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Integrated Analysis of the Value of Wetland Services in Coastal Adaptation; Methodology and Case Study of Hampton-Seabrook Estuary, New Hampshire

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Project Title - Integrated Analysis of the Value of Wetland Services in Coastal Adaptation; Methodology and Case Study of Hampton-Seabrook Estuary, New Hampshire

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Project Goal - Integrated assessment of economic and social values of wetland ecosystem services in urban adaptation to coastal climate change

Geographical Location of Study - Hampton, Seabrook, Hampton Falls, NH

Partners
Seabrook Hampton Estuary Alliance (SHEA) – Local non-governmental organization with mission “to protect the coastal and aquatic resources and preserve the Seabrook-Hamptons Estuarine System through Education, Community Outreach, and Research.”
Decision-makers(s)/End User(s) – Towns of Hampton, Seabrook, Hampton Falls

Matching Funds/Leveraging
Two hydrodynamic models of flooding were used – one from Advanced Environmental Modeling Service (AEMS), Dartmouth MA and one from the University of New Hampshire (UNH). The AEMS model and much of its data are part of the surge flood warning system for the Estuary, which is partially sponsored by NOAA. The UNH model development was funded by NOAA Coastal Resilience Project primary award number NA16NOW47300013 with subaward (A007-004) to UNH through the Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS). The implementation to the Hampton-Seabrook Estuary (HSE) was funded under this grant.

We built off of the SLAMM modeling sponsored by NH Fish and Game that was done for the NH coast. We also benefited from concurrent studies of the ecology and resilience of dune systems and local policy and management funded by NOAA through NH Sea Grant NA (award number NA14OAR4170083) and the NH Coastal Program of the NH Department of Environmental Services (award number NA13NOS4190042).

Through the PI, we are also interfacing with the NSF Research Collaboration Network (RCN) for Science, Engineering and Education for Sustainability (SEES) Project “Sustainable Adaptive Gradients in the Coastal Environment (SAGE): Reconceptualizing the Role of Infrastructure in Resilience” and the NOAA COCA grant to UMass Boston which started in Summer 2016, “Improving the Environment while Protecting Our Coasts: A Holistic Accounting of Ecosystem Services of Green Infrastructure and Natural and Nature-Based Features (NNBF) in an Urbanized Coastal Environment.”

Research Objective
Our research objective is to carry out an integrated assessment of the economic and social values of wetland ecosystem services as part of adaptation strategies to coastal climate change, specifically sea level rise and associated increases in erosion and coastal flooding.

Research Approach and Methodology
The work was carried out in three communities on the Hampton-Seabrook Estuary (HSE), New Hampshire; Hampton, Hampton Falls, and Seabrook. The HSE is an approximately 8 mile long barrier beach system with extensive back-barrier tidal wetlands. An inlet conducts tidal waters into and out of the estuary and drains the upland areas of this coastal watershed. The inlet is narrow (about 1000 feet across) and shallow (about 20 feet), and consists primarily of coarse grained sands in the center channel and progressively finer sediments to the banks. The sediment transport is high in the inlet and back bay, requiring regular dredging to maintain the navigation channels (Kedzierski, 1993; PDA, 2013). The mouth is characterized by a north jetty that extends about 0.2 miles into the ocean, and a half-jetty to the south side that is overtopped at high tides. Ocean waves are important to the sediment transport along the adjacent Hampton and Seabrook beaches, but are attenuated near the mouth by strong refraction away from the main channel and wave breaking over rocky outcrops offshore of the mouth and along the south side of the inlet. Inside the back bay, the wave field is generally small owing to the narrow inlet and limited fetch and thus surface wave velocities do not contribute to the circulation in the estuary.
Much of the barrier beach is densely developed with residential, tourist and commercial facilities and buildings; it is a major economic engine for New Hampshire. There is also less densely developed residential and commercial buildings on the peninsulas of the uplands and filled wetlands extending into the tidal wetlands and along the western border of the estuary, particularly in Hampton Falls. Parts of the region are already prone to coastal flooding and vulnerability will increase in the future due to SLR.

The Towns of Hampton and Seabrook all depend on the large tourism industry that is perched on a barrier system protecting the Estuary. The beach communities are particularly vulnerable to storm surges and rising sea levels, with portions of Hampton currently experiencing nuisance, or fair-weather flooding from spring tides. The choices made by these two communities and the residents and businesses composing them can have far-reaching effects on their safety, economy, quality of life and may differentially affect more socially-vulnerable portions of the communities. Inaction could result in devastating storm impacts that has the potential to destroy these communities. Engineering approaches that only use hard structures or grey solutions may weigh the communities down with severe debt, result in long term damage to the environment and degrade the charm and attractiveness of the area to tourists. On the other hand, allowing over-wash and marsh migration everywhere will reduce the number of people and tourists that benefit from the beaches and dunes, shellfish flats, marinas, fishing and marshes. Through hydrodynamic, social and habitat modeling and mapping, we have examined potential impacts and changes due to storms and sea level rise on the HSE and barrier beach complex (socio-economic-ecological system) and management approaches.

There is also evidence of flooding in the area by extreme precipitation and higher groundwater levels. Any management strategies for SLR and coastal flooding must also consider these threats, which were not examined in this research.

Tidal and storm surge flooding was modeled using a dynamic storm surge model known as FVCOM (http://fvcom.smast.umassd.edu/FVCOM/) under present and plausible sea level conditions. FVCOM requires the area to be discretized into a series of coastal grids. Within each grid and each flood event, the depth and velocities of flooding are calculated. Another NOAA project in the region is the application of the Sea Level Affecting Marshes Model (SLAMM) to predict the impacts of SLR on wetlands extent and composition along the NH coastline, including HSE. SLAMM is a software tool that divides coastal wetlands into grid of associated elevation and wetland categories established by the National Wetlands Inventory. As SLR occurs, it simulates the changes in the wetland characteristics and elevations. SLAMM models the processes of inundation, erosion, overwash, saturation, and accretion. We are combining these existing modeling efforts with integrated adaptation analysis to evaluate potential changes in wetland ecosystem services.

We determine the net benefits of integrating ecosystem services into adaptation for the HSE and their effectiveness using the following approach. The changes in the states of the wetlands and the barrier beach are determined under present and future conditions with a SLR of 0.73 m (subsidence is negligible in the area). This SLR is possible as early as 2060 or as late as the end of the century. The resulting changes in flooding that occur from these changes are determined
by running FVCOM with storms of various exceedance frequencies (e.g., the 10, 100, and 1000 year storms, where, for example, the 10 year storm is the storm resulting in a surge height that is equaled or exceeded with a probability each year of 0.10). The changes in the wetland categories are predicted by SLAMM. These steps determine the damages to the social, natural, and built environments from flooding if no adaptation is undertaken. An adaptation strategy and one variation of it are then evaluated focusing on preservation of the socio-economic systems of the barrier beach systems.

The economic damages to the built environment are measured by the expected discounted present value of the damages over the period from the present (assumed to be 2015) to 2060 for the associated no-action and adaptation strategies. Both the economic and social analysis are done at the scale of US Census Block Groups.

The determination of social impacts involves conducting a social impact assessment (SIA) and developing a social vulnerability index (SVI) for the area pertaining to the impacts of climate change on wetlands. SIA, a process that has been widely used in international settings, includes the processes of analyzing, monitoring and managing the social consequences, both positive and negative, of proposed plans, policies, and projects. Social vulnerability is defined as the susceptibility of a given population to harm from exposure to a hazard, directly affecting its ability to prepare for, respond to, and recover from extreme climate events. Social vulnerability is a function of diverse demographic and socio-economic factors that influence a community’s sensitivity to climate change. Studies show that social variables, such as age, race, and income affect the ability of an individual to prepare for, respond to, and recover from a natural disaster or other potential climate impacts. We identify and map a range of factors contributing to social vulnerability to climate change in the HSE. We engaged intensely throughout the process with the Seabrook-Hamptons Estuary Alliance (SHEA), a locally influential citizen group to obtain feedback on results. Other local organizations were also consulted.

The task descriptions are below.

Task 1. Understand present impacts of coastal flooding upon wetlands, and built and social systems.

Task 2. Using SLAMM and FVCOM, determine the changes in barrier beach and wetlands over time with climate change assuming no adaptation actions and the associated social and economic impacts.

Task 3. Working with stakeholders, develop adaptation actions in time and space to be implemented by public and private organizations.

Task 4. Evaluate impacts of Strategies.

Task 5. Dissemination of Results.
Accomplishments - Research Findings

The present impacts from coastal storms and high tides grow significantly over time due to SLR even over the relatively short period to 2060. Hydrodynamic model simulations of storm surge with and without sea level rise scenarios show that although flooding and inundation increases with increasing subtidal forcing and higher sea level, dissipation of the tide and storm surge in the estuary channel somewhat limits the maximum inundation that might otherwise be expected in the back marsh areas.

The estuary is dominated by high marsh, which lies high in the intertidal zone. By 2060 it will convert to mostly low marsh unless it can build very rapidly (greater than 5 mm/year). The marsh supports fisheries and many charismatic birds, some marsh dependent, and provides a culturally significant view-scape across the estuary. The Sea Level Affecting Marsh Model (SLAMM) was used to predict habitat changes due to 0.73 m SLR by 2060 under different accretion rates and levels of protection for developed areas that became intertidal. Although the relative amounts of high marsh and low marsh varied dramatically, the overall marsh area remained within 5% of the current levels and mostly increased if marsh accretion rates exceeded 2 mm/year. Limited areas of intertidal flats supporting shellfish presently exist, but in the near future these culturally important recreational shellfishing areas will convert to open water. However, areas that are currently low marsh will drown and may provide future shellfishing areas. The open water harbor is important for boating, access to coastal waters, and recreational fishing. Currently, the open water area is small, but may double in size by 2060 and the greater tides relative to the marsh elevation will create a different feel for the estuarine landscape in the future because high tides regularly will cover larger areas of the marsh with seawater.

Outside of the estuary on the oceanfront, beaches and dunes support tourism and intensive recreational use as well as federally protected nesting shorebirds (piping plover, least tern). Most of the outer beach is exposed to Gulf of Maine waters. Where there are existing floodwalls, rising sea levels will worsen the storm danger and damage to the integrity of the walls. Unless walls are raised, storms will also transport massive amounts of beach sediments over the walls and across the barrier system. Beaches will have less width and steep ramping to the walls will severely decrease the value of the beach for tourism. In areas with dune systems, very little change is predicted because the dynamic equilibria of the dune-beach system will allow the beach to build in elevation as sea level rises and the wind-driven dune building will continue. Bedrock outcrops (at Plaice Cove, Great Boar’s Head and the inlet) help reduce landward erosion.

The socio-economic impacts result in more people flooded as sea level rises, particularly of socially vulnerable populations, and more anchor institutions flooded. Residents presently living in the most socially vulnerable census blocks were 8.6 times more likely to be located in the flood zone, compared to those living in blocks with low social vulnerability. Under climate change, census blocks with high percentages of the population living in poverty were 17.7 times more likely to be located in the flood zone. This analysis more likely reflects the winter/spring population than the summer population.

The estimated annual expected value damages from surge flooding to buildings and contents in the present are approximately $0.90 M. In 2060 with SLR they are $4.8 M. Using a 7 %
discount rate, the present expected value of these damages between 2018 and 2060 is approximately $27 M. There are many sources of possible error in this value due to missing data, and exclusion of damages to infrastructure, human mortality and morbidity, lost business (particularly recreation), and other cascading and multiplier events. We also do not include the value of ecosystem services.

The adaptation goal focused on protecting the socio-economic systems of the barrier beach areas. Engineering approaches that only use hard structures or grey solutions may weigh the communities down with severe debt, result in long term damage to the environment and degrade the charm and attractiveness of the area to tourists. On the other hand, allowing over-wash and marsh migration everywhere will reduce the number of people and tourists that benefit from the beaches and dunes, shellfish flats, marinas, fishing and marshes.

Because marshes of limited area do not significantly decrease storm surge and there is limited wave activity on the western, inland side of the barrier beaches, the marshes may not directly contribute to reducing the flooding on the western side of the barrier beaches. Regional solutions such as building a berm or a floodwall (smaller footprint limits direct marsh losses) to limit land loss can be employed but will prevent some marsh migration. Individual site flood management actions such elevating buildings must also be employed there.

The most expensive adaptations are needed on the coastal side where the beach-dune system has been replaced by an armored shoreline (seawalls) designed for pedestrians and automobiles, but not beach-goers. These walls need to be fortified; their expansion opens an opportunity to provide alternate transportation pathways that are safe (bike lane), green space, and a more attractive promenade (increasing ecosystem services for residents and visitors). The beaches need to be nourished to provide sandy areas at high tide (especially in the northern areas) to better support the tourism industry. Oceanfront without walls or dune systems are especially vulnerable and could benefit from green adaptation solutions that construct and maintain sacrificial dunes at relatively low cost. Residential areas landward of existing dune fields were deemed the best protected and only required low cost adaptation decisions (e.g., building sand barriers at beach access cuts and maintaining dune health).

Heavily used roads that cross marshes on causeways will need to be raised. Although more expensive, roadways elevated above the marsh surface will reduce impacts from direct filling and provide better tidal exchange. Thus throughout the HSE, there are limited reasonable green options for coastal flood management.

The present value adaptation costs in 2018 including capital and maintenance costs discounted at 7 % is approximately $149 M. This adaptation cost is more than the previously estimated damage avoided cost or benefit of $27 M. Because, as noted earlier, this benefit estimate is significantly underestimated due to data and methodological limitations, we cannot really determine whether this project is cost-effective. A lower discount rate would also increase it cost-effectiveness.

Adaptation would mitigate some of the direct impacts to social vulnerable populations, but in some areas would require their investing in the protection of their individual residents instead of
being part of a possibly less costly regional solution. The adaptation plan could provide important public health benefits through the addition of the green elevated walkway (in place of current parking spaces) along the floodwall.

We met with several local non-governmental (NG) and mixed governmental and NG organizations over the research lifetime—one quite regularly over the grant lifetime. They generally support our findings. One possible troubling possibility is that 75% of respondents of one relatively small, but representative, sample agreed that convincing residents to support flood protection measures that may benefit home-owners in the flood zone, at the perceived ‘expense’ of those residents who do not live in the flood zone, is a significant challenge to municipal adaptation planning and emergency preparedness. In response to the statement, “Residents generally would be receptive to implementing the green/gray strategies presented”, 43% disagreed, 14% were neutral, and 43% agreed.

Our findings will also inform several state-level planning, policy, and programmatic initiatives.

As described above, the marshes themselves are not major contributors to present and future flood protection in the area. They are, of course, valuable for other reasons. Examples include habitat, runoff treatment, recreation, tourism, and carbon storage. An estimate of the annual values of these services in HSE are approximately $370 M under present and future SLR conditions. Thus their preservation should be a priority.

We did qualitatively consider wave impacts and changes in geomorphology, but decided that it would be highly unlikely for the general shape and function of the barrier system to change over the study period (2060) assuming the seawalls are maintained at elevations relative to SLR. We did not consider impacts from changes over time to extreme precipitation, groundwater levels, other stresses on marshes besides SLR, and changes in demographic characteristics such as summer tourists, second-home owners, and other factors over time.

**Accomplishments - Outreach and Communication Activities**

Over the study period, we regularly dialogued with the Seabrook Hamptons Estuary Alliance (SHEA), a stakeholder group representing the combined needs of the three communities for collaborative planning purposes. Approximately twice per year, we presented project updates and interim results at their regularly scheduled meetings. SHEA provided invaluable input as the project evolved, infusing local knowledge, and ensuring that findings were ground-truthed and that study activities aligned with current town/regional priorities.

For example, on May 24, 2017, we presented preliminary versions of maps and products to SHEA. It was noted that several community-identified anchor institutions and community assets will be flooded and that socially vulnerable populations will be more likely to reside in flood zones. Disparities may grow as populations age (notably, New Hampshire expects the elder population over age 65 to double by 2040, and 30% of this population is expected to have disability). Poverty may become more concentrated, in part due to lack of affordable housing options. Several SHEA members raised concerns about flooding from freshwater to the west of the estuary, and the need to preserve the beach as it is the economic engine for HSE because it provides considerable tax revenue to the towns, eg, as much as 70% of taxes to Hampton.
Revenue from the beach also adds to the state’s budget. Another SHEA member stated the importance of also protecting fishing and ecosystems. This sentiment had been voiced multiple times by residents at various SHEA meetings.

At a meeting with SHEA on January 24, 2018, we presented the preliminary green and grey adaptation options. SHEA members commented that these options are major actions but are necessary if some of the major residential, recreational, and economic activities in HSE are to function in the future. Financing of options was also discussed as a need. They recommended meeting with Selectmen and Planning Boards of the three towns in the future to discuss results.

Our team also presented findings at several important state and national public health meetings, including a presentation to the National Council of State and Territorial Epidemiologists Disaster Preparedness Subcommittee in February, 2017. Other activities are described in subsequent section on Accomplishments - Measuring Impact on Decision-Making.

Accomplishments - Measuring Impact on Decision-Making
The major needs of the decision-makers in the three towns related to this grant pertain to the management of present and growing coastal flooding. We are presently interfacing with the three towns through SHEA. Our results to date have so far only reinforced their experience in the estuary – which is an important ground-truth for our research. We also discussed some preliminary reactions to adaptation strategies with SHEA, and gathered feedback using a modified Q Sort Survey (see Accomplishments-Deliverables). We also met with members of the NH Coastal Adaptation Workgroup in April, 2018 to discuss in more detail their reactions to the adaptation strategies. We will make ourselves available to meet with Selectmen and Planning Board members in the future as needed. Although we have not yet developed indicators of effectiveness, our entire process aligns with a Health Impact Assessment framework that enables the current research findings to serve as a baseline for informing multi-sectoral decision-making and measuring change in various domains over time (e.g., environmental, social, economic, equity) (Boguszewski,2014; Brown, 2014).

Our findings will inform the following state-level planning, policy, and programmatic initiatives:

1) Upcoming NH Department of Transportation planning process for changes to Rt 1A
2) Ongoing Emergency Preparedness Planning initiatives through public health networks
3) Implementation of the NH Department of Health and Human Services Environmental Public Health Tracking grant; members of our study Team serve on the Technical Advisory Board for this initiative and provide regular updates at meetings (see Accomplishments-Deliverables section). Two state policy initiatives are being informed; HB511 (Establishes a commission to study environmentally-triggered chronic illness) and HB1356 (facilitates data sharing between the Departments of Environmental Services and Health and Human Services).
4) Ongoing dialogue with the Rockingham Planning Commission about various initiatives, including the High Water Mark Initiative (NH DES, 2017). The RPC is also working with Hampton, Seabrook, and Rye on their Community Rating applications and Floodplain Management Ordinances.
5) Providing input to the 2019 Community Health Needs Assessment (CHNA), a requirement under the Affordable Care Act that requires non-profit hospitals to conduct a
community health needs assessment every 3 years, including social and environmental hazards. Recent polls suggest that New Hampshire residents view healthcare providers as the most trusted source of information regarding environmental health concerns, underscoring the importance of educating/building capacity in this sector. (Bush, 2018).

Accomplishments - Deliverables produced
This section contains relatively detailed discussions of the research process and results – all deliverables. Eventually, this material will be incorporated into journal articles as well as more engagement with decision-makers.

1.0 Coastal Flooding

Model simulations for inundation and current velocities are accomplished with the Finite Volume Coastal Ocean Model (FVCOM; Chen, et al., 2003). FVCOM solves the primitive equations with hydrostatic pressure. Details of the model are provided in Chen, et al. (2003). In this work, we focus on the hydrodynamic component of the model that includes forcing from tides and subtidal (storm surge) water levels with and without sea level rise, and do not include wind-generated waves or surface wind stresses in the simulations. FVCOM discretizes the model domain into non-overlapping discrete unstructured triangular cells. Finest grid resolution near the shoreline and shallow areas is 30 meters. The data set was previously calibrated and verified by Chen. Simulations were first performed with the model to replicate historical flood events in 1997 and 2007 with and without SLR to determine the possible extent of flooding and to refine our analysis methodology.

Simulations were then conducted that spanned the tidal elevation approximately equal to the MHW datum for (1) present day sea level and no storm, (2) present day sea level and the 1% storm surge, (3) 2060 sea level projection of 0.73 meter with no storm, and (4) 2060 sea level projection of 0.73 meter with the 0.1%, 1%, and 10% storm surges - all synchronized with the tidal elevations associated with the Mean High Water datum. Water level hazard curves for tropical, extratropical, and the combined storms at North Atlantic Coast Comprehensive Study (NACCS; USACE, 2015) Save Pt. 2047 were computed based on the annual exceedance probability and this was used to select storms from the NACCS database that represents the subtidal forcing for the event that can be simulated with a hydrodynamic model. The resulting flooding in HSE under these conditions are in Figures 1.1-1.8.

Model simulations of storm surge with and without sea level rise scenarios show that although flooding and inundation increases with increasing subtidal forcing and higher stands of sea level, dissipation of the tide and storm surge somewhat limits the maximum inundation that might otherwise be expected. Maximum sea surface elevation of the modeled tides under present day sea level without storms shows minimal dissipation through the Hampton/Seabrook Estuary; however, with increased sea level the energy is strongly attenuated (by up to 20%) through the shallow, narrow sandy inlet, and is even greater (up to 40%) when storm surge is included. Average and maximum depth-integrated currents are shown to increase substantially by factors of 2-4 under storm surge both with and without sea level rise, and that currents are increase under sea level even without storm surge.
Figure 1.1- Mean High Water Flooding without SLR. Water depths deeper than 4 meters are assigned 4 m depth for display purposes.
Figure 1.2- Mean High Water Flooding with SLR. Water depths deeper than 4 meters are assigned 4 m depth for display purposes.
Figure 1.3 - 0.10 % Flood, no SLR
Figure 1.4 - 0.10% Flood with SLR
Figure 1.5 - 1 % flood with no SLR
Figure 1.6 - 0.1% flood with SLR
Figure 1.7 - 10 % Flood without SLR
Figure 1.8 – 10 % Flood with SLR

*Open water under normal tidal conditions appears dark.
2.0 Damage Costs of Flooding

As can be seen in Figures 1.1 and 1.2, there is not significant tidal flooding of the built environment at MHW either presently or with 0.73 m of SLR except in a few locations such as on Route 1, Winnicunet Road, and Route 286. With spring tide being 2 feet higher than MHW, more localized impacts are expected. Under MHW, however, there are no large scale cost impacts unless they result from poor surface water drainage and high groundwater tables – which we were not able to determine.

Surge flood damages to buildings and contents were based upon relationships from US Army Corps of Engineers (2003). Using data for local assessor’s offices, we assumed buildings were with 1 or 2 stories with no basements. If no information available on number of stories, we assumed 1 story. We only analyzed damages to residential and commercial buildings. Using the methods of Kirshen et al (2012), the estimated annual expected value damages in the present are approximately $0.90 M. In 2060 with SLR they are $4.8 M. Using a 7 % discount rate, the present expected value of these damages between 2018 and 2060 is approximately $27 M. There are many sources of possible error in this value; examples include the assessors’s databases missing 14 % to 33 % of building data in some census block groups (this was handled by dividing the damage estimates with the incomplete data by the percent of data not missing). In addition, only 2 building types were assumed. The damage estimate also excludes damages to infrastructure, human mortality and morbidity, and lost business and other cascading and multiplier events.

3.0 Adaptation Strategies

The goal of the adaptation strategy was to protect the high value economic activities of the built environment on the barrier beach with green and/or hybrid methods such that the functions of the coastal marshes were best maintained and cost and social impacts were managed. Therefore we examined a range of strategies to determine what might be most acceptable and their tradeoffs:

A. No adaptation actions including no autonomous actions
B. Hybrid – Green
C. Hybrid-Gray

Strategy A resulted in considerable flooding and damage to the built environment on the barrier beach as no adaptation actions taken. The impacts of this are analyzed in the above section and in subsequent sections.

Strategy B is shown in Figures 3.1-3.6 with the legend in Table 3.1. It is summarized in Table 3.2. Strategy C is the same as B except that the back-barrier berms in Hampton are replaced by floodwalls. This modification was made because the back-barrier berms require large footprints (see Section 5.0). We assumed floodwalls required minimal space; thus C allowed for the near-term existence of more marshes than B even though the landscape would be hardened more under C.
Educational displays and installations along the walkways in B and C could also be implemented. Studies have shown that public awareness of the ecosystem services provided by marshes are generally low (Burger, 2015), and stakeholders in the HSE also stated this as a concern. However, research has also shown that people who engage in outdoor recreational activities are more likely to value ecosystem services including dune protection, beach protection, and salt marsh protection (Burger, 2015). In the HSE, one way to raise public awareness could include providing educational displays and installations about the public health, safety, and economic co-benefits of the marsh along the elevated walkway proposed in Scenarios B and C. This could be done in conjunction with the High Water Mark Initiative which is already being implemented in the HSE to raise awareness about historical and future flooding and sea level rise. This approach has shown some success in prior studies (Larson et al. 2016).

We also considered evaluating an adaptation strategy of constructing a storm barrier across the inlet. This would be open at all times except during storms. This was concept was discarded because by blocking sediment from entering the inlet during storms, an important source of sedimentation to the marsh surface will be prevented and thus make adaptation more difficult. Studies in Louisiana indicate the important role of hurricanes, and by extension to our study, Northeasters, in salt marsh accretion (Turner et al. 2006, Smith et al. 2015). In addition, the oceanfront of the barrier beach in Hampton would still have to be protected, and Routes 1 and 286 would still need to be elevated to protect against flooding by normal high tides at sea levels 0.73 m higher than present day.

4.0 Cost Impacts of Adaptation

Unit costs of this option are in Table 3.2. As can be seen the total capital cost is approximately $320 M. Even though this underestimates the maintenance costs of beach nourishment, it is assumed that all maintenance costs are 1 % of the capital costs. It is further assumed that the system is built over time in the periods of 2020, 2030, 2040, and 2050 with capital costs in each period of $80 M. The present value costs in 2018 including capital and maintenance costs discounted at 7 % is approximately $149 M. This adaptation cost is more than the previously estimated damage avoided cost or benefit of $ $27 M. Because, as noted earlier, this benefit estimate is significantly underestimated due to data and methodological limitations, we cannot really state this project is not cost-effective; it actually may be cost effective. A lower discount rate would also increase it cost-effectiveness.

Green – Back-barrier berms
White- Areas provide own strategy such as elevation or retreat – must be above at least 10 ft NAVD88
Black- Elevated Road
Blue – Elevated Road on piers or culverts
Gold – Soft hardening by dune building and maintenance
Red – Existing Floodwall with elevated walkways on vegetated green strips so public can see over walls
Magenta – Critical Infrastructure to protect or relocate
Orange – Living Shoreline
Table 3.1 - Legend for Adaptation Strategy B

<table>
<thead>
<tr>
<th>Seabrook East</th>
<th>Notes</th>
<th>Unit Cost (from NACCS(2015))</th>
<th>Length (ft)</th>
<th>Capital Cost</th>
<th>Capital Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold - Soft hardening by dune building and maintenance</td>
<td>First cost @$4500/ft, then renourishment each 4 years @ $1200/ft</td>
<td>8446</td>
<td>30</td>
<td>23556000</td>
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<td>Block - Elevated Road</td>
<td>Route 1A</td>
<td>from Acct. (2013) 50% of cost of mixed highway and floodwall in urban area, 0.5 x $10000/ft</td>
<td>8448</td>
<td>89</td>
<td>88734000</td>
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<td>Mosquito - Critical Infrastructure to protect or relocate</td>
<td>Floodproof pier building</td>
<td>Estimated cost @ $190,000 for 1400 ft building</td>
<td>3 buildings</td>
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<td>Orange - Living shoreline</td>
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<td>$415/ft</td>
<td>500</td>
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<th>Length (ft)</th>
<th>Capital Cost</th>
<th>Capital Cost</th>
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<tbody>
<tr>
<td>Gold - Elevated Road on piers or curvets</td>
<td>Route 286 receptor treatment plant</td>
<td>from Acct. (2013) 50% of cost of mixed highway and floodwall in urban area, 0.5 x $10000/ft</td>
<td>6336</td>
<td>67</td>
<td>66528000</td>
</tr>
<tr>
<td>Mosquito - Critical Infrastructure to protect or relocate</td>
<td>Elevate Pud</td>
<td></td>
<td>1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wall Pint</td>
<td>perimeter @ $5000/ft (T wall)</td>
<td>2000</td>
<td>10</td>
<td>10000000</td>
</tr>
<tr>
<td>White - Areas provide own strategy such as elevation or retreat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>North of Seabrook</th>
<th>Notes</th>
<th>Unit Cost (from NACCS(2015))</th>
<th>Length (ft)</th>
<th>Capital Cost</th>
<th>Capital Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold - Soft hardening by dune building and maintenance</td>
<td>First cost @$4500/ft, then renourishment each 4 years @ $1200/ft</td>
<td>8376</td>
<td>14</td>
<td>14561600</td>
<td></td>
</tr>
<tr>
<td>Red - Existing Floodwall with elevated walkways on vegetated green strips so public can see overwalls</td>
<td>assumed to be same as levee @ $1600/ft</td>
<td>8336</td>
<td>13</td>
<td>13237600</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hampton West</th>
<th>Notes</th>
<th>Unit Cost (from NACCS(2013))</th>
<th>Length (ft)</th>
<th>Capital Cost</th>
<th>Capital Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold - Soft hardening by dune building and maintenance</td>
<td>First cost @$4500/ft, then renourishment each 4 years @ $1200/ft</td>
<td>2600</td>
<td>9</td>
<td>990000</td>
<td></td>
</tr>
<tr>
<td>Red - Existing Floodwall with elevated walkways on vegetated green strips so public can see overwalls</td>
<td>assumed to be same as levee @ $1600/ft</td>
<td>3600</td>
<td>39</td>
<td>37800000</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hampton East</th>
<th>Notes</th>
<th>Unit Cost (from NACCS(2015))</th>
<th>Length (ft)</th>
<th>Capital Cost</th>
<th>Capital Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue - Elevated Road on piers or curvets</td>
<td>Route 1</td>
<td>from Acct. (2013) 50% of cost of mixed highway and floodwall in urban area, 0.5 x $10000/ft</td>
<td>3000</td>
<td>32</td>
<td>31500000</td>
</tr>
<tr>
<td>Mosquito - Critical Infrastructure to protect or relocate</td>
<td>Estimated cost @ $190,000 for 1400 ft building</td>
<td></td>
<td>1</td>
<td>750000</td>
<td></td>
</tr>
</tbody>
</table>

| White - Areas provide own strategy such as elevation or retreat | | | |

<table>
<thead>
<tr>
<th>North of Hampton</th>
<th>Notes</th>
<th>Unit Cost (from NACCS(2013))</th>
<th>Length (ft)</th>
<th>Capital Cost</th>
<th>Capital Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold - Soft hardening by dune building and maintenance</td>
<td>First cost @$4500/ft, then renourishment each 4 years @ $1200/ft</td>
<td>2600</td>
<td>9</td>
<td>990000</td>
<td></td>
</tr>
<tr>
<td>Red - Existing Floodwall with elevated walkways on vegetated green strips so public can see overwalls</td>
<td>assumed to be same as levee @ $1600/ft</td>
<td>3600</td>
<td>39</td>
<td>37800000</td>
<td></td>
</tr>
<tr>
<td>White - Areas provide own strategy such as elevation or retreat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Total ($ millions) | 328 | 313.8327 |

Table 3.2 – Summary and Costs of Adaptation

Strategy C - Hybrid –Gray
This option differs from Strategy B in that the back barrier berms in Hampton are replaced by narrower floodwalls.

Cost Impacts
The floodwalls cost $5300/foot (NACCS, 2015). The berms were estimated to cost $1600/foot. This replacement changes to total cost from $320 M to $353 M. If these costs are allocated in the same manner as Option B, the total present value cost is $164 M.
Figure 3.1 - Seabrook East

Figure 3.2 - Seabrook West
Figure 3.3 - North of Seabrook

Figure 3.4 - Hampton East
Figure 3.5 Hampton West

Figure 3.6 - Hampton North
5.0 Environmental Impacts and Ecological Services

Environmental Results. Hampton Seabrook Estuary is shallow embayment characterized by extensive salt marshes and protected by barrier systems extending from Hampton to Salisbury, Massachusetts. Three towns in New Hampshire (Hampton, Hampton Falls and Seabrook) and one in Massachusetts (Salisbury) have lands in the estuary and barrier beaches. Each town but Hampton Falls have portions along the barrier beaches where intense development and tourism is concentrated and these towns depend on the economic benefits of tourism. The physical environment and management of the outer beach and inlet are dramatically different compared to the Estuary, so the discussion of our results (examining habitat changes by 2060 with 2.4 feet of sea level rise), will be split into two parts: oceanfront and estuary.

Estuary: Salt marshes and intertidal flats developed in the shallower portions of the estuary over the past 4,000 years during which time sea level has risen approximately 4.6 m (15 feet), based on the geologic record here (Keene 1971) and elsewhere in the region (Redfield 1972, Kelley et al. 1995). Because sea levels rose at a slow pace, about 1.1 mm per year (Keene 1971), salt marshes built several meters thick and formed a wide plain about the elevation of mean higher high water and cut by tidal channels. The largest channels conducting the tidal flow and land drainage are sub-tidal (e.g., Hampton River, Blackwater River). The original valleys cut by rivers following the last ice-age have mostly been filled in by salt marshes because the system was exposed to greater flooding as sea levels rose to produce this scenic estuary.

We have installed six benchmarks for the Surface Elevation Table (SET) to provide current measures of salt marsh building in this Estuary since 2013 (Figure 6.1). By 2016, marsh building was estimated at 1.71 mm/year and this value was used as a base rate for the marsh modeling (SLAMM). Subsequently, sediment additions to the marsh surface have averaged 2.49 (+/-0.15) mm/year (2013-2017) and overall marsh building has averaged 2.26 (+/-0.15) mm/year. Marsh peat decomposition and subsidence can be calculated as the difference between these two values: 0.25 mm/year. To simplify our discussion, we will refer to all marsh building as accretion, even though we recognize actual accretion may be slightly greater to offset peat decomposition and subsidence below the surface of the marsh. The marsh building data alone cannot indicate how well the marsh is keeping up with increases in sea level, current sea level trends for 2013 to 2017 are needed for comparison and they are typically unavailable until several years after the period of record.
Figure 6.1 - Salt marsh building at six locations in the Hampton Seabrook Estuary.

Each component of the estuary has an important role to play in the health of the system and support of human populations that live and visit the area. Tidal channels and rivers convey the tides and drain surface and groundwaters. They provide travel paths for aquatic organisms including all kinds of fish, from small forage fish (mummichog, sticklebacks and menhaden) to anadromous species (herring, white perch, shad) to recreational marine species (striped bass, bluefish). The intertidal flats support shellfish beds such as soft-shell clams, a recreational fishery, and mussel beds. Salt marshes have a particularly wide array of values to adjacent communities, ranging from important habitat, support of food webs and biodiversity, erosion control, dampening storm surges, nutrient cycling and carbon storage (Table 6.1).
**Table 6.1 - Functions and Values of salt marsh (from Short et al. 2000).**

<table>
<thead>
<tr>
<th>Number</th>
<th>Functions</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Primary production</td>
<td>Support of food webs, fisheries and wildlife</td>
</tr>
<tr>
<td>2</td>
<td>Canopy structure</td>
<td>Habitat, refuge, nursery, and settlement; support of fisheries</td>
</tr>
<tr>
<td>3</td>
<td>Organic matter accumulation</td>
<td>Support of food webs, counter sea level rise</td>
</tr>
<tr>
<td>4</td>
<td>Seed production/vegetative expansion</td>
<td>Maintenance of plant communities and biodiversity</td>
</tr>
<tr>
<td>5</td>
<td>Sediment filtration and trapping</td>
<td>Counter sea level rise, improve water quality, and support of fisheries</td>
</tr>
<tr>
<td>6</td>
<td>Epilithic and benthic production</td>
<td>Support of food web, fisheries and wildlife</td>
</tr>
<tr>
<td>7</td>
<td>Nutrient and contaminant filtration</td>
<td>Improve water quality and support of fisheries</td>
</tr>
<tr>
<td>8</td>
<td>Nutrient regeneration and recycling</td>
<td>Support of primary production and fisheries</td>
</tr>
<tr>
<td>9</td>
<td>Organic export</td>
<td>Support of estuarine, offshore food webs, and fisheries</td>
</tr>
<tr>
<td>10</td>
<td>Wave and current energy dampening</td>
<td>Protect upland from erosion and reduce flood-related damage</td>
</tr>
<tr>
<td>11</td>
<td>Self-sustaining ecosystem</td>
<td>Recreation, aesthetics, open space, education, landscape level biodiversity, and historical value</td>
</tr>
</tbody>
</table>

**SLAMM Results:** Coastal resource managers and town officials are increasingly anxious regarding climate change predictions and scenarios that show greater heat stress, large rainfall storm events and increasing rates of sea level rise. There is concern that the marshes will not be able to keep up with sea level rise, especially if rates exceed 5 mm per year, and adaptations by property owners and towns and state agencies may put marshes at greater risk for loss. We are using the SLAMM model to help identify important changes that might occur from greater rates of SLR and consider suggestions that protect communities, making them more resilient - but also protect and promote the natural capital of salt marshes so they may continue to benefit the communities adjacent to the Estuary. SLAMM includes storm impacts, but habitat type is driven more by day-to-day conditions rather than storms. Storms are certainly important, and conversion of one habitat type to another is more likely to occur following storms, but it is the elevation relative to mean sea level that the model uses to determine habitat types.

Present day conditions show the Estuary is dominated by high marsh, with some low marsh, tidal flats and subtidal channels (Figure 6.2). The marshes, which are an important cultural feature of the region since they provided valuable grass for livestock from the mid seventeenth to early twentieth centuries, are heavily ditched and crossed by roads and rail lines that impact the natural hydrology. Both tidal restrictions and ditching reduce marsh elevation (Roman and Burdick 2012, Vincent et al. 2013), the natural capital that allows high marsh to maintain itself above the critical elevation where it becomes flooded too often and converts to low marsh. Development is concentrated along the barrier beach system as well as Route 1, which crosses the northwestern portion of the estuary. The transition from intertidal salt marsh to upland is narrow and well-defined. The many drainages of freshwater flowing south or eastward into the estuary are often dammed with ponds or freshwater marshes and swamps above the dam (Figure 6.2).
Figure 6.2. SLAMM results for present day conditions showing 17 habitat types. High marsh is classified as irregularly flooded marsh (orange) and low marsh is flooded regularly (teal). Tidal flats (grey) and subtidal waters (blue) are also important habitat types within the Estuary.

By 2060, the marshes change dramatically from high marsh to low marsh (orange to teal) over most of the estuary (Figure 6.3), under the scenario of 0.73 m SLR with the marshes growing in elevation at 1.71 mm per year (current rate measured in 2016). The SLAMM map of results show most of the high marsh that exists today cannot maintain enough elevation relative to sea level and converts to low marsh as found by others (Donnelly and Bertness 2001). Bands of high marsh become established along the western shorelines as upland communities are replaced by scrub/shrub that will eventually be replaced by high marsh, but the conversion process can be slowed by trees (Field et al. 2016) and *Phragmites* (Smith 2014), which is a tall invasive grass with stands that are common along the upper marsh borders.

On the northeastern portion of the estuary behind the barrier system north of the inlet, the low marsh migrates east right up against the developed upland or overwash deposits that are carried from the ocean side into the marsh (yellow). This is the portion of the barrier system that is protected by a large, continuous seawall, but maintained in its present state, SLR will allow storm waves to overwash significant amounts of sediment on and past the developed barrier. The model output in Figure 6.3 is shown with development unprotected. That is, if the developed footprint is overwhelmed by conditions that indicate a different habitat should exist (in this case, upland to beach), the land cover is converted to the new habitat type. In the
southeastern portion where natural dunes still exist on the western portion of the barrier system, the higher sea level converts significant portions of the dunes into high marsh areas.

Most of the intertidal habitat that currently exists will be converted to open water by 2060 (Figures 6.2 and 6.3), resulting in the loss of prized shellfish beds. However, the areas that are currently low marsh near the mouth of the Estuary are predicted to convert to intertidal flats (Figure 6.3), so the loss of shellfish beds may be mitigated if the new areas (grey) can support shellfish.

![Image of SLAMM output](image)

**Figure 6.3.** SLAMM output for 2060 with 0.73 m sea level rise, 1.71 mm/yr accretion rate and development unprotected. Note the conversion of most of the high marsh (orange) to low marsh (teal) and new high marsh and transitional marsh (brownish green) at the upland edges.

Table 6.2 shows SLAMM outputs for various estuarine habitat areas that result from a variety of scenarios where accretion is changed from 0.0 to 6.0 mm per year. In addition, the models were run with development protected – that is the current infrastructure (roads, buildings, etc.) are maintained as such, regardless of changes to sea level. Undeveloped upland between roads and buildings (e.g., lawns) still revert to new habitat (e.g., beach or high marsh) where predicted to occur. The various areas of the different natural communities, habitats and uplands can be presented in tabular form and easily compared with existing conditions.
Currently, there exist 4437 acres of tidal marshes, with 90% classified as high marsh (large expansive meadows above the mean high tide) and 10% as low marsh (lower elevation marshes dominated by cordgrass and flooded twice daily (Table 2). With no or low rates of accretion, high marsh area plummets about 90% while low marsh area increases up to nine-fold (Table 2). Higher accretion rates would result in less dramatic shifts, but we do not know the ability of the marsh to build as the rate of sea level rise increases. Higher accretion rates lead to greater total marsh area by 2060, but total marsh area did not vary dramatically in the various model runs.

With 0.73 m (2.4 feet) of sea level rise by 2060, 535 acres of undeveloped uplands become intertidal by 2060 in all the scenarios run. In one run, we maintain a 1.71 accretion rate and allow development that floods regularly to become intertidal and convert to high marsh (with development unprotected). In this scenario, 180 acres of developed uplands are converted to intertidal habitat by 2060 (row 4, Table 6.2).

```
<table>
<thead>
<tr>
<th>Year and Scenario</th>
<th>Accretion Rate (mm/yr)</th>
<th>Open Water</th>
<th>Tidal Flats</th>
<th>High Marsh</th>
<th>Low Marsh</th>
<th>Developed Upland</th>
<th>Undeveloped Upland</th>
<th>Total Tidal Marsh</th>
<th>Other Cover Types*</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012 Current Accretion Rate</td>
<td>1.71</td>
<td>645</td>
<td>792</td>
<td>4017</td>
<td>420</td>
<td>2485</td>
<td>11676</td>
<td>4437</td>
<td>2548</td>
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<tr>
<td>2060 No Marsh Accretion</td>
<td>0.00</td>
<td>1095</td>
<td>680</td>
<td>593</td>
<td>3838</td>
<td>2485</td>
<td>11141</td>
<td>4431</td>
<td>2431</td>
</tr>
<tr>
<td>2060 Current Accretion Rate</td>
<td>1.71</td>
<td>1095</td>
<td>677</td>
<td>784</td>
<td>3651</td>
<td>2485</td>
<td>11141</td>
<td>4435</td>
<td>2431</td>
</tr>
<tr>
<td>2060 Current Accretion Rate **</td>
<td>1.71</td>
<td>1092</td>
<td>598</td>
<td>2565</td>
<td>2027</td>
<td>2305</td>
<td>11141</td>
<td>4594</td>
<td>2534</td>
</tr>
<tr>
<td>2060 Moderate Accretion Rate</td>
<td>4.00</td>
<td>1092</td>
<td>635</td>
<td>1455</td>
<td>3023</td>
<td>2485</td>
<td>11141</td>
<td>4477</td>
<td>2431</td>
</tr>
<tr>
<td>2060 High Accretion Rate</td>
<td>6.00</td>
<td>1092</td>
<td>598</td>
<td>2505</td>
<td>2011</td>
<td>2485</td>
<td>11141</td>
<td>4516</td>
<td>2431</td>
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<tr>
<td>2060 High Accretion Rate **</td>
<td>6.00</td>
<td>1092</td>
<td>598</td>
<td>2566</td>
<td>2026</td>
<td>2305</td>
<td>11142</td>
<td>4592</td>
<td>2535</td>
</tr>
</tbody>
</table>
```

* Includes inland waters and shores, inland / tidal fresh marshes and swamps, beaches and rocky intertidal areas
**Development is not protected but can convert to intertidal habitat

Table 6.2 - Natural resource and developed areas in H/S Estuary and potential changes by 2060 with 0.73 m (2.4 feet) of sea level rise. Areas are reported in acres.

Model results from SLAMM can also be compared graphically to show how areas of different intertidal habitats might change (Figure 6.4). In most of the scenarios presented, open water increases 450 acres (more than doubles) as tidal flats are converted to subtidal. But new tidal flats also form where low marsh is drowned, mitigating loss of this important habitat that supports shellfish. As a result, 112 to 194 acres of intertidal flats are lost, depending on the scenario examined.

When current conditions are compared with 2060 predictions based on 1.71 mm/year accretion, the areas of high and low marsh show a dramatic shift (Figure 6.4). The change in high and low marsh is more pronounced if there is no marsh accretion, as might occur if a tidal barrier was erected in the inlet. One of the potential adaptation responses would be to build a hurricane barrier across the inlet. Such a barrier would likely be open most of the time, but could reduce the accretion rate because storm events are responsible for much of the marsh accretion found in other regions (Turner et al. 2006, Smith et al. 2015). Building a hurricane barrier would increase resistance but not resilience of the human and natural communities of the estuary, as it would only forestall a catastrophic failure and flooding from a large storm event in a future with higher
and higher sea levels. Keeping tidal flow open and allowing the marshes and beaches to build in elevation as sea level rises seems like a better option when the adaptive cycle is considered (Holling 1986).

The loss of high marsh and gain of low marsh is less dramatic if marshes accrete at higher rates, from no accretion to 6.0 mm/year (Figure 6.4). Accretion has been measured at six locations in the Hampton Seabrook Estuary from 2011 to 2017, with average accretion at 1.71 mm/year as measured in 2016. Marshes in New Hampshire have been shown to accrete 4.3 mm/year if challenged with higher rates of SLR (Burdick, GBNERR unpublished data) as occurred between 2008 and 2010 (Goddard et al. 2015) and further measurements at Hampton Seabrook Estuary increased to 2.26 mm/yr by 2018. Therefore, SLAMM was run with 4.0 mm and 6.0 mm/year accretion rates to see if marsh response to rising sea levels would result in different outcomes.

With 6.0 mm/year accretion, SLAMM predicts slightly greater high marsh than low marsh area (Figure 6.4). The changes in the mapping results of SLAMM appear very less dramatic at 6mm/year compared with 1.71 mm/year (Figures 6.3 and 6.5). In this model run, development is protected, so the large swath of overwash of Hampton and North beaches leaves subtle, small scale changes; the processes leading to overwash still operate, but development that becomes intertidal is maintained in place. The conversion of high marsh to low marsh results in about half of each, rather than 90% low marsh at 1.71 mm/yr accretion rate.

Figure 6.4 - Areas of habitat in present day and 2060 under various marsh accretion scenarios ranging from no accretion to 6 mm/year. **SLAMM run with no protection for development.
Oceanfront and Inlet: North of the inlet, long, continuous seawalls dominate the beachfront interrupted by large rocky outcrops like Great Boars Head. The walls are maintained to protect the shore road (Route 1A), other infrastructure such as utilities, parking and sidewalks and to protect homes and businesses. Just north of the inlet, which is stabilized with jetties maintained by the US Corps of Engineers, is a portion of Hampton Beach State Park where development gives way to a wide beach and a large primary dune system. The other portions of the barrier developed with similar dunes, geologically, but human development has replaced the dunes, interrupting the dynamic erosion/building cycle found for such systems (Hill et al. 2004). South of the inlet, beachfront homes are sporadically protected by private seawalls until Hookset Street, whereupon a large extensive dune system, acquired and protected by the Town of Seabrook, continues through our study area into the town of Salisbury, Massachusetts.

At the low rates of sea level rise experienced through the last century, the Town of Hampton has been able to maintain seawalls and other upland infrastructure following storm damage. They have been less able to maintain a wide, tourism-friendly beach and northern areas are experiencing deflation and a slowly narrowing beach that is unavailable at mid to high tides. Sea level rise has increased from 1.7 to 3.3 mm per year in this century (Nicholls and Cazenave 2010) and wall maintenance costs have increased. Importation of sand to re-nourish shrinking beaches is being considered.
**SLAMM Results:** We have applied the habitat change model SLAMM over the estuary and barrier beach to identify where the most important changes may occur by the year 2060 as sea level continues to increase (we are using a scenario of 0.73 meters or 2.4 feet). While we do not expect all the changes to occur, or specific changes to occur at specific locations, the model results give us a picture of the types of changes we might expect if sea level increases 0.73 m.

Most of the outer beach is exposed to Gulf of Maine waters. It is backed by a continuous landward seawall and 2.4 feet of sea level rise will not result in high tides surpassing the wall. However, present day storms regularly throw salt water and cobble-sized stones over the walls, leading to road closures for safety and significant damage to the walls in Hampton. Rising sea levels will worsen the storm danger and damage to the integrity of the walls. Unless walls are raised, storms will also transport massive amounts of beach sediments over the walls and across the barrier system, despite the SLAMM run having development protected. Beaches will have less width and steep ramping to the walls will severely decrease the value of the beach for tourism. The SLAMM results with development unprotected show significant overwash through the developed sections of Hampton Beach that results in wide sediment deposits along the backside (western shore) of the barriers (Figure 6.3).

Southward of M Street the wall ends, and to the south homes have a variety of hard structures and small dunes that are susceptible to storm overwash, though these hard and soft structures help protect them from storm damage. Once the main section of the state park is reached, a large, wide primary dune cut by access paths protects large grassy parking lots. Very little change is predicted for this area because the dynamic equilibria of the dune-beach system will allow the beach to build in elevation as sea level rises and the wind-driven dune building is likely to continue. Bedrock outcrops (at Plaice Cove, Boar’s Head and the inlet) help reduce landward erosion, but beach nourishment will likely be needed to maintain beaches and development along the outer beach, especially where a seawall disrupts the natural cycle of sand movement between offshore bar, beach and dune (Hill et al. 2004).

South of the inlet, a portion of the shoreline (750 m of 2330 m total length) has little in the way of dune protection and will be increasingly susceptible to overwash and storm flooding. The seaside community of residences west of this stretch is very low in elevation and some models indicate flooding of roads and homes from storms and a rising groundwater table. Once Hookset Street is reached, wider dunes protect landward development (except at beach access paths that cut through the dunes) and SLAMM results do not show dramatic changes.

**Values of Tidal Marshes**
Economists and resource managers have been trying to assign a dollar value to marshes for decades, but salt marshes, similar to other wetlands, present some attributes that are very difficult to measure. Careful assessments show that most of the value for natural systems are not market-based but common values held in the public trust (de Groot et al. 2012). Thus, much of the value of coastal wetlands do not fit into a market paradigm. Assigning a dollar value to a good or service implies that over time that service or good will diminish in value (depreciate), but marshes become more valuable over time as we erode the natural capital of other, less well protected natural resources. The ecosystem services provided by marshlands also increase as we learn more about the ecological interactions they support and the natural capital they provide.
For example, the value of long term carbon storage was not considered an ecosystem service until the beginning of this century. Marsh ecosystems provide a long list of ecosystem services (Table 6.1) that stem from six main types of services: provisioning (e.g., fish), cultural and amenity values that include aesthetics and recreation, nutrient and waste cycling, flood/storm protection and erosion control, atmosphere and climate regulation, and support of biodiversity through habitat and refugia (MEA 2005). A further consideration is the value of an acre of marsh can be quite different depending on its location (adjacent to houses where flood and erosion reduction as well as aesthetics are important should be of greater value than a similar acre of marsh within a block of marsh 1,000 acres in size). This examination will not try to parse the type of salt marsh (low or high) or its location, but just consider the value of marshes in general with respect to adaptation options. Values will be in units of dollars per acre (0.405 hectares) per year to avoid the problems of monetary discount rates and habitat loss over time.

De novo assessment of ecosystem service benefits is beyond the scope of this research, so values developed by others will be used to establish comparisons between different climate change adaptation choices. The approach is termed the Benefit Transfer Method (BTM) and is used most appropriately when values developed elsewhere are calculated within similar socio-economic systems. For example, values calculated from New England are more likely to be applicable to the Hampton Seabrook Estuary than global values. Most early valuations used only one or two services, (Woodward and Wu 2001, Brander et al. 2006), but as we have begun to understand the critical values of nutrient and waste cycling as well as flood protection, newer assessments have tried to include them. More limited, earlier estimates proposed by Chmura et al. in 2012 based on Costanza et al. 1997 (updated by Geden et al. 2009) are recalculated to January 2018 values using the Consumer Price Index (CPI) as $7,355/acre/year (https://www.bls.gov/data/inflation_calculator.htm). Subsequently, de Groot et al. have tabulated the values of many ecosystem services for coastal wetlands at a global scale (Table 6.3). They found the value of tidal wetlands to be $96,102/acre/year, but did not include cultural, inspirational and aesthetic values. Their global results should be considered, but perhaps given less weight than regional analyses.

In a study of Long Island Sound, Kocian et al. (2015) used the BTM and included estimates for eight coastal wetland services: Food provisioning, Climate stability, Storm mitigation, Waste treatment, Habitat and nursery, Aesthetics, cultural and artistic inspiration, and Recreation and tourism (Table 6.3). They arrived at a range of values in $/acre/yr using 2012 dollars. The largest differences between low and high values were for Waste treatment and Cultural and artistic inspiration. With the costly choices faced by neighboring towns to the north and west for reducing nitrogen into the Great Bay Estuary (Stucker 2018), town officials and resources managers are well aware that waste processing is an important service. Piehler and Smyth (2011) calculated the value of tidal marshes from denitrification alone to be $15,100 per acre per year based on the North Carolina nutrient offset program. Further, marshes uptake nutrients in inorganic form in spring and summer and release them from aboveground portions in late fall and winter as complex biological forms. Rather than allowing the inorganic nitrogen to fuel eutrophication, marshes senesce and release nitrogen rich organic matter that sustains the valuable detrital food web of the estuary and coast.
Table 6.3 - Ecosystem service estimates tidal wetlands (January 2018 $/acre/year). * The Long Island Sound Study is by Kocian et al. 2015; ** Global estimates are from de Groot et al. 2012.

<table>
<thead>
<tr>
<th>Service</th>
<th>Long Island Sound*</th>
<th>Global**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Provisioning</td>
<td>1</td>
<td>698</td>
</tr>
<tr>
<td>Habitat</td>
<td>92</td>
<td>462</td>
</tr>
<tr>
<td>Disturbance Regulation</td>
<td>3,800</td>
<td>3,800</td>
</tr>
<tr>
<td>Climate Control</td>
<td>11</td>
<td>186</td>
</tr>
<tr>
<td>Waste Treatment</td>
<td>1,912</td>
<td>57,530</td>
</tr>
<tr>
<td>Recreation/Tourism</td>
<td>151</td>
<td>994</td>
</tr>
<tr>
<td>Cultural/Inspiration</td>
<td>5,733</td>
<td>13,591</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>11,699</td>
<td>77,260</td>
</tr>
<tr>
<td>in January 2018 (CPI)</td>
<td>12,408</td>
<td>81,941</td>
</tr>
</tbody>
</table>

Tourism, set at $994 at the high range shows marsh value for this service alone across the entire estuary (4322 acres) calculates to be annually $4.3 M. Considering the annual tourism benefits are critical for the economy of the two towns and are important sources of tax revenues for the state (NHCRHC 2016), this estimate seems reasonable.

Kocian et al. also presented asset values of coastal wetlands for carbon storage associated with natural capital and influence on the housing market that was not put on an annual basis for their ecosystem service, but values as a lump sum for 100 years and discounted over time (4%). For the purposes of this study, we will recognize the value of the natural capital without including it in the calculation of annual benefits.

For these reasons, the higher value, $82,000, is more appropriate for Hampton Seabrook Estuary and is surprisingly close to the global value proposed by de Groot et al. (2012) of $96,102/acre/year. When $82,000 per acre is applied over the Estuary in its current state and the projected changes based on a scenario of 0.73 (2.4 feet) SLR in 2060 we can see the potential effects of SLR on the value of ecosystem services provided by tidal marshes in the Estuary (Table 6.4). Since most of the marshes are high marsh, sitting upon thick peat deposits that only flood when high tides are near or above average, SLAMM results showed that 2.4 feet of sea level rise will convert most current high marsh to low marsh, but it will still be marsh. For that reason, the area of tidal marsh expected following 2.5 feet of SLR in 2060 only varies from 4,431 to 4,594 acres (SLAMM results, Table 6.2). If the marsh is allowed to migrate onto all the pervious surfaces (dirt lots, between houses, etc.), the seaward losses are balanced by landward migration, with the largest differences occurring between the footprints of developed land
allowed to revert to marsh or not. At $82,000/acre/year, 163 acres only amounts to $13 M/year (difference between rows 2 and 4, Table 6.4). Adaptation choices that erect berms to protect developed areas are likely to have much larger impacts.

<table>
<thead>
<tr>
<th>Year and Scenario</th>
<th>Development Protected</th>
<th>Tidal Marsh Area</th>
<th>Value (2018 $/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012 Current Accretion Rate</td>
<td>YES</td>
<td>4437</td>
<td>363,834,973</td>
</tr>
<tr>
<td>2060 No Marsh Accretion</td>
<td>YES</td>
<td>4431</td>
<td>363,339,035</td>
</tr>
<tr>
<td>2060 Current Accretion Rate</td>
<td>YES</td>
<td>4435</td>
<td>363,636,727</td>
</tr>
<tr>
<td>2060 Current Accretion Rate</td>
<td>NO</td>
<td>4594</td>
<td>376,708,000</td>
</tr>
<tr>
<td>2060 Moderate Accretion Rate</td>
<td>YES</td>
<td>4477</td>
<td>367,114,000</td>
</tr>
<tr>
<td>2060 High Accretion Rate</td>
<td>YES</td>
<td>4516</td>
<td>370,305,889</td>
</tr>
<tr>
<td>2060 High Accretion Rate</td>
<td>NO</td>
<td>4592</td>
<td>376,544,000</td>
</tr>
</tbody>
</table>

Table 6.4 - Estimated value of tidal marshes based on total marsh area and $82,000/acre/yr.

In the next section, we consider choices for adaptation to climate change (mostly storm and sea level rise impacts) and then examine the potential impacts to habitat types and their values from some of these choices by the towns (see environmental Impacts to ecosystem services section).

Adaptation Choices and Environmental Impacts to Ecosystem Services
The towns of Hampton and Seabrook all depend on a large tourism industry that is perched on a barrier system protecting the Estuary. The beach communities are particularly vulnerable to storm surges and rising sea levels, with portions of two communities currently experiencing nuisance, fair-weather or high tide flooding from spring tides. The choices made by these communities and the residents and businesses composing them can have far-reaching effects on their safety, economy, quality of life and may differentially affect more socially-vulnerable portions of the communities. Inaction could result in devastating storm impacts that has the potential to destroy these communities. Engineering approaches that only use hard structures or grey solutions may weigh the communities down with severe debt, result in long term damage to the environment and degrade the charm and attractiveness of the area to tourists. On the other hand, allowing over-wash and marsh migration everywhere will reduce the number of people and tourists that benefit from the beaches and dunes, shellfish flats, marinas, fishing and marshes. Through hydrodynamic, social and habitat modeling and mapping, we have examined potential impacts and changes due to storms and sea level rise on the Hampton Seabrook Estuary and barrier beach complex (socio-economic-ecological system).

Geography and history has resulted in Hampton armoring a large portion of their shoreline on the Atlantic Ocean. These walls, broken by Great Boars Head, have led to sand loss, especially along the northern portions. The walled areas would benefit from beach nourishment to protect walls and provide a sandy beach for tourists. To withstand more severe storms at greater sea levels, we recommend fortification and a re-design of the promenade having three components: a pedestrian walkway, greenway (20 to 40 feet wide) and a bicycle path. These three strips
forming the promenade should be designed so that pedestrians and beachgoers as well as bicyclists can see the water.

In contrast, two areas to the south: Hampton Beach State Park at the inlet and most of Seabrook Beach is protected by significant dune systems that are tall and wide. Aside from the designated and unofficial paths to the beach, these dunes can effectively protect landward development from sea level rise and storms. The nearshore, beach and dune system are in a dynamic equilibrium and so the beaches will build in elevation with sea level rise. Walkovers and post-storm maintenance to collect wind-blown sand (fencing and planting) or periodic nourishment are all that is needed to keep the park and landward communities protected from oceanic threats. North of Hookset Street to the Inlet and north of the State Park at the Inlet to M Street, dunes have been removed or are too small and disjunct to protect landward development. We recommend both Seabrook and Hampton work with residents to develop a dune protection system for these two areas. These could be narrow sacrificial dunes (to be rebuilt following severe storms) or wider dunes combined with beach nourishment. Beach nourishment and dune protection may work well in this geographic setting due to the bedrock outcrops at Plaice Cove, Great Boars Head and the Inlet which tend to help the barrier beaches form a linear barrier to seaward transgression.

Very high tides and storm surges will flood these barrier beach communities from the western sides; this is the most common route of tidal flooding. Current flooding associated with storm surges co-occurring with astronomical tides is made worse by strong easterly (or northeasterly) winds that fill the basin and even worse when followed by a change of wind direction from the west that piles water up on the west side of the barrier system. The western shores are mostly bordered by tidal marshes, so these are areas for potential marsh migration. Slightly higher elevations formed by old inlet deltas have been built upon and these residences are often surrounded by water as their roads flood (Glade Path, Island Path, River Street and Cross Beach Road). Erecting a hurricane barrier across the inlet would be expensive. It would protect development in the Estuary from big storms, but would not keep out ever increasing day-to-day flooding that is currently occurring from sea level rise and expected to worsen (Sweet et al. 2018). Residents on these and similar roads should consider lifting their homes, planning for emergency evacuations or relocating.

We recommend a linear berm be built along the western shore of the northern barrier beach to protect most of the community from flooding. It should be 4 feet in height and placement in the upland or marsh will determine impacts to the tidal marshes. If the center of a linear berm, 9,000 feet in length, is placed along the upland edge, about 2.5 acres of marsh will be lost immediately and the marsh will be prevented from migrating landward, leading to further and more significant losses over time. Linear berms around most of the barrier systems in the two towns would become very long (14 miles) and costly and have significant impacts to the marsh, both immediately and more so over time (Table 6.5). For these reasons, we recommend that the construction of most of the berms outlined below be the landowners’ responsibility.

The northernmost water body in the Estuary is Meadow Pond; a berm around it would be approximately 20,200 feet long. To the south of Winnacunnet Road, north of Route 101 and west of Great Boars Head is a circular feature dominated by high marsh that could be circled by 10,100 feet of berm. Just west of that area, south of Route 101 is a vulnerable area around Depot
Road, which could be protected by a 5,800 foot berm. The western side of the Hampton barrier system could be protected by a linear berm, 9,000 feet long, but if the berm were to follow the edge of existing marsh it would be 11,500 feet long. Also, if the berm were to protect the entire lengths of Glade Path and Island Path, this portion would need to be 11,000 feet long. South of the Inlet, in Seabrook a berm could be built around River Street and Cross Beach Road that would be 8,500 feet in length. Finally, beginning just south of the Seabrook back dune area, a 5,000 foot berm to protect residences and businesses could extend to and along Route 286 to the bridge over the Blackwater River, then south of Route 286 to the Salisbury town line (Table 6.5).

<table>
<thead>
<tr>
<th>Area</th>
<th>Town (H,S)</th>
<th>Recommended</th>
<th>Length (ft)</th>
<th>Immediate Marsh loss (acres)</th>
<th>Annual Costs in Ecosystem Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meadow Pond</td>
<td>H</td>
<td>No</td>
<td>20,200</td>
<td>5.56</td>
<td>456,309</td>
</tr>
<tr>
<td>Marsh area west of Great Boars Head</td>
<td>H</td>
<td>No</td>
<td>10,100</td>
<td>2.78</td>
<td>228,154</td>
</tr>
<tr>
<td>Depot Road Area</td>
<td>H</td>
<td>No</td>
<td>5,800</td>
<td>1.60</td>
<td>131,019</td>
</tr>
<tr>
<td>Berm west of Hampton Beach</td>
<td>H</td>
<td>No</td>
<td>11,500</td>
<td>3.17</td>
<td>259,780</td>
</tr>
<tr>
<td>Linear Berm</td>
<td>H</td>
<td>Yes</td>
<td>9,000</td>
<td>2.48</td>
<td>203,306</td>
</tr>
<tr>
<td>Protection of residences except Paths</td>
<td>H</td>
<td>No</td>
<td>11,000</td>
<td>3.03</td>
<td>248,485</td>
</tr>
<tr>
<td>Island Path and Glade Path</td>
<td>H</td>
<td>No</td>
<td>8,500</td>
<td>2.34</td>
<td>192,011</td>
</tr>
<tr>
<td>River Street and Cross Beach Road</td>
<td>S</td>
<td>No</td>
<td>5,000</td>
<td>1.38</td>
<td>112,948</td>
</tr>
<tr>
<td>Back Dune to Salisbury Line</td>
<td>S</td>
<td>No</td>
<td>72,100</td>
<td>19.86</td>
<td>1,628,705</td>
</tr>
<tr>
<td>Sum of Berms Not Recommended</td>
<td></td>
<td></td>
<td>9,000</td>
<td>2.48</td>
<td>203,306</td>
</tr>
<tr>
<td>Sum of Berms Recommended</td>
<td></td>
<td></td>
<td>72,100</td>
<td>19.86</td>
<td>1,628,705</td>
</tr>
</tbody>
</table>

Table 6.5. Potential berms on western barrier systems to protect development.

All of these added berms would be an expensive solution, especially where they protect only a handful of homes, and are not recommended. Direct marsh loss from filling (berm construction) would impact 20 acres of tidal marsh immediately, and probably much more as migration between residences would be prevented. The berm solution is temporary and roads, other infrastructure and houses will still need to be raised to avoid flood damage in the near future and rising groundwater tables in the coming decades. Because we know that sea levels will continue to rise beyond 2060, and the amount of vulnerable infrastructure and development in the two towns will expand, further adaptation (raising structures and roads, wet adaptations for some infrastructure, etc.) will be needed. The losses to marshes impacted by flooding adaptations could be partially offset if the homes and businesses that are most vulnerable and difficult to protect are abandoned and allowed to revert to natural habitat.

A particularly vulnerable area is the neighborhood just south of the inlet where very low elevations will lead to flooding by storms but also rising ground water tables. On a narrow sand barrier, water tables will be very responsive to SLR. Combined with storm surge and precipitation, the higher water tables will lead to flooding problems. Because portions of Route 1A south of the inlet are also very low in elevation, we recommend raising the highway and
constructing it to be a flood barrier to protect the communities eastward. Few environmental impacts to estuarine habitats are expected for this choice.

Elevating roads inland of the barriers should include Route 286, access to the WWTP, Route 1 at the Taylor River, Winnacunnet Road. Other roads may need to be raised (and perhaps whole neighborhoods on the barrier system), but these four are seen as critical. The increasing tidal prism will require new engineering for these transportation corridors, especially where they cross rivers and tidal creeks, and the marsh would most benefit from elevated sections where tides could pass underneath the road. Elevated sections of roadways would allow for improved tidal exchange and less impacts from direct fill as tall roads built on fill will require wider bases.

6.0 Social Vulnerability Assessment

Background and Methodology:
The determination of social impacts involves conducting a social impact assessment (SIA) and developing a social vulnerability index (SVI) for the area pertaining to the impacts of climate change on wetlands. SIA, a process that has been widely used in international settings, includes the processes of analyzing, monitoring and managing the social consequences, both positive and negative, of proposed plans, policies, and projects. Social vulnerability is defined as the susceptibility of a given population to harm from exposure to a hazard, directly affecting its ability to prepare for, respond to, and recover from extreme climate events. Social vulnerability is a function of diverse demographic and socio-economic factors that influence a community’s sensitivity to climate change. Studies show that social variables, such as age, race, and income affect the ability of an individual to prepare for, respond to, and recover from a natural disaster or other potential climate impacts.

A social vulnerability index (SVI) was developed based on the emergency preparedness literature (Flanagan et al., 2011; Cutter et al., 2013). The SVI is derived from publicly available data from the American Community Survey (ACS), which generates 5-year averages at the Census Tract level for 16 indicators of vulnerability. These are shown below:
The composite SVI reflects the number of indicators in a given census tract that exceed the 90th percentile for NH. Geographic Information Systems (GIS) maps were created to identify and “flag” tracts with higher levels of vulnerability (e.g., ≥5 indicators exceeding the 90th percentile) (NH DHHS). Based on these indicators, we identified and mapped a range of factors contributing to social vulnerability in the HSE. We added additional indicators, such as the Percent Rental Housing Units, the Percent Vacant Housing Units, and Anchor Institutions at the census block level, at the request of our community stakeholders and partners. This is due to the fact the HSE has a highly seasonal population with different demographic characteristics in the summer (higher income, beachfront vacation rentals) to the winter (lower income renters).

The study area contained a total of 759 census blocks, of which 536 were populated. The average population composition was 81% owner-occupied and 19% renter-occupied (although for some blocks the renter percentage was higher than 70%). A total of 17279 housing units were located in the study area (based on 2010 Census data). Of these units, 76% were occupied and 24% were vacant. These estimates reflect the time of the year when the Census is conducted (April), a time during which some seasonal homes are still vacant from the winter and the wealthier summer population has not yet moved back to the area. Thus, indicators are more likely to reflect the winter/spring population than the summer population. Due to project budget constraints, we do not use scenarios or projections of changes in the above social characteristics over time (e.g., income in 2045).

**Socioeconomic Status:**
1. Poverty (% of population living below the federal poverty level
2. Unemployment (% of those age 16 and over, unemployed and seeking work)
3. Per Capita Income (in inflation adjusted dollars)
4. Education (% of those 25+ without a high school diploma)
5. Health Insurance (% of those under the age of 65 living without health insurance)

**Household Composition/Disability:**
6. Children (% of the population under the age of 18)
7. Elderly (% of the population 65 and older)
8. Disability (% of the population 5 and older with a disability)
9. Single Parent (% of households with children and only a single parent)

**Minority Status/Language:**
10. Minority (% of households that are Hispanic or of non-white race)
11. Limited English (% of those age 5 and over who speak English less than “well”)

**Housing/Transportation:**
12. Large Apartment Buildings (% of housing unites in buildings with 10 or more units)
13. Mobile homes (% of mobile housing units)
14. Crowding (% of housing units with more than one person per room)
15. No Vehicle (% of households with no vehicle available)
16. Group Quarters (% of population living in group quarters)

**Composite Social Vulnerability Index (SVI_16) = sum of the above**
We conducted statistical analysis to evaluate relationships between higher social vulnerability and the likelihood of being impacted by coastal flooding, using the outputs from FVCOM and merging this data with the SVI data set at the Census Block unit of analysis. This was performed by creating a binary variable indicating whether a particular census block was flooded (1) or not flooded (0) under a given storm scenario. We used the 100 Yr Storm, with and without 0.73 meters of sea level rise (SLR) for these analyses. Logistic regression models were run using Flooded Blocks as the dependent variable, and the social vulnerability index as the independent variable. As shown in the subsequent sections, most of the social impacts were associated with coastal surge flooding versus tidal flooding.

Most of the social impacts associated with tidal flooding reflect indirect impacts (e.g., inconvenience) rather than direct health hazards. This is because as previous stated, there not significant tidal flooding of the built environment at MHW either presently or with 0.73 m of SLR.

**Surge Flooding Impacts**

Analysis at the block level shows that 19% of the 759 blocks in our study area were located in the flood zone using the 100 Yr Storm with no SLR, and 26% were in the flood zone using the 100 Yr Storm with 0.73 meters SLR. A summary is provided below:

### Social Vulnerability – Key Points

| Overall Impacts: Blocks Impacted by Flooding, 100 yr Storm, with and without 0.73 m SLR. |
| Total Flooded Blocks | 143 | 200 |
| % Blocks Flooded | 18.8% | 26.3% |
| Total Population Impacted | 8713 | 11475 |
| % Population Impacted | 33.8% | 43.4% |
| Total Housing Units Impacted | 6925 | 8713 |
| % Housing Units Impacted | 45.5% | 57.3% |

Sources:
2016 American Community Survey and 2010 Census
Furthermore, socially vulnerable population subgroups are more likely to be impacted by flooding. This is illustrated in the series of maps below. In the HSE, the most vulnerable tract was Tract 65008 in Hampton. This tract had 5 vulnerability indicators that were above the 90th percentile for New Hampshire (% population over age 65, % below Federal Poverty Level, % single parents, % unemployed, and % living in crowded housing). This tract also had high percentages of residents with disabilities, persons living in rental housing, without health insurance, and without access to a vehicle. Understanding the types of vulnerabilities that co-exist in the area can inform emergency preparedness and climate change adaptation planning efforts.

The second-most vulnerable tract was Tract 63002 in Seabrook. This tract had flags (above the 90th percentile) for the following indicators: percentage of the population over age 65, % with a disability, and % living in mobile homes. There was also a high percentage of residents with low education (no high school diploma). Two other tracts (Tract 65007 and 65006) had high percentages of residents over age 65.
In the HSE, one tract (shown in red) had five SV indicators flagged above the 90th percentile (indicating highest SV), one tract had 3 flags (pale green; moderate SV), two tracts had 2 flags (pink), one had 1 flag (purple; low SV); the remaining tracts had no indicators above the 90th percentile.

*Higher SVI indicates a higher total number of social vulnerability indicators above the 90th percentile for the state.

(100 Yr Storm, With .73 m SLR)
Percent Population Below Federal Poverty Level

(100 Yr Storm, No SLR)
Percent Population Below Federal Poverty Level

(100 Yr Storm, With .73 m SLR)
Percent Population Age>=65

(100 Yr Storm, No SLR)
Percent Population With No Car

(100 Yr Storm, No SLR)
Percent Population With No Car

(100 Yr Storm, With .73 m SLR)
Percent Population With a Disability

(100 Yr Storm, No SLR)
Percent Population With a Disability

(100 Yr Storm, With .73 m SLR)
Percent Renter-Occupied Housing

(100 Yr Storm, No SLR)
Percent Renter-Occupied Housing

(100 Yr Storm, With .73 m SLR)
Percent Vacant Housing Units

(100 Yr Storm, No SLR)
Percent Vacant Housing Units

(100 Yr Storm, With .73 m SLR)
Percent Population Living in Mobile Homes
Percent of Households with No Vehicle Available and Percent Single Parent

“Single Parent” - Households with minor children and no spouse present
Several important anchor institutions and community assets are located in the flood zone, as shown below:
Anchor Institutions 100 Yr Storm without SLR

Several important anchor institutions and community assets are located in or near the flood zone (using a list of places that stakeholders perceived to be important). For example, in Seabrook, the Seabrook school, the Wastewater Treatment Plant, and the Nuclear Power Plant are located in or near the flood zone.

Anchor institutions are places such as schools and hospitals that maintain important social and economic functions for the community. They provide measurable benefits children, families, and communities
Collectively, the maps provide information regarding different facets of social vulnerability that can be used to inform municipal planning and emergency response initiatives.

**Statistical Analysis:**
For the 100 Year Storm scenario with 0.73 meters of SLR, logistic regression models showed that each one unit increase in the SVI increased the likelihood of living in the flood zone by 1.71 (95% Confidence Interval (CI) 1.53-1.90). Thus, residents living in the most vulnerable census blocks (SVI=5, shown in red on the composite SVI maps) were 8.6 times more likely to be located in the flood zone, compared to those living in blocks with low SVI.

For the 100 Yr Storm With 0.73 m SLR, census blocks with high percentages of the population over age 65 were 6 times more likely to be located in the flood zone. Census blocks with high percentages of the population living in poverty were 17.7 times more likely to be located in the flood zone.

In summary, blocks with higher percentages of people who are older, poorer, living in rental homes, and lacking health insurance are significantly more likely to be located in the flood zone. Furthermore, these disparities may get worse over time as the population ages and poverty becomes may become more concentrated. New Hampshire’s population over age 65 is expected to double by 2040.
Key findings from the logistic regression models are shown in the Table below.

### Logistic Regression Model Results:
**Social Vulnerability and Odds of Being Located in the Flood Zone**

<table>
<thead>
<tr>
<th></th>
<th>100 Yr Storm, No SLR (Odds Ratio (95% Confidence Interval))</th>
<th>100 Yr Storm, With .73 m SLR (Odds Ratio (95% Confidence Interval))</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVI_16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Percentage Age 65+ (&gt;90th percentile)</td>
<td>1.50 (1.35-1.67)</td>
<td>1.71 (1.53-1.90)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>High Percentage Living in Poverty (&gt;90th percentile)</td>
<td>4.58 (3.10-6.77)</td>
<td>6.00 (4.19-8.60)</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

### Social Impacts of Adaptation
Social vulnerability is a function of exposure, susceptibility, and adaptive capacity. Exposure and susceptibility have been discussed in the previous sections, and Strategies B and C do not differ significantly in this regard. Under both of these scenarios, vulnerable residents would be afforded some protection due to protection of the built environment and anchor institutions, but the costs of flood-proofing individual homes (or choosing to relocate) would be borne by individual homeowners. This will place relatively higher burdens on residents of lower socioeconomic status. Those in low-income rental units may not be able to find other affordable housing; NH has very few options for low/mixed income housing.

Options B and C differ from Option A in terms of how they affect adaptive capacity. Although negative impacts from flooding may still affect vulnerable populations, both options B and C could provide important public health benefits through the addition of the green elevated walkway (in place of current parking spaces) along the floodwall. An important co-benefit may accrue in terms of increased population levels of physical activity (e.g., walking, bicycling) as a result of the green walkway. Physical activity is a modifiable risk factors that can play an important role in preventing major chronic diseases such as heart disease, diabetes, and cancer.
Researchers have demonstrated a positive dose-response relationship between the number of places to exercise and the likelihood of meeting physical activity recommendations for public health (Parks et al, 2003; Aytur et al, 2007).

Predictive algorithms can also be used to estimate the potential population health benefits associated with adding the green walkway. For example, using the World Health Organization’s Health Economic Assessment Tool (HEAT), we estimated that if the elevated green walkway increased physical activity by only 10 minutes per day for 40% of the population, this would result in a 14% reduction in the risk of mortality and substantial reductions in medical costs (WHO, 2016).

Importantly, from an environmental justice perspective, adding public greenspace and walkable areas may afford the greatest health benefits to people in lower socio-economic groups who typically have the least access (Aytur et al., 2007). As shown on the map, the walkway would be located in the most socially vulnerable census tract in the HSE.

Additionally, adding greenspace has been shown to afford many ‘indirect’ health benefits including stress reduction and better mental health. Mental health, heart disease, obesity, and diabetes were ranked as the top public health priorities in the most recent Community Health Needs Assessment (2016) for Rockingham County, which includes the towns in the HSE. Research suggests that walkable infrastructure may also support local economic development. Through evolving multi-sectoral partnerships, this study provides a springboard for raising awareness about the intersections between public health and climate change that may not have been considered previously. For example, emerging research suggests that one of the most important and costly ‘hidden’ impacts of flooding is its effect on mental health. Studies of severe flooding events in the United Kingdom suggest that approximately 90 percent of the public health costs of the floods may be attributable to long term mental health issues (Vardoulakis, 2012). Adaptation strategies that offer co-benefits for mental health and chronic disease prevention can be important aspects of building community resilience over time.

When comparing Options B and C, social impacts are generally not significantly different in terms of direct flood impacts to people or anchor institutions. With respect to indirect impacts, the public health benefits associated with building the green elevated walkway would apply to the B and C scenario. Option C may also provide an added societal benefit of preserving more of the ecosystem services of the marsh. The marsh is considered a very important cultural and recreational asset by many residents. Conversely, there may be a negative ‘cost’ to individual homeowners whose viewshed may be impacted by the new wall.

7.0 Stakeholder Survey – Summary of Results
A stakeholder survey was distributed to members of the Coastal Adaptation Workgroup (CAW) and the Seabrook Hamptons Estuary Alliance (SHEA), during April-May, 2018. The survey utilized a modified “Q Sort” methodology (Raadgever et al., 2008) in which participants were asked to rank 22 statements in terms of the extent to which they agree or disagree with the statement. The statements were generated from the literature and from issues that had been raised in prior stakeholder meetings. The statements were classified into two broad themes:
1) What are the greatest challenges to climate adaptation planning and emergency preparedness?

2) What are the greatest opportunities to address climate adaptation planning and emergency preparedness?

The Q Sort method is particularly appropriate for small sample sizes, since our main stakeholder group generally consisted of 12 individuals. Respondents (n=8) represented the following sectors: Municipal government (n=5); State government (n=1); Cooperative Extension (n=1); Other Watershed Organizations (n=1). Disciplines represented included engineering, environmental sciences, urban planning, social science, and policy.

Key findings from the survey are summarized below:

- 75% of respondents agreed that lack of resources (including financial resources and human resources/workforce capacity) poses the most significant challenge to municipal adaptation planning and emergency preparedness.

- 75% of respondents agreed that convincing residents to support flood protection measures that may benefit home-owners in the flood zone, at the perceived ‘expense’ of those residents who do not live in the flood zone, is a significant challenge to municipal adaptation planning and emergency preparedness.

- 62% of respondents agreed that tensions between state and municipal governance/policy issues around resources (including infrastructure, beaches, etc.) pose a significant challenge to adaptation planning and emergency preparedness.

- 62% of respondents agreed that having a high percentage of residents over age 65, including some with disabilities, poses a significant challenge to municipal adaptation planning and emergency preparedness.

- 62% of respondents agreed that residents generally would be receptive to implementing individual flood-proof measures to protect their homes and businesses.

- 50% of respondents agreed that there is good public understanding regarding basic flood literacy and safety (including how to safely evacuate, how to follow emergency procedures and communicate with emergency personnel, how to ensure food safety, adequate water and supplies) in Hampton/Seabrook/Hampton Falls. (One participant wrote that “it is getting better.”)

- Only 29% of respondents agreed that public understanding regarding the importance of the ecosystem, including the marsh and its ecosystem services, is generally good in Hampton/Seabrook/Hampton Falls.

In terms of ‘opportunities’, most respondents viewed the modeling and analyses provided by the current study as being very useful for informing climate adaptation planning and emergency preparedness. For example:

- 100% of respondents agreed that the model results showing the extent and depth of flooding under present and future storm conditions are useful for climate adaptation planning and emergency response purposes.

- 100% of respondents agreed that the study results showing impacts to the marsh are useful for climate adaptation planning purposes.
• 86% of respondents agreed that the study results showing impacts to vulnerable populations are useful for climate adaptation planning and emergency response purposes.
• 86% of respondents agreed that the study results showing damages to buildings under present and future storm conditions are useful for climate adaptation planning purposes.

Perspectives regarding the green/gray adaptation options presented were mixed. For example:

• In response to the statement, “The green/grey infrastructure options offer a technically feasible way to prepare for the impacts of future storms and sea level rise (SLR)”, 43% disagreed, 14% were neutral, and 43% agreed.

• In response to the statement, “The green/grey options offer a financially feasible way to prepare for the impacts of future storms and sea level rise (SLR)”, 71% disagreed, and 29% agreed.

• In response to the statement, “Residents generally would be receptive to implementing the green/gray strategies presented”, 43% disagreed, 14% were neutral, and 43% agreed.

Respondents also noted some other ways to prepare for the impacts of future storms and sea level rise (SLR). These included “exploring property purchase and more strict ordinances in our towns”, “revised/new ordinances”, and “thinking about actions to build social cohesion.” They also cited the importance of continuing to dialogue about finding effective ways to communicate about the potential co-benefits to adaptation strategies.

Significant Deviations from Proposed Workplan
Early in the research project, we had problems with applying the flood model to HSE. This was finally resolved in December 2017. Due to this significant delay, the final report was late but complete.

List of completed, peer and non-peer reviewed publications, white papers, or reports (with internet links if possible)
None completed yet. Several are planned.

List website addresses relevant to the project for further information (if available)
Not applicable.

List of presentations/seminars, photos, or other visuals related to project


**List of Media Coverage - Please share, if possible any media coverage**


**For Final Report please include - Powerpoint slide summarizing project and major accomplishments (should be in .pptx format). Separate submittal.**

**References**


Pease Development Authority [PDA], 2012, Division of Ports and Harbors annual dredge Report, Portsmouth, NH.


