

TEACR Engineering Assessment

Living Shoreline along Coastal Roadways Exposed to Sea Level Rise: Shore Road in Brookhaven, New York

This is one of nine engineering case studies conducted under the Transportation Engineering Approaches to Climate Resiliency (TEACR) Project.¹ This case study explores the feasibility of using a living shoreline to protect a coastal roadway against sea level rise and storm surge.

Overview

In this assessment, the research team investigated the potential impacts of predicted future sea level rise on flooding of a coastal roadway in the northeastern United States, and the potential use of a "living shoreline" to mitigate damage where possible. A living shoreline may include a combination of an engineered structure to attenuate wave energy, appropriate vegetation, and sand to stabilize the shoreline and provide nearshore habitat to allow native species of flora and fauna to flourish. The assessment focused on Shore Road, which parallels Mt. Sinai Harbor in the Town of Brookhaven located on the north shore of Long Island, New York. The road appears on maps dating

Case Study Snapshot

Purpose: Assess the vulnerability of a typical coastal roadway to sea level rise and extreme water levels and identify possible adaptations including the use of a living shoreline.

Location: Shore Road, Brookhaven, NY

Approach: Apply FHWA's ADAP methodology to evaluate a living shoreline as a natural and nature-based adaptation for protection of a coastal road threatened by erosion and inundation from tides, surge, and wave action that will be exacerbated by future sea level rise.

Key Findings: A living shoreline approach could provide protection for Shore Road for decades. The vulnerability of Shore Road to wave action at high tide will increase due to future sea level rise. The road's elevation is sufficient to prevent daily nuisance flooding; however, the embankment and shoulder require protection from wave action now to avoid continued failures.

Key Lessons: The vulnerability of existing infrastructure can be evaluated by determining the future year in which specific hazards become likely due to projected sea level rise. Natural and nature-based adaptation strategies, like living shorelines, have the potential to reduce vulnerabilities. Implementation of such approaches may be limited by state-specific regulations at this time.

¹ For more information about the project, visit the project website at: <u>https://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_re</u> <u>search/teacr/</u>

back to 1873 and was likely in use well before that considering the area was settled in the 17^{th} century.

This is an important analysis because there are approximately 60,000 road miles in the United States that are occasionally exposed to coastal storm surge and waves.² More road miles will be threatened as sea levels rise. Sea level rise will increase the vulnerability of existing low-lying transportation infrastructure (with more frequent and longer duration flood events) while also expanding the exposure of higher-elevation roadways to coastal flooding. However, the degree to which climate stressors will impact today's less vulnerable, higher-elevation infrastructure, is largely unknown. This can impede the design of suitable climate change adaptation strategies to reduce or prevent potential future damages.

In a 2014 report, Assessment of Key Gaps in the Integration of Climate Change Considerations into Transportation Engineering, FHWA identified a series of research gaps that represent critical barriers to integrating climate change into transportation engineering practices. ³ The following analysis addresses several of the identified knowledge gaps related to considering flooding along coastal roadways:

- Combining historical climate data with projected future climate changes;
- Incorporating sea level rise and storm surge projections into project design; and
- Understanding the secondary impacts of climate stressors.

Addressing these gaps provides a framework for evaluating the vulnerability of existing infrastructure to future climate change and storm impacts, and identifies potential adaptation options for mitigating those impacts using natural and nature-based methods. In this assessment, projected future sea levels are combined with return period storm water levels to determine the year in which the asset becomes vulnerable to a flood of a certain frequency. Historic and future sea level rise scenarios are used to bracket the range of potential climate scenarios and determine the years when certain thresholds are exceeded. The extent to which wave damage increases (secondary impact) as a function of future sea levels is considered in light of the damage it may cause to the roadway.

The research team evaluated the effects of future sea level rise on both nuisance and stormrelated flooding of Shore Road, which is shown at low tide and high tide in Figure 1. One of the results of this analysis is that Shore Road is not expected to experience daily flooding until around 2065 under the highest sea level rise scenario, but storm-related flooding and damage are happening now on a less frequent basis (i.e., yearly). The sections of roadway projected to

² FHWA "Highways in the Coastal Environment."

³ FHWA "Assessment of Key Gaps in the Integration of Climate Change Considerations into Transportation Engineering."

experience frequent inundation could benefit from natural and nature-based adaptation options like living shorelines, now, to prevent wave damage. However, some combination of natural features and engineered adaptations may be required to prevent flooding over the roadway in years to come.



Figure 1: Shore Road (looking west) and a portion of the existing revetment shown (a) at low tide and (b) just before high tide.⁴

Details of the assessment, which generally followed the steps of the Adaptation Decision-Making Assessment Process (ADAP) shown in Figure 2, are given in the following sections.

⁴ Photo credit: Bret Webb.



Figure 2: Adaptation Decision-Making Assessment Process (ADAP) Used for this Analysis (steps not completed are indicated in gray).

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Details of the Analysis

Step 1. Understand the Site Context

Shore Road is a low-lying coastal road that parallels the south shore of Mt. Sinai Harbor, a small coastal bay in the Town of Brookhaven located along the north shore of Long Island, New York (Figure 3 and Figure 4). This particular 0.25-mile section of Shore Road was chosen for three reasons:

- 1. The road has experienced erosion and failure of the embankment and is threatened by inundation due to sea level rise.
- 2. The Town was already pursuing the use of a living shoreline to stabilize the shoulder through a grant from NYSDOT.
- 3. This road is similar to many of the 60,000 miles of roadway in the United States that are occasionally threatened by coastal storm surge and waves, and potentially affected by long term sea level rise.⁵



Figure 3: Location of Shore Road indicated with star symbol in each of the images.⁶

⁵ FHWA "Highways in the Coastal Environment."

⁶ Left image source: Google Maps; right image source: Google Earth.



Figure 4: Location of asset and study area with surrounding terrain shown in the inset panel.⁷

The section of Shore Road considered in this adaptation assessment borders Mt. Sinai Harbor, a small coastal bay partially enclosed by a bay barrier beach adjacent to Long Island Sound. Mt. Sinai Harbor has an area of approximately 0.8 square miles and a substantial tide range of nearly seven feet. Except for the mooring area located throughout the northern portion of the harbor, the water body is relatively shallow having only a few feet of standing water at low tide; however, the depth increases to nearly 10 feet at high tide. Much of the harbor area consists of large stands of dense, emergent cordgrass marshes, with additional fringe marsh located along a majority of the harbor shorelines. The largest stands of marsh in the harbor total approximately 0.26 square miles, or roughly one-third of the total harbor area.

The public access provided to the water by the section of Shore Road evaluated in this assessment is extremely valuable. The access is used seasonally on a daily basis by commercial clam harvesters as well as recreational clam harvesters and other boaters/kayakers. Clamming is a part of this region's culture that dates back centuries and is important to the citizens. This section of Shore Road, and its shoulders, is also often used by the public to just sit and watch the water throughout the day.

Mt. Sinai Harbor and the surrounding coastal areas of Long Island Sound experience flooding primarily from extra-tropical storms like Nor'easters. The 1% annual chance flood elevation (i.e.,

⁷ Data source: Suffolk County, NY GIS database.

the 100-year return period storm) at the project location varies from +11 feet to +12 feet as shown on FEMA flood insurance rate maps (FIRMs). This area is not frequently impacted by hurricane storm surge. In fact, the return period of major hurricanes (> 96 knots) passing within 50 nautical miles of the area is approximately 70 years (or 1.4% annual probability event).

The historic rate of sea level rise for this part of Long Island is approximately 0.1 inches/year (2.44 mm/yr.) as calculated for the period 1957-1992 at Port Jefferson, the nearest location to the project study area with sea level trends reported by NOAA. This rate is similar to the average global eustatic rate of sea level rise, indicating negligible vertical land movement in this area.

Step 2. Facility Description

Shore Road is a low volume two-lane road connecting Crystal Brook Hollow Road on the west and North Country Road on the east with various suburban neighborhoods in-between. Shore Road provides public access to the water and several homes. All three of these roads provide service between state highways and rail networks in the inland community of Port Jefferson Station, which is located a couple of miles to the south and east of the town of Port Jefferson. The network of roads (Figure 3) around Mt. Sinai, including Shore Road, provide connections to Pipe Stave Hollow road, which borders the eastern shoreline of the harbor, ultimately connecting to Harbor Beach Road and providing access to the Town of Brookhaven's bay barrier beach park, marina facilities, a fishing pier, and a yacht club.

Similar to the surrounding residential streets, Shore Road is a flexible asphalt pavement road with twelve-foot-wide travel lanes in each direction and a crown (high point) along the centerline. The edge of pavement elevation along the north shoulder, facing the harbor, varies from +5.9 feet to +6.5 feet above sea level. This is approximately two feet above the Mean Higher High Water (MHHW) tidal datum at most locations along Shore Road. There is little to no shoulder remaining between the road and harbor, and the failing embankment is protected by a mixture of concrete debris, small rocks, and large boulders. There is a very narrow shoulder along the south side of the road, but much of it is located on private property.

According to the Town of Brookhaven, Shore Road may have been in use since establishment of the area in the late 17th century. The exact age of Shore Road is unknown but it appears on maps dating back to 1873 and the road is clearly visible in a 1947 aerial image of the location (Figure 5). Therefore, it is possible that the alignment and elevation of this roadway were established and the road in some form of use for the last two centuries: potentially long enough for mean sea level to have risen at least 1.5 feet over its existence, as described below.



Figure 5: Aerial imagery of Mt. Sinai Harbor (1947) showing Shore Road alignment.⁸

The shoulder and embankment of Shore Road have been failing for a number of years. The Town has addressed the issue by placing stone, concrete debris, and other rubble to form a portions of revetment (Figure 1) and portions of short seawalls (Figure 6), and has made minor repairs along the edge of pavement. The seawall/revetment material extends a few feet below high water and transitions, near vertically, to a natural grade sloping down to low water in the harbor. The natural slope is characterized by hand-sized cobbles, some medium to coarse sand, and local submerged aquatic vegetation like eelgrass.

⁸ Data source: Suffolk County, NY GIS database.



Figure 6: Typical short seawall/revetment along portions of Shore Road. Presence of algae at a consistent elevation denotes a biological datum that is just below high water. Photo taken at low tide.⁹

Step 3. Climate Stressors

The primary climate stressor affecting the vulnerability of Shore Road over the long term is sea level rise. However, storm surge and wave action have the potential to impact the road now and in the future. Sea level rise will, therefore, affect the damaging coastal processes for this asset in two ways.

Climate Stressors

- $\circ \quad \text{Sea Level Rise} \quad$
- Storm Surge
- **Waves**

As sea levels rise, this site may experience nuisance flooding, as is currently the case on nearby roads, during the astronomical high tides that occur twice daily. In addition, higher sea levels will lead to an increase in the magnitude and extent of inundation from storm water levels and increased exposure of the road and revetment to wave action over longer periods of the day. A similar nearby road, Pipe Stave Hollow Road, is already experiencing nuisance flooding twice daily during astronomical high tides, as is a nearby town park (Satterly Landing). So this climate stressor is already impacting local assets today.

Wave action will have the potential to damage the roadway shoulder and edge of pavement as increasing sea levels reach higher elevations on the roadway embankment. The potential for increased wave heights will grow proportionally with sea level rise. Therefore, wave crests and individual wave runup (i.e., wave-induced water rushing up a slope) events will reach higher

⁹ Photo credit: Bret Webb.

elevations on higher future sea levels. However, attenuation (i.e., reduction) of those waves through may be possible using a living shorelines approach.

Step 4. Climate Scenarios

To assess the vulnerability of Shore Road to long-term sea level rise, the research team collocated knowledge of site elevations, local tidal datums, projections of relative sea level rise under a range of future climate scenarios, and surge return period relationships. The research team had access to readily available data that satisfied these needs so no additional hydrodynamic or climate modeling was performed for this assessment.

Local tidal datums, tide ranges, extreme water levels, and historic rates of sea level rise were determined

Climate Data Overview

Level of Detail: Readily available data

Data Sources: NOAA, USACE, Owner

Scenarios: Low, intermediate, and high sea level rise projections; extreme water levels; and return period surge and wave data

Is exposure projected to change in the future? Yes, exposure to wave damage and inundation will increase with rising sea levels

using two nearby NOAA tide gages¹⁰ (Cedar Beach, Port Jefferson). The tidal datums of Mean Lower Low Water (MLLW) and Mean Higher High Water (MHHW) are shown relative to a representative ground surface elevation profile in Figure 7. The MLLW and MHHW tidal datums correspond to the average of lowest low tide and highest high tide elevations, respectively, over the present tidal epoch (1983-2001). The profile represents actual ground surface elevations surveyed near the eastern one-third of the study area.

¹⁰ The NOAA Tides & Currents data is accessible at: <u>http://tidesandcurrents.noaa.gov/.</u>



Figure 7: Profile of the existing ground surface elevations and tidal datums typical of the study area. This is an actual elevation profile taken perpendicular to Shore Road near the eastern end of the study area.¹¹

Historic and future rates of relative sea level rise were evaluated at the asset location. Historic rates of relative sea level rise were determined using the NOAA tide gage at Port Jefferson (Figure 8). That rate is approximately 0.1 inches per year (0.8 feet per century). The team evaluated relative sea level rise projections using the U.S. Army Corps of Engineers' (USACE) Sea-Level Change Curve Calculator¹² and corresponding adaptation guidance in EM 1165-2-212.¹³ These tools provide regionally-adjusted sea level rise projections that account for the effects of local vertical land movement under low, intermediate, and high sea level rise acceleration scenarios developed by the National Research Council (NRC) and IPCC projections (Figure 9). For the analysis of impacts, the research team considered the USACE low and high sea level rise projections to bracket the range of expected future sea levels (Table 1).

¹¹ Survey data provided by Town of Brookhaven.

¹² The USACE Sea Level Change Curve Calculator (2015.46) is accessible at: <u>http://www.corpsclimate.us/ccaceslcurves.cfm.</u>

¹³ USACE "Sea Level Change Considerations for Civil Works Programs."



Figure 8: Historic relative sea level rise data for Port Jefferson, NY.¹⁴



Relative Sea Level Change Projections - Gauge: 8514560, Port Jefferson, NY (05/01/2014)

Figure 9: Relative sea level rise projections for three climate scenarios from 2015 to 2100. Also shown are the elevation of edge of pavement (dashed line) and projected tidal range (shaded band) corresponding to the USACE high projection.¹⁵

https://tidesandcurrents.noaa.gov/sltrends/sltrends station.shtml?stnid=8514560

¹⁴ Source: NOAA Tides and Currents. Sea Level Trends. Mean Sea Level Trend for Port Jefferson, NY Station (8514560). Available at:

Sea Level Rise Scenario	Global Sea Level Rise from 1992 to 2100, feet (meters)	Local Relative Sea Level Rise from 1992 to 2100, feet (meters)
Low	0.66 (0.2)	0.87 (0.26)
Intermediate	1.64 (0.5)	1.90 (0.58)
High	4.92 (1.5)	5.19 (1.58)

 Table 1: Estimated global sea level and local relative sea level changes for the period 1992 to 2100.

The research team extracted local return period estimates for storm surge elevation and wave height from the U.S. Army Corps of Engineers' Coastal Hazards System.¹⁶ There were close to one dozen model output locations in and adjacent to Mt. Sinai Harbor, with one of the points being just a few dozen feet from the asset, Shore Road (Figure 10). The research team considered these data in combination with projected sea level rise and extreme water level statistics to assess the times at which Shore Road would be inundated under various future climate scenarios. The USACE methods for estimating fetch-limited waves were also used to evaluate wind-wave growth potential across Mt. Sinai Harbor.

¹⁵ Source: US Army Corps of Engineers Sea-Level Change Curve Calculator. Available at: <u>http://www.corpsclimate.us/ccaceslcurves.cfm</u>

¹⁶ The U.S. Army Corps of Engineers' Coastal Hazards System is accessible at: <u>https://chs.erdc.dren.mil/default.aspx.</u>



Figure 10: Frequency-based storm surge elevations and wave heights near Shore Road.

This assessment used a different approach, determining when a critical threshold will be reached, than many other similar assessments. Often, future scenarios of sea level rise lead to projections of vulnerabilities at specific planning horizons (e.g., 2050, 2100, etc.). That methodology constitutes an appropriate and important planning exercise for the design/planning of new infrastructure. In this study, however, the research team employed an alternate approach by acknowledging the asset's vulnerabilities to damaging surge and waves that exist today. Thus, the research team focused on the timeframe during which certain thresholds would be exceeded (e.g., the year in which the asset will flood twice daily during high tide) under a range of different sea level rise and storm scenarios. This approach was adopted because the asset already exists and the planning exercise is to identify possible adaptations to current and future vulnerabilities. So while a traditional approach would be to specify a year and determine the vulnerability, in this assessment the vulnerability was specified and the year in which it would occur was determined.

Using this alternative assessment procedure, the research team was able to suggest possible future dates for vulnerability to flooding under low and high sea level rise scenarios. The research team identified different vulnerability thresholds for yearly, monthly, and daily flooding. Performance of the asset under the low and high climate scenarios is described in the following section.

Step 5. Assess Performance Under Climate Scenarios

In the ADAP methodology shown in Figure 2, Step 5 is broken into Step 5a (assess performance highest impact scenario) and Step 5b (assess performance under all other scenarios). Similarly, Step 6 is also broken down into Step 6a (develop adaptation options for highest impact scenario) and Step 6b (develop adaptation options for other scenarios). The reason these steps are bifurcated is that it may be possible to streamline the analyses by first looking at the highest impact scenario. For example, if it is determined that the asset would not be damaged under the highest impact scenario, then there is no need to evaluate the asset performance for lower impact scenarios.

Facility Performance Overview

Lowest Impact Scenario: USACE low sea level rise projection

Highest Impact Scenario: USACE high sea level rise projection and a 1-year return period storm.

Key models, tools, and assumptions: NOAA and USACE data and SLR projection tools were used to determine future MHHW and extreme water level elevations. Frequent wave damage to the edge of pavement was assumed to occur when water levels were elevated enough to allow wave attack.

Is the structure resilient? No. The roadway will be inundated more frequently during high tides and damaged by waves more frequently.

Although the work was conducted in the order of Steps 5a, 6a, 5b, 6b, in this write up, we combine 5a and 5b into a single Step 5; we took a similar approach for Step 6. This approach was taken for improved ease of reading.

In Step 5, the research team considered two climate scenario intensities to bracket the range of potential future water levels. The USACE low (historic rate) and USACE high (NRC III) sea level rise projections, with regional adjustments, were used to determine when the asset would experience regular flooding due to tides and storms, and when frequent wave-induced damage to the edge of pavement would be likely. As described previously, the research team used this methodology because the roadway is already exposed to extreme water levels and waves and the most likely vulnerabilities are already known.

The research team considered the performance and resilience of the asset in two ways:

- 1. Inundation of the roadway during high water times decreases the level of service/function while also constituting a hazard to drivers.
- 2. The degree to which waves would frequently damage the shoulder, leading to failure of the edge of pavement.

The results of this performance assessment for roadway flooding and wave damage are provided in Table 2. The values shown represent the year when flooding or frequent damage is expected to occur for the selected sea level rise scenarios.

Scenario	1-yr Event Flooding	Monthly Flooding	Daily Flooding	Wave Damage
USACE Low	2025	2270 [*]	2300 [*]	2080
USACE High	2015**	2060	2065	2025

Table 2: Estimated year for Shore Road to experience regular flooding and/or damage.

^{*}Years beyond 2100 are reported for comparison only and these values should be interpreted as "not by 2100" ^{**}Indicates that asset currently floods, or would flood very soon, under this scenario

The research team evaluated the inundation of the asset using the USACE sea level rise guidance and web-based projection tools cited earlier. The asset was considered to be inundated when the sea level rise scenario yielded water surface elevations greater than the edge of pavement elevation (i.e., about +6 feet). The events considered for each sea level rise scenario included flooding due to a storm with a 1-year recurrence interval; monthly flooding due to tidal variability; daily flooding at high tide; and frequent damage due to wave action (see Table 2). Higher storm recurrence intervals were not considered since the asset already floods under a 2year return period storm event. Table 2 suggests that, for the high sea level rise scenario, monthly flooding of the asset due to tidal variability will begin around year 2060.

This analysis could be expanded to determine the year in which a specific depth of flooding over the roadway is achieved. For example, a 1-year return period storm would result in a flooding depth of one foot over the roadway by the year 2040 under the highest climate scenario considered. Such evaluations are made when specific safety or threshold criteria are known (e.g., maximum depth of flooding for safe vehicle operation, pedestrian safety, etc.).

The research team also considered the potential for frequent wave damage to the shoulder as a performance measure (see last column in Table 2). Previous wave damage to the shoulder has led to failure of the roadway embankment over time and is the reason why the slope is currently protected by a revetment. Damaging wave action is currently threatening the roadway, and higher sea levels will cause that damage to occur more frequently and at higher elevations on the embankment and shoulder. The threshold for frequent wave damage shown in Table 2 was assumed to occur when the wave crest elevation was at or near the edge of pavement elevation at high tide. For this assessment, the research team assumed that frequent wave damage to the shoulder would occur on a future sea level that allowed wave crests to attack the edge of pavement elevation continuously and before the roadway is completely inundated.

Step 6. Develop Adaptation Options

The research team considered three possible adaptation options to reduce the vulnerability and exposure of Shore Road to future sea level rise: 1) protect the asset with traditional engineering structures, 2) protect the asset with nature-based methods like living shorelines, and 3) abandon the asset. The first two options address vulnerability by increasing resilience. The third option,

Adaptation Options

Range of options:

- Traditional Protection (Armoring)
- Living Shoreline Protection
- Abandonment
- Relocation
- Elevation and Armoring

abandonment, does not specifically address vulnerability, but eliminates some responsibility at the expense of losing the asset. A summary of these options, including rough order of magnitude costs, is provided in Table 3. The cost estimates are rough order of magnitude estimates based primarily on the research team's experience with unit costs for similar projects around the country (not based on local prices). The cost of the traditional protection will be more than the cost of a living shoreline protection. Two other possible adaptations, relocation of the road and increasing the elevation of the road, were not specifically addressed as adaptation options for reasons described below.

Table 3: Summary	of adaptation	options and	rough order	of magnitude costs.
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Measure	Description	Pros	Cons	Construction Cost
Traditional Protection	Protect and/or reinforce the shoulder using revetment and wall	Increases resiliency to waves; postpones flooding	Increases shoreline armoring; eliminates marsh shoreline habitat; maintenance	\$1.3M
Living Shoreline Protection	Protect the road from wave damage using a living shoreline approach	Increases resiliency to waves; provides natural habitat; may keep pace with SLR	Regulatory hurdles; does not address flooding of roadway	\$0.5M
Abandon the Road	Abandon the asset and/or allow the pavement to fail	Removes long-term burden to asset owner; eliminates vulnerability	Dislocation or condemnation of private property; reduced public access to waterfront	\$5M

Option 1 – Traditional Protection

A common approach for protecting shore-parallel roads is to use traditional coastal engineering structures like rock revetments and vertical walls. Figure 11 shows a typical example where the roadway and shoulder are protected by a rock revetment and a vertical sheetpile wall (not visible under concrete cap) finished with a concrete cap. This combination of structures was selected by the research team for this Shore Road assessment because it can be designed to address two important vulnerabilities for coastal roads: the wave damage that is occurring now and the flooding that may worsen with future sea level rise. The sloping rock revetment is effective at absorbing wave energy and the porous nature of the structure reduces wave runup on the slope. Additionally, the rock revetment serves as scour protection at the base of the sheetpile wall. Placement of the vertical wall and concrete cap provide the additional elevation needed to protect against frequent flooding while simultaneously protecting the roadway from wave action during elevated water levels. An alternative which avoids the use of sheetpile could be a larger, taller form of rock seawall similar to the small, existing wall at Shore Road. Such vertical rock seawalls are common to the region. Essentially, the present day existing protection of Shore Road (see Figure 1 and Figure 6) is a low-budget form of armoring which is failing.



Figure 11: Example of traditional armoring and protection of a low-lying road along Mobile Bay, AL.¹⁷

A diagram of a possible form of the traditional armoring adaptation for Shore Road is shown in Figure 12. The diagram shows the approximate locations of Shore Road (left), a sheetpile wall with concrete cap running along the roadway shoulder, and a sloping rock revetment installed atop geotextile fabric. The revetment should be designed to withstand wave attack as described in HEC-25.¹⁸ The depth of sheetpile would have to be designed by a geotechnical engineer familiar with local soil conditions. Note that some scour is expected to occur at the toe of the revetment (i.e., at its lowest elevation) since it does not extend below the MLLW tidal datum. Appropriate scour countermeasures that address this failure mechanism are also described in HEC-25.¹⁹ The concept shown in the diagram could be designed to protect Shore Road by establishing a design crest elevation (and including surface drainage).

¹⁷ Photo credit: Scott Douglass.

¹⁸ FHWA "Highways in the Coastal Environment."

¹⁹ FHWA "Highways in the Coastal Environment."





Option 2 – Living Shoreline Protection

A living shoreline, which is an example of natural and nature-based protection,²⁰ could be used to protect Shore Road from wave damage. A living shoreline is generally defined as an alternative to bank and shoreline stabilization that uses natural and organic materials that complement the natural shoreline characteristics while providing suitable habitat for local species. A living shoreline can be a preferred alternative to traditional shoreline armoring when designed properly and used appropriately, particularly along sheltered shorelines like the one found here.²¹

Some sections of Shore Road east and west of the study area are already protected by stable, healthy saltwater marshes. One of these marshes, shown in Figure 13, serves as a useful reference site by demonstrating a suitable living shoreline adaptation. In this series of photographs taken throughout a tidal cycle, a marsh protected by large boulders along its edge is seen at low tide, near high tide, and then finally at high tide. The large boulders here appear to be native but placed there intentionally during construction of the public park area at Satterly Landing to prevent erosion. The engineering of living shorelines is evolving but a fundamental principle of any nature-based design is to let nature be the guide for the design engineer. The living shoreline adaptation considered here seeks to replicate the existing natural marsh habitat in the lee of those boulders near Satterly Landing in combination with other coastal engineering techniques appropriate for this location.

²⁰ USACE "Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience."

²¹ NRC "Mitigating Shore Erosion along Sheltered Coasts."



Figure 13: Existing marsh site near Satterly Landing shown at (a) low tide, (b) near high tide, and (c) at high tide. Arrows show consistent locations (boulder) and elevations (marsh) in each frame.²²

A diagram of a possible form of a living shoreline marsh for Shore Road is shown in Figure 14. The living shoreline is a constructed marsh that parallels the 0.25-mile of roadway, with large boulders placed along the toe (seaward edge) of the marsh to retain the fill and reduce wave energy. The rocks would be placed in segmented groups to allow wave diffraction (i.e., bending of wave crests and scattering of wave energy) to create a stable equilibrium shoreline position in the gaps. Nearshore segmented breakwater systems and headland pocket beach systems are related forms of coastal engineering used for shore stabilization²³ which can be successfully adapted to marsh creation projects. The small "pockets" that form in the gaps are not only effective at stabilizing the shoreline position, but they also reduce the amount of rocks needed along the toe while increasing the total length of intertidal shoreline and marsh edge. These gaps also provide ingress and egress for mobile species (fishes and crabs) as well has human users.



Figure 14: Diagram of constructed marsh living shoreline with segmented toe protection boulders for Shore Road.

Figure 15, a profile diagram through the constructed marsh, shows the addition of clean sand fill to establish a suitable marsh slope (preferably one that matches those in the study area); the large boulders placed at the toe of the fill; a continuous placement of suitable geotextile fabric along the landward side of the boulder placements to prevent loss of fill at the toe; and plantings

²² Photo credit: Bret Webb.

²³ FHWA "Highways in the Coastal Environment."

of appropriate saltmarsh (Spartina alterniflora) and saltmeadow (Spartina patens) cordgrass below and above the MHHW tidal datum, respectively.



Figure 15: Diagram of constructed marsh profile showing Shore Road (left), clean sand fill, toe protection boulders, and vegetation plantings below and above the MHHW tidal datum (not to scale).

With exception of the geotextile fabric, all materials could be sourced locally and should match the native conditions and characteristics as closely as possible. For example, the size and gradation of fill material should match that of the native material as closely as possible and vegetative plantings could be transplanted from nearby donor marshes. The research team was told that large boulders are readily available in this area of Long Island.

In this concept, the existing revetment has been buried by the fill to provide some redundancy for protection of the roadway. Note that a typical profile in one of the marsh gaps/pockets would have a modestly steeper slope and no boulder or geotextile at the toe. The shoreline slopes in these pockets will equilibrate over time to the reduced wave energy in the gaps and consist of a mixture of sandy beach and marsh plants. The result will be a series of pocket beaches backed by dense saltmarsh.

Option 3 – Abandonment

Abandonment of the road will essentially result in the elimination of the responsibility, on the part of the asset owner, for the asset. Abandonment of Shore Road could take different forms:

- The asset owner could abandon the roadway and, after failure, remove it from service with no plan for repair;
- The asset owner could abandon the roadway by deeding it over to local property owners as a private drive; or
- The asset owner could abandon the roadway altogether and acquire the private parcels that it provides access to.

While abandonment is sometimes included as an adaptation option in general planning studies, there are related legal issues which may prevent it from being a realistic option for transportation organizations and it does nothing to increase the asset's resilience to future climate change. Additionally, the cost of abandoning this asset may exceed the actual costs of protecting the road.

In this case, abandonment is a fairly extreme option and would not likely be considered for a number of reasons. First, the asset is not expected to experience routine flooding and damage for a number of years. Second, the cost of adaptation is not exceedingly high. Finally, the road currently serves as the only means by which a number of property owners access their homes.

Other Options

The long-term vulnerability of Shore Road is a function of future sea levels. Assuming the embankment and shoulder are successfully stabilized by some natural or structural means (see the previous adaptation strategies), use of the asset requires that it is not frequently flooded. Other possible adaptation options that increase the long-term resilience to flooding include elevating the roadway in place and/or relocating the asset to a higher elevation.

In-place elevation of the roadway by fill and paving is not practical as it would over-steepen the embankment, possibly leading to increased failure of the shoulder. The local terrain and limited right-of-way along the south shoulder of Shore Road make realignment of the roadway somewhat impractical, mostly because of the small benefits it provides.

Some combination of realignment and relocation to a higher elevation along the southern hillside would greatly reduce the vulnerability of Shore Road and allow the embankment to maintain an appropriate slope, but would require easement/right-of-way acquisitions, modifications to the private drives along Shore Road, and a considerable amount of construction fill.

Step 7. Assess Performance of Adaptation Options

Protection of the roadway by either traditional armoring or a living shoreline addresses the immediate vulnerability of the asset by reducing its exposure to damaging wave action. The traditional armoring approach explicitly addresses the long-term flooding issue as described above and below, but that issue is not critical yet. The living shoreline approach provides different habitat values in that intertidal marsh grasses will replace tidal flats and a vertical wall. The general performance of these two adaptation strategies are briefly described below and some comments regarding constructability and maintenance are also provided.

Option 1 - Traditional Protection

The traditional adaptation approach addresses two vulnerabilities of the roadway—wave damage today and flooding in the future—without the need for increasing the elevation of the roadway itself. In this case, the vertical sheetpile wall and concrete cap provide the additional elevation needed to reduce the vulnerability to flooding from still water and wave overtopping

(passing of water of water over the top of the cap as result of the wave action). To be effective, the wall and cap installation would need to extend outside of the study area to sections of the road that are currently at higher elevations and, therefore, less vulnerable to flooding.

The crest elevation for the seawall cap will limit future flooding. For example, the addition of +1 ft. of protection provided by a wall and cap could potentially delay the onset of daily nuisance flooding by 15 years from 2065 to 2080 under the USACE high scenario. That same level of protection could also prevent the asset from flooding under a 2-yr return period storm event until about 2025. As stated earlier, the asset already floods under this storm scenario. A more thorough analysis of these potential benefits is given in Table 4.

Table 4: Estimated years for Shore Road to experience flooding and wave overtopping under existing conditions (no adaptation) and with the addition of +1 ft. and +2 ft. of protection using the traditional adaptation.

Scenario	Crest Elevation	2-yr Storm	1-yr Storm	Wave Overtopping	Daily Flooding
USACE Low	None	2015**	2025	2080	+2300*
	+1 FT	2080	2150*	2155*	
	+2 FT	2205*	2275*	2235*	-
USACE High	None	2015**	2015**	2025	2065
	+1 FT	2025	2040	2040	2080
	+2 FT	2050	2060	2055	2095

*Years beyond 2100 are reported for comparison only and these values should be interpreted as "not by 2100" **Indicates that asset currently floods, or may flood very soon, under this scenario

Other considerations related to this traditional adaptation include constructability and maintenance. In terms of constructability, most of the work could be performed from the existing roadway with the closure of one lane of traffic. The construction methods and materials would be familiar to most general coastal waterfront construction firms. Additionally, some maintenance of the revetment toe may be needed to address scour when waves attack the toe at lower tides.

Finally, some provision for drainage would have to be made along the section of roadway behind the wall and cap. Currently, there is no stormwater collection system and runoff drains from the roadway into the harbor. This would lead to ponding behind the adaptation in the absence of drainage improvements. This problem would be compounded during storm events where the water level and/or waves rise above the cap elevation. Careful consideration must be given in this circumstance, particularly if any collection system would drain into the harbor, to ensure that the drainage system does not provide a secondary pathway for flooding during elevated water levels.

Option 2 - Living Shoreline Protection

The living shoreline adaptation can also eliminate the repetitive wave damage that the asset experiences at high tide. The existing saltmarshes along the roadway are already doing this now: in those areas, there is little to no wave damage present and there is no revetment either. Laboratory investigations²⁴ show that Spartina alterniflora marshes are effective at reducing wave heights by as much as 90% over a horizontal distance of 30 ft. (i.e., through the marsh). Existing marshes in the study area extend 70 ft. to 100 ft. from the edge of pavement out into the harbor, and the constructed marsh described here would be of similar size. The elevation of the new marsh will essentially protect the shoulder from waves. Therefore, the constructed marsh should be very effective at reducing wave damage along the shoulder. However, the living shoreline itself does nothing to eliminate the potential for flooding when water levels are above the roadway elevation.

Considering future sea level rise, some studies suggest that saltmarshes are at least keeping pace with the present-day rate of sea level rise in the Long Island Sound area.^{25 26} This suggests that the living shoreline adaptation may function as well in the future as it does at the time of construction with regards to wave height attenuation and protection of the roadway shoulder.

In terms of constructability, the techniques for construction will be less common but should be easily accomplished by a coastal marine contractor with restoration experience. The material costs could be considerably less than the traditional adaptation described earlier. Also, the living shoreline adaptation would require little to no maintenance over time. There may be a need for some adaptive management including providing supplemental plantings through the first several growing seasons depending on the success of the planted marsh and related to sand movement in response to the establishment of a new equilibrium with the structures.

Step 8. Conduct Economic Analysis

This step was not completed for this adaptation assessment in large part because of the uncertainties related to the adaptation options evaluated.

Step 9. Evaluate Additional Considerations

Obtaining the required coastal construction permits will be more straightforward for the traditional armoring adaptation option than the living shoreline adaptation option. Placement of a constructed marsh seaward of the existing seawall/revetment will encounter different,

²⁴ USACE "Laboratory Studies of Wave Attenuation through Artificial and Real Vegetation."

²⁵ Cochran, J.K., Hirschberg, J.W., and Dere, C. "Atmospheric Deposition of Metals to Coastal Waters (Long Island Sound, New York U.S.A.): Evidence from Saltmarsh Deposits."

²⁶ Orson, R.A., Warren, R.S., and Niering, W.A. "Interpreting Sea Level Rise and Rates of Vertical Marsh Accretion in a Southern New England Tidal Marsh."

significant, and less commonly addressed regulatory issues. One way to address these may be with a special variance as a living shoreline demonstration project. The variance would be required to address two specific regulatory issues in the State of New York: activities seaward of mean high tide and filling of water bottoms.

Restrictions set by the New York Department of Environmental Conservation limit any activity seaward of the mean high-water line and at Shore Road this line is close to the top of the existing revetment.

While it is possible, in some cases, to obtain permits for such projects, filling of water bottoms is typically severely restricted. Therefore, a strong justification would have to be made regarding the environmental benefits of the living shoreline outweighing the impacts associated with the partial filling of the existing water bottoms. Essentially, this project will be trading the habitats of the natural intertidal flats (with a newly engineered wall structure to protect the road) for the constructed intertidal and high marsh of the living shoreline project. Similar projects have been allowed as demonstration projects with some level of required monitoring around the country. The regulatory framework in some states (e.g., Alabama, Maryland, Mississippi, New Jersey, North Carolina) has been modified to allow such projects, where they are suitable alternatives to traditional shoreline armoring, under general coastal construction permits.

Step 10. Select a Course of Action

The preferred course of action is to initially use a living shoreline to protect Shore Road from wave action at high tide. This adaptation addresses the current vulnerability of Shore Road to wave damage at a relatively low cost while recognizing that the roadway, due to its existing elevation, may not be impacted by routine flooding for many years. Also, use of the living shoreline is likely to have positive impacts on habitat and water quality in the harbor and complements future wetlands restoration activities in the harbor planned by the asset owner. Burial of the existing seawall/revetment would provide a measure of redundancy during storm events, with the constructed marsh placed seaward of it.

Step 11. Develop a Facility Management Plan

In light of the uncertainty in future sea level rise projections, adaptive management may play an important role in determining when additional protection of the roadway is needed to prevent or reduce the frequency of flooding. Some combination of the traditional and living shoreline protection could be used in the future, whereby a sheetpile wall and concrete cap are added in between the roadway and constructed marsh. A small vegetated berm along the roadway shoulder, in combination with the living shoreline protection, could potentially work just as well and stave off flooding for a considerable time.

Lessons Learned

During the course of this study, the project team identified the following lessons learned:

- A living shoreline is a suitable adaptation measure that addresses protection of Shore Road.
- Low-lying coastal roads may require some combination of protection and increased elevation to reduce their vulnerability to flooding and wave overtopping.
- Living shorelines can be used in conjunction with traditional engineering protection to provide a more complete and resilient system of protection.
- Even where living shorelines may not provide comprehensive protection in the long term, they can be used as cost- and environmentally-appropriate measures that provide initial resilience until a more traditional, engineered structure is added for greater protection.
- Climate stressors, like sea level rise, are likely reducing the functionality of some older transportation infrastructure already, a situation that will likely worsen with time.
- Existing sea level rise projections and frequency-based storm surge data provide information suitable for performing adaptation assessments in some cases.

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