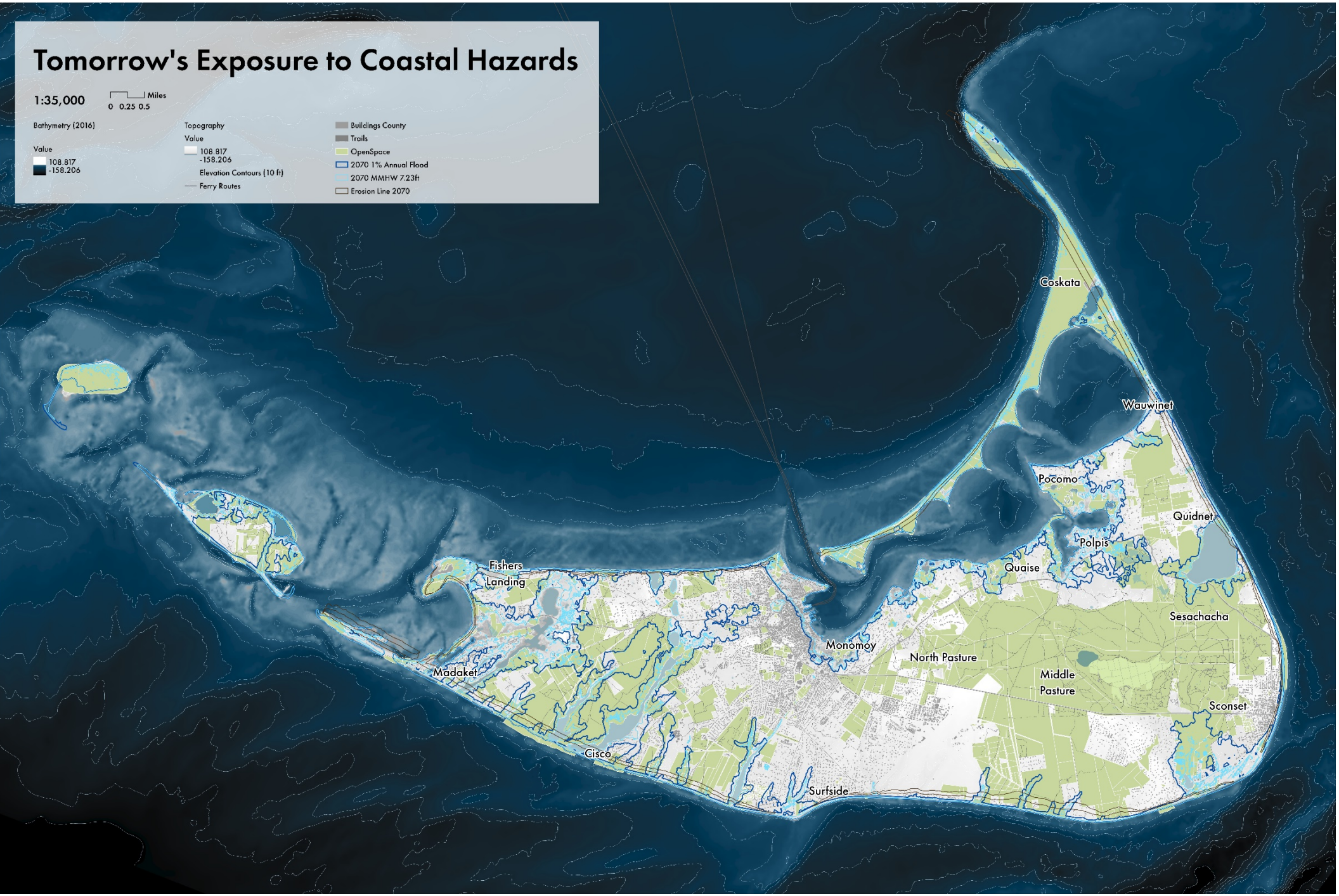
Madaket
Cisco
Surfside


Tomorrow's Exposure to Coastal Hazards
1:35,000
Miles
0 0.25 0.5
Bathymetry (2016)
Value
108.817
-158.206
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Buildings County
Trails
OpenSpace
2070 1% Annual Flood
2070 MMHW 7.23ft
Erosion Line 2070
Coskata
Wauwinet
Pocomo
Quidnet
Polpis
Quaise
Sesachacha
Fishers
Landing
Monomoy
North Pasture
Middle
Pasture
Sconset
Madaket
Cisco
Surfside

Overview of the Process

The CRP will include a long-term adaptation plan for the entire island along with detailed feasibility and implementation guidance for near-term projects, applicable over the next 10 years. The process for developing this plan combines climate science, community engagement, engineering and technical analysis, urban and landscape planning and design, and implementation planning. The CRP will involve examination of a range of flood protection options, including structural, non-structural, ecological, and policy-based measures. By engaging a wide range of community groups in the process, the Town is ensuring that the Coastal Resilience Plan can move forward into implementation based on broad based input and support. The plan will be completed in Fall 2021 and involve several phases of public outreach and engagement as summarized in **Section 3 Engaging the Community** (see **Figure 3** for project schedule). Public health and safety will be a priority throughout the process, and the Project Team will look for creative ways to engage the community while adhering to COVID-19 guidance and restrictions.

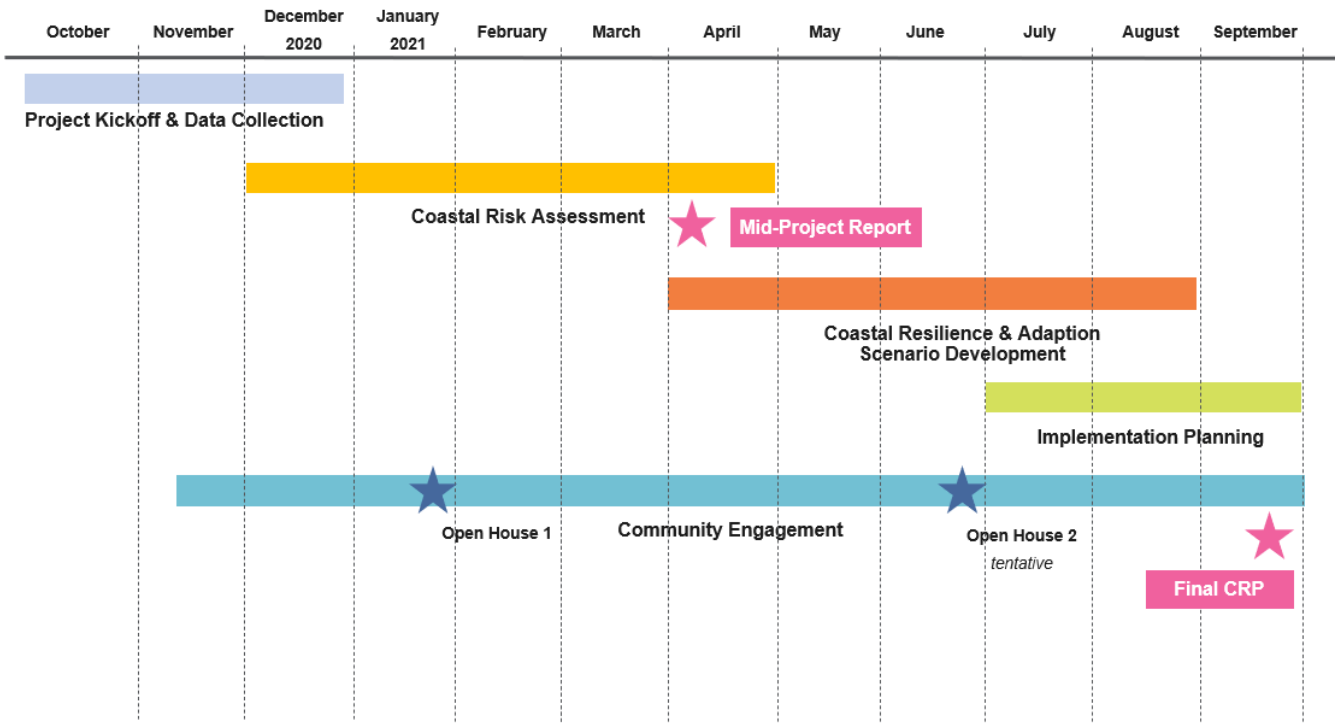
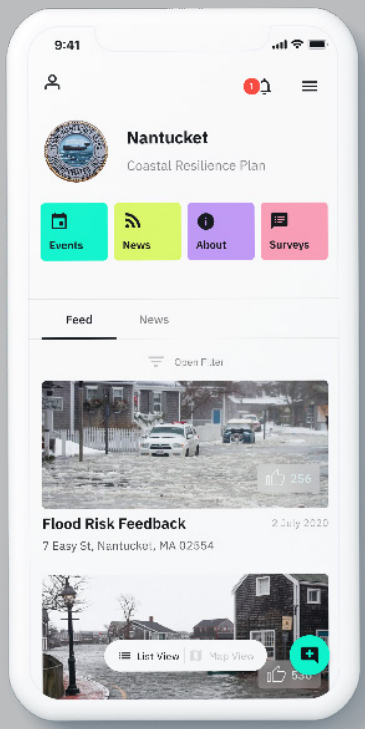


Figure 3. Nantucket CRP Project Schedule

Project Team

The Town of Nantucket, through the Department of Natural Resources, is leading the creation of the Coastal Resilience Plan. A broader team of Town Departments will provide guidance throughout the process, including the Administration, Planning, Public Works, Sewer, Health, Energy, and Fire and Police Departments. In addition, a number of Town Committees, Boards, and Commissions will play a role in the project. The Coastal Resilience Advisory Committee will serve as the primary citizen committee steering the process.

An interdisciplinary team of consultants supports the work, led by the engineering firm Arcadis, which includes local and global experts in coastal engineering, hydrodynamic modeling, civil and structural engineering, transportation, urban design, implementation planning, and community engagement. Additional design, engagement, planning, historic preservation, and implementation support is provided by Arcadis subconsultants Stoss, ONE Architecture and Urbanism, and The Craig Group.



Tell us what's important to you using the Nantucket CRP App!

In collaboration with Irys, the Nantucket Coastal Resilience Plan Project Team has launched the Irys App – a tool to help facilitate two-way engagement as we move forward with the development of the Coastal Resilience Plan.

Using the Irys App, you can:

Provide Input: Provide feedback throughout the development of the Nantucket Coastal Resilience Plan. Users can choose from providing input by location, providing input by category, and responding to survey questions.

Find Events: Find opportunities to participate in future Nantucket Coastal Resilience Plan events!

View Project Updates: Track project progress and view information about project developments.

Build Community: Follow your feed! View community input and interact with other app users.

The Irys App is available for download now on iOS and Android devices.

Use the QR code to download today!

1.2 Overview of Coastal Resilience Concepts

Coastal risks can never be entirely removed, but they can be reduced through planning, capital investment, and changes to policies and regulations. While hazard mitigation planning and disaster preparedness have been part of local, state, and federal planning for decades, the increasing coastal risks projected to occur with climate change and sea level rise have led many coastal and inland communities to draw on the related concepts of resilience and adaptation. By planning for resilience and creating pathways for adaptation, the challenges presented by sea level rise and climate change can create opportunities to channel resources toward more robust, reliable, and redundant systems and infrastructure that support community safety, well-being, and vibrancy into the future.

Resilience

Resilience refers to the ability of communities and systems to withstand, recover from, and adapt to shocks and stresses. Creating a climate resilient community requires intentional, proactive action on the part of local leaders with community input and support to put in place systems, capacities, and redundancies that reduce risk and have the ability to transform with evolving conditions over time. The resilience transformation process can help communities turn climate challenges into opportunities for positive growth and change that benefit the community in multiple ways.

Adaptation

Adaptation is the ongoing process by which a community may assess future climate risks and develop a roadmap of investment and action to evolve systems, capacities, and infrastructure in response to future risks and manage the uncertainties that go along with them. Adaptation involves putting in place the capacity for future modifications that may be necessary as conditions change.

Figure 4. Communities can build their capacity for climate resilience by engaging stakeholders in a multi-step planning and implementation process

Understanding Risk, Consequence, Vulnerability, and Criticality

It is important that a community understand the factors that contribute to flood and erosion risk in order to make informed decisions regarding the appropriate actions to mitigate risk and build resilience. The concepts introduced below are used in the CRP to help quantify and prioritize coastal risks on Nantucket, as will be discussed in **Section 5 Coastal Risk and Exposure Analysis**. Risk can be calculated at any scale by multiplying the probability that an event, such as flooding or erosion, will occur by the consequences of that event (see **Figure 5**). This equation can be applied to a single facility/structure or to a community overall. Adaptation and resilience are the approaches we used to reduce the consequences of hazards over time.

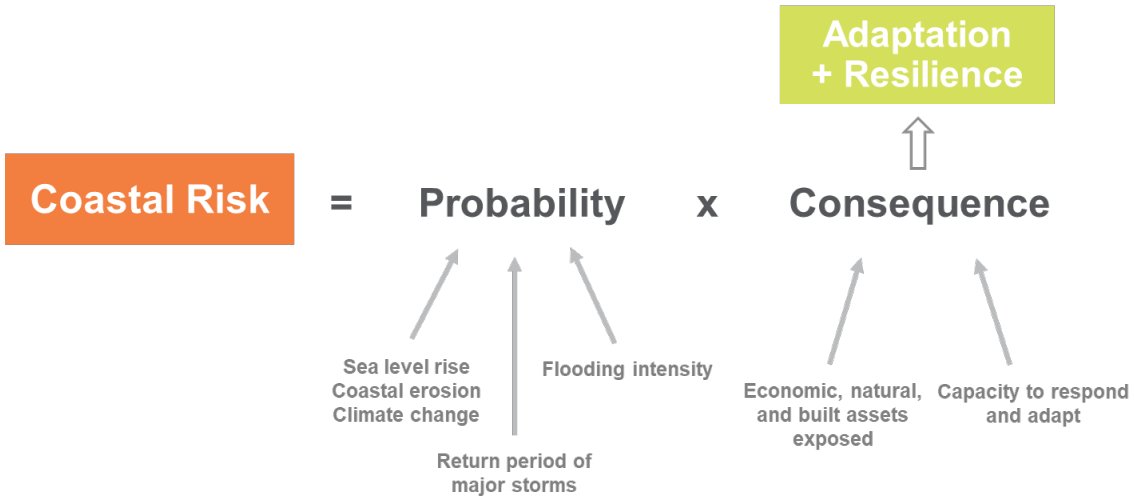


Figure 5. Coastal risk is a function of the probability that event will occur and the consequences of that event. By adapting to risk over time, we can reduce consequences and build community resilience.

The probability of flooding is generally correlated with the associated depth of flooding. As the expected magnitude of a flood event increases, the probability of occurrence decreases. The greater the magnitude of an expected storm, the less likely the event is expected to occur. For example, a storm such as Winter Storm Grayson in 2018 or the No Name Storm of 1991, both of which caused widespread impacts on Nantucket, would be expected to have a lower likelihood of happening in a given year compared to a storm with lesser impacts, such as the types of Nor'easters that pass by Nantucket on an annual basis. Nevertheless, even high-probability (frequent) flood events can result in significant loss if a community is not prepared. The probability of flood events of various magnitudes (often described in terms of annual exceedance probability (AEP) or the chance of a certain flood depth and magnitude being met or exceeded in a given year) can be identified using a variety of sources. Many communities rely on the FEMA Flood Insurance Rate Maps but in some cases, including Nantucket, other locally available flood hazard models, such as the North Atlantic Coast Comprehensive Study or Massachusetts Coastal Flood Risk Model can be referred to as the "best available" flood hazard information.

The probability of a flood event occurring also depends on the frame of reference. For example, a 1% annual chance of flooding today translates to a roughly 25% or 1 in 4 chance of flooding over the course of a 30-year home mortgage.

The consequence of flood impacts could include many factors, ranging from property damage to regional economic loss, which might occur because of industry disruption and small business collapse. For certain critical

facilities, consequences increase with the importance of a facility to the community, particularly as the community prepares for, responds to, or recovers from a storm. A primary driver of flood or erosion-related consequences is continued growth of a community and associated infrastructure in vulnerable areas. Refocusing growth outside of floodplains or erosion hazard areas can reduce risk and better enable implementation of coastal adaption approaches.

Vulnerability is another important concept related to consequence. In the simplest terms, vulnerability refers to the characteristics of a facility or community that increase susceptibility to impacts from flooding. Example factors that contribute to flood vulnerability include age and condition of buildings and infrastructure, construction type, location, structure and grade elevations, land uses, as well as site flood probability and type of flooding. For example, a single-story timber house with a basement would likely be more vulnerable to the impacts of flooding than a two-story masonry house with an elevated first floor, even if both structures were located in areas with the same likelihood of flooding.

Criticality refers to the relative importance of a facility or service. The American Society of Civil Engineers (ASCE) Standard 24 on Flood Resistant Design and Construction is often used to assign criticality for facilities, as well as to help prioritize facilities for mitigation. State building codes, including Massachusetts', will often translate ASCE standards into risk classes based on importance to community life and safety, with the most critical facilities, such as hospitals, emergency response facilities, and evacuation routes, ranking highest. Often there are specific standards enforced through code that need to be met for the most critical facilities and decision-makers should consult the applicable codes and standards to understand these requirements. Criticality can also be assigned based on locally driven values and needs. For example, on Nantucket the infrastructure supporting access to mainland – ferry terminals, wharfs, and airports -- takes on a level of criticality that they may not have in other locations. The importance of assigning criticality is in helping local decision-makers prioritize facilities, systems, and assets for mitigation investment. Risk to critical facilities on Nantucket is discussed in greater detail in **Section 5 Coastal Risk and Exposure Analysis.**

1.3 Recent and Ongoing Coastal Resilience Studies that Inform the CRP

Nantucket has undertaken a number of coastal resilience planning projects in recent years. The goal of the CRP is to build on and complement these studies, not to duplicate or supplant work that has already been done. The most relevant recent and ongoing resilience studies are summarized below.

Municipal Vulnerability Plan (MVP) Summary of Findings (2019)

The Municipal Vulnerability Preparedness program is led by the Commonwealth of Massachusetts and provides cities and towns with funding and technical assistance for planning and project implementation to advance community climate resilience. Participation in the program involves two steps. First, communities may apply for funding to complete a vulnerability assessment and develop action-oriented resiliency plans driven by a highly participatory community process. Once the community has developed its plan, it is certified as an MVP community by the Commonwealth and is eligible to apply for MVP Action grant funding to help fund implementation of the plan and/or additional studies.

The MVP process on Nantucket engaged stakeholders through a Community Resilience Building (CRB) workshop to document input from the community on the island's strengths and weaknesses related to climate change and actions that can be taken to advance community resilience. The final MVP Summary of Findings report was completed in April 2019.

There were several top-priority actions recommended through the MVP planning process, most notably the creation of municipal Resilience Coordinator position, the development of resilience plans for travel routes to and from the mainland, and resilience planning for the community's critical infrastructure systems. The prioritized actions outlined in the Summary of Findings establish a basis for understanding community priorities on Nantucket and also opens funding opportunities through state Action Grants for near-term projects that may be recommended by the CRP.

Hazard Mitigation Plan (HMP) (2019)

The natural Hazard Mitigation Plan for Nantucket investigated ways to reduce damage from likely hazards, maintain the islands emergency response capabilities, and protect the existing town infrastructure and other resources from natural disasters. It aimed to establish a platform for informing the public about risk, increasing access to funding sources, and improving the post disaster recovery responses. In the most recent iteration of the HMP, completed in 2019, the main areas of focus included: access to the mainland, isolation within the island, historic resources, power supply resilience, and adaptation to climate change.

The HMP listed priority mitigation actions. These mitigation actions pertain to multiple hazards including earthquakes, wildfires, and hurricanes. Completed recommendations from the HMP that the CRP can utilize include:

- Become an MVP community
- Complete hydrologic study of the Fulling Mill Brook Watershed
- Consider suitability of Schools as Emergency Shelters
- Assess vulnerability of historic structures
- Develop Comprehensive Stormwater Management Plan
- Develop standard operating procedure (SOP) for opening and closing of Children's Beach Tide Gate

Coastal Risk Assessment and Resiliency Strategies (2020)

Building on both the MVP planning process and the HMP, the Resilience Assessment and Strategies study aimed to assess Nantucket's resilience to the threats posed by rising sea levels, including storm surge, coastal flooding, and erosion. Specifically, the intention of the report was to:

- Formally Assess Risk and Vulnerability using GIS mapping
- Present a menu of tools to achieve resilience goals
- Identify policy changes necessary for implementing recommended resilience tools

The Coastal Risk Assessment and Resiliency Strategies study provided a preliminary assessment of island-wide risk and vulnerability, as well as an overview of actions that can be taken to reduce risk and improve resilience. The toolkit provides a foundation from which the CRP can build. The suite of resilience measures included:

- Shoreline protection
- Community Infrastructure protection
- Property protection
- Regulatory Tools
- Procedural Tools
- Public & Institutional Tools

The recommendations were modeled around the three basic adaptation approaches: retreat, accommodation, and protection. The adaptation framework also serves as a starting point for the CRP resilience framework.

Resilient Nantucket: Designed for Adaptation (2021)

Based on recommendations from the HMP, the Town moved forward with the development of resilient design guidelines upon receipt of a Municipal Vulnerabilities Preparedness Action Grant from the Commonwealth. These supplemental design guidelines to the well-established, model design guidance "Building with Nantucket in Mind" provides standardized guidance from the National Park Service on adapting historic buildings and sites to flooding.

In addition, the MVP grant is supporting the compilation of a resilience "toolkit" to provide information on flood risk, flood preparedness, flood insurance, flood recovery, and flood adaptation alternatives for historic properties, cultural sites, and the island's larger cultural landscape. Multiple partners are working together on this project to further public awareness regarding the challenges of climate change. The *Resilient Nantucket Toolkit* offers technical assistance and funding resources to assist private and public sector property owners and organizations with their adaptation efforts and support the implementation of the HMP goals, objectives, and actions.

Finally, the *Resilient Nantucket Public Forum: Designed for Adaptation*, hosted by the Town of Nantucket with sponsorship support of Town of Nantucket, Commonwealth of Massachusetts MVP program, Nantucket Preservation Trust, ACKlimate Nantucket, Preservation Institute Nantucket, Nantucket Historical Association, Preservation Massachusetts, and ReMain Nantucket, will serve as a showcase for international and national experts and authorities in climate science, adaptation planning, climate change policy, natural resource protection, historic preservation and real estate. Hosted April 22 (Earth Day) through April 24, 2021 this forum also highlights the next phase of resilience work on Nantucket, the Coastal Resilience Plan.

1.4 Key Findings of this Report

This report documents findings from the first half of the CRP process and focuses on the following topics:

- **Existing Conditions** – Understanding Nantucket's context in order to situate future plans for coastal resilience and adaptation in a thorough understanding of the island's history and the natural and built systems that support life on Nantucket
- **Community Engagement** - Engaging the Nantucket community in the CRP process and asking key questions about community priorities and visions to help orient the plan's preliminary recommendations in a direction that is consistent with community values and objectives
- **Risk Evaluation** - Assessing and quantifying the risks that flooding and erosion pose to Nantucket today and how these risks will increase over time due to projected sea level rise in order to focus coastal resilience and long-term adaptation plans and to help substantiate CRP implementation

Sea levels have increased eight inches of between 1965 and 2019 on Nantucket. These changes are already altering life on the island, as flooding becomes more frequent and erosion more drastic, and the community's experience of the coastline is likely to continue to shift in the decades to come. **As documented in this report, coastal risks to homes, businesses, infrastructure, and natural resources will increase across the island through the end of the century. Action will need to be taken to adapt to these realities.**

Nantucket Context

The aspects that make Nantucket an attractive place to live, work, and visit, the characteristics that give it its "island-ness" – the ocean, beaches and bluffs, harbors and bays, historic character, and the ways in which humans have altered and occupied the coastline over time – are also the aspects that create the need for coastal resilience planning to ensure that Nantucket can continue to adapt to changing conditions and evolving risks. Life on Nantucket is not the same as it is on the mainland and the systems and infrastructure that support quality of life for the community must be carefully designed, operated, and maintained to support community wellbeing.

These existing systems include the transportation infrastructure that people use to travel to, from, and across the island, food and water systems, healthcare facilities, utility lines, parks and open space, and natural ecosystems. **Mapping of the systems and facilities that support life on Nantucket found that while some essential facilities are at limited risk from coastal hazards due to their location – Nantucket Cottage Hospital, for example – others are exposed to significant risk today and in the future, including Steamboat Wharf and many of the roadways relied upon for intra-island travel. The CRP will draw on the existing conditions analysis, along with the risk analysis, to develop recommended approaches for adapting at-risk systems and infrastructure to reduce risk to community wellbeing over time.**

Community Engagement

Through the first phases of the engagement process, the community raised several **common challenges** faced by people on the island, **core tensions** that continually arise and must be accounted for in implementing coastal resilience solutions, **key priorities** that form the backbone of the community's vision for a resilient Nantucket, and **long-term visions** toward which the CRP should set its aims.

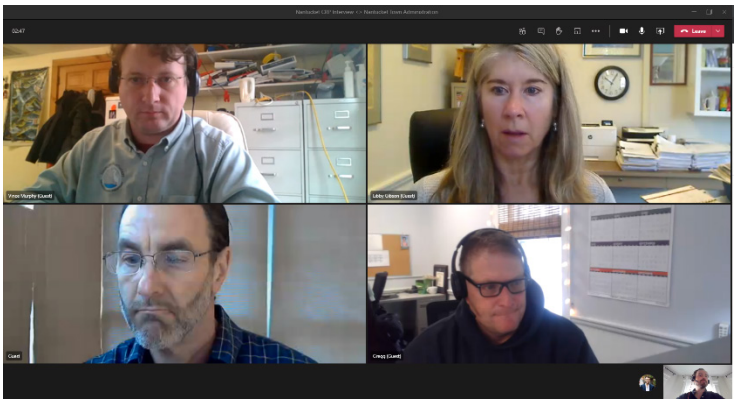


Figure 6. Virtual interview between the Project Team and Nantucket Town Administration Staff

Common challenges the community faces include:

- Increasing flooding and erosion hazards causing widespread impacts
- A need for greater public awareness and understanding of the issues
- Understaffed and underfunded Town capacity
- Lack of a centralized entity or coordinated approach to resilience
- Barriers to implementation of site-specific mitigating measures
- Challenges with aligning efforts with sustainability and climate mitigation co-benefits
- Existing data gaps and other data challenges

Core tensions noted by the community include:

- A need for compromise, as not all areas will be viable to protect and not all desired solutions will be feasible
- Misalignment of policy and regulatory needs at the local level and regulations at the Commonwealth level
- Maladaptive development practices and norms
- Tensions between approaches historic/aesthetic preservation and energy/food resilience

The community's key priorities include:

- Maintaining Nantucket's one-of-a-kind character
- Implementing nature-based solutions wherever feasible, minimizing ecological impacts
- Protecting critical infrastructure
- Ensuring continuity of service at ferry terminals and maritime facilities
- Engaging a diverse range of public voices
- Developing a clear and actionable CRP

The community's long-term visions include:

- A future Nantucket that continues to embody the island's best characteristics and strives to become more resilient and sustainable
- A comprehensive, island-wide approach to resilience
- An adaptable and dynamic CRP that evolves over time
- Greater Town leadership in implementing and governing for resilience
- A multi-departmental approach to resilience

Coastal Risk and Exposure

As noted above, risk from coastal hazards on Nantucket is significant and will grow over time. The risks threaten to significantly upend the aspects of Nantucket that give it its character, sustain its economy, and ensure health and safety for residents and visitors. The key findings from the risk and exposure analysis documented in this report are summarized below. Additional discussion of these findings is provided in **Section 5 Coastal Risk and Exposure Analysis.**

If no flood or erosion mitigation is implemented on Nantucket,

- **From now through 2070, 3,438 structures** are at risk from flooding and erosion, with the cumulative expected annual damages totaling **$1.2 Billion**, including:
    - **$932 Million** in **direct physical damage** to buildings
    - **$115 Million** in **direct economic disruption** to businesses in the study area
    - **$61 Million** in **direct social disruption**, including relocation costs, health costs from injuries and mental stress, and lost income due to health issues
    - **$40 Million** in **indirect and induced economic losses**
    - **$19 Million in federal, state, and local tax impacts**
- **86% of at-risk buildings are residential, accounting for 68% of the total risk, and though only 7% of at-risk buildings are commercial, they account for 26% of the total risk**
- **At least 41% of at-risk buildings are historic and account for 64% of the total risk**
- **At least 7% of buildings are tourism-related, accounting for 26% of the total risk**
- **33 community facilities are at risk, with over $46 Million in expected damages. Many of these facilities are essential to community safety and wellbeing.**
- **From now through 2100, the following infrastructure and services may be exposed and at risk of loss of service:**
    - **10 miles of public and private roadway** may be out of service[1] at monthly high tide by 2030, **20 miles** by 2050, **29 miles** by 2070, and **45 miles** by 2100, resulting in impaired access across the island
    - **6 miles of public and private roadway is vulnerable to erosion** by 2030, **33 miles** by 2100, also resulting in impaired access across the island
    - **By 2030, public roadways leading to the Steamship authority wharf could experience a frequent loss of service at monthly high tide. By 2050, the Steamship authority wharf will**

[1] Loss of service for roadways is defined as being subject to more than 6 inches of inundation, the depth of water at which it is unsafe to drive to a small passenger car

be completely cut off from surrounding roadways at monthly high tide. This poses a significant risk to access to and from the island, as well as critical supply lines.

- **From now through 2100, the following open spaces and natural resources will be exposed and at risk of loss of service and/or changes to the ecosystem**
    - **312 acres of public open space** is vulnerable to erosion by 2030 and up to **1,754 acres** could be vulnerable by 2100, reducing opportunities for recreation and enjoyment for the community
    - **719 acres of priority natural communities** could be impacted by monthly high tide by 2030, **926 acres** by 2050, **1,187 acres** by 2070, and **1573 acres** by 2100, resulting in potential changes to these ecosystems
    - Up to **268 additional acres** of wetland resource areas compared to today may be submerged by monthly high tide by 2030, **424 additional acres** by 2050, **645 additional acres** by 2070, and **1,055 additional acres** by 2100. Without plans for marsh migration or other mitigation steps, these resources may be impaired or lost.

1.5 The Next Steps

The findings of this report form the foundation for the next phases of the CRP process, including definition of geographic focus areas for more detailed analysis, development of resilience and adaptation scenarios, refinement of recommended resilience projects and adaptation pathways, and plans for implementation. During the next phase, the Project Team will continue to engage the Nantucket community through small group meetings, virtual platforms such as Irys, and the second Community Open House tentatively planned for early summer.

Be sure to check the Coastal Resilience Plan website for the latest project news and for additional ways to get involved!

2 Overview of Nantucket

Estimates for the effective population of Nantucket range from between 11,000 to over 17,000 year-round residents, a combination of life long Nantucketers and those who have arrived on the island fulltime later in life, locally known as “wash ashores.” The island is also known for its seasonal influx of vacationers, who rent or own vacation homes on the island, returning each season to the one-of-a-kind beaches and other coastal environs that characterize Nantucket. By most estimates, the population on the island increases to more than 50,000 during the summer months in a normal year, though this number dropped in 2020 and may remain lower in 2021 due to the COVID-19 pandemic. The aspects that make Nantucket an attractive place to live and visit, the characteristics that give it its “island-ness” – the ocean, the beaches and bluffs, tidal ponds, historic character, and the ways in which humans have altered and occupied the coastline over time – are also the aspects that create the need for coastal resilience planning to ensure that Nantucket can continue to adapt to changing conditions and evolving risks. This section provides an overview of Nantucket with a focus on the people, places, histories, and services that provide the foundation for the community’s future resilience.

2.1 Life on the Coast

By virtue of its location, history, and geomorphology, Nantucket is and always has been highly exposed to a range of coastal hazards, most notably flooding and erosion. Depending on how one experiences Nantucket, as a year-rounder, a seasonal resident, visitor, or worker, one’s perception of these coastal hazards is likely to vary, but everyone who knows Nantucket also knows what it is to live not just beside, but also with, the ocean. Climate change and sea level rise are already altering life on Nantucket, with eight inches of rise between 1965 and 2019 (Figure 7), and the community’s experience of the coastline is likely to drastically change in the decades to come. It will exacerbate and create new coastal challenges, eroding shorelines more rapidly and making areas of the island vulnerable to flooding in ways that are not experienced today. The Nantucket of today will need to change and adapt to these realities.

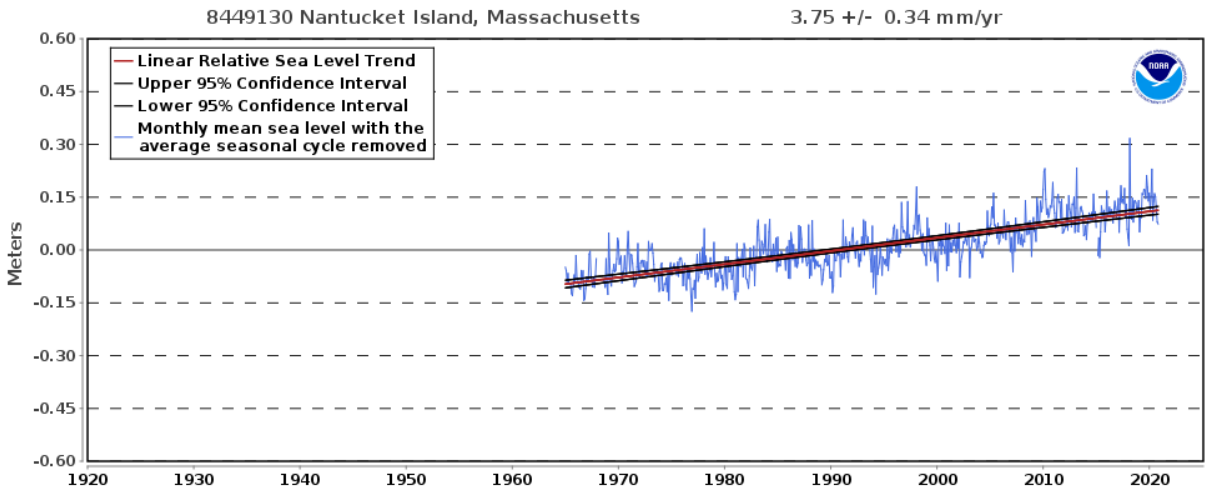


Figure 7. Historic SLR at 8449130 Nantucket Island, Massachusetts

Recent Storms Events

Memories of significant storm events are ever present in the minds of Nantucketers, from the No Name storm of 1991 to the more recent events. Two major Nor'easter storms impacted the island in 2018. Both Winter storm Grayson and Winter Storm Riley caused water levels to rise in Nantucket Harbor, approaching the level of the 100 year or 1% annual chance storm, a marker of a major coastal flood event. As just one example of the cascading ways in which such an event can disrupt daily life, the extreme cold coupled with the high stormwater caused a sewer force main from the downtown area to fail and discharge sewage into the harbor, impacting water quality and the health of the fishery on which many Nantucket residents rely for income. The two storms led to storm tides that were among the highest ever recorded for Nantucket. Even more recently, the passing Hurricanes Paulette and Teddy hundreds of miles offshore led to erosion on the South Shore with the loss of 140-plus feet of beach on the south shore in just a month. Several winter storms during the fall and winter of 2020 and 2021 had major impacts across the island as well, leading to flooding in downtown and significant erosion along the south shore. **Appendix A**, from the 2019 Town of Nantucket Hazard Mitigation Plan, summarizes recent storm events and their impacts on the community.

2.2 Environmental History of Nantucket

Physical Setting and Climate

The Town of Nantucket is located east of Martha's Vineyard, and south of Mainland Massachusetts Cape Cod area. Nantucket Island and the Town of Nantucket are both the main features within the County of Nantucket which includes both Tuckernuck and Muskeget Island. Nantucket also features 88 miles of shoreline which is a primary attraction for tourists in the summer months.

The island was formed by the Laurentide Ice Sheet that was associated with the last North American glaciation, dating back to less than 25,000 years ago. As the glacier pushed south to the existing location of Nantucket, piles of clay, silt and sand, known as moraines, were deposited ahead of the glacier to form the high points on the island. These current-day locations include the cliffs at Sankaty Head, Folger Hill, Shawkemo Hills, and Sauls Hills.

Notable features on the island include high bluffs at Sankaty Head and the Nantucket Cliffs. The Sankaty Head bluffs are located on the eastern end of the island near Siasconset, while the Nantucket cliffs are located at the northern edge near the Jetties, Brant Point, and Downtown.

The main bodies of water surrounding Nantucket include Nantucket sound to the north, as well as the Atlantic Ocean which surrounds the east and south of the island. There are several harbors on the island, with some being semi-sheltered and others completely sheltered. Nantucket Harbor and Polpis Harbor reside on the northern portion of the island. Madaket Harbor lies towards the west end of the island near Tuckernuck island.

Nantucket's climate is characterized by distinct seasons with average temperatures ranging from the low 30s in January to the upper 60s in July. Nantucket experiences an average precipitation of about 43 inches per year, with snowfall ranges between 12 to 24 inches per year. Massachusetts average annual precipitation has been increasing for over a decade, and Nantucket has been on par with this increase. Models predict that each season will bring an increased precipitation amount to Nantucket, compared to previous years. Climate change projections for Massachusetts indicate that precipitation patterns are changing, and more significant changes in the amount, frequency, and timing of precipitation in future years are anticipated.

Figure 8. (next page) Map showing the existing topography and bathymetry of Nantucket, including major water bodies Nantucket Sound, the Atlantic Ocean, Nantucket Harbor, Madaket Harbor. Note the relationship between the island's low-lying coastal areas in Downtown, Madaket, Ell Point, and around Polpis Harbor, and the 1% annual chance floodplain.

Nantucket Island Topography and Bathymetry
1:35,000
Miles
0 0.25 0.5
Contours
Elevation Contours (10 ft)
Bathymetry (2016)
Value
108.817
-158.206
1% Annual Chance Or 100-Year Storm
Topography
Value
108.817
-158.206
Inland Water Bodies
Atlantic Ocean
Northern Nearshore
Trap/ Pot Waters Area
Nantucket Sound
Muskeget
Island
Tuckernuck
Island
Madaket
Harbor
Nantucket
Harbor
Polpis
Harbor

2.3 Historical Perspectives

Nantucket Emerges, Indigenous Peoples, European Colonization

Nantucket emerged as the last of the Laurentide Ice Sheet retreated leaving behind the hills, valleys, creeks, and ponds that are a hallmark of Nantucket's natural beauty. The first indigenous peoples, the Wampanoag, began to appear on Nantucket's shores approximately 12,000 years ago. They lived a semi-nomadic life on the coast, evidence by archaeological discoveries and the Wampanoag oral traditions. In 1641, William, Earl of Sterling, deeded Nantucket to Thomas Mayhew, beginning the European settlement of the Island. The first settlement, Sherburne, was along the north shore at Capaum Harbor, now called Capaum Pond. The tides shifted sand closing off the harbor and causing the settlement to relocate to where it is today by 1720.

Whaling Period and Conservation Conscious

The Whaling Period of Nantucket, while creating a population boom, did not cause the sprawl of urban living to the interior of the Island. Instead, the lot size shrank as more people subdivided lots to create the historic, tight, rectangular lots of today. Areas that were wetlands, such as along Washington Street and Brant Point, remained relatively untouched, as well as areas that were seen as naturally significant. Nantucketers, unlike much of the United States in the 19th Century, emphasized the conservation of natural spaces and the minimal spread of human interruption to the Island's natural processes. This can be partly attributed to land for sheep grazing, but also to the Whaling Period itself. Whaling was the economic driver and revolved around economic core areas such as the Town of Nantucket and Sconset. This does not mean that agriculture and animal husbandry was uncommon, especially since ships arriving could bring the goods the island needed. By the end of the Whaling Period, there were 111 farms of various sizes producing barley, corn, potatoes, and cranberries (U.S. FWS). As the Whaling Period began its decline, focus did turn to agriculture and animal husbandry, but it was not the economic driver as the Island searched for a new identity.[2]

Identity in Conservation and Preservation

The Nantucket Historical Association was founded in 1894 in a conscious effort to preserve the history of the Island, especially since Whaling, the primary economy, began its decline fifty years earlier causing people to leave Nantucket in search of opportunity. This early effort was focused on important people, such as Maria Mitchell and the Maria Mitchell Association (1902), as well as historic landscapes, such as the cobblestone streets protected by the Nantucket Protective Association (1919). While the first design guidelines for the Island were agreed upon in 1937, Nantucket did not get its first historic district until 1955 when the State ruled the legislation constitutional and declared Nantucket, Sconset local historic districts.

The preservation and conservation movements moved parallel on Nantucket, particularly under the leadership of Walter Beinecke, Jr. (1918-2004). Beinecke not only assisted in founding Nantucket Preservation Trust in 1957, but also Nantucket Conservation Foundation in 1963, the same year the Conservation Commission received its enabling legislation to enforce and regulate the natural environment from the Massachusetts Wetland Protection Act. Designated a National Historic Landmark in 1975, the Island of Nantucket, was recognized as historically significant for its early efforts in architectural preservation and land conservation. This significance as a leader in the early preservation movement led to Nantucket serving as home to the University of Florida's Preservation Institute Nantucket (PIN), the oldest preservation field school in the United States. PIN students continue the documentation of Nantucket's built and natural history, but now with a sense of urgency anticipating the impacts of climate change, rising tides and eroding coastlines on this fragile, unreplaceable Island community.

[2] Much of the preceding information drawn from Pauline Chase-Harrell and Brian Pfeiffer, "Nantucket Historic District", National Register of Historic Places Nomination Form (Washington, DC: U.S. Department of the Interior, National Park Service, 2018).

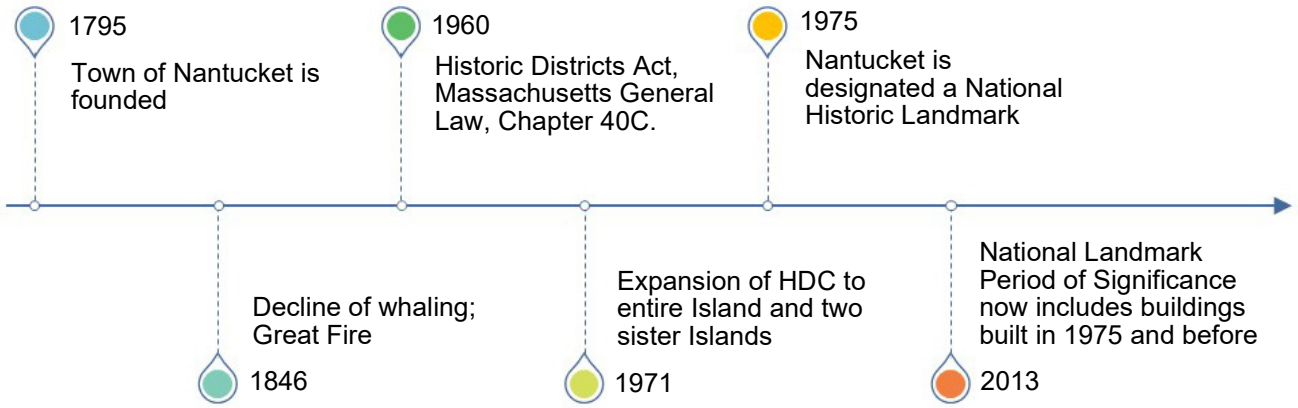


Figure 9. Summary timeline of key dates in Nantucket's history and preservation movement

2.4 Nantucket Today

The Nantucket Community

Nantucket's effective population ebbs and flows dramatically over the course of the year, and it can be challenging to derive a definitive estimate. The 2018 American Community Survey (ACS) 5-year estimates (surveyed between 2014-2018) estimates 11,100 people live in Nantucket year-round. However, local estimates and detailed analyses by Nantucket Data Platform indicate a permanent population of up to 17,200 residents, including adults and children. According to the 2018 ACS 5-Year estimates, the most year-round population-dense part of the island is the central-southern census tract (census tract 9502) consisting roughly of the Cisco and Miacomet neighborhoods. On an average Saturday in July, however, the vast majority of Nantucket's effective population–inclusive of visitors–typically concentrates in the Downtown and Brant Point neighborhoods. A high seasonal residential population–estimated at an additional 11,000 at 100-percent occupancy by Nantucket Data Platform's study–and high volume of seasonal visitors, particularly in July and August can cause the effective population of the island to swell to over 54,000 in the summer months. More details on Nantucket demographics can be found in **Appendix B**.

Key Considerations for Equitable Resilience Planning

- While the median household income on Nantucket is quite high relative to other places, some residents still experience **poverty and may be unhoused.**
- Low-income and homeless populations have **limited access to resources** needed to adapt to the impacts of coastal hazards and climate change. Any negative effects experienced by these populations are likely to have consequences far exceeding those experienced by populations with access to the means to recover and adapt. As such, it is critical that these highly vulnerable populations are made visible and have a voice in any adaptation process. As they are likely to bear a disproportionately high share of the collective risk Nantucket faces, their resilience must serve as a measure of Nantucket's resilience as a whole.
- Although the majority of Nantucket's year-round and seasonal effective populations are white, Nantucket comprises communities of **multiple backgrounds and ethnicities**, including immigrant communities and some populations with limited English-speaking proficiency. Historically, such communities are often marginalized, which is correlated with higher levels of social vulnerability. In planning equitably for Nantucket's future resilience, a special effort should be made to ensure these communities are robustly engaged and to minimize any barriers to collaboration in the process.
- Residents and visitors of **many ages and with varying capabilities** use and enjoy Nantucket. Accessibility should play an essential role in any project evaluation process and aim to be as broad and inclusive as possible.

Systems and Services that Support Quality of Life on Nantucket

Whether one is a lifelong resident, a more recent arrival, a seasonal visitor, business owner, a worker, or a combination thereof, life on Nantucket is characterized by the unique needs and conditions of living 30 miles out to sea. Life on Nantucket is not the same as it is on the mainland and the systems and infrastructure that support quality of life for the community must be carefully designed, operated, and maintained in order to continue to support community wellbeing. These systems and infrastructure include the transportation infrastructure that people use to travel to and from and across the island, food and water systems, healthcare facilities, energy, parks and open space, and natural ecosystems. This section details the key systems that support quality of life on Nantucket and the risks to which will be discussed in **Section 5 Coastal Risk and Exposure Analysis.**

Transportation

The Town is comprised of transportation networks that both connect the island to the mainland and allow travel within the island. People travel to and from Nantucket by boat and by air. The Nantucket Memorial Airport is a critical transportation facility serving the community as it provides access to the mainland for goods and services, as well as for residents and visitors that support the island economy. The airport has been operated and maintained by the Town's Airport Commission for over 60 years. According to data from the Town, the airport sees approximately 100-125 thousand commercial passengers each year. While the Airport Commission is responsible for ensuring the airport is in good working condition, the Federal Aviation Administration (FAA) is in charge of controlling and ensuring the safety within Nantucket's airspace. As will be discussed in **Section 5 Coastal Risk and Exposure Analysis**, erosion, and to a lesser degree flooding, along the southern shore of the island threatens airport infrastructure.

There are also multiple ferry lines that provide year-round access to the island. Both the Hy-Line Cruises and Steamship Authority use high-speed passenger catamarans for their services with trips from the mainland. The

Steamship Authority also operates a vehicle and passenger ferry with a two-and-a-half-hour travel time from Hyannis. The Steamship Authority Dock, also known as Steamboat Warf, is the main entry point for a majority of the food, supplies, and other resources that are utilized on the island. Although the Hy-Line ferry service transports minimal freight and supplies, the ferry service is responsible for transporting numerous passengers to and from the mainland and into Straight Wharf. In addition to the previously listed ferry services, the Freedom Cruise Line departs from Harwich Port, MA and the high-speed ferry with Seastreak arrives at the island after leaving from New York City, NY or New Bedford, MA. There are community concerns regarding isolation from the mainland from temporary loss of ferry services, along with air travel, due to high winds and an increase in storm intensity. In addition to these ferry terminals, there are numerous private docks located across the island and official and unofficial public boat ramps with varying facilities. These are located at Children's Beach (the only official public boat launch in Nantucket Harbor and/or Polpis Harbor), Washington Street Extension, Polpis, Walter Barrett's Pier, and Byron Coffin Pier (also known as Jackson's Point Pier). These amenities support recreational boating and the fishing industry.

Nantucket is served by a network of public and private roadways and bridges. All public roadways are under local jurisdiction, except for Milestone Road which is under the jurisdiction of the Commonwealth of Massachusetts. The Nantucket Regional Transit Authority shuttle buses, also known as the WAVE, provides transportation services amongst these roadways. There are also four taxi companies and numerous car rental agencies that provide services for mobility around the island. Major roadways in the downtown area include Washington Street, Easy Street, and Broad Street. These critical public roadways in Downtown provide access to the ferry terminals. To the east side of the island, Madaket Road is also a critical public roadway as it is the only evacuation route from Madaket Village and Smith Point to central areas of the island. Hummock Pond Road is also an evacuation route and provides inland access from Cisco. To the west, Polpis Road is the main arterial connecting the Polpis area to Downtown and it also extends through Quidnet and into the 'Sconset neighborhood. The section of Polpis Road along the southwest edge of Sesachacha Pond is prone to flooding during high wind events and when the pond is not drawn down during springtime. If Polpis Road and Milestone Road, both of which are evacuation routes, simultaneously flooded, the 'Sconset neighborhood would be isolated. In the 'Sconset neighborhood, Baxter Road provides access to private homes, Sankaty Head Lighthouse, and the bluffs in this area, and is exposed to erosion risk. **Figure 10** shows the location of the primary transportation systems and facilities on Nantucket.

Figure 10. (next page) Map showing the primary transportation systems and facilities on Nantucket, including primary routes and evacuation routes, local roads, and facilities to support travel to and from the island, such as Steamboat Wharf and Nantucket Memorial Airport.

Transportation
Scale 1:35,000
0
0.5
1
2
Miles
Airports
Seaports
Marinas
Public Boat Ramps
Ferry Routes
Bus Stops
Evacuation Routes
Road Access
Public paved
Public unpaved
Private paved
Unknown paved
Private unpaved
Inter-Island
Harwich Port-Nantucket
Hyannis-Nantucket
Muskeget Island Airport
Tuckernuck Airport
Coskata
Wauwinet
Wauwinet Road
Pocomo
Quidnet
Quidnet Road
Polpis
Polpis Road
Quaise
Sesachacha
Fishers Landing
Cliff Road
Old North Wharf
Steamship Authority
Nantucket Town Pier
Hy-Line Cruises
Madaket Road
Madaket Marine
Madaket
Monomoy
North Pasture
Middle Pasture
Old South Road
Milestone Road
Sconset
Tom Nevers Road
Nantucket Memorial Airport
Cisco
Surfside Road
Miacomet Road
Surfside

Land Use and Districts

Land use in coastal areas helps inform the evaluation of risk and also the set of coastal resilience and adaptation approaches that might be appropriate for a given area, based on land use type, density of development, or environmental character. As part of a coastal resilience strategy, land use changes may be necessary to address increasing risk, shifting patterns of land use from historic patterns to account for evolving hazards. Current land use in Nantucket mainly consists of low density residential, small-scale commercial and industrial uses institutional, and open space, much of it protected as conservation lands. The entire island is listed as a National Historic Landmark by the National Park Service, and both the downtown area and the Siasconset neighborhoods are designated Local Historic Districts regulated by the Historic District Council. New residential development on the island is largely limited to new single-family homes. Due to a combination of zoning, wetland protection regulations, and the prominence of protected open space, new development is not common directly adjacent to the shoreline in most areas. Nevertheless, many private residences exist in flood and erosion prone areas, as will be discussed in **Section 5 Coastal Risk and Exposure Analysis.**

Commercial uses are primarily located in the Downtown and Mid-Island. The Mid-Island area has been identified by the Town as a potential location for future commercial growth. There is relatively little planned major development, aside from residential construction, outside of Mid-Island and Downtown.

Schools, municipal buildings, healthcare facilities, and additional institutional use buildings, along with primary transportation centers, are concentrated in the more densely populated areas of Downtown and Mid-Island. Land uses and districts across Nantucket are provided in **Figure 11** and **Figure 12.**

Historical District and Landmarks

As stated previously in **Section 2.3 Historical Perspectives,** the Old Town Nantucket and Village of Siasconset was part of the legislation solidifying the constitutionality of historic districts within the Commonwealth in 1955. This is before the National Historic Preservation Act of 1966 which recognized the national preservation movement which began in earnest with the preservation of Mount Vernon by the Mount Vernon Ladies Association in 1853.

The two local historic districts of Nantucket Town and the Village of Sconset consisted of their downtown urban areas which set a period of significance for buildings built prior to 1850, anything outside of the period is considered non-contributing. In 1971 the district was expanded to include the entirety of the Town of Nantucket, not just the Old Town. In 1966, the Nantucket Historic District was designated a National Historic Landmark, which was later expanded to the entire Island and two sister Islands.

The most recent updates to the National Historic Landmark designation expand the period of significance to 1975, therefore any building built on, or prior to 1975 is contributing to the Landmark's historic significance. It also recognizes that the historic built environment was created in response to the natural environment. Therefore, below we list the landmarks of both as one cannot be separated from the other.

Urban cores of Nantucket Town and the Village of Siasconset—both were recognized in early preservation efforts as essential to the culture and essence of the Island. They also have unique topography, Sconset placed upon a cliff and the last remains of a traditional whaling village, and Nantucket Town placed inside an amphitheater-like bowl with the harbor as the stage. There are many buildings and locations within each that are essential to telling the story of the Island, and prioritization to protect these resources is necessary in climate action and preparedness planning.

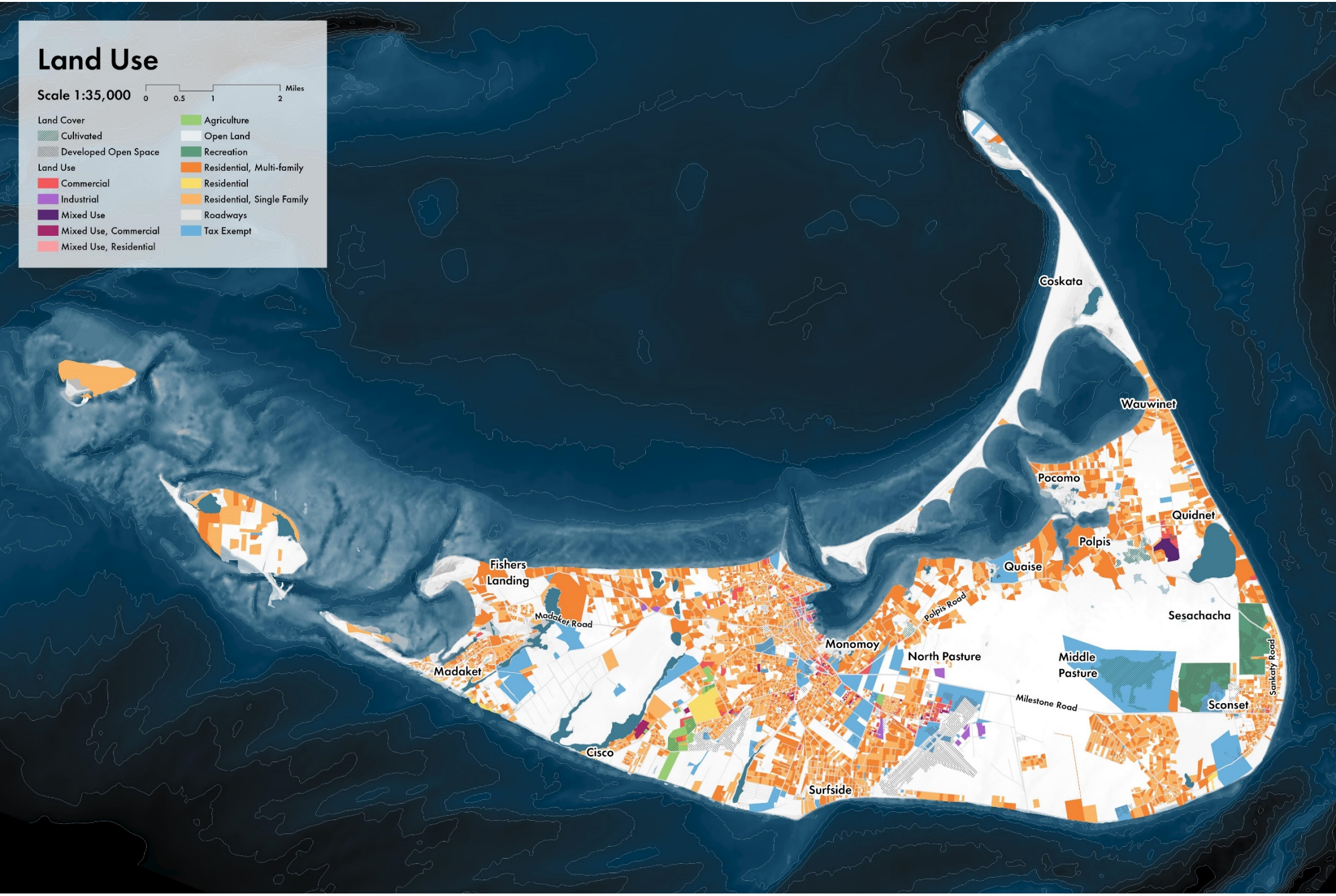
Madaket—Inside the recognized bounds of Madaket are a few contributing elements of the Landmark's historic context, its cultural landscape. First, it was where contact was made between the European settlers and indigenous Wampanoag in the late fall or early winter of 1659. It is also home to the earliest public works project-

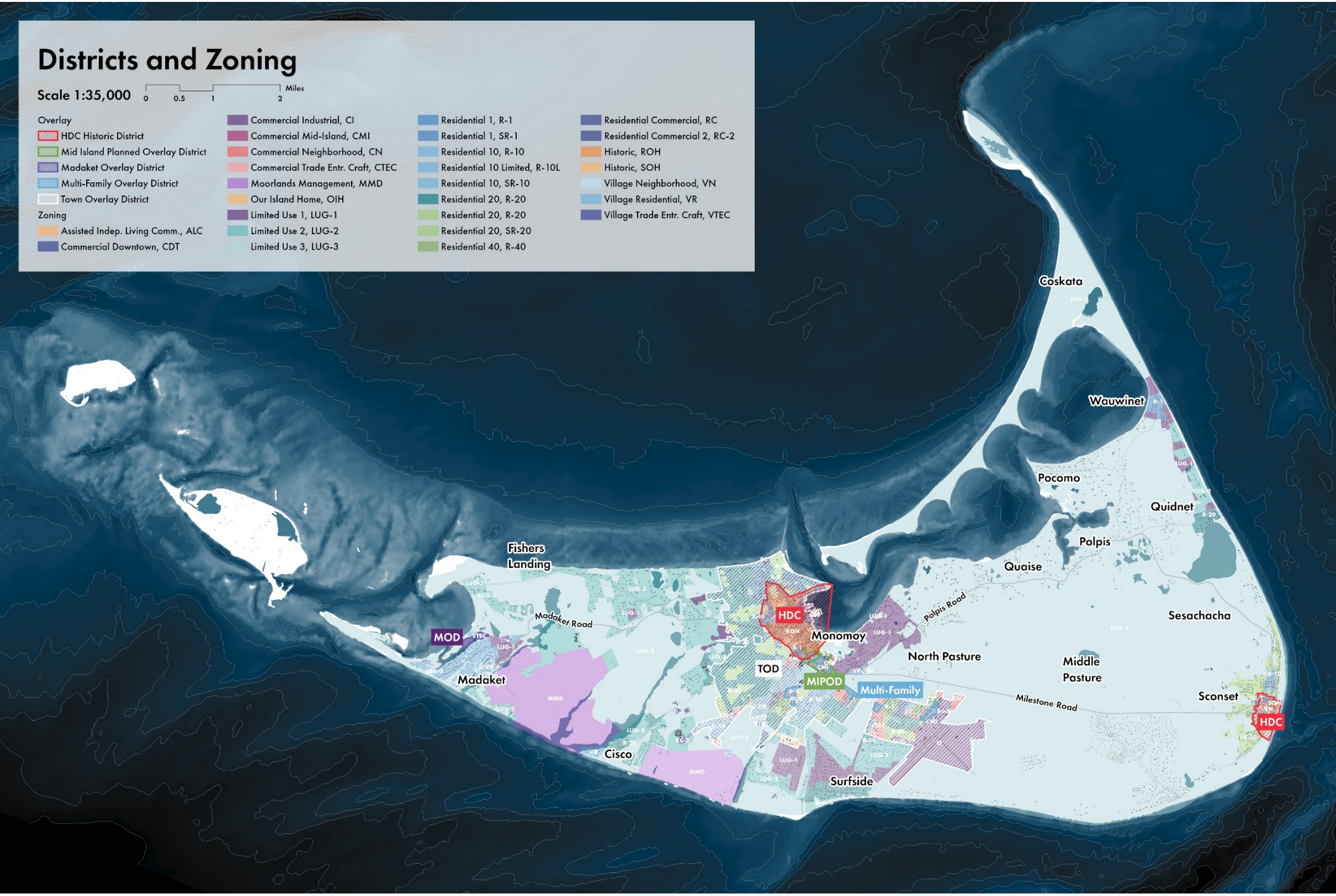
Madaket Ditch - which was dug in the 1660s as a cooperative project between the Wampanoag and settlers to provide better fishing. It supported an intangible heritage of harvesting Alewives and eels, but this fishing heritage is at risk of being lost. It is also known for important people such as Madaket Millie (1907-1990), who began a lifelong mission of rescuing people off the coasts of Nantucket starting at the age of ten. She was honored by the U.S. Coast Guard for seventy-eight years of service and awarded the Meritorious Public Service Commendation.

Terminal Moraine—much of Nantucket's landscape was shaped by the last Glacial Maximum 21,000± years ago. The hills and higher elevations, such as Altar Rock, were where the ice rested, and the ponds in this area, such as Sesachacha, were formed when ice under the sand melted and created a depression. The southern portion of the Island, such as the Moors, Hither Creek, Long Pond, and Madequecham Valley were outwash plains that formed as water poured off the ice sheet as it retreated. These areas are home to protected species of flora and fauna, as well as globally protected landscapes such as heathlands and sandplain grasslands.

Figure 11. (next page) Map showing the location of primary land uses by parcel across Nantucket

Figure 12. (following page) Map showing the location of zoning and historic districts across Nantucket


Land Use
Scale 1:35,000
0
0.5
1
2
Miles
Land Cover
Cultivated
Developed Open Space
Land Use
Commercial
Industrial
Mixed Use
Mixed Use, Commercial
Mixed Use, Residential
Agriculture
Open Land
Recreation
Residential, Multi-family
Residential
Residential, Single Family
Roadways
Tax Exempt
Coskata
Wauwinet
Pocomo
Quidnet
Polpis
Quaise
Sesachacha
Fishers Landing
Madaket Road
Polpis Road
Monomoy
North Pasture
Middle Pasture
Sankaty Road
Sconset
Milestone Road
Madaket
Cisco
Surfside


Districts and Zoning
Scale 1:35,000
0
0.5
1
2
Miles
Overlay
HDC Historic District
Mid Island Planned Overlay District
Madaket Overlay District
Multi-Family Overlay District
Town Overlay District
Zoning
Assisted Indep. Living Comm., ALC
Commercial Downtown, CDT
Commercial Industrial, CI
Commercial Mid-Island, CMI
Commercial Neighborhood, CN
Commercial Trade Entr. Craft, CTEC
Moorlands Management, MMD
Our Island Home, OIH
Limited Use 1, LUG-1
Limited Use 2, LUG-2
Limited Use 3, LUG-3
Residential 1, R-1
Residential 1, SR-1
Residential 10, R-10
Residential 10 Limited, R-10L
Residential 10, SR-10
Residential 20, R-20
Residential 20, R-20
Residential 20, SR-20
Residential 40, R-40
Residential Commercial, RC
Residential Commercial 2, RC-2
Historic, ROH
Historic, SOH
Village Neighborhood, VN
Village Residential, VR
Village Trade Entr. Craft, VTEC
Coskata
Wauwinet
Pocomo
Quidnet
Polpis
Quaise
Sesachacha
Fishers Landing
Madaket Road
Polpis Road
MOD
HDC
Monomoy
TOD
MIPOD
Multi-Family
North Pasture
Middle Pasture
Milestone Road
Sconset
Madaket
Cisco
Surfside
HDC

Wastewater, Water, and Energy Systems

Wastewater

According to the Town of Nantucket Sewer Department Capacity, Management, Operation and Maintenance (CMOM) Program Manual Nantucket has a separated sewer system for wastewater, with approximately 70 miles of sewer mains, 14 publicly owned pumping stations, and two municipal wastewater treatment facilities. Wastewater in the Towner Sewer District, comprised primarily of the Brant Point, Downtown, and Monomoy neighborhoods, is conveyed to Surfside Wastewater Treatment Facility (WWTF). The Surfside WWTF collects flows from four sub-areas and provides biological treatment for a daily flow of up 7.7 million gallons per day (MGD). The second municipal wastewater facility treats wastewater flows for the Siasconset Sewer District. The Siasconset WWTF was designed to provide treatment for a daily flow of up to 0.43 MGD. The average daily flows that are conveyed to the plant fluctuates significantly due to the seasonal population changes in this neighborhood and wet weather flows from precipitation events. Businesses and homeowners that are not in either of the two sewer districts rely primarily on septic systems for wastewater treatment and distribution.

The Town developed a CMOM Program to enhance the sanitary sewer system operation and reliability and help mitigate sanitary sewer overflows (SSO). SSOs release untreated sewage to waterbodies when the sewer system is overwhelmed with increased flow and exceeds the designed capacity. These overflows can lead to poor water quality if the overflows are recurring and adds additional health hazards to flood risk and existing social vulnerabilities. Nantucket is complying with the requirements of the Environmental Protection Agency for preventing sewer overflows and back-ups.

Water

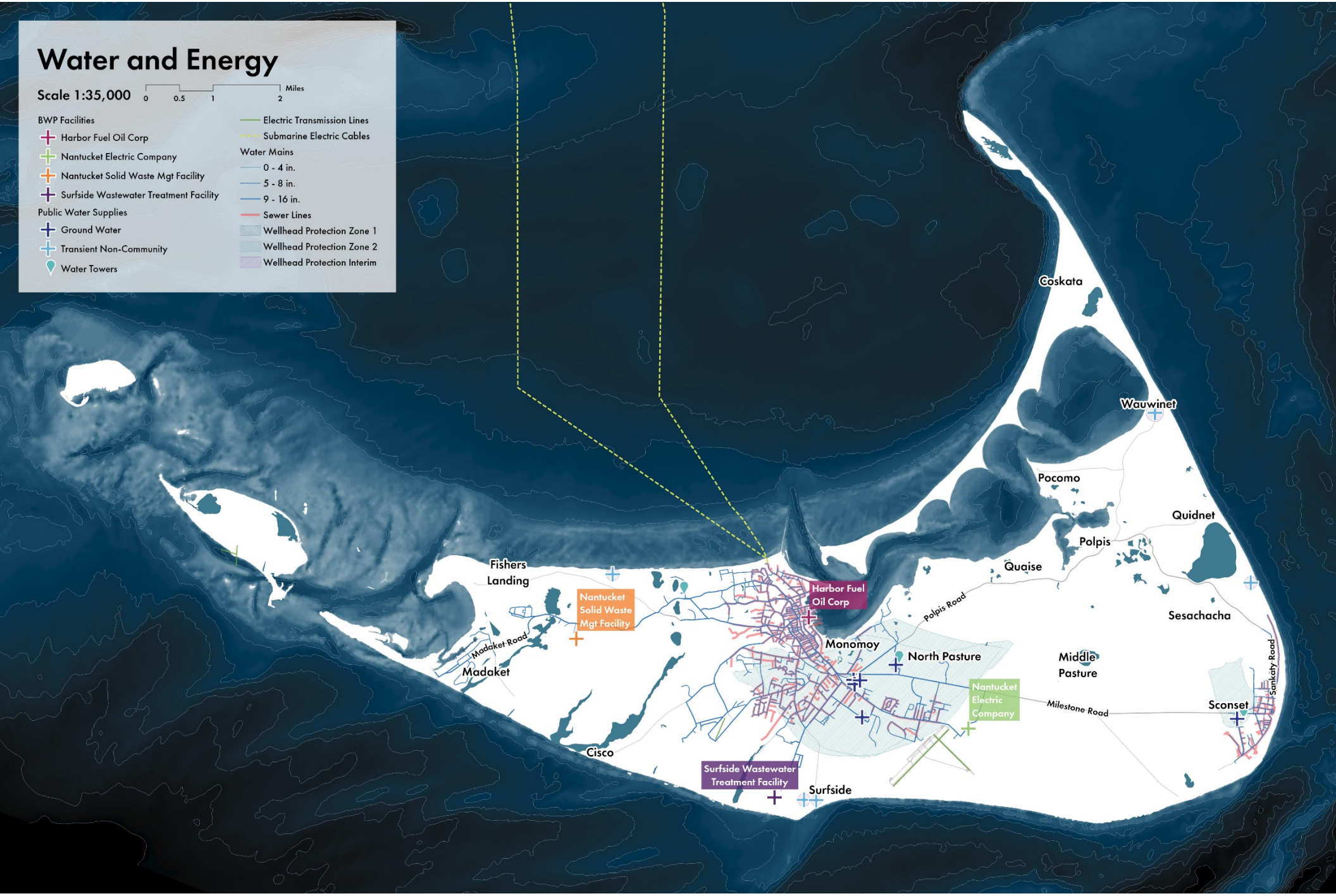
The Wannacomet Water Company (WWC), a municipal department, provides potable water and fire protection to the island. Private wells are also another source of drinking water. The WWC is overseen by two separate elected commissions and the Siasconset service area continues to have its own commission. The WWC collects its water from five wellfields, with four located in the central part of the island and one in Siasconset. In order to limit the risk of contamination of the water sources, wellhead protection districts and regulations around these wellfields have been established.

Energy

Nantucket receives electricity through two undersea cables, one from Hyannis and the other from Harwich, that enter the island in the Jetties area and then connect to the Candle Street National Grid Substation. From the Candle Street substation, electricity is distributed to the rest of Town primarily through overhead powerlines. Some locations receive electricity through underground powerlines. Transformers are located throughout the island.

The fuel tank farm, located on Industry Road, is operated by Harbor Fuel Corporation and provides gasoline, propane, diesel, and heating oil to the community. In summer of 2019, the fuels from the old tank farm located at the Downtown waterfront were transported to the new tank farm in a less populated and developed area to reduce risks to the population. The facility is a now outside of the floodplain and more accessible during storm events. Fuels are delivered to the tanks at the farm by tanker trucks that arrive at Steamboat Wharf.

Figure 13. (next page) Map showing the location of known Town-owned or regulated water and energy systems on Nantucket.


Water and Energy
Scale 1:35,000
0
0.5
1
2
Miles
BWP Facilities
Harbor Fuel Oil Corp
Nantucket Electric Company
Nantucket Solid Waste Mgt Facility
Surfside Wastewater Treatment Facility
Public Water Supplies
Ground Water
Transient Non-Community
Water Towers
Electric Transmission Lines
Submarine Electric Cables
Water Mains
0 - 4 in.
5 - 8 in.
9 - 16 in.
Sewer Lines
Wellhead Protection Zone 1
Wellhead Protection Zone 2
Wellhead Protection Interim
Coskata
Wauwinet
Pocomo
Quidnet
Polpis
Quaise
Sesachacha
Fishers Landing
Nantucket Solid Waste Mgt Facility
Harbor Fuel Oil Corp
Polpis Road
Madaket Road
Madaket
Monomoy
North Pasture
Middle Pasture
Nantucket Electric Company
Milestone Road
Sconset
Sankaty Road
Cisco
Surfside Wastewater Treatment Facility
Surfside

Community Assets and Services

A range of community assets and services support quality of life on Nantucket. Community assets and services are the places and benefits that are often taken for granted but that are integral to the safety and security of a population. These range from everyday establishments such as grocery stores and pharmacies, to places of learning and knowledge such as libraries and schools, to emergency services, such as fire and police. These assets and services are important in every community but on an island are even more critical as community lifelines. Major assets and services identified for this plan are shown in **Figure 14.**

The Nantucket community is served by range of essential services located in Town Facilities, including fire and police from the Public Safety Facility (4 Fairgrounds Road), public health from the Public Health Office (3 East Chestnut Street), a range of infrastructure services supported from the Department of Public Works (188 Madaket Road), among many other Town facilities being studied under the Town Facilities Master Plan.

In addition to Town facilities, there are numerous private facilities, including the island's primary medical provider, Nantucket Cottage Hospital, major grocery stores, Stop n' Shop (2) and Bartlett's Farm, numerous houses of worship, and many museums and nonprofit organizations providing education, entertainment, and support to the community.

Nantucket's resilience is in large measure a function of how resilient these facilities and services that support life on the island are. Without these places, quality of life would be significantly diminished, and, in some cases, the safety and wellbeing of the community are severely compromised. The Coastal Resilience Plan will evaluate risks to the assets and services and seeks opportunity to protect and enhance the value and benefit they bring to the community.

Figure 14. (next page) Map showing the location of community facilities and services, including utilities, emergency services, community facilities, and public amenities such as boat ramps on Nantucket

Community Assets and Services
1:35,000
Miles
0 0.25 0.5
Bathymetry (2016)
Value
108.817
-158.206
Topography
Value
108.817
-158.206
Elevation Contours (10 ft)
Ferry Routes
Buildings County
Trails
OpenSpace
2070 1% Annual Flood
Airport
Transportation
Community Facilities and Services
Emergency Services
Utilities
Sewer
Mains
TransmissionLines
Coskata
Wauwinet
Pocomo
Quidnet
Polpis
Quaise
Sesachacha
Fishers Landing
Monomoy
North Pasture
Middle Pasture
Sconset
Madaket
Cisco
Surfside

Parks and Open Space

Open space is one of the primary features that define the character and identity of Nantucket, as well as its desirability as a place to live and visit. Access to open and green space is an important indicator of overall community health and can be a driver of community resilience, particularly where open space provides multiple health, ecological, and risk reduction benefits. Much of the protected open space on Nantucket is under the stewardship of private conversation organizations, such as the Nantucket Conservation Foundation, Trustees of Reservations, Audubon Society, and other Nantucket-based land trusts. The Nantucket Land Bank also acquires and manages land for conservation, recreation, and agriculture. More than half of the land on Nantucket is protected open space. These properties provide myriad ecological benefits to animals and birds, as well as recreational trails and other resources for community benefit. Major parks and open space properties identified for this plan are shown in **Figure 15.**

In addition to privately owned open spaces, there are 14 Town-owned parks, including:

- Passive park properties (Coffin Park, Mill Hill Park, and Consue Springs)
- Active parks (Winter Park, Nobadeer Athletic Complex, Delta Fields, and Tom Nevers Park)
- Neighborhood pocket parks (Lincoln Circle and Hulbert Avenue & Easton Street Circles)
- Beach properties (Dionis, Jetties, Children's, Fisherman's, Surfside)

The Town has been in the process of planning for its parks and open spaces in order to better serve community needs. In winter 2020, the Parks and Recreation Master Plan was published, including a needs assessment that identified a number of concerns. These concerns ranged from insufficient active recreation facilities for the communities growing needs, to lacking resources for operations and maintenance of existing facilities, to more consistent oversight of field uses.

Like the rest of the country and world, life on Nantucket has been significantly altered by the global pandemic. The pandemic and the need for social distancing has likely changed how community members see the role of open space in their daily lives. Improved access to open space and coastal resilience are often compatible objectives. The Coastal Resilience Plan will evaluate risks to Town parks and protected open space and seek to make recommendations for coastal resilience that add open space benefits for the community.

Figure 15. (next page) Map showing the location public and private protected open spaces and parks on Nantucket

Parks and Open Spaces
1:35,000
Miles
0 0.25 0.5
Bathymetry (2016)
Value
108.817
-158.206
Topography
Value
108.817
-158.206
Elevation Contours (10 ft)
2070 1% Annual Flood
Ferry Routes
Buildings County
Trails
Open Space
Public-Non-Profit
Public-Town-Owned
Public-Federally-Owned
Public-State-Owned
Private Non-Profit
Other
Cranberry Bog
DIONIS BEACH
LINCOLN CIRCLE
JETTIES BEACH
COFFIN PARK
HULBERT AVE. AND EASTON STREET CIRCLE
CHILDREN'S BEACH
MILL HILL PARK
CONSUE SPRINGS
NOBADEER
DELTA FIELDS
WINTER PARK
ATHLETIC COMPLEX
FISHERMAN'S BEACH
SURFSIDE BEACH
TOM NEVERS PARK

Habitat and Natural Resources

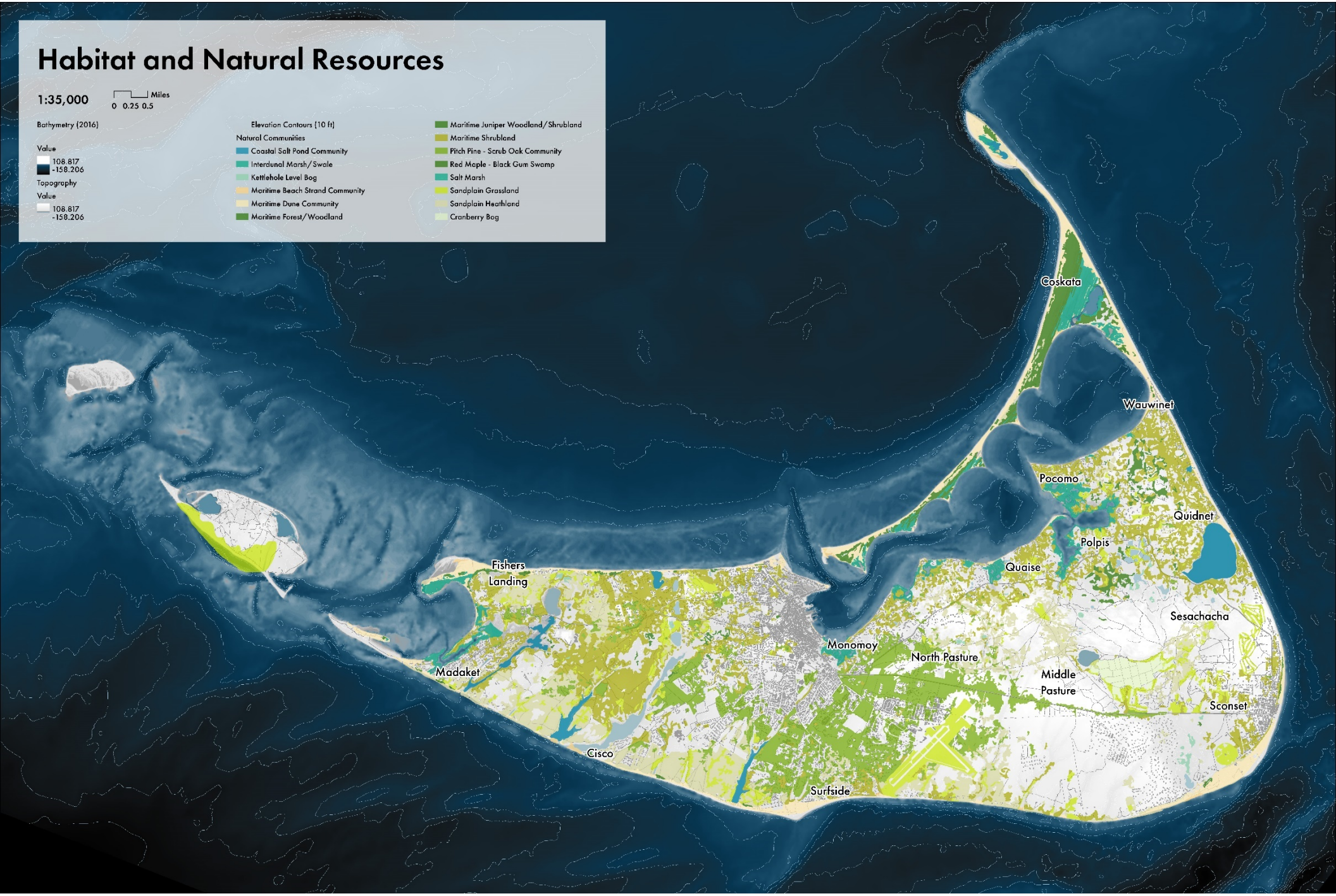
The island's natural habitats and resources contribute to Nantucket's natural beauty, biodiversity, and support quality of life for the community. As a relatively small island, Nantucket is fortunate to have an array of habitats and natural area types. Barrier beaches are located around the island, primarily at Coatue, Great Point, Coskata, and Haulover, and protect Nantucket Harbor from the open waters of the Atlantic Ocean and Nantucket Sound. Smaller barrier beach habitats have been formed at Smith Point and Eel Point. While the barrier beaches form the seaside habitats in locations, just inland sand dunes provide additional habitat, as well as natural protection for upland communities. Salt marshes are also commonly located on the back side of the barrier beach dune system. The sandplain grasslands are upland plant communities found primarily on the southern part of the island where meltwater from the glaciers deposited fine sand and debris. 95% of the world's sandplain grassland is found on Nantucket. Coastal heathlands are comprised of many of the same plants as the sandplain grasslands but are not dominated by grasses and are located in the central and northern areas of the island on nutrient poor sand and gravelly soils. Both of these habitats were unique to the North American coastlines, and now a majority of the remaining grasslands and heathlands are found on Nantucket and Martha's Vineyard. On Nantucket, scrub oak and pitch pines are common species that have invaded the grasslands and heathlands and caused overgrowth. Other natural communities on the island include hardwood forests, pond, and bogs.

Natural resources such as wetlands and coastal floodplains provide protection from flooding, but their health and longevity are threatened by sea level rise. State and local regulations have been established to protect wetland resource areas from development and other factors so that they may continue to provide natural flood protection, diminish wave action, and also provide habitat for many species of plants and animals.

The priority Natural Communities and wetland resource areas identified for this plan are shown in **Figure 16.**

Threatened and endangered species of plants, birds, insects, and other animals are supported by the habitats and protecting these species and habitats is a priority for the community. Many of these species and habitats are found throughout the 16,000 plus acres of conservation land on Nantucket. These conservation lands, with a majority being open to public use, are vital to Nantucket's identity, attracting residents and visitors for activities including birdwatching, hiking, boating, fishing, swimming, and environmental education.

Figure 16. (next page) Map showing the location of priority Natural Communities and wetland resource areas on Nantucket


Habitat and Natural Resources
1:35,000
Miles
0 0.25 0.5
Bathymetry (2016)
Value
108.817
-158.206
Topography
Value
108.817
-158.206
Elevation Contours (10 ft)
Natural Communities
Coastal Salt Pond Community
Interdunal Marsh/Swale
Kettlehole Level Bog
Maritime Beach Strand Community
Maritime Dune Community
Maritime Forest/Woodland
Maritime Juniper Woodland/Shrubland
Maritime Shrubland
Pitch Pine - Scrub Oak Community
Red Maple - Black Gum Swamp
Salt Marsh
Sandplain Grassland
Sandplain Heathland
Cranberry Bog
Coskata
Wauwinet
Pocomo
Quidnet
Polpis
Quaise
Sesachacha
Fishers Landing
Monomoy
North Pasture
Middle Pasture
Sconset
Madaket
Cisco
Surfside

3 Engaging the Community

Community engagement is fundamental to creating a CRP that meets the goals and priorities of the Nantucket community and has a broad coalition of support for implementation over the near- and long-term. The community engagement process for the CRP includes four phases over the course of the project, including:

- A listening tour during the early phase of the project to understand priority objectives and concerns
- Community wide engagement to define a long-term vision and strategic priorities for Nantucket's coast
- Community wide engagement to present and vet preliminary recommendations
- Engagement around the finalization and launch of the plan to help continue momentum toward early implementation steps

3.1 Community Engagement Plan

At the outset of the planning process, the Project Team developed a Community Engagement Plan that documents the overall goals, schedule, and engagement approach for the CRP. It outlines the Project Team's approach to reach community groups and stakeholders during the CRP process while adhering to social distancing and public health guidelines established by the Town and State during the COVID-19 pandemic. **Figure 17** shows the community engagement schedule through the conclusion of the process.

The complete Community Engagement Plan can be downloaded here.

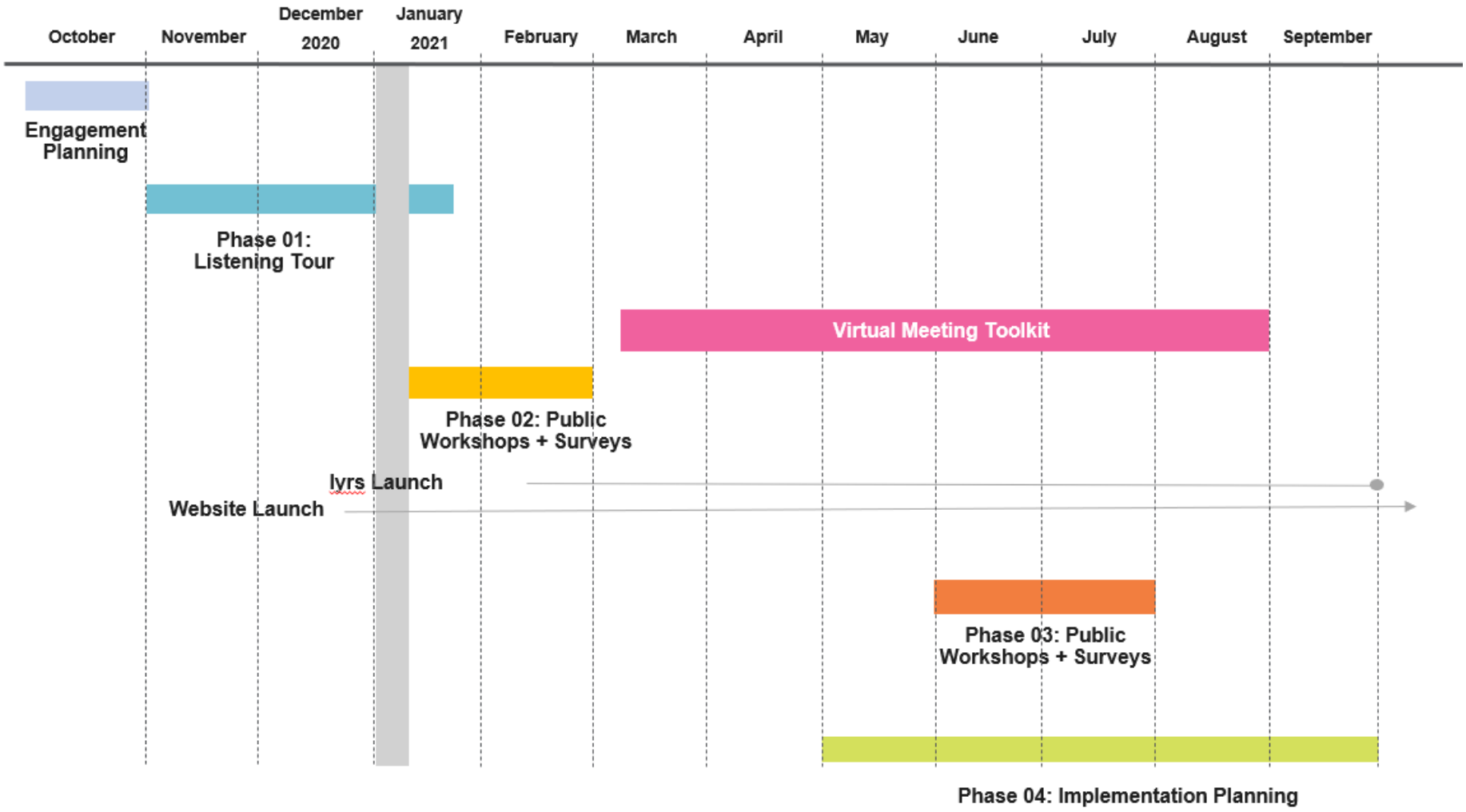


Figure 17. Community Engagement Schedule for the Nantucket Coastal Resilience Plan

3.2 Community Engagement Process To-Date

Listening Tour

From November 2020 to January 2021, the Project Team conducted a listening tour consisting of detailed project briefings and interviews with key stakeholders on Nantucket. The goals of the listening tour are summarized below.

- Identify key questions that require deeper understanding through ongoing engagement
- Collect need-to-know information on risks and vulnerabilities
- Understand what is important to the community
- Build consensus on the goals of the CRP
- Create relationships with key groups

The Project Team conducted detailed project briefings and interviews with 125+ staff and community members across 21 departments, boards, commissions, and organizations as part of the listening tour, including:

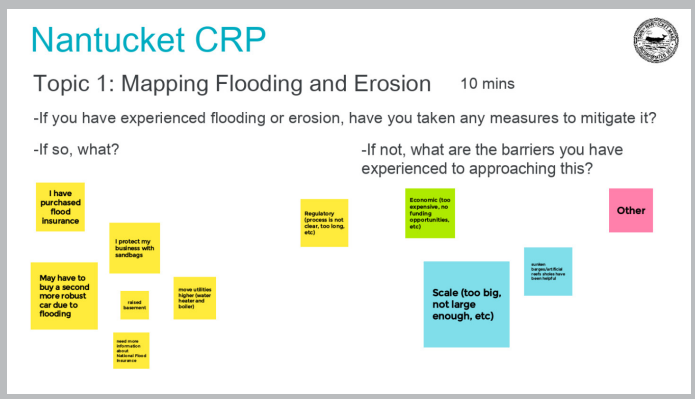
- ACKlimate Nantucket
- Coastal Resilience Advisory Committee
- Department of Public Works
- Emergency Management
- Harbor Master's Office
- Harbor and Shellfish Advisory Board
- Historic District Commission
- Nantucket Civic League, including many civic league member associations
- Nantucket Conservation Commission
- Nantucket Coastal Conservancy
- Nantucket Conservation Foundation
- Nantucket Historical Commission
- Nantucket Island Chamber of Commerce
- Nantucket Land Bank
- Nantucket Land Council
- Natural Resources Department
- Planning and Land Use Services
- Planning Board
- Remain Nantucket
- Select Board

Community-Wide Engagement

Since January 2021, the Project Team has been undertaking a multi-pronged approach to engaging Nantucket's broader community, inclusive of year-round residents, seasonal residents, workers, visitors, and other people who experience the island. The key objectives of this process are to:

- Generate broad awareness on and off island of the planning process
- Discuss the long-term coastal resilience vision for Nantucket
- Generate shared understanding of risks and resilience concepts
- Review areas of concern related to coastal flooding and erosion
- Ensure the community knows how to stay informed and involved

To kick off this process, the Project Team launched a website for the CRP, serving as a hub for detailed project information and ways to get involved for the general public. A Virtual Public Open House was held on January 28, 2021, which saw 160+ attendees. This event included a presentation introducing the CRP and core resilience concepts, in addition to structured small group discussions and a Q&A with members of the public.



Nantucket CRP Open House on January 28th, 2021

The first Open House for the Nantucket CRP was held on the evening of January 28, 2021. Due to Town and State public health guidance and to ensure health and safety for all, the event was convened virtually using Zoom. Over 200 people registered for the event and over 160 attended. The event promoted in advance using the Town's website, social media, a local events calendar, local e-newsletters, email blasts, and attendance at Town committee and Board meetings. The structure of the event included a presentation introducing the CRP and core resilience concepts, in addition to structured small group discussions and a Q&A with members of the public.

Highly interactive small group discussions focused on several key questions, including:

- What areas concern you the most as related to flooding and erosion?
- What steps have you taken to mitigate flooding and erosion?
- What do you value most about living on Nantucket? What would you want to keep the same? What would you be willing to change?
- What do you want to see for yourself and further generations?

The images at left provide samples of the input collected during the breakouts.

A video of the Open House can be view here: Virtual Public Open House

The Project Team has since leveraged the high level of engagement from the Virtual Open House event to follow-up regularly with e-mail blasts keeping the community informed on project updates. Town staff and members of the Coastal Resilience Advisory Committee have also been working with the Project Team to expand the reach of the engagement to members of the community to have not been regularly engaged in prior planning efforts.

Additionally, in collaboration with Irys, the Project Team launched and promoted the Irys App for iOS and Android devices in early February 2021 as a tool to help facilitate two-way engagement throughout the development of the CRP. As of late March, the app has been downloaded by 85 users. The Irys App allows users to:

- Provide feedback throughout the development of the Nantucket Coastal Resilience Plan. Users can choose from providing input by location, providing input by category, and responding to survey questions
- Find opportunities to participate in future Nantucket Coastal Resilience Plan events
- Track project progress and view information about project developments
- Follow community input and interact with other community members

Figure 18. The Virtual Meeting Toolkit is a downloadable resource for anyone who wants to learn about, discuss, and provide input to the Coastal Resilience Plan. An easy-to-use form enables everyone to quickly provide ideas and priorities to the Project Team

On March 11, 2021, the Project Team released an additional set of engagement tools for public use: a Virtual Meeting Toolkit and Resilience Storytelling Cards. The Virtual Meeting Toolkit (**Figure 18**) is downloadable for anyone to use to host and facilitate conversations about Nantucket's resilient future with their friends, neighbors, colleagues, and community. The toolkit is designed to be highly accessible (available in both English and Spanish), providing self-explanatory presentation materials, FAQs, and detailed instructions for providing feedback to the Project Team. As a supplement to this, downloadable and printable Resilience Storytelling Cards can be used to facilitate an activity for participants to share a drawing, image, story, or anything else about what a resilient Nantucket looks like to them. The Project Team is encouraging members of the community to share their cards using social media or by email.

3.3 Key Findings and Takeaways

What We've Heard: Major Themes

Through the listening tour and community-wide engagement process, the Project Team heard the community raise several **common challenges** faced by people on the island, **core tensions** that continually arise and must be accounted for in implementing coastal resilience solutions, **key priorities** that form the backbone of the community's vision for a resilient Nantucket, and **long-term visions** toward which the Coastal Resilience Plan should set its aims. The key challenges, tensions, priorities, and long-term visions which the Project Team heard from Nantucket stakeholders and the public are briefly summarized below.

Key Challenges

- The effects of **flooding and erosion hazards** are increasingly being felt by the general public as they give rise to numerous public safety issues in areas previously not thought to be at risk, in addition to the known areas of immediate concern such as Downtown, Madaket, Brant Point, and other areas. Sea level rise is increasing the potential for loss of critical infrastructure, ecological resources and habitats, public access, and economic value throughout the island, in addition to impacts to property and business owners. Intermittent loss of roadways and access across the island when it floods is a concern, as are the chronic flooding issues that sea level rise will increasingly pose in the future. Inadequate stormwater

drainage in some places exacerbates these concerns as increased stormwater flooding compounds the risk of flooding, particularly Downtown.

- There is a need for increased **public awareness and understanding** about the flooding and erosion hazards Nantucket faces, how this could impact people directly, as well as what can be done about it, the lack of which often lead to widespread unpreparedness, resistance to change, and panic when storm events strike.
- The Town is **understaffed and underfunded** in general and specifically in relation to the scale of action needed to address increasing coastal risks. Additional capacity is needed to take on the responsibilities a comprehensive, island-wide resilience approach would require, and to monitor everything going on across the island that have implications for Nantucket's future resilience.
- There are many ongoing **parallel efforts and plans** related to resilience without a central entity or coordinated process tying them into cohesion.
- Property owners and residents face a number of **barriers to implementation** of site-specific mitigating measures, including slow and complicated permitting processes as well as a lack of funding opportunities compounded with the high cost associated with such measures.
- Although many stakeholders believe it is critical to pursue **sustainability and climate mitigation** co-benefits as an integral part of any resilience or climate adaptation effort, the fluidity and ambiguity of the concept of sustainability have made it challenging to align key entities around a common definition and understanding. This has presented obstacles to both public education about and implementation of sustainability initiatives that must be part and parcel of any resilience approach.
- Existing **data gaps** in and other data challenges with the island's infrastructure mapping present as obstacles to developing a comprehensive, island-wide resilience approach.

Key Tensions

- In general, project stakeholders emphasized that a spirit of **compromise** is essential, as not everything will be viable to protect given increasing erosion and sea level rise, and prioritization will be necessary. For example, while multi-beneficial nature-based solutions are broadly favored amongst the general public, there are likely to be spaces and places where such solutions may not be feasible. Retreat and acquisition strategies for private property will also be important to consider in specific circumstances but will have to be considered alongside their potential economic and social impacts.
- **Policy and regulatory strategies**, such as updated land use and zoning requirements, will play a critical role in Nantucket's future resilience in relation to the built environment. However, current zoning bylaws and building codes are controlled by the Commonwealth and more stringent rules and regulations cannot be implemented by the Town. This presents a tension in setting higher standards in Nantucket while contending with limitations imposed at a higher scale of governance.
- Current **development practices** and norms conflict with a future built environment that is resilient. Private property owners continue to operate independently–often building in coastal areas facing erosion hazards at their own risk–and are not incentivized to relocate their developments until they experience the full effects of coastal hazards, resulting in reactive planning. Given these existing norms, any approach that aims to restrict development is likely to be met with significant opposition and must be carefully crafted to encourage resilient development.
- Various stakeholders noted tensions between two key island-wide goals that are essential to any resilience effort: **historic and aesthetic preservation, and energy and food resilience**. Community members and project stakeholders highlighted the importance of both–the critical need to maintain Nantucket's historic and aesthetic character, as well as the need for Nantucket to pursue alternatives to its existing reliance on delivery of fuel and food, which can be at risk if access points and other

transportation infrastructure are inundated. However, sustainable approaches to energy and food resilience and redundancy are often seen as inimical to aesthetic preservation.

Key Priorities

- Community members and project stakeholder continually emphasized that the island of Nantucket has a **one-of-a-kind character** that must be preserved. While it is essential to protect the island from coastal hazards and climate risk, it must not be at the expense of the elements which contribute to this unique sense of place, which include Nantucket's ecological resources and habitats, the coastal viewshed and access to the water, the historic built environment and cultural landscape, and–critically–community diversity and strong social bonds between year-round residents. These elements also lend themselves to a thriving year-round economy on which many residing both on and off the island depend for their livelihoods.
- **Nature-based solutions** should be implemented wherever feasible with a clear emphasis on minimizing ecological impacts and maximizing ecological and public access benefits. Proposed gray infrastructure and hard-armoring solutions should be kept to a minimum. The community would like to work to preserve Nantucket's beaches and coast into the future for as long as possible.
- The CRP should prioritize protecting **critical infrastructure**. Transportation infrastructure, power cables and substations, water systems, data lines, water treatment facilities, maritime facilities, and the airport will all require a high level of protection and strategies to prepare for sea level rise, tidal events, and freezing weather. These systems are Nantucket's lifeline and community members were unanimous in highlighting the need to ensure continuity of service.
- **Ferry terminals and maritime facilities**, specifically, are of unique importance to Nantucket and serve as critical infrastructure in their function as access points to supply chains such as fuel and food, as well as waste disposal. Community members and project stakeholders continually cited accessibility to the island as a major concern due to increased storm frequency and sea level rise with impacts not only to supply of critical resources, but also for commuters and visitors.
- It is critical that the CRP process engage a **diverse range of public voices** and ensure that the public is educated about the issues at hand. The process should be inclusive and reflective of all voices–not just the loudest or wealthiest–in order to generate a community-wide vision for Nantucket's future, and should serve to generate public discussion and get people in the spirit of compromise. Consensus-building is of critical importance.
- The CRP must be **clear and actionable**, rather than serving as just a summary of knowledge. The plan should delineate responsible parties, methods of prioritizing action, and specific opportunities and options down to a hyper-local scale, while also providing resources for property owners to take action.

Long-Term Visions

- In general, community members and project stakeholders want to see a **future Nantucket** that continues to embody the island's unique characteristics, whose coastal and ecological resources thrive and are accessible to all, that is self-sufficient in its reliance on energy, food, and other critical systems, that continues to support a vibrant and diverse community, that is affordable and supports economic security for year-round residents, that is more sustainable and leaves a smaller negative environmental footprint, and that is open-minded and flexible in its approach to adapting to climate change. Nantucket should be a place for today's young people and future generations to enjoy in the future, even if some aspects of today's Nantucket will need to change in order to adapt to new conditions.
- The CRP should pave the way for a **comprehensive, island-wide** approach to resilience that also accounts for various hyper-local conditions appropriately.

- The CRP should be designed to be **adaptable and dynamic in the long-run**, incorporating an inherent flexibility into its structure to accommodate long-term changes and updates as Nantucket further evolves its approach to island-wide resilience.
- The Town should work to lead by example in implementation with **public projects**, setting a high standard for resilience in municipal properties. A centralized entity focused on resilience could go a long way in achieving this vision.
- A **multi-departmental approach** involving improved communication, collaboration, and file-sharing between Town bodies is a long-term goal for many project stakeholders.

How Findings Inform the Project

Community engagement serves as the backbone of the CRP process by helping to document concerns related to coastal risks, establish a vision for Nantucket's resilient future, and reach consensus around the pathways that will be taken to achieve this future. The community engagement undertaken to date for the CRP has focused on informing the community about the project, understanding priority risks and concerns related to flooding and erosion, and establishing a shared vision for long-term resilience. The outcomes of the engagement process thus far will inform the project in the following ways:

1. Alignment of Preliminary Recommendations with Community Values and Visions

The Project Team will draw in the challenges, tensions, priorities, and long-term visions highlighted by the community to guide and directly inform the development of preliminary approaches for advancing coastal resilience. The preliminary approaches will be further discussed and refined through the second Community Open House planned for early summer 2021.

2. Iteration and Refinement of Solution Development and Prioritization

As the project continues, the Project Team will continue working with the community iteratively to:

- Develop evaluation criteria for the project that can be used to help prioritize specific coastal resilience proposals for implementation.
- Define opportunities for coastal resilience solutions to add value to the community through co-benefits such as new or improved access to the water, economic opportunity, and ecological services, among others.

3. Maintaining Momentum

The momentum and relationships generated through the CRP community engagement process, both on the island between various stakeholder groups, and between the Nantucket community and external stakeholders such as state regulatory agencies, will serve as an ongoing foundation for implementation of and future updates to the CRP.

4 Coastal Hazards on Nantucket

The CRP process involves detailed evaluation of the coastal risks across Nantucket. This evaluation helps the community understand areas that are at risk from coastal hazards such as flooding and erosion, how these hazards will change over time due to sea level rise, how to prioritize areas for adaptation, and what types of adaptation or resilience investments may be necessary and appropriate in each area. This section provides an overview of the types of coastal hazards addressed through the CRP, as well as key terms and data sources that are used to understand the risks they pose to Nantucket.

4.1 Overview of Coastal Hazards

Risk assessment begins with an evaluation of hazards. Understanding the hazards to which Nantucket is exposed and the likelihood or probability of exposure over time helps the community evaluate the degree of risk for buildings, assets, infrastructure, and systems.

Definition of Coastal Hazards

Hazard refers to an event or condition that has the potential to be dangerous or harmful. The CRP focuses on natural hazards driven by coastal processes on Nantucket. The island is affected by four primary types of coastal hazards: high tide flooding, coastal flooding, coastal erosion, and groundwater table rise. Each of these hazards impacts Nantucket today to various degrees, but will become increasingly frequent, damaging, and disruptive in the decades ahead due to sea level rise.

Figure 19. "Sunny Day" tidal flooding on Easy Street in Downtown Nantucket, November 2020

High Tide Flooding

High tide flooding, often referred to as "nuisance" flooding or tidal flooding, is defined by the National Oceanic and Atmospheric Administration (NOAA) as flooding that leads to public inconveniences, such as road closures, overwhelmed storm drains, and deterioration of public infrastructure (e.g., roads). This type of flooding is becoming increasingly common as sea levels rise and land subsides in coastal communities, resulting in a greater likelihood that high tide will overtop existing bulkheads and other coastal structures leading to flooding of inland areas. Nantucket is already experiencing nuisance flooding concerns in certain locations, particularly on Easy Street in Downtown, where a Town report a six-fold increase in the frequency of tidal flooding over the last 40 years. Tide gauge records indicate that since 1963 Nantucket Harbor has experienced 0.14 inches of sea level rise (SLR) per year. The NOAA tide gauge for Nantucket is located on Steamboat Wharf and is one of only a few locations in Massachusetts with localized tracking of historic sea level rise. NOAA also notes that Nantucket is projected to experience higher levels of SLR than the global average, which is consistent with similar SLR projections provided by the Commonwealth of Massachusetts. The rate of rise is projected to accelerate and an additional 1 to 11 feet is expected by the end of the century. The mean SLR expected by 2100 is 4.23 feet, but it should be noted that the mean does not represent an expected outcome based on probabilistic analysis. As sea levels continue to rise, high tide flooding will become an increasingly common and disruptive occurrence across Nantucket without further action to mitigate its impacts.

Figure 20. Coastal flooding in Downtown Nantucket, December 2020

Coastal Flooding

Coastal flooding is defined as the submergence of low-lying land by seawater – often as a result of storm surge. Coastal flooding can occur via multiple pathways, including direct flooding and/or overtopping or breaching of an existing barrier, such as a bulkhead. Climate change, with its associated rise in sea levels, as well as the possibility for an increase in the frequency and/or the intensity of storms and changes in wave climates, can be expected to increase the risks from coastal flooding in most coastal locations, including Nantucket.

Nantucket has previously drawn on a range of flood risk modeling and mapping to evaluate exposure to coastal flooding, including FEMA's Flood Insurance Rate Maps (FIRMs) and associated Flood Insurance Study (FIS) and studies undertaken by local and regional experts, such as the stormtide pathways analysis prepared by the Center for Coastal Studies in Provincetown. The Town's 2020 Coastal Risk Assessment and Resiliency Strategies Report provides an overview of the coastal flood modeling produced for the North Atlantic Coast Comprehensive Study (NACCS) conducted by the United States Army Corps of Engineers (USACE). Based on the robust modeling and the inclusion of a wave setup component in the NACCs data, the report recommends that "figures from the NACCS study should be used for resiliency planning unless more updated water level figures are released in the future." The Commonwealth of Massachusetts is in the process of producing the Massachusetts Coastal Flood Risk Model (MC-FRM) drawing on robust numerical modeling across a range of storm and future climate conditions. These data will be recommended as best available for coastal areas of Massachusetts. More detail on this dataset is included below in **Section 4.2 Coastal Hazard Data Sources**.

Coastal flooding resulting from storm surge can result in significant damage and disruption to homes, businesses, infrastructure, and ecosystems. With six inches of flooding, roadways become unsafe for travel. Waves associated with storms can severely damage buildings and infrastructure located along the coast. Waves and the associated currents also erode unprotected shorelines, which can undermine building foundations and destroy roads and other forms of infrastructure, as discussed in the next section.

Figure 21. Coastal erosion impacting a private access road, September 2020

Coastal Erosion

Erosion is defined as the geological process in which earthen materials, including minerals, rocks, soil, and sand, are worn away and transported by natural forces, such as wind and water. Climate change, with its associated rise in sea levels, as well as the possibility for an increase in the frequency and/or the intensity of storms and changes in wave climates, can be expected to increase the risks of coastal erosion in most coastal locations, including Nantucket.

With Nantucket's shoreline composed primarily of compacted sandy soils, it is and has always been susceptible to coastal erosion. Portions of the island's shorelines have already lost more than one hundred feet of coast depth in just the past decade, and, with SLR, the erosion process is anticipated to accelerate.

Shoreline and dune erosion rates are influenced at several time scales; periodic storm events can cause erosion at orders of magnitude higher than longer terms rates. One important factor is that both sandy beach and dune erosion typically follows a pattern of erosion (storm or seasonal) followed by a period of recovery during which the beach is naturally replenished. Conversely, bluff erosion is generally episodic, occurring during significant storm events and once the bluff slope is eroded, there is no recovery. It should be noted that some bluff erosion factors, like wind, precipitation, and runoff, may be more constant and not episodic. Additionally, structures such as residences on cliff tops increase the bearing weight which can contribute to cliff slope failure. Property owner landscaping practices like replacement of stabilizing vegetation with shallow root species such as grass can also accelerate bluff erosion.

Figure 22. Potential Groundwater Emergence on Brant Point, November 2020

Groundwater Table Rise

Groundwater table (or water table) rise refers to the increase in the level of groundwater underneath a landmass, such as the Island of Nantucket, primarily driven by an increase in sea levels. According to the United States Geological Survey (USGS), coastal water tables will rise as groundwater levels are pushed up by landward intrusions of seawater due to SLR. This consequence of SLR is even more noteworthy in regions with shallow water tables, as SLR can push the water table above the surface, resulting in a phenomenon called groundwater emergence.

Near the shoreline, the groundwater table in unconfined aquifers typically fluctuates with daily tides. The tidal influence on the groundwater table decreases with distance from the shoreline. As sea level rises, the water table will likely rise as well, and, for lower-lying regions with a shallow depth to the water table, this could mean that the groundwater may eventually pond above the land surface, causing inundation even though the area is not at, or directly connected to, the shoreline. The increased groundwater table could create new wetlands and expand others, change surface drainage, expand saturated soil conditions, and/or inundate the land, depending on local topography. Flooding may be especially intense seasonally when high tide coincides with large rainfall events.

A rising groundwater table can cause destabilization of soils and building foundations, subsidence, as well as infiltrate underground utilities. This can result in significant structural damages as soils lose their capacity to bear weight, and cause corrosion and other operations and maintenance challenges for subsurface utilities and foundations.

Figure 23. Stormwater flow and ponding in streets in Downtown Nantucket, November 2020

Precipitation

Precipitation is an important consideration when assessing impacts from coastal flooding and SLR. Climate change projections for the Commonwealth of Massachusetts indicate that precipitation (including both rainfall and snowfall) patterns are changing, and more significant changes in the amount, frequency, and timing of precipitation in future years are anticipated. Increases in total rainfall can impact the frequency of flooding events, especially in areas where stormwater and drainage infrastructure has not been adequately designed to manage the increased flows. In addition to chronic flooding in low lying areas due to high tides, SLR will also impact the ability of the stormwater system to provide adequate drainage as outfall pipes will be submerged more frequently, causing drains to surcharge during heavy rainfall events. This is problematic when stormwater flows onto streets, impacting vehicular traffic, as well as onto properties, resulting in property damage. This study will consider the potential for projected increases in precipitation to exacerbate coastal and nuisance flooding. Additionally, some coastal defense measures can change surface flow drainage patterns and therefore interior drainage systems will need to be accounted for in the design and costing of proposed flood defense infrastructure.

4.2 Coastal Hazard Data Sources

Many datasets are available for assessing coastal hazards on Nantucket, as summarized in **Appendix C**, from a variety of local, state, federal, and private sources. As part of this study, a comprehensive review of the available datasets was conducted in order to reach a recommendation for the best-in-class datasets for the purposes of the CRP. This section outlines the recommended "best available" coastal hazard datasets for Nantucket.

Sea Level Rise Projections and Scenarios

Rising sea levels will exacerbate high tide flooding, coastal flooding, groundwater table rise, and coastal erosion. Although a significant degree of uncertainty exists around the amount of future SLR that can be expected over what time horizon, for planning and design purposes it is often necessary to select specific SLR projections and scenarios based on an evaluation of available data, long-term needs, and risk tolerance. The selected projections must be frequently reevaluated in light of new information.

The analysis of tidal and coastal flooding for the CRP draws on State-specific SLR projections developed by the Commonwealth of Massachusetts in 2018. While the Town draws on SLR projections from National Oceanic and Atmospheric Administration (NOAA) for its interim SLR policy adopted by the Coastal Resilience Advisory Board and Select Board, the data provide by the Commonwealth provide the most up-to-date relative SLR projections for Nantucket. These localized projections are downscaled from regional and international projections using approaches consistent with 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 methodology includes a probabilistic assessment of future sea levels using medium (RCP 4.5) and high (RCP 8.5) greenhouse gas concentration scenarios with considerations for two methods of estimating ice sheet loss based on expert elicitation and process-based numerical models. A full overview of the methodology can be reviewed is the Massachusetts Statewide and Major Basins Climate Projections report (March 2018). **Figure 24** compares the State and NOAA SLR curves and highlights the degree of uncertainty surrounding SLR projections, particularly for long-term projections.

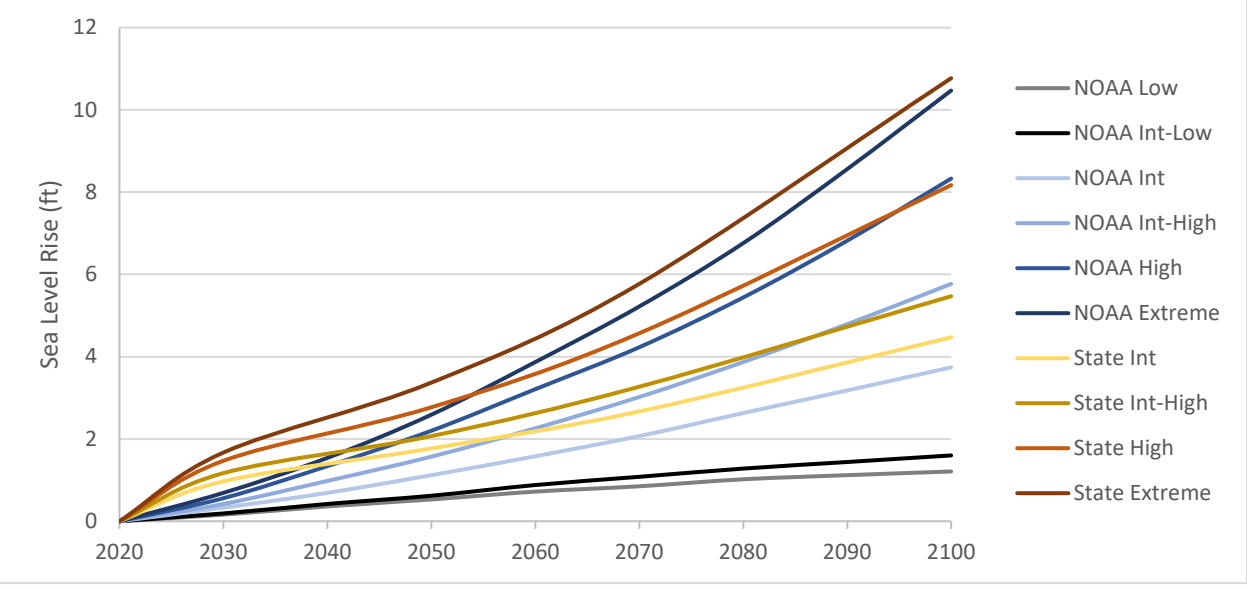


Figure 24. Nantucket SLR projections for NOAA and Massachusetts State methodologies normalized to 2020.

In addition to selecting a set of SLR projections, an individual SLR scenario should also be established for planning and design purposes. The Town has expressed a desire to plan for a **high SLR scenario** from NOAA in the interim SLR Policy. Based on this, the CRP will utilize the high scenario from the Commonwealth's projections.

The recommended adoption of the Commonwealth's high scenario is based on current science and knowledge around anticipated SLR, science and knowledge that are rapidly evolving. Because of the likely future variability in SLR projections as new data and techniques emerge, it is recommended that the Town continually monitor the state of the science and update plans and designs as appropriate based on the latest published, peer-reviewed results.

Coastal Flooding

A number of available datasets from federal, state, and regional entities can be used to examine exposure to coastal flooding, but most are not sufficient for coastal resilience planning due to limited consideration of future conditions, spatial extent, and/or the range of storm intensities.

The Massachusetts Coastal Flood Risk Model (MC-FRM) represents the best available flood hazard data for Nantucket as it is most recent, has the highest spatial resolution, and considers the widest range of present and future storms. This dataset was developed for the Massachusetts Department of Transportation (MassDOT) to assess coastal flood risk to transportation systems and has already been used in vulnerability assessments for Woods Hole and Falmouth, and will be the recommended best available flood hazard data for coastal Massachusetts by the Resilient Massachusetts Action Team. The dataset provides state-wide high resolution annual flood exceedance probability and inundation depth maps based on stillwater flooding for the present, 2030, 2050 and 2070. Projections for 2100 are not available as of the writing this report but are expected later this year. Flood depth maps are provided for 0.1%, 0.5%, and 1% annual exceedance storms.

MC-FRM's numerical modeling uses dynamic coupling of the Advanced Circulation Model (ADCIRC) for water levels and velocities, and Unstructured Simulated Waves Nearshore (UNSWAN) for wave generation and transformation. Modeling also considers wave runup and overtopping along coastal structures for determining inland ponding elevations. Future sea levels are determined using the Commonwealth of Massachusetts' adopted SLR projections, based on the high scenario. Exceedance probability is based on a Monte Carlo simulation of a suite of historic and synthetic storms. The model mesh allows for coarse resolution of the entire Atlantic Ocean and fine resolution (up to 2-3m) along the shoreline statewide.

Coastal Erosion

The response of shoreline change rates to SLR is currently a topic of ongoing research, however, most opinions expect the rate of shoreline erosion to increase with SLR. The erosion study completed by FEMA in 2020 provides projections for future erosion hazards and includes factors for SLR using a methodology based on historic observed erosion rates (feet per year of erosion). The FEMA study provides the "best available" erosion hazard data as it includes both historic erosion data and considers future SLR conditions. However, the FEMA study does not consider the episodic nature of coastal erosion which can be orders of magnitude greater than average yearly rates. This is especially of concern for coastal bluff shorelines that do not recover as beaches and dunes do.

To supplement the FEMA data, additional modeling will be performed at two shoreline locations – one bluff and one sandy beach and dune (the same typologies considered in the FEMA study) – to evaluate beach, dune, and bluff response to infrequent storm event conditions. With the results from the numerical simulations, a comparison to the FEMA projections is made to better understand how infrequent storms are represented by the FEMA methodology.

Groundwater Table

Existing information on groundwater for Nantucket is provided by United States Geological Survey (USGS). USGS manages 10 groundwater wells across the Island. Well depths vary from approximately 21 to 100 feet deep. The most recent measurements were on December 16, 2020, with water tables varying from as shallow as 5.42 feet below the land surface (“BLS”) on the western part of the Island in Madaket, to 44.23 BLS near Nantucket Memorial Airport. The groundwater assessment for the Nantucket CRP leverages the data publicly available from USGS.

5 Coastal Risk and Exposure Analysis

Risk is the potential for a hazard to have negative impacts. In terms of flooding and erosion, this means the potential for water or shoreline change to create damage and disruption to buildings, assets, and systems. Coastal risk represents the interaction between coastal hazards, where people live and work, and the systems and structures that support the way of life that Nantucket cherishes. Climate change is going to increase coastal risks over the coming century and beyond, due to sea level rise, more intense and frequent storms, as well as other factors not directly considered as part of this study.

The purpose of the risk assessment is to analyze and communicate this risk so that the Nantucket community can take proactive steps towards mitigation before coastal hazards cause significant damage and disruption. Additional information on the methodologies and assumptions used for the risk analysis is provided in **Appendix D**.

5.1 Goals of the Analysis

The overarching goal of the coastal flood and erosion risk analysis is to quantify and understand the risk to buildings, infrastructure, assets and services, and natural resources on Nantucket under a scenario in which no actions are taken by either the Town or private property owners to reduce risk. For structures, this information is presented in terms of direct physical damage to buildings and contents, impacts to residents, and economic losses to workers, businesses, and the Town. The methods used for the analysis account for increasing risk over time by estimating each structure's risk due to flooding and erosion in 2020, 2030, 2050, and 2070, assuming 4.3 feet of sea level rise by 2070. Risk is then interpolated for each year between 2020 and 2070 to develop a full understanding of the changing risk. Expected cumulative losses are calculated and communicated in net present value at various scales, from defined geographical areas to individual structures. For linear infrastructure, such as roads and sewers, and other resources, such as parks and open space, risk is presented in terms of exposure and anticipated loss of service under various flood and erosion scenarios. Based on the analysis, areas of concentrated risk can be identified to help inform the location of coastal resilience infrastructure and/or adoption of new regulations. The risk analysis results are also used to help communicate risk to the public, as well as to evaluate the cost effectiveness of resilience approaches and designs.

Risk to structures on Nantucket is provided in dollar values (net present value with a 3% discount rate) to summarize expected cumulative losses from today to 2070 due to both flooding and erosion. This analysis includes all flood and erosion scenarios, based on available date, that could impact a structure each year. The dollar values provide a basis for comparing expected losses to the cost of interventions to prevent those losses.

Coastal Risk Analysis Goals

Goal 1: Understand and help communicate risk to buildings, infrastructure, community assets and services, and natural resources across Nantucket due to coastal flooding and erosion today and in the future.

Goal 2: Help make the case for investments in coastal resilience by quantitatively assessing the impact of coastal flood and erosion damage if no flood protection or erosion control infrastructure is built**.**

Goal 3: Understand long-term exposure to and losses from flooding and erosion across the island.

5.2 How to Use and Understand the Results of the Coastal Risk Analysis

The results of the coastal risk analysis presented below can be used in a variety of ways to inform risk-based decision making and coastal resilience planning. Before presenting the results of the analysis, it is helpful to first put the analysis in the appropriate context and describe how the results can and will be used for the CRP and other purposes to advance resilience and adaptation objectives on Nantucket.

For General Planning

The primary purpose of the coastal risk analysis performed for the CRP is to inform general planning. The results of the analysis can be used in a variety of ways for planning projects, including public communication of coastal risks, prioritization of areas for additional analysis and intervention based on concentrated coastal risk, understanding of risk for specific structures, assets, or services, and as the basis of developing cost-effective approaches for reducing risk through policy or structural changes. The analysis can also be used to guide general land use planning and policy changes to align development and environmental regulations with present and future coastal risks.

For Scenario Development and Prioritization

An important result of the risk analysis is a data-driven understanding of how risk and exposure will change over time, both in terms of the depth and extent of flooding and changes to the shoreline due to erosion. These changes in risk over time allow Town policymakers and review bodies to better understand what may happen if no actions are taken to reduce risk over time. This no action scenario provides the basis for developing additional scenarios that do involve investments in coastal risk reduction and adaptation. Because the results of the analysis are presented in terms of dollars, the benefits that various adaptation scenarios provide can be quantified in terms of loss avoidance. This in turn can be used to prioritize projects based on effectiveness and benefits, along with other considerations and community input.

For Capital Planning

The risk analysis can also be used for the purposes of understanding the risk to specific assets or infrastructure systems, such as roadways, bridges, sewers, and public buildings, and to areas where these assets and systems

may be planned in the future. Town staff and other review bodies can use the results of the analysis to prioritize assets and infrastructure for adaptation or relocation based on the timing and degree of risk exposure. This information can also be integrated as a screening tool within the current Capital Improvement Planning processes to create alignment between capital expenditure, infrastructure needs, and present and future coastal risks.

For Addressing the Needs of the Most Vulnerable

Historical legacies of disinvestment, inequities in access to quality jobs, housing, and healthcare, and barriers to participation in public processes mean that some Nantucket residents and visitors are more vulnerable than others to the immediate and long-term impacts of flooding and erosion. By combining the results of the coastal risk analysis with information on factors that may contribute to social or economic vulnerability, interventions can be targeted for areas that best advance risk reduction for those most in need.

Key Definitions for Understanding Quantitative Risk

The glossary below defines a number of terms used in the following section in reference to risk quantification.

Direct Physical Damages are the sum of the damages to buildings and their contents.

Direct Economic and Social Disruption includes economic losses such as output (which includes wages paid, business income, taxes on production and imports, and other property income) as well as social disruption costs such as the cost of mental stress, injury, lost productivity, and relocation.

Total Direct Losses are the sum of direct physical damages and direct economic and social disruption.

Indirect and Induced Losses are calculated for the area to give greater insight into the regional economic impacts.

- **Indirect Economic Losses** are due to business-to-business purchases in the supply chain.
- **Induced Economic Losses** are due to effects stemming from household income spending, after removal of taxes, savings, and commuter income.

Total Losses are the sum of direct, indirect, and induced losses.

Output represents the value of industry production, which includes employee compensation, proprietor income, taxes on production and imports, and other property income.

Infrastructure and service loss impacts are not quantified in dollar values. Any values referencing infrastructure (such as transportation) are in reference to industry impacts, not service loss or damage to unique structures.

Exposure represents as assessment of people, property, assets, and infrastructure exposed to a hazard and often represented quantitatively though counts of buildings, people, and/or infrastructure exposed.

5.3 Key Findings

Risk from coastal hazards on Nantucket is significant and will grow over time. The key findings from the risk and exposure analysis are summarized below. Additional discussion of these findings is provided in subsequent sections of this report.

If no flood or erosion mitigation is implemented on Nantucket,

- **From now through 2070, 3,438 structures** are at risk from flooding and erosion, with the cumulative expected annual damages totaling **$1.2 Billion**, including:
    - **$932 Million** in **direct physical damage** to buildings
    - **$115 Million** in **direct economic disruption** to businesses in the study area
    - **$61 Million** in **direct social disruption**, including relocation costs, health costs from injuries and mental stress, and lost income due to health issues
    - **$40 Million** in **indirect and induced economic losses**
    - **$19 Million in federal, state, and local tax impacts**
- **86% of at-risk buildings are residential, accounting for 68% of the total risk, and though only 7% of at-risk buildings are commercial, they account for 26% of the total risk**
- **At least 41% of at-risk buildings are historic and account for 64% of the total risk**
- **At least 7% of buildings are tourism-related, accounting for 26% of the total risk**
- **33 community facilities are at risk, with over $46 Million in expected damages. Many of these facilities are essential to community safety and wellbeing.**
- **From now through 2100, the following infrastructure and services may be exposed and at risk of loss of service:**
    - **10 miles of public and private roadway** may be out of service[3] at monthly high tide by 2030, **20 miles** by 2050, **29 miles** by 2070, and **45 miles** by 2100, resulting in impaired access across the island
    - **6 miles of public and private roadway is vulnerable to erosion** by 2030, **33 miles** by 2100, also resulting in impaired access across the island
    - **By 2030, public roadways leading to the Steamship authority wharf could experience a frequent loss of service at monthly high tide. By 2050, the Steamship authority wharf will be completely cut off from surrounding roadways at monthly high tide.** This poses a significant risk to access to and from the island, as well as critical supply lines.
- **From now through 2100, the following open spaces and natural resources will be exposed and at risk of loss of service and/or changes to the ecosystem**
    - **312 acres of public open space** is vulnerable to erosion by 2030 and up to **1,754 acres** could be vulnerable by 2100, reducing opportunities for recreation and enjoyment for the community

[3] Loss of service for roadways is defined as being subject to more than 6 inches of inundation, the depth of water at which it is unsafe to drive to a small passenger car

- **719 acres of priority natural communities** could be impacted by monthly high tide by 2030, **926 acres** by 2050, **1,187 acres** by 2070, and **1573 acres** by 2100, resulting in potential changes to these ecosystems
- Up to **268 additional acres** of wetland resource areas compared to today may be submerged by monthly high tide by 2030, **424 additional acres** by 2050, **645 additional acres** by 2070, and **1,055 additional acres** by 2100. Without plans for marsh migration or other mitigation steps, these resources may be impaired or lost.

5.4 Coastal Risk and Exposure Analysis

This section details the results of the quantitative and qualitative coastal risk analysis. The results are presented in categories that correspond to buildings, infrastructure, and services that support quality of life on Nantucket and sustain it as a community. In addition to quantitative and spatial data, each section presents a brief synopsis of how the risk presented relates to lived experience and potential impacts to health and safety of the population, as well as the unique factors that given Nantucket its character and identity.

Risk to Buildings

At a Glance

- **3,438 structures** at risk from flooding and erosion, with $1.2 billion of damage expected in next 50 years
- **86% of at-risk buildings are residential, accounting for 68% of the total risk, a**nd though only **7% of at-risk buildings are commercial, they account for 26% of the total risk**
- **At least 41%** of buildings are historic, with $710 million in expected damages
- At least 6% of buildings are tourism-related, with $290 million in expected damages
- **33** community facilities at risk, with $**46** million in expected damages

There are over 12,792 buildings on Nantucket. Coastal risks pose an existential threat to many of the buildings that support Nantucket's identity and economy. Over **3,438 structures are at risk of flooding or erosion, totaling $1.2 billion in expected damage over the next 50 years**. Of these, **93% are residences or commercial structures**, meaning that coastal risks will directly and significantly impact the places people on Nantucket live, work, and visit. Also at risk are **33 community facilities totaling more than $46 million in expected damages.** These structure support services that Nantucket relies on for overall community health and wellbeing.

One of the chief goals of the coastal risk assessment is to quantify the risk to buildings and structures on Nantucket due to coastal flooding and erosion. This analysis covered all buildings larger than 500 square feet across all use types and locations, including private residences, Town-owned buildings, shops, restaurants,

offices, and others. Based on a comprehensive building inventory developed using the Town's GIS and assessor's data, analysts determined the number of buildings and structures that are at risk of flooding and erosion from now through 2070.

The flooding analysis estimated the present value of cumulative expected damages over that time frame based on building type and depth of flooding. Direct damages include physical damages, which represent the sum of the damages to buildings and their contents, along with economic and social disruption, which includes economic losses such as wages paid, business income, and other property income, as well as social disruption costs such as the cost of mental stress, injury, lost productivity, and relocation. The methodology for calculating for these metrics are described in detail in Appendix D, and results are summarized below by risk type in **Table 1**.

The results in Table 1 indicate that flooding is the primary driver of risk to structures on Nantucket, with 2,578 buildings at risk of flooding at a total risk of $710 Million. There are an additional 470 buildings at risk of erosion, but not flooding, through 2070 with a total risk of $190 Million. Lastly, 390 buildings are at risk of flooding and erosion, totaling $210 Million. In the cases where a building is at risk of flooding and erosion, annual flood risk is accrued until the building is projected to be lost to erosion, at which point the building is considered a total loss (see Appendix D for more detailed methodology on total loss due to erosion).

The direct economic losses create cascading impacts to business-to-business purchases in the supply chain (known as indirect economic losses), along with impacts to household income spending (known as induced economic impacts). The economic impact also takes a toll on federal, state, and local tax revenue. The indirect and induced losses pile on an additional $40 million of losses, and $19 million in tax revenue impacts, bringing the total losses over the next fifty years up to $1.2 billion. **Figure 25** provides a map of total risk to buildings across Nantucket. The size of the graduated circles correlates to the degree of risk to each building, highlighting areas of concentrated risk.

Table 1. Direct Risk by Hazard Type - Present Value Losses, No Action Scenario. 2020-2070, 3% Discount Rate

Category	Direct Physical Damage	Direct Economic and Social Disruption	Total Risk	Building Count
Flooding Only	$580,000,000	$140,000,000	**$710,000,000**	**2,578**
Erosion Only	$170,000,000	$17,000,000	**$190,000,000**	**470**
Flooding and Erosion	$190,000,000	$21,000,000	**$210,000,000**	**390**
Total	**$930,000,000**	**$180,000,000**	**$1,100,000,000**	**3,438**

Figure 25. (next page) Map showing total risk to buildings across Nantucket and flood and erosion hazard areas. The size of the graduated circles correlates to the degree of risk to each building, highlighting areas of concentrated risk.

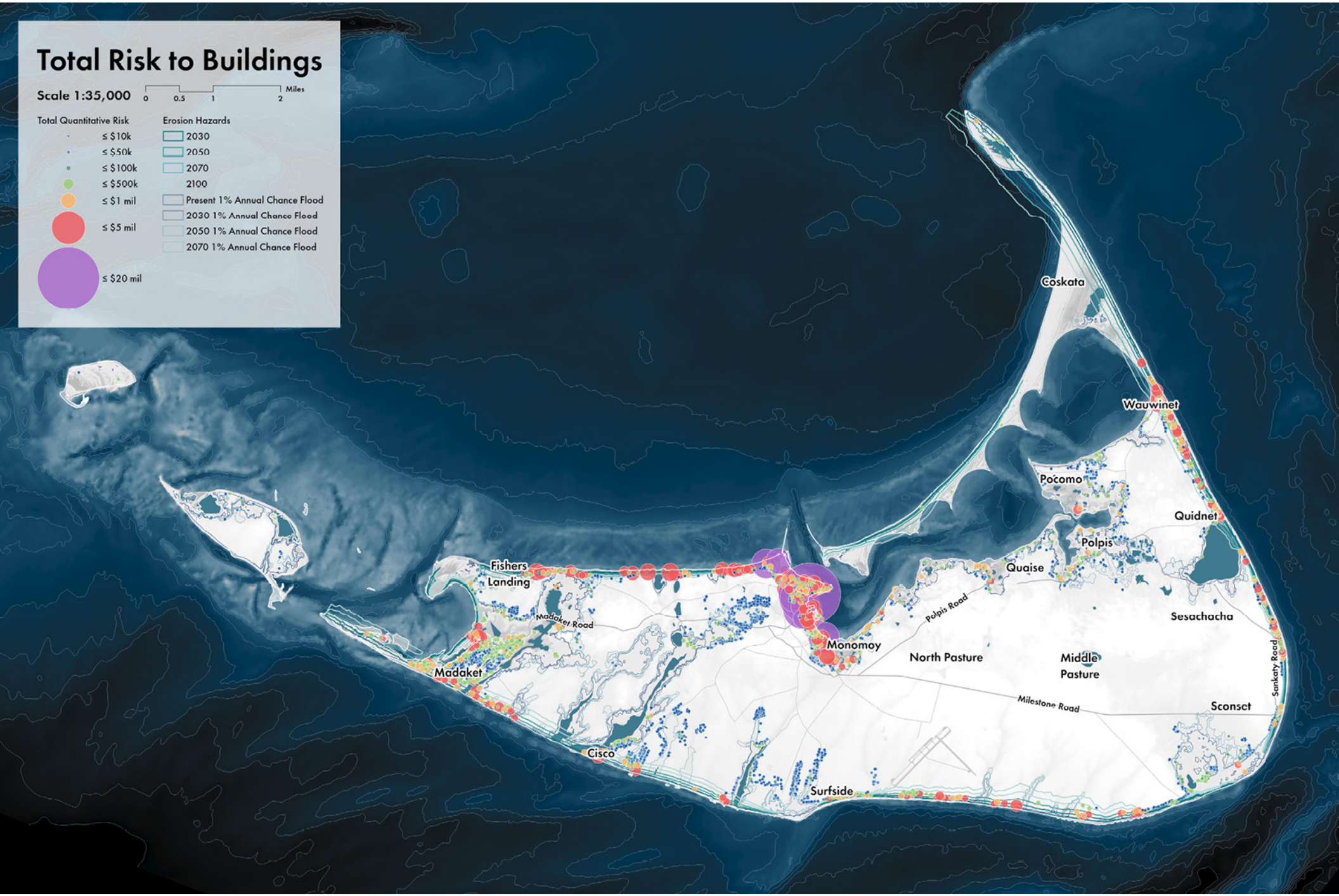

Total Risk to Buildings
Scale 1:35,000
0
0.5
1
2
Miles
Total Quantitative Risk
≤ $10k
≤ $50k
≤ $100k
≤ $500k
≤ $1 mil
≤ $5 mil
≤ $20 mil
Erosion Hazards
2030
2050
2070
2100
Present 1% Annual Chance Flood
2030 1% Annual Chance Flood
2050 1% Annual Chance Flood
2070 1% Annual Chance Flood
Coskata
Wauwinet
Pocomo
Quidnet
Polpis
Quaise
Sesachacha
Fishers Landing
Madaket Road
Polpis Road
Monomoy
North Pasture
Middle Pasture
Madaket
Milestone Road
Sconset
Sankaty Road
Cisco
Surfside

Figure 26 shows a breakdown of the buildings and structures risk by use category. The vast majority of at-risk buildings are private residences (2,973, 86%). Commercial structures, mostly located in Downtown, are the second most impacted use (241, 7%). These data are further broken down by location and structure type in **Appendix E** but are reported in here in summary form. **Figure 27** provides a map of total risk to buildings across Nantucket by year of exposure to the 1% annual chance flood or erosion hazards. The size of the graduated circles correlates to the degree of risk to each building, highlighting areas of concentrated risk. The color of the circle helps show how flood exposure increases over time.

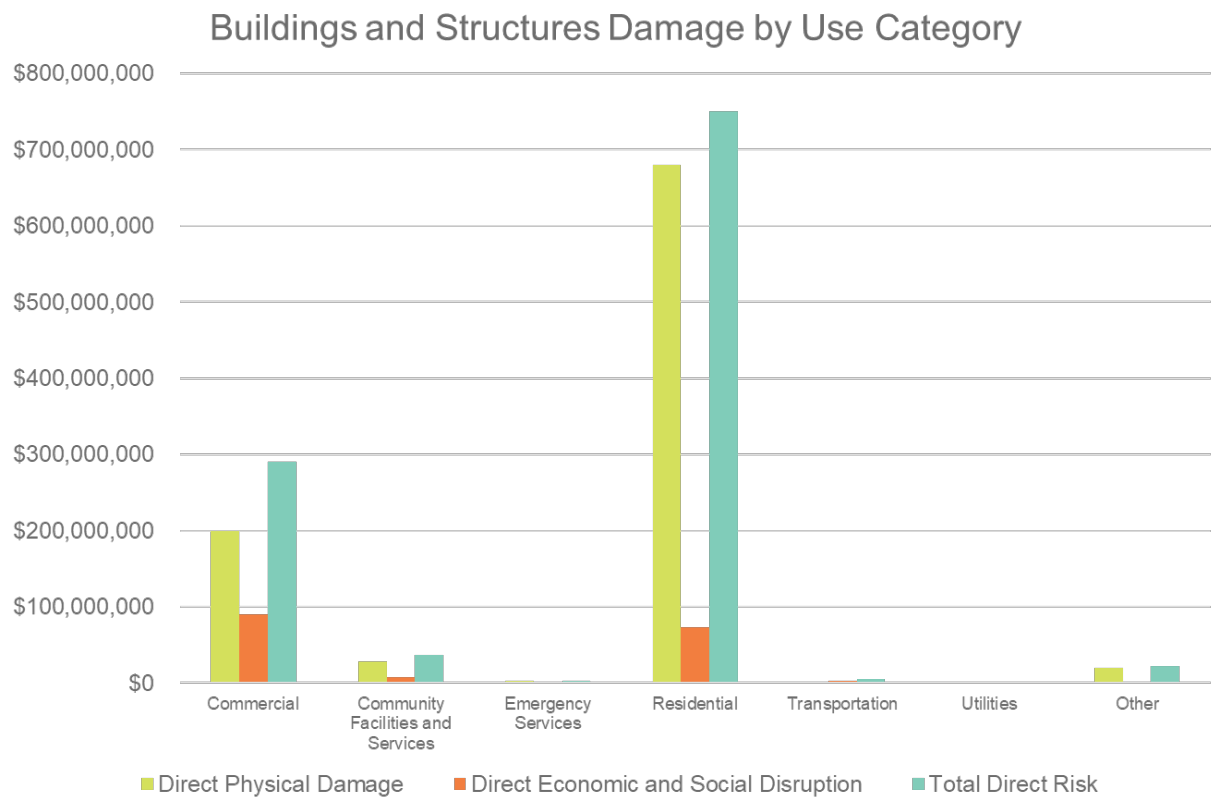
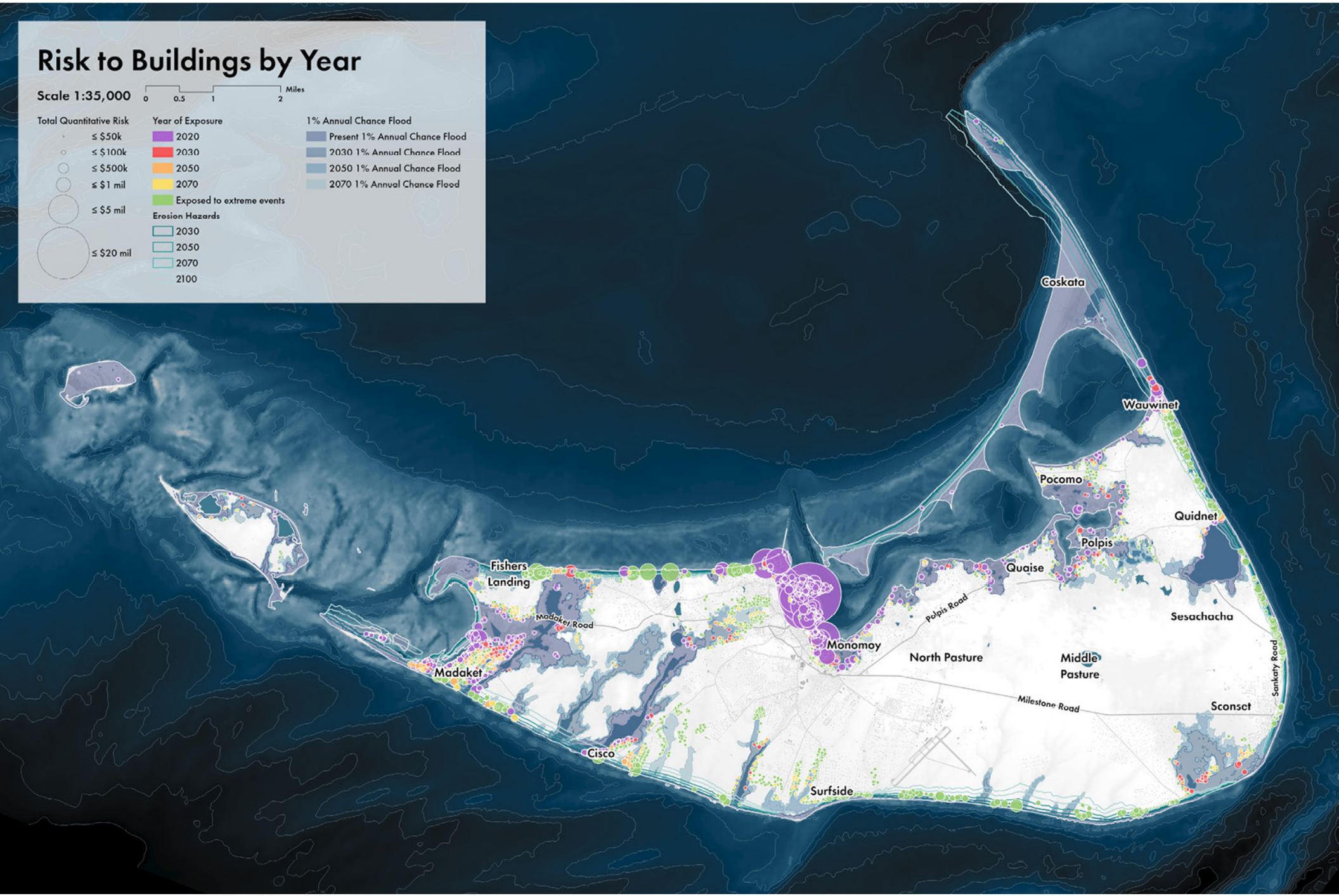


Figure 26. Buildings and Structures Damage by Use Category

Figure 27. (next page) Map showing total risk to buildings across Nantucket by decade of exposure to the 1% annual chance flood or erosion hazards. The size of the graduated circles correlates to the degree of risk to each building, highlighting areas of concentrated risk. The color of the circle helps show how flood exposure increases over time. Green circles represent structures at risk of floods with a lower than 1% annual chance of occurring in a given year.


Risk to Buildings by Year
Scale 1:35,000
0 0.5 1 2 Miles
Total Quantitative Risk
≤ $50k
≤ $100k
≤ $500k
≤ $1 mil
≤ $5 mil
≤ $20 mil
Year of Exposure
2020
2030
2050
2070
Exposed to extreme events
Erosion Hazards
2030
2050
2070
2100
1% Annual Chance Flood
Present 1% Annual Chance Flood
2030 1% Annual Chance Flood
2050 1% Annual Chance Flood
2070 1% Annual Chance Flood
Coskata
Wauwinet
Pocomo
Quidnet
Polpis
Quaise
Sesachacha
Fishers Landing
Madaket Road
Polpis Road
Monomoy
North Pasture
Middle Pasture
Madaket
Milestone Road
Sconset
Sankaty Road
Cisco
Surfside

The analysis also enables further evaluation of risk for certain groupings of structures and uses that support Nantucket's identity and economy, including tourism and historic structures, as described below.

Buildings and Structures Supporting Tourism

The tourism industry is the heart of Nantucket's economy. In addition to world-class beaches and scenery, destinations such as the Whaling Museum, local landmarks such as the Brant Point Lighthouse, and many shops and restaurants located throughout the historic downtown attract thousands of visitors annually. However, many of these destinations are located on the coast, and therefore vulnerable to flooding and erosion. While there are many unquantifiable aspects of Nantucket that make it an attractive destination, one of the ways to measure the risk that coastal hazards pose to Nantucket's future as a destination is to analyze risk to the buildings and structures that support the tourism industry. This can complement other ways of understanding this risk, such as by measuring loss of service of open spaces or roadways that people depend on when they visit Nantucket. **This analysis found that buildings containing uses directly supporting the tourism industry (e.g., hotels, restaurants, car rental shops, museums) represent approximately 26% of total risk on Nantucket and 6% of buildings at risk. Figure 28** shows a breakdown of the buildings and structures risk by use category. Damage or disruption to tourist destinations and supporting uses, whether from flooding or erosion, could have a severe impact on the local economy, especially to year-round residents who rely on tourism for income.

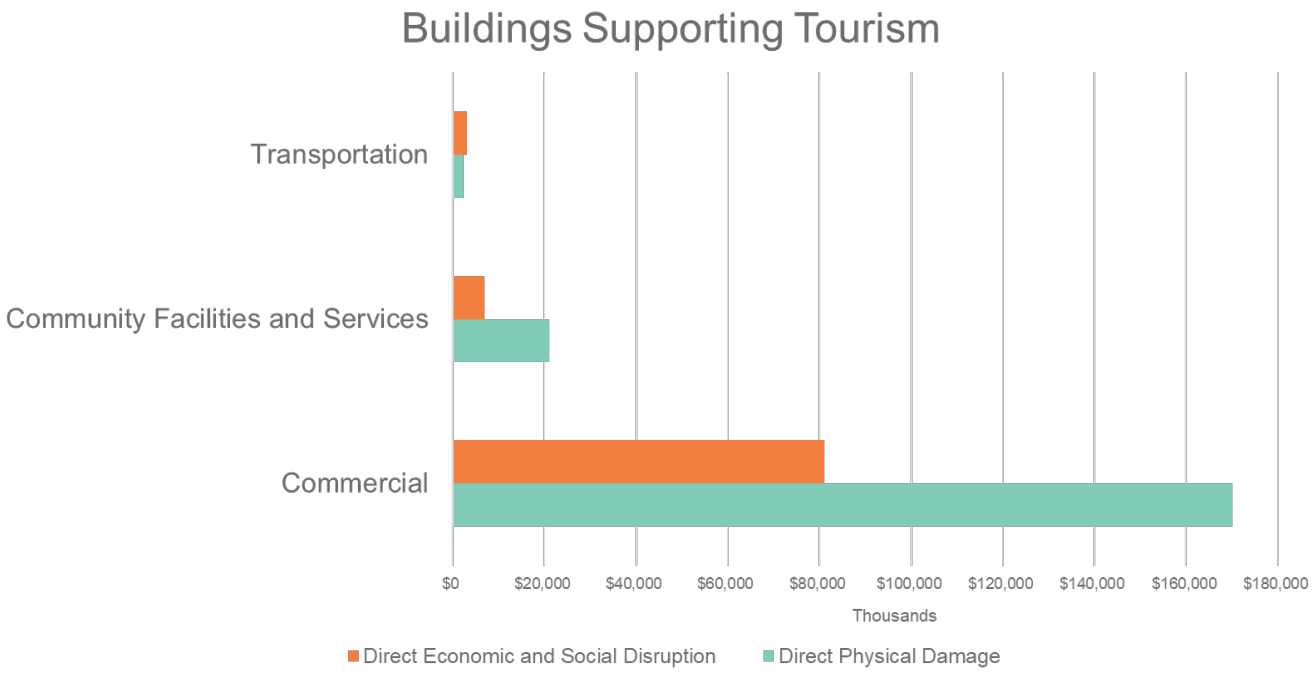


Figure 28. Expected Risk to Buildings Supporting Tourism

Historic Structures

Nantucket is a National Historic Landmark, a testament to the importance of the island to the nation's history and to the character of its built environment. Preserving this character is a top priority for the community and is currently the focus of the *Resilient Nantucket: Designs for Adaptation* project. As addressed through that project, climate change, and sea level rise in particular, raise fundamental questions about what preservation means in the context of environmental risks. While Nantucket's landmark status and historic character are defined by far more than buildings, this analysis found that the risk to buildings that are designated or identified as historic structures on Nantucket is very significant. Buildings located in the two local historic districts (Downtown Nantucket and Siasconset) or included in the Massachusetts Historical Commission inventory of buildings represent **at least 65% of the total risk on Nantucket and 41% of the buildings at risk. The expected damaged to these buildings between now and 2070 totals $710,000,000. Table 2** below summarized risk to historic structures.

Table 2. Expected Damage and Disruption to Historic Structures

Category	Direct Physical Damage	Direct Economic and Social Disruption	Total Risk	Building Count
Downtown Nantucket Historic District	$260,000,000	$94,000,000	**$360,000,000**	**617**
Siasconset Historic District	$7,300,000	$740,000	**$8,100,000**	**69**
MHC Inventory[4]	$300,000,000	$40,000,000	**$340,000,000**	**724**
Total	**$570,000,000**	**$130,000,000**	**$710,000,000**	**1,410**

[4] The Massachusetts Historical Commission inventory includes buildings, structures, and objects with the most common local, state, and federal historic designations as well as structures inventoried by MHC but not designated with one of the previous designations.

Risk to Transportation Systems

At a Glance

- By 2070, **29 miles of roads** on Nantucket will flood with more than 6 inches of water at high tide, and **23 miles of road** will be at risk of loss due to erosion
- **Four bridges will likely lose service due to monthly high tides by 2050**:
  - Madaket Rd. Bridge
  - Madaket Rd Culvert at the Gut
  - N. Cambridge St. Culvert
  - Red Barn Rd. Bridge
- Primary airport buildings are not at risk of flooding or erosion, but the airport could experience damage and disruption to the runway and perimeter fencing over time due to flooding and erosion
- **Steamboat Wharf could be partially cut off from roads at monthly high tide by 2030. By 2050, the wharf will be completely cut off from surrounding roadways at monthly high tide.**

The largest risk to transportation on Nantucket comes from flooding at the Steamboat Wharf. By 2030, the roads leading to the wharf could lose service at the monthly high tide. As one of the only means of traveling to and from the island, and a crucial link in the island's access to goods and services, it has a crucial role in any emergency scenario.

Transportation systems, including roadways, water crossings (bridges and culverts), airports, and ferry terminals are essential to everyday life on Nantucket and to the island's resilience. Not only do these systems enable people to move around the island as they travel to and from work, to visit the homes or friends and family, or to purchase groceries, they also serve as access to the mainland, a key dependency that ensures an uninterrupted flow of the goods and services on which residents rely. Damage and disruption to the transportation system has the potential to reduce quality of life by limiting access to the places people want or need to go and to impact health and safety where access to parts of the island could be cutoff or in the case of access to the mainland being significantly disrupted.

Roadways and Bridges

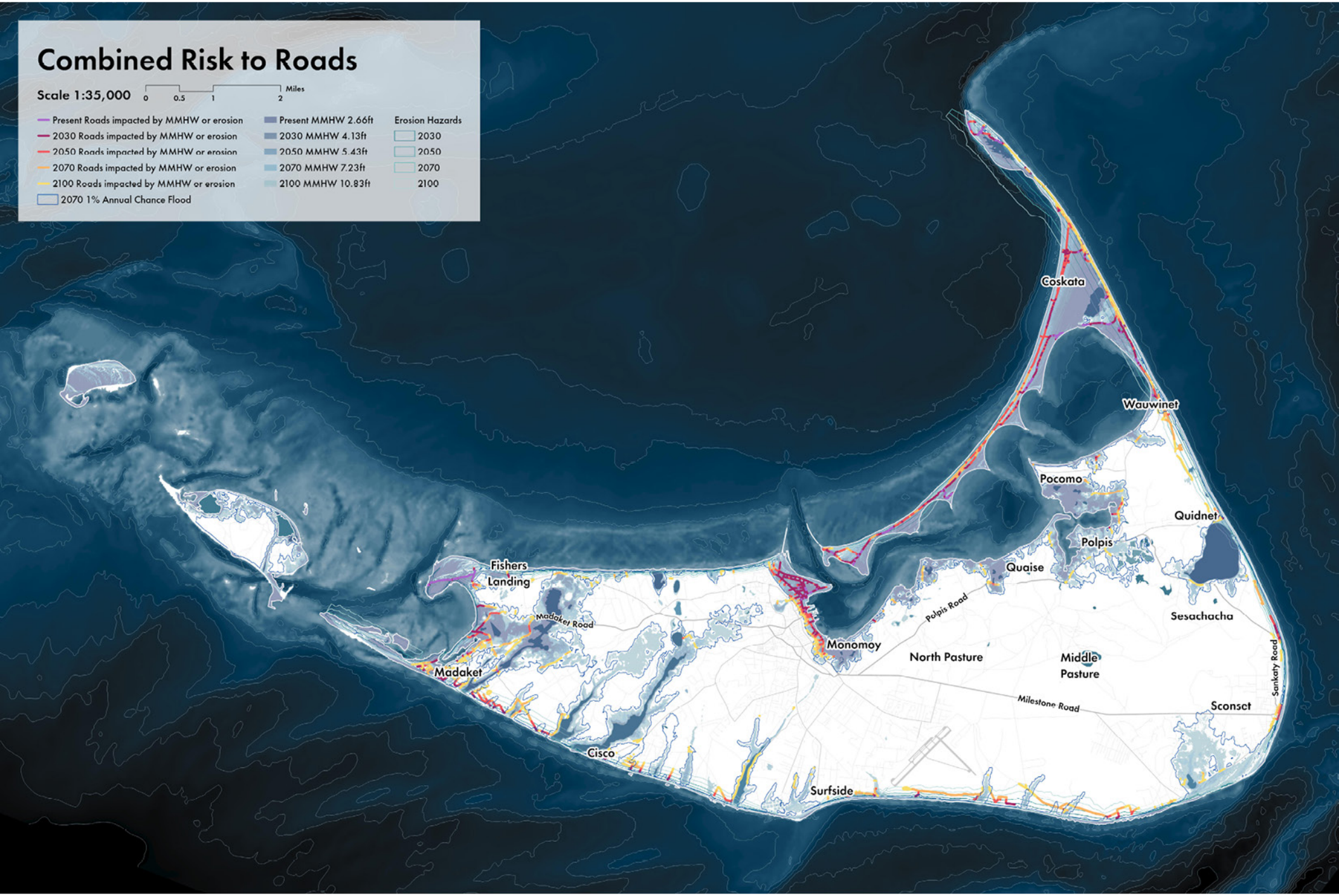
Table 3, below, summarizes the linear miles of roadway that are expected to experience loss of service due to flooding and erosion between 2020 and 2100. Loss of service for flooding is defined as being inundated by 6 or more inches of water or being exposed to loss from erosion. As shown in **Table 3**, by 2030 over 10 miles of roadway could experience reduced or loss of service at monthly high tide. This number grows by roughly 10 miles by 2050 and again by 9 miles by 2070 for a total of 29.1 miles of roadway with lost or reduced service. An even greater number of roadways could be damaged or experience episodic loss of service during a severe coastal flood event (1% annual exceedance probability) between now and 2070. Erosion poses another threat, with up to 23.4 miles of roadway vulnerable from loss from erosion by 2070, much of which is private but nevertheless poses significant risk to residents who rely on these roads for access to their properties.

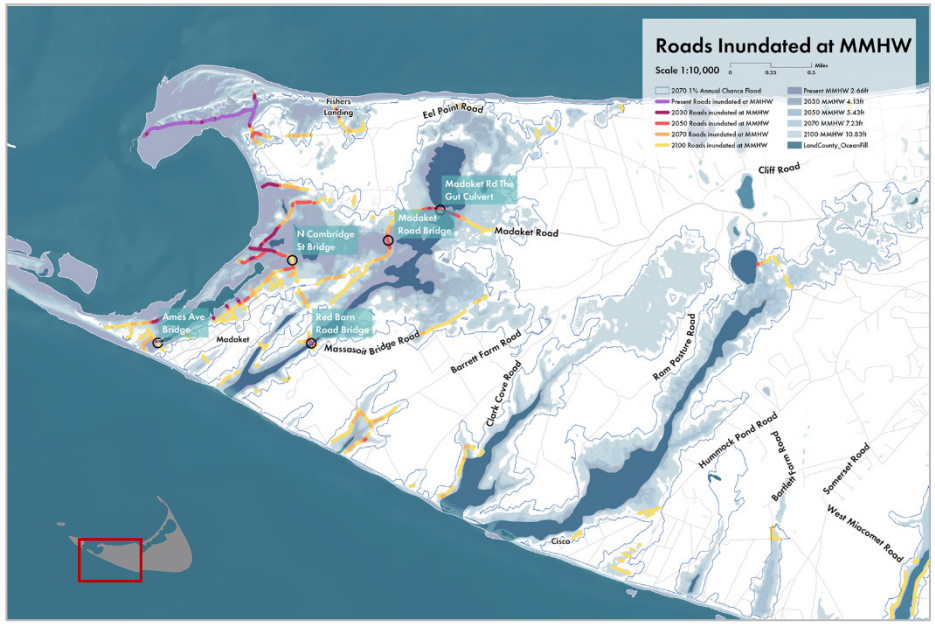
Table 3. Loss of Service for Roadways and Bridges due to MMHW, 1% annual chance storm, and erosion.

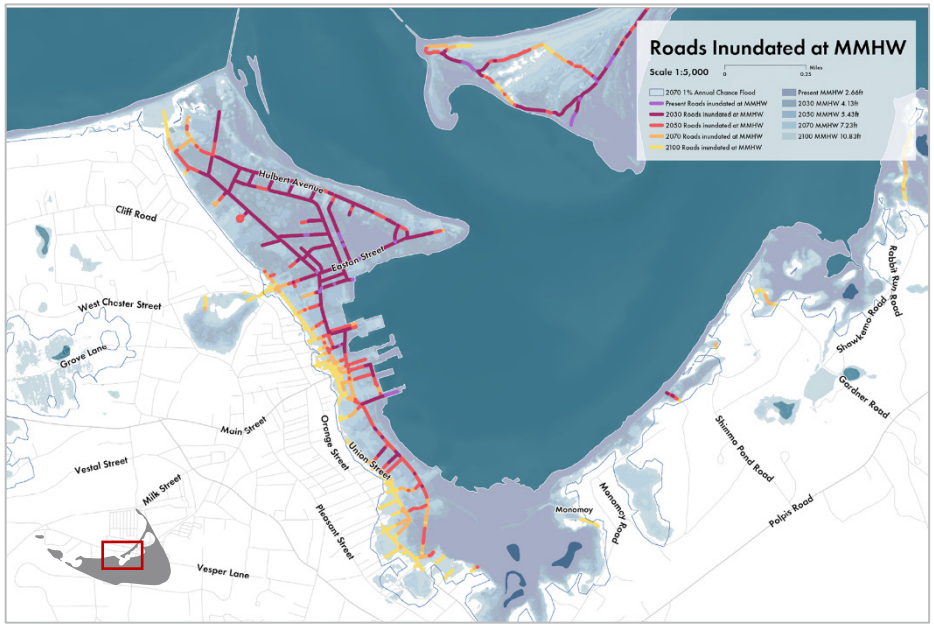
	Loss of Service at Monthly High Tide (miles)					Loss of Service during 1% Annual Chance Storm (miles)					Loss of Service due to Erosion (miles)			
	Today	**2030**	**2050**	**2070**	**2100**	**Today**	**2030**	**2050**	**2070**	**2100**	**2030**	**2050**	**2070**	**2100**
Public	0.1	3.9	6.4	8.9	15.6	12.4	16.1	19.2	22.7	N/A	0.6	2.5	4.6	6.8
Private	0.7	4.4	11.5	17.4	24.2	20.6	23.1	27.4	32.2	N/A	3.1	6.4	14.6	21.8
Unknown	0.9	1.8	2.4	2.8	5.6	6.0	6.8	7.5	8.1	N/A	2.0	3.4	4.2	4.6
Total	**1.7**	**10.1**	**20.3**	**29.1**	**45.4**	**39**	**46**	**54.1**	**63**	**N/A**	**5.7**	**12.3**	**23.4**	**33.2**

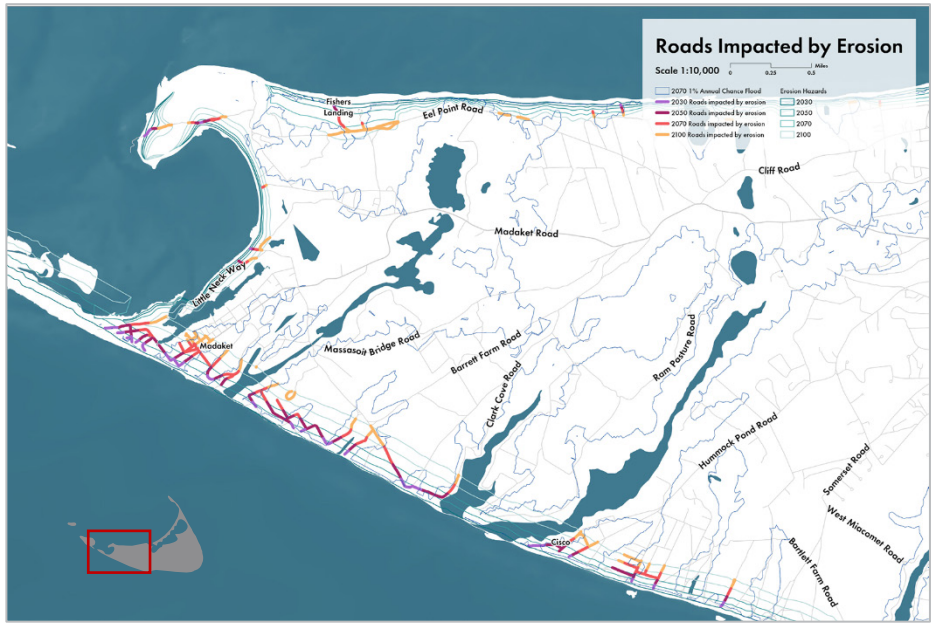
Figure 29. (next page) Map showing roadways at risk of permanent or frequent loss of service due to erosion or inundation during monthly high tides today through 2100.

Figure 30. (following page) Inset maps showing closer views of roadways and bridges at risk of permanent or frequent loss of service due to erosion or inundation during monthly high tides today through 2100.


Combined Risk to Roads
Scale 1:35,000
0
0.5
1
2
Miles
Present Roads impacted by MMHW or erosion
2030 Roads impacted by MMHW or erosion
2050 Roads impacted by MMHW or erosion
2070 Roads impacted by MMHW or erosion
2100 Roads impacted by MMHW or erosion
2070 1% Annual Chance Flood
Present MMHW 2.66ft
2030 MMHW 4.13ft
2050 MMHW 5.43ft
2070 MMHW 7.23ft
2100 MMHW 10.83ft
Erosion Hazards
2030
2050
2070
2100
Coskata
Wauwinet
Pocomo
Quidnet
Polpis
Quaise
Sesachacha
Fishers Landing
Madaket Road
Polpis Road
Monomoy
North Pasture
Middle Pasture
Madaket
Milestone Road
Sconset
Sankaty Road
Cisco
Surfside


Roads Inundated at MMHW
Scale 1:10,000
Fishers Landing
Eel Point Road
Madaket Rd The Gut Culvert
Madaket Road Bridge
N Cambridge St Bridge
Ames Ave Bridge
Red Barn Road Bridge
Madaket
Massasoit Bridge Road
Barrett Farm Road
Clark Cove Road
Ram Pasture Road
Cliff Road
Madaket Road
Hummock Pond Road
Bartlett Farm Road
Somerset Road
West Miacomet Road
Cisco


Roads Inundated at MMHW
Scale 1:5,000
Hulbert Avenue
Cliff Road
Easton Street
West Chester Street
Grove Lane
Main Street
Orange Street
Union Street
Vestal Street
Milk Street
Pleasant Street
Vesper Lane
Monomoy
Monomoy Road
Polpis Road
Shimmo Pond Road
Shawkemo Road
Gardner Road
Robert Ross Road


Roads Impacted by Erosion
Scale 1:10,000
Fishers Landing
Eel Point Road
Cliff Road
Madaket Road
Long Neck Way
Madaket
Massasoit Bridge Road
Barrett Farm Road
Clark Cove Road
Ram Pasture Road
Hummock Pond Road
Somerset Road
West Miacomet Road
Bartlett Farm Road
Cisco

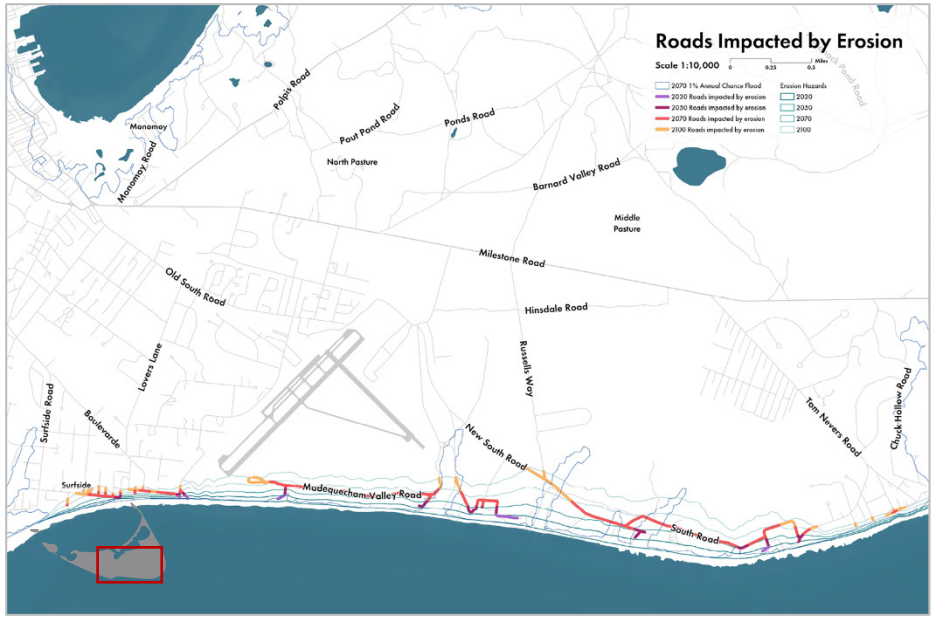

Roads Impacted by Erosion
Scale 1:10,000
Monomoy
Monomoy Road
Polpis Road
Pout Pond Road
Ponds Road
North Pasture
Barnard Valley Road
Middle Pasture
Milestone Road
Old South Road
Hinsdale Road
Lovers Lane
Surfside Road
Boulevarde
Surfside
Russells Way
New South Road
Madequecham Valley Road
South Road
Tom Nevers Road
Chuck Hollow Road

Table 4 below summarizes the timeline for expected loss of service of bridges and culverts due to flooding and erosion between 2020 and 2100. Loss of service for flooding is defined as being inundated by 6 or more inches of water on top of or on the lead up to the bridge or culvert, or being exposed to erosion. Each of these water crossing could be damaged or experience episodic loss of service during a severe coastal flood event today (1% annual exceedance probability), which has important consequences related to access to parts of the island served by these bridges during an emergency, including Madaket and Smith Point. These water crossings are also at risk of loss of service at monthly high tide between 2030 and 2100, the consequence of which would also be reduced access to and potential isolation for parts of the island.

Table 4. Bridges and Culverts - Expected year of loss of use due to MMHW, 1% AEP, and Erosion

Bridge/Culvert	Loss of Service at Monthly High Tide	Loss of Service during 1% Annual Chance Storm	Loss of Service due to Erosion
Ames Ave Bridge	2100	2020	2050
Madaket Rd Bridge	2050	2020	N/A
Madaket Rd Culvert at the Gut	2030	2020	N/A
N Cambridge St Culvert	2050	2020	N/A
Red Barn Rd Bridge	2050	2020	N/A

Nantucket Airport

The Nantucket Airport is located at higher elevation relative to other areas of the island. The primary structures supporting the airport's operations are located inland and therefore are not at risk of coastal flooding or erosion through 2100. However, some of the supporting infrastructure of the airport is at risk, including the fencing around the perimeter, paving at the end of the runway, and land area providing the runway approach. The fencing required by the FAA to surround the airport property could be inundated during Mean Monthly High Water (MMHW) in 2100. This same fencing is also vulnerable to impacts from a 1% annual chance event today and into the future, though the exposure does not substantially increase over time due to the steep elevation change. The fencing is vulnerable to loss due to erosion by 2030 or sooner. The end of the runway paving is vulnerable to loss due to erosion by 2100. **Table 5** below summarizes the flooded or eroded area within the airport fence for current and future flooding and erosion scenarios. **Figure 31** shows areas vulnerable to loss from erosion today through 2100.

Figure 31: Map showing the projected impacts of erosion to property at Nantucket Memorial Airport

Table 5. Expected impacts to Nantucket Airport from flooding and erosion

	Inundation at Monthly High Tide (square feet)		Inundation from 1% Annual Chance Storm (square feet)				Area Lost Due to Erosion (square feet)			
	2070 and earlier	2100	Today	2030	2050	2070	2030	2050	2070	2100
Impacted Area	0	26,383	890	956	1,071	1,280	92,440	279,198	617,308	1,539,228*

** Includes loss of paving at southern end of runway*

Steamboat Wharf - Steamship Authority

The Steamship Authority is Nantucket's strongest tie to the mainland, seeing over 620,000 passengers per year and serving as the primary means by which goods and services reach the island. Steamboat Wharf, located in downtown Nantucket at the intersection of Broad and East Street is the primary berthing location for ferries carrying people, vehicles, and supplies to and from Nantucket. Without an auxiliary docking location for Steamship Authority vessels, the Wharf is one of the most essential pieces of infrastructure on the island. The Wharf itself is higher in elevation (approximately 5.5 feet NAVD88) than the surrounding streets that provide access to it. By 2030, Easy Street may begin experiencing more frequent loss of service at monthly high tide than it does today. By 2050, all roadways (Easy Street, Broad Street, and auxiliary access roads to Steamboat Wharf) are projected to experience loss of service during monthly high tide. By 2070, this may be a daily occurrence. Also by 2070, the Wharf itself is projected to be subject to inundation at monthly high tide.

The Wharf is also exposed to the 1% annual chance coastal flood today and into the future. **Table 6** shows the monetary risk to structures on the wharf from 2020-2070, with a 3% discount rate. This does not include the wharf structure itself. As will be discussed below in **Risk to Essential Community Facilities and Services,** the exposure of access to this critical lifeline, as well as of the Wharf itself, represents a significant risk to the community, with cascading impacts ranging from economic loss due to a drop in island visitors to reduced access to essential supplies, such as food, medicine, and other goods. In the context of a disaster and the subsequent recovery period, this risk becomes even more pronounced as the damage to the Wharf could hamper recovery efforts.

Figure 32: Map showing risk of loss of service during monthly high tide to Steamship Authority operations at Steamboat Wharf from today through 2100.

Table 6. Expected risk to the Steamship Authority

Community Facilities	Direct Physical Damage	Direct Economic and Social Disruption	Total Risk	Building Count
Steamship Authority	$2,300,000	$3,000,000	$5,200,000	3

Risk to Essential Community Faciities and Services

At a Glance

- Essential community facilities are places such as emergency response, grocery stores, schools, that are essential to community safety and wellbeing
- **33 community facilities are at risk over the next 50 years, with over $46 Million in expected damages**
- Each asset was assigned a criticality score and a risk score, and those were used to calculate a priority score
- **Top 5 priority assets**:
  - Steamship Authority
  - Sheriff Office (County) and NRTA
  - Stop & Shop
  - Coast Guard Station Brant Point
  - Nantucket Town Hall, RMV, and Superior Court

Community facilities and services, including the fire department, ferry terminal, police station, schools, grocery stores, places of worship, and more, are the heart of Nantucket. These types of structures and places, and the services they provide, are vital to community health and wellbeing and are integral to the successful recovery of the community after a major disaster.

As shown **Table 7**, 47 total buildings across 33 facilities providing essential services to Nantucket are at risk from flooding and/or erosion by 2070, totaling over $46 million in expected damages. This includes anticipated impacts to services that are essential to community health and safety, such as Steamboat Wharf and fire and police stations, as well as places that bring joy and entertainment, such as the Whaling Museum. It is also important to note the risk of damage and loss of service to one of the island's two major grocery stores. While food is available from a variety of local markets spread across the island, the larger grocery stores (one located Downtown and the other Mid Island) are the primary sources of food for residents and visitors. It is imperative to understand the risk that these facilities and services face so that measures can be taken to ensure that are able to serve their functions without disruption.

Table 7. Present value losses, no action scenario, 2020-2070, 3% discount rate

Community Facilities	Direct Physical Damage	Direct Economic and Social Disruption	Total Risk – Flooding and Erosion	Building Count
Coast Guard	$1,300,000	$91,000	$1,400,000	2
College Facilities	$950,000	$6,800	$960,000	5
Town Concessions	$5,400,000	$3,200,000	$8,700,000	5
Steamboat Wharf/ Steamship Authority	$2,300,000	$3,000,000	$5,200,000	3
Fire Station	$42,000	$810	$42,000	1
Grocery Stores	$3,100,000	$2,200,000	$5,300,000	1
Town Housing	$1,400,000	$340,000	$1,700,000	3
Libraries/Museums	$11,000,000	$1,000,000	$12,000,000	8
Lighthouses	$1,300,000	$420,000	$1,700,000	6
Long-term Care	$1,600,000	$880,000	$2,400,000	1
Places of Worship	$350,000	$19,000	$360,000	2
Police Station	$1,400,000	$100,000	$1,500,000	1
Post Office	$560,000	$43,000	$610,000	1
Power Facilities	$610,000	$59,000	$670,000	1
Town Administration	$2,900,000	$170,000	$3,100,000	2
Waste Facilities	$190,000	$64,000	$250,000	5
Total	**$34,402,000.00**	**$11,593,610.00**	**$45,892,000.00**	**47**

As part of the risk assessment, each community asset or facility was also assigned a criticality score, calculated based on several factors. Criticality refers to the importance of an asset in the event of a flood. For example, evacuation prior to a storm is often necessary, so transportation to the mainland from Nantucket would be considered highly critical to the safety of residents.

One tool that informs this analysis is the Flood Design Class (FDC), as described in ASCE 24-14. The FDC is a number from 1-4 that determines what level of protection a building is required to have, with 4 being the highest level of protection. In this analysis, it is used as an analog for criticality.

The most important factor in criticality determinations is the use of the facility in question. If a facility is involved in emergency response or public health, it will necessitate a higher criticality score, as its loss of function would impact many residents. For this analysis, we assigned each facility a primary function from this list:

- Infrastructure (6)
- Emergency Response (8)
- Public Health, Safety, Physical Well-Being (4)
- Quality of Life (1)
- Ecosystem/Environmental Health (3)

The numbers in parentheses represent the weight given to each category. Primary functions were given 3 points, secondary functions 2 points, and tertiary functions 1 point. The category weight was then multiplied by the function scores, summed, and multiplied by the facility's FDC. Additional points were given to facilities with an impact on social equity, and facilities owned by the Town.

This criticality scoring resulted in the below top 5 most critical facilities shown in **Table 8**.

Table 8. Top 5 facilities by criticality score

Facility	Criticality Score
Nantucket Memorial Airport	152
Steamship Authority	148
Sheriff Office (County) and NRTA	140
Public Safety Facility & IT Department	140
State Police Station D-6	140

Next, using the results of the quantitative risk analysis, each facility was given a risk score, in the form of a percent of total risk. The top five facilities by risk are shown in **Table 9**.

Table 9. Top 5 facilities by risk score

Facility	Risk Score
Whaling Museum	16%
Jetties Concession Building	14%
Stop & Shop	12%
Steamship Authority	11%
Nantucket Town Hall, RMV, and Superior Court	6%

The criticality scores were then multiplied by the risk scores to calculate the priority score for each facility. The top five facilities by priority are shown in **Table 10**.

Table 10. Top 5 facilities by priority score

Facility	Priority Score
Steamship Authority	16.88
Sheriff Office (County) and NRTA	4.57
Stop & Shop	4.50
Coast Guard Station Brant Point	3.99
Nantucket Town Hall, RMV, and Superior Court	1.92

This ranking scoring of risk based on criticality can be used as framework for prioritizing assets and services for risk reduction and adaptive measure, including new flood risk mitigation steps, relocation of facilities or assets, or creation of redundant systems to provide service if the primary facility or service experiences loss of function. Recommendations for these types of actions will be included in the CRP based on the prioritization scores included here and in **Appendix F.**

Risk to Utilities

At a Glance

- **1 substation building and 4 wastewater treatment buildings** on Nantucket are at risk of flooding due to the monthly high tide by 2050.
- By 2100, **3.5 miles of water and sewer lines** could be lost to erosion

Flooding to subgrade infrastructure can be especially difficult to quantify, and expensive to repair and remediate, given the number of unknowns often associated with these systems. Saltwater flooding has the potential to disrupt access to these essential utilities and can accelerate deterioration, necessitating more frequent maintenance and higher operating costs. Erosions poses a more direct threat, where portions of the systems can be exposed and lost during severe events.

Nantucket is served by a variety of utilities systems, many of which are located below ground and designed to manage water. The stormwater and wastewater systems on the island are critical to both the health and safety of residents, and the health of local ecosystems.

Information on the location of the water management system on Nantucket is limited, but it is helpful to map exposure to direct more detailed analysis of specific vulnerabilities. With proper operation and maintenance, most storm sewers, water mains, and other linear utilities can withstand periodic impacts from flooding. However, drainage networks can also serve as conduits for flooding. With no backflow preventers in place, sewer outfalls and storm drains can back up with sea water, causing flooding in basements, streets, and buildings. For example, a Town-led study of tidal flooding on Easy Street in Downtown Nantucket identified the need for new duck bill tide gates to reduce the risk that water from the harbor could enter the drainage network and flood adjacent roadways.

In addition to subgrade infrastructure, some utilities, most notably the electrical grid and solid waste management, depend upon infrastructure that is located above ground in structures. Damage or disruption to these structures from either flooding or erosion can have cascading downstream and upstream impacts such as a loss of electricity to critical facilities. Impacts to solid waste management facilities can cause disruption to waste collection and disposal, which would have an outsized impact on an island the size of Nantucket.

To analyze the risk to utilities on Nantucket, analysts reviewed the following:

- Exposure of buildings and structures that provide utility services
- Counts of buildings exposed to any flooding under the scenarios below.
- Feet of linear utilities potentially exposed

Under the no action scenario, a number of facilities related to utility systems will be exposed to flooding and erosion. **Table 11** summarizes the timeline for expected loss of service due to tidal flooding and coastal flooding. Note that the tables do not convey the extent of cascading impacts to other services on the island, such as power outages, but do capture risks that lead to these cascading impacts. For example, loss of service to the electrical substation located downtown could result in loss of power over portions of the island which in turn presents additional risks, such as loss of service for facilities that do not have backup power supplies.

Table 11. Expected exposure to flooding and erosion for utility facilities

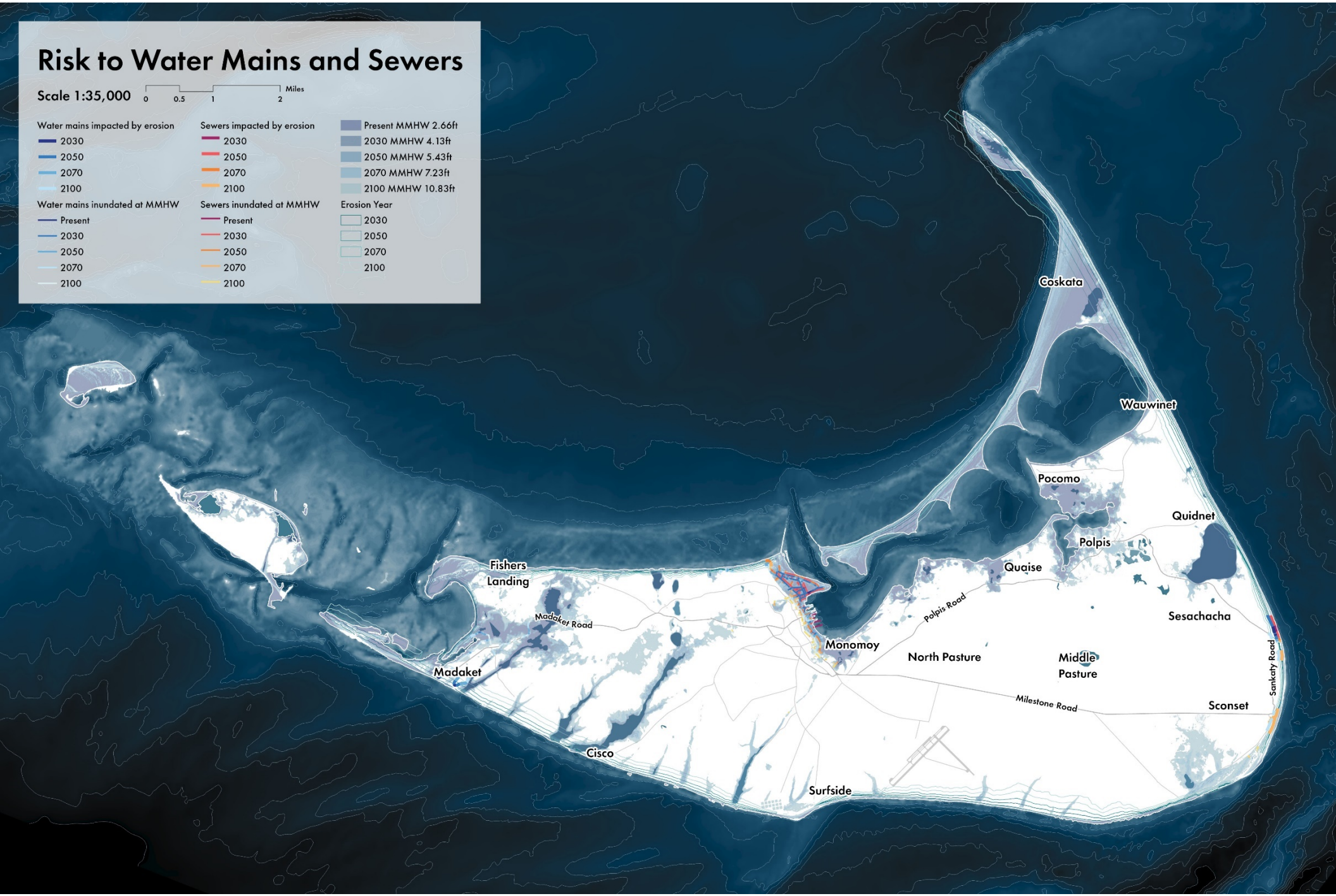
Utility	Number of Buildings	Monthly High Tide	1% AEP Coastal Flood	Erosion
Downtown Electrical Substation	1	2050	2020	N/A
Nantucket Solid Waste MGT Facility	4	2050	2070	N/A

Under the no action scenario, a number of utility systems will be exposed to flooding and erosion. As noted above, these systems exist largely below grade but are included here to document potential exposure of the system or access to the system from overland flooding and/or erosion. **Table 12** summarizes the linear miles of utilities that are expected to experience loss of service due to flooding and erosion between 2020 and 2100. Loss of service for flooding is defined as being inundated by 6 or more inches of water or falling outside of a projected erosion hazard line for a given decade.

Table 12. Expected disruption to sewer and water service due to flooding and erosion

	Damage or Disruption during 1% Annual Chance Storm (linear miles)				Damage or Disruption at Monthly High Tide (linear miles)					Loss Due to Erosion (linear miles)			
	Today	2030	2050	2070	Today	2030	2050	2070	2100	2030	2050	2070	2100
Sewer	8.0	8.6	9.4	11.0	0.5	3.5	5.6	7.0	9.0	0.1	0.4	0.5	1.1
Water	9.7	10.9	12.3	14.7	0.3	3.5	5.8	7.4	10.9	0.2	0.7	1.3	2.4
Total	**17.7**	**19.5**	**21.7**	**25.7**	**0.8**	**7**	**11.4**	**14.4**	**19.9**	**0.3**	**1.1**	**1.8**	**3.5**

Figure 33. (next page) Map showing known Town-owned water mains and sewers exposed to flooding at monthly high tide and erosion today through 2100


Risk to Water Mains and Sewers
Scale 1:35,000
0
0.5
1
2
Miles
Water mains impacted by erosion
2030
2050
2070
2100
Sewers impacted by erosion
2030
2050
2070
2100
Present MMHW 2.66ft
2030 MMHW 4.13ft
2050 MMHW 5.43ft
2070 MMHW 7.23ft
2100 MMHW 10.83ft
Water mains inundated at MMHW
Present
2030
2050
2070
2100
Sewers inundated at MMHW
Present
2030
2050
2070
2100
Erosion Year
2030
2050
2070
2100
Coskata
Wauwinet
Pocomo
Quidnet
Polpis
Quaise
Sesachacha
Polpis Road
Fishers Landing
Madaket Road
Monomoy
North Pasture
Middle Pasture
Madaket
Milestone Road
Sconset
Sankaty Road
Cisco
Surfside

Risk to Parks and Open Space

At a Glance

- **2,878 acres of open space** will be impacted by the monthly high tide by 2070
- **4,487 acres of open space** will be at risk due to the 1% annual chance storm by 2070
- **1,754 acres of open space** will be disrupted by erosion by 2100

Conservation and protection of open space have long been important values to Nantucket residents. While the island has significant open space resources enjoyed by all, coastal risks will threaten these resources over time, impacting the community's health and wellbeing. Erosion poses the most direct risk due to the potential for loss of land area, but reduced access and impacts to ecological services due to coastal flooding and flooding at high tide also threatens public enjoyment, community wellbeing, ecosystem health.

There are over 17,000 acres of parks and open space on Nantucket. The majority of that open space (74%) is controlled by private entities and land trusts, including the Nantucket Land Bank and Nantucket Conservation Foundation (Nantucket's largest landowner). Conservation of open space has long been one of the most important values for Nantucket residents, leading, for example, to the creation of the Nantucket Land Bank in 1983, the first such entity in the United States. This structure has resulted in roughly half of the land on Nantucket being protected open space.

Publicly accessible open space, owned by both private and public entities, provides many benefits to the Nantucket community, including aquifer protection, wildlife habitat, recreation, and increased property values. However, much of the island's open space will be at risk as sea levels continue to rise and erosion worsens. By 2070, 2,878 acres of open space will experience disruption due to the monthly high tide, increasing to 4,054 acres in 2100. Even more open space will be at risk during the 1% annual chance storm, as shown below.

The graphs below **Figure 34, Figure 35, Figure 36** summarize the acreage of open space that is expected to experience loss of service due to flooding between 2020 and 2100. **Figure 37** shows exposure of parks and open spaces to flooding from monthly high tide and coastal storms today through 2100.

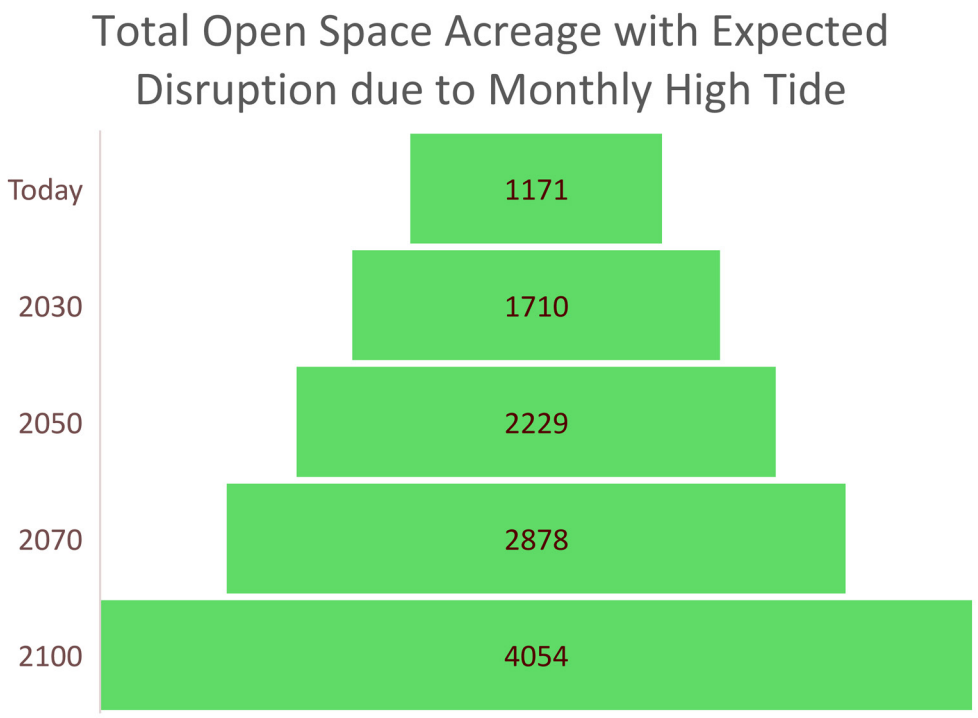


Figure 34. Open space disruption due at Monthly High Tide

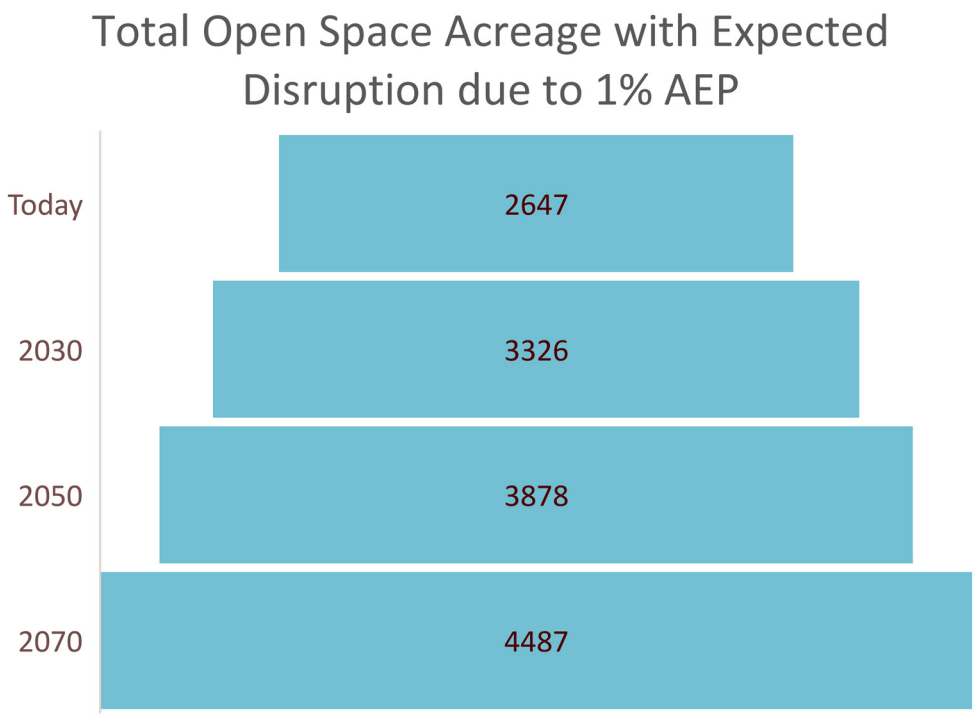


Figure 35. Open space disruption due to 1% AEP storm

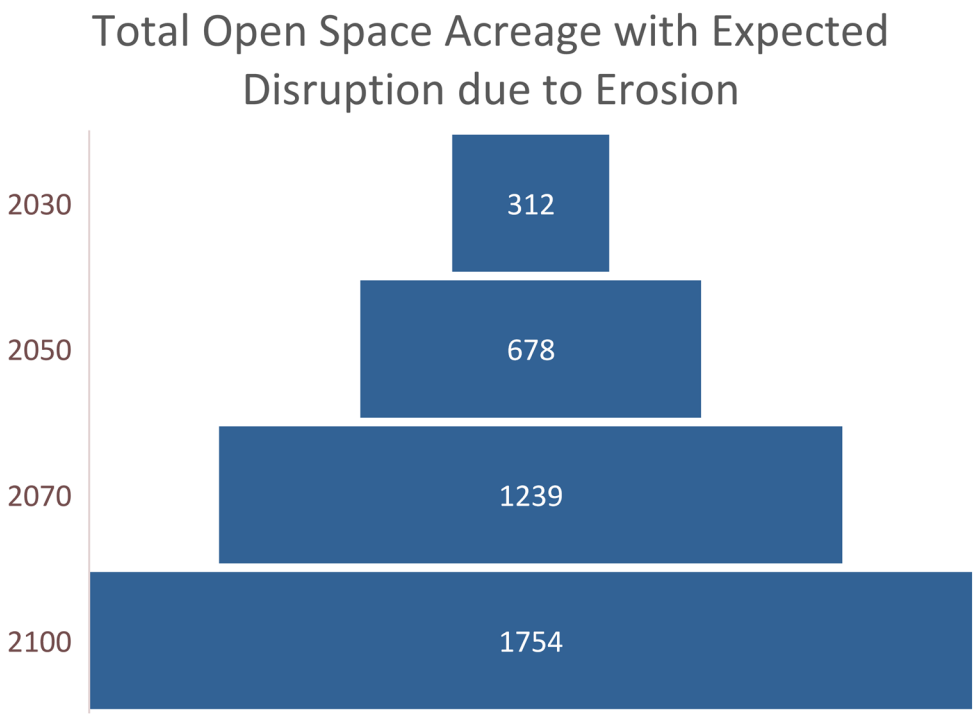
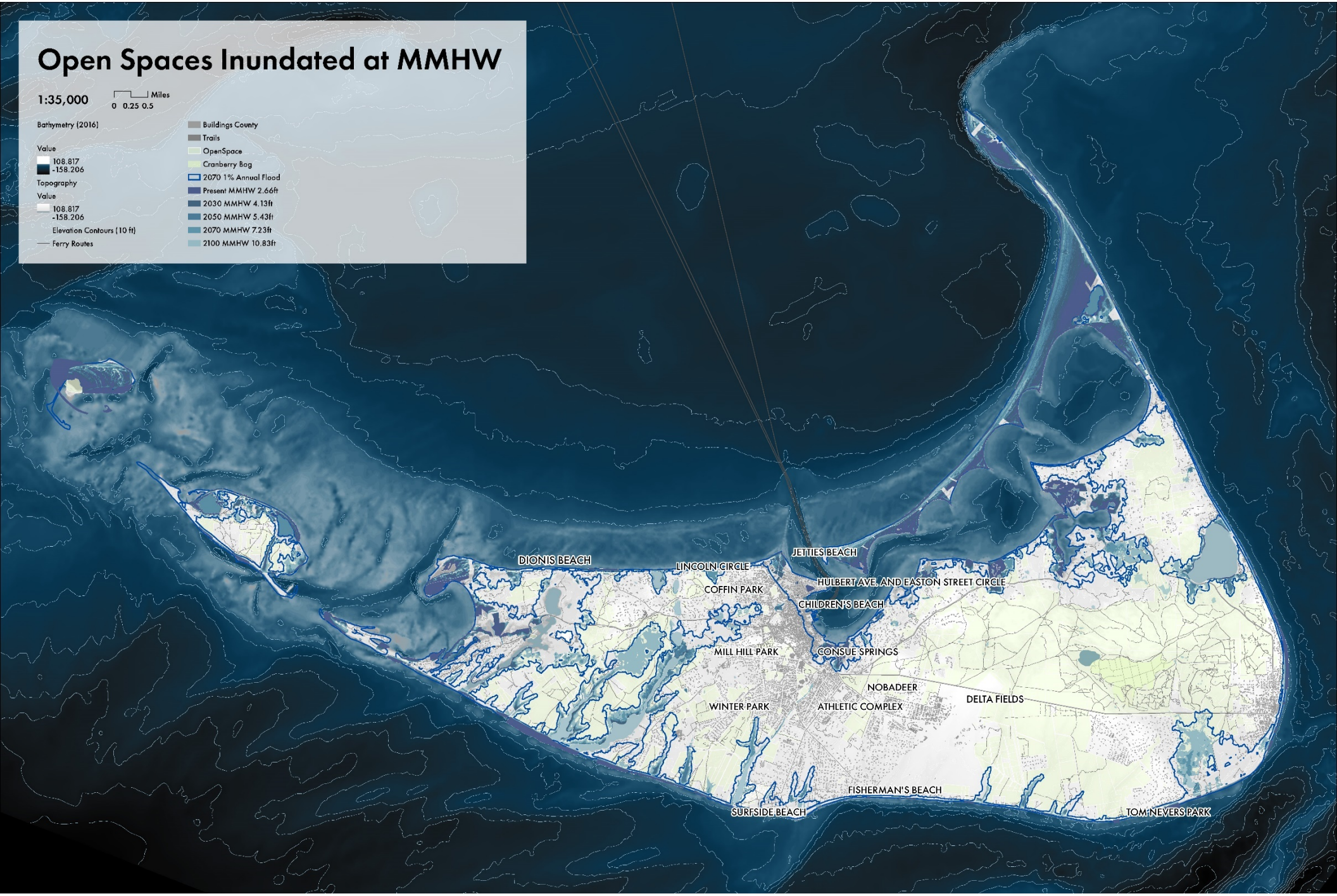


Figure 36. Open space disruption due to erosion

Figure 37. (next page) Map showing exposure of parks and open spaces to flooding from monthly high tide and coastal storms today through 2100


Open Spaces Inundated at MMHW
1:35,000
Miles
0 0.25 0.5
Bathymetry (2016)
Value
108.817
-158.206
Topography
Value
108.817
-158.206
Elevation Contours (10 ft)
Ferry Routes
Buildings County
Trails
OpenSpace
Cranberry Bog
2070 1% Annual Flood
Present MMHW 2.66ft
2030 MMHW 4.13ft
2050 MMHW 5.43ft
2070 MMHW 7.23ft
2100 MMHW 10.83ft
DIONIS BEACH
LINCOLN CIRCLE
JETTIES BEACH
COFFIN PARK
HULBERT AVE. AND EASTON STREET CIRCLE
CHILDREN'S BEACH
MILL HILL PARK
CONSUE SPRINGS
NOBADEER
DELTA FIELDS
WINTER PARK
ATHLETIC COMPLEX
FISHERMAN'S BEACH
SURFSIDE BEACH
TOM NEVERS PARK

Risk to Habitat and Natural Resources

At a Glance

- **1,340 acres of wetland resource area** and **1,187 acres of priority Natural Communities** will be impacted by the monthly high tide by 2070
- **1,703 acres of wetland resource area** and **1,999 acres of priority Natural Communities** will be impacted by the 1% annual chance flood by 2070
- **241 acres of wetland resource area** and **938 acres of priority Natural Communities** will be impacted by erosion by 2100

Natural resource areas provide many benefits and ecological services for Nantucket and their protection is a priority for the community. Loss of these resources due to flooding and erosion, reduces the ecological, resilience, economic benefits they provide.

Natural resources provide many benefits and ecological services for Nantucket and their protection is a priority for the community. These benefits and services include:

- Natural buffers that stabilize shorelines and protect coastal areas from storm damage and sea level rise.
- Biogeochemical functions that improve water quality by functioning as “living filters”
- Critical to supporting health of commercial and recreational fisheries
- Critical habitat for nesting, foraging and migratory birds. This in turn supports recreational birding that brings additional tourism, commerce, and enjoyment to the Nantucket community.
- Proximity to natural amenities and associated recreational opportunities and aesthetic benefits increases property values and is one of the primary drivers of tourism to Nantucket.
- On Nantucket, the conservation of habit and natural resources has historical ties, and the significance of the island’s historic areas is linked to proximity to the ocean, wetlands, and other sensitive open spaces.

Coastal flooding poses significant risk to rare habitat and especially to coastal wetlands, which are among the most susceptible ecosystems to climate change and sea level rise. Although Nantucket has strong wetland protection regulations and several conversation organizations working diligently to protect wetland ecosystems, wetlands are nevertheless already threatened due to historic and current anthropogenic disturbances (e.g., shoreline hardening, bank erosion, invasive species, and water quality degradation). In addition, the resilience of coastal wetlands and ability to adapt to sea level rise may be limited by surrounding upland land uses, decreased sediment inputs, and decreased plant productivity. This combination of forces acting on coastal wetlands could overwhelm the natural compensatory mechanisms and increase vulnerability to marsh drowning over time.

For the purpose of this report, risk to critical ecosystems was analyzed based on exposure of mapped natural communities. These areas represent various natural communities of biodiversity conservation interest in Massachusetts, drawing on records maintained in the Natural Heritage & Endangered Species Program (NHESP) database. The analysis focused on areas ranked as priority for conservation due to their rareness and/or ecological value. Wetland resource areas are mapped based on available GIS data from the Massachusetts Department of Environmental Protection and are suitable for planning level analysis for the purposes of understanding potential impacts to resource areas. This analysis includes beaches, marshes, forests, bogs, swamps, and other resource areas. As part of the next phases of the CRP planning process, data from the Sea

Level Affecting Marshes Model (SLAMM) will be used to evaluate potential recommendations for wetland protection and restoration in the context of projected sea level rise.

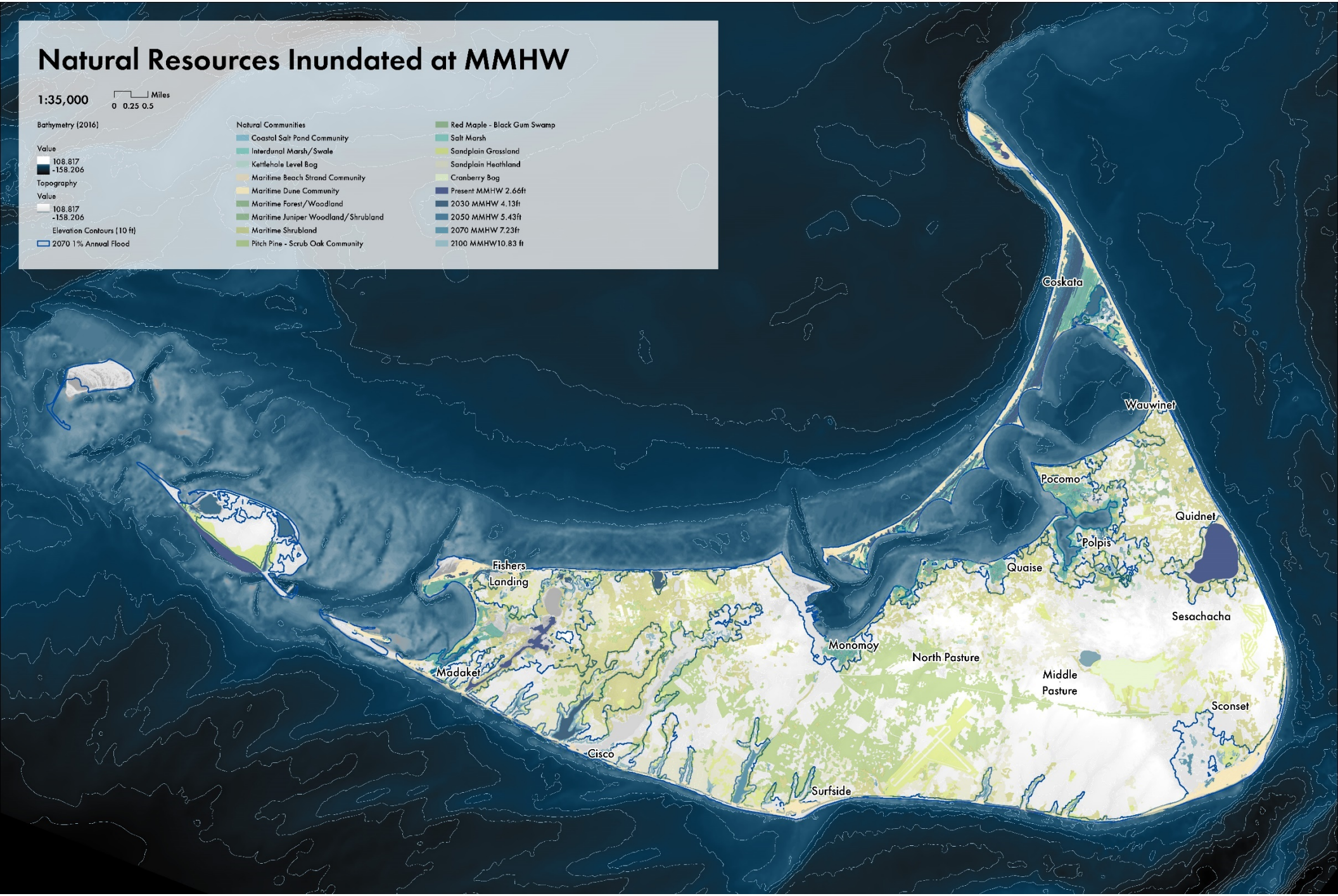
Table 13 summarizes the acreage of natural resource area that is expected to be exposed to flooding and erosion between 2020 and 2100. Much of the mapped natural resource area on Nantucket exists within floodplains today. Areas exposed to monthly high tide today may be adapted to these present-day conditions, but with increasing rates of sea level rise, these areas may not be able to adapt quickly enough to changing tidal conditions and are thus vulnerable to drowning. By 2070, for example, up to 645 additional acres of wetland resource area will experience flooding at monthly high tide, compared to today. 718 additional acres of priority Natural Communities could similarly be exposed to monthly high tide by 2070. Erosion presents another risk factor to these resources, including impacts of up to 162 acres of wetland and 633 acres of Natural Communities by 2070. **Figure 38 and Figure 39** show maps of the exposure of these resources to flooding and erosion from today to 2100.

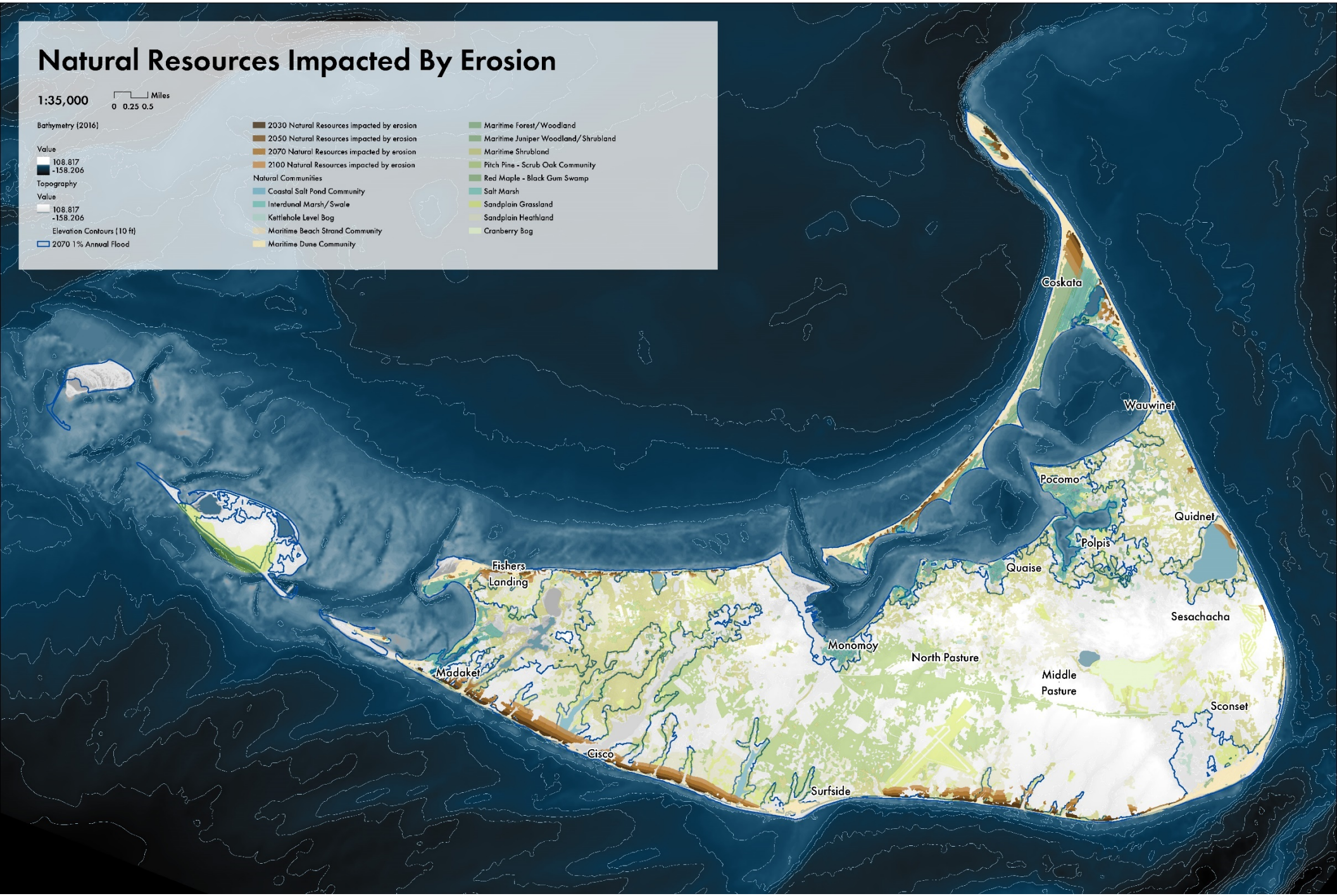
Table 13. Expected exposure of habitat and natural resources to flooding and erosion

	Inundation during 1% Annual Chance Storm (acreage)					**Inundation at Monthly High Tide (acreage)**					**Loss Due to Erosion (acreage)**			
	Today	**2030**	**2050**	**2070**	**2100**	**Today**	**2030**	**2050**	**2070**	**2100**	**2030**	**2050**	**2070**	**2100**
Natural Communities – Ranked S1 or S2	1,097	1,423	1,675	1,999	N/A	469	719	926	1,187	1,573	139	332	633	938
Wetland Resource Areas	1,058	1,375	1,526	1,703	N/A	695	963	1,119	1,340	1,750	11	54	162	241

Figure 38. (next page) Map showing exposure of natural resources, including Priority Natural Communities and wetlands, to monthly high tide today through 2100

Figure 39. (following page) Map showing exposure of natural resources, including Priority Natural Communities and wetlands, to erosion hazards today through 2100


Natural Resources Inundated at MMHW
1:35,000
Miles
0 0.25 0.5
Bathymetry (2016)
Value
108.817
-158.206
Topography
Value
108.817
-158.206
Elevation Contours (10 ft)
2070 1% Annual Flood
Natural Communities
Coastal Salt Pond Community
Interdunal Marsh/Swale
Kettlehole Level Bog
Maritime Beach Strand Community
Maritime Dune Community
Maritime Forest/Woodland
Maritime Juniper Woodland/Shrubland
Maritime Shrubland
Pitch Pine - Scrub Oak Community
Red Maple - Black Gum Swamp
Salt Marsh
Sandplain Grassland
Sandplain Heathland
Cranberry Bog
Present MMHW 2.66ft
2030 MMHW 4.13ft
2050 MMHW 5.43ft
2070 MMHW 7.23ft
2100 MMHW10.83 ft
Coskata
Wauwinet
Pocomo
Quidnet
Polpis
Quaise
Sesachacha
Fishers Landing
Monomoy
North Pasture
Middle Pasture
Sconset
Madaket
Cisco
Surfside


Natural Resources Impacted By Erosion
1:35,000
Miles
0 0.25 0.5
Bathymetry (2016)
Value
108.817
-158.206
Topography
Value
108.817
-158.206
Elevation Contours (10 ft)
2070 1% Annual Flood
2030 Natural Resources impacted by erosion
2050 Natural Resources impacted by erosion
2070 Natural Resources impacted by erosion
2100 Natural Resources impacted by erosion
Natural Communities
Coastal Salt Pond Community
Interdunal Marsh/Swale
Kettlehole Level Bog
Maritime Beach Strand Community
Maritime Dune Community
Maritime Forest/Woodland
Maritime Juniper Woodland/Shrubland
Maritime Shrubland
Pitch Pine - Scrub Oak Community
Red Maple - Black Gum Swamp
Salt Marsh
Sandplain Grassland
Sandplain Heathland
Cranberry Bog
Coskata
Wauwinet
Pocomo
Quidnet
Polpis
Quaise
Sesachacha
Fishers Landing
Monomoy
North Pasture
Middle Pasture
Sconset
Madaket
Cisco
Surfside

Groundwater Rise

Flooding due to rising groundwater has distinct characteristics that set it apart from the more familiar flooding caused by direct overland coastal and tidal flooding. Whereas coastal storm flooding is fast and temporary, groundwater flooding tends to be slow and chronic. When SLR lifts the coastal water table, impacts can include higher corrosion rates of buried infrastructure, increased basement flooding, reduced stormwater and wastewater sewer capacity, soil contaminant mobilization, soil instability, and eventually the creation of wetlands as groundwater emerges to the surface. Based on anecdotal information, groundwater emergence is already occurring in some areas, including around the Finance Department building on Washington Street where new wetlands are forming and at 27 Washington Street.

Not only does groundwater flooding have impacts distinct from coastal inundation flooding, but it also has unique solutions. While seawalls are effective against temporary storm surge, they don not substantially impact the long-term movement of groundwater. Thus, the response options for a rising water table tend to fall into the categories of groundwater drainage/pumping, raising structures, or gradual retreat. The viability of each option is highly dependent upon local conditions. Thus, making an initial broad assessment that determines the likelihood of groundwater flooding is useful for determining what areas should be targeted for more detailed hydrogeological assessments.

The water table elevation map in this study was constructed from well data from 10 USGS wells on Nantucket Island. Monthly water level measurements were taken over multiple years for each well—most of them dating back to the 1980s. The highest water table readings (smallest depth-to-water) across Nantucket Island occurred in the spring of 1994. However, the island's water table has been fairly stable over the past 30 years but with a trend of a slowly rising water table (see **Figure 28**). Likewise, high rainfall events that substantially raise the water table are expected to occur more frequently with climate change. Thus, the highest measured reading was used as a conservative estimate.

Figure 40 shows the projected depth to groundwater today and for several future scenarios across the island. While additional technical analysis would be necessary to fully evaluate the risks posed by groundwater table rise to structures and infrastructure, this analysis shows several areas where future groundwater will rise to within six feet of surface, potentially causing flooding in basements, low-lying areas, and corroding subsurface infrastructure. Most concerning are areas where depth to groundwater is below three feet, including the island's most low lying areas such as Downtown and Madaket, In certain pockets, such as Brandt Point, it is not uncommon to see groundwater emergence today, as noted in **Section 4.1 Overview of Coastal Hazards.** Mapping of depth to groundwater for present in **Figure 41** supports this observed condition. With sea level rise, depth to groundwater is expected to decrease across the island over time, as shown the mapping in **Figure 42,** posing significant challenges for low-lying areas. By 2100, areas such as Downtown may experience widespread groundwater emergence. Addition maps are provided in **Appendix D.**

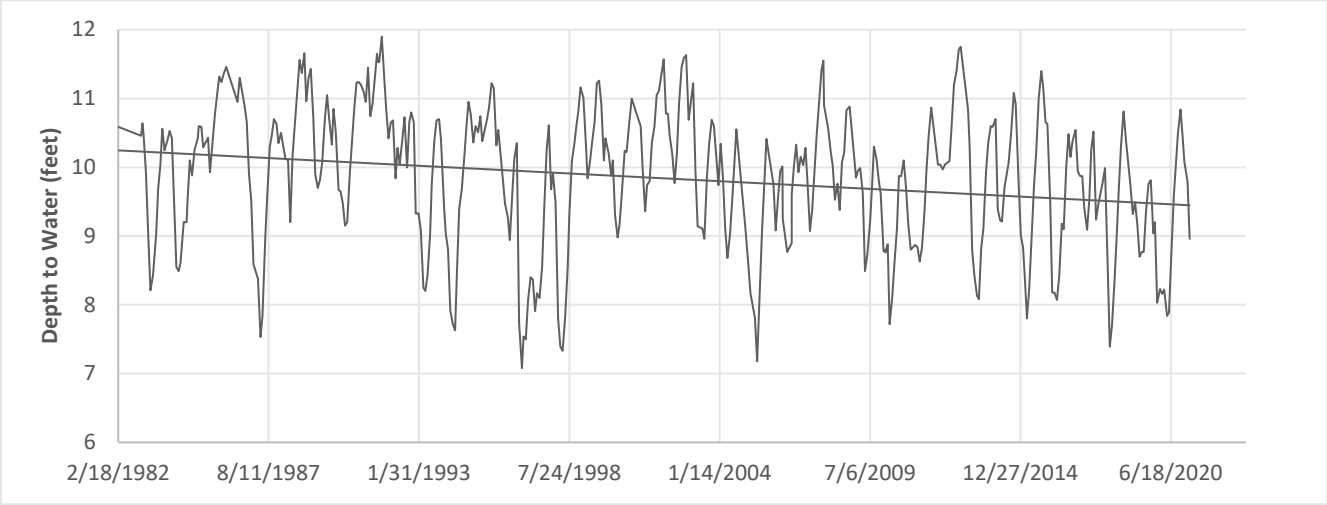
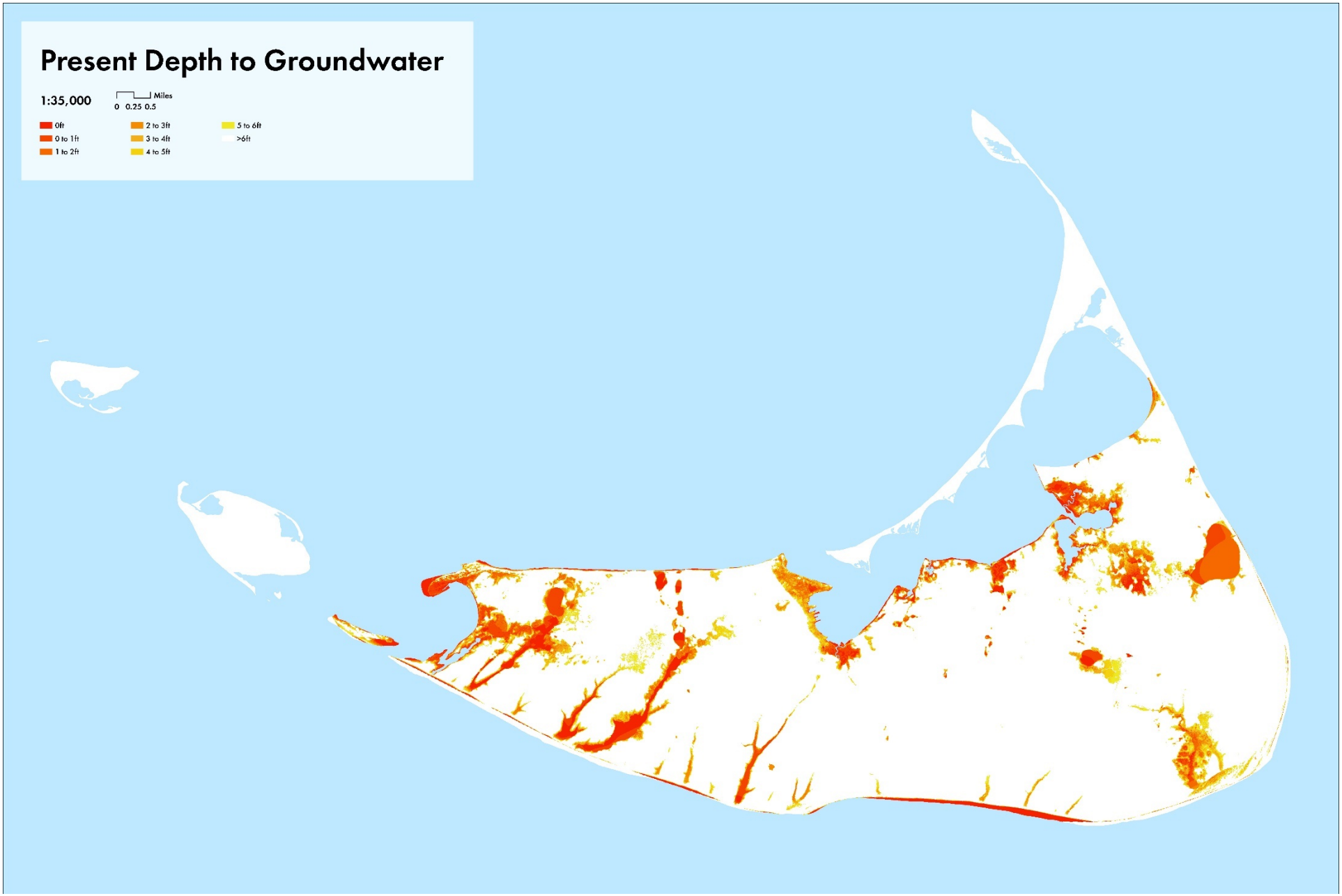
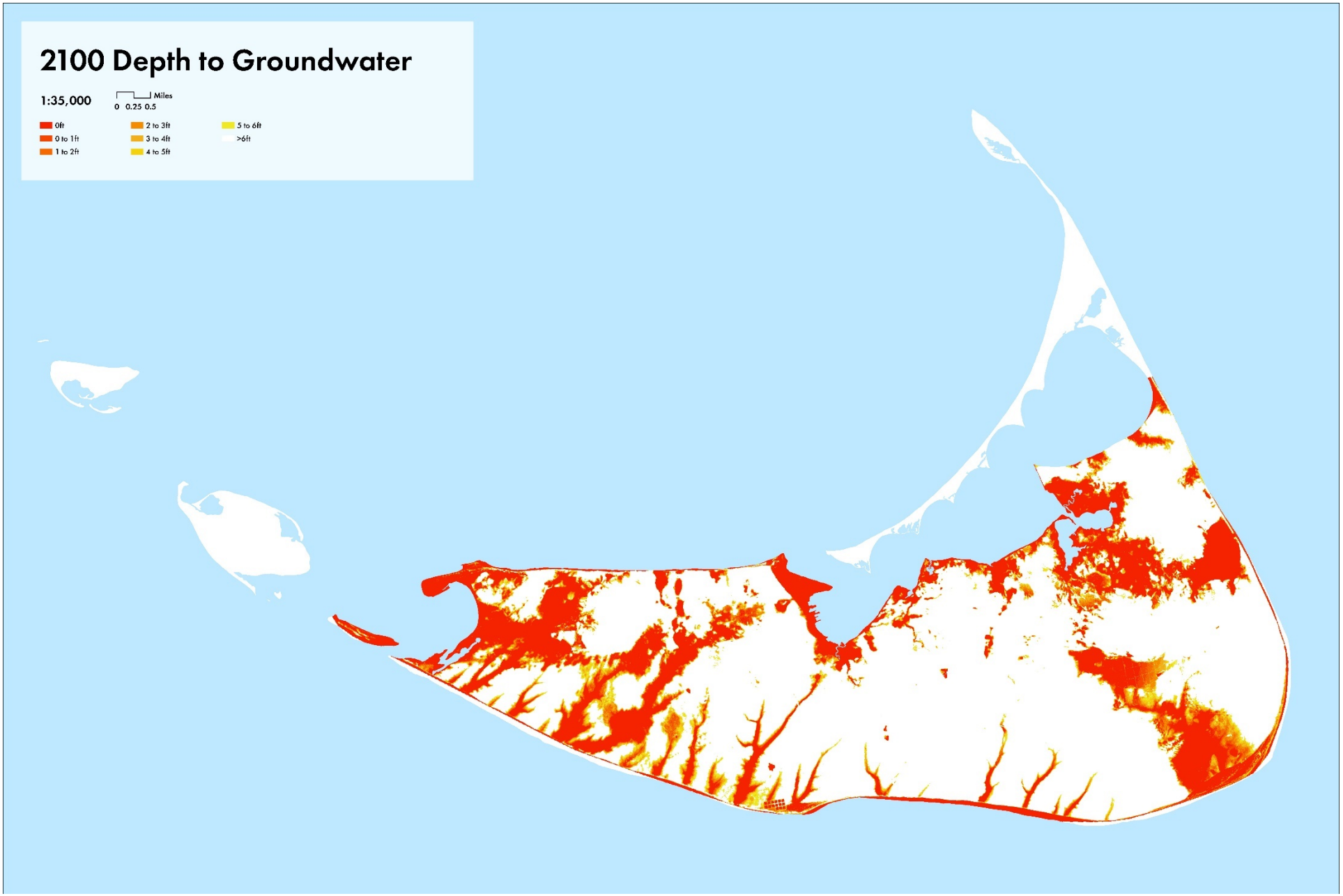


Figure 40. A graph of published monthly well data for well MA MWB 107 with a trendline showing the water table rising over time (depth to water is decreasing)

Figure 41. (next page) Map showing estimated depth to groundwater across Nantucket today

Figure 42. (following page) Map showing potential depth to groundwater with sea level rise across Nantucket in 2100


Present Depth to Groundwater
1:35,000
Miles
0 0.25 0.5
0ft
0 to 1ft
1 to 2ft
2 to 3ft
3 to 4ft
4 to 5ft
5 to 6ft
>6ft


2100 Depth to Groundwater
1:35,000
Miles
0 0.25 0.5
0ft
0 to 1ft
1 to 2ft
2 to 3ft
3 to 4ft
4 to 5ft
5 to 6ft
>6ft

6 Conclusion

This report documents the status of the Coastal Resilience Plan at its mid-point, including analysis of:

- **Existing Conditions** – Mapping and description of Nantucket's context helps situate future plans for coastal resilience and adaptation in a thorough understanding of the island's history and the natural and built systems that support life on Nantucket
- **Community Engagement** - Engaging the Nantucket community in the CRP process and asking key questions about community priorities and visions helps orient the plan's preliminary recommendations in a direction that is consistent with community values and objectives
- **Risk Evaluation** - Assessing and quantifying the risks that flooding and erosion pose to Nantucket today and how these risks will increase over time with projected sea level rise helps focus coastal resilience and long-term adaptation plans on the most pressing concerns and substantiates the project's implementation

As documented in this report, coastal risks to homes, businesses, infrastructure, and natural resources will increase across the island through the end of the century. Action will need to be taken to adapt to these realities. The central objective of the CRP will be draw on the information and analysis included in the report to recommend proactive steps the Town and community can take to begin the long-term adaptation process, including new infrastructure, nature-based solutions, changes to by-laws and regulations, process-based and programmatic changes for Town departments and review bodies, and homeowner guidance and education.

Preliminary Focus Areas for Solution Development

The findings of this report will help inform geographic and topic-based areas of focus for the CRP. Preliminary discussion of these focus areas is provided below. Additional evaluation of coastal risks in these locations, as well as other focus areas to be defined through the process, will be necessary as part of the solution development and adaption pathway planning phases of the project.

Focus Areas

Downtown Nantucket and Brandt Point

- Widespread near- and long-term risk from flooding to homes, businesses, infrastructure, and essential facilities, including Steamboat Wharf. Groundwater emerges also poses a significant challenge in these areas. These risks threaten the sense of identity and character that define Nantucket as well as the places that help support the island's tourism-based economy.

Madaket, Ell Point, Smith Point

- Widespread near- and long-term risk from flooding and erosion to homes, businesses, and infrastructure. Risk to roadways and bridges creates isolation risk for residents. Long-term sea level rise combined with shoreline change due to erosion threaten to significantly reduce quality of life.

Polpis Harbor

- Although less densely settled than other areas of the island, flooding poses a significant risk in the near- to mid-term. This risk to structures and infrastructure combines with threats to the area's natural resources, which are vulnerable to chronic tidal inundation.

South Shore and Siasconset

- Along the South Shore and Siasconset, coastal erosion threatens structures and infrastructure located along these areas' beaches and coastal bluffs. These risks become especially pronounced toward the end of the century.

Transportation Systems

- Both erosion and flooding threaten to disrupt service to the network of public and private roadways and bridges that provide access across the island. Risks to the roadway network are particularly pronounced in Madaket, Downtown, and along Polpis Road, where tidal flooding may impact service by 2030. A number of roads that provide access to private residences along the South Shore and in Siasconset are vulnerable to erosion from 2030 through the end of the century.

Essential Facilities and Services

- Essential facilities and services on Nantucket are concentrated in or near Downtown, where, as noted above, flooding poses risks in both the near- and long-term. These at-risk facilities and services include Steamboat Wharf, an electrical substation, one of Nantucket's two primary grocery stores, a Town-owned retirement facility, Town administrative offices, the Coast Guard Brant Point, and others.

Open Space and Natural Resource Systems

- Across Nantucket, publicly- and privately-owned protected open spaces are at risk from damage and disruption from flooding and erosion, including public parks such as Tom Nevers Field and destinations such as Jetties Beach. Risk to these places threatens to reduce public access to and enjoyment of the waterfront. Risk of erosion and flooding, especially chronic tidal flooding, also threatens the health of ecosystems and wetlands that increase biodiversity and serve as natural buffers to coastal flooding.

Next Steps

The findings of this report lay the groundwork for the next phases of the CRP process, including refinement of focus areas for detailed analysis, development of resilience and adaptation scenarios, refinement of recommended resilience projects and adaptation pathways, and the implementation roadmap. During the next phase, the Project Team will continue to engage the Nantucket community through small group meetings, virtual platforms such as Irys, and the second Community Open House tentatively planned for early summer 2021.

Appendix A

Recent Coastal Events

Summary of Recent Storm Events and Impacts (Source: Hazard Mitigation Plan)

Date	Event	Impact Summary
Sept. 3, 2010	Tropical Storm Earl	Tropical storm force winds and high surf; Madaket Beach submerged; Seawater overtopped beach and entered Long Pond; At least $20,000 in property damage
Aug. 28, 2011	Tropical Storm Irene	Trees downed across Nantucket; Sustained winds of 48 to 63 miles per hour; At least $30,000 in property damage
Oct. 29, 2012	Hurricane Sandy	High winds and coastal flooding; Broadway and streets east; impassable; Damage at the harbor marina; Straight Wharf flooded
Feb. 9, 2013	Blizzard of 2013	Very strong winds, snow, storm surge; Easy Street and Washington Street flooded up to three feet; Beach Street flooded up to two feet; Wauwinet Road near East Fire Springs Road flooded; Water up to Nantucket Hotel on Easton Street in Brant Point; Main Street flooded to Club Car Restaurant; Significant beach erosion occurred
March 7, 2013	Coastal Flood	Hulbert Avenue, Washington, Broad, Easton, and Easy Streets impassable; Sheep Pond Road flooded; Building foundation eroded
Jan. 3, 2014	Coastal Flood	Several roads along Nantucket Harbor flooded; Easy, Broad, and Washington Street impassable
March 26, 2014	Coastal Flood	Flooding at Straight Wharf, on Easy Street, and in Brant Point
Nov. 2, 2014	Coastal Flood	Easy Street closed
Jan. 27, 2015	January 2015 Blizzard	Very strong winds; Moderate to major coastal flooding; Flooding on north and northeastern facing beaches; Flooding in downtown; Francis Street at Union Street, Washington Street from Commercial Street and Easy Street, Broad Street from Easy Street to South Water Street, and South; Beach Street closed; Parts of Brant Point flooded; Town pier severely damaged; Structural damage and seawall failure occurred
Feb. 15, 2015	Snow Storm	Heavy snow; Minor flooding at Children's Beach boat ramp; Barrier beach at Folger's Marsh breached; Francis Street closed at Union Street; Washington Street closed from Commercial Street to Francis Street
Jan. 24, 2016	Coastal Flood	Flooded boat ramps in Madaket; Easy Street flooded 4 to 12 inches
Feb. 8, 2016	Coastal Flood	Front yards on Washington Street flooded; Easy Street, lower Broad Street, Commercial Street flooded; Several roads in Brant Point closed; Traffic circle at Easton Street and Hulbert Avenue impassable
Sep. 5, 2016	Named Storm Hermine	Rain and below-tropical-storm force winds; Some wind damage to trees; Multiple small boats sunk or dragging-anchor in Nantucket Harbor

Date	Event	Impact Summary
Aug. 16, 2017	Erosion	12-foot waves on south shore; Strong rip currents
Sep. 21, 2017	Tropical Storm Jose	Strong wind gusts and heavy downpours; Rainfall reached about 6 inches; Minor coastal flooding; Four sailboats sunk due to rainfall; Several boats washed ashore
Oct. 30, 2017	Tropical Storm Philippe	Winds and waves on western coastline; Waves and swells washed over head of Hither Creek; Wetland filled with sand
Jan. 3-5, 2018	Winter Storm Grayson	Rain, wind, and coastal flooding; Low-lying areas of Downtown flooded; Easton Street flooded four feet; Homes on Washington Street shifted on foundations; More than 20 people rescued; At least two families displaced; Town opened the emergency shelter
Jan 30, 2018	Coastal Flood	Storm surge and snow; Easy Street, Easton Street, and Washington flooded.
March 2-4, 2018	Winter Storm Riley	Storm surge lasted multiple tide cycles; Buildings sustained flood damage; High winds and waves caused erosion and direct impact to buildings; Many roads impassable; Brant Point isolated, cut off at Easton Street and Cobblestone Hill; Sesachacha Pond breached; Polpis Road overtopped, undermined; Scouring at Madaket Road; Erosion at Children's Beach

Appendix B

Key Demographic Trends

Key Nantucket Demographic Trends

Nantucket's effective population ebbs and flows dramatically over the course of the year, and it can be challenging to derive a definitive estimate. The 2018 American Community Survey (ACS) 5-year estimates (surveyed between 2014-2018) estimates 11,100 people live in Nantucket year-round. However, local estimates and detailed analyses by Nantucket Data Platform indicate a permanent population of up to 17,200 residents, including adults and children. According to the 2018 ACS 5-Year estimates, the most year-round population-dense part of the island is the central-southern census tract (census tract 9502) consisting roughly of the Cisco and Miacomet neighborhoods. On an average Saturday in July, however, the vast majority of Nantucket's effective population–inclusive of visitors–typically concentrates in the Downtown and Brant Point neighborhoods. A high seasonal residential population–estimated at an additional 11,000 at 100-percent occupancy by Nantucket Data Platform's study–and high volume of seasonal visitors, particularly in July and August can cause the effective population of the island to swell to over 54,000 in the summer months. According to Nantucket Data Platform, the vast majority (approximately 86-89%) of families visiting in the summer are of white ethnicity and with mixed levels of income, mostly exceeding $50-75K and with approximately 13-16% exceeding $200K.

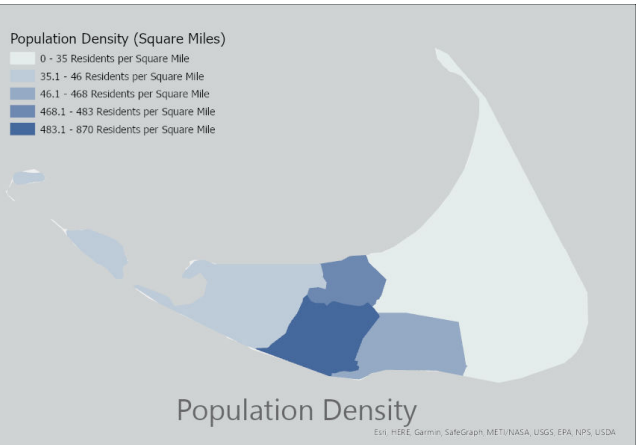
According to Nantucket Data Platform, while the majority of workers in Nantucket live and work on the island, a small number of year-round workers–estimated at 365 workers–commute to Nantucket from elsewhere. In the summer months, Nantucket sees an approximate additional 6,600 seasonal workers. 2019 IMPLAN data indicates an annual average of approximately 12,500 employed people in Nantucket, adjusting for seasonality.

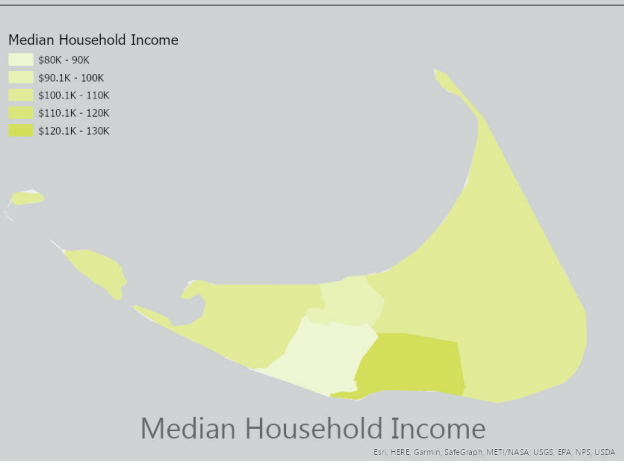
Despite notable quantitative data limitations and anecdotal comments emphasizing that the existing data is not fully representative of Nantucket's communities, the 2018 ACS 5-Year estimates can help provide an estimated accounting of Nantucket's spatial demographic distribution across the island by census tract. Based on this available data, the Project Team broadly identified parts of the island where certain sub-populations are more concentrated relative to their total population. For example, despite Nantucket's overall year-round population being approximately 88% white, 19.1% and 8.6% of the population in Nantucket's middle two census tracts, respectively (census tracts 9501 and 9502, consisting roughly of the area from Cisco and Miacomet north toward Downtown), consist of individuals who are non-white–higher relative to other census tracts on the island. Census tract 9502, consisting of the Cisco-Miacomet neighborhoods, also has the highest relative concentration of Hispanic or Latino individuals (7% of the population of that census tract) in addition to the highest relative concentration of individuals who speak English less than very well (3.7%).

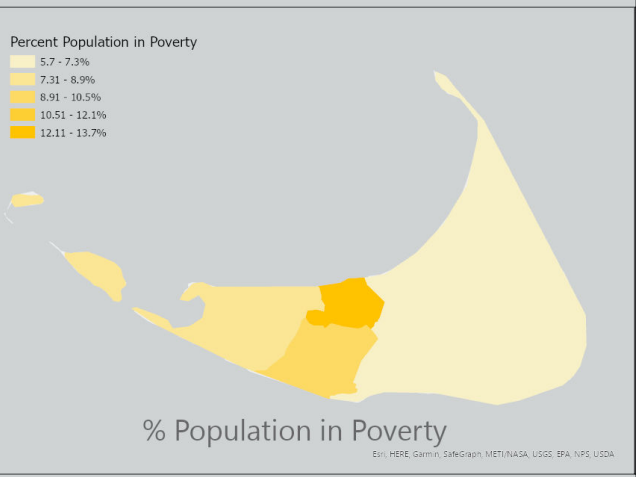
A handful of other demographic factors align with indicators used to determine a census tract's level of social vulnerability relative to the rest of the nation by the University of South Carolina (USC) Hazards & Vulnerability Research Institute (HVRI) Social Vulnerability Index (SoVI). SoVI ranks Nantucket's two middle census tracts–Cisco-Miacomet (9502) and Brant Point-Downtown (9501)–as being in the 44.8th and 54.1st national percentiles of social vulnerability, respectively. While not considered particularly highly socially vulnerable relative to the national scale of the index, these central areas nonetheless have a far higher concentration of socially vulnerable households than Nantucket's western and eastern neighborhoods, which score lower SoVI percentiles ranging from 5.4th to 14.8th. This is corroborated by a brief survey of 2018 ACS data across the census tracts with higher SoVI rankings, which identifies 13.7% of individuals in the Brant Point-Downtown tract (9501) and 9.3% of individuals in the Cisco-Miacomet tract (9502) who fall below the federal poverty level. Analysts expect these numbers may in fact be higher as the ACS may not accurately account for Nantucket's notable homeless population. While still high relative to the national median income, these same two central census tracts have the lowest median household incomes on the island, at $86,630 and $99,167, respectively. By comparison, wealthier households appear to represent a higher relative percentage of census tract 9504, consisting of the Surfside-Madequecham neighborhoods, which has a median household income of $124,189.

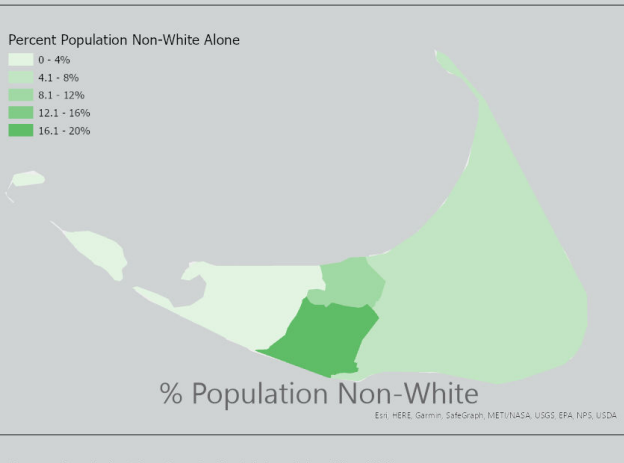
Nantucket Demographic Trends by Census Tract

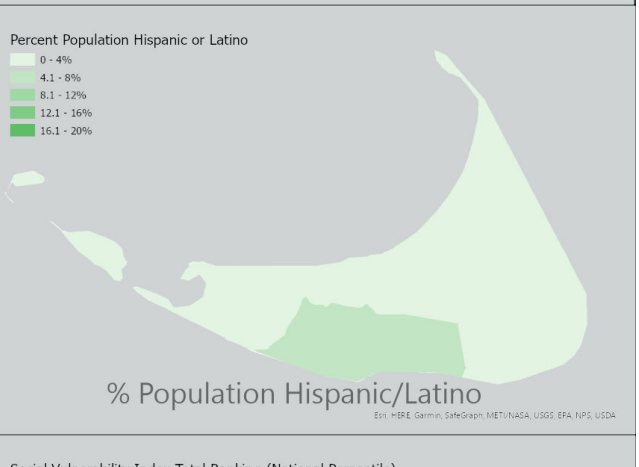
Data: 2018 American Community Survey 5-Year Estimates
USC HVRI Social Vulnerability Index

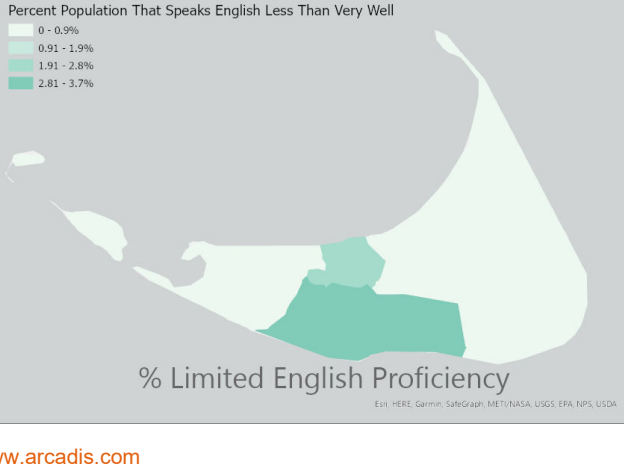


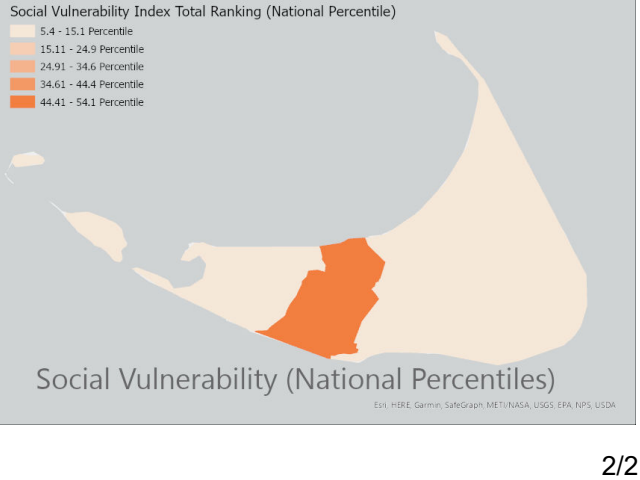












Appendix C

Coastal Hazard Assessment Methodology Memo

SUBJECT
Nantucket Coastal Resilience Plan
Coastal Hazard Assessment Approach

TO
Vincent Murphy, Coastal Resilience Coordinator
Department of Natural Resources
Town of Nantucket

DATE
March 18, 2021

OUR REF
30055145

COPIES TO
Coastal Resilience Advisory Committee

FROM
Arcadis

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1. Introduction

The Nantucket Coastal Resilience Plan (CRP) will provide a long-term adaptation plan for the County of Nantucket, along with detailed feasibility and implementation guidance for near-term projects over the next 10 years. The CRP planning process will involve analysis of risk and vulnerability, examination of a range of flood protection options, and recommendations for new policies and investments in nature-based and grey infrastructure. The project team will work in close partnership with the Nantucket community and other groups to develop the CRP. The plan will be completed in Fall 2021.

The purpose of this memorandum is to document the data and methodologies used to assess coastal hazards on Nantucket. Coastal resilience planning begins with an assessment of coastal hazards, including storm surge, waves, sea level rise (SLR), tidal inundation, and erosion. The approaches described here will be used to evaluate risks from flooding and erosion, develop target design flood elevations, and inform solution development and conceptual design. This document is based on prior resilience planning by the Town, an evaluation of available data, industry standard best practices, expert engineering and scientific opinion, and relevant State and Federal standards and guidelines.

This document corresponds to the executed scope of work dated September 23, 2020, specifically Task 3 Methodology, Environment, and Identifying Coastal Flood and Erosion Hazards.

2. Project Area

Nantucket County consists of Nantucket Island and its sister islands of Tuckermuck and Muskeget. Together, Nantucket County comprises a roughly 48 square mile island located in Nantucket Sound approximately 30 miles from the mainland on Cape Cod, Massachusetts. Elevations range from sea level to 111 feet above sea level.

The Nantucket CRP is an all-island plan focusing on the entire 88 miles of coastline, as depicted in Figure 1. The project area encompasses an array of built and natural conditions, from the historic town centers in downtown and Siasconset (also referred to as “Sconset” and “‘Sconset”), to bays and tidal estuaries, to natural coastal bluffs along the South Shore, to the sparsely populated islands of Tuckermuck and Muskeget.

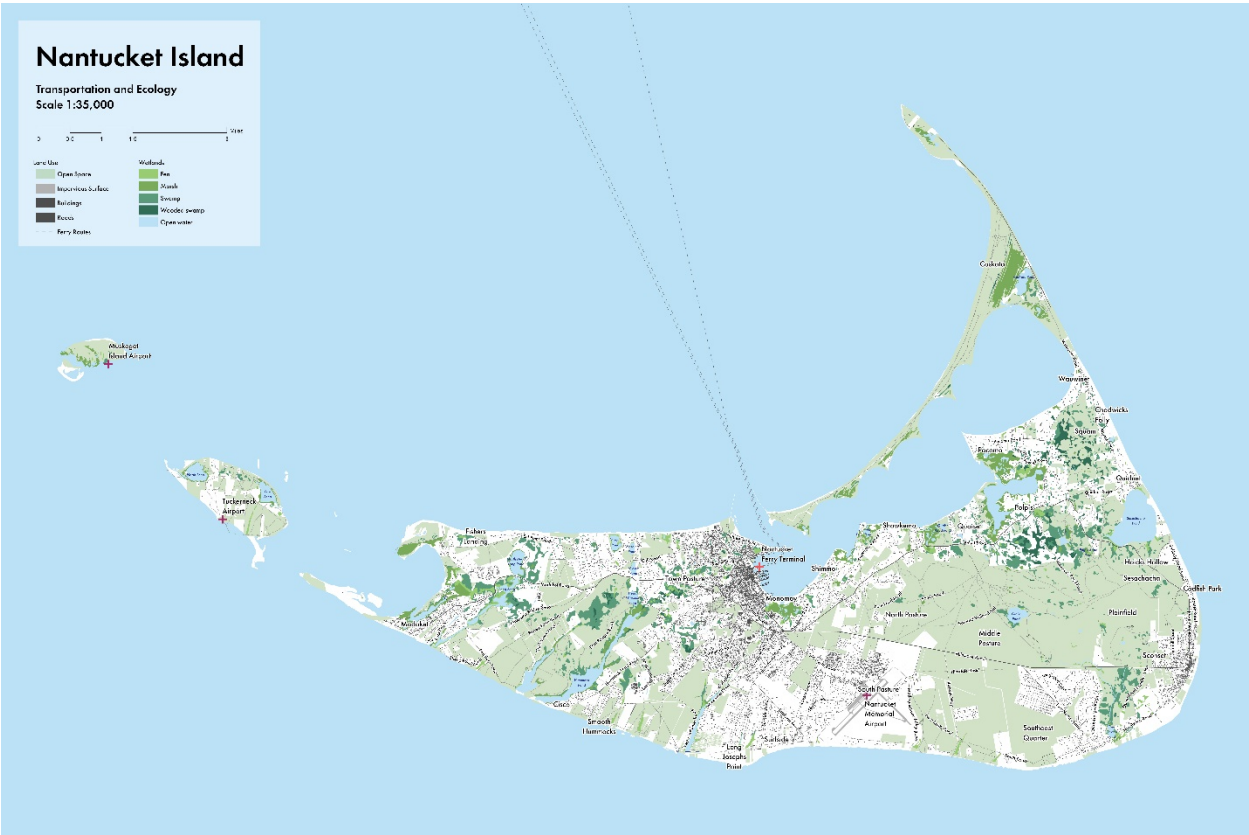

Figure 1: Map of the Project Area Comprising the Town and County of Nantucket

3. Nantucket Island Hydrogeology and Climate Change

As described in greater detail in the Town of Nantucket's Hazard Mitigation Plan:

> *Nantucket is located in the Atlantic Coastal Plain, a broad belt along the eastern seaboard of the United States and the Gulf of Mexico, extending from the mouth of the Rio Grande to Cape Cod. The region is generally characterized by sedimentary rock formations and thick unconsolidated sediment deposits that extend to the continental shelf. Nantucket was formed by the Laurentide continental ice sheet associated with the last North American glaciation, less than 25,000 years ago. Cape Cod, Martha's Vineyard, Block Island, and Long Island have similar origins. Sometime after 23,000 years ago, the glacier reached its maximum advance at a position marked by the islands of Nantucket and Martha's Vineyard. The terminal moraine of this glacier consists of unsorted glacial till (ranging from clay, silt, and sand to boulders) and extends from Nantucket Harbor to Siasconset ("Sconset"), including the Shawkemo Hills, Sauls Hills, Folger Hill, and the cliffs at Sankaty Head.*

A geologic map of Nantucket is presented in Figure 2. With Nantucket's shoreline composed of primarily compacted sandy soil, it is susceptible to coastal erosion. Portions of the island's shorelines have already lost more than one hundred feet of coast depth in just the past decade, and, with climate change, the erosion process is anticipated to accelerate, as will be described in greater detail in Section 6.

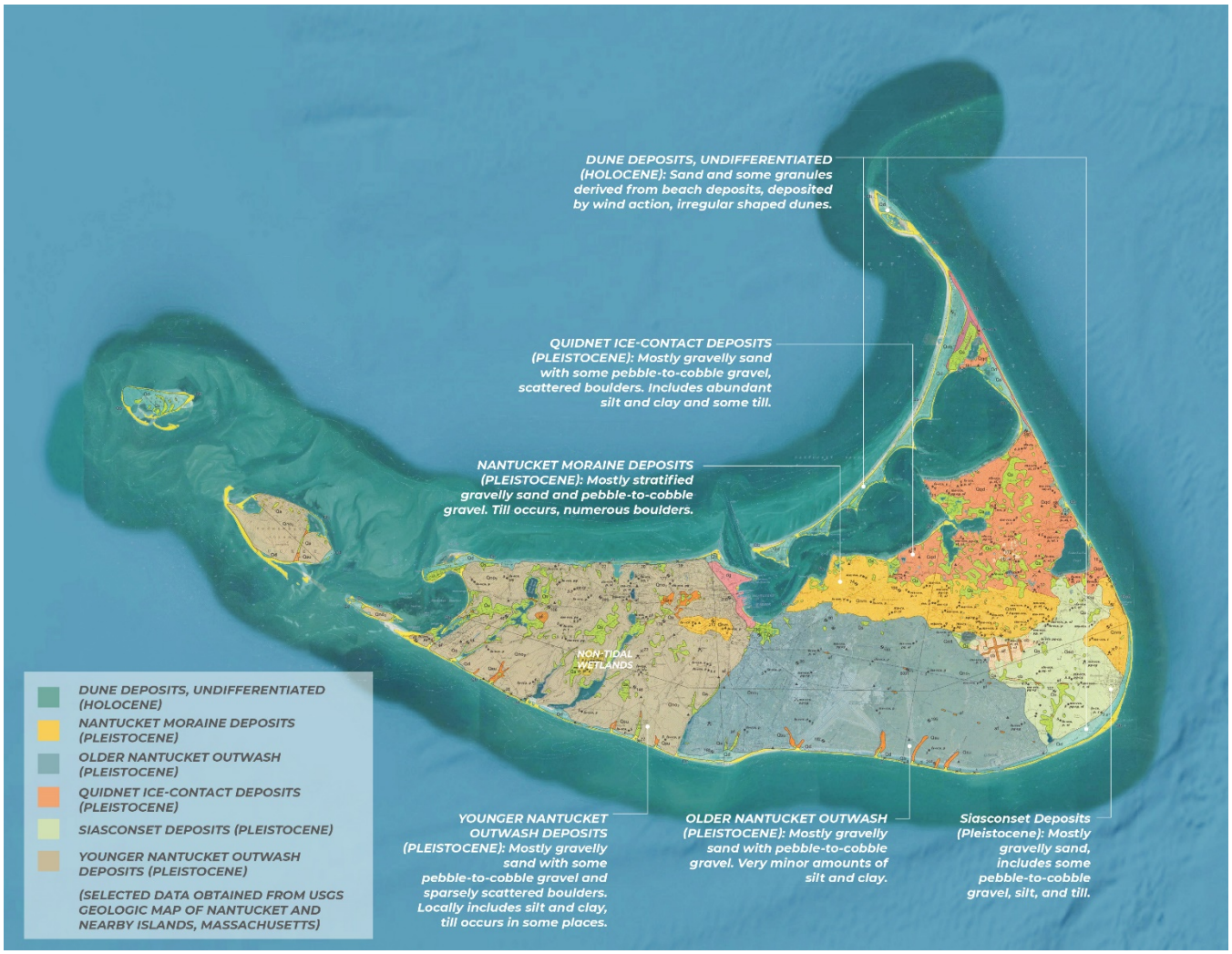

Figure 2: Nantucket Island Geologic Map (Based on USGS Data)

Nantucket's soils are generally porous above the till, or glacial sediment, which also makes it susceptible to the impacts of climate change. The porous soils store freshwater in their void space, creating a surface reservoir or aquifer, which Nantucket uses for its water supply. However, as sea levels rise, there can be a number of impacts on groundwater which can negatively impact the community. These are outlined below.

In addition to SLR, porous soils provide a void space for water from storm surge to travel beneath a flood defense structure, creating an uplift pressure under the structure. Seepage barriers or "cutoff walls" lengthen the seepage path and restrict the movement of water beneath the structure, as diagrammed in Figure 3. While there is the potential for seepage control during periodic coastal storm events, it is very challenging to address groundwater increases due to SLR during non-storm conditions because the groundwater will have greater time to travel around any seepage barrier.

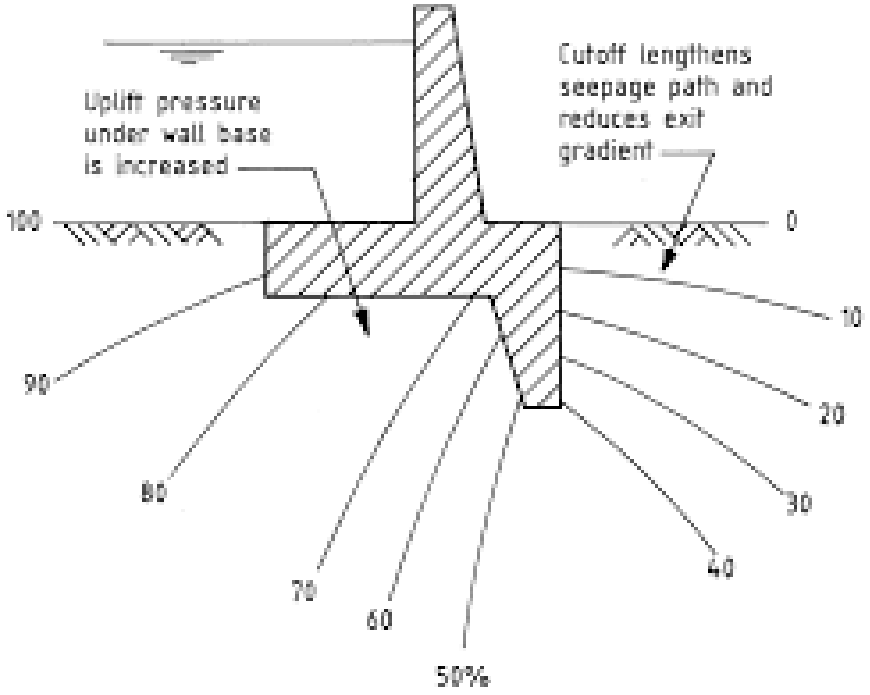

Figure 3: Seepage path for floodwalls and flood embankments (Source: TU Delft)

4. Overview of Coastal Hazards on Nantucket

By virtue of its location, history, and geomorphology, Nantucket is and always has been highly exposed to a range of coastal hazards, many of which are exacerbated by climate change. This section introduces prominent coastal hazards for Nantucket – high tide flooding, coastal flooding, coastal erosion, and groundwater table rise. A brief overview on changes in precipitation is also presented as they relate to coastal flooding. Section 6 describes the methodology and datasets that will be used to assess each of these hazards. Additional detailed risk and vulnerability analysis – how these hazards affect buildings, infrastructure, systems, services, and natural resources— will be produced in subsequent phases of this study.

High Tide Flooding

High tide flooding, often referred to as “nuisance” flooding or tidal flooding, is defined by the National Oceanic and Atmospheric Administration (NOAA) as flooding that leads to public inconveniences, such as road closures, overwhelmed storm drains, and deterioration of public infrastructure (e.g., roads).[i] This type of flooding is becoming increasingly common as sea levels rise and land subsides[1] in coastal communities, resulting in a greater likelihood that high tide will overtop existing bulkheads and coastal measures and flood inland areas. Nantucket is already experiencing nuisance flooding concerns in certain locations, particularly on East Street in Downtown, where a Town report notes a six-fold increase in the frequency of tidal flooding over the last 40 years.[ii] According to NOAA, high tide flooding has increased across the U.S. by approximately 50 percent over the last 20 years and 100 percent compared to 30 years ago. As sea levels continue to rise, high tide flooding will become an increasingly common occurrence without further action to mitigate its impacts.

[1] Subsidence refers to the gradual settling or sinking of the ground due to underground material movement (NOAA)

Coastal Flooding

Coastal flooding is defined as the submergence of low-lying land by seawater – often as a result of storm surge. Coastal flooding can occur via multiple pathways, including direct flooding and/or overtopping or breaching of an existing barrier, such as a bulkhead. Climate change, with its associated rise in sea levels, as well as the possibility for an increase in the frequency and/or the intensity of storms and changes in wave climate, can be expected to increase the risks of coastal flooding in most coastal locations, including Nantucket.[iii] Due to limited peer reviewed publications and climate science predicting the potential changes in storm surge characteristics due to climate change, only the effects of SLR in elevating storm surge are considered in this study.

The Town of Nantucket has previously drawn on a range of flood risk modeling and mapping to evaluate exposure to coastal flooding, including FEMA's Flood Insurance Rate Maps and associated Flood Insurance Study[iv] and studies undertaken by local and regional experts, such as the stormtide pathways analysis prepared by the Center for Coastal Studies in Provincetown.[v] The Town's 2020 Coastal Risk Assessment and Resiliency Strategies Report provides an overview of the coastal flood modeling produced for the North Atlantic Coast Comprehensive Study (NACCS) conducted by the United States Army Corps of Engineers. Based on the robust modeling and the inclusion of a wave setup component in the NACCs data, the report recommends that "figures from the NACCS study should be used for resiliency planning unless more updated water level figures are released in the future." The Commonwealth of Massachusetts is in the process of producing a statewide coastal flood risk model drawing on robust numerical modeling across a range of storm and future climate conditions. These data will be recommended as best available for coastal areas of Massachusetts. More detail on this dataset is included below in Section 6.

Coastal flooding resulting from storm surge can result in significant damage and disruption to homes, businesses, infrastructure, and ecosystems. Waves associated with storms can severely damage buildings and infrastructure located along the coast. Waves and the associated currents also erode unprotected shorelines, which can undermine building foundations and destroy roads and other forms of infrastructure. Storm surge creates extra depth of water, and when water is deeper, waves travel further inland; storm surge and SLR lead to deeper water and more favorable conditions for waves.

Coastal Erosion

Erosion is defined as the geological process in which earthen materials, including minerals, rocks, soil, and sand, are worn away and transported by natural forces, such as wind and water. Climate change, with its associated rise in sea levels, as well as the possibility for an increase in the frequency and/or the intensity of storms and changes in wave climate, can be expected to increase the risks of coastal erosion in most coastal locations, including Nantucket.[vi]

With Nantucket's shoreline composed primarily of compacted sandy soils, it is and has always been susceptible to coastal erosion. Portions of the island's shorelines have already lost more than one hundred feet of coast depth in just the past decade, and, with climate change, the erosion process is anticipated to accelerate.

Shoreline and dune erosion rates are influenced at several time scales; periodic storm events can cause erosion at orders of magnitude higher than longer terms rates. One important factor is that both sandy beach and dune erosion typically follows a pattern of erosion (storm or seasonal) followed by a period of recovery (for example the difference between a typical winter beach profile and a summer

profile). Conversely, bluff erosion is generally episodic, occurring during significant storm events and once the bluff slope is eroded, there is no recovery. It should be noted that some bluff erosion factors, like wind, precipitation, and runoff, may be more constant and not episodic. Additionally, structures such as residences on cliff tops increase the bearing weight which can contribute to cliff slope failure. Property owner landscaping practices such as replacement of stabilizing vegetation with shallow root species like grass can accelerate bluff erosion.[vii]

As part of the CRP, waves, water levels (return period storms), and SLR will be considered as the primary drivers for erosion, and other factors, such as wind and stormwater runoff also contributing as secondary factors as appropriate.

Groundwater Table Rise

Groundwater table (or water table) rise refers to the increase in the level of groundwater underneath a landmass, such as the Island of Nantucket, primarily driven by an increase in sea levels. According to USGS, coastal water tables will rise as groundwater levels are pushed up by landward intrusions of seawater due to SLR. This consequence of SLR is even more noteworthy in regions with shallow water tables, as SLR can push the water table above the surface, resulting in a phenomenon called groundwater emergence.

Figure 4: Potential Groundwater Emergence on Brant Point (Team Site Visit - 11/12/2020)

While the potential for coastal tidal inundation due to SLR is well documented, it is largely unrecognized that low-lying coastal areas may also be vulnerable to groundwater inundation Groundwater inundation can lead to nuisance flooding in low-lying areas and in basements and overtime will lead to conversion of dry land to wetlands. The main factors that may determine the degree of SLR groundwater inundation in any one specific location include:

- The proximity of the water table to the ground surface,
- The local geology, including the distance to the shoreline,
- The local hydrology, and
- Increases in precipitation and infiltration that can lead to temporary increases in the water table
- Anthropogenic factors, such as groundwater extraction or addition.

Near the shoreline, the groundwater table in unconfined aquifers typically fluctuates with daily tides. The tidal influence on the groundwater table decreases with distance from the shoreline. As sea level rises, the water table will likely rise as well, and, for lower-lying regions with a shallow depth to the water table, this could mean that the groundwater may eventually pond above the land surface, causing inundation even though the area is not at, or directly connected to, the shoreline. The increased groundwater table could create new wetlands and expand others, change surface drainage, expand saturated soil conditions, and/or inundate the land, depending on local topography. Flooding may be especially intense seasonally when high tide coincides with large rainfall events.[viii]

A rising groundwater table can cause destabilization of soils and building foundations, as well as infiltrate underground utilities. This can result in significant structural damages as soils lose their capacity to bear weight, and cause corrosion and other operations and maintenance challenges for subsurface utilities and foundations. In addition, Nantucket extracts groundwater through two municipal wellfields, as well as private wells scattered around the Island, for water supply. Rising seas could compromise the quality of the sole aquifer by accelerating saltwater intrusion into the surface reservoir or by exposing the wellhead to overland coastal flooding.

Precipitation

Precipitation is an important consideration when assessing impacts from coastal flooding and SLR. This study will evaluate the potential for projected increases in precipitation to exacerbate coastal and nuisance flooding, as well as the need for additional planning for interior drainage on the land side of any proposed flood defense infrastructure.

Climate change projections for the Commonwealth of Massachusetts indicate that precipitation (including both rainfall and snowfall) patterns are changing, and more significant changes in the amount, frequency, and timing of precipitation in future years are anticipated. The Northeastern United States has experienced the most dramatic increases in precipitation intensity.[ix] Increases in total rainfall can impact the frequency of flooding events, especially in areas where stormwater and drainage infrastructure has not been adequately designed to manage the increased flows. In addition to chronic flooding in low lying areas due to high tides, SLR will also impact the ability of the stormwater system to provide adequate drainage as outfall pipes will be submerged more frequently, causing drains to surcharge during heavy rainfall events. This is problematic when stormwater flows onto streets, impacting vehicular traffic and emergency vehicles, as well as onto properties, resulting in property damage. Through a GIS-based analysis using outfall invert elevations (where available) areas which could be more susceptible to greater levels of flooding under increased rainfall events will be identified.

Additionally, some coastal defense measures can change surface flow drainage patterns and therefore interior drainage systems will need to be accounted for in the design and costing of proposed flood defense infrastructure.

5. Relevant Consensus Standards

This section summarizes the relevant State and Federal standards and guidelines that have been considered as part of the development of the coastal hazard assessment methodology. This is based on the data and guidance that is publicly available and/or adopted as of January 2021.

Commonwealth of Massachusetts

Massachusetts Building Code (780 CMR, Section 120.G)

This section of the state building code outlines standards for structures in flood-prone areas or coastal dunes, stating that buildings must comply with the code's requirements for construction and elevation. Includes requirements for floodproofing and/or elevation of new buildings and structures, substantial improvements, replacement or substantial repair of a foundation and lateral additions that are substantial improvements above the base flood elevation on the adopted FEMA Flood Insurance Rate Maps for the community. In flood hazard areas subject to high velocity wave action, two feet of freeboard are required above the base flood elevation. One foot of freeboard is required for non-residential buildings that utilize dry floodproofing below the base flood elevation.

ASCE 24

Published by the American Society of Civil Engineers (ASCE), Flood Resistant Design and Construction, ASCE 24, is a referenced standard in the International Codes® (I-Codes®). FEMA deems ASCE 24 to meet or exceed the minimum National Flood Insurance Program (NFIP) requirements for buildings and structures.

While the identification of flood prone structures is based on flood hazard maps, studies, and other public information, ASCE 24 provides the minimum requirements for design and construction of structures located in flood hazard areas and subject to building code requirements. ASCE 24 also includes a "Flood Design Class" that bases requirements for a structure based on allowable risk. The standard includes requirements for the following:

- Basic siting and design and construction requirements for structures in flood hazard areas
- Minimum elevations for the lowest floor, flood-damage resistant materials, and floodproofing measures, each corresponding to the structure's Flood Design Class
- Structures in coastal high-hazard areas (V Zones) and Coastal A Zones
- Flood damage resistant materials
- Dry floodproofing and wet floodproofing

Resilient MA Action Team (RMAT) Climate Resilience Design Standards and Guidelines (Draft)

RMAT is a State inter-agency team comprised of representatives from each Secretariat. The RMAT is tasked with monitoring and tracking the State Hazard Mitigation and Climate Adaptation Plan (SHMCAP) implementation process, making recommendations to and supporting agencies on plan updates, and facilitating coordination across State government and with stakeholders, including cities, towns, and businesses.

One of the key RMAT initiatives is the creation of Climate Resilience Design Standards and Guidelines. According to RMAT, "this project aims to develop resilience standards, guidelines, and a project

screening tool grounded in scientific methodology using the best available climate science data in Massachusetts, and that improves over time to incorporate new science, additional or changing climate hazards, and on-going stakeholder feedback. The focus of this project is to integrate climate resilience in projects with physical assets owned and maintained by state agencies and to provide guidance of Cities and Towns planning and undertaking their own capital improvement programs. When complete in early 2021, these tools will be accessible at ResilientMA.org, and are likely to become relevant to state grant-funded projects throughout the Commonwealth."[x]

The draft Climate Resilience Design Standards outline a process for establishing a consistent basis-of-design across various projects in the Commonwealth for climate parameters: SLR and storm surge, extreme precipitation, and extreme heat. The process uses an assessment of asset type, useful life, and criticality to provide recommended planning horizon, return period or confidence interval, design criteria, and tiered methodology for calculating design criteria values, including design flood elevations. For coastal flooding and SLR, the standards reference the Massachusetts Coast Flood Risk Model (MC-FRM) that is currently being developed by MassDOT. The MC-FRM is a probabilistic hydrodynamic model that uses the values for SLR adopted by the Commonwealth of Massachusetts (RCP 8.5 scenario). MC-FRM is discussed in greater detail in Section 6.

MA Statewide and Major Basins Climate Projections, Northeast Climate Science Center at the University of Massachusetts (2018)

The Northeast Climate Science Center at the University of Massachusetts Amherst developed downscaled projections for changes in temperature, precipitation, and SLR for the Commonwealth of Massachusetts. The projections are intended to enable municipalities, industry, organizations, state government and others to utilize a standard, peer-reviewed set of climate change projections.[xi]

Future sea level projections are provided for the Massachusetts coastline at established tide gauge stations, including Nantucket, MA. The methodologies and data underlying these projections, as well as the projections themselves, are discussed in Section 6 of this memorandum.

Federal

FEMA – 44 CFR 65

The Federal Emergency Management Agency (FEMA) establishes standards for the National Flood Insurance Program (NFIP) in 44 CFR Parts 59, 60, 65, and 70. Part 65 covers the identification and mapping of special hazard areas, including the process and regulations for revising the regulatory floodplain based on the construction of new structures. This includes design criteria, engineering standards, and operations and maintenance protocols required for levee certification. One important factor covered by the coastal levee standard are freeboard requirements.

FEMA Coastal Construction Manual

The FEMA Coastal Construction Manual provides guidance for designing and constructing flood resistant residential buildings in coastal areas. It offers professional guidance to designers, engineers, and contractors to assist in the creation of homes and communities less vulnerable to flooding, including through siting and design and construction decisions. While not a FEMA standard, the manual provides important guidance for floodplain construction.

6. Coastal Hazard Assessment Methodology

This section outlines the proposed data sources and methodologies for assessing coastal hazards on Nantucket, including high tide flooding, coastal flooding, coastal erosion, and groundwater table rise. The methodologies described herein are based on two principles: (1) basing analysis on best-in-class, peer-reviewed approaches to assess coastal hazards while considering the most relevant and widely accepted data appropriate for an area-wide study; and (2) developing an approach that is consistent with other statewide planning and risk analyses such that Nantucket could pursue state and federal funding for resilience projects based on the work completed as part of this effort.

One of the key early benefits of the CRP will be to establish a recommendation of a Best Available Dataset for the Town's planning and for public communication of risk. Establishing a single dataset for each coastal hazard will help ensure that future projects are based on consistent data and approaches, while reducing confusion among the public and decision-making bodies regarding the data that should be utilized.

Data Sources

Many datasets are available for assessing coastal hazards on Nantucket, as summarized in Appendix A. These datasets come from a variety of local, state, federal, and private sources. As part of this study, analysts reviewed the available datasets in order to reach a recommendation for the best-in-class datasets for the purposes of the CRP. This section outlines the available and recommended coastal hazard datasets.

Sea Level Rise Projections and Scenarios[2]

Rising sea levels will exacerbate high tide flooding, coastal flooding, groundwater table rise, and coastal erosion. Although a significant degree of uncertainty exists around the amount of future SLR that can be expected over what time horizon, for planning and design purposes it is often necessary to select specific SLR projections and scenarios based on an evaluation of available data, long-term needs, and risk tolerance. The selected projections must be frequently reevaluated in light of new information. The following paragraphs briefly describe the SLR data that is currently available for Nantucket as well as a recommendation on the projections and scenario to adopt for the CRP.

The U.S. Army Corps of Engineers (USACE) provides local sea level curves through the online Sea-Level Change Curve Calculator.[xii] Projections are available for multiple methodologies, including NOAA 2017[xiii], which is the basis of the Town's interim adopted SLR policy. This methodology provides scenario-based probabilistic projections of national sea levels to 2100 with considerations for emissions scenarios (low - RCP[3] 2.6, medium - RCP 4.5, and high - RCP 8.5), ice sheet and glacial mass changes, thermal expansion, atmosphere-ocean dynamics, changes in land water storage, and vertical

[2] According to the International Panel on Climate Change (IPCC), in general usage, a projection can be regarded as any description of the future and the pathway leading to it. However, a more specific definition for the term "climate projection" is used by the IPCC when referring to model-derived estimates of future climate. A "scenario" is a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold. A projection may serve as the raw material for a scenario, but scenarios often require additional information (e.g., about baseline conditions). A set of scenarios is often adopted to reflect the range of uncertainty in projections. (IPCC)

[3] Representative Concentration Pathways: Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover (Moss et al., 2008).

land movement due to isostatic adjustment, tectonics, and sediment compaction. Tide gauge records indicate that since 1963 Nantucket Harbor has experienced 3.75mm of SLR per year (Figure 5).[xiv] NOAA also notes that Nantucket is projected to experience higher levels of SLR than the global average, with scenarios for Nantucket displayed in Figure 6. The rate of rise is projected to accelerate and an additional 1 to 11 feet is expected by the end of the century.[xv] The mean SLR expected by 2100 is 4.23 feet, but it should be noted that the mean does not represent an expected outcome based on probabilistic analysis.

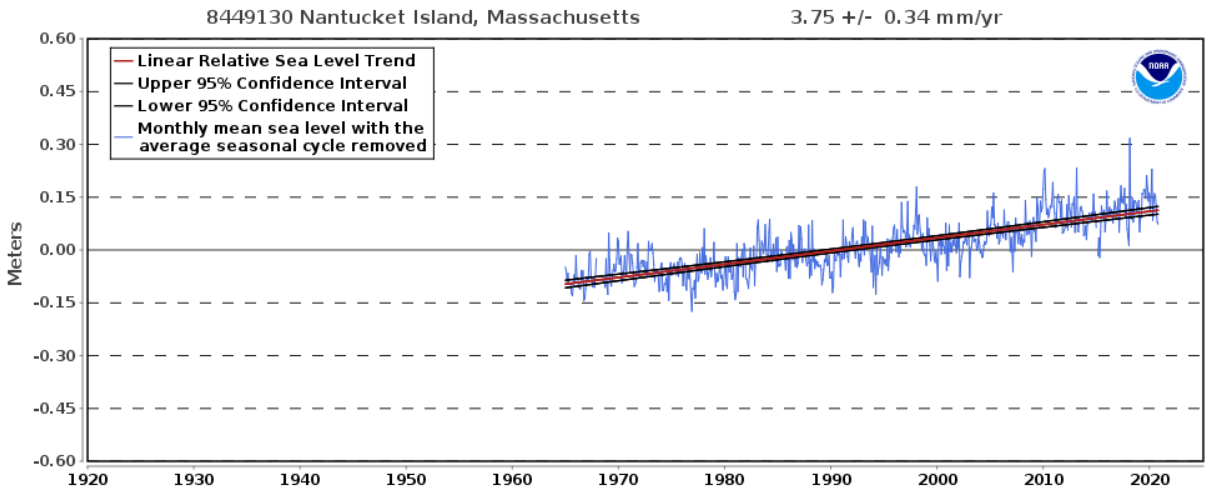

Figure 5: Historic SLR at 8449130 Nantucket Island, Massachusetts

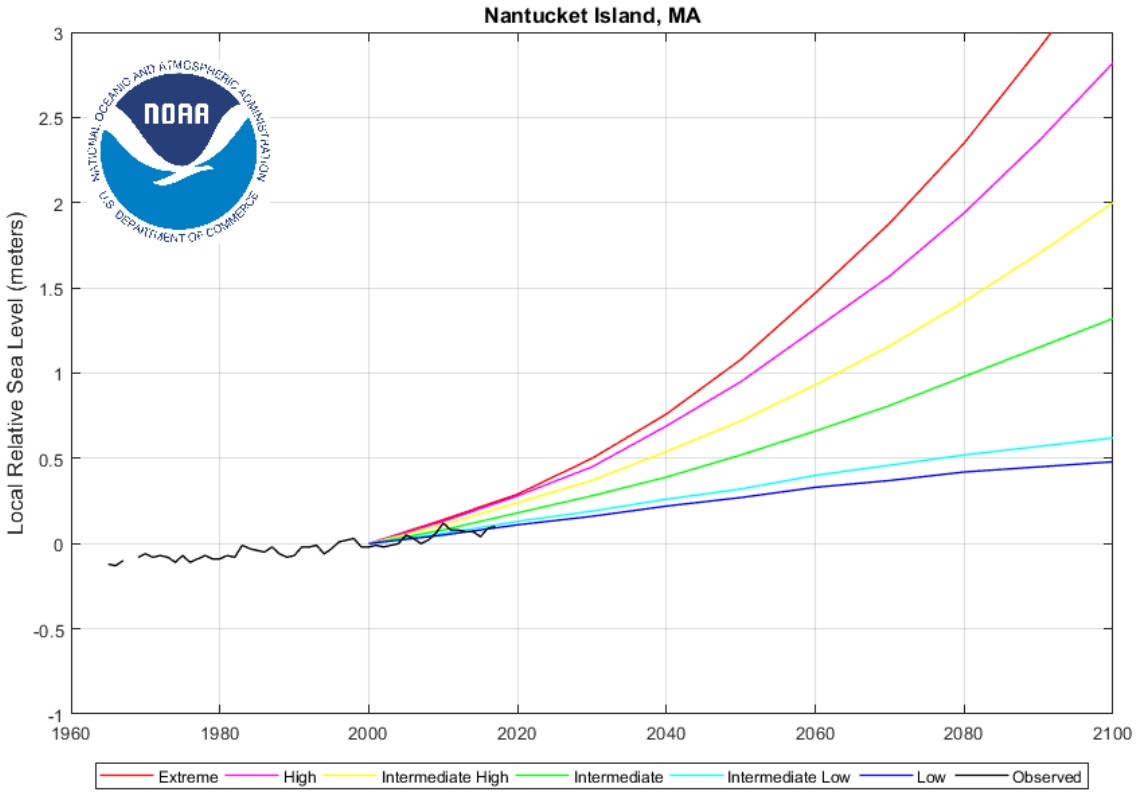

Figure 6: Annual Mean Relative Sea Level Since 1960 and Regional Scenarios at 8449130 Nantucket Island, Massachusetts

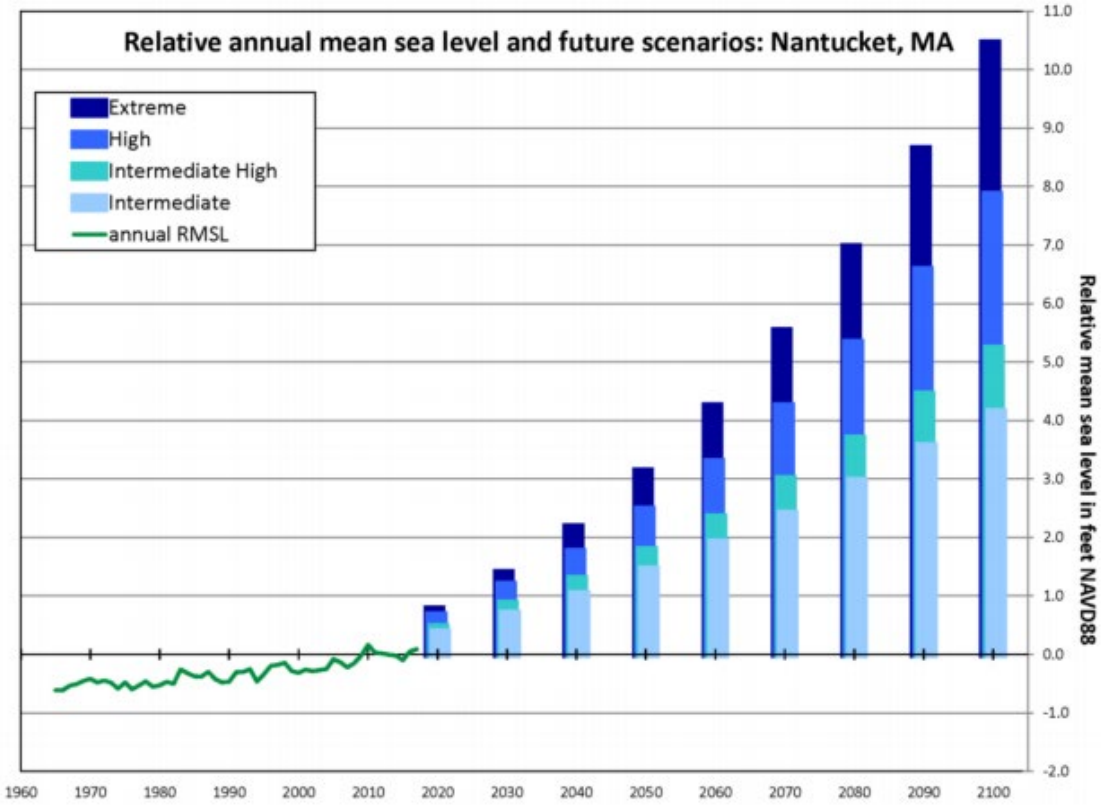

Figure 7: Relative Annual Sea Level Rise and Future Scenarios for Nantucket, MA from Massachusetts Statewide Climate Projections (Northeast Climate Science Center, UMASS Amherst)

An additional set of Massachusetts-specific SLR projections has been adopted by the Commonwealth of Massachusetts in 2018, as shown in Figure 7.[xvi] These data provide the most up to date relative SLR projections for the state and are downscaled from regional and international projections using approaches consistent with the International Panel on Climate Change, the 2017 National Climate Assessment, and the Global and Regional Sea Level Rise Scenarios for The United States (NOAA). The methodology includes a probabilistic assessment of future sea levels using medium (RCP 4.5) and high (RCP 8.5) greenhouse gas concentration scenarios with considerations for two methods of estimating ice sheet loss based on expert elicitation and process-based numerical models. A full overview of the methodology can be reviewed is the Massachusetts Statewide and Major Basins Climate Projections report (March 2018). Figure 8 compares the State and NOAA (Town adopted) SLR curves and highlights the degree of uncertainty surrounding SLR projections, particularly for long-term projections.

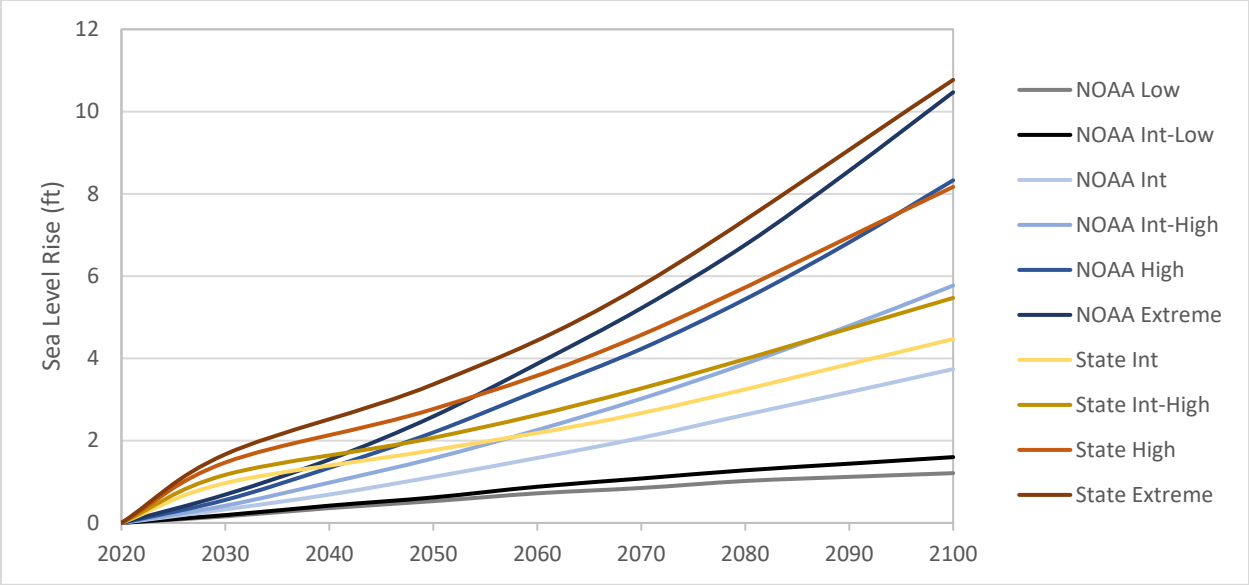

Figure 8: Local SLR projections for NOAA and Massachusetts State methodologies normalized to 2020.

Recommended Sea Level Rise Scenarios and Projections

Our assessment is that the Town's coastal resilience planning should refer to the SLR projections adopted by the Commonwealth of Massachusetts as best available data. This recommendation is based on three observations.

First, the State's projections are the most up to date and are based on the latest developments in climate science.

Second, using the State's projections will enable use of the same inputs for the tidal flooding and coastal flooding assessment methodologies, as discussed below.

Third, it will ensure the Town's planning and design for coastal resilience infrastructure are consistent with recommended State standards and approaches.

In addition to selecting a set of SLR projections from one source, an individual SLR scenario must be established for planning and design purposes. The Town has expressed a desire to plan for a high SLR scenario from NOAA in the interim SLR Policy adopted by the Coastal Resilience Advisory Board and the Select Board. We concur with this approach given the current scientific understanding of the expected increasing pace of SLR over the century and recommend that high scenario from the Commonwealth's projections be adopted.

The recommended adoption of the Commonwealth's high scenario is based on current science and knowledge around anticipated SLR, science and knowledge that are rapidly evolving. Because of the likely future variability in SLR projections as new data and techniques emerge, it is recommended that the Town continually monitor the state of the science and update plans and designs as appropriate based on the latest published, peer-reviewed results.

As described in Section 5, the Commonwealth of Massachusetts, through the Resilient MA Action Team, is in the process of adopting statewide resilience standards for planning and design. These standards draw on the Commonwealth's Massachusetts-specific SLR projections, as described above. The standards also draw on the coastal flood modeling and mapping generated using the Massachusetts Coastal Flood Risk Model (MC-FRM), described in a subsequent section. The MC-

FRM's future flood mapping uses SLR projections consistent with high scenario being used by the State.

Flood Hazard Data

A review of available flood hazard data for Nantucket was completed, with available datasets summarized in Table 1. While several datasets are available, most are not sufficient for coastal resilience planning due to limited consideration of future conditions, spatial extent, and/or the range of storm intensities.

Table 1: Available flood hazard datasets.

Dataset	Relevant Data	Considerations	Date of Latest Revision
Massachusetts Coast Flood Risk Model (MC-FRM)	Island-wide inundation depths and annual exceedance probability for 0.2%, 1%, 2%, and 10% events at present, 2050, and 2070.	Best available hazard data provided by Commonwealth of Massachusetts	2019
FEMA Flood Insurance Rate Maps (FIRM)	Island-wide storm surge inundation extents for 0.2% and 1% storms.	Based on historic storms with no consideration for future sea levels Only 2 storm intensities considered	06/2014
FEMA Flood Insurance Study (FIS)	Stillwater and base flood elevations at transects for 0.2%, 1%, 2%, and 10% storms.	Based on historic storms with no consideration for future sea levels Limited spatial resolution	06/2014
NHC – SLOSH	Inundation extent for category 1 through 4 hurricanes	No consideration of future sea levels No relation to storm exceedance probability or consideration of nor'easters	10/2013
Storm Tide Pathways	Inundation extent in 0.5ft intervals from 5ft to 13ft	No consideration for future sea levels, but could be correlated with different scenarios No relation to storm exceedance probability, but could be correlated with different scenarios	6/2016
NACCS	The North Atlantic Coast Comprehensive Study Includes range of annual exceedance probability for present and future	Recommended coastal flood risk dataset in Coastal Risk Assessment and Resiliency Strategies Report (2020) Superseded by MC-FRM as best available data for Massachusetts	2015

Recommended Flood Hazard Data

We recommend that the Massachusetts Coastal Flood Risk Model (MC-FRM) dataset be adopted by the Town as the Best Available Flood Hazard Data as it represents the most recent data, has the highest spatial resolution, and considers the widest range of present and future storms. This dataset was developed for the Massachusetts Department of Transportation to assess coastal flood risk to transportation systems at risk to future sea levels and coastal storms and has already been used in vulnerability assessments for Woods Hole[xvii] and Falmouth,[xviii] and will be the recommended Best Available Flood Hazard Data for coastal Massachusetts by RMAT. The dataset provides state-wide high resolution annual flood exceedance probability and inundation depth maps based on stillwater flooding for the present, 2030, 2050 and 2070. Projections for 2100 are expected later this year; if desirable, preliminary coastal flooding maps for 2100 can be generated by adding the appropriate SLR increment for 2100 to the 2070 coastal flood elevations. Flood depth maps are provided for 0.1%, 0.5%, and 1% annual exceedance storms. The SLR projections used for MC-FRM are based on the high projections being used by the Commonwealth of Massachusetts. Table 2 summarizes the outputs that is currently accessible for MC-FRM. Table 3 compares FEMA and MC-FRM stillwater levels (SWL) for the 1% AEP at two sample transects. While the values are comparable, in these cases the modeling provided by MC-FRM indicates higher stillwater elevations.

MC-FRM's numerical modeling uses dynamic coupling of the Advanced Circulation Model (ADCIRC) for water levels and velocities, and Unstructured Simulated Waves Nearshore (UNSWAN) for wave generation and transformation. Modeling also considers wave runup and overtopping along coastal structures for determining inland ponding elevations. Future sea levels are determined using the Commonwealth of Massachusetts' adopted SLR projections.[xix] Exceedance probability is based on a Monte Carlo simulation of a suite of historic and synthetic storms. The model mesh allows for coarse resolution of the entire Atlantic Ocean and fine resolution (up to 2-3m) along the shoreline statewide.

Table 2: Coastal flooding datasets currently available through MC-FRM

Annual Exceedance Probability	Return Period	Data Currently Available	Climate Years
5%	20-year	Probability of inundation	2030, 2050, 2070
2%	50-year	Probability of inundation	2030, 2050, 2070
1%	100-year	Probability of inundation, flood depths	2030, 2050, 2070
0.5%	200-year	Probability of inundation, flood depths	2030, 2050, 2070
0.2%	500-year	Probability of inundation	2030, 2050, 2070
0.1%	1000-year	Probability of inundation, flood depths	2030, 2050, 2070

Table 3: Comparison of 1% stillwater levels (SWL) from FEMA's FIS and MC-FRM model results at Madaket and Downtown Nantucket.

FEMA FIS Transect	FEMA 1% SWL (ft NAVD88)	MC-FRM Average 1% SWL (ft NAVD88)
34 (Madaket)	6.1	7.38
27 (Downtown)	6.1	6.40

Coastal Erosion Data

There have been several studies looking at coastal erosion on Nantucket, though only one study provides predictive data on future erosion with SLR (as documented in Table 4 below). Previous studies have relied on measurements of changes in shoreline position over time, resulting in estimates of erosion rates in terms of average feet per year of shoreline change. The response of shoreline change rates to SLR is currently a topic of ongoing research, however, most opinions expect the rate of shoreline erosion to increase with SLR. The recent erosion study for Nantucket completed by FEMA makes recommendations for modifying existing shoreline erosion rates with a factor to account for SLR. Sandy shoreline and dune erosion rate changes are directly proportional to SLR and bluff erosion is proportional to a factored SLR rate. Discussion of the recommended data and approaches for the assessment of future coastal erosion is described in the following section.

Table 4: Available coastal erosion and shorelines change datasets

Dataset	Relevant Data	Considerations	Date of Latest Revision
Massachusetts Shoreline Change Project	Historic shoreline and shoreface data.	Viewable data and metadata suggest that future projections were not evaluated.	06/2013 USGS
FEMA CEHM	Coastal Erosion Hazard Maps. Current and future coastal erosion hazard areas.	Provides baseline understanding of current and future erosion zone delineation for multiple SLR scenarios	07/2019 FEMA
SLAMM	Sea Level Rise Affecting Marsh model results showing SLR impacts on marsh distribution and shorelines Provides results for 2030, 2050, 2070, and 2100	Only viewable data is available	CZM
Sconset Beach and Bluff Surveys	Semi-annual beach and bluff surveys from 1994 to date. Documented in various "Southeast Nantucket Beach Monitoring Reports"	Historic data only – no future projections	June 2020 Woods Hole Group

Groundwater Table Data

Existing information on groundwater for Nantucket County is provided by United States Geological Survey (USGS). USGS manages 10 groundwater wells across the Island, as shown in Figure 9, where it records periodic measurements. Well depths vary from approximately 21 to 100 feet deep. The most recent measurements were on December 16, 2020, with water tables varying from as shallow as 5.42 below the land surface ("BLS") on the western part of the Island in Madaket, to 44.23 BLS near Nantucket Memorial Airport.

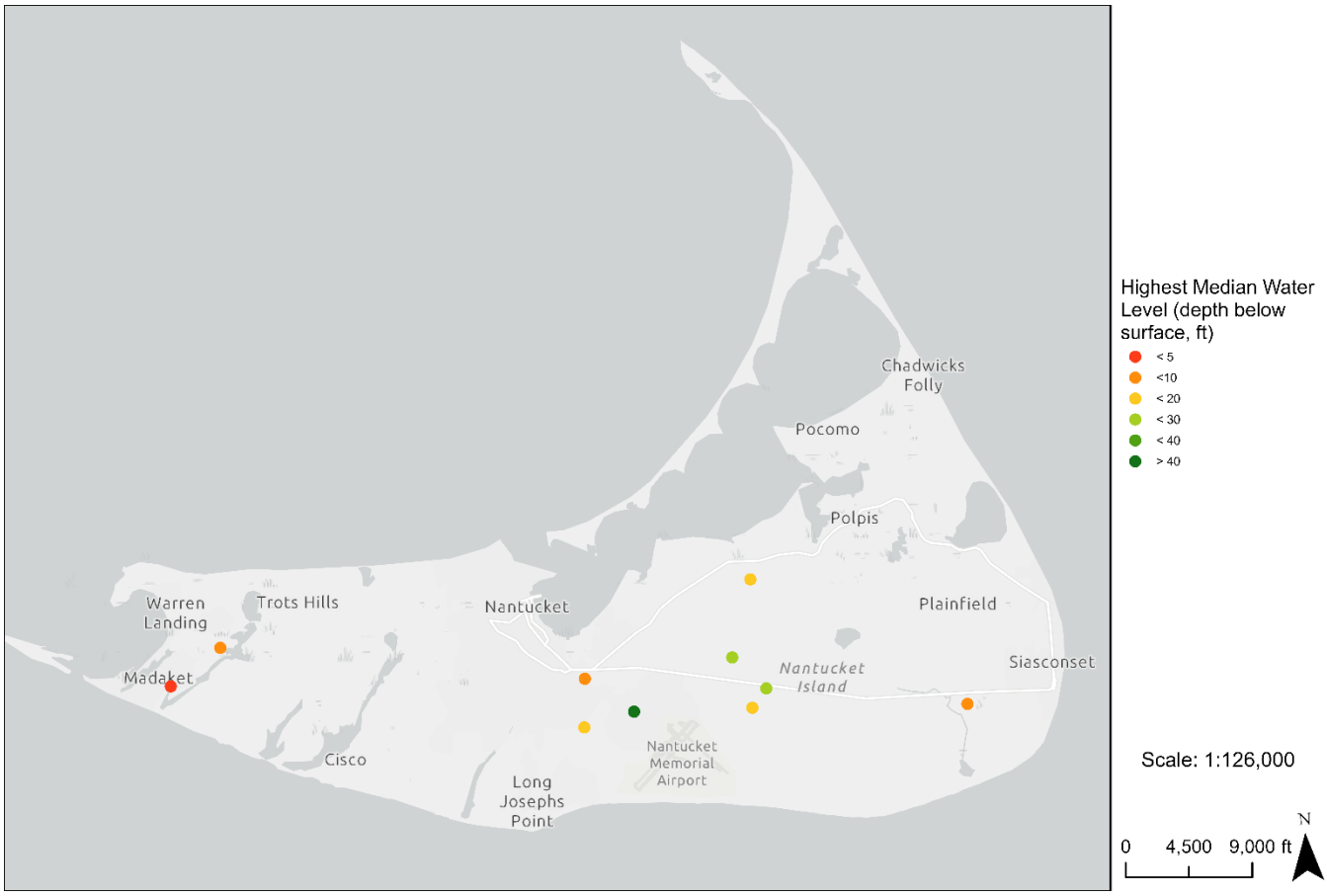

Figure 9: Nantucket groundwater levels from most recent readings (12/16/2020).

Recommended Groundwater Table Data

The USGS annually monitors groundwater levels in thousands of wells in the United States, including 10 on Nantucket. As such, the groundwater assessment for the Nantucket CRP should leverage the data publicly available from USGS.

Recommended Approaches

This section outlines additional considerations related to approaches used to assess coastal risk based on the recommended data sources described in the previous section.

Nuisance Flood Risk Assessment

SLR will drive increasing high tide flooding on Nantucket in the coming decades. Tidal observations are available in Nantucket Harbor at Station ID 8449130 along with subordinate stations at Great Point, Eel Point, and on Muskeget Island.

Based on the “High” scenario for future SLR provided by the State, as discussed earlier in this section, we propose to use mean monthly high water (MMHW) as the tidal level representative of nuisance flooding since the frequency of traditional daily tidal datums (e.g., mean higher-high water or mean high water) is too extreme to be considered “nuisance.” For example, tidal flooding of a street on a daily

basis is not a nuisance, it is a significant disruption to everyday life. By examining monthly high water, decision makers are able to understand potential future nuisance issues and address them through mitigation or adaptation actions before the flooding increases in frequency and becomes disruptive. MMHW is typically exceeded 25-35 times a year and is meant to approximate an identified tipping point of 30 floods per year.[xx] Separate mapping layers will be produced to assess future daily tidal conditions based on MHHW values. Table 5 below summarizes the elevations of MMHW and MHHW for Nantucket based on the NECSC 2018 (State) High projections.

We are currently planning to base the analysis of nuisance flooding on tidal benchmark data available from the Nantucket Harbor Tide Station as reasonably representative for the whole island. This approach is based on the observation that the difference in tidal levels in other areas likely to experience nuisance flooding issues, such as Madaket Harbor, would have little impact on the outcomes of the area-wide analysis conducted for the CRP. It is important to note that the coastal flooding analysis will use MC-FRM, which is based on modeling that accounts for differences in predicted surface water elevations between the Harbor and other areas of the island.

Table 5: Water surface elevations for present and future tidal conditions based on NECSC 2018 (State) High SLR projections.

Year	MHHW (ft NAVD88)[4]	MMHW (ft NAVD88)
Present	1.53	2.66
2030	3.00	4.13
2050	4.30	5.43
2070	6.10	7.23
2100	9.70	10.83

These projected future sea levels can be used to determine high tide flood exposure using a bathtub mapping approach. Current high tide water levels can be added to SLR values for a given year to identify locations where land, infrastructure, and structures are below the stillwater level and at risk of nuisance flooding. This approach can be modified to consider flood pathways by excluding discontinuous areas with elevations lower than the flood elevation. This approach is less appropriate for Nantucket as it does not account for wave overtopping and assumes that barriers to flow pathways would remain intact during a storm. As an example, the relatively high elevations of dunes along Nantucket's numerous coastal ponds could indicate that there is no flood pathway from the ocean to the pond and low-lying areas in the vicinity. In reality, there is still risk to these areas if the narrow strip of shore breaches, if waves runup causes water to overtop the dunes, or due to seepage of sea water through the porous sediments of beaches and dunes. Additionally, these low-lying areas would be at risk of flooding from precipitation. For these reasons, a simple bathtub approach is most appropriate for Nantucket. For example, Figure 10 depicts areas that would be inundated at MMHW at 2050 sea levels. While it may be appropriate to remove the smaller areas north of Quidnet, this approach would not adequately depict risk around Sesachacha Pond.

[4] Elevations can be converted from NAVD88 to Mean Sea Level (MSL) by subtracting 0.27 feet.

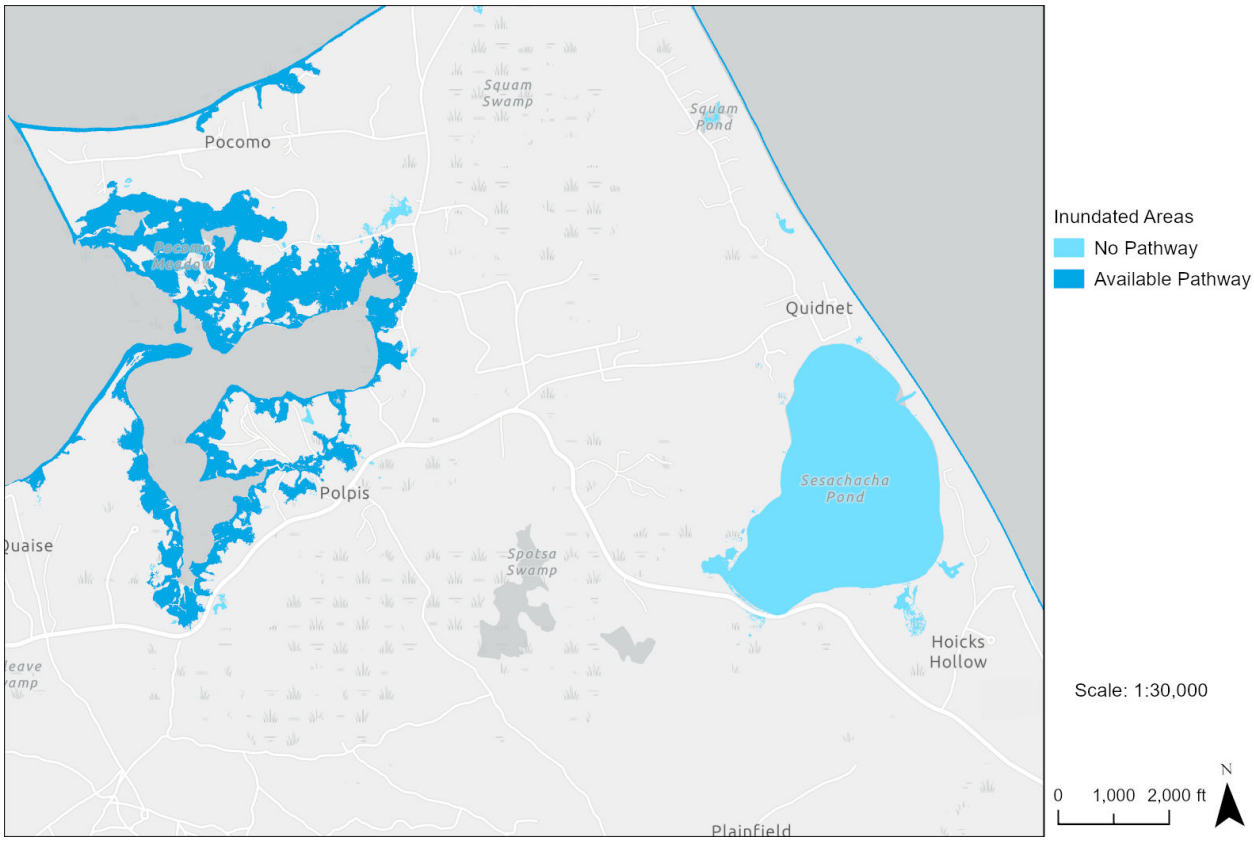

Figure 10: Bathtub inundation map for 2050 sea levels at MMHW. Inundated areas represent locations where ground elevation is less than the stillwater level (4.86ft NAVD88). Areas with "No Pathway" would be removed by a modified bathtub approach.

Coastal Flood Risk Assessment

The recommended flood hazard approach will use MC-FRM data to evaluate risks associated with coastal stillwater flooding. Additional detail on the coastal flood risk analysis will be detailed in a subsequent memorandum.

Wave hazards are an additional risk factor associated with coastal flooding. The standard outputs of the MC-FRM model being developed by MassDOT will include wave crest heights; however, these data are not anticipated for public release until April 2021.[xxi] In order to evaluate wave risk, an alternative approach is therefore proposed. This approach uses water depths provided by MC-FRM to calculate depth limited wave heights based on the formula below. The formula calculates wave crest evaluation based on the percent of wave height above the stillwater elevation (0.7), the depth limited breaking factor (0.78), and the water depth at a given location (see Figures 11 and 12)

Wave Crest Elevation = Stillwater elevation + .7 X .78 X Water Depth

This approach is consistent with FEMA guidelines for determining DFEs. It does not account for certain coastal processes (wave runup, overtopping, dunes, erosion) that are typically considered by FEMA in determining DFEs. However, we believe for an area wide study such as the CRP, this method will provide a useful tool for risk and vulnerability assessment. It is not intended as a substitute for more detailed analyses that would likely be needed for design of coastal structures.

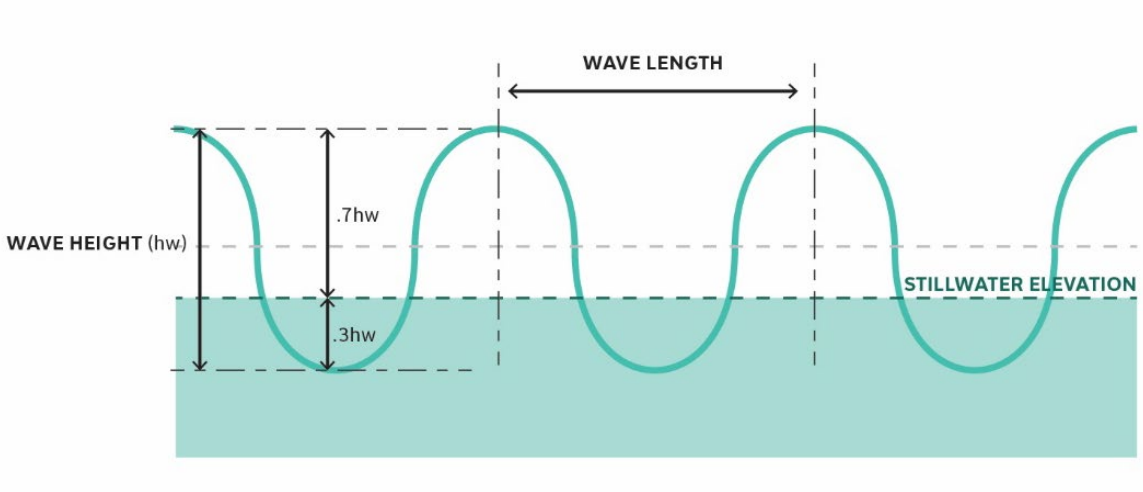

Figure 11: Diagram of wave period and height, including portion of wave above stillwater elevation (0.7hw)

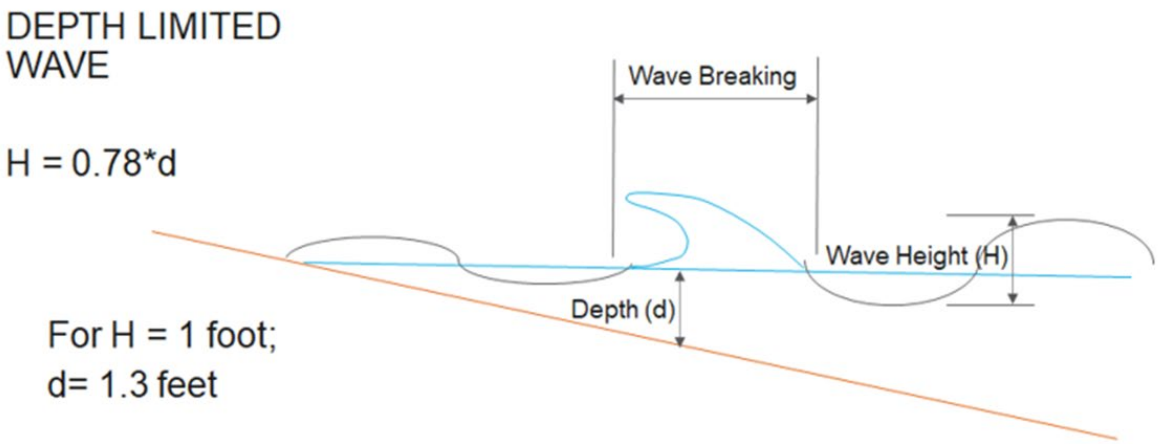

Figure 12: Diagram of wave height calculation based on water depth

This formula can be used to create water depth limited area to define the general area of moderate wave hazard, generally including exposed coastal areas with at least two feet of water depth. This approach will also be used to establish wave crest elevations used for Mitigation Design Elevations, as discussed in Section 7.

Coastal Erosion Hazard Assessment

The following methodologies are recommended for assessing coastal erosion hazards on Nantucket. The erosion study completed by FEMA in 2020 provides projections for future erosion hazards and include factors for SLR. The methodology is based on historic observed erosion rates (feet per year of erosion). The FEMA study provides the “best available” erosion hazard data as it includes both historic erosion data and considers future SLR conditions. However, the FEMA study does not consider the episodic nature of coastal erosion which can be orders of magnitude greater than average yearly rates. This is especially of concern for coastal bluff shorelines that do not recover as beaches and dunes do.

Our approach for the coastal hazard assessment will be to select two (2) shoreline locations; one bluff and one sandy beach and dune (same typologies considered in the FEMA study) and utilize numerical modeling to evaluate beach, dune and bluff response to infrequent storm event conditions. With the results from the numerical simulations, a comparison to the FEMA projections can be made to develop a better understanding of how infrequent storms are represented by the FEMA methodology.

Numerical Model

Arcadis proposes to use the SBEACH numerical model for the erosion assessment. The SBEACH model is a two-dimensional cross shore numerical model for calculating dune and beach erosion from storm waves and water levels.[xxii] This model is empirically based and developed from a large database of net cross shore sand transport rates and geomorphic change measured in large wave flumes. This model was then verified using field data on both the east and west coast of the U.S. The SBEACH model is driven using time series of wave height and period in deep water, water level, median grain beach size (d_{50}) and initial profile shape with cross shore distance and elevation. This numerical model is one of the industry standard cross shore models and has been used effectively in multiple locations in the Northeast by Arcadis engineers including Long Island, NY and Saco, ME.

Calibration

Cross shore shoreline change models have a number of variables that are adjusted to tune to local conditions. We plan to use available post storm survey data (example pre- and post- Hurricane Sandy) to calibrate the SBEACH model sediment transport parameters such as the transport rate coefficient, transport rate decay multiplier, and slope dependent terms. We are currently evaluating the available data sets, especially around the Siasconset area, for use in calibrating the model.

Data Input

We are currently considering using offshore wave height and period as well as water levels available through the North Atlantic Coast Comprehensive Study (NACCS).[xxiii] This data is available for a suite of 125 storms with extraction nodes surrounding the Nantucket Island at water depths sufficient to provide deep water waves (Figure 13). Storms with appropriate return period would be selected. Another approach could be to request storm data for specific points from the MC-FRM study. However, the timing on this data request may not fit well with the CRP project schedule.

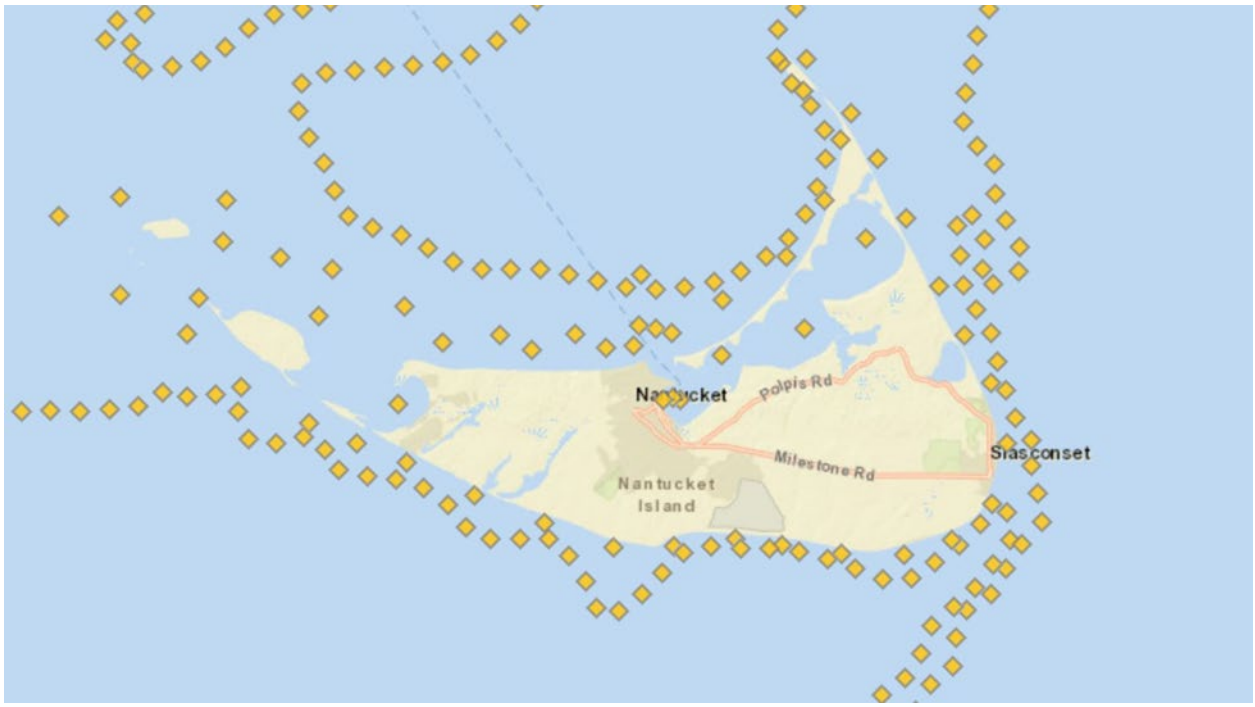

Figure 13: NACCS Coastal Hazards Web portal Nodes – for storm data extraction.

For topography, we will utilize the 2016 USGS CoNED Topobathymetric Model data that is being used for rest of the CRP work.[xxiv]

We are currently researching available grain size information. Previous work at Siasconset provides median grain size of 0.4 mm.

Modeling Approach

At one representative bluff location and one representative beach/dune location, a shore perpendicular transect will be constructed. The variations in SLR and storm conditions that will be modeled in SBEACH are summarized in Table 6. Given the focus of the CRP erosion analysis will be on understanding risk to property and assets over the next 10 to 15 years, the modeling will focus on the 2030 and 2050 planning horizon. FEMA's erosion analysis will be used to understand longer term impacts. Results will be summarized as a loss of bluff, beach or dune(feet) per storm event.

Table 6: SLR years and return period storms proposed for SBEACH modeling approach. SLR scenarios will be based on high projections provided by Commonwealth of Massachusetts. Storm data derived from NACCS unless MC-FRM data is available for analysis.

Year / SLR Scenario	Return Period Storm
Present	10, 25, 50, 100
2030	10, 25, 50, 100
2050	10, 25, 50, 100

Data Analysis

The SBEACH results will be compared to the FEMA erosion projections at the selected transect locations. A qualitative analysis will be provided to better define how the average erosion rates from the FEMA study represent potential erosion from infrequent storm events. Depending on the results of the SBEACH analysis, recommendations will be made on how the FEMA erosion projections should be used in the overall coastal hazard assessment.

Groundwater Table Rise Assessment

The consideration of groundwater coastal resilience assessments is discussed in Rozell (2020).[xxv] For the assessment of potential groundwater flooding induced by SLR at Nantucket Island, the recommended method is detailed in Plane, E.; Hill, K.; May, C. (2019) "A Rapid Assessment Method to Identify Potential Groundwater Flooding Hotspots as Sea Levels Rise in Coastal Cities".[xxvi] A diagram of the process in shown in Figure 14.

The proposed approach is to create an interpolated water table surface using existing well data and known points where the water table intersects the ground surface, such as at streams and at the shore. Once an estimated water table is generated, the depth to groundwater is calculated from the Digital Elevation Model (DEM). Future SLR scenarios can be simulated by adjusting the water table surface to move vertically with SLR.

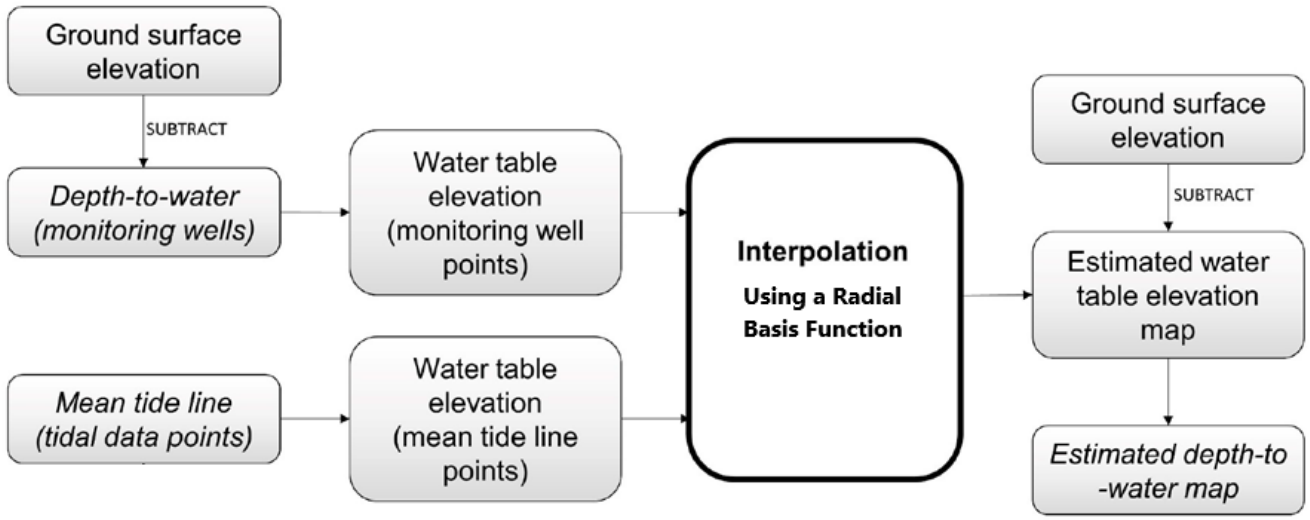

Figure 14: Diagram representing a Rapid Assessment Method to Identify Potential Groundwater Flooding Hotspots as Sea Levels Rise in Coastal Cities

7. Establishing Design Flood Elevations

This section describes the process that will be used to establish the target level of protection and associated Design Flood Elevation (DFE) that will be recommended for project planning and conceptual design.

When considering flood risk and vulnerability, as well as potential mitigation actions, it is important to identify a goal level of protection. The goal level of protection is the flood elevation at which risk mitigation measures would be designed to limit damage and service interruption. This flood elevation should, where feasible, correlate to the flood probability that is in accordance with industry standards and federal, state, and local regulations. Level-of-protection decisions should also ultimately be based on several factors including, but not limited to:

- Allowable risk tolerance and asset criticality
- Specific codes governing new and existing buildings and infrastructure; these requirements often provide the freeboard (safety factor) appropriate to the assigned risk category
- Best available flood hazard data
- Additional factors that may exacerbate flood risk at the site, including expected SLR (SLR) or increased rainfall due to climate change, and wave height

There are three primary elements that contribute to the DFE. The basic formula for determining the DFE is:

$$Stillwater\ elevation\ (including\ projected\ SLR) + Wave\ Crest\ Elevation + Freeboard = DFE$$

Additional detail on each of these components is outlined below.

Stillwater Elevation

The stillwater elevation provides the basis for the DFE and is defined based on the projected water surface elevation associated with various Annual Exceedance Probabilities and future SLR projections. As described in Section 6, the Massachusetts Coastal Flood Risk Model is recommended. The stillwater level includes the effect of wave setup but does not include wave runup, described in greater detail below.

The selection of the appropriate stillwater elevation is determined by risk tolerance. For example, *what probability of risk is tolerable for a given area or asset?* Selection of the 0.1% annual exceedance probability event would suggest a very low risk tolerance whereas selection of an event with a 5% annual exceedance probability would suggest a higher tolerance for risk.

Another consideration related to the selection of stillwater elevations is the design life of the asset and the potential for future adaptability. The appropriate future stillwater elevation including SLR should be selected based on the asset type and intended design life. A flood wall intended to protect a neighborhood through 2070 may rely on a different future stillwater elevation than a new building expected to last until 2050.

Wave Considerations

The primary consideration in determining the DFE will be wave crest elevation. As introduced earlier, this will be estimated by taking the 0.7x the significant wave height and adding that to the SWEL. This will be the method utilized for most areas; however, for areas shoreward of the existing bulkhead or

dune line, waves will most likely be depth limited – there is a physical limit to how high a wave can be for a given water depth before the wave breaks. In this instance, the maximum depth limited wave height can be estimated as 0.78x the water depth.

For areas at the intersection of the water and land during a design event (the shoreline), there are other wave characteristics that must be considered when determining the DFE. For example, in coastal settings, the expected waves heights and wave runup must be added to the expected stillwater surface elevations. This particularly relevant on Nantucket where waves heights often exceed three feet.

Wave Runup & Overtopping

Wave runup is a local phenomenon that occurs at the coastal waterline. When waves approach the shore, their momentum may allow them to propagate up beaches and dunes. Wave runup is a critical component of the design of coastal interventions. When considering wave loading on structures or wave runup on flood protection structures, additional modeling is required.

Wave overtopping, or the amount of water that is allowed to overtop the coastal defense must be determined. Tolerable wave overtopping rates are typically based on criteria summarized in EuroTop (Pullen et al. 2007) to prevent impacts to critical transportation routes immediately behind the flood protection system and to prevent damage to the flood protection system itself. A diagram of wave runup and overtopping is shown in Figure 15.

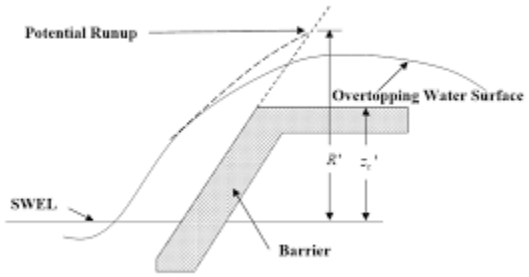

Figure 15: Wave Runup and Overtopping (Source: FEMA Guidance For Flood Risk Analysis and Mapping)

Wave runup and overtopping is very site specific, and it would be difficult to accurately account for these processes for the CRP. Some potential options would be to include a “special hazard area” requiring site specific analyses; or projecting offshore wave heights as the DFE a certain distance inland (offsets); or increasing freeboard requirements to account for runup and overtopping.

Freeboard

Freeboard is a margin of safety usually expressed in feet above a flood level for purposes of floodplain management. Freeboard tends to compensate for the many unknown factors that could contribute to flood heights greater than the height calculated for a selected design storm, such as variability in wave action and uncertainties in projected SLR.

Codes and guidance documents, including the Massachusetts Building Code and American Association of Civil Engineers (ASCE), provide standards for freeboard based on risk category. Generally, the higher the intensity of use or criticality of an area or facility, the higher the freeboard. Selection of the appropriate freeboard for Nantucket will depend on the project type and scale.

Process for Determining Design Flood Elevations

The following process is proposed for establishing DFE for projects recommended by the CRP:

1. Determine intended useful life and criticality of asset or capital improvement
   - The useful life, or the anticipated life expectancy of an asset or capital improvement, is used to inform the design of the project. The project useful life may extend beyond the design life with regular maintenance and periodic reinvestment.
   - Criticality refers to the relative importance of a facility, asset, or service. The higher the criticality of facility, asset, or service, the higher priority it becomes for risk mitigation and the more conservative the risk mitigation approach should be. Generally, buildings and other structures whose failure could pose a substantial hazard to the community are considered highest criticality.

2. Consider future adaptability

   - Given the uncertainty associated with climate change and SLR, it is often necessary to plan for adaptability over time, rather than fixed targets, particularly for projects with expected design lives over 50 years. Using this approach, projects can be designed to account for the need for future adaptability to higher design elevations or alternative approaches.
   - For example, a project can be designed for mitigation through a certain time horizon (e.g., 2050) but with a longer-term horizon in mind (e.g., 2070). Evaluation of the changing conditions can then inform future adaption to a higher level of protection if needed.

3. Use intended design life and risk tolerance to select the appropriate design storm event and stillwater flood elevation

   - If the asset is being constructed in 2020 and has an intended design life of 50 years, use stillwater elevations for projected flood extents and elevations for 2070
   - A higher risk tolerance would result in the selection of a higher probability design storm/return period (higher percent AEP), while a lower risk tolerance would result in a lower probability design storm/return period (lower percent AEP).
   - For example, a flood wall with a 50-year design life that protects critical assets would likely have a low risk tolerance. In this case, selection of the stillwater elevation for the 1% or 0.2% annual exceedance probability flood in 2070 would likely be appropriate.

4. If applicable, add the anticipated wave crest height to the selected stillwater elevation.

   - Note inland areas may not be exposed to waves and thus will not require the addition of wave crest heights
   - If you do not have available information on wave crest heights, the following formula can be used to calculate the heights: Stillwater elevation + .7 X .78 X Water Depth

5. Add freeboard based on criticality and risk tolerance

   - Freeboard is generally recommended to be at least one foot above the expected elevation of flood water, but regulations may require additional freeboard depending on asset type and criticality.
   - Requirements are provided by FEMA and ASCE 24 based on risk category

8. Summary of Recommendations

This memorandum has documented the recommended data and methodologies for assessing coastal hazards on Nantucket. The recommendations described in earlier sections are summarized in Table 7. The goal of these recommendations to establish consensus standards for Best Available Coastal Hazard Data for Nantucket. Once reviewed and accepted by the Town, these data will be used for risk and vulnerability analysis and to inform the definition of DFEs, coastal resilience and adaption approaches, and conceptual designs.

Table 7: Summary of recommended coastal hazard datasets and approaches

Hazard	Recommended Best Available Dataset	Recommended Approach
High tide flooding / Nuisance flooding	NECSC SLR projections for the Commonwealth of Massachusetts (2018)	High projections for SLR will be used to evaluate exposure to flooding at Mean Monthly High Water (MHHW) and Mean Higher-High Water (MHHW)
Coastal Flooding	Massachusetts Coastal Flood Risk Model (MC-FRM) (2019)	MC-FRM data will be used to assess exposure and risk to coastal flooding across annual exceedance probabilities for present, 2030, 2050, 2070, and if appropriate 2100. MC-FRM uses seal level rise projections consistent with the high projections provided by the Commonwealth of Massachusetts.
Coastal Erosion	FEMA Region I Coastal Erosion Study – Nantucket County	For representative transects; additional analysis utilizing SBEACH and statistically methods to understand how FEMA study represents episodic erosion
Groundwater Table Rise	USGS groundwater levels from 10 Nantucket wells	A rapid assessment methodology recommended in Plane, E.; Hill, K.; May, C. (2019) will used to evaluate coastal areas that may be susceptible to groundwater emergence with SLR in 2030, 2050, 2070, 2100.

In addition to the coastal hazard assessment approach, this memorandum also lays out the proposed approach for establishing target Design Flood Elevations (DFEs). DFEs represent the goal level of protection to which risk mitigation measures are designed to limit damage and service interruption. The proposed methodology is based on the recommended Best Available Flood Hazard Data and

establishes a flexible process for defining DFEs by asset types, criticality, design/service life, and risk tolerance. The methodology also includes consideration of core resilience concepts such as adaptability over time and can be incorporated into a flexible adaption approach, as recommended by RMAT.

End Notes

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[ii] Larson, Charles D., 2020. High Tides and Flooding on East Street: A progress report and key findings. Town of Nantucket.
[iii] Robert J Nicholls and Richard S.J Tol, 2006. Impacts and responses to sea-level rise: a global analysis of the SRES scenarios over the twenty-first century. Accessed February 1, 2021. https://royalsocietypublishing.org/doi/full/10.1098/rsta.2006.1754
[iv] Federal Emergency Management Agency, Flood Insurance Study Number 25019CV000A, Effective June 9, 2014. https://map1.msc.fema.gov/data/25/S/PDF/25019CV000A.pdf?LOC=b05d44393e7ae2e2a5333e4959688032
[v] Mark Borrelli, PhD, Steve T. Mague, Theresa L. Smith, and Bryan Legare, 2017. Empowering Coastal Communities to Prepare for and Respond to Sea Level Rise and Storm-related Inundation: A Pilot Project for Nantucket Island. Center for Coastal Studies Provincetown.
[vi] Robert J Nicholls and Richard S.J Tol, 2006.
[vii] Masselink, G., Hughes, M. G. (2003) Introduction to Coastal Processes and Geomorphology, Oxford University Press, NY.
[viii] Rotzoll, Kolja and Charles H. Fletcher, 2012. Assessment of groundwater inundation as a consequence of sea-level rise. Accessed February 1, 2021. https://www.nature.com/articles/nclimate1725?message-global=remove
[ix] Massachusetts Climate Change Projections, Northeast Climate Science Center at University of Massachusetts Amherst. Accessed February 1, 2021. https://nescaum-dataservices-assets.s3.amazonaws.com/resources/production/MA%20Statewide%20and%20MajorBasins%20Climate%20Projections_Guidebook%20Supplement_March2018.pdf
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[xii] United States Army Corps of Engineers (USACE). Sea-Level Change Curve Calculator. Accessed February 1, 2021. https://cwbi-app.sec.usace.army.mil/rccslc/slcc_calc.html
[xiii] Sweet, W.W.V., Kopp, R., Weaver, C.P., Obeysekera, J.T.B., Horton, R.M., Thieler, E.R. and Zervas, C.E., 2017. Global and regional sea level rise scenarios for the United States. National Oceanic and Atmospheric Administration (NOAA). US Global Research Program. Accessed February 1, 2021. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf
[xiv] Nantucket Island, MA - Station ID: 8449130
[xv] Range based on review of sea level rise curves provided by multiple sources. 0.78ft (USACE 2013 Low and CARSWG 2016) is the lowest projection while 10.77ft (Commonwealth of Massachusetts/NECSC Extreme) is the highest.

[xvi] Massachusetts Climate Change Projections, Northeast Climate Science Center at University of Massachusetts Amherst. Accessed February 1, 2021. https://nescaum-dataservices-assets.s3.amazonaws.com/resources/production/MA%20Statewide%20and%20MajorBasins%20Climate%20Projections_Guidebook%20Supplement_March2018.pdf
[xvii] Woods Hole Group, Inc. 2020. Woods Hole Village Climate Change Vulnerability Assessment and Adaptation Plan.
[xviii] Woods Hole Group, Inc. 2020. Coastal Resiliency Planning for the Surf Drive Area.
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[xxv] Rozell, Daniel J. 2020. Coastal Resiliency Groundwater Considerations. The Groundwater Association.
[xxvi] Plane, E.; Hill, K.; May, C. (2019) "A Rapid Assessment Method to Identify Potential Groundwater Flooding Hotspots as Sea Levels Rise in Coastal Cities"

Additional references related to coastal erosion:

Komar, P.D. (1998) Beach Processes and Sedimentation, Prentice Hall, NJ

USACE (2015a) North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk, Main Report.

USACE (2015b) North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk, Appendix D-2: Commonwealth of Massachusetts.

Appendix D

Coastal Risk and Exposure Analysis Methodologies

Coastal Risk and Exposure Analysis Methodologies

Quantitative Risk Assessment

The quantitative risk analysis is based on an assessment of the expected damages from a range of flood events and erosion scenarios for the entire island of Nantucket if no actions are taken by the Town, residents, or businesses to reduce this risk. The assessment is based on outputs from the Massachusetts Coastal Flood Risk Model, including the 1% (100 year), 0.5% (200 year), and 0.1% (1,000-year) annual chance storms for present-day, 2030, 2050. and 2070.[1] Exposure at the mean higher high water (MHHW) event, along with potential exposure to coastal erosion was also analyzed for each time horizon. The data sources for the hazards addressed through the analysis are described in **Section 4.2 Coastal Hazard Data Sources and in Appendix C.**

By having data for the same annual exceedance probability flood events over time, analysts develop an understanding of how risk to a structure increases due to rising sea levels and other factors related to climate change. Using this approach, the available flood hazard scenarios were used to extrapolate future annual exceedance probabilities for a range of flood events. For instance, today's 1% annual exceedance probability flood is likely to happen much more frequently in the future, meaning that the annual probability of flooding increases over time. The methods used for this risk analysis account for this by calculating each structure's risk of flooding at different depths each year to develop a full understanding of the risk over time. Properties that are flooded so frequently that they may be unusable if mitigation actions are not implemented are also identified, and the impact of the loss of those properties is quantified as a one-time full building loss. Similarly, properties that are exposed to erosion in 2030, 2050, or 2070 will also be considered unusable and incur a one-time loss.

Risk through 2070 is assessed under the no action scenario, which determines losses if no flood protection measures are implemented. These losses can be compared to the losses under the recommended alternative that does involve flood protection measures. Risk is reported at the island-wide scale and can be reported at the neighborhood and district scale as needed.

Loss Metrics

Based on the approach summarized above, the following damages are quantified in dollar amount at the structure level and are reported island wide, as well as for sub-areas to be defined through the project process.

1. *Direct Physical Damages:*
   Analysts calculated both building and contents damages value for vulnerable structures using structure and contents depth-damage functions (DDFs) from the USACE North Atlantic Coast Comprehensive Study (NACCS).
2. *Direct Economic Disruption:*
   Analysts identified chronically flooded properties for which total loss of function will occur if no project is implemented, and account for their losses separately. Direct economic disruption represents the sum of commercial relocation costs and direct business interruption losses. Commercial relocation costs consist of one-time relocation costs, lost income experienced by property owners who lease their buildings, and

[1] Coastal flood hazard data from MC-FRM are not yet available for 2100. If this data becomes available, the 2100 horizon can be added to the coastal flood hazard analysis.

rental costs for displaced property owners. Direct business interruption includes losses of business income, employee compensation, and other property income.

3. *Social Disruption:*
   Social disruption captures losses due to physical injuries, mental stress, loss productivity, and residential relocation. Losses due to injuries, mental stress, and lost productivity are all calculated based on standard FEMA values applied to the exposed population. Analysts quantified the cost of physical injuries to residents from evacuation, cleanup, or repair of a damaged/destroyed home based on a scaled fraction of the value of a statistical life, equal to $15,200 per injury.[2] It is assumed based on a post-Sandy CDC report that 10.4% of the population impacted by flooding would sustain an injury.[3] Mental stress losses are quantified as the cost for 30 months of treatment for mental stress caused by the negative effects of flooding on social and economic resources, equal to $2,761 per person impacted by flooding. Lost productivity is measured as the productivity share of 30 months of work per worker impacted by flooding, equal to $9,872 per worker.[4] Residential relocation costs include per-diem costs for lodging and meals and incidental expenditures (M&IE) for the duration of displacement, based on standard federal per-diem rates for Nantucket, equal to $76 per person per day for lodging and $227 per household per day for ME&I.[5]

4. *Regional Indirect, and Induced Economic Impacts*:
   Analysts calculated regional indirect and induced economic impacts. Jobs impacts and industry output losses will be reported.

5. *Tax Revenue:*
   Analysts calculated corporate tax, personal tax, social insurance tax, and tax on production and imports at the federal, state, and local level. Tax on production and imports includes sales tax, property tax, severance tax, special assessments, excise tax, and other taxes.

6. *Loss of frequently flooded properties*:
   Analysts identified frequently flooded properties for which total loss of function will occur if no project is implemented, and account for their losses separately.

The expected annual losses for each metric, which represents the probable loss that may occur within any given year to 2070, are calculated to determine the aggregate of high-impact, low-frequency events with low-impact, high-frequency events. Expected annual loss is calculated by integrating the event-based loss estimates over the corresponding exceedance probabilities, as shown in Figure 6. For this analysis, integration is estimated using the trapezoidal rule. The annual loss calculation can reveal that frequent events with less severe consequences have a greater impact on risk than infrequent events with more severe consequences.

[2] 2020 FEMA standard values report, escalated to 2020 using CPI inflation calculator from BLS
[3] https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6342a4.htm#
[4] FEMA BCA Toolkit; 2012 dollars escalated to 2020 using CPI inflation calculator from BLS
[5] US General Services Administration, https://www.gsa.gov/travel/plan-book/per-diem-rates/per-diem-rates-lookup/?action=perdiems_report&state=MA&fiscal_year=2021&zip=&city=Nantucket

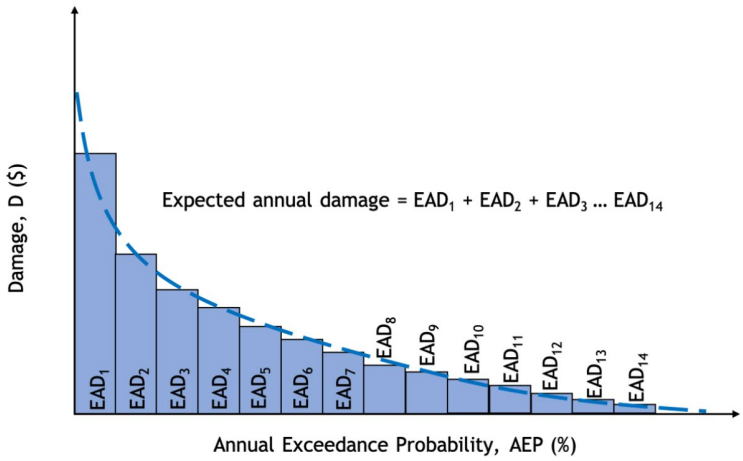


Figure 1: Annualization curve example. Source: Colorado Water Conservation Board

Risk is ultimately presented as a present value loss, which represents the cumulative expected annual losses from 2020 to 2070, discounted back to 2020 values. The discounting rate used to incorporate the time value of money is 3 percent.

Qualitative Risk Assessment

In addition to the quantitative risk analysis for buildings and structures, community assets, services, and infrastructure in the categories listed below are also mapped against flood and erosion exposure with direct impacts qualitatively discussed. The exposure analysis and mapping is used to communicate risk to these infrastructure, assets, and services and help the Town prioritize flood protection and erosion control measures, as appropriate.

- **Linear transportation infrastructure**, including roads, bridges, ferry terminals, and airports
- **Community assets and services**, including hospitals, fire stations, and cultural institutions
- **Critical Facilities**, including transportation facilities and emergency services
- **Linear subsurface utility infrastructure,** including sewers and water mains
- **Parks and open space,** including public parks and privately-owned protected open space
- **Habitat and natural resources,** including priority natural communities and wetland resource areas

In cases where structures are associated with the above services (for example, a hospital or fire station) the direct and indirect risk to the buildings serving these purposes can also be quantified in dollar figures, but not in terms of loss of service.

This qualitative risk assessment is based on the following flood and erosion scenarios to represent risk from recurrent tidal flooding, coastal flooding from a significant storm event, and projected future erosion hazard areas.

- **Tidal flooding** (Mean Monthly High Water) today and in 2030, 2050, 2070, and 2100
- **Coastal flooding** with a 1% annual exceedance probability (1 in 100 annual chance) today and in 2030, 2050, and 2070[6]

[6] Coastal flood hazard data from MC-FRM are not yet available for 2100. If this data becomes available, the 2100 horizon can be added to the coastal flood hazard analysis.

- **Coastal erosion hazard areas** in 2030, 2050, 2070[7], and 2100

Nantucket groundwater study

A water table elevation map (WTEM) was created to assess the future likelihood of groundwater flooding in Nantucket due to sea level rise (SLR). Flooding due to rising groundwater has distinct characteristics that set it apart from the more familiar flooding caused by direct overland inundation during storms and high tides. Whereas coastal storm flooding is fast and temporary, groundwater flooding tends to be slow and chronic. When SLR lifts the coastal water table, impacts can include higher corrosion rates of buried infrastructure, increased basement flooding, reduced stormwater and wastewater sewer capacity, soil contaminant mobilization, soil instability, and eventually the creation of wetlands as groundwater emerges to the surface.

Not only does groundwater flooding have impacts distinct from coastal inundation flooding, it also has unique solutions. While seawalls are effective against temporary storm surge, they don't substantially impact the long-term movement of groundwater. Thus, the response options for a rising water table tend to fall into the categories of groundwater drainage/pumping, raising structures, or gradual retreat. The viability of each option is highly dependent upon local conditions. Thus, making an initial broad assessment that determines the likelihood of groundwater flooding is useful for determining what areas should be targeted for more detailed hydrogeological assessments.

Methodology

The approach taken here is based on the method developed by Plane et al. (2019) which describes a rapid assessment method for groundwater flooding as applied to the San Francisco Bay area. This approach was also used by both Hoover et al. (2017) and Hummel et al. (2018). For example, in the Hummel et al. (2018) study, well data from the San Francisco area over a 20-year period was used to create a maximum water table elevation map for land close to San Francisco Bay. A water table surface was constructed by interpolating between groundwater monitoring wells and additional reference points at the shoreline to account for the shoreline water table being approximately at the mean tide line. SLR effects were approximated with a linear rise of water table.

The WTEM in this study was constructed from well data from 10 USGS wells on Nantucket Island. Monthly water level measurements were taken over multiple years for each well—most of them dating back to the 1980s. The highest water table readings (smallest depth-to-water) across Nantucket Island occurred in the spring of 1994. However, the island's water table has been fairly stable over the past 30 years but with a trend of a slowly rising water table (see Figure 1). Likewise, high rainfall events that substantially raise the water table are expected to occur more frequently with climate change. Thus, the highest measured reading was used as a conservative estimate.

[7] The 2070 erosion zone was interpolated based on the 2019 FEMA Erosion Study using GIS. It is suitable for general planning and risk analysis purposes only.

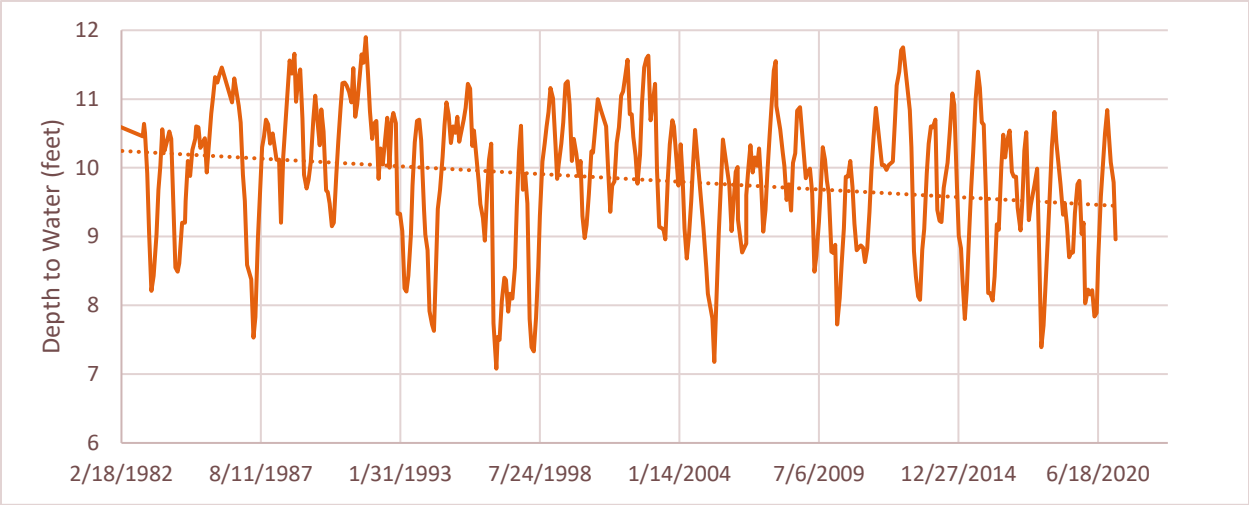


Figure 2: A graph of published monthly well data for well MA MWB 107 with a trendline showing the water table rising over time (depth to water is decreasing)

Tide data would normally be taken from the Nantucket Island, MA NOAA tide station (#8449130) to determine local mean sea level but the gauge is not referenced to NAVD88. However, the tide gauge at Chatham, MA (#8447435), under 30 miles away, shows that MSL is at approximately 0 ft NAVD88 with high tide at about 2.5 ft NAVD88.

In addition, the elevation of the water table at the coast tends to be higher than mean sea level due to asymmetric tidal flow (Turner et al. 1997). That is, seawater tends to surcharge the coastal water table during high tide at a higher rate than it drains out during low tide. The result is a small offset between mean sea level and the water table at the shore. Plane et al. (2019) used a 1-foot offset at the coast to account for this phenomenon. Previous groundwater modeling has confirmed the appropriateness of this offset in sandy glacial soils of the Northeastern US.

In addition to USGS groundwater monitoring wells and shoreline reference points, inland water bodies (natural ponds and streams) that were likely to intersect the water table (Winter 1999) were also included as known water table reference points. This technique has been used to map the coastal aquifer in Delaware (Martin and Andres 2008).

The water table surface was generated using a radial basis function interpolation. Such methods are preferred for water table generation with a small unevenly spaced dataset because the method can generate a smooth surface that goes through all data points and does not require measuring the highest point in the water table.

A map of the depth to groundwater was generated by subtracting the WTEM from a recent (2016) digital elevation model (DEM) of Nantucket Island (Figure 2). SLR was accounted for by adding the expected SLR for each future scenario to this depth-to-water map.

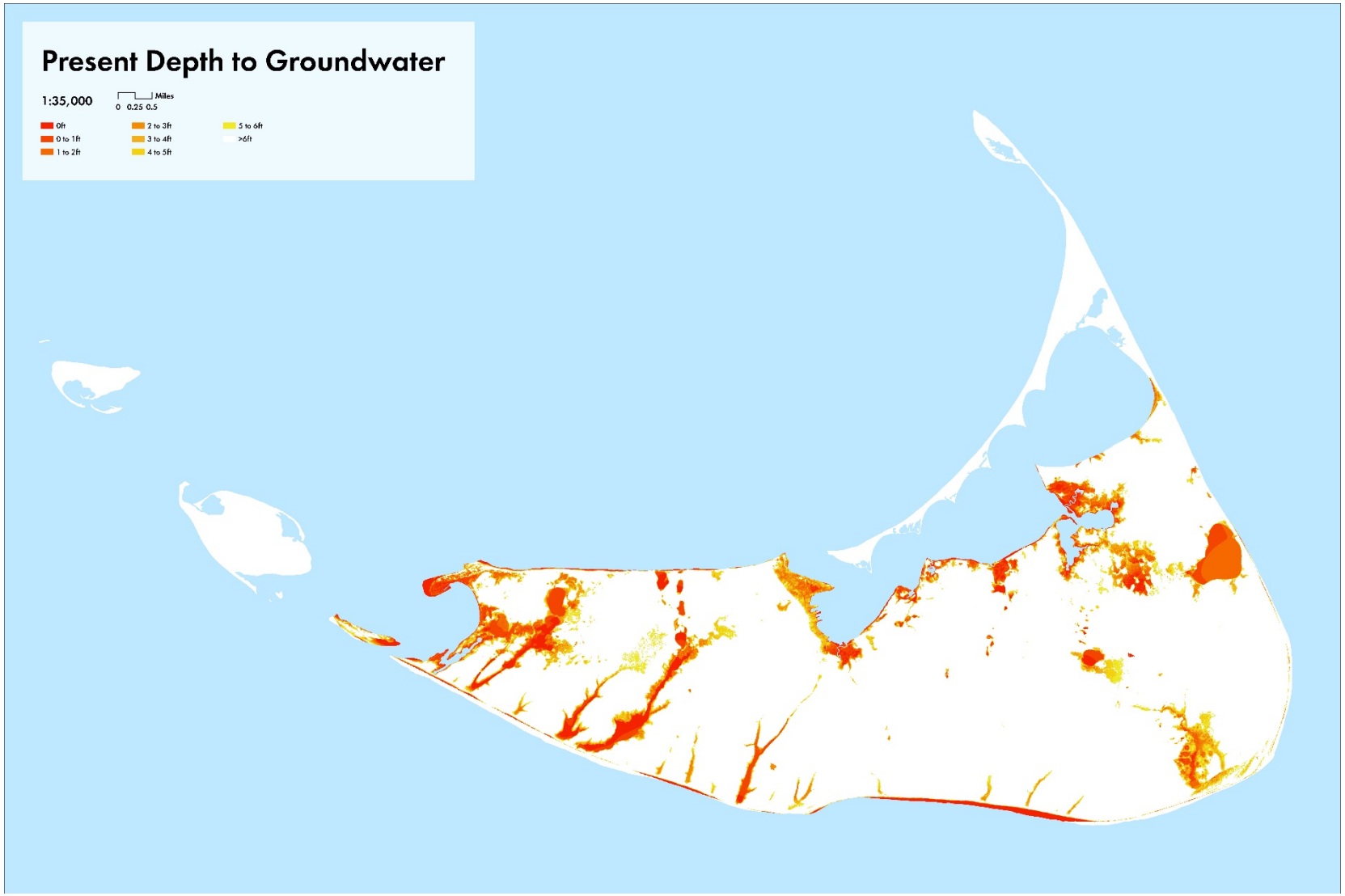
Figure 3: Current conditions depth-to-water map for main portion of Nantucket Island (distance from surface to water table in feet) Unmapped portions had insufficient data, but the water table is expected to be very shallow in those areas.

Discussion

Depth-to-water groundwater maps created by the method described above should be used with caution. Some sources of uncertainty include:

1. Water tables can vary depending on many factors including tides, season, droughts, and heavy precipitation. The water table near the shore is often tidally influenced but also tends to be relatively stable over time because it is constrained by mean sea level. Further inland, the water table can vary by much larger amounts depending on longer term precipitation trends and any changes in groundwater pumping.
2. In general, water tables tend to mimic the surface topography. However, a lack of inland wells or surface water features at every high and low spot means that the smoothed interpolated water table surface may be overestimated or underestimated when the terrain has rapid gradient changes. Thus, hilly areas and areas with few wells have higher uncertainty. In addition, areas with “perched” water tables can make the coastal water table appear more variable; this can be difficult to judge without knowledge of the local hydrogeology and ample well data.
3. Groundwater pumping or dewatering of below-grade infrastructure (basements) can depress the local water table lower than expected to occur naturally. However, this is likely a minor contribution on Nantucket Island where soil conditions encourage rapid water movement.

While these caveats restrict the groundwater map usage, the maps still provide valuable insight regarding areas of concern that should be monitored and assessed in the future. See the following pages for present-day and projected future depth to groundwater mapping.


Present Depth to Groundwater
1:35,000
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2 to 3ft
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5 to 6ft
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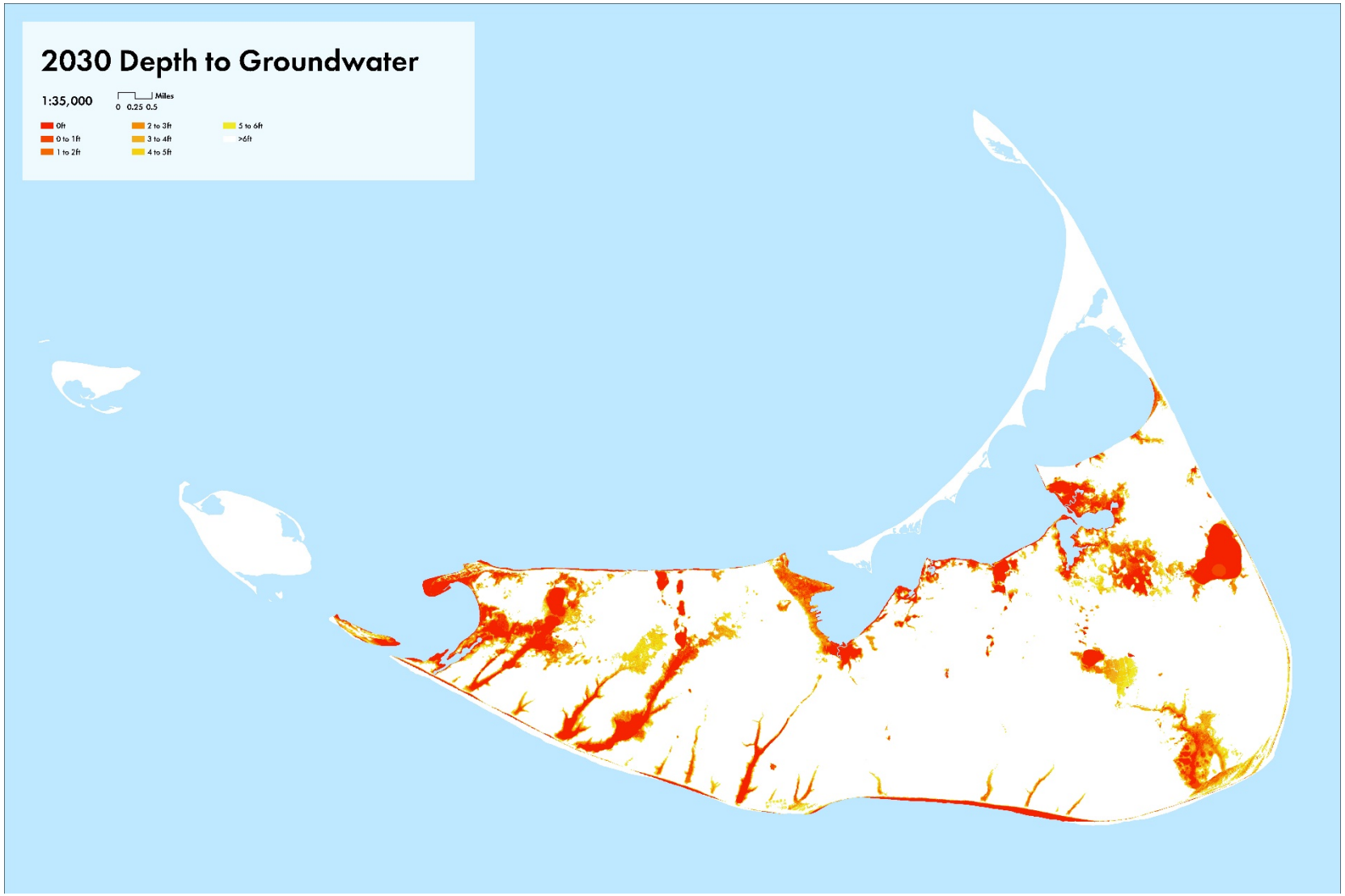
2030 Depth to Groundwater
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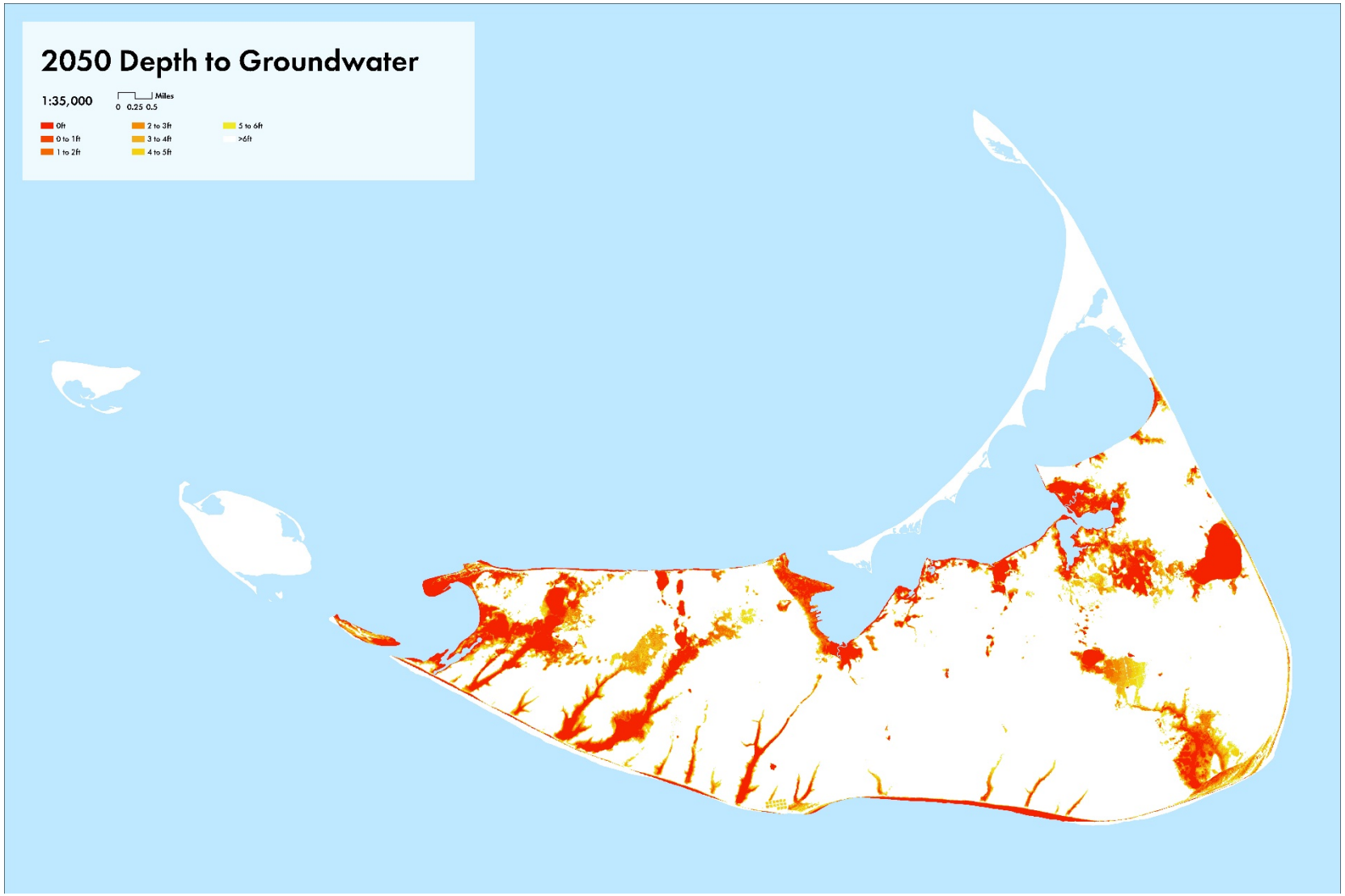
2050 Depth to Groundwater
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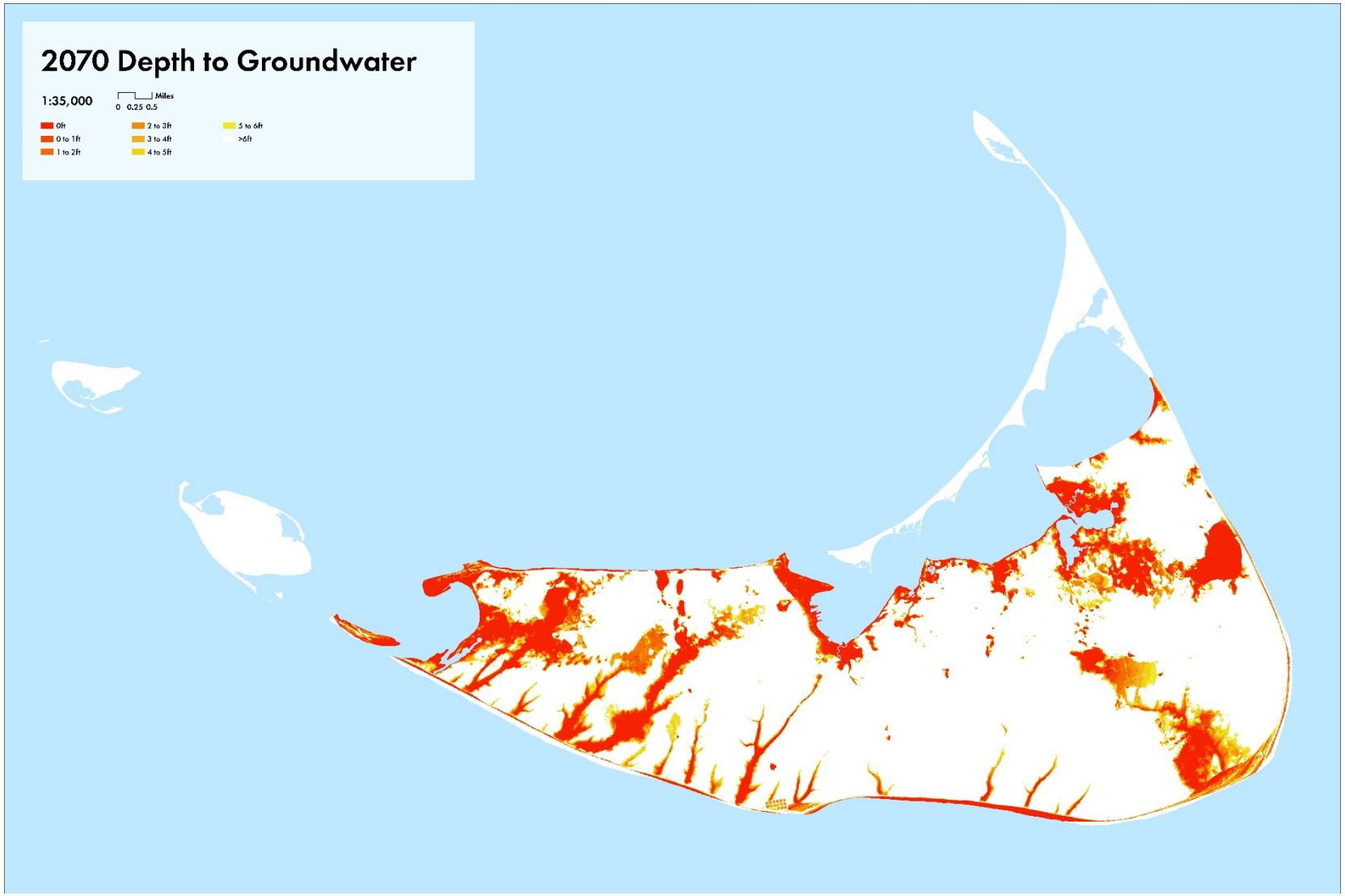
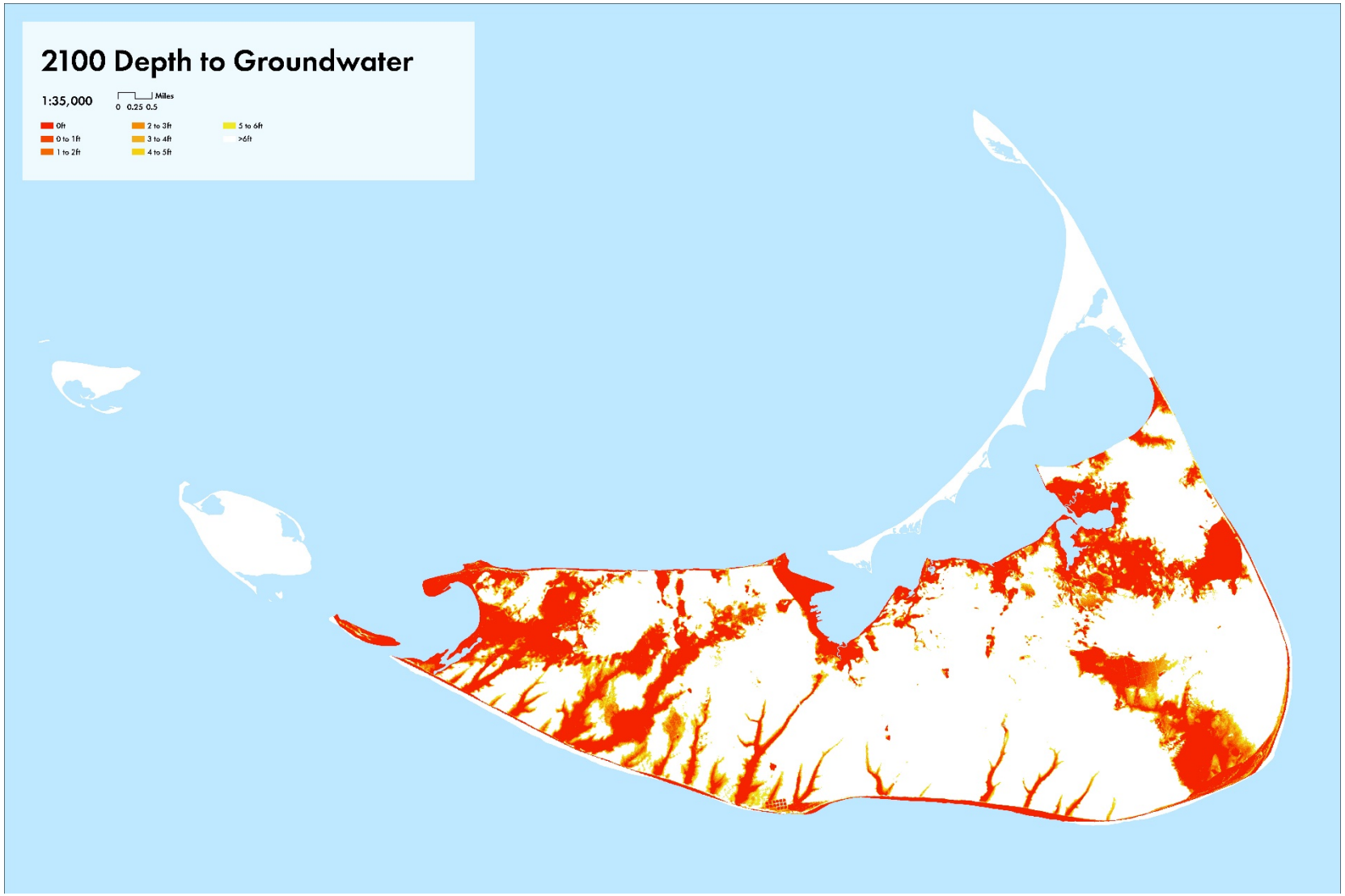
5 to 6ft
>6ft


2070 Depth to Groundwater
1:35,000
Miles
0 0.25 0.5
0ft
0 to 1ft
1 to 2ft
2 to 3ft
3 to 4ft
4 to 5ft
5 to 6ft
>6ft


2100 Depth to Groundwater
1:35,000
Miles
0 0.25 0.5
0ft
0 to 1ft
1 to 2ft
2 to 3ft
3 to 4ft
4 to 5ft
5 to 6ft
>6ft

Appendix E

Flood Risk Data

Flood Risk Data for Charts in Project Report

Category	Direct Physical Damage	Direct Economic and Social Disruption	Total Direct Risk	Building Count
Commercial	$200,000,000	$90,000,000	**$290,000,000**	**241**
Community Facilities and Services	$28,000,000	$8,300,000	**$37,000,000**	**35**
Emergency Services	$2,800,000	$190,000	**$3,000,000**	**4**
Residential	$680,000,000	$73,000,000	**$750,000,000**	**2,973**
Transportation	$2,300,000	$3,000,000	**$5,200,000**	**3**
Utilities	$800,000	$120,000	**$930,000**	**6**
Vacant	$0	$0	**$0**	**59**
Other	$20,000,000	$1,400,000	**$22,000,000**	**117**
Total	**$930,000,000**	**$180,000,000**	**$1,100,000,000**	**3,438**

Figure 1. Buildings and Structures Damage by Use Category

Category	Direct Physical Damage	Direct Economic and Social Disruption	Total Risk	Building Count
Commercial	$170,000,000	$81,000,000	$250,000,000	198
Community Facilities and Services	$21,000,000	$6,800,000	$27,000,000	20
Transportation	$2,300,000	$3,000,000	$5,200,000	3
Total	**$190,000,000**	**$91,000,000**	**$290,000,000**	**221**

Figures 24. Buildings and Structures Supporting Tourism - Present Value Losses, No Action Scenario. 2020-2070, 3% Discount Rate

	Damage or Disruption at Monthly High Tide (acreage)					Damage or Disruption during 1% Annual Chance Storm (acreage)					Damage or Disruption due to Erosion (acreage)			
	Today	**2030**	**2050**	**2070**	**2100**	**Today**	**2030**	**2050**	**2070**	**2100**	**2030**	**2050**	**2070**	**2100**
Public - Town	7.2	8.9	10.7	13.5	18.1	10.2	12.2	13.6	17.0	N/A	2.7	4.9	7.8	10.5
Public – State and Federal	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.4	N/A	0.2	0.3	0.3	0.3
Public – Non-Profit	18.6	22.6	27.6	35.6	62.7	22.1	40.6	57.8	78.8	N/A	5.2	10.5	19.1	28.7
Other (Private and Land Trusts)	82.9	127.3	168.6	218.0	295.7	213.3	255.9	288.5	320.6	N/A	22.6	47.2	87.9	123.4

Figure25, 26, and 27. Open space disruption due to flooding and erosion

Appendix F

Asset Prioritization Data

Asset ID	Name	Category	Subcategory	Flood Design Class	Infrastructure	Emergency Response	Public Health, Safety, Physical Well Being	Quality of Life	Ecosystem/ Environmental Health	Tourism Flag	Social Equity Flag	Town Owned	Criticality Score	Risk Score	Priority Score
NAID_0048	Steamship Authority	Transportation	Steamship Authority	4	3	2		1		1	1		148	11%	**16.88**
NAID_0007	Sheriff Office (County) and NRTA	Emergency Services	Police Station	4		3	2	1			1	1	140	3%	**4.57**
NAID_0064	Stop & Shop	Community Facilities and Services	Grocery	3			3				1		39	12%	**4.50**
NAID_0061	Coast Guard Station Brant Point	Emergency Services	Coast Guard	4		3	2						128	3%	**3.99**
NAID_0037	Nantucket Town Hall, RMV, and Superior Court	Community Facilities and Services	Town Administration	2			3	2			1	1	32	6%	**1.92**
NAID_0102	Whaling Museum	Community Facilities and Services	Library/Museum	3				3		1			12	16%	**1.89**
NAID_0047	Electrical Substation	Utilities	Power	3	3		2						78	1%	**1.14**
NAID_0005	Jetties Concession Building	Community Facilities and Services	Concession	2				3		1			8	14%	**1.09**
NAID_0017	Police Department Housing (Dorms)	Community Facilities and Services	Housing	2			3	2					28	3%	**0.98**
NAID_0046	University of Massachusetts Nantucket Field Station	Community Facilities and Services	College	3			3						36	2%	**0.73**
NAID_0044	Nantucket Atheneum	Community Facilities and Services	Library/Museum	3				3		1		1	15	5%	**0.73**
NAID_0034	Our Island Home	Community Facilities and Services	Long-term Care	3				3			1		12	5%	**0.64**
NAID_0100	Nantucket Lifesaving Museum	Community Facilities and Services	Library/Museum	3				3		1			12	3%	**0.32**
NAID_0004	Tom Nevers Sheds	Community Facilities and Services	Concession	2				3		1			8	4%	**0.31**
NAID_0113	Natural Resources Department	Community Facilities and Services	Town Administration	2			3		2			1	38	1%	**0.30**
NAID_0054	Old Brant Point Lighthouse	Community Facilities and Services	Lighthouse	1			3			1		1	14	2%	**0.22**
NAID_0028	Nantucket Solid Waste MGT Facility	Utilities	Waste	1	3		2		1			1	30	1%	**0.17**
NAID_0008	Madaket Fire Station	Emergency Services	Fire Station	4		3	2					1	132	0%	**0.12**
NAID_0068	Post Office	Community Facilities and Services	Post Office	2				3				1	8	1%	**0.11**
NAID_0104	Nantucket Lightship Basket	Community Facilities and Services	Library/Museum	3				3		1			12	1%	**0.10**
NAID_0002	Children's Beach/Grandstand Concession	Community Facilities and Services	Concession	2				3		1			8	1%	**0.10**
NAID_0106	Artists Association of Nantucket Washington St	Community Facilities and Services	Library/Museum	3				3		1			12	1%	**0.09**
NAID_0095	University of Florida Foundation	Community Facilities and Services	Library/Museum	3				3		1			12	1%	**0.09**
NAID_0016	Female Lifeguard Housing	Community Facilities and Services	Housing	2			3	2					28	0%	**0.08**
NAID_0040	St. Mary-Our Lady of the Isle	Community Facilities and Services	Place of Worship	3				3					9	1%	**0.07**

Asset ID	Name	Category	Subcategory	Flood Design Class	Infrastructure	Emergency Response	Public Health, Safety, Physical Well Being	Quality of Life	Ecosystem/ Environmental Health	Tourism Flag	Social Equity Flag	Town Owned	Criticality Score	Risk Score	Priority Score
NAID_0056	Great Point (Nantucket) Light	Community Facilities and Services	Lighthouse	1				3		1		1	5	1%	**0.06**
NAID_0052	Nantucket Cliff Range	Community Facilities and Services	Lighthouse	1			3			1		1	14	0%	**0.05**
NAID_0050	Sankaty Head Light	Community Facilities and Services	Lighthouse	1			3			1		1	14	0%	**0.04**
NAID_0051	Brant Point Light	Community Facilities and Services	Lighthouse	1			3			1		1	14	0%	**0.03**
NAID_0096	Nantucket Aquarium	Community Facilities and Services	Library/Museum	3				3		1			12	0%	**0.03**
NAID_0060	Preservation Institute Nantucket	Community Facilities and Services	College	3			3						36	0%	**0.02**
NAID_0001	Surfside Beach Concession Building	Community Facilities and Services	Concession	2				3		1			8	0%	**0.00**
NAID_0087	Rev Josephn Griffin Hall	Community Facilities and Services	Place of Worship	3				3					9	0%	**0.00**
NAID_0082	Nantucket Memorial Airport	Transportation	Airport	4	3	2		1		1	1	1	152		
NAID_0010	Public Safety Facility & IT Department	Emergency Services	Police Station	4		3	2	1			1	1	140		
NAID_0038	State Police Station D-6	Emergency Services	Police Station	4		3	2	1			1	1	140		
NAID_0011	Main Fire Station	Emergency Services	Fire Station	4		3	2					1	132		
NAID_0009	Siasconset Fire Station	Emergency Services	Fire Station	4		3	2					1	132		
NAID_0049	Tuckernuck Fire Station	Emergency Services	Fire Station	4		3	2					1	132		
NAID_0033	Nantucket Cottage Hospital	Emergency Services	Hospital	4		3	2						128		
NAID_0071	North Pasture Pump Station	Utilities	Water	4	3		2					1	108		
NAID_0021	North Pasture Water Tower	Utilities	Water	4	3		2					1	108		
NAID_0072	Siasconset Pump Station	Utilities	Water	4	3		2					1	108		
NAID_0025	Siasconset Water Tower	Utilities	Water	4	3		2					1	108		
NAID_0023	State Forest Pump Station	Utilities	Water	3	3		2					1	81		
NAID_0019	Surfside at Windy Way	Utilities	Sewer	3	3		2			1			81		
NAID_0020	Wannacomet Water Company Office	Utilities	Water	3	3		2					1	81		
NAID_0024	Washing Pond Water Tower	Utilities	Water	3	3		2					1	81		
NAID_0022	Wyers Valley Pump Station	Utilities	Water	3	3		2					1	81		
NAID_0045	Harbor Fuels Oil Corp Tanks	Utilities	Power	3	3		2						78		
NAID_0027	Nantucket Electric Company	Utilities	Power	3	3		2						78		
NAID_0057	Public Boat Ramp	Transportation	Boat Ramp	3	3					1			57		
NAID_0058	Public Boat Ramp	Transportation	Boat Ramp	3	3					1			57		
NAID_0059	Public Boat Ramp	Transportation	Boat Ramp	3	3					1			57		
NAID_0112	Nantucket Childrens Center	Community Facilities and Services	Daycare	3			3	2			1		45		
NAID_0107	Small Friends of Nantucket	Community Facilities and Services	Daycare	3			3	2			1		45		
NAID_0062	Bartlett's Farm	Community Facilities and Services	Grocery	3			3			1	1		42		

Asset ID	Name	Category	Subcategory	Flood Design Class	Infrastructure	Emergency Response	Public Health, Safety, Physical Well Being	Quality of Life	Ecosystem/ Environmental Health	Tourism Flag	Social Equity Flag	Town Owned	Criticality Score	Risk Score	Priority Score
NAID_0108	Isaac Coffin Lancastrian School	Community Facilities and Services	Private School	3			3	2					42		
NAID_0030	Nantucket Elementary & Intermediate School	Community Facilities and Services	Public School	3			3	2					42		
NAID_0018	Nantucket High & Cyprus Pierce Middle Schools	Community Facilities and Services	Public School	3			3	2					42		
NAID_0029	Nantucket Lighthouse School	Community Facilities and Services	Private School	3			3	2					42		
NAID_0035	Nantucket New School	Community Facilities and Services	Private School	3			3	2					42		
NAID_0063	Stop & Shop	Community Facilities and Services	Grocery	3			3				1		39		
NAID_0015	Employee Housing	Community Facilities and Services	Housing	2			3	2			1	1	32		
NAID_0012	Town Housing #5A & B	Community Facilities and Services	Housing	2			3	2			1	1	32		
NAID_0013	Town Housing#7A & B	Community Facilities and Services	Housing	2			3	2			1	1	32		
NAID_0014	Male Lifeguard Housing	Community Facilities and Services	Housing	2			3	2					28		
NAID_0114	Ames Ave Bridge	Transportation	Bridge	1	3							1	19		
NAID_0116	Madaket Rd Bridge	Transportation	Bridge	1	3							1	19		
NAID_0118	Madaket Rd The Gut Culvert	Transportation	Bridge	1	3							1	19		
NAID_0117	N Cambridge St Bridge	Transportation	Bridge	1	3							1	19		
NAID_0115	Red Barn Rd Bridge	Transportation	Bridge	1	3							1	19		
NAID_0006	Former Fire Station	Emergency Services	Fire Station	1			3					1	13		
NAID_0091	1800 House	Community Facilities and Services	Library/Museum	3				3		1			12		
NAID_0103	Artists Association of Nantucket Amelia Dr	Community Facilities and Services	Library/Museum	3				3		1			12		
NAID_0094	Macy Thomas House	Community Facilities and Services	Library/Museum	3				3		1			12		
NAID_0092	Maria Mitchell Association	Community Facilities and Services	Library/Museum	3				3		1			12		
NAID_0105	Maria Mitchell Association Library	Community Facilities and Services	Library/Museum	3				3		1			12		
NAID_0098	Maria Mitchell Observatory	Community Facilities and Services	Library/Museum	3				3		1			12		
NAID_0097	Monaghan, Hanna and Gertrude House	Community Facilities and Services	Library/Museum	3				3		1			12		
NAID_0088	Museum of Afro American History	Community Facilities and Services	Library/Museum	3				3		1			12		
NAID_0101	Nantucket Historical Association	Community Facilities and Services	Library/Museum	3				3		1			12		
NAID_0090	Nantucket Historical Association Jethro House	Community Facilities and Services	Library/Museum	3				3		1			12		

Asset ID	Name	Category	Subcategory	Flood Design Class	Infrastructure	Emergency Response	Public Health, Safety, Physical Well Being	Quality of Life	Ecosystem/ Environmental Health	Tourism Flag	Social Equity Flag	Town Owned	Criticality Score	Risk Score	Priority Score
NAID_0055	Nantucket Ice Arena	Community Facilities and Services	Recreation	3				3		1			12		
NAID_0099	Nathaniel Macy House	Community Facilities and Services	Library/Museum	3				3		1			12		
NAID_0026	The Residence at Sherburne Commons	Community Facilities and Services	Long-term Care	3				3			1		12		
NAID_0093	William Hadwen House	Community Facilities and Services	Library/Museum	3				3		1			12		
NAID_0084	Christian Science Society of Nantucket	Community Facilities and Services	Place of Worship	3				3					9		
NAID_0039	Congregation Shirat HaYam & Second Congregational	Community Facilities and Services	Place of Worship	3				3					9		
NAID_0085	First Congregational Church	Community Facilities and Services	Place of Worship	3				3					9		
NAID_0083	Jehovahs Witness Nantucket	Community Facilities and Services	Place of Worship	3				3					9		
NAID_0086	Lighthouse Baptist Church	Community Facilities and Services	Place of Worship	3				3					9		
NAID_0041	Nantucket United Methodist Church	Community Facilities and Services	Place of Worship	3				3					9		
NAID_0042	Nantucket Worship Group	Community Facilities and Services	Place of Worship	3				3					9		
NAID_0089	St Pauls Episcopal Church	Community Facilities and Services	Place of Worship	3				3					9		
NAID_0032	St. Paul's Church	Community Facilities and Services	Place of Worship	3				3					9		
NAID_0031	Summer Street Church	Community Facilities and Services	Place of Worship	3				3					9		
NAID_0036	Sunday Mass at Union Chapel at Siasonset	Community Facilities and Services	Place of Worship	3				3					9		
NAID_0003	Delta Fields Concession	Community Facilities and Services	Concession	2				3		1			8		
NAID_0065	Post Office	Community Facilities and Services	Post Office	2				3				1	8		
NAID_0066	Post Office	Community Facilities and Services	Post Office	2				3				1	8		
NAID_0067	Post Office	Community Facilities and Services	Post Office	2				3				1	8		
NAID_0109	Camp Richard	Community Facilities and Services	Recreation	2				3					6		
NAID_0110	Nantucket Boys and Girls Club	Community Facilities and Services	Recreation	2				3					6		
NAID_0111	Nantucket Community Music Center	Community Facilities and Services	Recreation	2				3					6		

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THE NANTUCKET YOUTH CLIMATE COMMITTEE PRESENTS:

CLIMATE CAFE

Join us for a community discussion about climate impacts on our local environment. All are welcome!

Saturday, April 10, 2021
3 PM

EVENT HOSTED BY MASS AUDUBON AND NANTUCKET HIGH SCHOOL

ReMain Nantucket Fund

Mass Audubon

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