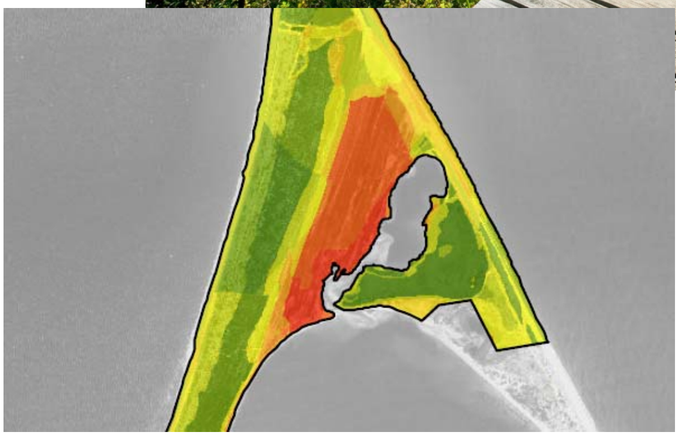
Climate Vulnerability Assessment
Coastal Properties
Trustees of Reservations



Prepared For:
Trustees of Reservations
200 High Street
Boston, MA 02110

Prepared By:
Woods Hole Group, Inc.
A CLS Group Company
81 Technology Park Drive
East Falmouth, MA 02536

October 2017

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East Falmouth MA 02536
(508) 540-8080

EXECUTIVE SUMMARY

Conservation managers confront diverse and ever-changing threats to the properties they are charged with maintaining and protecting. Long term planning to sustainably manage and protect diverse assets for a wide range of uses is central to this mission. The Trustees of Reservations (Trustees) manages over 100 special places and 26,000 acres around Massachusetts (Trustees, 2014) . The properties they manage include more than 70 miles of coastline (Trustees, 2014), an area that is subject to climate driven changes in sea level, storm surge and inundation. From the Castle at Castle Hill to popular public beaches, cultural and historical points, rare and endangered species habitats, lighthouses and salt marshes, the Trustees oversee diverse assets. They are charged with managing these properties to conserve habitat, protect cultural resources and provide exciting and diverse educational and recreational activities for visitors. Consideration of climate change driven vulnerabilities was a natural addition to the planning process reflecting the sustainable, long-term commitment to stewardship and public access.

The potential impact of climate change is far-reaching and uncertain, threatening not only specific uses at individual properties, but also the overall mission of properties. From rising sea levels to increased storm intensity and frequency, managers must evaluate the threat and respond. Climate vulnerability assessments (CVAs) have been used to evaluate the likelihood that future storms and sea level rise will inundate infrastructure such as roadways and key public buildings. The Trustees partnered with Woods Hole Group to complete this CVA, which is comprised of two components. The first component is a risk-based vulnerability assessment – a calculation of the coastal vulnerability index (CVI) for individual assets (hard infrastructure, natural resources and historical/cultural resources) to facilitate their ranking in terms of inundation probability and asset value. The second component is an evaluation of potential wetland/coastal habitat migration/loss due to sea level rise using the Sea Level Affecting Marshes Model (SLAMM) (Woods Hole Group, 2016).

Practitioners use a two-step approach to evaluate the risk-based vulnerability and generate a CVI for each asset. The first step includes an evaluation of the probability of inundation (i.e. the likelihood that a portion of a property will be inundated with storm driven water in the future). The probabilistic climate change inundation models provide probability of inundation estimates for all parts of each property for two future modeled years – 2030 and 2070. Use of probabilities of inundation allow managers to compare scenarios based on a number of influencing forces such as tides, winds, elevation of coastal areas, sea level rise estimates, storm surge, and waves. A one-time inundation may not result in total asset loss, but for screening purposes there is comparative value in determining what is wet and what is dry (and the probability of that condition occurring) under future scenarios. In contrast to assuming a static sea level elevation increase and additional storm surge, probabilistic hydrodynamic models provide inundation profiles from which the most vulnerable and least vulnerable areas can be identified. These are powerful models that can also generate additional endpoints such as the depth and residence time of flooding.

The second step in the analysis is central to accomplishing the overall goal of prioritizing adaptations to ensure that the Trustees are maximizing the effectiveness and efficiency of their investment to protect vulnerable assets. This step focuses on determining the value of the assets (an asset is a feature of a property that Trustees value in terms of meeting their mission). Assets are scored using multiple criteria to capture the diverse ways that a given asset can add value and assist the Trustees in meeting their mission. Referred to as consequence scoring because managers evaluate the consequence of inundation for different assets, Trustees' multidisciplinary experts scored each asset. The scoring criteria were selected to characterize the importance of each asset to meeting the overall mission of the Trustees. Ultimately, the scores for the individual criteria are added together to develop a total consequence score for each asset.

The probability of inundation (a percent) and the consequence score (a total across multiple scoring criteria) are combined (multiplied) to evaluate the risk-based vulnerability of each asset through a CVI. A CVI is calculated for every mapped asset on all coastal properties for 2030 and 2070. The assets and properties can be ranked based on this combined probability and consequence score to prioritize adaptation investments.

In terms of ranking vulnerable assets using the CVI, vegetation communities and priority habitats have the highest CVIs and the properties with the most vulnerable assets are Crane Beach, World's End, Cape Poge Wildlife Refuge and Coskata-Coatue Wildlife Refuge. Natural resources tend to have higher CVIs because they represent larger portions of the properties, they are located close to the water and they are valued in order to meet important conservation goals. Of course access roads, infrastructure and beaches are also valued and in some cases vulnerable but cover less area than natural resources..

In addition to calculation of CVIs, the CVA also includes an assessment of wetland transition. The SLAMM outputs provide insights into the shifting in wetland types from present to 2030 and 2070. The wetland assessment reveals a loss of freshwater wetlands, uplands and irregularly flooded marshes and expansion of regularly flooded salt marshes, open water and tidal flats across coastal properties.

The result of the analysis revealed that every property has some vulnerability to future inundation, but a subset of properties are ranked most vulnerable based on this analysis. They include: Cape Poge Wildlife Refuge, Coskata-Coatue Wildlife Refuge, Crane Beach, Crane Wildlife Refuge, Long Point Wildlife Refuge, Wasque and World's End.

With inundation vulnerability modeling completed for assets and properties, the focus shifts to selecting and implementing adaptation projects to build resilience and protect Trustees' properties in order to "preserve, for public use and enjoyment, properties of exceptional scenic, historic, and ecological value". This is no small task and represents the unique challenge and opportunity of managing multiple disconnected properties to protect individual but interconnected assets on a property while also managing vulnerabilities across the various properties simultaneously. The adaptations fall into three general categories: protection, accommodation and retreat. Protection strategies are developed to prevent water from reaching sensitive assets, and typically are designed as barriers (in various forms) to keep flood waters out. Accommodation strategies are designed to allow sensitive assets to be exposed to flood waters while minimizing the potential damage to those assets. Finally, Retreat strategies are implemented to relocate sensitive assets away from vulnerable areas and allow climate change impacts to occur with minimal consequence. While the organization and vulnerability ranking of assets are complete, additional study will be required to develop specific adaptation projects. For example, wave, shoreline change and sediment transport modeling are required to optimize coastal projects, hydrodynamic modeling is needed when water flows require management and surveys are needed to understand current conditions and facilitate permitting.

This Report provides a rich database of vulnerability data and the opportunity to engage diverse groups in seeking to protect these valuable assets. Moving the property specific results into the Trustees web page will provide access to anyone seeking more information about specific properties. Search tools and GIS viewers can allow users to navigate to properties and evaluate how vulnerabilities change through time and what portion of a property is most vulnerable. Monitoring programs tuned to the level of vulnerability offer the opportunity to gather data to inform future adaptations, monitor change and verify model predictions and engage the network of volunteers in the process of protecting these assets. Trustees' leadership in large-scale vulnerability planning will benefit regional natural resource/sensitive habitat planning as well. Because of the acreage managed, the unique features of the different properties and opportunities to expand and/or collaborate with other land conservation partners, managers can look to protect specific habitat types regionally. Climate change will present many challenges, but the understanding of what may be lost paired with the vision of maximizing biodiversity and protecting special areas allow the Trustees to make data driven decisions about balancing loss in one area retreat, with expansion or conversion (accommodation) in other areas, while protecting the most sensitive and unique habitats.

Table of Contents

List of Figures

List of Tables

ACRONYMS

ADCIRC	ADvanced CIRCulation model
BH-FRM	The Boston Harbor Flood Risk Model
CA/T	Central Artery/Tunnel Project
CDFs	Cumulative probability Distribution Functions
CVA	Climate Vulnerability Assessment
CVI	Coastal Vulnerability Index
FHWA	Federal Highway Administration
LiDAR	Light Detection and Ranging
MA CZM	Massachusetts Coastal Zone Management
MassDOT	Massachusetts Department of Transportation
NACCS	North Atlantic Coast Comprehensive Study
SLAMM	Sea Level Affecting Marshes Model
SLR	Sea level rise
SWAN	Simulating Waves Nearshore
Trustees	Trustees of Reservations

1.0 INTRODUCTION

As climate change presents ever more complex and unpredictable threats to coastal properties, landowners require tools to understand the risks, differentiate among property assets based on value and vulnerability and ultimately protect vulnerable resources through adaptation and building resiliency. Dynamic probabilistic climate and storm based modeling combined with an asset valuation approach offers managers a risk-based tool for protecting the assets that are most at risk and most valued.

1.1 BACKGROUND

Since 1891, The Trustees of Reservations (Trustees) have acquired and managed special places in Massachusetts. These include 32 coastal reservations (8,000 acres) that are distributed along the entire coast of the state (Figure 1-1).

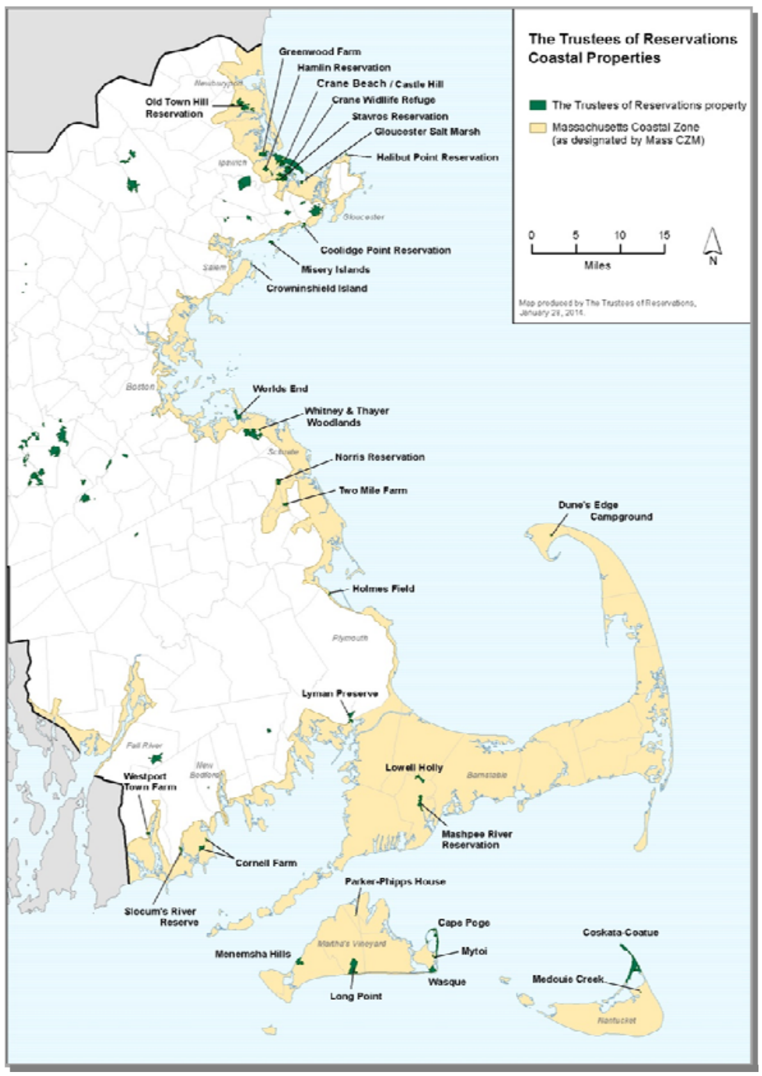

Figure 1-1. Map of Trustees of Reservations Coastal Properties

Understanding the risks to these properties is central to ensuring that the Trustees' mission to protect the scenic, historic and ecological values of these properties is maintained. These properties include diverse assets such as:

- 39 Parking Areas
- 103 Buildings
- 106 Other Structures
- 60 miles of trail
- 158 Cultural Resources points
- 48 State-listed Species
- Over 100 Vegetation Communities.

The Trustees initiated a project with Woods Hole Group to evaluate the climate and storm driven inundation probabilities across the coastal reservations, develop a system by which to objectively value the diverse assets and combine the probability of inundation with the asset values to facilitate strategic property management and decision-making to continue to meet the Trustees' mission.

1.2 CLIMATE VULNERABILITY ASSESSMENT AND PLANNING

Incorporation of climate change driven vulnerabilities was a natural addition to the planning process reflecting the sustainable, long-term commitment to stewardship and public access. The probabilistic modeling approach, paired with asset valuation provides decision makers with the data needed to identify vulnerable areas and prioritize resiliency projects to protect the most vulnerable and valuable areas.

1.2.1 Objective

The analysis focused on three guiding questions:

1) What is the probability of flooding across coastal properties?
2) What assets, properties, regions are vulnerable and what should be protected (what is the relative value of different assets)?
3) What adaptations are best suited to moderate different vulnerabilities and how should the Trustees prioritize those adaptations?

The assessment framework, coastal vulnerability index (CVI) and Sea Level Affecting Marshes Model (SLAMM) outputs provide managers with the tools and data required to make informed decisions. Ultimately, the Trustees will need to decide the most effective and efficient approach to protect their assets; the CVI highlights the priorities with respect to managing vulnerabilities to the combined impacts of sea level rise and storm surge, and SLAMM reveals long-term wetland transitions.

1.3 OVERVIEW OF ASSESSMENT

There are two components of the CVA:

- CVI calculation; and,
- SLAMM wetland transition analysis.

1.3.1 CVI Calculation

The process relies on two independent lines of evidence. They include:

- the probability of inundation; and,
- the consequence of that inundation.

These inputs are combined to calculate CVIs in the risk-based vulnerability assessment. Vulnerability is used to emphasize the potential impact of inundation to different assets with varying value to the overall mission of the Trustees.

Inundation Probability Modeling

Using a dynamic probabilistic modeling approach, probabilities of inundation are calculated for properties in 2030 and 2070. The models are described in more detail in Section 2.0. In general, the model uses tide, wave, elevation, storm, wind and sea level rise data to predict inundation probabilities across the landscape.

Consequence Scoring

Assets are all of the components of the property that bring some value to that property. The asset categories are: buildings; infrastructure; cultural resource points; parking areas; roads; trails; primary habitat for species; vegetation communities; and Boston Community Gardens.

They vary from habitat to infrastructure and the value may be monetary or non-monetary (e.g. ecosystem values).

Coastal Vulnerability Index

The CVI is a risk-based vulnerability assessment that combines the inundation probability and consequence scores for each asset.

CVI = probability of flooding x consequence score

The CVI is a powerful planning tool providing the data necessary for Trustees' managers to identify, develop and implement adaptation and resiliency projects to protect coastal assets.

1.3.2 SLAMM Wetland Transition Analysis

Using LiDAR elevations, wetland classifications, sea-level rise, tide range, and accretion and erosion rates for various habitat types, SLAMM assesses potential coastal habitat change into the future. The model output is acreage distribution among wetland habitat types (and one upland category) over the specified time period.

2.0 MODELING

Models are central to forecasting the impacts of future climate change. This analysis relies on two different modeling approaches. First, inundation modeling is used to generate the probabilities of inundation based on future storm climatology, SLR projections, and wave, tidal and elevation data. These probabilities are used in combination with consequence scores to arrive at the CVIs. Second, SLAMM provides projections of the impacts of SLR on coastal habitat. Both are described briefly below and in greater detail in Appendix D.

2.1 INUNDATION MODELING TO SUPPORT CVI CALCULATIONS

Depending on the property location, one of two inundation models is used to support the CVI calculations. Results from the Boston Harbor Flood Risk Model (BH-FRM) were used for Trustees properties along the North Shore, Boston Harbor, South Shore, and Cape Cod Bay. Results from the North Atlantic Coast Comprehensive Study (NACCS) were adapted for Trustees properties adjacent to Buzzards Bay, along the southern coast of Cape Cod, and on Martha's Vineyard and Nantucket. Both models provide probabilities of inundation describing the extent and magnitude of flooding. These results were used to create inundation maps. The maps display the probability that a given location will be inundated at least once during the modeled year due to combined effects of SLR and storm surge. The probability of inundation (chance of flooding) was extracted from these model results for each asset on Trustees' properties.

2.1.1 Sources of Inundation Model Results

Boston Harbor Flood Risk Model

The vulnerability assessment of Trustees properties along the North Shore, Boston Harbor, South Shore, and Cape Cod Bay uses the Boston Harbor Flood Risk Model (BH-FRM) (Bosma et al. 2015) (Table 2-1). The BH-FRM was developed by Woods Hole Group, UMass Boston and UNH for MassDOT to assess the vulnerability of the Central Artery/Tunnel Project (CA/T) to climate change (specifically SLR and storm surge), which employs a physics-based approach to predict future flood risks, and provides results to inform adaptation planning (Bosma et al. 2015).

The BH-FRM tightly couples the ADvanced CIRCulation model (ADCIRC) with the Simulating Waves Nearshore model (SWAN). ADCIRC is a two-dimensional hydrodynamic circulation model that uses bathymetric data and meteorological forcing factors to calculate water surface elevations and tidal circulation on a variable resolution model grid. SWAN is designed to capture wave generation, propagation, and transformation by accounting for physical processes associated with waves (e.g., white capping, bottom friction, shoaling, and refraction). The coupling of these two models allows for the dynamic exchange of physical process information during several time steps, providing an accurate representation of water surface elevations, winds, waves, and flooding throughout Boston Harbor. The model incorporates climate change influences on sea level rise, tides, waves, storm track, and storm intensity.

Sea level rise modeling scenarios in BH-FRM include 2030 and 2070 time horizons, and bracket ranges used in the United States National Climate Assessment (Parris et al, 2012). The SLR projections used for 2030 and 2070 in the BH-FRM were 0.62 feet (19 cm) and 3.2 feet (98 cm), respectively, and have been adjusted for local subsidence following Kirshen et al. (2008).

Using a Monte Carlo statistical approach, the BH-FRM simulates the combined effects of the various SLR projections and thousands of storm scenarios (both hurricanes and nor'easters), producing the range of water surface elevations associated with the various probability levels for a particular modeling out year, which help decision makers prioritize adaptation investments.

North Atlantic Coast Comprehensive Study

The vulnerability assessment of Trustees properties adjacent to Buzzards Bay, along the southern coast of Cape Cod, and on Martha's Vineyard and Nantucket uses the USACE's NACCS model results (Table 2-1). NACCS (Nadal-Caraballo, et al 2015) was developed by the USACE to assess the vulnerability of North Atlantic coastal areas (Virginia to Maine) to climate change (specifically SLR and storm surge), which (like BH-FRM) employs a physics-based approach to predict future flood risks. For areas south of Cape Cod, NACCS model results were preferable to BH-FRM model results due to the regional suitability of storm set selections.

NACCS couples ADCIRC and STWAVE to represent the interaction between storm surge and waves along the coastal zone and (using wind, pressure field, deep water wave, and local wind and wave inputs) provide water surface elevation Annual Exceedance Probabilities (AEP).

2.1.2 Use of Model Results

Direct Model Results

Governor Hutchinson's Field, World's End, and all Boston Community Gardens are within the BH-FRM study area where the model grid extends over land at high resolution (Table 2-1); for these properties, BH-FRM results are extracted directly. The probability of inundation results were mapped in ArcGIS.

Probabilistically Informed Light Detection and Ranging (LiDAR) Analysis

For the remaining Trustees properties, where high resolution over land BH-FRM results were not available, it was necessary to use a probabilistically-informed LiDAR analysis, essentially evaluating inundation over the existing land topography/elevation. The source of probabilistic information is detailed in Section 2.1.1.

2.1.3 Asset Inundation Data Extraction

The model results for 2030 and 2070 were used to develop inundation probability maps for all Trustees properties in this assessment. These maps are helpful in understanding the potential impact and pathways of flooding, but also provide data to inform the assessment of individual asset vulnerability at each property. The probability of inundation for each asset was summarized, in ArcGIS, by calculating the minimum, maximum, and spatially-weighted average values from all (1-meter resolution) raster pixels within the footprint of each asset. Although the maximum inundation probability is helpful in assessing the worst-case scenario for each asset, the spatially weighted average was preferred for planning purposes since it is not disproportionately influenced by small areas of (potentially inconsequential) high probability. The result of this process is an asset database containing all assets across Trustees properties with 2030 and 2070 inundation probability summary statistics. This asset vulnerability database is the base of information for the CVI calculations.

2.2 SLAMM MODELING

2.2.1 Background

The Sea Level Affecting Marshes Model (SLAMM)[1] is useful in predicting resource area responses to physical changes, such as sea-level rise.

Woods Hole Group utilized SLAMM to assess the effects of sea-level rise on coastal wetlands statewide for the Massachusetts Office of Coastal Zone Management (MA CZM) (Woods Hole Group, 2016). MA CZM will utilize the results of these models to identify areas along the Massachusetts coast where wetlands can and cannot migrate and adapt to sea level rise, given current elevations and development. In doing so, the project lays the groundwork to assess potential barriers to landward migration of salt marshes and supports the advancement of adaptation strategies and policy change.

The SLAMM Model results presented and reviewed in this report are drawn from the MA CZM project (Woods Hole Group, 2016).

2.2.2 Model Description

The SLAMM modeling is described in detail in Woods Hole Group (2016). A brief summary from that Report is provided below.

SLAMM was developed explicitly to address the potential impacts that sea-level rise may induce on marsh systems. While the model allows for a significant number of inputs, the most influential and important parameters are LiDAR elevations, wetland classifications, sea-level rise, tide range, and accretion and erosion rates for various habitat types.

[1] SLAMM was originally developed with EPA funding in the 1980s. Since then it has gone through a number of updates and iterations. The most recent update to the model at the time of this project's data analysis, SLAMM 6.2, contains added capabilities and increased model flexibility than previous versions.

The SLAMM model predicts wetland change from computations of relative sea level change for each cell in each time step. In addition to the effects of inundation, second-order effects occur due to changes in the spatial relationship to various coastal processes, such as wave action. For example, if the fetch for wind-driven waves is greater than 9 km, the model assumes moderate erosion. However, if the cell is exposed to the open ocean, severe erosion of wetlands is assumed. Where abundant freshwater wetlands are present, their changes are more often linked to salinity penetration rather than solely to inundation levels (Woods Hole Group, 2016).

2.2.3 Application to CVA

The SLAMM results for each of the Trustees' properties are used in this analysis to provide insights into the impact of long-term changes in sea level on the transition of the most sensitive coastal habitats – wetlands. Whereas the CVI provides a probability of inundation (and associated asset values) occurring in the modeled year due to the combined effects of SLR and storm surge (an episodic event), SLAMM predicts the continuous change that accompanies sea level rise.

From a planning perspective, these data are valuable for long-term planning and provide the Trustees with the opportunity to:

- Evaluate long-term, cross property shifts in habitat types and update mission goals accordingly;
- Plan adaptation strategies for those wetlands deemed essential to meeting mission goals;
- Identify wetlands where natural transitions do not impact the mission and in fact may enhance the mission;
- Manage land acquisition and current properties to allow for wetland migration inland where possible.

The SLAMM results are integrated into the property summaries including recommendations regarding how to interpret and, if useful, act upon the predictions. Woods Hole Group (2016) provides SLAMM Model details and summaries at various scales.

3.0 CONSEQUENCE SCORING

Assigning a value to an asset reflecting the relative importance to meeting an organization's mission is a challenging process. For Towns, existing evacuation or emergency plans explicitly identify the resources necessary to protect the citizens (e.g. fire station, evacuation centers, police department, primary roadways, bridges). Engineers can assign a critical inundation elevation above which specific infrastructure is deemed a complete loss, but evaluating natural resources based on a critical inundation elevation is not possible. While the Trustees' reservations have important access and use infrastructure for the properties, the core to the mission of the properties is a focus on the value of cultural, ecological and recreational assets.

This process requires careful consideration of the values that underlie the mission and how to balance competing goals to protect the activities that are central to the Trustees reservation. Ultimately, experts in infrastructure, ecology, history, culture, recreation and engineering are asked to evaluate the value the features that make each property unique. Ranking is required because resources are limited and, after consideration, some climate driven changes may not adversely influence the contribution of certain assets to meeting the mission.

3.1 OVERVIEW OF PROCESS

The goal of consequence scoring is to evaluate the features of a property that are central to meeting the mission of the Trustees to conserve habitat, protect cultural resources and provide exciting and diverse educational and recreational activities for visitors. The iterative process draws on each manager's specific area of expertise, and institutional knowledge about how the assets align with the values of the organization. The power of the process lies in the discussions among experts and score reviews. Reaching a consensus on the scoring criteria is essential. Given limited resources, protecting everything is not a realistic option, nor should it be.

3.2 SCORING CRITERIA

Consequence scoring relies on identifying scoring criteria that are objective, reflect the range of assets on a property and evaluate direct mission contribution with additional criteria that capture how an asset supports the mission. The three mission categories include natural resources, cultural resources and visitor experience.

The final criteria used to score the assets were selected based on an iterative process with input from a group of different Trustees' stakeholders (see Appendix E). The team selected two criteria to capture each including integrity or quality and significance. Integrity focuses on the structure, viability, quality and stability of the natural resource, cultural/historical resource and visitor experience, whereas the significance criterion describes the uniqueness of an asset. Including both integrity and significance allows the scorers to differentiate among those assets that may be of poor quality, but still represent a rare feature of a property. Because visitors are central to the mission of Trustees, the extent to which an asset contributes to public programs is also important. Finally, the impact of an asset on revenue and the contribution to operations and access are also needed to distinguish among assets.

Both the sensitivity of an asset and the cost to replace are included as considerations, but do not contribute directly to the asset scores. The sensitivity and replacement cost are important considerations underlying the selection of actual adaptation projects, but don't directly speak to the value of an asset in the CVI process. When evaluating potential adaptation projects, both will help to differentiate which projects are viable.

The final scoring criteria are highlighted within the blue box in Table 3-1. Notes provide additional descriptions about each criterion.

Table 3-1. Final Consequence Evaluation Scoring Criteria

Category of Consequence Criteria	Proposed Combined Criteria (per individual asset) Scoring from 0-5 0 = not impacted, 1 = slight value impact, 3 = moderate value impact, 5 = high value impact	Weighting Factor	Note
Ecological	**Natural Resource Integrity**	**1**	The structure, composition, viability, and function of an ecosystem or habitat / community type
	Natural Resource Significance	**1**	Rarity, uniqueness, and importance within a local or regional context
Cultural / Historic	**Cultural Resource Integrity**	**1**	Retains material attributes associated with its social values, including ways in which materials were put together, relationship between different parts of a resource and the aesthetic qualities that resulted; it is the exact geographic location of a resource and the nature of its setting
	Cultural Resource Significance	**1**	Rarity, uniqueness, and importance within a local or regional context
Recreation / Visitor Experience	**Visitor Experience Quality**	**1**	The enjoyment and experience that the visitor takes away with them. Includes trails, amenities, recreational sites, and scenic experience and enjoyment of the landscape
	Visitor Experience Significance	**1**	Rarity, uniqueness, and importance within a local or regional context
Public Programming	**Public Programs**	**1**	Relevancy of asset or resource to public programming, events, tours, education (1 <= 25% impact, 3 >= 50% impact, 5 = all programming affected).
Financial	**Revenue Impact**	**1**	Impact to revenue income
Operations	**Operational Support**	**1**	Impact to access and support for operations / facilities
Resiliency	**Sensitivity to Coastal Flooding**	**1**	Sensitivity to damage or loss from changing environmental conditions driven by coastal flooding (1 = slight sensitivity, quick recovery, 3 = moderate sensitivity, slow recovery, 5 = no recovery, complete loss)
Financial	**Replacement Cost**	**1**	Cost to replace or restore asset or resource if lost or significantly damaged (1 <= $10k, 3<= $100k, 5 >= $1M

Each criterion is scored from 1-5 with 5 representing the most valuable, and scores for all of the criteria are summed to arrive at a total consequence score for a given asset.

3.3 FINAL SCORES

The total scores for each asset are normalized to a scale of 0-100 as follows:

$$\frac{\text{Sum of Asset Score Criteria}}{\text{Maximum Possible Asset Score}} \times 100$$

The maximum possible asset score is: 9 criteria x maximum of 5/criterion = 45.

The final criteria scores are provided in Appendix A (by property and asset).

4.0 COASTAL VULNERABILITY INDEX

The CVI combines the vulnerability estimates and the consequence or value of each asset to provide a comparative index for use in prioritizing assets for adaptation projects. The CVI is calculated using this equation:

CVI = probability of flooding x consequence score

As summarized in Section 3.0, the asset scores range from 0-100. Inundation probabilities vary from 0% - 100%. The CVI is the product of those values, i.e. the maximum possible score is 100 x 100 = 10,000).

The CVI calculation is presented diagrammatically in Figure 4-2.

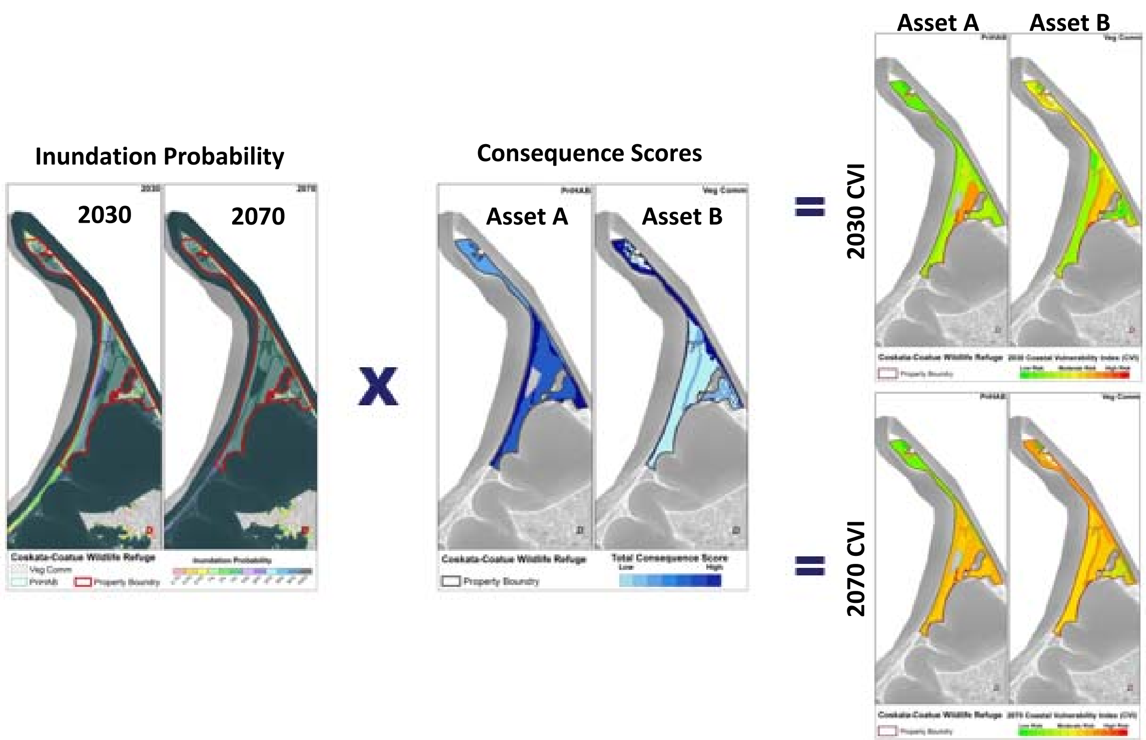

Figure 4-1. Sample of CVI Calculation (Coatue Wildlife Refuge)

CVIs are not absolute scores. They are useful for comparing the risk of assets but there is no specific breakpoint above which some action is required. In the summary figures in Appendix A, a composite CVI is presented for each property. The composite CVI is calculated as the sum of all asset CVIs at a given pixel. The scale for these figures is qualitative (low to high with color coding) in order to facilitate interpretation and comparison across properties.

The CVIs are presented in Appendix A and Appendix B.

5.0 RESULTS

5.1 OVERVIEW

The results of the analysis are presented in tables and maps. The results are presented by property and by asset. Both are valuable as planners access the data to decide what to protect, how to protect it and for updating management plans to account for future challenges and opportunities.

A review of the results reveals the following general trends:

CVI Calculations

Habitats (vegetation communities and priority habitats) have the highest CVIs because these are larger areas it is likely that some portion of a habitat will have a high probability of inundation, they are central to the Trustees mission and protection of threatened species, i.e. highly valued, and habitats tend to be located close to shoreline (or part of). However, these areas may also be resilient and tolerant of episodic inundation. Therefore, a habitat with a high CVI will not always require adaptation or protection;

There is a convergence of assets with high CVIs on specific properties providing the opportunity to plan adaptations that protect multiple assets (Figure 6-1);

Although buildings, cultural resources, parking lots tend to have lower CVIs, some of these have a high probability of inundation. For example, Argilla Road on the Crane Estate has a high probability of inundation in 2070 and 2030 from storm surge, with eventual exposure to daily tidal inundation. Even though the consequence scores favored ecological assets on this property, managers understand that the property cannot be accessed without this road. This property-specific knowledge is complementary to the CVI results.

The property profiles in Table 5-1 and in Appendices A and B provide property and asset-specific CVI results. The majority of properties have a mix of natural and infrastructure-focused assets that would benefit from adaptation planning in the future.

SLAMM Results

The SLAMM Model results are presented as changes in acreage of 17 different habitats focused on wetland types generally, although upland is also included. Trends are evaluated (from a present-day basis) at 2030 and 2070 as changes in the distribution (acreage) of the different habitat types.

Wetland transitions include a shift from irregularly flooded, inland wetlands, and upland areas to tidal flats, regularly flooded, open ocean, estuarine beach/intertidal.

As sea levels rise, habitats transition to the presence of more sea water (and as land is available behind the wetlands, shift away from the shore);

Woods Hole Group (2016) compares SLAMM results in more detail for the north shore (Great Marsh) to the results for Cape Cod Vineyard Sound West (Cape) and identifies interesting patterns:

- Initial changes (2030) are small in Great Marsh, while the initial magnitude of change on the Cape are large;
- Dry land decreases at an increasing magnitude at each model time-step in Great Marsh and the Cape;
- Irregularly flooded marsh is replaced by regularly flooded marsh in later modeling periods, although the total wetland area increases over the study period in Great Marsh. In contrast, the largest change on the Cape is irregularly flooded marsh is replaced by estuarine open water or tidal flats;
- Small shifts in open ocean and transitional salt marsh are apparent in Great Marsh; small changes in transitional salt marsh are also predicted on the Cape.

  Wetland transitions occur on most of the coastal properties – the Trustees will need to determine where landward transition can occur, which wetlands should be allowed to follow natural transition processes and where adaptations should be implemented to protect a specific wetland type.

Figure 5-1 presents the properties with the highest CVIs for a given asset and also the highest concentration of vulnerable assets.

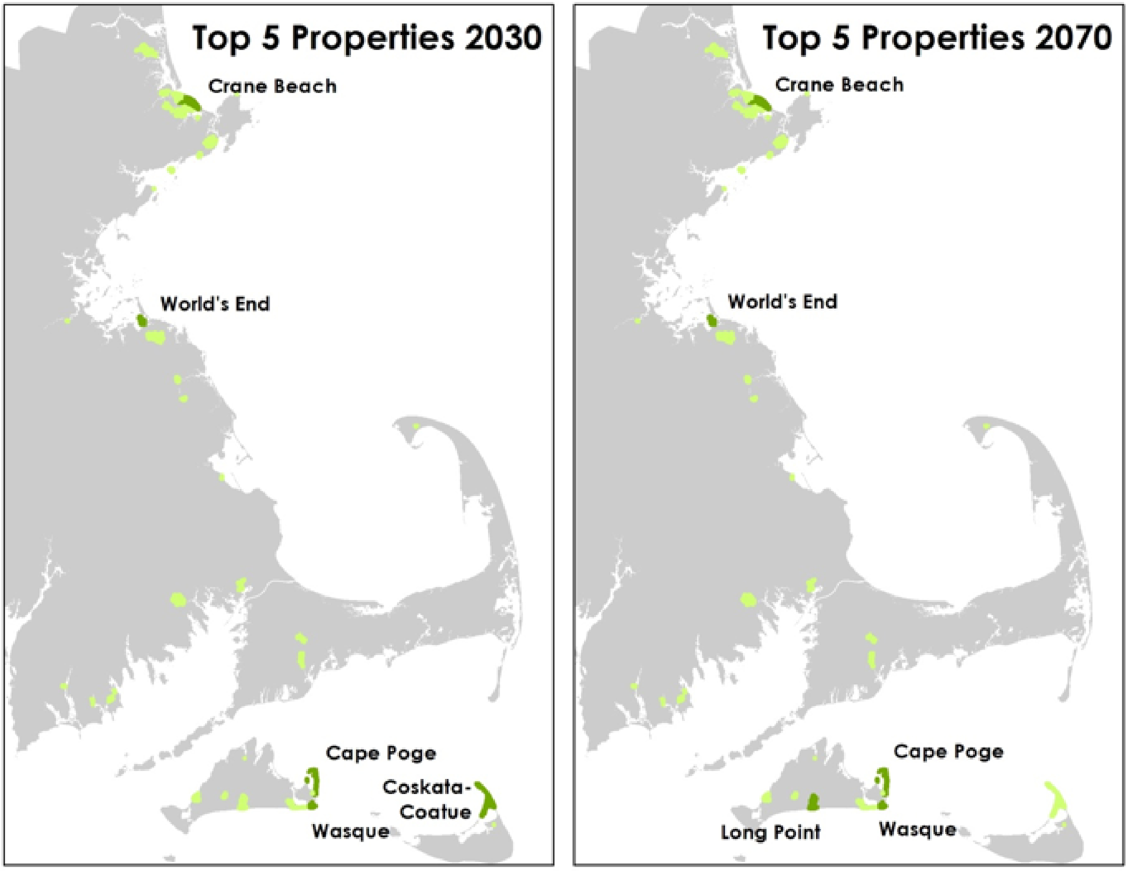

Figure 5-1. Five properties that contain the highest CVIs and highest concentration of vulnerable assets in 2030 and 2070.

The results are presented by property, by asset class, and for the SLAMM Model in Appendices A, B and C respectively. Appendix A provides management recommendations when possible.

5.2 PROPERTY PROFILES

Each property has a unique combination of assets, vulnerabilities and CVIs. Table 5-1 summarizes the results and provides strategic planning considerations. The Trustees provided input on the long-term planning considerations. The planning considerations focus on specific vulnerabilities at each property. Though not covered in detail for each property, planning considerations should also include:

- Consideration of the scale. The considerations presented are focused on within property adaptations. Ecologically, for example, consideration of regional habitat and threatened species goals would necessitate planning across property boundaries;

- After considering near term adaptations developed in the adaptation profiles, the next management step involves stepping back and taking stock of the remaining vulnerabilities. A prioritization framework can be developed to guide this process and incorporate considerations that expand on the CVI rankings;

- Monitoring programs (discussed in Section 7.0) provide the opportunity to collect data necessary to inform the planning process;

- The planning considerations are based on the vulnerability screening. Modeling, site-/asset-specific studies and monitoring data are required to develop more specific plans for each property;

- The work the Trustees completed is innovative and will capture the attention of partners. The knowledgebase provides potential partners with confidence that investments are based on sound science and will have the most direct impact on protecting not only the Trustees' assets, but also those of neighbors and coastal development inland of the Trustees' properties; and,

- The Regulatory landscape is very dynamic. Careful tracking of changes that might impact what projects can be permitted (and which ones might be limited) and which activities are required will help to define what can be implemented. Grant programs are also changing and planning considerations should be tuned to maximize the potential for grant funding.

Appendix A provides more detailed property summaries including the number of acres with different inundation probabilities, summary of asset vulnerabilities, SLAMM results, and recommendations. A site profile map is included for each property and presents the inundation probability for 2030 and 2070 and the composite[2] CVI maps for 2030 and 2070. Appendix B and Section 5.3 provide an evaluation of the highest CVIs by asset type. The property specific SLAMM Model results are presented in Appendix C.

[2] A composite CVI is calculated by adding the CVIs for overlapping assets at each pixel/point on a map. The red areas on the map indicate areas with assets that are highly vulnerable and also highly valued.

Table 5-1. Summary of CVA Results by Property

Property	Overview of CVI Results	% of Total Property with Inundation Probability = 100%		Strategic Planning Consideration[3]
		2030	2070	
Cape Pogue Wildlife Refuge	• Highest CVIs natural resources • Primary habitat for 7 protected species • Lighthouse highly valued but low inundation probability leading to a low CVI • SLAMM predicts an increase in estuarine open water, estuarine beach and open water; loss of irregularly flooded marsh, upland, tidal fresh marsh and transitional marsh	37%	68%	• Exposed property • High inundation probability for the property in both study years • Focused mission – wildlife refuge • Emphasis on natural systems on this property with threatened species habitat • Green infrastructure adaptations should be considered in the future to the areas with highest CVIs • Monitor key access points – causeway, bridge, trails and determine what type of future access is needed given that mission is wildlife refuge • Trails around the property should be maintained
Castle Hill	• Highest CVIs natural resources • Cultural resources also have higher CVIs than other infrastructure assets • Access points have comparatively high CVIs • Important recreational beaches have high CVIs • SLAMM Predicts a clear shift from irregularly flooded marsh to regularly flooded marsh in 2070 with little change to other wetland categories in 2030	40%	46%	• An important property because of the multiple uses and favored public recreation areas • Diverse assets with access challenges that warrant action • Important cultural resources • Resiliency planning projects are in development at adjacent Crane Beach property • Key buildings have negligible probability of inundation
Coolidge Reservation	• Comparatively few assets • Inundation probability less than 5% in 2030 and less than 40% in 2070 on average • Inundation probability is 100% along the beach in 2030 and covers Clarke Pond in 2070. • The CVIs remain low throughout a combination of the lower inundation probability, few assets and	3%	35%	• Although the consequence scores were lower than other properties, there is a small section of exposed beach that will be more frequently inundated. Periodic monitoring is recommended to track changes in the beach. • If the changes in the beach are to be managed a wave study should be conducted to better plan future nourishment activities • Clarke Pond – having shifted from a salt marsh to a freshwater

[3] Note: Trustees provide input regarding the assets on each property. These are combined with general recommendations.

Property	Overview of CVI Results	% of Total Property with Inundation Probability = 100%		Strategic Planning Consideration[3]
		2030	2070	
	lower comparative consequence scores. • SLAMM predicts a shift from nontidal swamp/Clarke Pond to a more regularly flooded marsh			pond, is likely to shift back as inundation becomes more frequent. Some living shoreline enhancements may slow the process, but the shifting is natural and not surprising given the proximity of the pond to the shoreline. • The sea wall integrity should be monitored
Cornell Farm	• The average CVI is comparatively low and the majority of the assets are vegetation communities. • Probability of inundation is high and increases from 2030 to 2070 • There is s shift away from tidal swamp to regularly flooded marsh; nontidal swamp/irregularly flooded marsh to estuarine beach/tidal flat; transitional marsh/scrub-shrub also increases – an indication of more seawater inundation particularly in 2070; the upland area remains fairly stable	17%	55%	• Given the lower CVIs and despite the inundation probability, monitoring is the recommended approach • This property is not located on the immediate coast – as a result increasing inundation and a shift to tidal flat and regularly flooded marsh are the primary concerns. The transitions that are occurring are not surprising given that the property falls between two coastal bays. Allowing the transition may be warranted. • The upland areas show minimal change over time
Coskata-Coatue Wildlife Refuge	• The CVIs are elevated given the exposure of the property and the value placed on its assets. The average CVI in 2070 is 2244. • Nearly all the assets are vulnerable to some extent in 2030 and 2070 • The CVIs are highest near the tip of the property and around Coskata Pond	49%	83%	• Given the exposure and dynamic nature of this location, actions to protect valuable assets should be balanced with long term options for access and use. Retreat should be considered for some areas. • Green infrastructure buffers along the trails would help stabilize these areas, re-routing may be necessary • Coskata Woods Track – monitor because it is highly valued.
Crane Wildlife Refuge	• Over 70% of the property has a 100% probability of inundation in 2030 and 2070 • The CVIs are in the medium to low range, with a few areas of medium-high CVIs • The majority of the assets are vegetation and habitats • SLAMM predicts a clear shift from irregularly flooded marsh to regularly flooded marsh in 2070, and an increase in tidal flats and open water.	73%	75%	• Monitor as the adaptations occurring at Crane Beach are implemented. Work on Argilla Road will influence this area and should help better control overall inundation. • Other planned efforts in the refuge may have a positive impact on this area (e.g. the salt hay subsidence project) • Reconcile how this area fits in with the larger wildlife refuge habitat. • Evaluate and monitor conditions on Choate Island and ferry access points to the island because inundation probabilities are high and access may be interrupted

Property	Overview of CVI Results	% of Total Property with Inundation Probability = 100%		Strategic Planning Consideration[3]
		2030	2070	
Crane Beach	• The CVIs along the shore are in the medium to high range, with lower CVIs in the higher portions of the property. • The popular beach and plover habitat are in an area with 100% probability of inundation in 2030 and 2070 • Inundation probability is also over 100% along Argilla Road with elevated probabilities in the parking and facility areas in 2070 • SLAMM shows a clear shift from irregularly flooded marsh to regularly flooded marsh in 2070, and loss of ocean beach • Open ocean and estuarine open water also increase in 2070, with decreases in uplands and non-tidal swamps	38%	48%	• Building resilience along the east facing beach is important – coastal processes studies are the first priority, followed by the design of beach nourishment studies • The entrance road is another high priority and should be raised with culvert expansion (with operable gate) near the entrance gate • These activities may help restore degraded wetland areas • Monitoring is also an important component at this vulnerable site • Monitor infrastructure (store, office, parking) after adaptations in surround areas are completed.
Crowninshield Island	• The CVIs on average are low throughout and inundation probability is near 100% around the periphery of the property • The only assets are trails and vegetation community • The majority of the assets are vegetation and habitats • SLAMM predicts little change in from 2011 to 2030 and 2070 - some increase in ocean beach and open ocean	29%	39%	• Because of the low CVIs and access requiring a boat, there is little need for immediate action at this property. Access may be cutoff – implications should be considered in future management planning.
Dunes' Edge Campground	• There is a comparatively low probability of inundation in 2070 (<20%) only and the CVIs are similarly low. • A road and vegetation community have a low probability of inundation in 2030 and 2070 • SLAMM does not predict any change in the wetland types through 2070	0%	0%	• No additional adaptation work is needed at this facility • Longer term/interval monitoring is advisable, and coordination with Provincetown to identify critical flood pathway.

Property	Overview of CVI Results	% of Total Property with Inundation Probability = 100%		Strategic Planning Consideration[3]
		2030	2070	
Gloucester Salt Marsh	• CVIs are moderate with only two asset classes – priority habitat and vegetation community • The average inundation probability is high in both 2030 and 2070 • SLAMM predicts a clear and profound shift from irregularly flooded marsh to regularly flooded marsh in 2070; in addition to an increase in estuarine beach and tidal flat	98%	99%	• Given the low CVI and high probability of inundation – the natural transition in wetland type over the next 60 years is difficult to stop • Potential pilot area for thin-layer deposition
Goodale Lots	• CVIs are low in both years, but inundation probability is nearly 100% over most of the property in 2030 and 2070 • The only asset is the vegetation community • SLAMM predicts a clear and profound shift from irregularly flooded marsh to regularly flooded marsh in 2070; in addition to an increase in estuarine beach and tidal flat	95%	96%	• Reconcile how this area fits in with the larger wildlife refuge habitat • The salt hay work in nearby areas may be expanded to stabilize sediment loss in this area. • Potential pilot area for thin-layer deposition (beneficial reuse of dredged material to restore or enhance salt marshes and help them maintain elevation at pace with sea level rise)
Governor Hutchinson's Field	• CVIs are low in both years, and inundation probability is also low with the exception of the bank areas on the Neponset River • Much of the property has 0% probability of inundation in 2030 and 2070 • SLAMM predicts no clear change in the wetland habitats on the site from 2030 to 2070	4%	5%	• Monitor bank of Neponset River for sloughing. No potential inundation of property due to elevation.
Greenwood Farm	• The CVIs are low throughout most of the property with some moderate CVIs closer to the Ipswich River • The probability of inundation is 100% over most of the property in 2030 and 2070 • There are diverse assets on the property buildings and infrastructure that are vulnerable in 2070; other assets are vulnerable in 2030 and 2070 • SLAMM results are consistent with other	77%	80%	• Given the low CVI and high probability of inundation – the natural transition in wetland type may fit within the long-term plans. • Some buffering along the bank of the river with green infrastructure may prevent storm surge impacts • Monitor access and infrastructure with possible future resiliency actions

Property	Overview of CVI Results	% of Total Property with Inundation Probability = 100%		Strategic Planning Consideration[3]
		2030	2070	
	reservations in this region – a clear shift between 2030 and 2070 from irregularly flooded marsh to regularly flooded marsh and an increase in estuarine beach/tidal float and nearby estuarine open water. Some fresh tidal marsh also emerges in 2070.			
Hales Brook and Sippican River	• The CVIs are low throughout most of the property, elevated inundation probabilities occur along the river and a few lower areas; elsewhere the probabilities are more diverse • SLAMM predicts the appearance of regularly flooded marsh, and estuarine beach/tidal flat in 2070 and the arrival of transitional marsh/scrub-shrub in 2030 and 2070 along with a reduction in nontidal swamp and inland fresh marsh.	2%	6%	• Bridge and trail sections in the higher vulnerability areas should be monitored. Though the CVIs are low, some routing maintenance might protect infrastructure • Wetland transitions should be monitored and aligned with the goals for this property. This transition is occurring at many of the properties. • Consider the stability of Hathaway Dam and its flood control – monitor and possibly model scenarios to evaluate stability and need to build resilience.
Halibut Point Reservation	• Very low CVIs and probability of inundation • Vegetation community is the only vulnerable asset type • SLAMM confirms that the majority of the site consists of upland areas with narrow bands of regularly flooded marsh, transitional marsh/scrub and ocean flat along the coast	1%	2%	• Because the inundation probability is so low and the coast is largely rocky, little adaptation is required at this property.
Hamlin Reservation	• Low to Moderate CVIs and 100% probability of in inundation in 2030 and 2070 over 70% of the property. • Multiple assets are vulnerable to inundation in 2030 and 2070 including: cultural points, priority habitat, vegetation community, roads and trails • SLAMM results are consistent with other reservations in this region – a clear shift from irregularly flooded marsh in 2070 to regularly	72%	77%	• With low CVIs it is unclear how high a priority this property should occupy in the management plan of all coastal properties. • Rare species are found along causeway – monitor and future adaptations will have to consider these species. • Potential pilot area for thin-layer deposition

Property	Overview of CVI Results	% of Total Property with Inundation Probability = 100%		Strategic Planning Consideration[3]
		2030	2070	
	flooded marsh, a decrease in Transitional Marsh, Scrub-shrub and an increase in estuarine beach/tidal float, tidal swamp and tidal fresh marsh. Some fresh tidal marsh also emerges in 2070.			
Holmes Reservation	• Very low CVIs and probability of inundation • Vegetation community is the only vulnerable asset type • SLAMM predicts no clear wetland change over the assessment period.	3%	5%	• Potential site for coastal bank restoration. Consider vulnerabilities on Nelson Street Park and other properties connected via culvert
Leland Beach	• The CVIs cover the full range from low to the high and all of the assets face potential inundation in 2030 and 2070 • This property has many priority habitats that are vulnerable to inundation • SLAMM predicts loss of irregularly flooded marsh and replacement with estuarine open water and transitional marsh/scrub in 2070; ocean beach actually increases as doe	28%	50%	• Focus on the priority habitats should include monitoring and building resilience • Some trail rerouting may be necessary.
Long Point Wildlife Refuge	• The CVIs cover the full range from low to the high and all of the assets face potential inundation in 2030 and 2070 • Highly vulnerable beach and dune along the coast; also, a shift in areas behind the dune from lower probability of inundation in 2030 to 100% probability in 2070 • SLAMM results indicate loss of ocean beach through the modeling period, expansion of open ocean and a decrease in tidal swamp at the head of Long Cove;	3%	24%	• The overtopping is not a concern and should be allowed to occur • Parking lot may need study in 2070 • Monitor priority habitats and trails
Lyman Reserve	• The CVIs are on the low to medium low end of the scale and the probability of inundation is 100% in a narrow part of this property	9%	13%	• The lower reaches of this property in close proximity to Buttermilk Bay are already flooded at various times of the year. The increased probability over time is part of a natural

Property	Overview of CVI Results	% of Total Property with Inundation Probability = 100%		Strategic Planning Consideration[3]
		2030	2070	
	• All of the asset classes are represented on this property and all have some probability of inundation in 2030 and 2070 • SLAMM predicts loss of irregularly flooded marsh, increases in estuarine open water and estuarine beach/tidal flat, and a small increase in 2030 followed by a decrease in 2070 of the regularly flooded marsh			transition • Monitoring and potential isolated green infrastructure/buffer protections of specific assets may be warranted. • The bridge and causeway should be monitored and may be moved if needed in the future. • Much of the property can be left to naturally transition and there is room for marsh migration upstream.
Mashpee River Reservation	• CVIs are low with isolated moderate areas; inundation probabilities are also low with the exception of some isolated stretches along the river • Cultural points, priority habitat, trails and vegetation communities are vulnerable in 2030 and 2070, while roads are vulnerable in 2070. • SLAMM predicts loss of tidal swamp and irregularly flooded march, increases in estuarine open water and a small increase in 2030 followed by a decrease in 2070 of the regularly flooded marsh and estuarine beach/tidal flat	4%	5%	• Future predictions are in line the current dynamics in the system. An increase in the probability of inundation over a larger, but still small portion of the property occurs from 2030 to 2070 • There is little room for migration of wetlands
Medouie Creek	• CVIs are low in 2030 and moderate in 2070, with inundation probabilities less than 20% in 2030 and 100% (over 60% of the property) in 2070 • Priority habitat and vegetation communities are vulnerable in 2030 and 2070, while infrastructure is not vulnerable • SLAMM predicts the that transitional marsh/scrub-shrub dominate, replacing non-tidal swamp in 2070	0%	64%	• Changes in this wetland do not appear until 2070. Given the length of time before the transition occurs, a monitoring program tuned to the goals for this property is recommended. • Some protections of priority habitat may be implemented in the future.
Menemsha Hills	• CVIs are low in 2030 and in 2070 with the exception of moderate CVI's immediately on the coast; inundation probabilities are 0% over most of this property with the exception of the beach and low-lying area at northern boundary	3%	3%	• High elevation areas not vulnerable, but toe of bank could be eroded, resulting in sloughing of upland areas. This is a natural process, with no immediate threat to infrastructure, which should be allowed to occur. • Monitor beach stairs, trail along beach and shoreline artifacts.

Property	Overview of CVI Results	% of Total Property with Inundation Probability = 100%		Strategic Planning Consideration[3]
		2030	2070	
	• Cultural points, infrastructure, trails and vegetation communities are all vulnerable in 2030 and 2070, but limited extent and tend to be lower consequence • SLAMM predicts a loss of ocean beach in 2070 and a gain in open ocean in 2070			
Misery Islands	• CVIs are low in 2030 and in 2070; inundation probabilities are 0% over most of this property with the exception of a narrow coastal band with probabilities of 100% in 2030 and in 2070 • Cultural points, trails and vegetation communities are vulnerable in 2030 and 2070, but limited extent and have low consequence • SLAMM predicts some loss of estuarine beach/tidal flat and increase in ocean beach, estuarine open water, and open ocean in 2070	12%	15%	• Document vulnerable cultural resources. • Re-route trails as necessary, but otherwise no action.
Mytoi	• CVIs are low in 2030 and in 2070; inundation probabilities expand from 2030 and 2070 with 100% probability along property periphery • Only vegetative communicates are vulnerable in 2030, but building, parking and vegetation communities are vulnerable • SLAMM predicts loss of upland, inland open water, irregularly flooded marsh and tidal swamp in 2030 with complete loss of irregularly flooded marsh and tidal swamp transitional marsh by 2070; transitional marsh/scrub-shrub, regularly flooded marsh, estuarine beach/tidal flat and estuarine open water all appear in 2070	12%	24%	• In low lying areas along the salt marsh and Poucha Pond where wetland changes are expected in 2030 and 2070 should be monitored to confirm that the property continues to meet its mission. • Evaluate areas of potential vulnerability for tolerance of plantings to salt water intrusion. Consider value of a barrier at the road to block storm surge if saltwater inundation is problematic.
Norris Reservation	• CVIs are low in 2030 and low to scatter low-moderate in 2070; inundation probabilities expand from 2030 and 2070 in the southern portion of the property with 100% probability along southern	8%	17%	• Wetland transitions are predicted, but limited in extent due to topography. Vulnerable trails and boathouse should be investigated. A monitoring program paired with consideration of how the changed wetlands will impact the mission of this

Property	Overview of CVI Results	% of Total Property with Inundation Probability = 100%		Strategic Planning Consideration[3]
		2030	2070	
	periphery of the property; much of the remainder of the property has 0% probability of inundation • A building, cultural points, infrastructure, priority habitat, trails and vegetation community are all vulnerable in 2030 and 2070; a road becomes vulnerable in 2070 • SLAMM predicts loss of upland, nontidal swamp, inland fresh marsh, inland open water, and irregularly flooded marsh; tidal fresh marsh, regularly flooded marsh, estuarine beach/tidal marsh, estuarine open marsh and tidal swamp all increase in 2030 and 2070.			property are recommended. • Evaluate Gordon Pond Dam (vulnerable in 2070) and potential removal for wetland restoration to North River.
Norton Point Beach	• CVIs are moderate to high in 2030 and expand further in 2070; inundation probabilities expand from 2030 and 2070 with 100% probability over much of the property • A building, infrastructure, parking, priority habitat, roads, trails and vegetation community are all vulnerable in 2030 and 2070; • SLAMM predicts loss of upland, loss of ocean beach, and gain in open ocean in 2030 and 2070.	62%	83%	• As a barrier beach this area is highly vulnerable to storm inundation and sea level rise. It is also in a high energy zone with potential for overwash and breaching events. Natural processes should be allowed to continue here, with some consideration given to targeted interventions to protect rare species habitat. • Loss and movement of eastern beach is not an issue. This analysis does not account for dynamic beach processes. The entire south coast/beach needs to be treated the same to ensure the future supply of sand
Old Town Hill	• CVIs are low to low-moderate in 2030 and expand further in 2070; inundation probabilities expand from 2030 and 2070 with 100% probability over half of the property • Cultural points, infrastructure, priority habitat, roads, trails and vegetation community are all vulnerable in 2030 and 2070; • SLAMM predicts loss of upland, loss of nontidal swamp, loss of irregularly flooded marsh and after an uptick in 2030 a lost in acreage of tidal swamp in	42%	48%	• This is a dynamic wetland property with saltmarsh and tidal river. The transition from non-tidal to tidal and more regularly flooded conditions should be monitored closely • Loss of sediment/subsidence, erosion and other forces of change may be managed as changes appear and mission is threatened.

Property	Overview of CVI Results	% of Total Property with Inundation Probability = 100%		Strategic Planning Consideration[3]
		2030	2070	
	2070; Transitional marsh/scrub-shrub, regularly flooded marsh, estuarine beach/tidal flat, estuarine open water all increase in 2030 and 2070.			
Slocum's River Reserve	• CVIs are low in 2030 and 2070; inundation probabilities expand from 2030 and 2070 with 100% probability of inundation in the land adjacent to the River • Priority habitat, trails and vegetation community are all vulnerable in 2030 and 2070; • SLAMM predicts loss of upland, estuarine open water and irregularly flooded marsh, with the appearance of tidal fresh marsh, regularly flooded marsh, estuarine beach/tidal flat in 2070, and expansion of tidal swamp	12%	18%	• This is a dynamic wetland property with saltmarsh and tidal river. The transition from non-tidal to tidal and more regularly flooded conditions should be monitored closely • Loss of sediment/subsidence, erosion and other forces of change may be managed as changes appear and mission is threatened.
Stavros Reservation	• CVIs are low to moderate in 2030 and 2070; and inundation probabilities are high in 2030 and 2070 with 100% probability of inundation over much of the property • Priority habitat and vegetation community are vulnerable in 2030 and 2070; • SLAMM predicts loss of upland and • irregularly flooded marsh, with the appearance of transitional marsh/scrub-shrub and estuarine beach/tidal flat in 2070, and expansion of regularly flooded marsh in 2030 and 2070	63%	64%	• A monitoring plan focusing on subsidence and priority habitats is recommended with actions to mitigate subsidence. • Bluff erosion is not a concern.
The FARM Institute	• CVIs are low in 2030 and 2070; and inundation probabilities are low in 2030 and 2070 with no portion of the property having 100% probability of inundation • Priority habitat and vegetation community are vulnerable in 2030 and 2070; • SLAMM predicts no change in the upland habitat	0%	0%	• Because of the low CVIs, low inundation probabilities and the lack of wetlands, the existing management and monitoring programs should suffice.

Property	Overview of CVI Results	% of Total Property with Inundation Probability = 100%		Strategic Planning Consideration[3]
		2030	2070	
	(no wetland habitat is present)			
Two Mile Farm	• CVIs are low to moderate in 2030 and 2070; and inundation probabilities are elevated for a small portion of the property in 2030 and 2070 with 100% probability of inundation in less than 20% of the area • Priority habitat and vegetation community are vulnerable in 2030 and 2070; • SLAMM predicts loss of upland and irregularly flooded marsh, with the appearance of transitional marsh/scrub-shrub and expansion of regularly flooded marsh in 2030 and 2070	16%	17%	• Wetland transitions are predicted, but limited in extent due to topography. Vulnerable trails and should be re-routed if necessary. • In this case inundation may help control phragmites • Monitoring should focus on the most vulnerable bank areas along the North River. Future buffers/green infrastructure projects could stabilize this area.
Wasque	• CVIs are low over much of the property, but the CVIs are high close to the shore in 2030 and 2070; and inundation probabilities are elevated for coastal portions of the property in 2030 and 2070 with 100% probability of inundation in less than 35-45% of the area • Infrastructure, Parking, Priority habitat, roads, trails and vegetation community are vulnerable in 2030 and 2070; • SLAMM predicts loss of upland, estuarine beach, ocean beach and irregularly flooded marsh, with expansion of regularly flooded marsh, estuarine open water and open water in 2030 and 2070	35%	39%	• This is a high energy environment subject to periodic erosion and rebuilding. Natural processes should be allowed to continue here, with some consideration given to targeted interventions to protect rare species habitat. Planning strategy should revolve around eventual retreat and potential future shoreline configurations. • Westside Parking Area 2070 – consider moving or abandoning • Westside Driveway will need to be evaluated in 2070
Westport Town Farm	• CVIs are low in 2030 over much of the property, but coastal portions of the property shift to moderate CVIs in 2070. • Cultural points, trails and vegetation community are vulnerable in 2030 and 2070; • SLAMM predicts loss of upland, irregularly flooded marsh and tidal swamp with expansion of	1%	17%	• Wetland transitions are predicted, but limited opportunity for migration due to topography. Vulnerable trails should be re-routed if necessary.. • Monitoring should focus on the key transition areas along the east branch of the Westport River • Model loss of high marsh in 2070 to determine what adaptations might be feasible

Property	Overview of CVI Results	% of Total Property with Inundation Probability = 100%		Strategic Planning Consideration[3]
		2030	2070	
	transitional marsh/scrub-shrub, regularly flooded marsh, estuarine beach/tidal flat, and estuarine open water in 2030 and 2070			• Future buffers/green infrastructure projects could stabilize this area
World's End	• CVIs are low to moderate in 2030 and 2070 while the inundation probability is 100% along the shorelines, around the crossing to the island and the saltmarsh • Buildings, Cultural points, infrastructure, Priority Habitat, Roads Trails and Vegetation community are vulnerable in 2030 and 2070; • SLAMM predicts loss of upland, non-tidal swamp, inland fresh marsh, irregularly flooded marsh with expansion of transitional marsh/scrub-shrub, regularly flooded marsh, estuarine beach/tidal flat, and estuarine open water in 2030 and 2070	20%	21%	• Previous adaptations – a bridge and opening water exchange around the salt marsh should continue to be monitored and additional work on the opening may be warranted. • The trail crossing/causeway to World's End is vulnerable. A green infrastructure resiliency project could protect against future erosion and preserve access in the long term considering sea level rise; • In some cases, the conversions and transitions might be helpful (e.g. grassland near Loud Lot, Damde Meadows marsh, the Bar) – more study should be considered. • The coastline is eroding in places (trees are seen slumping into the water). These areas should be monitored and studies. Future shoreline restoration may be warranted in the future.
Boston Community Gardens	• CVIs are 0 in 2030 and low in 2070 while the vulnerability is less than 5% for a small subset of the gardens (18 out of 56) • Buildings, Cultural points, infrastructure, Priority Habitat, Roads Trails and Vegetation community are vulnerable in 2030 and 2070; • SLAMM results are not applicable to urbanized areas	0%	0%	• The gardens are in an urbanized area that is not vulnerable to storm inundation in 2030. In 2070, a small subset of gardens face a low probability of inundation, but the CVIs are also low. • Given that the inundation probability starts to increase in 2070 – long-term garden planning should focus on strategically locating new gardens in areas with no vulnerability.

5.3 ASSET SUMMARY

The CVI results can be organized and analyzed in a number of different ways. In the previous subsection, the CVIs are organized by property. In Appendix B, the CVIs are organized by the 8 asset classes. They include:

- Buildings
- Cultural Points
- Infrastructure
- Parking
- Primary Habitat Species
- Roads
- Trails
- Vegetation Communities.

When reviewing the results, consider comparisons within an asset class (from the most at risk the least within an asset) and across asset classes (some assets as a group are more at risk than other assets). The highest CVI in one asset class may be less than the CVIs in another class (e.g. Vegetation Communities compared to Parking).

The results of the asset evaluation include (in general order of CVI magnitude from high to lower):

- Vegetation communities have the highest CVIs and, consistent with what one would expect, beaches are most at risk in this asset class. World's End, Menemsha Hills, Cape Poge Wildlife Refuge, Wasque, Costkata-Coatue Wildlife Refuge, Crane Beach/Castle Hill and Long Point Wildlife Refuge are the properties with the highest at-risk vegetation communities.

- Priority Habitats and trails have the next highest CVIs. Wildlife found in the at-risk habitats include piping plover, northern harrier, and least, roseate and common terns. The most at risk properties with respect to priority habitats include – Cape Poge Wildlife Refuge, Wasque, and Coskata-Coatue Wildlife Refuge.

- At-risk trails are found on a number of different properties. Leland Beach (Leland Inner Track), Meneshma Hills (Beach Loop – on Beach), World's End (Bridge Carriage Road, Viewing Blind Trail), Coskata-Coatue Wildlife Refuge (Entrance Track) and Crane Beach (Red Trail Back) have the 5 highest CVIs for trails.

- Infrastructure CVIs are highest for Argilla Road Culvert (Crane Beach), Wasque Pt Stairs (Wasque), Damde Meadows Bridge (World's End), Crane-side Ferry Dock (Crane Beach) and Choate-side Ferry Dock (Crane Wildlife Refuge).

- The highest CVIs for cultural points include, for example, back dike and causeway (World's End), shipwreck and saltwater pool ruins (Misery Islands), stone pier (Crane Wildlife Refuge) and Packard bog (Lyman Reserve)

- CVIs are highest for the following roads: Argilla Road (Crane Beach), Dirt Road to Ferry (Crane Beach), Parking area turn around (Crane Beach), Gatehouse Driveway (Castle Hill), Newman Road (Old Town Hill).

- Building CVIs are the highest for the Gatehouse (Cape Pogue Wildlife Refuge), Longboat Barn (Crane Wildlife Refuge), Boat House (Norris Reservation), Ranger Station (World's End), Ranger Station – Gate (Crane Beach). The CVIs drop off as the vulnerability approaches 0.

- The most at-risk parking areas include Town Parking Lot at Dike Road (Cape Poge Wildlife Refuge), Crane Beach Main Parking Area (Crane Beach). The CVIs and vulnerabilities drop off after these two parking areas.

5.4 SLAMM MODEL RESULTS

SLAMM Model results are presented in Appendix C. Each property has a one-page summary that includes a series of three maps capturing wetland category distribution in present day, 2030 and 2070. There is a tabular summary and a graphical summary illustrating the change in hectares during the different time periods.

6.0 ADAPTATION STRATEGIES

The mission of Trustees is to "preserve, for public use and enjoyment, properties of exceptional scenic, historic, and ecological value". Recognizing the potential impacts of sea level rise and storm surge at its coastal properties, Trustees initiated this risk-based vulnerability assessment. The CVI provides the data required to identify properties and assets that are most valued and most vulnerable. The final step is to prioritize adaptation projects for the most vulnerable assets/properties. This section provides a framework for integrating the results of the CVI and SLAMM assessments with existing property management plans to develop phased, effective and efficient adaptation strategies in line with Trustees' mission, and presents conceptual plans for five (5) high priority sites. Further suggestions for potential adaptation projects may be found in the Recommendations section of each Site Profile (Appendix A).

6.1 OVERVIEW

The Trustees employ a decision-making process that considers how management decisions further the mission to conserve habitat, protect cultural resources and provide exciting and diverse educational and recreational activities for visitors. Although the overall goal of protecting these properties into the future is clear, the individual mission components may not always align – e.g. protecting habitat for an endangered species may limit recreational activities. The Trustees rely on mission-specific experts (i.e. ecologists, infrastructure managers, cultural and historic resource specialists) to guide the process. Deciding on which assets to protect, what properties to focus on and resilience projects that accomplish the protection goals while allowing the missions to be met, requires consideration of historical trends, multiple scale planning goals and defensible, high-quality data to support decision-making. The results presented in this report provide an important line of evidence, but the results do not, in and of themselves, point to specific projects. Finding a balance among the three mission goals requires planners to apply a vision that considers distribution of habitat types across all holdings, identify trends in assets that may require attention (e.g. long-term loss of a specific habitat type or emergence of a new habitat type) and maintaining a portfolio that maximizes opportunities for continued enjoyment of the properties. The strength of this process is based on applying a tested framework and collaborating with diverse experts that can balance asset specific expertise with the larger vision and values of the Trustees.

In this Section, the CVIs and property specific results are used to identify specific, high priority projects. The results of the CVA can be applied to multiple components of the long range sustainable planning process to ensure that the properties are maintained and public access continues. Opportunities for use of the data include, for example:

- Development of multi-scale adaptation strategies that include protection of key assets, building resilience over an entire property that is particularly vulnerable and identifying adaptation projects that will build resilience over a larger region and add to the protections for communities.

- Design and implementation of monitoring programs to establish baseline conditions such as beach condition, nesting areas, and rare species and monitor change through time. In many cases, existing monitoring programs may provide an understanding of the condition of a location and additional components can be added to support the selection of appropriate adaptation approaches.

- The distribution of properties and facilities can also be guided by these results. When new facilities such as bath houses, parking lots or trails are required, managers can access the CVA results to identify the portion of a property that is least vulnerable to climate impacts (i.e. lower CVIs – low probability of inundation and low comparative value or areas where wetland change is either not likely or the transition is to a less valued wetland type). Additionally, the results may aid in the selection of new acquisitions and the determination of whether an existing property should be allowed to transition naturally.

- Finally, the results can encourage and drive regional collaborations. The work completed by the Trustees has value for neighboring landowners and communities located inland of the reservations. Protections planned at Trustees' properties may impart benefits to surrounding landowners.

Because Trustees manage coastal properties throughout Massachusetts for multiple uses and strive to protect scenic, historic, and ecological resources, it is important to recognize the full range of strategies for adapting to climate-induced SLR and storm surge that may be implemented: Protection, Accommodation, and Retreat.

Protection strategies are developed to prevent water from reaching sensitive assets, and typically are designed as barriers (in various forms) to keep flood waters out. Accommodation strategies are designed to allow sensitive assets to be exposed to flood waters while minimizing the potential damage to those assets. Finally, Retreat strategies are implemented to relocate sensitive assets away from vulnerable areas and allow climate change impacts to occur with minimal consequence.

The development of adaptation strategies for all Trustees coastal properties may leverage any of these three approaches, individually or in combination, to address coastal vulnerability and protect natural and anthropogenic resources while managing for long-term change. Any Trustees adaptation project must find the appropriate balance between intervention and allowing natural processes to play out in order to continue to carry out the mission of the organization; additionally, the appropriate balance will likely differ for each property and even among assets at the same property. In addition, it is very likely that an adaptation at a property will impact many different assets; the scale of the vulnerability and adaptation is an important consideration when seeking a balanced approach. With limited resources, there may be cross property opportunities as well. For example, it may be possible to enhance or expand a sensitive habitat on one property to gain additional ecosystem services, while allowing a similar habitat to follow natural transitions shifting to different ecosystem services. In the end, the total ecosystem services from that habitat type may increase on one property and decrease on another, but remain steady in terms of the full portfolio of Trustees holdings.

In order to prioritize investment in and maximize the protective return of climate change adaptation projects for Trustees properties and assets, the assessment took into consideration a number of lines of evidence, including:

- Probability of inundation and its temporal progression
- CVI scores of individual assets
- Composite CVI scores across each property
- SLAMM model results
- Adaptive capacity of the asset to episodic and/or periodic inundation
- Economy of intervention (the potential for one adaptation project to have cascading benefits to multiple assets)

Prioritizing the development of five (5) concept-level adaptation projects for this assessment was an iterative process. First, a screening level assessment of asset-specific and property-specific composite CVI scores identified high priority properties for further consideration. Next, a reanalysis of these asset-specific and composite CVIs (in parallel with other lines of evidence) identified effective and efficient adaptation strategies for the high-risk assets at those high priority properties. Throughout the process of prioritizing properties and assets for adaptation projects, the timeframe of potential impacts was a key consideration. Overall, primary focus for immediate or near-term adaptation proposals was on properties and assets with high 2030 CVI scores, since these are the assets demonstrating the most pressing needs. The vulnerability assessment brackets the uncertainty in long-term 2070 predictions and allows for refinement in future iterations; however, the development and prioritization of any near-term adaptation project must necessarily consider potential impacts in the long-term (2070 CVI scores). In many cases, near-term adaptation projects can be designed with built-in flexibility and modularity such that the degree of protection can be adjusted/augmented over time as required. For vulnerabilities that are not expected to present in the near-term (low 2030 CVI, but high 2070 CVI), the recommended approach is to monitor these assets in the near-term in order to refine the timing and scope of future actions. The layered approach to prioritization facilitated careful and strategic development and prioritization of adaptation strategies across multiple properties, which can serve as a model approach as Trustees activates further planning in this regard.

6.2 PRIORITIZATION OF PROPERTIES

Given that the Trustees mission is to preserve the exceptional qualities of its "special places", directing limited resources to a limited number of adaptation projects inevitably leads to difficult choices. By design, the CVI scoring helps to focus adaptation on those assets with high vulnerability and high consequence scores (the most vulnerable and valuable). However, given the range and scale of assets managed by Trustees (infrastructure, cultural resources, habitat) at its 35 coastal properties, it was necessary to first narrow the focus by screening and prioritizing at the property scale.

The prioritization of properties was accomplished by weighing a few lines of evidence. First, lists of the properties containing the most at-risk assets (highest CVIs) and the properties containing the highest counts of high-risk assets (top 5^{th} percentile of all CVI scores) in 2030 and 2070 were compiled (Figure 5-1). Next, the composite CVI maps (Appendix A) were reviewed to identify properties with spatially concentrated highly vulnerable assets (multiple overlapping high CVI assets[4]). Finally, Trustees leadership provided input and identified their high-profile properties, in terms of use, revenue generation, as well as ecological and historical significance. The lines of evidence were in agreement and identified the following priority properties for more detailed adaptation evaluation:

- Cape Poge Wildlife Refuge
- Coskata-Coatue Wildlife Refuge
- Crane Beach
- Crane Wildlife Refuge
- Long Point Wildlife Refuge
- Wasque
- World's End

6.3 ADAPTATION PROJECT SELECTION PROCESS

With a prioritized list of the properties that are most in need of adaptation to protect assets, the next step in the process is to narrow the focus to the most vulnerable and valued assets on the selected properties. The process of developing adaptation priorities for each Trustees property is similar to the selection of the priority properties in the previous section; it is iterative and based on multiple lines of evidence. The primary screening tool to identify candidate areas for adaptation projects is the CVI assessment. High CVI scores are associated with assets that are particularly at risk. Ultimately, the concurrence of high value and high vulnerability indicates that adaptations are needed for a given asset(s). Woods Hole Group reviewed the high CVI assets, focusing especially on areas containing multiple high CVI assets (composite CVI score) to determine:

- Which assets are vulnerable
- The probability of inundation and how that changes over time
- Where the strategic areas might be for various adaptation strategies (Protect/Accommodate/Retreat)

Since the hydrodynamic model addresses the combined effects of SLR and storm surge at Trustees properties, the probability of inundation and resulting CVI scores represent vulnerability to episodic flooding. To determine whether an asset might be exposed to

[4] A composite CVI (See Summary Figures by property in Appendix A) is calculated as a sum of the CVIs for each asset at each point (pixel) over the property. For example, a point on a property may have a habitat layer with a CVI = 1,000, a sensitive species layer with a CVI of 2,500 and a trail with a CVI of 800. In this case, the composite CVI would equal 4,300. This area of the site could then be compared to other parts of the site in terms of its cumulative (or composite) vulnerability.

periodic flooding (long term SLR and migration of the tidal range), SLAMM model results were consulted.

Some assets, such as infrastructure, may be particularly vulnerable to episodic flooding because the high water can limit access and functionality and even cause permanent damage (e.g. erosion, salt water fouling of equipment, damage to culverts). Other assets, such as ecological systems, may be able to accommodate and/or recover from episodic inundation. Similar consideration was given to the resiliency of assets exposed to future periodic (tidal) flooding. In all cases, the adaptive capacity of the asset was considered when developing adaptation strategies. Adaptation strategies that address episodic flooding typically fall on the Protect-Accommodate portion of the spectrum, while the strategies that address periodic flooding typically fall on the Accommodate-Retreat portion.

Finally, Woods Hole group sought to identify opportunities for maximizing the economy of intervention in the development of all adaptation strategies. There are many ways to achieve this when planning adaptation interventions. The most direct way in this assessment was concentrating on areas with high CVI assets and high composite CVI scores (where multiple highly vulnerable assets are co-located). Another way to achieve economy of intervention for Trustees adaptation was to identify projects that build resiliency in natural systems and infrastructure that cascades over time and/or space to reduce vulnerability for other assets. For instance, a beach nourishment project not only provides a buffer protecting adjacent infrastructure and habitat from inundation and erosion but also can, by design, contain a sacrificial element that provides a migrating buffer and habitat enhancement as the sediment is transported.

In all cases, Woods Hole Group made every effort to identify solutions that align with the Trustees mission. Specifically, Retreat is recommended for certain assets as necessary. Additionally, for areas where Accommodation or Protection are necessary, the proposed adaptation is rooted (to the greatest extent practicable) in habitat restoration/enhancement and green infrastructure.

6.4 ADAPTATION MATRIX

In total, five (5) proposed priority adaptation projects address vulnerability at two (2) priority properties – Crane Beach and World's End. The adaptation matrices for these priority projects are presented in Tables 6-1 through 6-5.

Each adaptation matrix provides an overview of the proposed adaptation project. The matrix identifies the property and site, and reviews the adaptation in terms of which assets are being addressed, the specific vulnerabilities and values of the assets, a brief overview of the elements of the proposed adaptation project and the recommended phasing of interventions, and finally a preliminary cost estimate supported by a listing of additional analyses to be conducted prior to project design/development.

Because these five (5) proposed priority adaptation projects are conceptual in nature, each will likely require additional refinement as well as site investigations to support design and permitting. In general, the recommended additional studies to better understand existing conditions and potential impacts (and, therefore, to support more informed adaptation design) may include:

- Wave studies to more accurately predict flooding in areas open to wave attack, run-up, and overtopping;
- Shoreline change studies and sediment transport modeling to optimize the design of beach nourishments;
- Hydrodynamic modeling to select appropriately sized culverts for wetland restorations;
- Comprehensive monitoring programs to evaluate variation over time, better define trends and identify/confirm vulnerabilities;
- Survey to document existing conditions in support of design and permitting.

In some cases, potential SLR and storm surge may not significantly impact Trustees high value assets in the near term, but may do so in the long term (later planning horizon). In these instances, the recommendation is to monitor and adopt an adaptive management approach. A table summarizing the recommendations for each area is provided below.

Table 6-1. Crane Estate – Castle Neck Creek Marsh Restoration

Adaptation Planning Matrix	**Project #1: Crane Estate – Castle Neck Creek Marsh Restoration**
General Description of the Site	Tidal wetland situated between Castle Hill and Crane Beach, providing storm surge buffering and important habitat (among other ecosystem services).
Overview of inundation probabilities (Map) 2030 and 2070	2030: 100% 2070: 100%
Overview of asset value (describe what makes the asset valuable)	Contains a mix of emergent cattail and phragmites wetlands, salt marsh, red maple swamp, and maritime shrub thickets. Provides habitat for common tern and least tern, borders habitat for seabeach needlegrass. Bordered by Argilla Road and Castle Hill Exit Driveway. Nearby vulnerable cultural assets include Castle Hill floodgate, spring site, archeological site, and dump.
Site overview (aerial photo) with markup of conceptual adaptation	See "Crane Estate Resiliency Project" map
Narrative description of adaptation	Replace undersized Argilla Road culvert to restore full tidal range to Castle Neck Creek marsh. In addition to restoring degraded marsh habitat, the project will allow Castle Neck Creek marsh to accommodate storm surge from the Castle Neck River and buffer upland habitat, infrastructure, and cultural resources from potential future inundation.
List of assets protected by adaptation	Argilla Road Castle Hill Exit Driveway Castle Hill cultural points (4) Seabeach needlegrass habitat Restores current phragmites to native salt marsh
Timeline of Adaptation	
Current action	Model (hydrodynamic), design, and construct
By 2030	Monitor
By 2070	Monitor
Range of Costs	Design: $50,000 Permit: included in Argilla Road project Construction: $150,000 - $200,000
Adaptation Development Components	Modeling/Assessment: Hydrodynamic model, survey

Table 6-2. Crane Beach – Crane Beach Resiliency

Adaptation Planning Matrix	**Project #2: Crane Estate – Crane Beach Resiliency**
General Description of the Site	Barrier beach extending east from Steep Hill down Castle Neck and terminating at the Essex Bay inlet. Provides recreational opportunities and storm surge buffering to landward dune system, interdunal habitats, trails, and infrastructure.
Overview of inundation probabilities (Map) 2030 and 2070	2030: 30% - 100% 2070: 50% - 100%
Overview of asset value (describe what makes the asset valuable)	Crane Beach is an important recreational resource that generates significant revenue. The beach and overwash areas provide crucial nesting and foraging habitat to R/T/E shorebirds.
Site overview (aerial photo) with markup of conceptual adaptation	See “Crane Estate Resiliency Project” map
Narrative description of adaptation	Perform beach nourishment in eroded pocket fronting the main recreational area of Crane Beach, which has experienced significant long-term erosion. Initial placement will expand the useable beach area and prevent potential wave run-up/overtopping near parking lots. As the sand migrates downdrift, it will provide additional buffering and protection to the dunes, interdunal habitats, and trails. As the sand approaches the tip of Castle Neck it will enhance nesting shorebird habitat.
List of assets protected by adaptation	Crane Beach Castle Neck archaeological sites (3) Dune and interdunal habitat (from erosion) Seabeach needlegrass habitat (from erosion) Plover and tern habitat (enhancement)
Timeline of Adaptation	
Current action	Model (wave, sediment), design, and construct
By 2030	Monitor, re-nourishment as necessary
By 2070	Monitor, re-nourishment as necessary
Range of Costs	Design: $75,000 Permit: $75,000 Construction: $1,250,000 - $2,500,000
Adaptation Development Components	Modeling/Assessment: Coastal processes study (wave, sediment transport, shoreline change), survey

Table 6-3. Crane Beach – Crane Beach Infrastructure Adaptation

Adaptation Planning Matrix	**Project #3: Crane Estate – Crane Beach Infrastructure Adaptation**
General Description of the Site	Developed areas at Crane Beach that support Trustees programming.
Overview of inundation probabilities (Map) 2030 and 2070	2030: 10% - 100% 2070: 50% - 100%
Overview of asset value (describe what makes the asset valuable)	Crane Beach is an important recreational resource that generates significant revenue. The various visitor support assets are crucial to maintaining programming at Crane Beach and ensuring future access to the property.
Site overview (aerial photo) with markup of conceptual adaptation	See "Crane Estate Resiliency Project" map
Narrative description of adaptation	Phased-in construction of vegetated berms along the downslope edges of the Crane Beach parking areas and turn-arounds (including the Town of Ipswich lot), tied into Argilla Road Adaptation Project to prevent storm surge from Castle Neck River and creek from inundating the parking lots and associated facilities. Flood-proof buildings at Crane Beach as a redundancy measure. Allow for storm surge accommodation zone south of Crane Beach Main Parking Area, and plan for managed retreat at the Dirt Road to Ferry to accommodate sea level rise. Implement flood-proofing measures at Longboat Barn (if necessary).
List of assets protected by adaptation	Crane Beach Main Parking Area Town of Ipswich Parking Area Parking Area Turnaround Dirt Road to Ferry Crane Beach Ranger Station – Gate Crane Beach Store and septic tank Crane Beach Bathhouse and septic tanks Crane Beach Maintenance Shed Longboat Barn Crane Beach cultural/archaeological points (3) Dune Shrub Thicket Red Maple Swamp Seabeach needlegrass habitat
Timeline of Adaptation	
Current action	Model waves to vet front-side dune intervention Flood-proof Longboat Barn (if necessary) Plan/design Dirt Road to Ferry retreat Plan/design initial berm implementation
By 2030	Assuming Argilla Road projects installed: Monitor, construct berm as necessary

Adaptation Planning Matrix	**Project #3: Crane Estate – Crane Beach Infrastructure Adaptation**
	Implement Dirt Road to Ferry retreat
By 2070	Assuming Argilla Road projects installed: Construct berm as necessary Monitor Dirt Road to Ferry, elevate as necessary
Range of Costs	Design/Permit: $225,000 Construction: $1,875,000 Note: above costs are for vegetated berms and do not include costs for building floodproofing or storm surge accommodation zone.
Adaptation Development Components	Modeling/Assessment: Wave run-up and overtopping study, survey

Table 6-4. Crane Beach – Argilla Road Adaptation

Adaptation Planning Matrix	**Project #4: Crane Estate – Argilla Road Adaptation**
General Description of the Site	Access road to Crane Beach
Overview of inundation probabilities (Map) 2030 and 2070	Fox Creek crossing: 2030: 5% - 50% 2070: 10% - 100% Limited tidal inundation by 2070 Castle Neck Creek crossings: 2030: 50% - 100% 2070: 100% Extensive tidal inundation by 2070
Overview of asset value (describe what makes the asset valuable)	Castle Hill and Crane Beach are important recreational and cultural resources that generate significant revenue. Argilla Road is the only access road for both properties.
Site overview (aerial photo) with markup of conceptual adaptation	See "Crane Estate Resiliency Project" map
Narrative description of adaptation	Elevate low-lying segments of Argilla Road crossing Castle Neck Creek and Fox Creek, and resurface with permeable paving.
List of assets protected by adaptation	Argilla Road
Timeline of Adaptation	
Current action	Plan/design
By 2030	Elevate segments crossing Castle Neck Creek
By 2070	Elevate segments crossing Fox Creek
Range of Costs	Design: $110,000 Permit: $30,000 Construction: $900,000
Adaptation Development Components	Modeling/Assessment: Survey

Table 6-5. World's End – Access Adaptation

Adaptation Planning Matrix	**Project #5: World's End – Access Adaptation**
General Description of the Site	World's End access road (Martins Lane) and carriage road (The Bar) connecting the drumlins.
Overview of inundation probabilities (Map) 2030 and 2070	Martins Lane: 2030: 0% - 20% 2070: 25% - 50% The Bar: 2030: 50% - 100% 2070: 50% - 100%
Overview of asset value (describe what makes the asset valuable)	World's End is an important recreational and cultural resource, as well as a natural resource within a heavily urbanized area. Martins Lane is the only access road to the property. The Bar is the only access to the northern drumlins which represents nearly one third of the total area of the property. The landscape on both drumlins was designed by Frederick Law Olmstead.
Site overview (aerial photo) with markup of conceptual adaptation	See "World's End Resiliency Project" map
Narrative description of adaptation	Construct a raised berm with flanking living shorelines along The Bar to protect The Neck Carriage Road from further erosion and potential future inundation. As needed in future, reconstruct Martins Lane sea wall to be a modular seawall with fronting living shoreline.
List of assets protected by adaptation	Martins Lane and access to property The Bar and access to northern drumlin
Timeline of Adaptation	
Current action	Construct berm and living shoreline at The Bar
By 2030	Monitor bank erosion on drumlins and implement bank stabilization projects as needed
By 2070	Monitor Martins Lane, rebuild seawall as needed Monitor bank erosion on drumlins and implement bank stabilization projects as needed
Range of Costs	Design/Permit: $125,000 Construction: $900,000 Note: above costs are for berm / living shoreline and do not include costs for seawall or coastal bank stabilization.
Adaptation Development Components	Modeling/Assessment: Coastal processes study (wave, sediment transport, shoreline change), survey

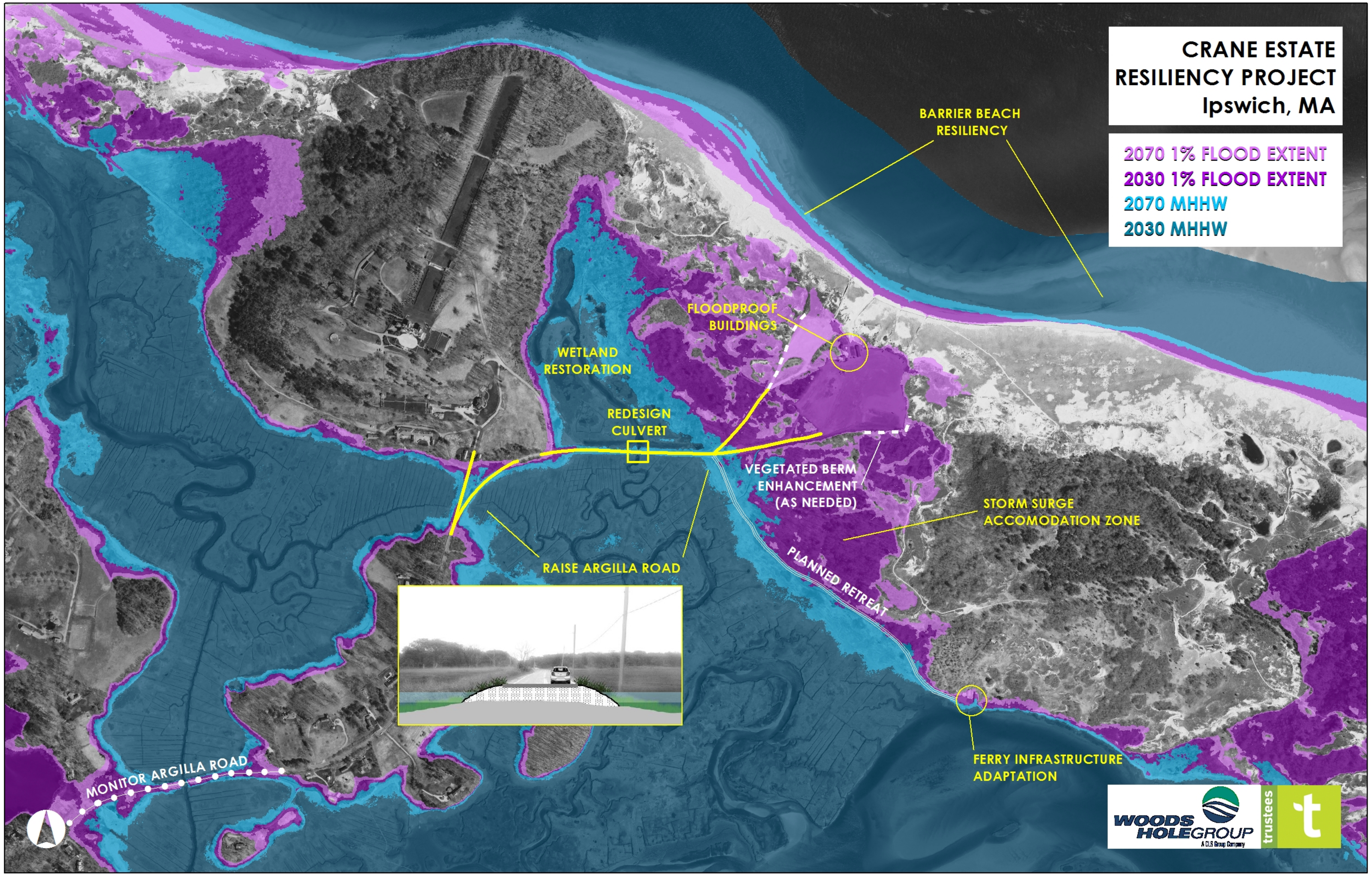

Figure 6-1. **Crane Estate Resiliency Projects**

Figure 6-2. World's End Resiliency Project

7.0 RECOMMENDATIONS – NEXT STEPS

This project is innovative in its reach and expansion to non-infrastructure assets. The Trustees is positioned to be a leader in regard to regional vulnerability assessment and, importantly, planning to maximize protection and mission goals. There are opportunities to expand collaboration with Towns, academia, the state and other non-profits with a leadership role to leverage nature-based adaptations to climate vulnerabilities.

With knowledge of climate vulnerability of over 2,000 assets across 32 coastal properties and conceptual adaptation plans for the most valued and vulnerable properties, the Trustees are now considering what the next steps should be. Given that not every vulnerability can be managed or may even need to be managed, the next steps focus on developing and/or enhancing monitoring programs to track change and update the modeling and developing outreach focused on sharing the data and analyses within and outside of the Trustees networks. Each is discussed in more detail below.

7.1 MONITORING PROGRAMS AND MODEL UPDATES

Monitoring programs should be established to track vulnerable assets through time, identify critical thresholds for intervention, and provide data to justify any proposed adaptation projects. They provide an interim step that the Trustees can take to build a database on the status of vulnerable assets/properties that may not require adaptation in the near term. The programs can also inform planned adaptation work. For example, the advance modeling work can be made more efficient with current monitoring data. While monitoring programs and impact thresholds would typically be customized to the asset or property, a general framework is provided below along with typical metrics for analysis.

In general, a tiered framework should be implemented for monitoring Trustees' vulnerable assets. Assets for monitoring should be identified by CVI score (above some threshold to be determined) and tiered by anticipated impact time horizon. Assets with high CVIs in the near-term should be monitored more frequently than those with longer-term impacts. Additionally, the frequency of monitoring should be consistent with the anticipated frequency of impact (e.g. beaches change more frequently than wetlands).

Developing a baseline of asset conditions for these vulnerable assets, as well as identifying relevant thresholds of change, will be critical for prioritizing and planning adaptation interventions on an organization-wide basis, as well as for providing evidence to regulatory agencies demonstrating the need for action. Depending on the asset, baseline information could be developed either from existing (statewide or regional) datasets or from site-specific surveys. It would also be useful to leverage the baseline information to track (via property manager or volunteer reporting) the frequency and intensity of impacts over time. Such a database could refine prioritization over time.

Metrics to be monitored for Trustees' assets include:

Beach

- Shoreline position (historical data, survey or remote sensing)
- Shoreline change transects (historical data to focus on hotspots, supplemented by shoreline position monitoring)
- Elevation profile (survey or remote sensing)

Dune

- Toe of dune position (survey or remote sensing)
- Edge of vegetation position (survey or remote sensing)
- Elevation profile (survey or remote sensing)

Coastal Bank

- Toe of bank position (survey or remote sensing)
- Top of bank position (survey or remote sensing)
- Elevation profile (survey or remote sensing)

Marsh

- Extent of marsh (existing data, survey or remote sensing)
- Extent of vegetation communities (existing data or survey, potential for remote sensing)
- Elevation of marsh platform (survey or remote sensing)
- Position of channel (survey or remote sensing)

Trails

- Develop critical water surface elevations and monitor property-specific water levels
- Track inundation and erosion events (manager/volunteer reporting)

Roads

- Develop critical water surface elevations and monitor property-specific water levels
- Track inundation and erosion events (manager/volunteer reporting)

Parking

- Develop critical water surface elevations and monitor property-specific water levels
- Track inundation and erosion events (manager/volunteer reporting)

Buildings

- Develop critical water surface elevations and monitor property-specific water levels

Other Infrastructure

- Develop critical water surface elevations and monitor property-specific water levels

Using the monitoring data and the project GIS library of vulnerability map layers, the Trustees are encouraged to revisit and reflect on the consequence scoring process. Also, model inputs reflect the data available at any given time. Updating the model every 5-10 years is also recommended and may be focused on specific areas of concern.

7.2 OUTREACH

In addition, this analysis and process are well-suited to developing outreach programs for specific properties, schools and communities and to communicate this information in new ways. For example, Trustees could:

- Incorporate vulnerability/adaptation information into Trustees communications, “Places” webpages, printed and on-line trail maps, and Go Trustees mobile application;
- Develop a keyword on webpages to enable properties to be searched by vulnerability to SLR and storm surge;
- Develop events and programming related to vulnerability/adaptation, including climate-related tours, exhibits, and lectures, as well as expansion of climate-related installations of “Art & The Landscape”;
- Develop “Explore On Your Own” programming related to vulnerability/adaptation to encourage visitors to engage on these issues; and/or,
- Create volunteer opportunities to monitor vulnerable assets and climate indicators, potentially develop a citizen science app to encourage the collection of these data.

Outreach to academic institutions could also benefit the process. For example, given that a subset of the vulnerable properties are small, isolated and fragmented salt marsh parcels, there is an opportunity to explore innovative adaptations and monitoring programs. These properties could be proving grounds, or adaptation laboratories for new approaches that could eventually, if proven, be scaled up to larger properties. For example, there is a potential collaboration with UNH proposed to evaluate an innovative use of salt grasses to manage subsidence in the wetlands around Castle Hill.

As Trustees scientists and planners explore this data further and gain a better understanding of which habitats and species are vulnerable, there will be opportunities to not only manage habitats within and across Trustees properties, but prioritize acquisitions to maximize diversity, protect unique habitats, encourage stability and achieve long term conservation goals. Trustees could focus future strategic acquisitions on areas that can either maintain or transition to the habitats and landscapes that are at risk on other properties. Managers could also identify properties (or portions of properties) that may serve as climate refugia, and develop management plans to encourage these conditions.

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