D. ALTERNATIVES ASSESSMENT

The Towns of Marshfield and Duxbury have evaluated alternatives for incorporating more resilient strategies for shore protection that will mitigate the effects of climate change, improve storm damage protection, reduce wave overtopping, provide protection for the existing shore protection structures, and can be adjusted to respond to changes in sea level. Rather than abandon the existing management approach, the Towns are seeking alternatives that will augment the current practices which include repair and maintenance of existing shore protection structures, elevating structures, buying out property owners, and regulating development in high hazard areas.

In preparation for the alternatives assessment, the study area was divided into fourteen (14) different beach areas based on the natural and anthropogenic features along the coastline. Primary factors used in the beach characterization were shoreline type, wetland resources, width of the high tide beach and intertidal zone, presence/absence of shore protection structures, and type of structure. The grouping of similar stretches of coastline was used to help guide the alternatives assessment, and eventually to select the most appropriate resiliency approach for each beach.

The goal of the alternatives analysis was to identify and evaluate reasonable, practicable, and feasible alternatives that will enhance the resiliency of the shoreline, while minimizing short and long-term impacts. To start, a variety of shore protection alternatives were identified and evaluated broadly in terms of their suitability for the Marshfield and Duxbury shoreline. The initial evaluation looked at three primary factors in determining suitability. These included (1) ability of the alternative to provide the necessary level of shore protection, (2) level of expected environmental impact, and (3) estimated costs associated with construction, and maintenance. Alternatives considered included hard (i.e., seawalls and revetments) and soft (i.e., beach and dune nourishment) engineering solutions, hybrid or innovative approaches, and continuing with the existing management approach, or *status quo*. Results from the initial broad evaluation of alternatives were then used as the basis for a more detailed assessment of alternatives for site-specific beaches along the Marshfield and Duxbury shoreline.

1.0 Beach Characterization

The shoreline in the study area was divided into fourteen (14) different beach areas as shown in Figure D-1. A summary of wetland resources, beach and nearshore characteristics, and types of shore protection structures for each beach area is provided in Table D-1. The initial alternatives assessment broadly considered the suitability of various hard, soft and hybrid alternatives for the Marshfield and Duxbury shoreline. The more detailed assessment that followed then evaluated the alternatives for each of the fourteen (14) beach areas.

Figure D-1. Marshfield and Duxbury beach segments.

Table D-1. Wetland Resources, Beach and Nearshore Characteristics, and Types of Shore Protection Structures for the Marshfield and Duxbury Beach Segments.

Beach	Wetland Resources	Beach & Nearshore Characteristics	Shore Protection Structure
Rexhame Public	coastal beach coastal dune barrier beach	public beach with sandy dune that extends across barrier beach; mixed grain size beach (sand, gravel and cobble) with relatively wide high tide beach and moderately wide intertidal zone	NA
Rexhame	coastal beach barrier beach (N end) rocky intertidal shore	private beach with mixed grain size (sand, gravel and cobble); bisected by partially submerged headland known as Beadle Rock; high tide beach narrows south of Beadle Rock while width of intertidal zone increases significantly	low-lying concrete seawalls and rock revetments bisected by unprotected beach access paths
Winslow Ave.	coastal beach coastal dune barrier beach (N end)	public beach with cobble dune and mixed grain size beach (sand, gravel); moderately wide high tide beach and wide gently sloping intertidal zone	NA
Fieldston	coastal beach	private beach with mixed grain size (sand, gravel); narrow high tide beach and wide gently sloping intertidal zone	concrete seawall
Sunrise	coastal beach barrier beach rocky intertidal shore	private beach with mixed grain size (sand, gravel); narrow high tide beach and wide gently sloping intertidal zone	concrete seawall with rip rap toe protection in places
Ocean Bluff	coastal beach rocky intertidal shore	private beach with mixture of grain sizes (sand, gravel and cobble); anchored at south by ~ 600 ft long low-profile groin; no high tide beach; narrow intertidal zone at north end that widens to gently sloping intertidal zone towards groin	concrete seawall with stone revetment at the toe; stone revetment at the southern end
Hewitt's Point	coastal beach rocky intertidal shore	private beach with mixture of gravel and cobble; steeply sloping and narrow high tide beach and intertidal zone	stone revetment at northern end and concrete seawall at central and southern end
Brant Rock	coastal beach barrier beach rocky intertidal shore	private beach with mixture of gravel and cobble; steeply sloping and narrow high tide beach and intertidal zone; anchored at south by ~750 groin to naturally occurring rocky outcrop known at Brant Rock	concrete seawall
South Brant Rock	coastal beach barrier beach rocky intertidal shore	private beach with mixed grain size (sand, gravel and cobble); narrow high tide beach and wide gently sloping intertidal zone	concrete seawall with rip rap toe protection; rubble mound revetment; concrete seawall with stone revetment at toe
Blackman's Point	coastal beach coastal bank rocky intertidal shore	private beach with eroding coastal bank and mixed grain size beach (sand, gravel and cobble); narrow high tide beach fronted by partially submerged rocky outcrop	NA
Blue Fish Cove	coastal beach barrier beach	private beach with mixed grain size (sand and gravel); moderately wide high tide beach and intertidal zone	low-lying rubble mound revetments
Green Harbor	coastal beach coastal dune barrier beach	public beach with sandy dune and beach; extensive high tide beach and dune area with wide and gently sloping intertidal zone	NA
Bay Ave.	coastal beach coastal dune (N end) barrier beach rocky intertidal shore	private beach with mixed grain size (sand and gravel); moderately wide high tide beach at the north that disappears to the south; wide and gently sloping intertidal zone	concrete seawall with rip rap toe protection in places
Gurnet Rd.	coastal beach coastal dune (middle) barrier beach	private beach with mixed grain size (sand and gravel); no high tide beach in the north that gradually widens to the south; wide and gently sloping intertidal zone	concrete seawall with rip rap toe protection in places

2.0 Alternatives Considered

2.1 Maintain Existing Management Approach – *Status Quo*

This alternative makes no changes to the existing management approach for the Marshfield and Duxbury shorelines. Both Towns would continue with repairs and maintenance of the existing shore protection structures, on an as needed basis. While the existing structures will continue to provide the last line of defense against landward retreat of the shoreline, storm damages to public and private properties caused by wave overtopping and flooding will not be addressed by this alternative. Wave interaction with the shore protection structures will continue to lower the beach elevations, expose structure foundations, and undermine the base of the shore protection structures. With future impacts of climate change and sea level rise, the *status quo* alternative will result in increased wave overtopping and flooding, thereby threatening public safety, health, and welfare. Implementation of this alternative as the only management approach will place the residential properties and public infrastructure at increasing risk, as the shore protection structures continue to degrade, and the beaches continue to erode.

The *status quo* alternative does nothing to restore sediment to critically eroded beaches, and instead continues to exacerbate the erosion problem. The ability of the affected beaches to provide wildlife habitat for shorebirds and to serve as a recreational resource will continue to be adversely impacted. As such, this alternative provides no environmental benefit to the system.

Historical data from Federal Emergency Management Agency (FEMA) flood insurance claims, as well as town records on costs associated with repairs and maintenance to the existing shore protection structures, emergency services during storms, and post storm clean up were used to estimate future costs of the *status quo* alternative. Costs for each town projected over the next 30 years are shown in Table D-2.

Table D-2. Projected Costs Over Next 30 Years to Maintain Existing Management Approach.

Town	FEMA Repetitive Loss Claims	Shore Protection Structure Repairs	Storm Related Public Services	Total
Marshfield	\$15.1 million	\$51.0 million	\$7.5 million	\$73.6 million
Duxbury	\$5.0 million	\$16.4 million	\$5.7 million	\$27.1 million

Projections shown for the FEMA repetitive loss claims were calculated using claims data from 1978 to 2017. The average annual payout over this time period was assumed to continue with an inflation rate of 3%. Future costs shown for repair of the existing shore protection structures were based on contractor bids for upcoming work and engineering department estimates and include annual inflation of 3% over the next 30 years. Projections for storm related public services were generated from town records for past events. The average cost per year was assumed to continue with an inflation rate of 3%.

The projections shown in Table D-2 should be considered conservative, as they do not factor in the influence of sea level rise, increased storm intensity or increased storm frequency on costs to the towns. The potential for lost tax revenue from a lowering of property values and a reduced income from tourism due to the loss of recreational resources are additional factors that the towns will face with the *status quo* alternative. This analysis of the *status quo* alternative provides a basis for comparison with other shoreline resiliency solutions identified for site-specific beaches in Section 3.0 below.

2.2 Enhance and/or Enlarge Existing Seawalls and Revetments

Seawalls and revetments are currently the main form of shore protection along the developed shorelines of Marshfield and Duxbury. In fact, 83% of the shoreline in Marshfield contains hard shore protection structures, and 91% of the developed shoreline in Duxbury has hard shore protection structures. The Towns have spent considerable resources over the years to repair and maintain the shore protection structures, and this work is expected to continue into the future. However, as described above for the *status quo* alternative, regular repair and maintenance of the structures, with no additional resiliency measures, will do nothing to fix the problems of wave overtopping, flooding, or damage to public and private infrastructure. As such, the possibility of enhancing and/or enlarging the existing shore protection structures was evaluated as an alternative.

Engineering analyses of overtopping at the Marshfield and Duxbury shore protection structures were conducted to determine whether increasing the crest elevation of the structures would have a measurable impact on overtopping rates. Engineering guidance from the U.S. Army Corps of Engineers (USACE, 2002) indicates that structural damage to buildings can be avoided when average overtopping rates are less than $3x10^{-4}$ $ft^3/sec/ft$ ($3x10^{-5}$ $m^3/sec/m$) (Figure D-2). Overtopping calculations using the Euro top method (van der Meer, 2016) were performed on the existing shore protection structures under 10-yr and 50-yr storm events. Results indicated overtopping rates above the U.S. Army Corps of Engineers threshold for structural damage at all existing shore protection structures along the Marshfield and Duxbury shoreline, with the exception of Rexhame Beach and Hewitt's Point Beach. The calculations were then updated to identify reductions in overtopping associated with increasing the crest elevation of the shore protection structures. Crest elevations necessary to avoid structural damage to buildings from overtopping were determined for each beach segment with coastal engineering structures. The analyses were performed for the 10-yr and 50-yr storm events and for a projected sea level rise scenario of 2 ft, corresponding to the 2040 to 2060 time frame.

Seawall and/or revetment modifications could also include the addition of a revetment along the seaward toe of the existing structures as a way of reducing wave overtopping. A similar shore protection design was implemented by the U.S. Army Corps of Engineers at Roughans Point in Revere in the late 1990s (D-3). Based on this design, conceptual revetment modifications that would protect against overtopping during a 50-yr storm with 2 ft of sea level rise were evaluated for the Marshfield and Duxbury shorelines. While providing significant overtopping protection, the revetment modifications would extend seaward of the existing walls by approximately 50 to75 ft, depending on local nearshore topography. Without the placement of nourishment in front of the modified revetments, this alternative would result in the loss of large areas of coastal beach.

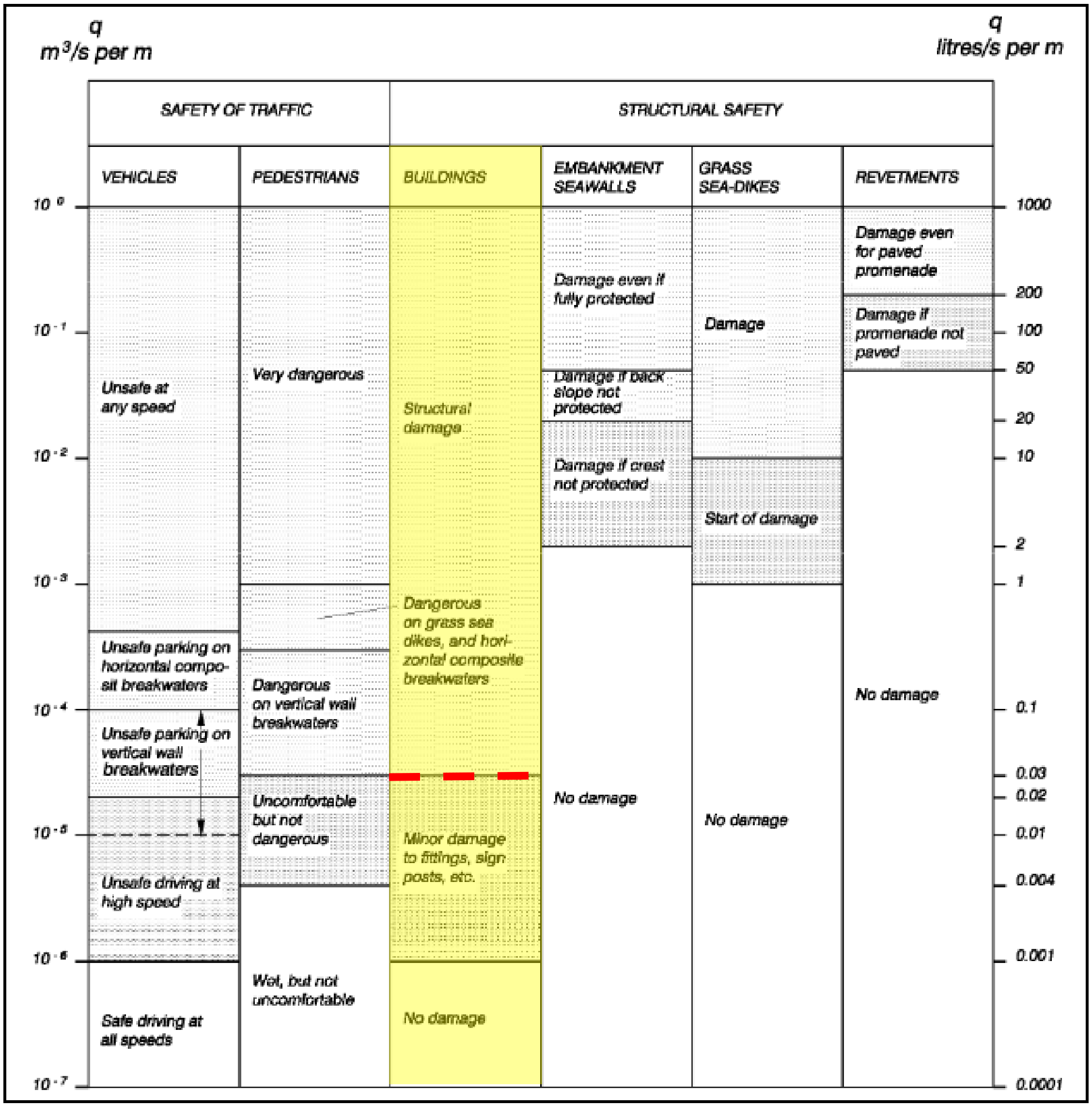

Figure D-2. Critical Values of Average Overtopping Discharges (USACE, 2011).

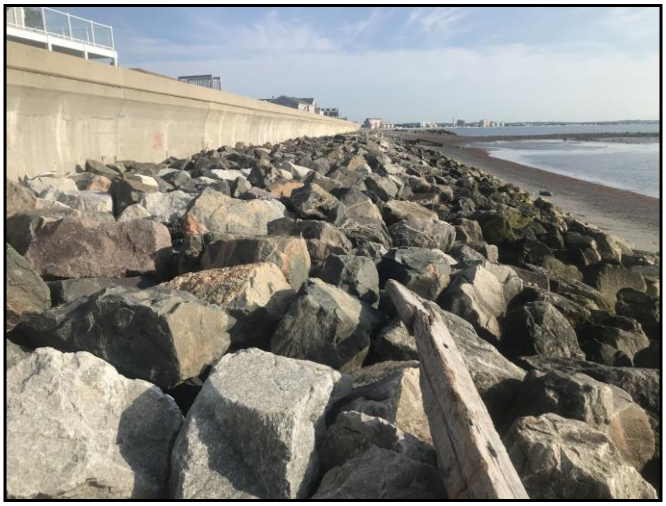

Figure D-3. Example of revetment extension in front of Rougan's Point seawall.

As with the *status quo* alternative, the enlargement of seawalls and revetments does nothing to restore sediment to critically eroded beaches, and instead continues to exacerbate erosion. The ability of the affected beaches to provide wildlife habitat for shorebirds and to serve as a recreational resource will continue to be adversely impacted. As such, this alternative provides no environmental benefit to the system.

Enhancing or enlarging the seawalls and/or revetments was only considered for locations where shore protection structures currently exist. Local, state and federal regulations generally prohibit new coastal engineering structures on barrier beaches and coastal dunes like those present along the Marshfield and Duxbury shorelines. Environmental permitting required to enhance or enlarge existing shore protection structures can be difficult and time consuming. In addition, compensatory mitigation in the form of beach nourishment is often required for projects proposing significant modifications to existing structures. In fact, recent permits issued to the Towns of Marshfield and Duxbury for enhancement of structures damaged by the March 2018 storms required the Towns to pursue permitting for compensatory beach nourishment.

The costs to raise the seawalls and revetments to elevations that would provide sufficient storm damage protection was evaluated based on construction estimates provided by the Towns of Marshfield and Duxbury for planned work on the Bay Ave. and Gurnet Rd. shore protection structures. The costs were estimated between $7,000 and $9,000 per linear ft. The higher costs would be for areas where existing buildings and roads are close enough to the structures, where steel sheeting would be required to ensure stability of the landward infrastructure. Costs to add a revetment along the seaward toe of the existing structures were estimated based on costs reported for the U.S. Army Corps of Engineers Rougans Point project (USACE, 1991). Assuming a 3% rate of inflation since 1991, current costs for extension of the revetment in 2020 would be $7,000 to $9,000 per linear ft.

2.3 Offshore Breakwaters

Offshore breakwaters are a shore protection alternative designed to reduce wave action in the lee of the structure to minimize and/or eliminate beach erosion. Beaches in the lee of the breakwater have calmer wave conditions that potentially allow for sediment deposition and beach accretion. Typically, this type of shore protection is provided from a single large offshore rubble mound (rock) structure, or a series of shorter segmented breakwaters oriented parallel to the shoreline. The structure is installed on the sea floor and extends into the water column to trigger wave breaking during storms.

A few criteria must be met for a breakwater to be effective at breaking storm waves and dissipating wave energy. The breakwater must be designed with enough profile (vertical height) off the bottom and large enough crest width relative to wavelength (width in offshore direction) to cause storm waves to trip and break. A low and/or narrow structure will not trigger wave breaking and therefore not be a viable shore protection alternative. The profile height of the structure becomes an issue with large tide ranges and/or substantial storm surges. The crest of the structure must be set at a height to cause wave breaking during storms when the water levels are elevated and can be further amplified by high tides.

Sediment trapped behind a breakwater is derived from the ambient littoral drift. However, in heavily armored or sediment starved areas like Marshfield and Duxbury, sediment accumulation is impacted significantly by the lack of material in the littoral system. In other words, even with a properly designed breakwater, there is no guarantee that sediment will accumulate along the adjacent beaches. Trapping the natural littoral drift can also be a concern for erosion of downdrift beaches. Artificially nourishing behind the breakwaters to an equilibrium planform may prevent downdrift erosion for some finite period of time (until more nourishment is required), and the longshore transport may continue, unaffected by the breakwater.

Conceptual designs for offshore breakwaters at Fieldston/Sunrise Beach and Bay Ave./Gurnet Rd. Beach were developed based on similar analyses conducted for North Scituate Beach and Surfside Road (Applied Coastal Research and Engineering, Inc., 2016). The designs were modeled after the existing stone breakwater at Winthrop Beach, MA which is located along the approximate -15 ft NAVD88 depth contour. The conceptual designs included a system of offshore breakwaters located approximately 900 ft from the shoreline and extending 3,340 ft in the longshore direction (Figures D-4 and D-5). The individual breakwater segments would be 330 ft long and separated by 100 ft gaps. A total of 8 segments would be needed to span the shoreline at each beach. The breakwater segments would have a crest elevation of 8.5 ft NAVD88, a crest width of 12 ft, and side slopes of 2V:3H. The structure crests would extend above the water level at all stages of the tide but would be submerged by approximately 2 ft of water during a 100-yr storm event. The reduced water depth over the structure would cause waves to break offshore as the pass over the breakwater.

The footprint of the conceptual breakwaters at Fieldston/Sunrise and Bay Ave./Gurnet Rd. Beaches would be approximately 6.3 acres per site. As such, the structures would alter a significant area of benthic habitat and areas that are used for shellfishing. These impacts to the environment, along with the potential for adverse impacts to downdrift beaches would present significant challenges during the permitting process. Additionally, the conceptual design for the Bay Ave./Gurnet Rd. Beaches is located in close proximity to the U.S. Army Corps of Engineers disposal area for sediment dredged from Green Harbor. While there is no data to suggest this material makes its way back to the beach, a breakwater in this location would eliminate any possibility of onshore transport of the material, thereby removing a possible source of sediment to the already starved beaches.

The volume of stone needed to build the breakwater at either beach would be approximately 134,400 cubic yards. Assuming a cost of $125/ton to source the stone and build the breakwater, the estimated cost for construction at one site would be approximately $22.5 million. Based on the likelihood for minimal sediment accumulation in the lee of the breakwaters, the expected area of impact, and the cost, this alternative was determined to be unsuitable for use along the Marshfield and Duxbury shorelines.

Figure D-4. Conceptual design for offshore breakwater offshore of Fieldston and Sunrise Beaches.

Figure D-5. Conceptual design for offshore breakwater offshore of Bay Ave and Gurnet Rd. Beaches.

2.4 Beach Nourishment

One of the primary causes of coastal erosion is a deficit of sediment within the coastal system. To offset this deficit, the placement of beach nourishment is a common alternative for improving the longevity of the shoreline where such a project is economically feasible. Beach nourishment would add sediment in front of the seawalls and revetments, or along the natural sections of beach, to create a wider beach that would dissipate wave energy and increase protection for public and private property that is currently threatened by wave overtopping.

Beach nourishment can be implemented as part of a large-scale engineered project that is designed to provide storm damage protection for a specific level of storm (i.e., 20 or 50-yr return period storm), or it can be implemented in conjunction with a dredging project that beneficially reuses dredged material to add sediment to the littoral system. Typically, the engineered projects call for a large volume of sediment to meet the design criteria while beneficial reuse projects involve smaller volumes that add material to a sediment starved system. The expectations and results associated with each type of nourishment project are different; beneficial reuse projects are designed to keep sediment in the littoral system, but not necessarily to provide any specific level of protection, while engineered projects are designed to provide a specific level of storm damage protection.

After a beach nourishment project is constructed, coastal processes act to reshape the nourishment to create a new equilibrium profile. Storms can also act on the nourishment to modify its shape. During these processes, sediment is transported in both the cross-shore and longshore directions. Material that moves offshore is typically not lost, as it serves to dissipate wave energy naturally during high energy wave conditions and can be transported back onshore during lower energy conditions (Figure D-6). Longshore transport of sediment from a beach nourishment project must be factored into the design, including the potential for impacts to sensitive resources and increased shoaling in nearby navigation channels and harbors. Over time, longshore transport carries sediment away from the project footprint and renourishment is required to maintain the desired level of storm damage protection. As such, a maintenance plan for periodic renourishment is necessary for this alternative to be an effective long-term management strategy. The service life of a beach nourishment project, and the expected renourishment interval, is estimated using wave and sediment transport modeling, where renourishment is typically considered when the project has lost 70% to 80% of material from the original footprint.

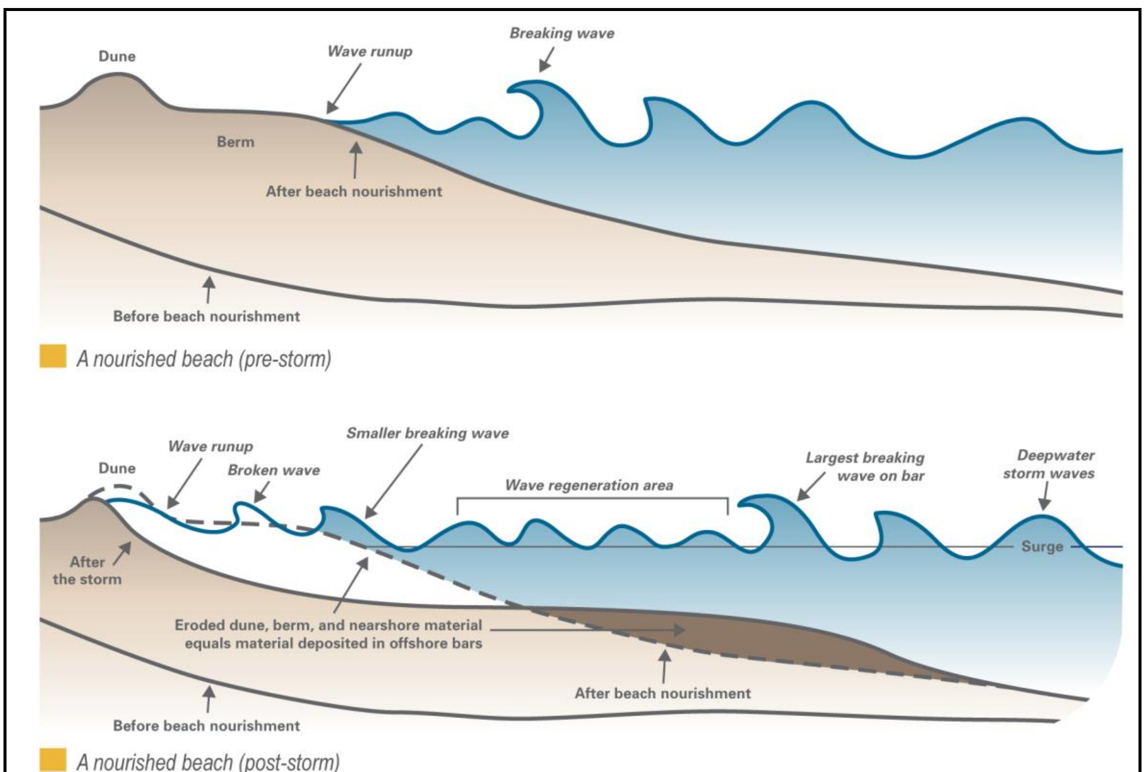

Figure D-6. Beach nourishment response to storm waves and increased water levels (USACE, 2020).

Sediment for beach nourishment can be sourced from upland or offshore borrow sites, or in the case of beneficial reuse, it can be obtained from nearby dredging projects. The use of upland sediment typically involves trucking. For large-scale projects this can require a significant number of round-trip truck deliveries that can result in traffic and noise impacts. Compatibility between upland and native beach sediment is also an issue that must be addressed, as the grain size distribution of the source material should be similar to, or larger, than the native beach sediment. If an offshore borrow site is used, sediment is usually pumped directly to the beach nourishment location. Offshore borrow sites can provide large quantities of clean sand suitable for beach nourishment; however, the process of designating and permitting an offshore borrow site in Massachusetts can be lengthy and costly. This is primarily due to studies of environmental impacts that must be performed to designate an appropriate offshore borrow site. Beneficial reuse of sediment from nearby dredging projects can either be directly pumped to the beach or transported via truck. Here again, grain size compatibility between the dredged material and the receiving beach must be considered for beneficial reuse projects.

While beach nourishment is a widely accepted method of building coastal resiliency, there is the potential for adverse impacts if not carefully designed and constructed. Impacts to water quality caused by increased turbidity occur during placement and this can adversely impact finfish and shellfish; however, the turbidity is temporary during construction and impacts can be minimized by following time of year windows protective of sensitive species. Beach nourishment can also impact benthic communities and nearshore resource areas as sediment is placed directly on intertidal or subtidal habitats or is transported to these areas through cross shore and longshore transport. These impacts to benthic communities are generally considered to be short-lived as the species are resilient to high energy environments and able to recolonize relatively quickly. Impacts to nearby resources like rocky intertidal and navigation channels can be minimized and/or avoided by careful design that is based on an understanding of coastal processes and directions of sediment transport.

Beach nourishment at appropriate sites along the Marshfield and Duxbury shoreline would mitigate on-going erosion, improve storm damage prevention and flood control for public and private properties, enhance habitat for shorebirds, and improve the beaches as recreational resources. There would be a positive impact to property values in the area, as well as increased protection for the existing seawalls and revetments that provide the last line of defense. The improvement in shore habitat would require a management program to protect threatened and endangered species. Engineered beach nourishment designs would provide specific levels of protection with known requirements for renourishment. With permits in place for the larger scale engineered projects, the Towns would be able to accept material from nearby dredging projects for beneficial reuse, provided the sediment is compatible.

Costs for beach nourishment in Marshfield and Duxbury were determined assuming use of an upland sand source that would be trucked to the site. The costs include purchase of the nourishment material, trucking, and placement on the beach according to the engineering design. Based on projects at other sites in southeast Massachusetts, average costs of $30 per cubic yard were used.

2.5 Dune Nourishment

Construction of new dunes, or enhancement of existing dunes, can be an effective soft engineering method to improve shoreline resiliency. This alternative involves placement of sediment near the landward edge of the beach to increase the elevation and width of the dune. The larger dune provides storm damage protection by reducing flooding and overtopping. The new dune sediment can also serve as a source of material for nearby beaches, thereby contributing material to the littoral system.

Dune nourishment is appropriate in areas where there is a sufficient setback or distance from fluctuations of the daily tide. When dunes are constructed without a high tide beach in front of them, the sediment is easily washed away during periods of high tides and storms. Constructed dunes must also fit with the surrounding landscape, taking into consideration the elevation and location of the adjacent infrastructure and natural features. Crest elevation, crest width, and side slopes are design criteria that can be adjusted to maximize the protective nature of the dune while also fitting the dune into the surrounding landscape. Dune nourishment can be constructed as a stand along resiliency measure, or in conjunction with a beach nourishment project. Ongoing maintenance of constructed dunes must be considered, especially after storm events where dunes are badly eroded. Sediment type for dune construction should be compatible with the existing dune material, or with that of other nearby natural dunes. Dune nourishment can be performed using sandy sediments, or in certain high energy environments, it is more appropriate to use cobble sized material.

Dune nourishment at appropriate sites along the Marshfield and Duxbury shoreline would mitigate on-going erosion and improve storm damage prevention and flood control for public and private properties. In areas mapped as Priority and Estimated Habitat by the Natural Heritage and Endangered Species (NHESP) Program, the designs would need to maintain the habitat value of the existing resources.

Costs for dune nourishment in Marshfield and Duxbury were determined assuming use of an upland sand source that would be trucked to the site. The costs include purchase of the nourishment material, trucking, and placement on the beach according to the engineering design. Based on projects at other sites in southeast Massachusetts, average costs of $30 per cubic yard were used. Where appropriate, costs for beach grass plantings were estimated at $1/sq ft of restored dune.

2.6 Intertidal Boulder Field

Portions of the Marshfield shoreline have naturally occurring rocky outcrops in the intertidal and subtidal zones. These areas are composed of a mixture of bedrock and/or coarse-grained cobbles and boulders. They serve as habitat for various species of macroalgae, crustaceans and finfish. These rocky outcroppings occur primarily in the areas between south Sunrise Beach, through Brant Rock to Blue Fish Cove. Rexhame Beach also contains an intertidal rocky outcrop known as Beadle Rock. In addition to providing complex habitat for marine organisms, these areas also help to attenuate wave energy during average and low energy events. The intertidal boulder field alternative would place additional rock in these areas to improve wave attenuation and storm damage protection during more severe storm events.

The intertidal boulder field alternative would be applicable only in areas that currently exhibit rocky outcroppings, as sandy substrata would not provide the structural base needed to support randomly placed large boulders. A mixture of stone sizes between 8 and 12 ton boulders would be placed in the intertidal zone in a random pattern. The boulders would serve to dissipate wave energy before it reaches the infrastructure along the shoreline and would also provide habitat benefits. It should be noted that the purpose of the nearshore boulder field would be to enhance storm damage protection through wave attenuation rather than accumulating sediment along the beach. Figure D-7 shows an example of a natural rocky intertidal area offshore of Rexhame Beach with a large boulder similar in size to boulders that would be used for this alternative. Conceptual layouts of intertidal boulder fields at Ocean Bluff, South Brant Rock and Blakeman's Beach are shown in Figures D-8 and D-9.

Figure D-7. Natural rocky intertidal shore at Rexhame Beach showing a large boulder similar in size to those considered for the intertidal boulder field.

Before proceeding with this alternative, additional engineering design would be required to identify the optimum stone placement and volume of material needed to achieve the desired level of storm damage protection. While the intertidal boulder field alternative would enhance the habitat value of the intertidal zone significantly, the path for environmental permitting and review of this resiliency method has not been tested in Massachusetts. Given the potential for improved storm damage protection using natural materials and methods, while also enhancing habitat value, there is optimism that the regulatory agencies will embrace the intertidal boulder field as an acceptable resiliency measure.

Costs associated with construction would include sourcing the boulders, transporting them to the site, and placing them in the intertidal zone. For the purposes of developing a unit cost it was assumed that the stones would be trucked to the site and placed using equipment accessed via the beach. A cost of $2,680 per linear foot of beach was estimated for an intertidal boulder field approximately 60 ft wide, based on data developed for a pilot project in Boston Harbor.

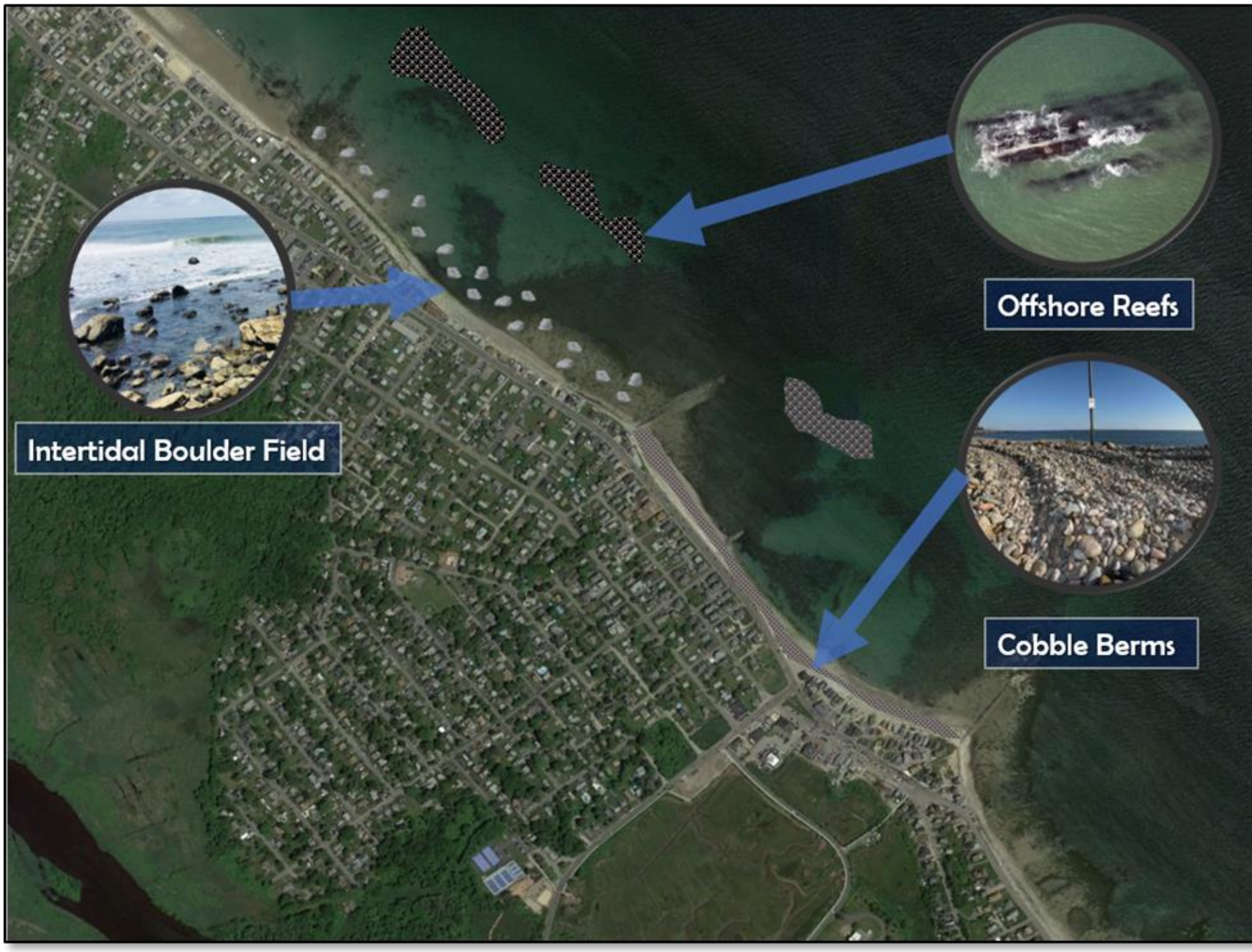

Figure D-8. Conceptual layout for intertidal boulder field and cobble berms at Ocean Bluff and Hewitt's Point.

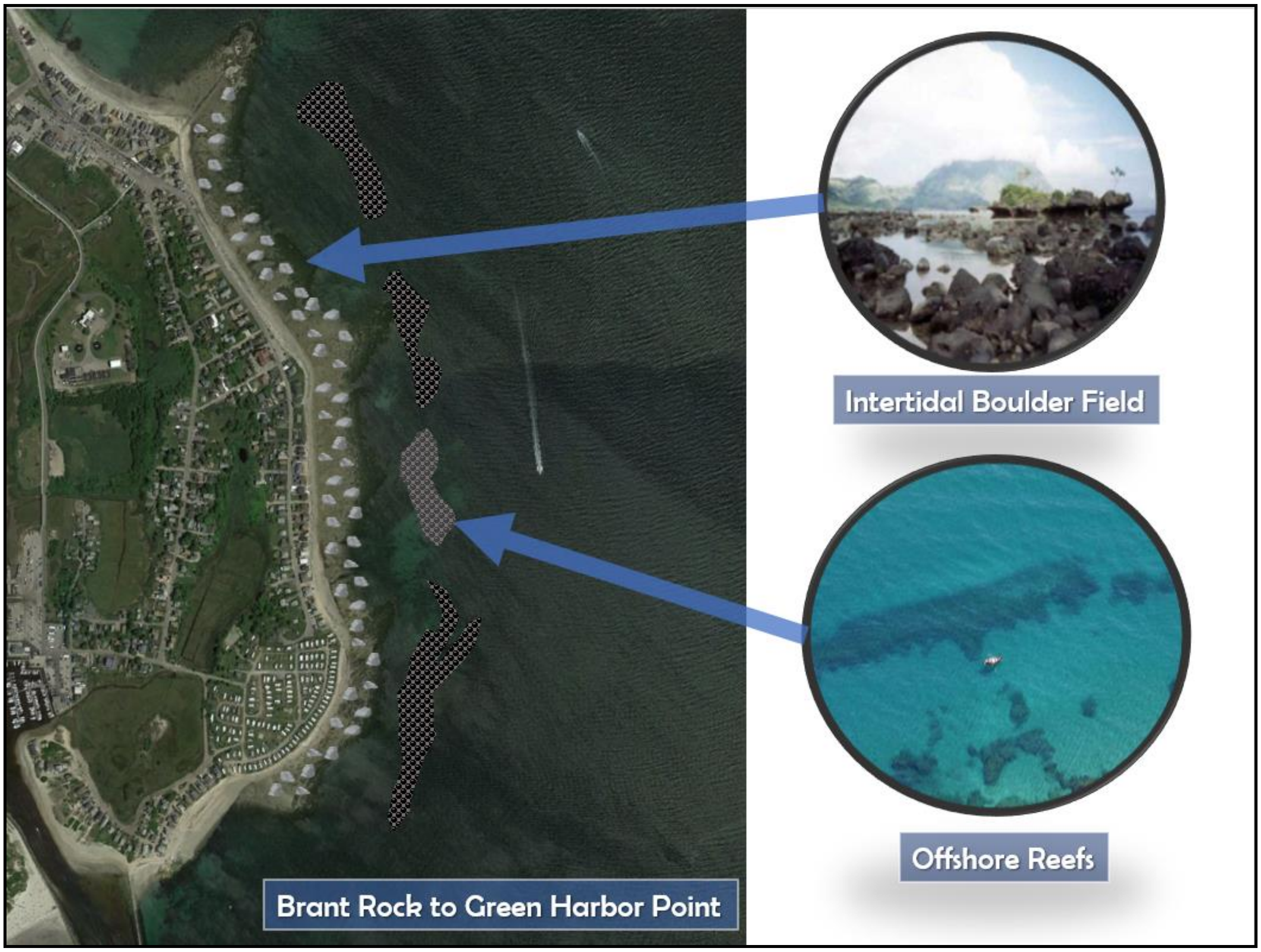

Figure D-9. **Conceptual layout for nearshore boulder field at South Brant Rock and Blackman's Point.**

2.7 Constructed Reefs

Constructed offshore reefs are a hybrid shore protection alternative that serve as the first line of defense focusing on breaking wave energy before it reaches the shoreline, while also creating hard bottom habitat. Artificial reefs have been constructed using a variety of concrete structures, natural rock, steel and other traditional hard materials (Figure D-10). The reefs essentially act as submerged breakwaters that provide little to no wave attenuation during periods of smaller wave activity, but force larger waves to break, thereby reducing wave energy reaching the shoreline.

Much like offshore breakwaters, there are key criteria that must be met for an artificial reef to be effective at breaking storm waves and dissipating wave energy. The reef must be designed with enough profile (vertical height) off the bottom and width at the top to cause storm waves to trip and break. They should also be placed in rocky seafloor areas with little sediment cover to prevent shifting, scour, and/or burial of the reef. The profile height of the reef presents an issue in areas of large tide range and/or substantial storm surge, since the structure must be submerged at all stages of the tide and yet still cause wave breaking during storms with increased water levels.

Figure D-10. Constructed reef elements; Reef Ball (left photo) and Layer Cake Reef Ball (right photo). (Harris, 2009).

For the Marshfield and Duxbury shoreline with an average tide range of 9.0 ft, constructed reefs submerged at low tide would provide little to no wave attenuation during storms with elevated water levels. Reefs constructed with crests high enough to trigger storm waves to break would be emergent during much of the daily tide, which would minimize the benefits for fisheries and shellfish habitat. Consequently, artificial reef structures were determined to provide little benefit to the Marshfield and Duxbury coastline in terms of storm damage protection and control of wave overtopping.

2.8 Managed Retreat

For the most vulnerable areas, managed retreat from the shoreline was also included as a potential alternative. This alternative was considered for sections of the shoreline that show a high probability of inundation given future protections of sea level rise. Results from the Massachusetts Coast Flood Risk Model (MC-FRM) were used to identify areas where managed retreat should be considered. MC-FRM simulates a full suite of processes that affect coastal water levels, including tides, waves, winds, storm surge, sea level rise, wave setup, and overtopping. The model was developed by Woods Hole Group for the Massachusetts Department of Transportation (MassDOT) as a tool to quantitatively incorporate climate change influences on sea level rise, tides, waves, storm track and storm intensity for the 2030, 2050, 2070, and 2100 time horizons. Model results provide discrete risk estimates for each time horizon to assist with both near- and long-term coastal resiliency planning. In particular, accurate and precise assessments of the exceedance probability of combined SLR and storm surge is provided to help identify areas of existing and near-term vulnerability requiring immediate action, as well as areas that will benefit from long-range planning for future preparedness and risk reduction.

Preliminary MC-FRM data for the Marshfield and Duxbury shoreline indicate high annual probabilities of flooding for certain sections of the coastline by the 2050 time horizon (Figures

D-11 through D-13). For example, by 2050 areas at Brant Rock, Blue Fish Cove, Bay Ave and Gurnet Rd beaches show 100% probability of flooding at least once during the year, with water coming from both the open ocean and Green Harbor or Duxbury Bay.

In these locations, a long-term option may be for the Towns to buy-out and remove the buildings and restore the land. This of course would require cooperation between the property owners and the Towns but would offer benefits by moving residents to safer locations and restoring the natural functions of the barrier beaches. For the purposes of this evaluation, costs associated with a buy-out program were based on the assessed value of the properties as reported in the Marshfield and Duxbury 2020 assessor's databases. Loss of tax revenue was also factored into the cost of this alternative. These resulting costs are likely the minimum that will be required as market value for oceanfront property is usually higher than the assessed value. Given that the managed retreat alternative is more of a long-term option, the costs were computed for 2050 and included a 3% increase in assessed value and tax revenue over the next 30 years.

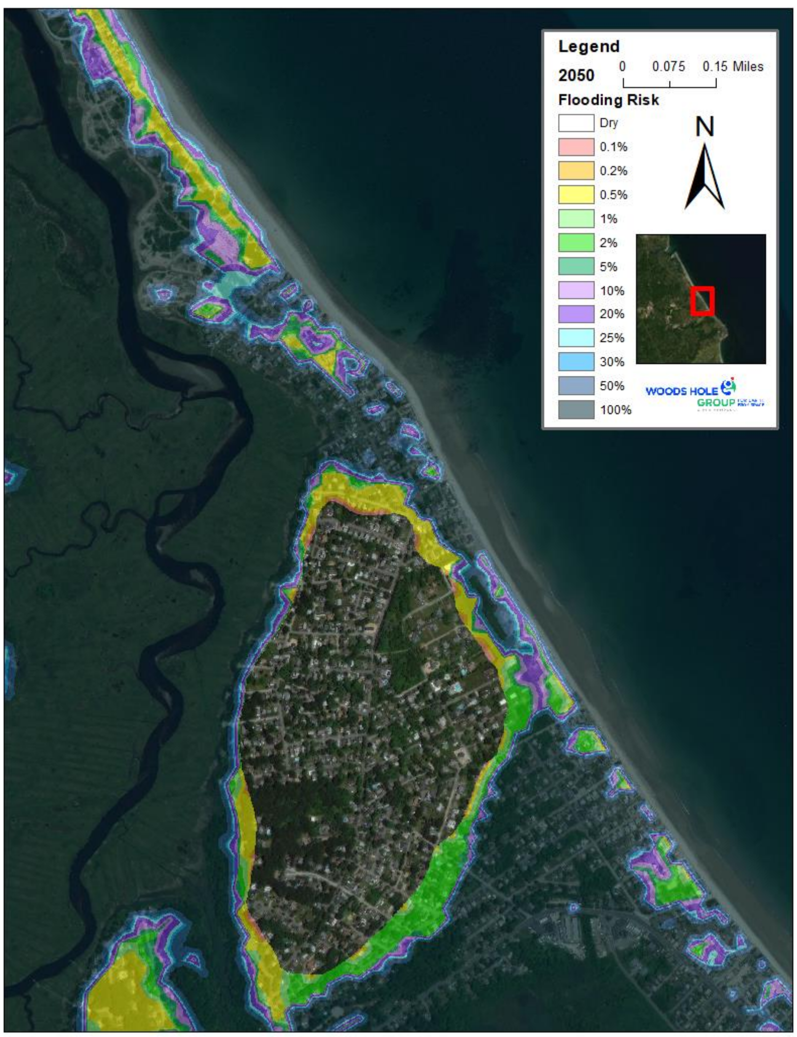

Figure D-11. Preliminary MC-FRM model results showing flood risk probabilities in 2050 for Rexhame Beach, Winslow Beach, and Fieldston Beach.

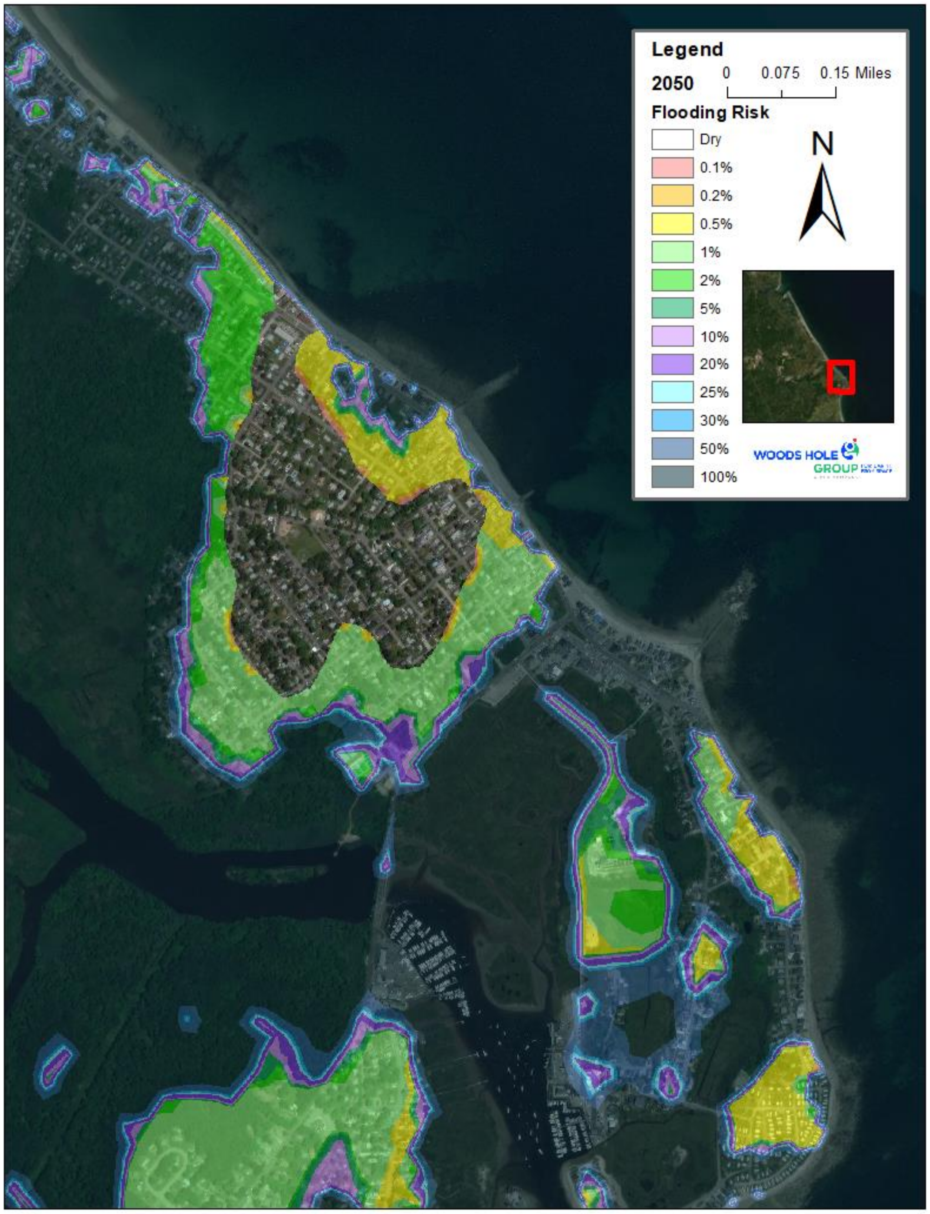

Figure D-12. Preliminary MC-FRM model results showing flood risk probabilities in 2050 for Sunrise Beach, Ocean Bluffs, Hewitt's Point, Brant Rock and Blue Fish Cove Beaches.

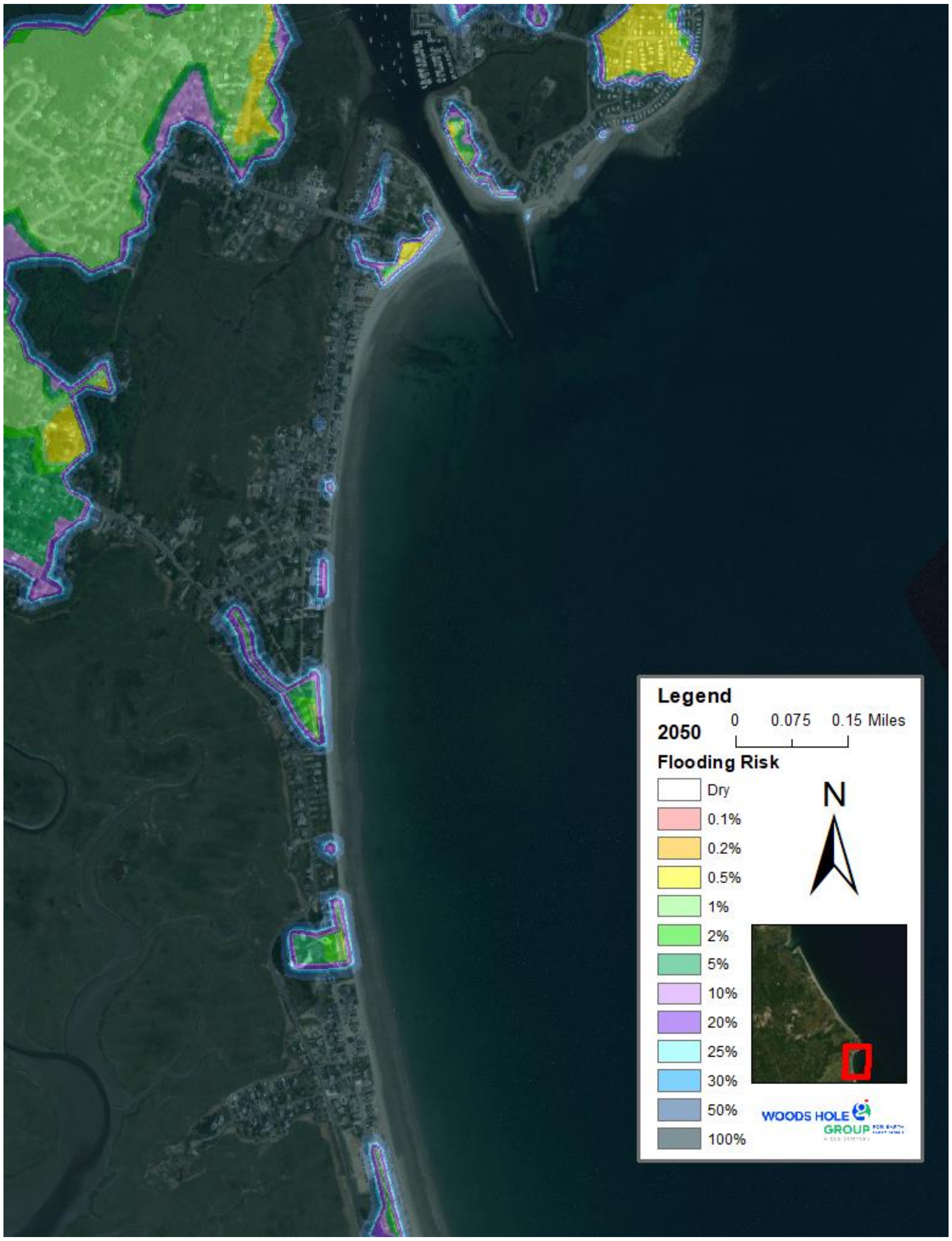

Figure D-13. Preliminary MC-FRM model results showing flood risk probabilities in 2050 for Bay Ave and Gurnet Rd. Beaches.

3.0 Assessment of Alternatives for Site-Specific Beaches

The following section discusses the shore protection and resiliency alternatives considered at each of the fourteen (14) site-specific beaches. Information gathered during the broad assessment of alternatives (Section 2.0) was used in combination with the site-specific beach characteristics to evaluate appropriate alternatives for each site. Engineering judgement was used to assess the applicability of different options, taking into consideration engineering feasibility, performance and long-term viability, potential environmental impacts, and cost. This information was then used to select the most appropriate alternative(s) for each beach. At some sites, both short- and long-term alternatives were identified. While emphasis was placed on identification of soft engineering approaches for increasing shoreline resiliency, depending on the beach, it was not always feasible to identify an appropriate soft engineering solution. For these beaches, further investigation and engineering design will be needed by the Towns before proceeding with a final plan for enhanced shore protection and improved resiliency.

3.1 Rexhame Public Beach

Rexhame Public Beach is an important recreational resource for the Town of Marshfield. It also provides wildlife habitat for state-listed shorebirds. The relatively wide high tide beach and coastal dune system provide storm damage protection for adjacent developed areas and the South River ecosystem. Shoreline change between 1978 and 2014 at Rexhame Public Beach has been both erosional and accretional with rates ranging from -0.95 to 0.59 ft/yr, including a wide uncertainty range (Figure C-15). Despite the relatively low rates of beach erosion, the seaward toe of the dune has retreated approximately 25 ft since 2010 (Figure D-14). Due to the relatively high rates of dune erosion and the desire by the Town to maintain Rexhame Beach as a recreational resource for the public, alternatives for beach and dune nourishment were evaluated. The *status quo* alternate was also considered as well as managed retreat for a longer-term alternative.

3.1.1 Maintain Existing Management Approach – *Status Quo*

The Town's currently maintains three controlled access paths between the parking lot and the beach. Sand fencing is used along the toe of the dune to help accumulate wind blown sediment and keep foot traffic off the dunes. The Town has accepted sediment for beneficial reuse from nearby dredging projects in the past; however, there is not a regular or frequent program for nourishment of the beach or dunes.

At its narrowest point, the dune in front of the parking lot is approximately 90 ft wide. Assuming no increase in the current rate of dune erosion, it would take just under 30 years before the dune is completely removed. However, this estimate does not factor in rising sea level or an increased frequency and intensity of storms associated with climate change. These factors will increase the rate of dune erosion and vulnerability of public infrastructure at Rexhame Public Beach. As an example, FEMA guidelines indicate that dunes must have a cross-sectional area above the 100-yr stillwater level greater than 540 sq ft in order to withstand a 100-yr storm event. The current dunes at Rexhame Beach do not meet this FEMA criteria, and as such significant erosion and loss of dune resource can be expected during a 100-yr storm. Continuing with the status quo at Rexhame Beach places the public resources at risk within the near future.

Figure D-14. Recent dune erosion at Rexhame Public Beach.

3.1.2 Beach and Dune Nourishment

Three (3) beach and/or dune nourishment alternatives were developed for Rexhame Public Beach. One alternative included dune restoration only (Rexhame Public – Alt 1), the second included dune restoration in combination with beach nourishment (Rexhame Public – Alt 2) and the third included beach nourishment only (Rexhame Public – Alt 3). The design elements, footprint areas and nourishment volumes for each alternative are provided in Table D-3. All alternatives for Rexhame Public Beach extended along the entire 1,980 ft stretch of undeveloped barrier beach (Figure D-15). Most of the beach area is owned by the Town of Marshfield and open to the public. The Sea Rivers Trust owns the northern most undeveloped parcel immediately north of Rexhame Public Beach (Figure D-15). Coordination between the Town and the Trust will be required to explore the possibility of securing public access easements if nourishment on the Trust property is funded by the Town.

The level of storm damage protection provided by the existing dunes at Rexahme Public Beach was quantified using the cross-shore sediment transport model XBeach. The same model was used to evaluate performance of the three nourishment alternatives when exposed to 10-yr and 50-yr return period storms. An evaluation of longshore transport was also performed to predict the design life of the nourishment alternatives. The longshore transport, or spreading analysis, used analytical methods to estimate the percentage of fill remaining within the project area through time. A median grain size of 0.35 mm was assumed for the dunes at Rexhame Public Beach based on grain size data gathered in support of this study.

Table D-3. Beach and Dune Nourishment Alternatives Evaluated for Rexhame Public Beach.

Alternative	Resiliency Type	Design Elements	Footprint Area (acres)	Volume (cu yds)
Rexhame Public – Alt 1	dune nourishment	dune crest elev. = 28 ft NAVD88 dune crest width = 30 ft dune seaward slope = 1:5	5.34	47,240
Rexhame Public – Alt 2	dune + beach nourishment	dune crest elev. = 28 ft NAVD88 dune crest width = 30 ft dune seaward slope = 1:5 berm elev. = 9.5 ft NAVD88 berm width = 75 ft nearshore slope = 1:12	14.92	82,570
Rexhame Public – Alt 3	beach nourishment	berm elev. = 11 ft NAVD88 berm width = 100 ft nearshore slope = 1:15	14.09	129,000

Figure D-15. Beach/dune nourishment alternatives considered for Rexhame Public Beach.

Results of the 10-yr and 50-yr storm simulations on the existing dune are shown in Figure D-16. The modeling shows erosion along the seaward face of the dune, with average retreat of 15 ft for the 10-yr storm and 28 ft for the 50-yr storm; however, the dune is not overtopped in either case. Sediment eroded from the face of the dune is transported offshore to the intertidal and subtidal zones below 0 ft NAVD88. The model results are consistent with performance of the dunes during past storms and with retreat of the dune toe illustrated in Figure D-14. Based on this information and application of the FEMA 540 rule, the existing dunes at Rexhame Beach can be considered to provide protection for a 50-yr return period storm, but not for a 100-yr event.

Figures D-17 and D-18 show performance of the beach and dune nourishment alternatives during 10-yr and 50-yr storms, respectively. The model results show similar dune erosion and nearshore deposition patterns for Rexhame Public - Alt 1 and Alt 2 under both the 10-yr and 50-yr storm simulations. Rexhame Public – Alt 3 shows greater dune erosion with more material transported to the nearshore zone. Even though significantly more sediment (129,000 cy) is needed to construct Rexhame Public – Alt 3, it does not provide a greater level of storm damage protection for the dunes. Rexhame Public – Alt 1 provides a similar level of protection to Rexhame Public – Alt 2 and requires 57% of the volume.

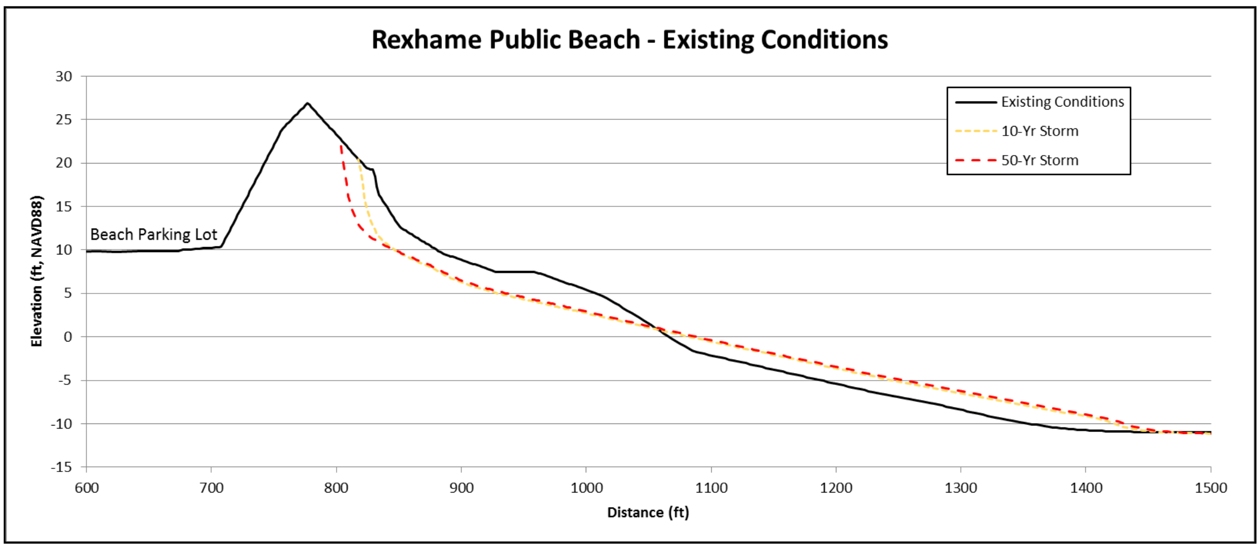

Figure D-16. XBeach model results for the existing dunes at Rexhame Public Beach for 10-yr and 50-yr storm events.

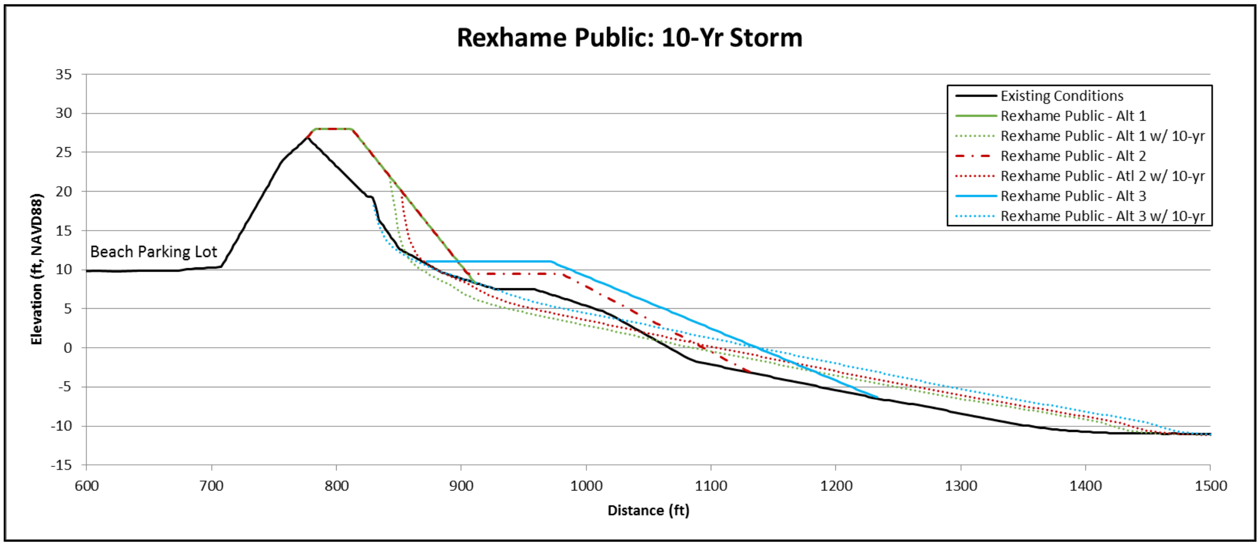

Figure D-17. XBeach model results for beach and dune nourishment alternatives at Rexhame Public Beach for a 10-yr storm event.

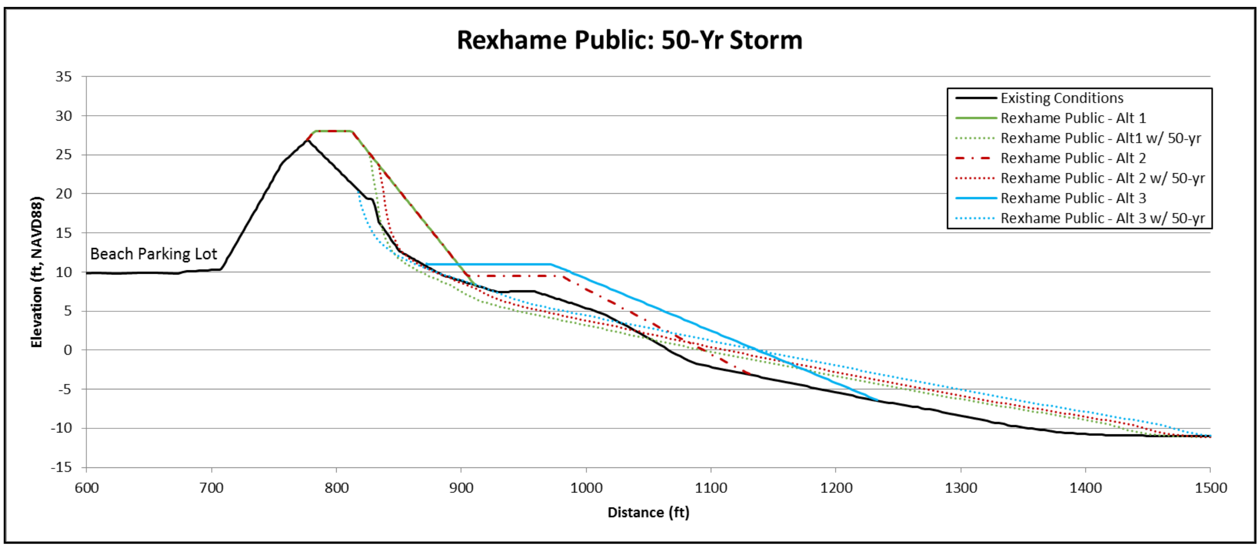

Figure D-18. XBeach model results for beach and dune nourishment alternatives at Rexhame Public Beach for a 50-yr storm event.

Design life computations were performed on the two nourishment alternatives for Rexhame Public Beach. Under average non-storm conditions, the dunes are just outside the zone of longshore transport, and therefore the design life computations were not applicable to the dune only alternative. The volume of nourishment remaining in the original project footprints as a function of time is shown in Figure D-19. The ranges shown for each project reflect variations in design life with and without background erosion rates for Rexhame Public Beach. The fill material is shown to initially spread relatively quickly, as indicated by the decrease in percentage of fill remaining, as the shoreline adjusts to a new equilibrium. This behavior is typical of beach nourishment response, since a large perturbation has been added to the coastline. After a few years, however, this trend begins to decelerate and the material remaining stabilizes.

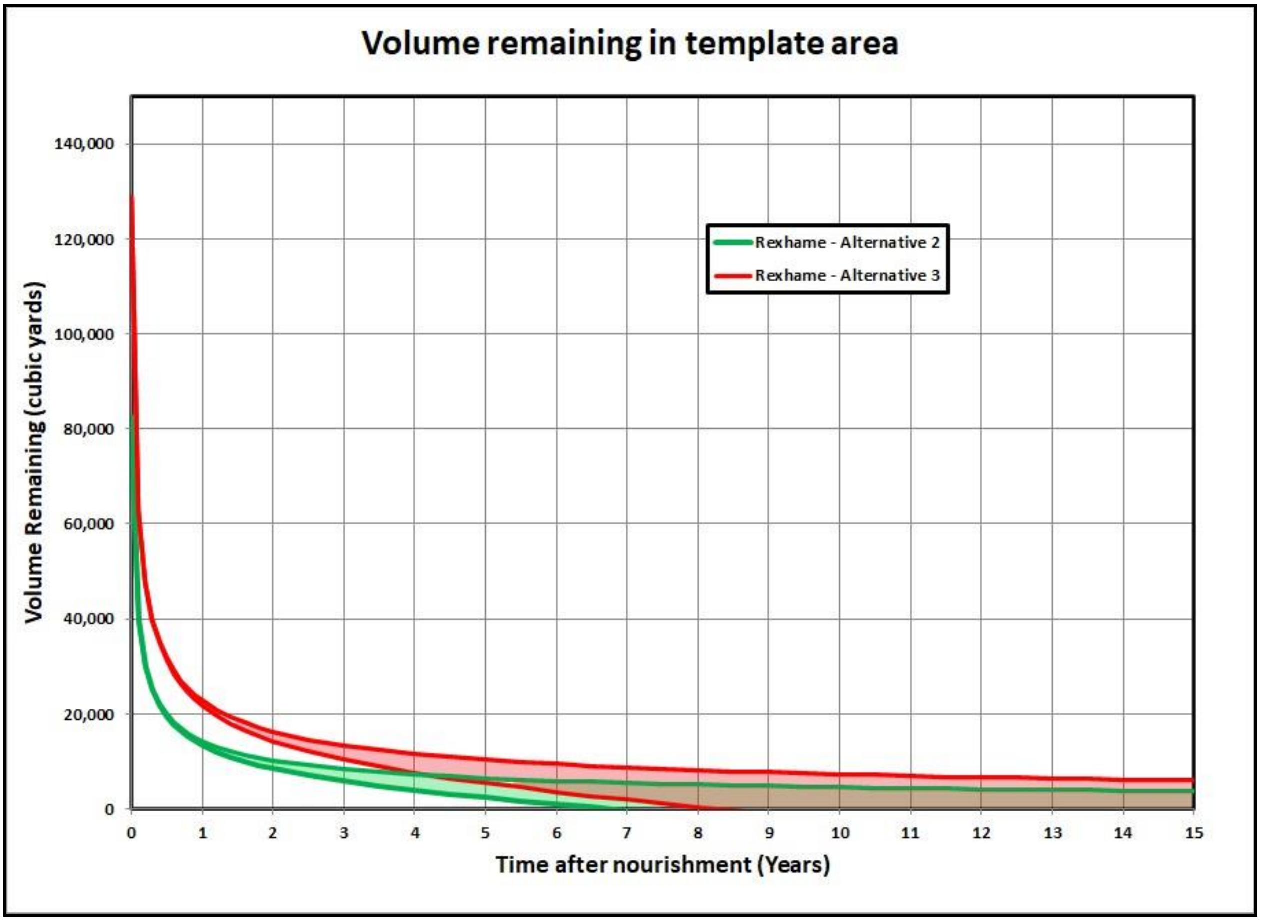

Figure D-19. Service life estimates for beach nourishment alternatives at Rexhame Public Beach.

Costs associated with the Rexhame Public Beach alternatives are summarized in Table D-4. The costs include the sand purchase, trucking, spreading and planting of beach grass for the two alternatives that include dunes. Projected costs over the next 30 years are also provided assuming renourishment every 6 years for Rexhame Public – Alt 2 and every 8 years for Rexahme Public – Alt 3, when the design life calculations indicate that all material has eroded from the original project footprint. The rule of thumb for renourishment when 70% to 80% of the volume is lost from the footprint was not used at this site, since the goal of the nourishment is to provide sediment to the littoral system and protect public beach resources. A renourishment interval of 10 years was utilized for Rexhame Public – Alt 1, in order to maintain a minimum dune width of 60 ft, given the background erosion rate of 2.8 ft/yr.

Table D-4. Costs Associated with Beach and Dune Nourishment Alternatives at Rexhame Public Beach.

Resiliency Alternative	Initial Construction Cost	Costs Over Next 30 Years
Rexhame Public – Alt 1	$1.42 million	$5.00 million
Rexhame Public – Alt 2	$2.48 million	$13.63 million
Rexhame Public – Alt 3	$3.87 million	$14.51 million

3.1.3 Managed Retreat

Managed retreat of the public beach facilities at Rexhame is an option in the long-term when erosion and/or flooding threatens the parking lot. One option would be to eliminate a portion, or all, of the parking lot and restore the dune in a more landward location. This alternative would impact public access during the summer when the parking lot fills to capacity. Without changes to the fee structure for resident beach stickers and daily parking fees, a reduction in parking at Rexhame Public Beach would result in decreased revenue. Long-range plans for off-site parking and providing a shuttle service for beach users were included as recommendations in the Town's 2018 Beach Management Plan (Woods Hole Group, 2018). Costs associated with acquisition of property for off site parking and running the shuttle service would also be incurred with the managed retreat alternative.

3.2 Rexhame Beach

The developed portion of Rexhame Beach between Parker and Porter Streets contains approximately 270 single family homes on lots averaging 0.14 acres in size. Most of the ocean facing properties have some form of hard shore protection, either seawalls or revetments. Recent shoreline change data between 1978 and 2014 show net accretion with average rates on the order of +1.0 ft/yr, although the data show a high degree of uncertainty (Figure C-15). Nearshore areas along the center of Rexhame Beach contain naturally occurring rocky intertidal resources. This feature acts to attenuate incoming waves and provides a natural form of shore protection for developed areas of Rexhame Beach during low energy storm events. However, the developed infrastructure continues to be vulnerable to larger storms. The beach areas are privately owned. To protect the existing rocky intertidal resources while enhancing the resiliency of the shoreline, both hard engineering and hybrid alternatives were considered. The *status quo* alternate was also considered as well as managed retreat for a longer-term alternative.

3.2.1 Maintain Existing Management Approach – *Status Quo*

Existing management in the Rexhame Beach area of Marshfield is primarily undertaken by the property owners on a site by site basis. FEMA data from 1978 to 2018 for this area indicate between 10 and 20 repetitive loss properties with total claims between $0.85 and $1.7 million (Figure C-37). Town records specific to Rexhame Beach for providing emergency services during storms or post-storm clean up are not available; however, costs to continue providing these services under the *status quo* alternative are expected to increase in the future given the impacts of climate change. FEMA flood insurance claims are also expected to increase with this alternative.

3.2.2 Enhance and/or Enlarge Shore Protection Structures

The average crest elevation of the shore protection structures along Rexhame Beach is 16.8 ft NAVD88 and the average elevation of the beach at the toe of the structures 7.3 ft NAVD88.

These conditions, in combination with the shallower water depths over the rocky intertidal resource, result in relatively low overtopping rates during current day 10-yr and 50-yr storms. However, when considering a 2 ft increase in sea level by 2040 to 2060, the structures will need to be increased in height by approximately 1.5 ft to reduce overtopping rates to levels that would prevent structural damage to the adjacent homes. Costs associated with raising the structures 1.5 ft for the entire 3,025 ft long stretch of Rexhame Beach would be approximately $21.18 million. Given that the structures are privately owned, it is assumed these costs would be borne by the property owners.

3.2.3 Intertidal Boulder Field

The existing rocky intertidal resource in the nearshore area of Rexhame Beach provides an optimum location for additional wave attenuation through construction of an intertidal boulder field. The primary goal of the boulder field would be to reduce wave overtopping during high energy storms and future conditions with sea level rise. Additional engineering would be needed to design the boulder field to ensure reductions in wave overtopping for specific storm events; however, assuming a conceptual design with a 60 ft wide boulder field along the entire 3,025 ft stretch of Rexhame Beach, estimated costs for construction would be $8.11 million. The footprint of the boulder field would be approximately 181,500 sq ft.

3.2.4 Managed Retreat

Managed retreat from the shoreline at Rexhame Beach was considered as an option for the long-term as a way to reduce coastal vulnerability. Preliminary results from the MC-FRM model show that portions of Rexhame Beach will have a 100% probability of flooding by 2050 (Figure D-11). As such, the managed retreat alternative would be appropriate to phase in over the next 30 years. The 2020 assessor's database shows property values for the first row of homes most affected by coastal flooding and wave overtopping to be $26.50 million. Annual tax revenue to the town from these property owners is approximately $353,220. Close coordination between the town and affected property owners would be required, and federal and/or state monies would be needed to help the town with property acquisitions.

3.3 Winslow Ave. Beach

The Winslow Ave. Beach area between Porter St. and Rexhame Rd. has lower density development that other areas of Marshfield and the structures are set back 250 to 400 ft from the beach. The area east of South Circuit Ave. contains 42 single family homes on lots averaging 0.41 acres in size. The properties are not protected by coastal engineering structures. Instead a broad and low-lying cobble dune separates the residences from the coastal beach. Shoreline change data between 1978 and 2014 show accretion and erosion ranging from +1.0 to -1.2 ft/yr, with a high degree of uncertainty (Figure C-15). The beach is owned by the Town of Marshfield and open to the public for recreational purposes, although parking is not provided, and access is limited to two locations. Alternatives considered for Winslow Ave. Beach included *status quo*, dune nourishment/enhancement, and managed retreat.

3.3.1 Maintain Existing Management Approach – *Status Quo*

The Town does not have an active program for management of Winslow Ave. Beach and FEMA data from 1978 to 2018 show no repetitive loss properties (Figure C-37). As such, there are no current costs associated with the *status quo* alternative. However, given the high probability for increased flooding and storm damages resulting from the impacts of climate change, future management activities will likely be required to reduce vulnerability of the natural and built environment.

3.3.2 Dune Nourishment

Two (2) dune nourishment alternatives were developed for Winslow Ave. Beach. Winslow – Alt 1 included a dune with crest elevation of 15.5 ft NAVD88 and Winslow – Alt 2 included a dune with crest elevation of 17 ft NAVD88. Both dune alternatives were designed to blend with existing landforms at the north and south ends of the project. The design elements, footprint areas and nourishment volumes for each alternative are provided in Table D-5. Both alternatives extended along the entire 1,540 ft length of the existing dune (Figure D-20) which is owned by the Town of Marshfield.

Table D-5. Dune Nourishment Alternatives Evaluated for Winslow Ave. Beach.

Alternative	Resiliency Type	Design Elements	Footprint Area (acres)	Volume (cu yds)
Winslow – Alt 1	dune nourishment	dune crest elev. = 15.5 ft NAVD88 dune crest width = 30 ft dune seaward slope = 1:7	3.7	11,200
Winslow – Alt 2	dune nourishment	dune crest elev. = 17 ft NAVD88 dune crest width = 40 ft dune seaward slope = 1:7	4.5	17,850

Figure D-20. Dune nourishment alternatives considered for Winslow Ave. Beach.

The level of storm damage protection provided by the existing dunes at Winslow Ave. Beach was quantified using the cross-shore sediment transport model XBeach-G. The same model was used to evaluate performance of the dune nourishment alternatives when exposed to 10-yr and 50-yr return period storms. A median grain size of 19.0 mm was assumed for the dunes at based on grain size data gathered in support of this study. Results of the 10-yr and 50-yr storm simulations on the existing dune are shown in Figure D-21. The modeling shows overtopping and landward migration of the dune crest during both storm simulations. A portion of sediment eroded from the dune is transported landward as overwash, and some sediment is transported offshore to the intertidal and subtidal areas.

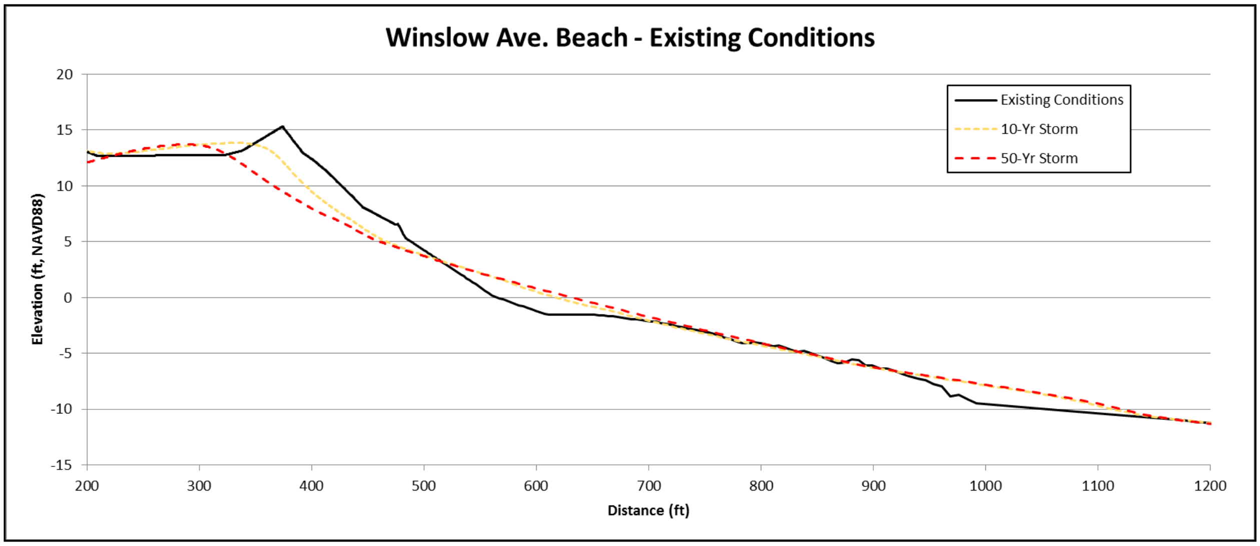

Figure D-21. XBeach-G model results for the existing dunes at Winslow Ave. Beach for 10-yr and 50-yr storm events.

Figures D-22 and D-23 show performance of the dune nourishment alternatives during 10-yr and 50-yr storms, respectively. For the 10-yr storm, the model predicts that most of the Winslow – Alt 1 dune will be eroded, leaving the profile similar to current day conditions. The Winslow – Alt 2 design withstands the 10-yr storm and leaves enough dune in place to provide flood protection for future storms (Figure D-22). The 50-yr storm simulations show overwash and landward retreat of both alternatives. The crest elevations of the dunes would be approximately 0.5 to 1 ft lower than the existing dunes. Both alternatives would reduce flooding and wave impacts on the adjacent developed properties during a 50-yr storm but would require renourishment to restore the dune to the design elevations and widths.

Costs associated with construction of the Winslow Ave. dune alternatives are summarized in Table D-6. The costs include purchase of the cobble, trucking to the site, and spreading. Projected costs over the next 30 years are also provided assuming renourishment every 10 years.

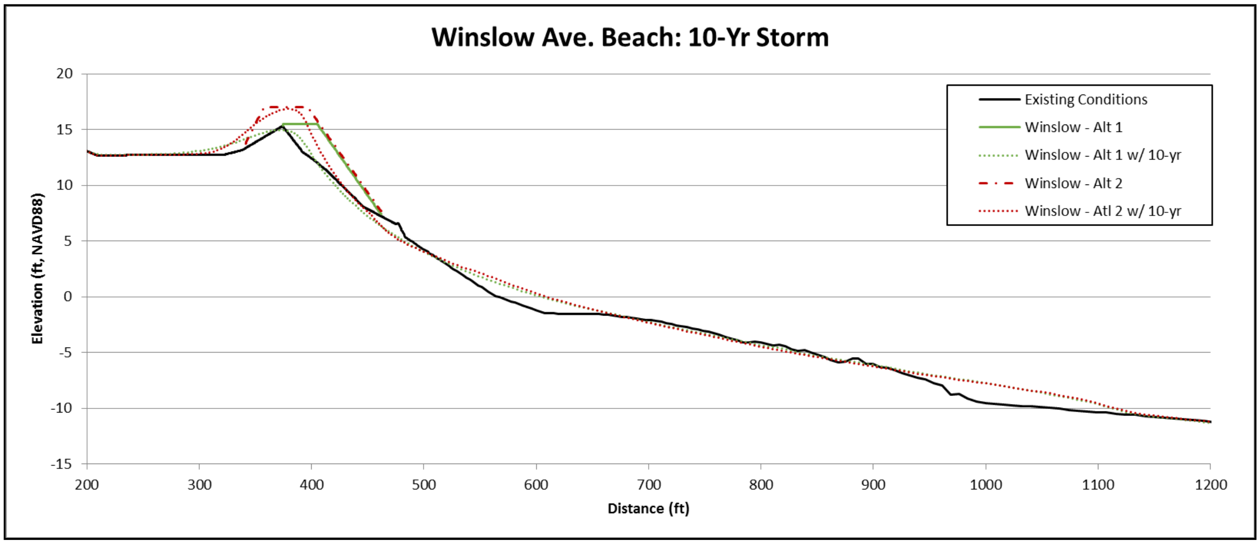

Figure D-22. XBeach-G model results for dune nourishment alternatives at Winslow Ave. Beach for a 10-yr storm event.

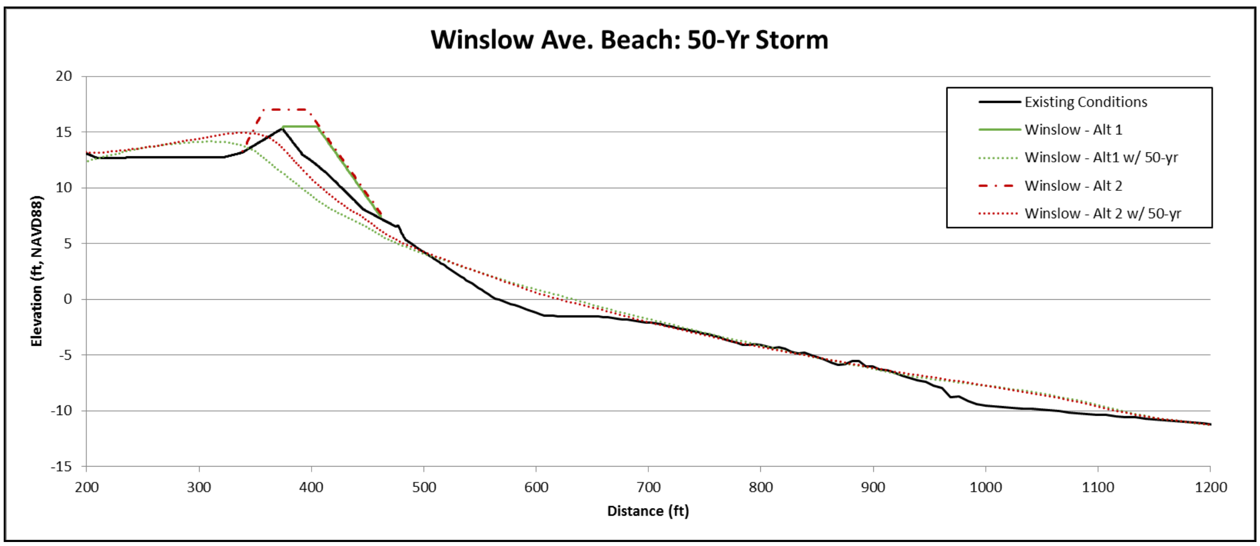

Figure D-23. XBeach-G model results for dune nourishment alternatives at Winslow Ave. Beach for a 50-yr storm event.

Table D-6. Costs Associated with Dune Nourishment Alternatives at Winslow Ave. Beach.

Resiliency Alternative	Initial Construction Cost	Costs Over Next 30 Years
Winslow – Alt 1	$336,000	$1.01 million
Winslow – Alt 2	$535,500	$1.61 million

3.3.3 Elevate Homes

Elevating the first row of homes in the Winslow Ave. area was considered as an option for the long-term as a way to reduce coastal vulnerability. Preliminary results from the MC-FRM model show that the first row of homes is vulnerable to flooding by 2050. Assuming a cost of $125,000 per home, it would cost approximately $1.13 million to elevate the 9 homes vulnerable to flooding by 2050. Close coordination between the town and affected property owners would be required, and federal and/or state monies would be needed to help the property owners with elevating the structures.

3.4 Fieldston and Sunrise Beaches

The Fieldston and Sunrise Beach areas of Marshfield are densely developed with single family homes. Approximately 151 homes are located in the Fieldston area and 395 homes in the Sunrise area; lot sizes average 0.12 acres. Vertical seawalls extend along the entire 5,675 ft stretch of beach. While the Town of Marshfield completed projects between 2012 and 2018 to rebuild and increase the elevation of the seawalls at Fieldston and Sunrise Beaches, the beaches on the seaward side of the seawalls are privately owned. Recent shoreline change data between 1978 and 2014 show a trend of increasing erosion from north to south. Rates of erosion are as high as -2.0 ft/yr at the southern end of Sunrise Beach (Figure C-15), although in many areas the seawall prevents further retreat of the shoreline and storm waves interacting with the seawalls have resulted in a lowering of the beach elevation. Wave overtopping during storms can cause significant damage in this area. Resiliency measures considered for Fieldston and Sunrise Beaches included the *status quo* alternative and enhancing the existing shore protection structures. Beach/dune nourishment was also considered as a way to restore sediment to the system while also protecting the seawalls from further damage and reducing the potential for wave overtopping. Finally, managed retreat was considered as a long-term alternative.

3.4.1 Maintain Existing Management Approach – *Status Quo*

Future management by the Town of Marshfield for Fieldston and Sunrise Beaches includes regular maintenance of the recently rebuilt seawalls. FEMA data from 1978 to 2018 indicate between 10 and 20 repetitive loss properties for Fieldston Beach and between 30 and 40 repetitive loss properties for Sunrise Beach (Figure C-37). Total claims for this period were $0.89 million for Fieldston Beach and $1.80 million for Sunrise Beach. Table D-7 provides a summary of costs to maintain the *status quo* for these beaches over the next 30 years, including estimated costs for providing storm related public services. Continuing with the current management approach will be costly and will do nothing to increase the resiliency of the coastline.

Table D-7. Projected Costs Over Next 30 Years to Maintain Existing Management Approach for Fieldston and Sunrise Beaches.

Beach	FEMA Repetitive Loss Claims	Maintenance of Shore Protection Structure	Storm Related Public Services	Total
Fieldston	$0.72	$0.22 million	$0.54 million	$1.50 million
Sunrise	$1.48 million	$0.39 million	$0.94 million	$2.80 million

3.4.2 Enhance and/or Enlarge Shore Protection Structures

The crest elevation of the seawalls in Fieldston and Sunrise is 18.6 ft NAVD88. The elevation of the beach at the toe of the seawalls decreases from 4.4 ft to -0.5 ft NAVD88 from north to south. Under existing conditions, wave overtopping capable of causing structural damage to adjacent homes occurs during a 50-yr storm event at Fieldston Beach and during 10-yr and greater storms at Sunrise Beach. Table D-8 provides a summary of seawall crest increases that would be needed to prevent structural damage during 10-yr and 50-yr storm events, with current sea levels and with 2 ft of sea level rise (SLR) expected between the 2040 and 2060 time horizon. Based on existing elevations of the infrastructure landward of the seawalls, and the design of the seawalls themselves, it is likely that crest increases greater than 4 ft would not be practical without significant modifications to the sites. Costs associated with raising the structures 0.5 – 4.0 ft along the entire 5,675 ft of Fieldston and Sunrise Beach would be between $39.73 and $51.08 million. Given that the enlarged structures would not provide the necessary protection during future sea level rise scenarios, this alternative would require further modifications to the seawalls such as adding a revetment along the seaward toe.

Table D-8. Storms Capable of Causing Structural Damage to Buildings from Wave Overtopping at Fieldston & Sunrise Beaches and Seawall Elevation Increases Needed to Avoid Damaging Wave Overtopping.

Beach Scenario	10-Yr Storm	50-Yr Storm	10-Yr Storm + 2 ft SLR	50-Yr Storm + 2 ft SLR
Fieldston Beach				
Existing Seawall Overtopped	No	Yes	Yes	Yes
Seawall Increase	0	0.5 ft	5.0 ft	7.5 ft
Sunrise Beach North				
Existing Seawall Overtopped	Yes	Yes	Yes	Yes
Seawall Increase	0.5 ft	3.5 ft	7.5 ft	> 8.0 ft
Sunrise Beach South				
Existing Seawall Overtopped	Yes	Yes	Yes	Yes
Seawall Increase	> 8.0 ft	> 8.0 ft	> 8.0 ft	> 8.0 ft

3.4.3 Beach and Dune Nourishment

Three (3) beach and dune nourishment alternatives were developed for the Fieldston and Sunrise Beach areas. The design elements, footprint areas and nourishment volumes for each alternative are provided in Table D-9. All alternatives extended along the entire 5,675 ft stretch of privately-owned beach (Figure D-24). Coordination between the Town and private property owners is currently underway to secure rights of entry for construction and public access easements.

Cross shore modeling of existing conditions and the three (3) nourishment alternatives was performed for 1-yr, 2-yr and 10-yr storm events. The modeling considered the mixed grain size beach and assumed 50% sand at 0.35 mm and 50% gravel at 10.2 mm. Spreading analysis were also performed to estimate the percentage of fill remaining within the project area through time. Results of the spreading analysis were used to develop a schedule for renourishment.

Table D-9. Nourishment Alternatives Evaluated for Fieldston and Sunrise Beaches.

Alternative	Resiliency Type	Design Elements	Footprint Area (acres)	Volume (cu yds)
Fieldston/Sunrise – Alt 1	dune + beach nourishment	dune crest elev. = 13 ft NAVD88 dune crest width = 20 ft dune seaward slope = 1:5 berm elev. = 8.0 ft NAVD88 berm width = 55 ft nearshore slope = 1:20	37.0	339,350
Fieldston/Sunrise – Alt 2	dune + beach nourishment	dune crest elev. = 13ft NAVD88 dune crest width = 30 ft dune seaward slope = 1:5 berm elev. = 9.5 ft NAVD88 berm width = 90 ft nearshore slope = 1:12	30.5	389,770
Fieldston/Sunrise – Alt 3	beach nourishment	berm elev. = 11 ft NAVD88 berm width = 100 ft nearshore slope = 1:15	34.0	409,100

Figure D-24. Nourishment alternatives considered for Fieldston and Sunrise Beaches.

Results of the 1-yr, 2-yr and 10-yr storm simulations on the existing beaches at Fieldston and Sunrise show scour along the toe of the seawalls and a general lowering of the beach (Figure D-25). Sediment eroded from the beach is transported seaward of the MLW line, extending as far as 500 ft from the seawalls. These model results are consistent with performance of the beaches during past storms and with a long-term lowering of the beach elevation observed in the historical LiDAR data (Figure C-16).

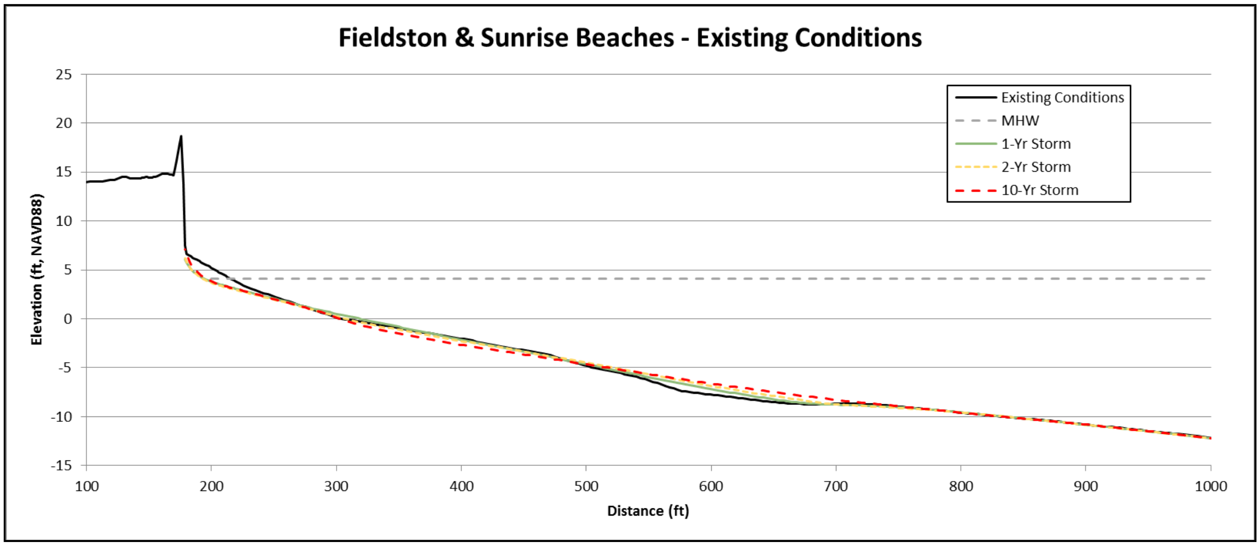

Figure D-24. XBeach and XBeach-G model results for existing conditions at Fieldston & Sunrise Beaches for 1-yr, 2-yr and 10-yr storm events.

Figures D-25 through D-27 show performance of the nourishment alternatives during 1-yr, 2-yr and 10-yr storms, respectively. The model results for the 1-yr storm show erosion of the berm with all three alternatives; Alt 3 with the highest elevation berm shows the greatest scarping (Figure D-25). The dunes in Fieldston/Sunrise – Alt 1 and 2 remain intact with the 1-yr storm. Retreat of the MHW line is greatest with Alt 2 at 46 ft and lowest with Alt 1 at 36 ft. Sediment eroded from the upper portion of the beach is transported seaward to the intertidal and subtidal portions of the beach with all alternatives.

For the 2-yr storm, all three nourishment alternatives show erosion of the berm (Figure D-26). Fieldston/Sunrise – Alt 1 and Alt 2 lose most of the berm and some material from the toe of the dune. Fieldston/Sunrise – Alt 3 loses approximately one-half the width of the nourished berm. Retreat of MHW is greatest with Alt 2 ad 56 ft and lowest with Alt 1 and Alt 3 at 49 ft. All of the alternatives show that sediment eroded from the upper portion of the beach is transported seaward to the intertidal and subtidal zones.

With a 10-yr storm, the cross shore modeling for Fieldston/Sunrise - Alt 1 shows erosion of the entire berm and removal of most of the dune (Figure D-27). Significant berm and minor dune toe erosion also occur with Fieldston/Sunrise - Alt 2, while Alt 3 shows removal of approximately one-half of the berm. Retreat of the MHW line ranges from 62 ft with Alt 1 and Alt 3, to 69 ft with Alt 2. Sediment eroded from the upper portion of the beach is transported seaward to the intertidal and subtidal portions of the beach with all alternatives.

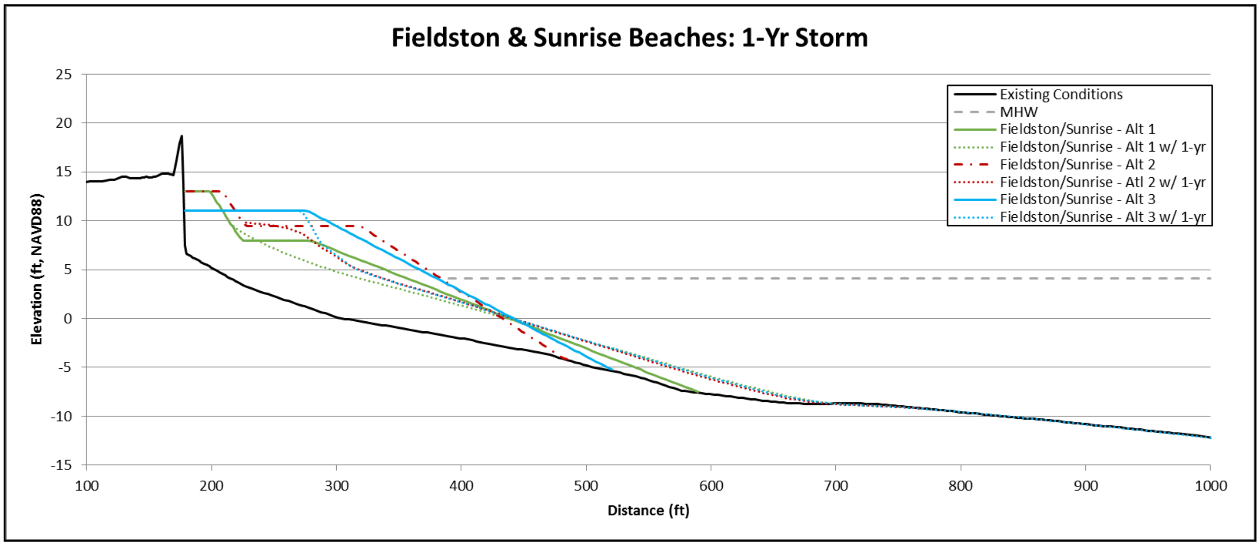

Figure D-25. XBeach and XBeach-G model results for nourishment alternatives at Fieldston and Sunrise Beaches for a 1-yr storm event.

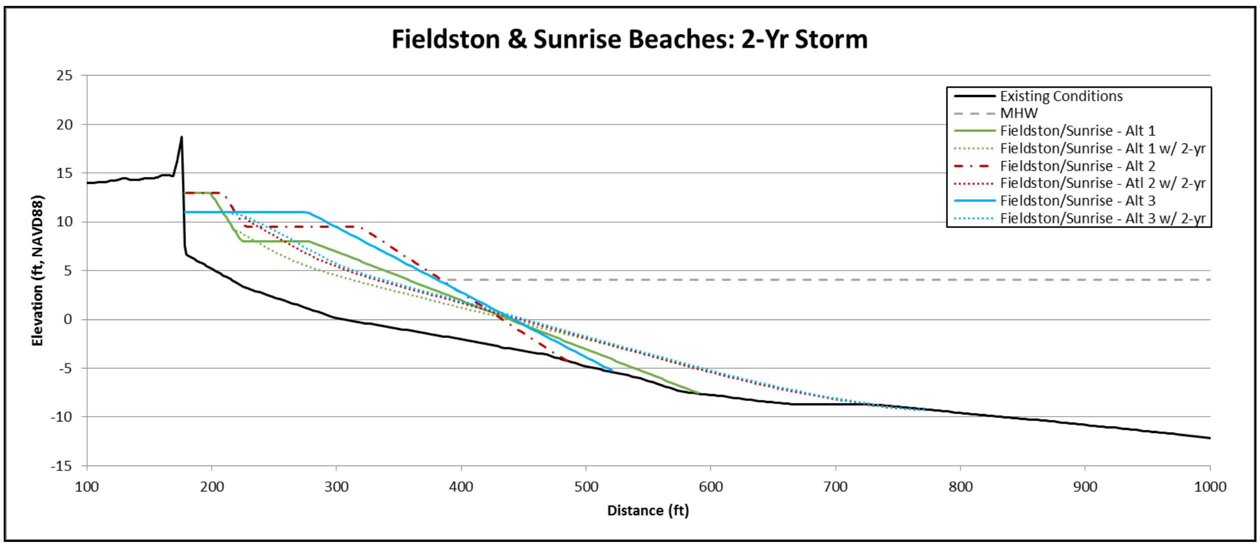

Figure D-26. XBeach and XBeach-G model results for nourishment alternatives at Fieldston and Sunrise Beaches for a 2-yr storm event.

Results of the design life computations showing volume of nourishment remaining in the original footprints as a function of time for the Fieldston and Sunrise Beach alternatives are shown in Figure D-28. The fill material is shown to initially spread relatively quickly, as indicated by the decrease in percentage of fill remaining, as the shoreline adjusts to a new equilibrium. Based on the criteria that renourishment should be performed when 70% to 80% of the volume is lost from the original footprint, the modeling suggests that renourishment will be needed 1.5 to 4.0 years after initial construction. Fieldston/Sunrise – Alt 2 has the longest service life and Fieldston/Sunrise – Alt 1 has the shortest service life.

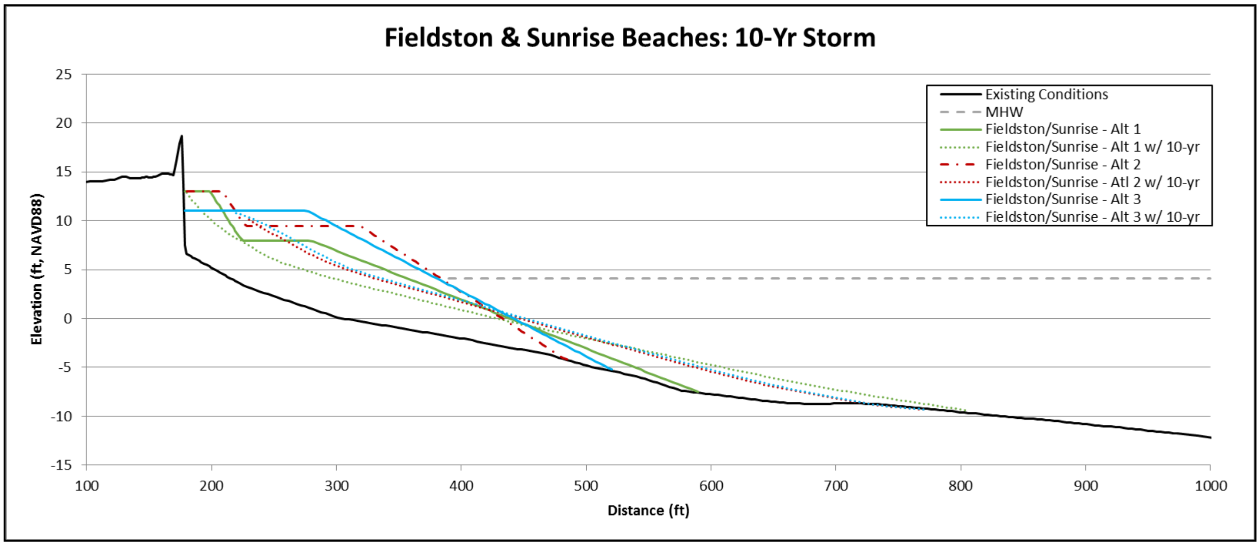

Figure D-27. XBeach and XBeach-G model results for nourishment alternatives at Fieldston and Sunrise Beaches for a 10-yr storm event.

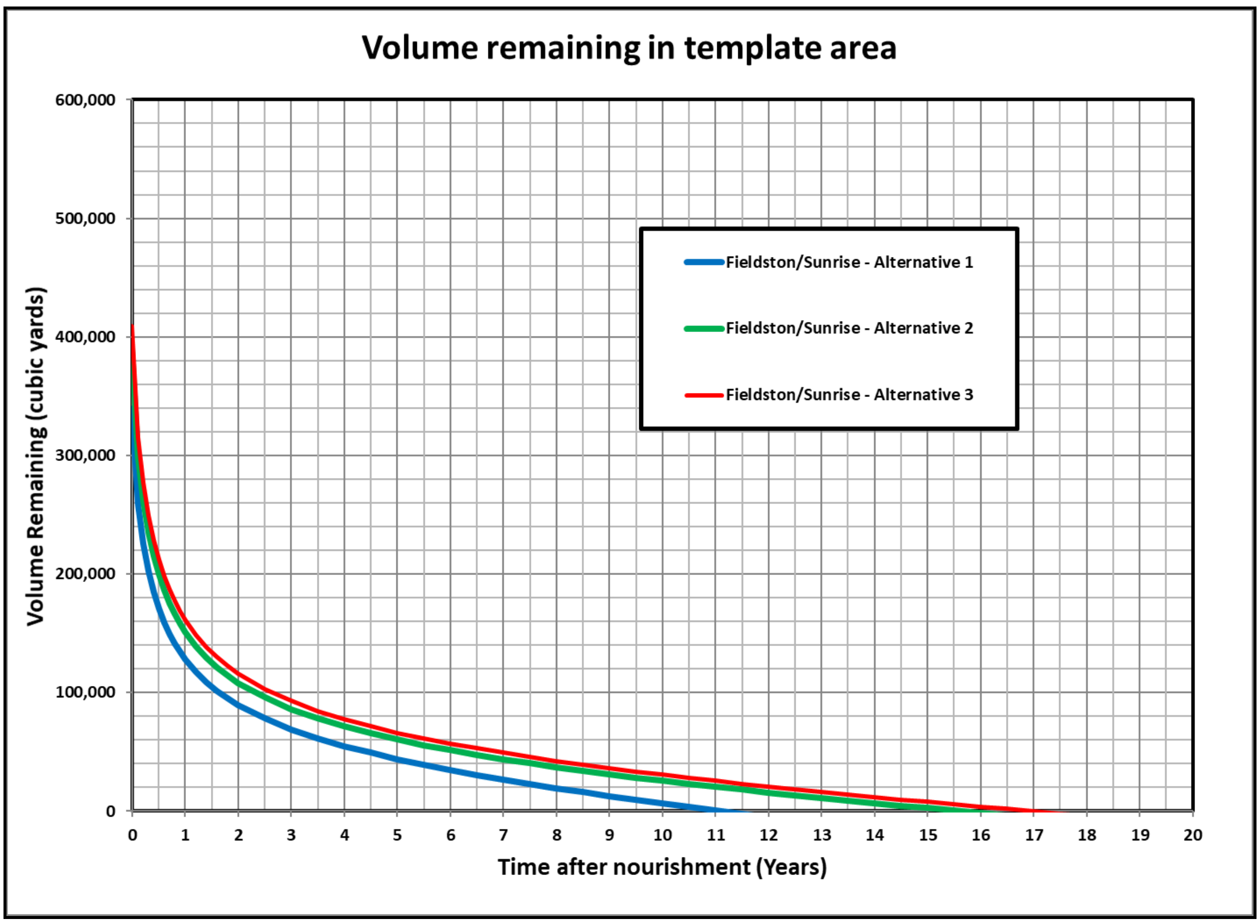

Figure D-28. Service life estimates for beach nourishment alternatives at Fieldston and Sunrise Beaches.

Figure D-29 shows the width of the beach berm over time for the three Fieldston and Sunrise nourishment alternatives. As with the service life estimates, the berm width decreases rapidly during the first year following construction. By year 2 the berm widths for Alt 2 and Alt 3 are estimated to be 25 to 30 ft and only 15 ft for Alt 1.

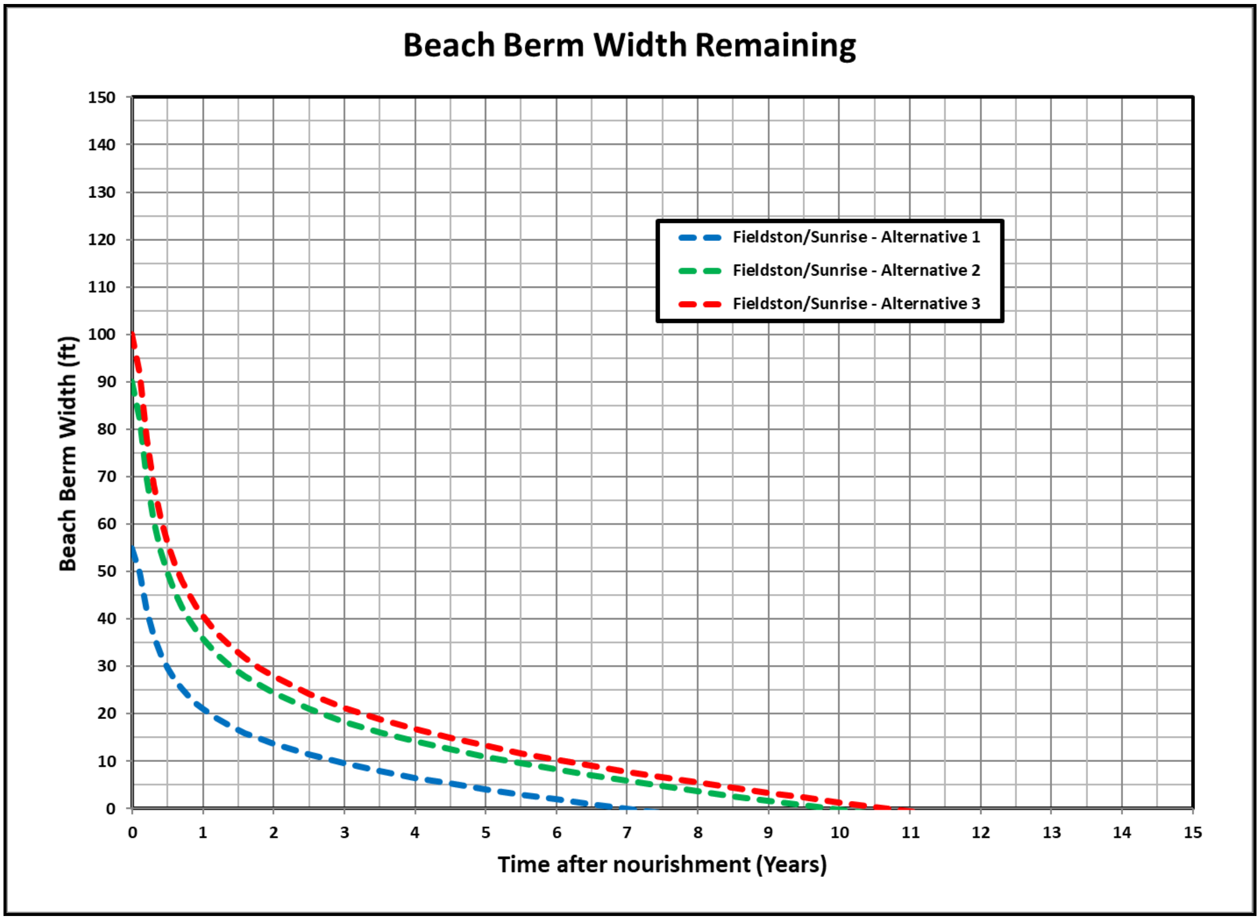

Figure D-29. Berm width over time for beach nourishment alternatives at Fieldston and Sunrise Beaches.

Impacts of the three (3) Fieldston/Sunrise nourishment alternatives on rates of wave overtopping were also evaluated. Calculations summarized in Table D-8 indicate that existing rates of wave overtopping increase from north to south along Fieldston and Sunrise Beaches, with damaging overtopping occurring at Sunrise Beach during a 10-yr storm event and greater. Beach profile data for the 10-yr storm scenarios from XBeach and XBeach-G were used to evalute changes in overtopping rates for each alternative. The calculations showed a 100% reduction in wave overtopping for all three (3) alternatives indicating no damage to buildings from overtopping during a 10-yr storm event.

Over time as additional storms and longshore spreading act to reshape the nourishment, the elevation of the beach in front of the seawalls will lower and the risk of overtopping will increase. To quantify the critical beach elevation at which damaging wave overtopping starts to occur, additional calculations were performed for Fieldston and Sunrise Beaches. For the 10-yr and 50-yr storms, damaging overtopping will begin to occur when the beach drops to an elevation of 3.5 ft and 4.5 ft NAVD88, respectively. For Fieldston/Sunrise – Alt 1 the berm would have to lower 3.5 to 4.5 ft to reach the critical elevation. Because the starting berm elevations for Fieldston/Sunrise – Alt 2 and Alt 3 are higher, the beach would have to lower between 5 and 7.5 ft to reach the critical elevation for damaging wave overtopping.

Costs associated with the Fieldston and Sunrise Beach alternatives are summarized in Table D-10. The costs include the purchase of sand purchase, trucking, and spreading following the design template. Projected costs over the next 30 years are also provided assuming renourishment every 6 years when 80% of the volume is lost from the original footprint.

Table D-10. Costs Associated with Nourishment Alternatives at Fieldston and Sunrise Beaches.

Resiliency Alternative	Initial Construction Cost	Costs Over Next 30 Years
Fieldston/Sunrise – Alt 1	$10.18 million	$91.62 million
Fieldston/Sunrise – Alt 2	$11.69 million	$76.00 million
Fieldston/Sunrise – Alt 3	$12.27 million	$92.92 million

3.4.4 Managed Retreat

Managed retreat from the shoreline at Fieldston and Sunrise Beaches was considered as an option for the long-term as a way to reduce coastal vulnerability. Preliminary results from the MC-FRM model show that portions of Fieldston and Sunrise Beach will have a 100% probability of flooding by 2050 (Figures D-11 and D-12). While the model data indicate flood pathways from both the ocean and the Green Harbor River system, the most vulnerable properties will be those closest to the ocean that will experience damaging wave overtopping in combination with flooding (Figures D-30 and D-31). The 2020 assessor's database shows property values for the first row of homes most affected by coastal flooding and wave overtopping to be $18.62 million in Fieldston and $32.17 million in Sunrise. The combined annual tax revenue to the town from property owners is approximately $677,020. To pursue this alternative over the next 30 years, close coordination between the town and affected property owners would be required, and federal and/or state monies would be needed to help the town with property acquisitions.

Figure D-30. Fieldston Beach showing properties vulnerable to overtopping with potential costs for managed retreat along the first row of homes.

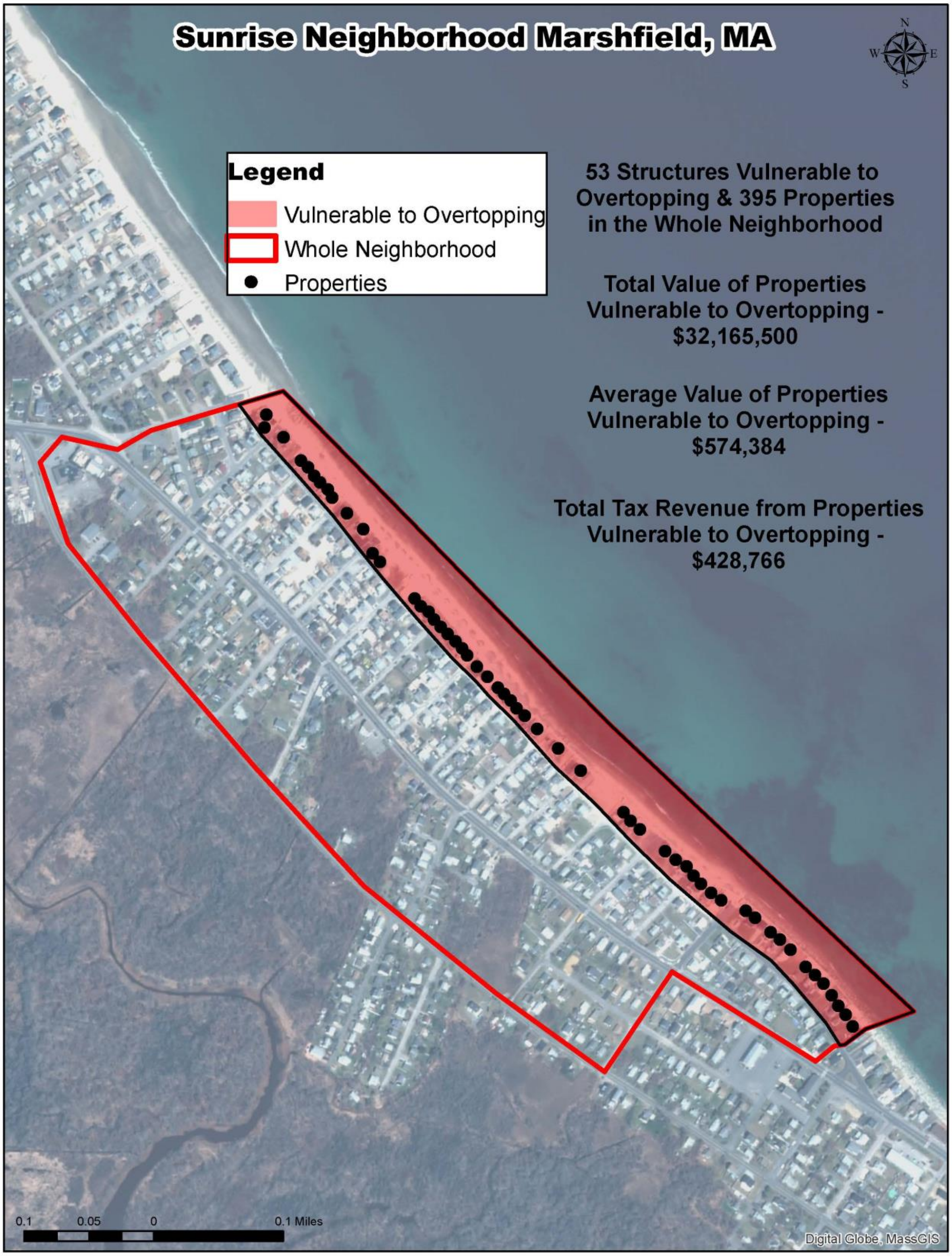

Figure D-31. Sunrise Beach showing properties vulnerable to overtopping with potential costs for managed retreat along the first row of homes.

3.5 Ocean Bluff, Hewitt's Point, Brant Rock and South Brant Rock Beaches

The area of Marshfield between Ocean Bluff and South Brant Rock is developed with single family homes and a small pocket of commercial development in the Brant Rock area. Approximately 152 homes and businesses on lots averaging 0.17 acres in size are located in the area seaward of Ocean St., Dyke Rd., and the north end of Island St. A combination of seawalls and/or revetments extends along the entire 7,645 ft stretch of beach. The Town has performed maintenance on these structures over the past 20 to 30 years and has developed costs for future work as summarized in Table D-11. For the most part, the beaches on the seaward side of the shore protection structures are privately owned. Recent shoreline change data between 1978 and 2014 show erosion rates as high as -2.0 ft/yr at Ocean Bluff, decreasing to a nearly stable shoreline at the South Brant Rock area (Figure C-15). In many areas the seawalls/revetments have prevented further retreat of the shoreline and storm waves interacting with the seawalls have resulted in a lowering of the beach elevation. Nearshore areas of the Ocean Bluff to South Brant Rock shoreline contain naturally occurring rocky intertidal resources. To protect the existing rocky intertidal resources while enhancing the resiliency of the shoreline, both hard engineering and hybrid alternatives were considered. The *status quo* alternate was also considered as well as managed retreat for a longer-term alternative.

3.5.1 Maintain Existing Management Approach – *Status Quo*

Future management by the Town of Marshfield for the Ocean Bluff to South Brant Rock area includes regular maintenance of the existing seawalls and revetments. FEMA data from 1978 to 2018 indicate a total of 45 repetitive loss properties along this section of beach (Figure C-37). Total claims for this period were $30,830 for Ocean Bluff, $4.04 million for Brant Rock and $2.13 million for South Brant Rock. Table D-11 provides a summary of costs to maintain the *status quo* for these beaches over the next 30 years, including estimated costs for providing storm related public services. Continuing with the current management approach will be costly and will do nothing to increase the resiliency of the coastline.

Table D-11. Projected Costs Over Next 30 Years to Maintain Existing Management Approach for Beaches Between Ocean Bluff and South Brant Rock.

Beach	FEMA Repetitive Loss Claims	Maintenance of Shore Protection Structure	Storm Related Public Services	Total
Ocean Bluff	$25,220	$8.81 million	$0.49 million	$9.33 million
Hewitt's Point	$0	$9.27 million	$0.31 million	$9.57 million
Brant Rock	$3.31 million	$3.27 million	$0.35 million	$6.92 million
South Brant Rock	$1.74 million	$10.22 million	$0.85 million	$12.81 million

3.5.2 Enhance and/or Enlarge Shore Protection Structures

The crest elevation of the seawalls and revetments between Ocean Bluff and South Brant Rock range between 18.4 ft and 20.7 ft NAVD88. The elevation of the beach at the toe of the shore protection structures ranges from -0.85 ft to 4.65 ft NAVD88. Under existing conditions, wave overtopping capable of causing structural damage to adjacent homes occurs during a 10-yr storm event and greater at Ocean Bluff, Brant Rock and South Brant Rock Beaches. Hewitt's

Point Beach experiences lower rates of overtopping primarily because the elevation of the cobble beach in front of the shore protection structure is higher than the surrounding beaches. Table D-12 provides a summary of seawall crest increases that would be needed to prevent structure damage during 10-yr and 50-yr storm events, with current sea levels and with 2 ft of sea level rise (SLR) expected between the 2040 and 2060 time horizon. Based on existing elevations of the infrastructure (i.e., homes, roads), and the design of the shore protection structures themselves, it is likely that crest increases greater than 4 ft would not be practical without significant modifications to the sites. Costs associated with raising the structures 0.5 – 4.0 ft at each beach would be between $10.58 and $29.23 million. Given that the enlarged structures would not provide the necessary protection during future sea level rise scenarios, this alternative would require further modifications to the seawalls such as adding a revetment along the seaward toe, at additional cost and impact to the beach resources.

Table D-12. Storms Capable of Causing Structural Damage to Buildings from Wave Overtopping between Ocean Bluff and South Brant Rock Beaches and Structure Elevation Increases Needed to Avoid Damaging Wave Overtopping.

Beach Scenario	10-Yr Storm	50-Yr Storm	10-Yr Storm + 2 ft SLR	50-Yr Storm + 2 ft SLR
Ocean Bluff Beach				
Existing Seawall Overtopped	Yes	Yes	Yes	Yes
Seawall Increase	> 8.0 ft	> 8.0 ft	> 8.0 ft	> 8.0 ft
Hewitt's Point Beach				
Existing Seawall Overtopped	No	No	Yes	Yes
Seawall Increase	0 ft	0 ft	4.0 ft	6.5 ft
Brant Rock Beach				
Existing Seawall Overtopped	Yes	Yes	Yes	Yes
Seawall Increase	0.5 ft	3.5 ft	8.0 ft	> 8.0 ft
South Brant Rock Beach				
Existing Seawall Overtopped	Yes	Yes	Yes	Yes
Seawall Increase	3.5 ft	8.0 ft	> 8.0 ft	> 8.0 ft

3.5.3 Nearshore Boulder Field

The existing rocky intertidal resources in the nearshore areas of Ocean Bluff, Hewitt's Point, Brant Rock and South Brant Rock provide an optimum location for additional wave attenuation through construction of an intertidal boulder field. The primary goal of the boulder field would be to reduce wave overtopping during high energy storms and future conditions with sea level rise. Additional engineering would be needed to design the boulder field to ensure reductions in wave overtopping for specific storm events; however, assuming a conceptual design with a 60 ft wide boulder field along the entire 7,645 ft stretch of beach, estimated costs for construction would be $20.49 million. The footprint of the boulder field would be approximately 458,700 sq ft.

3.5.4 Managed Retreat

A plan for managed retreat from the shoreline between Ocean Bluff and South Brant Rock was considered as an option for the long-term as a way to reduce coastal vulnerability. Preliminary results from the MC-FRM model show the highest probabilities of flooding by 2050 to be located along the south end of Ocean Bluff, Brant Rock and the southern end of South Brant Rock (Figure D-12). While the model data indicate flood pathways from both the ocean and the Green Harbor River system, the most vulnerable properties will be those closest to the ocean that will experience damaging wave overtopping in combination with flooding. The 2020 assessor's database shows property values for homes and businesses most affected by coastal flooding and wave overtopping to be $57.10 million. Annual tax revenue to the town from these property owners is approximately $761,084. Figures D-32 and D-33 show the affected properties for the Brant Rock and South Brant Rock areas. To pursue this alternative over the next 30 years, close coordination between the town and affected property owners would be required, and federal and/or state monies would be needed to help the town with property acquisitions.

3.6 Blackman's Point Beach

Blackman's Point contains a seasonal campground with manufactured homes and recreational vehicles that is open from May 1 to September 30. The campground is located at the top of a coastal bank and the bank is covered with loose boulders. Nearshore areas of Blackman's Point contain extensive rocky intertidal resources composed of bedrock and cobbles. The campground and adjacent beach are privately-owned, and maintenance of the shoreline is not performed by the Town of Marshfield. Recent shoreline change data between 1978 and 2014 show a relatively stable shoreline (Figure C-15). Given the seasonal use of the area and the low erosion rates, only two alternatives were considered; *status quo* and managed retreat.

3.6.1 Maintain Existing Management Approach – *Status Quo*

Maintaining the existing management approach for Blackman's Point would require no action from the Town of Marshfield. Owners of the manufactured homes and recreational vehicles in the first row along the top of the coastal bank are required to remove the structures in the off season to avoid storm damage. As long as this practice continues, vulnerability to coastal storms will be minimized.

3.6.2 Managed Retreat

Managed retreat from Blackman's Point campground was considered as an option for the long-term to reduce risks caused by climate change. Preliminary results from the MC-FRM model show 100% probability of flooding in 2050 across the southern end of the campground (Figures D-12 and D-13). As such, the managed retreat alternative includes abandoning the most vulnerable section of the campground over the next 30 year period. Costs associated with this alternative were not available at the time this document was prepared.

Figure D-32. Brant Rock showing properties vulnerable to overtopping with potential costs for managed retreat for the most vulnerable properties.

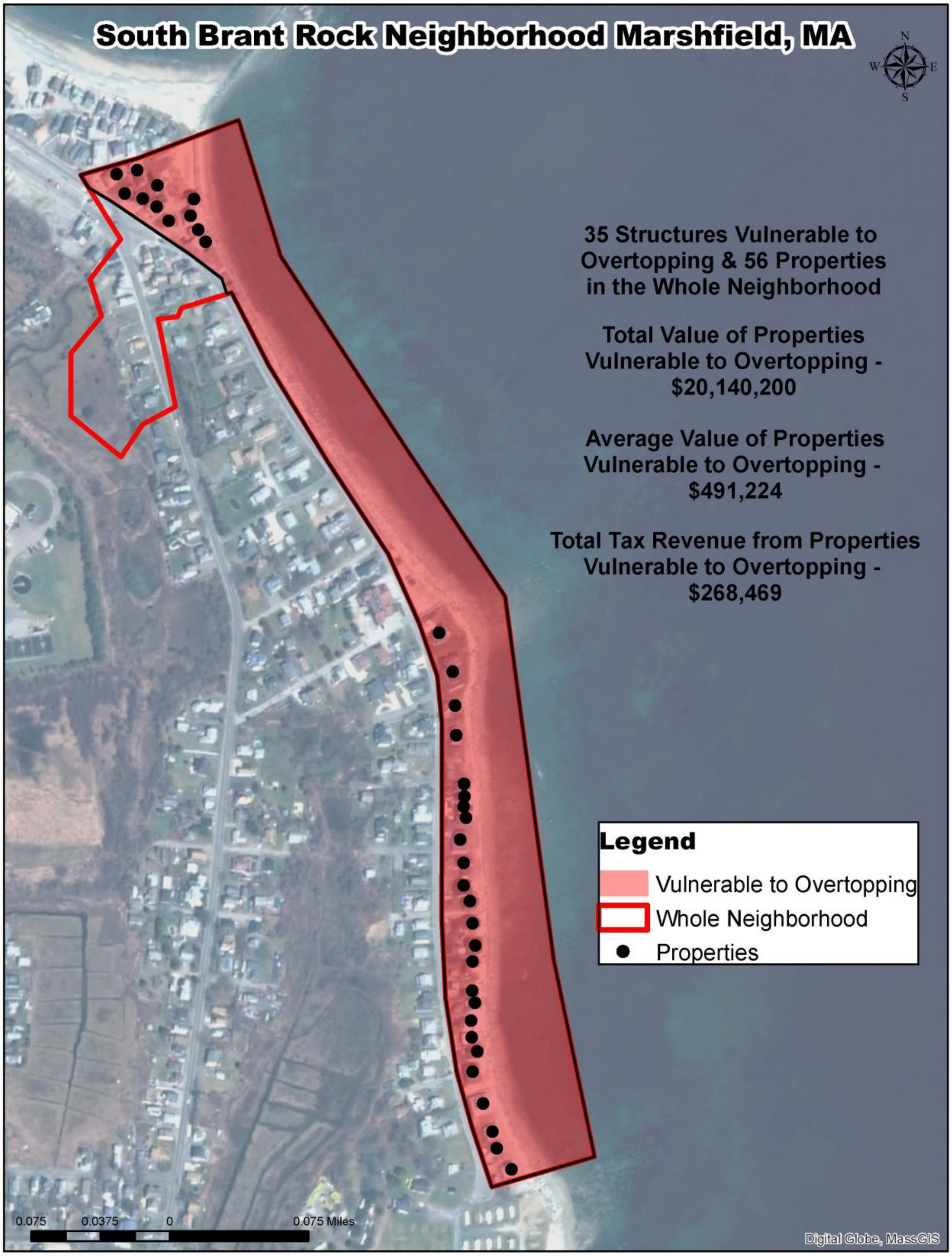

Figure D-33. South Brant Rock showing properties vulnerable to overtopping with potential costs for managed retreat for the most vulnerable properties.

3.7 Blue Fish Cove Beach

The Blue Fish Cove area of Marshfield is developed with single family homes on a narrow and low-lying barrier beach that separates Green Harbor River from the Atlantic Ocean. The area seaward of A St. and north of the Green Harbor jetty includes approximately 26 homes on lots averaging 0.20 acres in size. The ocean facing homes at the northern end of Blue Fish Cove Beach are protected by stone revetments. The homes at the southern end of Blue Fish Cove have loose stones placed directly on the beach. A large outcropping of bedrock is located on the beach east of the Green Harbor jetty. Recent shoreline change data between 1978 and 2014 show a relatively stable shoreline (Figure C-15). The beaches and shore protection structures in the area are privately owned. As such, the only resiliency measures considered by the Town of Marshfield for Blue Fish Cove were *status quo* and managed retreat.

3.7.1 Maintain Existing Management Approach – *Status Quo*

Maintaining the existing management approach for Blue Fish Cove Beach would require no action from the Town of Marshfield. Since the existing structures are owned and maintained by the property owners, it is assumed that all costs associated with maintenance would be covered by the owners. With future increases in sea level, it is assumed that the *status quo* alternative will not provide the necessary level of protection needed to protect the homes from damages caused by flooding and wave overtopping.

3.7.2 Managed Retreat

Managed retreat from the shoreline in the Blue Fish Cove area was considered as an option for the long-term to reduce coastal vulnerability. Preliminary results from the MC-FRM model show 100% probability of flooding across the entire barrier beach by 2050 (Figure D-13). Given the vulnerability of this area to flooding from both the ocean and Green Harbor, costs associated with retreat of all homes from the Blue Fish Cove area were considered. The 2020 assessor's database shows property values for all 24 homes affected by coastal flooding and wave overtopping in 2050 to be $12.86 million (Figure D-34). Annual tax revenue from these properties is $171,446. To pursue this alternative over the next 30 years, close coordination between the town and affected property owners would be required, and federal and/or state monies would be needed to help the town with property acquisitions.

3.8 Green Harbor Beach

Green Harbor Beach is located immediately west of the entrance to Green Harbor and is protected by the jetty that runs along the western side of the harbor. The Town owns and operates a popular public beach at Green Harbor. The beach width averages 140 ft to 230 ft and is backed by an extensive system of coastal dunes. There are 19 developed properties at Green Harbor Beach located landward of the coastal dunes along Bay Ave. Most of the properties are developed with single family homes on lots averaging 0.13 acres in size. The beach is approximately 585 ft long and does not contain any shore protection structures. Although recent shoreline change data between 1978 and 2014 show a trend of erosion (Figure C-15), aerial photographs dating back to 2001 in Google Earth indicate little change in the location of MHW or the toe of the dune. Given the wide sand beach and dune system in combination with the stable shoreline, only two alternatives were considered; *status quo* and managed retreat.

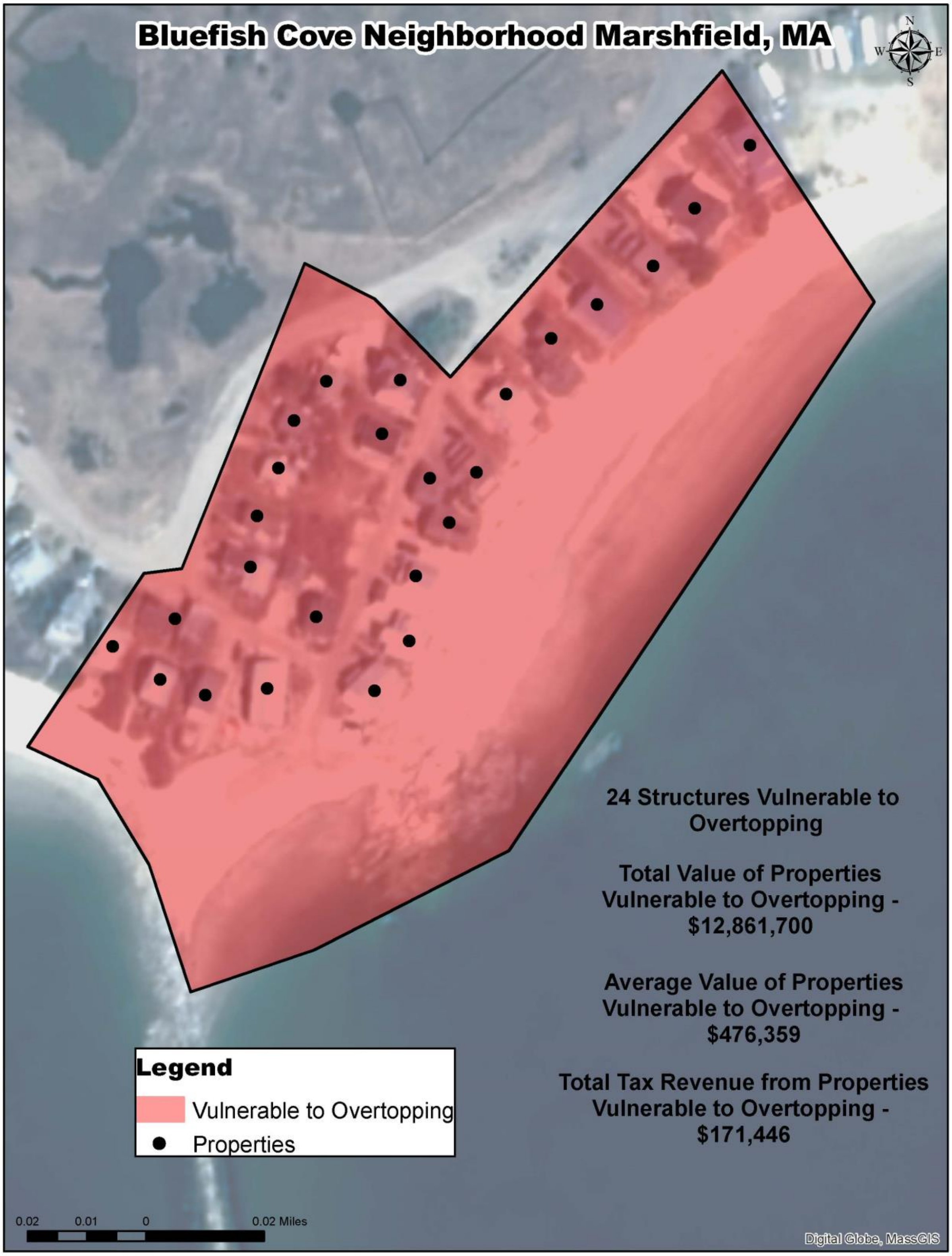

Figure D-34. Blue Fish Cove area showing properties vulnerable to flooding and overtopping with potential costs for managed retreat.

3.8.1 Maintain Existing Management Approach – *Status Quo*

The Town's currently maintains one controlled access path between the parking lot and Green Harbor Beach. A second access path from the end of Bay Ave runs along the Green Harbor jetty. Sand fencing is commonly installed along the toe of the dune to help accumulate wind-blown sediment and keep foot traffic off the dunes. Many years ago, the Town accepted sediment for beneficial reuse from dredging in Green Harbor; however, for the past twenty-five (25) years sediment dredged from the Harbor has been placed in a nearshore disposal site near the Marshfield/Duxbury town line. As such, there is not a regular or frequent program for nourishment of the beach at Green Harbor. The *status quo* alternative would continue the current practices to manage the public beach. Although the primary dune does not meet FEMA's criteria for providing protection during a 100-yr event, the 100 ft to 300 ft wide feature provides a natural and resilient buffer to coastal storms.

3.8.2 Managed Retreat

Managed retreat from the shoreline at Green Harbor Beach was considered as an option for the long-term to reduce coastal vulnerability. Preliminary results from the MC-FRM model show a high probability of flooding across the entire barrier beach by 2050 (Figure D-13). Given the vulnerability of this area to flooding from both the ocean and Green Harbor, costs associated with retreat of all homes from the Green Harbor Beach area was considered. The 2020 assessor's database shows property values for all homes affected by coastal flooding in 2050 to be $20.18 million. To pursue this alternative over the next 30 years, close coordination between the town and affected property owners would be required, and federal and/or state monies would be needed to help the town with property acquisitions.

3.9 Bay Ave. and Gurnet Rd. Beaches

The Bay Ave. and Gurnet Rd. Beaches are located along the barrier beach north and south of the Marshfield and Duxbury town line. Bay Ave. barrier beach in Marshfield is developed with 125 single family homes on average lot sizes of 0.37 acres. In Duxbury, the barrier beach (excluding Marginal and Pine Point Rds.) is developed with 165 single family homes on average lot sizes of 0.21 acres. Vertical seawalls extend along the entire 6,010 ft stretch of beach. The seawalls in this area are in poor condition, having sustained damage most recently during the winter 2018 storm season. Both towns are either in the process of repairing the seawalls or planning to repair them in the next few years. Permits issued for the seawall repairs include a condition for beach nourishment to restore sediment to the system and to provide protection for the seawalls. Most of the beaches in this area are privately owned. Recent shoreline change data between 1978 and 2014 show a trend of decreasing erosion from north to south (Figure C-15). Rates of erosion are as high as -2.0 ft/yr along Bay Ave. in Marshfield and decrease to approximately -0.5 ft/yr along Gurnet Rd. in Duxbury. In many places the seawalls have prevented further retreat of the shoreline and storm waves interacting with the seawalls have resulted in a lowering of the beach elevation. Wave overtopping during storms can cause significant damage in this area. Resiliency measures considered for Bay Ave. and Gurnet Rd. Beaches included the *status quo* alternative and enhancing the existing shore protection structures. Beach/dune nourishment was also considered to restore sediment to the system while also protecting the seawalls from further damage and reducing the potential for wave overtopping. Finally, managed retreat was considered as a long-term alternative.

3.9.1 Maintain Existing Management Approach – *Status Quo*

Future management by the Towns of Marshfield and Duxbury for the Bay Ave. and Gurnet Rd. Beaches includes regular maintenance of the seawalls that are currently or planned to be rebuilt. FEMA data from 1978 to 2018 indicate between 20 and 30 repetitive loss properties for Bay Ave. and between 30 and 40 repetitive loss properties for Gurnet Rd. Beach (Figure C-37). Total claims for this period were $2.13 million for the Bay Ave. properties and $3.04 million for the Gurnet Rd. properties. Table D-13 provides a summary of costs to maintain the *status quo* for these beaches over the next 30 years, including estimated costs for providing storm related public services. Continuing with the current management approach will be costly and will do nothing to increase the resiliency of the coastline.

Table D-13. Projected Costs Over Next 30 Years to Maintain Existing Management Approach for Bay Ave. and Gurnet Rd. Beaches.

Beach	FEMA Repetitive Loss Claims	Maintenance of Shore Protection Structure	Storm Related Public Services	Total
Bay Ave.	$1.74 million	$ million	$0.51 million	$ million
Gurnet Rd.	$2.49 million	$ million	$1.07 million	$ million

3.9.2 Enhance and/or Enlarge Shore Protection Structures

3.9.2 is pending data from the towns The crest elevation of the seawalls in Fieldston and Sunrise is 18.6 ft NAVD88. The elevation of the beach at the toe of the seawalls decreases from 4.4 ft to -0.5 ft NAVD88 from north to south. Under existing conditions, wave overtopping capable of causing structural damage to adjacent homes occurs during a 50-yr storm event at Fieldston Beach and during 10-yr and greater storms at Sunrise Beach. Table D-14 provides a summary of seawall crest increases that would be needed to prevent structural damage during 10-yr and 50-yr storm events, with current sea levels and with 2 ft of sea level rise (SLR) expected between the 2040 and 2060 time horizon. Based on existing elevations of the infrastructure landward of the seawalls, and the design of the seawalls themselves, it is likely that crest increases greater than 4 ft would not be practical without significant modifications to the sites. Costs associated with raising the structures 0.5 – 4.0 ft along the entire 5,675 ft of Fieldston and Sunrise Beach would be between $39.73 and $51.08 million. Given that the enlarged structures would not provide the necessary protection during future sea level rise scenarios, this alternative would require further modifications to the seawalls such as adding a revetment along the seaward toe.

Table D-14. Storms Capable of Causing Structural Damage to Buildings from Wave Overtopping at Bay Ave. and Gurnet Rd. Beaches and Seawall Elevation Increases Needed to Avoid Damaging Wave Overtopping.

Beach Scenario	10-Yr Storm	50-Yr Storm	10-Yr Storm + 2 ft SLR	50-Yr Storm + 2 ft SLR
Bay Ave. Beach				
Existing Seawall Overtopped	Yes	Yes	Yes	Yes
Seawall Increase	7.0 ft	> 8.0 ft	> 8.0 ft	> 8.0 ft
Gurnet Rd. Beach				
Existing Seawall Overtopped	No	Yes	Yes	Yes
Seawall Increase	0	3.5 ft	6.0 ft	> 8.0 ft

3.9.3 Beach and Dune Nourishment

Three (3) beach and dune nourishment alternatives were developed for the Bay Ave. and Gurnet Rd. Beach areas. The design elements, footprint areas and nourishment volumes for each alternative are provided in Table D-15. All alternatives extended along the entire 6,010 ft stretch of privately-owned beach (Figure D-35). Coordination between the Town and private property owners is currently underway to secure rights of entry for construction and public access easements.

Table D-15. Nourishment Alternatives Evaluated for Bay Ave. and Gurnet Rd. Beaches

Alternative	Resiliency Type	Design Elements	Footprint Area (acres)	Volume (cu yds)
Bay Ave/Gurnet Rd – Alt 1	dune + beach nourishment	dune crest elev. = 11 ft NAVD88 dune crest width = 20 ft dune seaward slope = 1:5 berm elev. = 8.0 ft NAVD88 berm width = 85 ft nearshore slope = 1:20	50.3	313,160
Bay Ave/Gurnet Rd – Alt 2	dune + beach nourishment	dune crest elev. = 13ft NAVD88 dune crest width = 30 ft dune seaward slope = 1:5 berm elev. = 9.5 ft NAVD88 berm width = 90 ft nearshore slope = 1:12	36.4	511,030
Bay Ave/Gurnet Rd – Alt 3	beach nourishment	berm elev. = 11 ft NAVD88 berm width = 100 ft nearshore slope = 1:15	41.5	527,740

Cross shore modeling of existing conditions and the three (3) nourishment alternatives was performed for 1-yr, 2-yr and 10-yr storm events. The modeling considered the mixed grain size beach and assumed 50% sand at 0.38 mm and 50% gravel at 11.5 mm. Spreading analysis were also performed to estimate the percentage of fill remaining within the project area through time. Results of the spreading analysis were used to develop a schedule for renourishment.

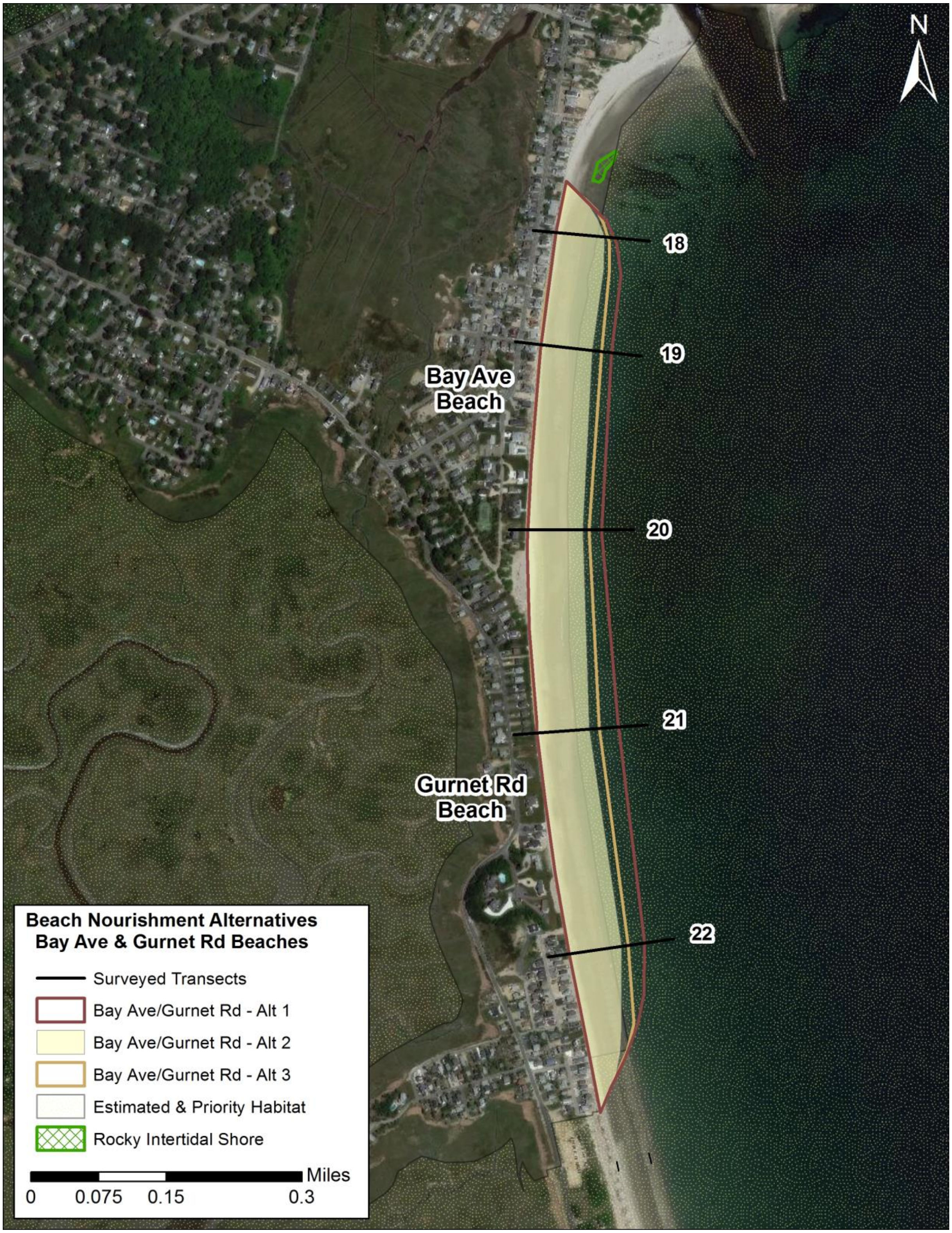

Figure D-35. Nourishment alternatives considered for Bay Ave. and Gurnet Rd. Beaches.

Results of the 1-yr, 2-yr and 10-yr storm simulations on the existing beaches at Bay Ave. and Gurnet Rd. show scour along the toe of the seawalls and a general lowering of the beach (Figure D-36). Sediment eroded from the beach is primarily transported to the intertidal zone approximately 80 ft from the seawalls. These model results are consistent with performance of the beaches during past storms and with a long-term lowering of the beach elevation observed in the historical LiDAR data (Figures C-18 and C-19).

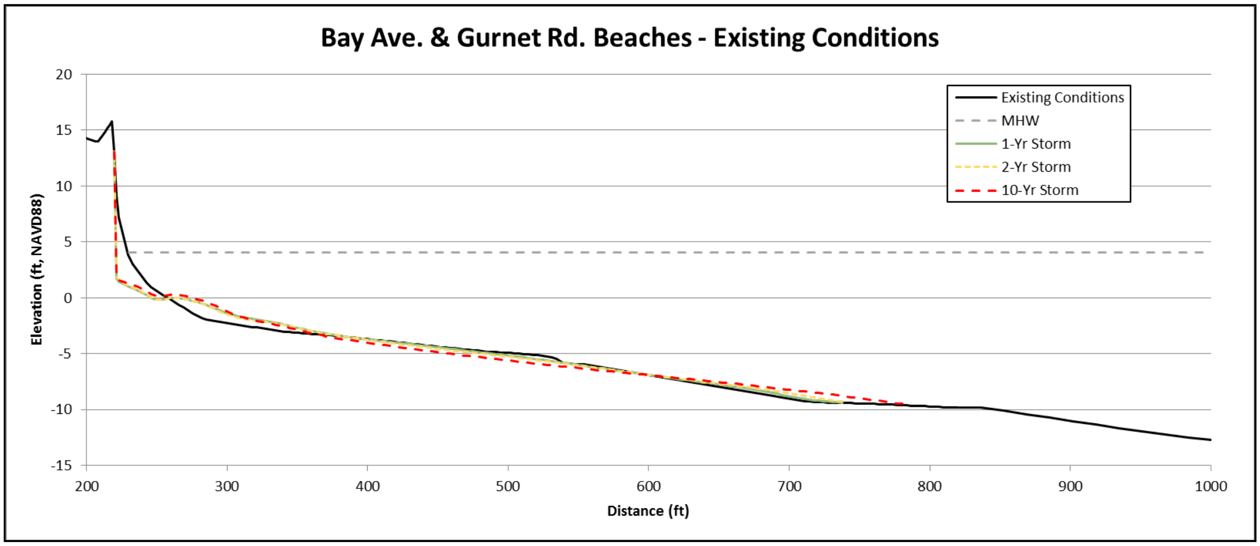

Figure D-36. XBeach and XBeach-G model results for existing conditions at Bay Ave. and Gurnet Rd. Beaches for 1-yr, 2-yr and 10-yr storm events.

Figures D-37 through D-39 show performance of the nourishment alternatives during 1-yr, 2-yr and 10-yr storms, respectively. The model results for the 1-yr storm show erosion of the berm with Bay Ave/Gurnet Rd – Alt 1 and Alt 2. The berm remains intact with Alt 3, but there is scarping of the beach immediately below the berm. The dunes in Bay Ave/Gurnet Rd – Alt 1 and Alt 2 remain intact with the 1-yr storm. Retreat of the MHW line is greatest with Alt 2 at 43 ft and lowest with Alt 1 and 26 ft. Sediment eroded from the upper portion of the beach is transported seaward to the intertidal and subtidal portions of the beach with all alternatives.

For the 2-yr storm, all three nourishment alternatives show erosion of the berm (Figure D-38). Bay Ave/Gurnet Rd – Alt 1 and Alt 2 lose most of the berm and some material from the dune. Bay Ave/Gurnet Rd – Alt 3 loses approximately one-third the width of the nourished berm. Retreat of MHW is between 39 and 42 ft with all three alternatives. Sediment eroded from the upper portion of the beach is transported seaward to the intertidal and subtidal portions of the beach with all scenarios.

With a 10-yr storm, the cross-shore modeling shows very similar results for all three alternatives (Figure D-39). The dunes and berm are eroded and the level of the beach immediately in front of the seawalls drops to 7.6 ft NAVD88 for Bay Ave/Gurnet Rd - Alt 1, 8.5 ft NAVD88 for Alt 2 and 9.0 ft NAVD88 for Alt 3. Retreat of the MHW line is greatest with Alt 1 at 121 ft and smallest with Alt 3 at 104 ft. Sediment eroded from the upper portion of the beach is transported seaward to the intertidal and subtidal portions of the beach with all alternatives.

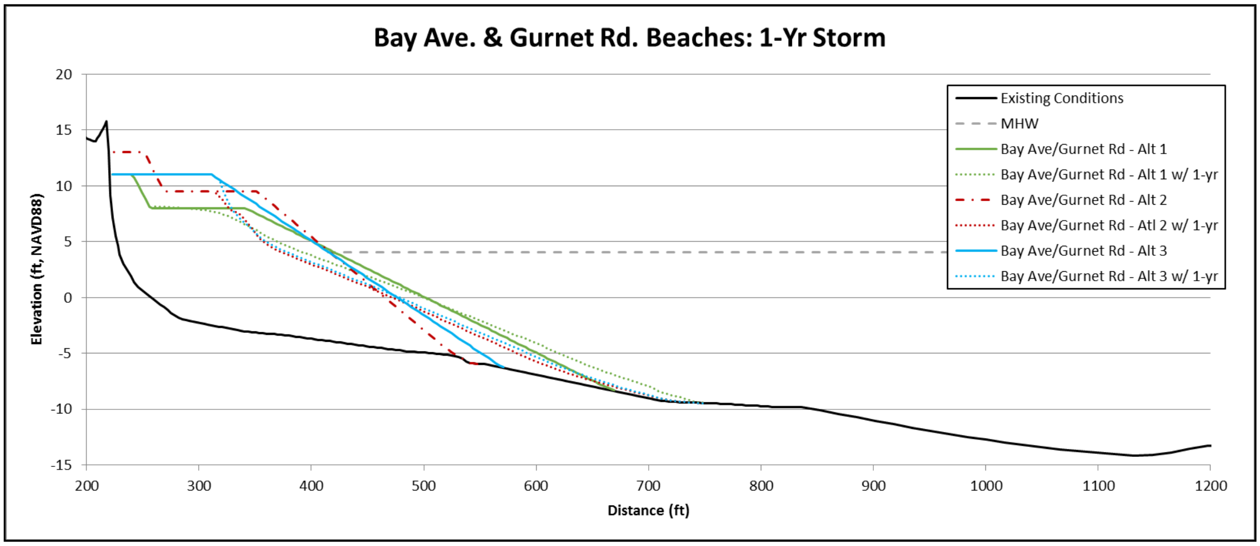

Figure D-37. XBeach and XBeach-G model results for nourishment alternatives at Bay Ave. and Gurnet Rd. Beaches for a 1-yr storm event.

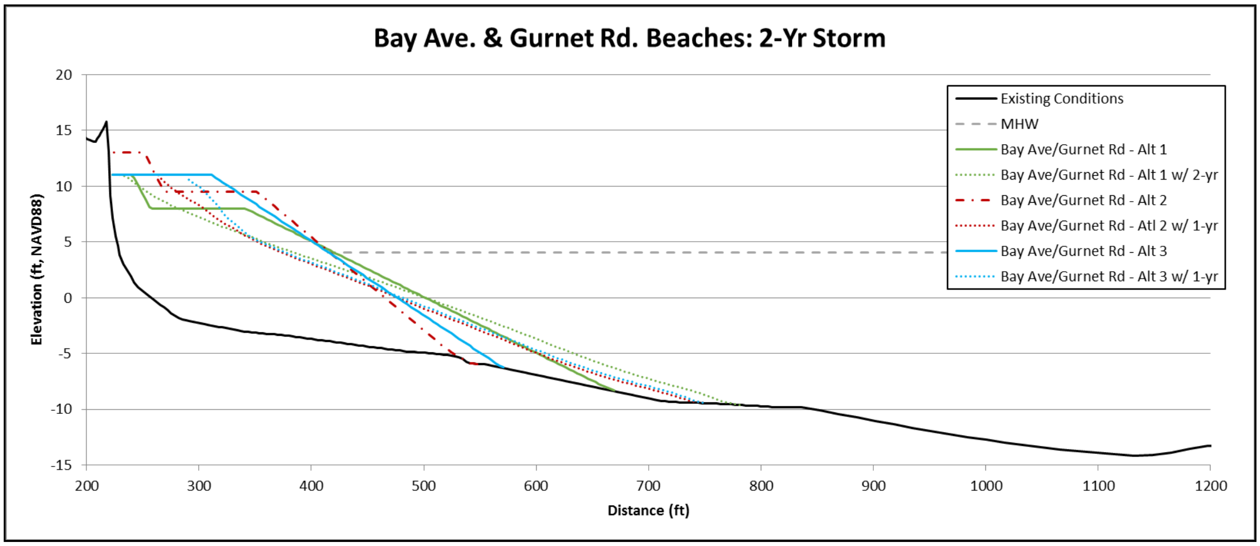

Figure D-38. XBeach and XBeach-G model results for nourishment alternatives at Bay Ave. and Gurnet Rd. Beaches for a 2-yr storm event.

Results of the design life computations for the Bay Ave. and Gurnet Rd. Beach alternatives are shown in Figure D-40. The fill material is shown to initially spread relatively quickly, as indicated by the decrease in percentage of fill remaining, as the shoreline adjusts to a new equilibrium. Based on the criteria that renourishment should be performed when 70% to 80% of the volume is lost from the original footprint, the modeling suggests that renourishment will be needed between 3 and 5.5 years after initial construction. Bay Ave/Gurnet Rd – Alt 1 has the shortest service life and Bay Ave/Gurnet Rd – Alt 3 has the longest service life. The service life of a nourishment project at Bay Ave. and Gurnet Rd. Beaches could be extended through beneficial reuse of sediment dredged annually from Green Harbor. With annual renourishment of 30,000 cy from the harbor dredging, the service life of Alt 1 would be increased by 5 to 6 years (Figure 41).

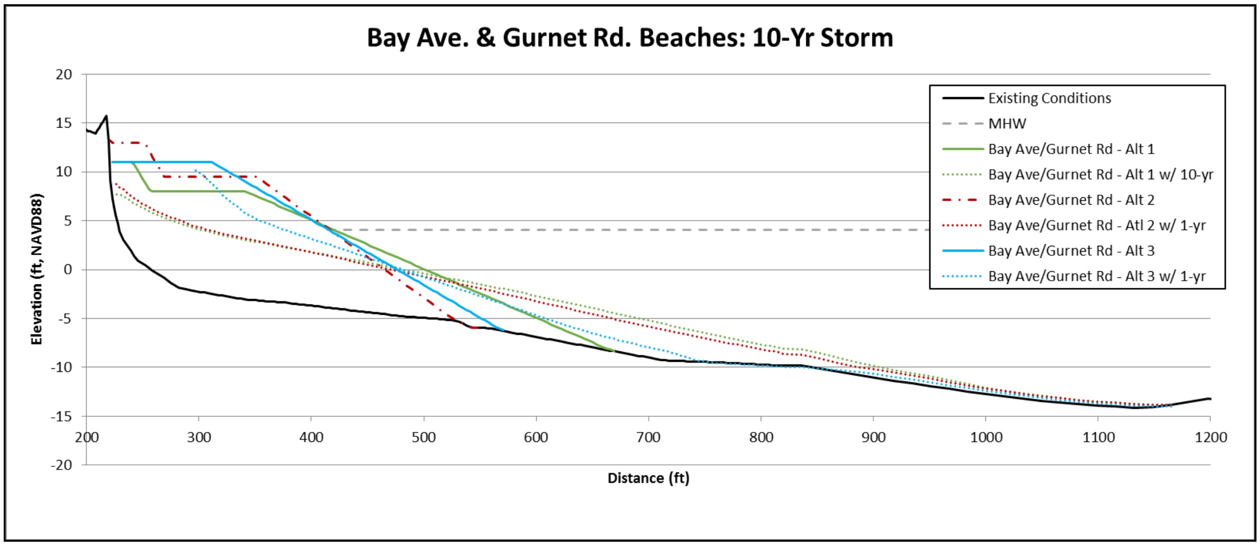

Figure D-39. XBeach and XBeach-G model results for nourishment alternatives at Bay Ave. and Gurnet Rd. Beaches for a 10-yr storm event.

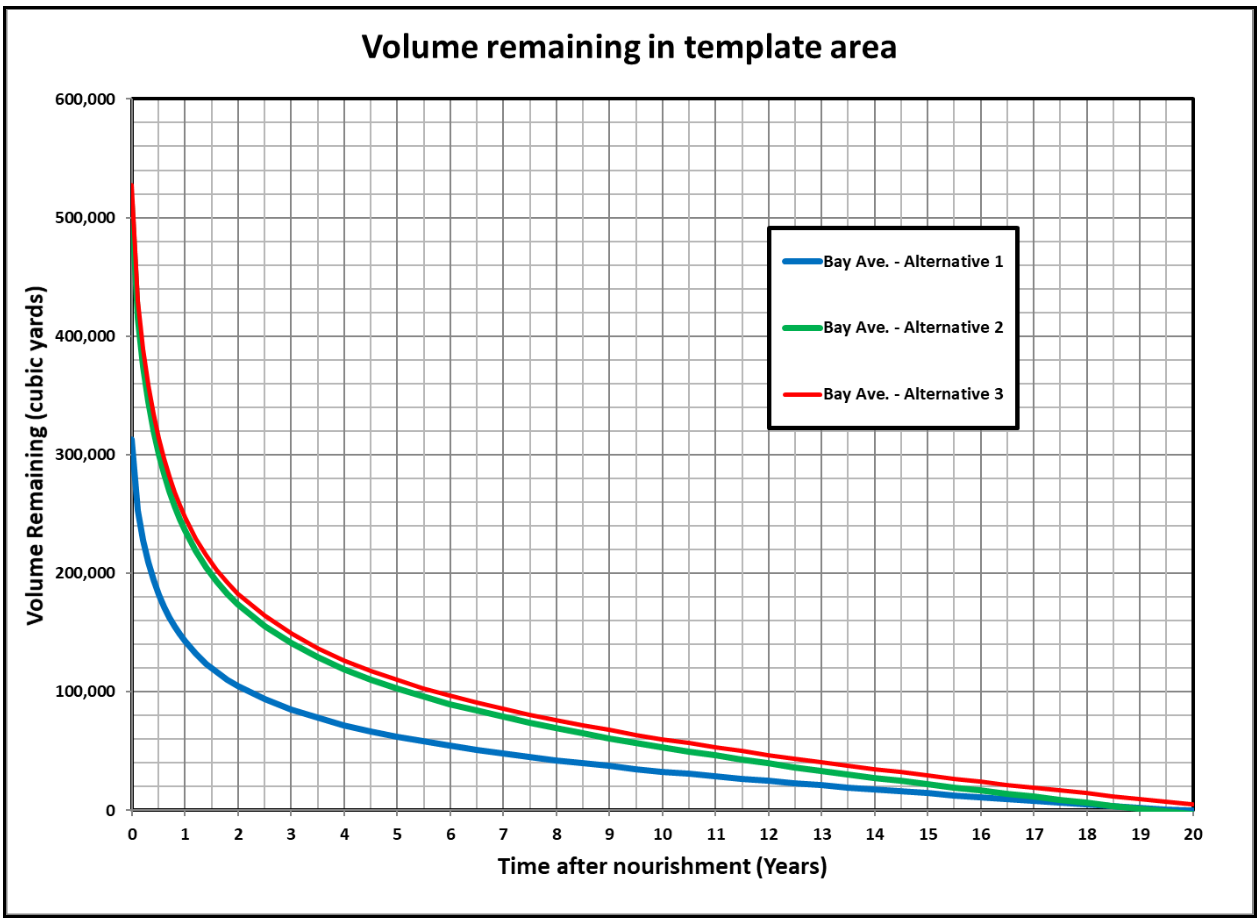

Figure D-40. Service life estimates for beach nourishment alternatives at Bay Ave. and Gurnet Rd. Beaches.

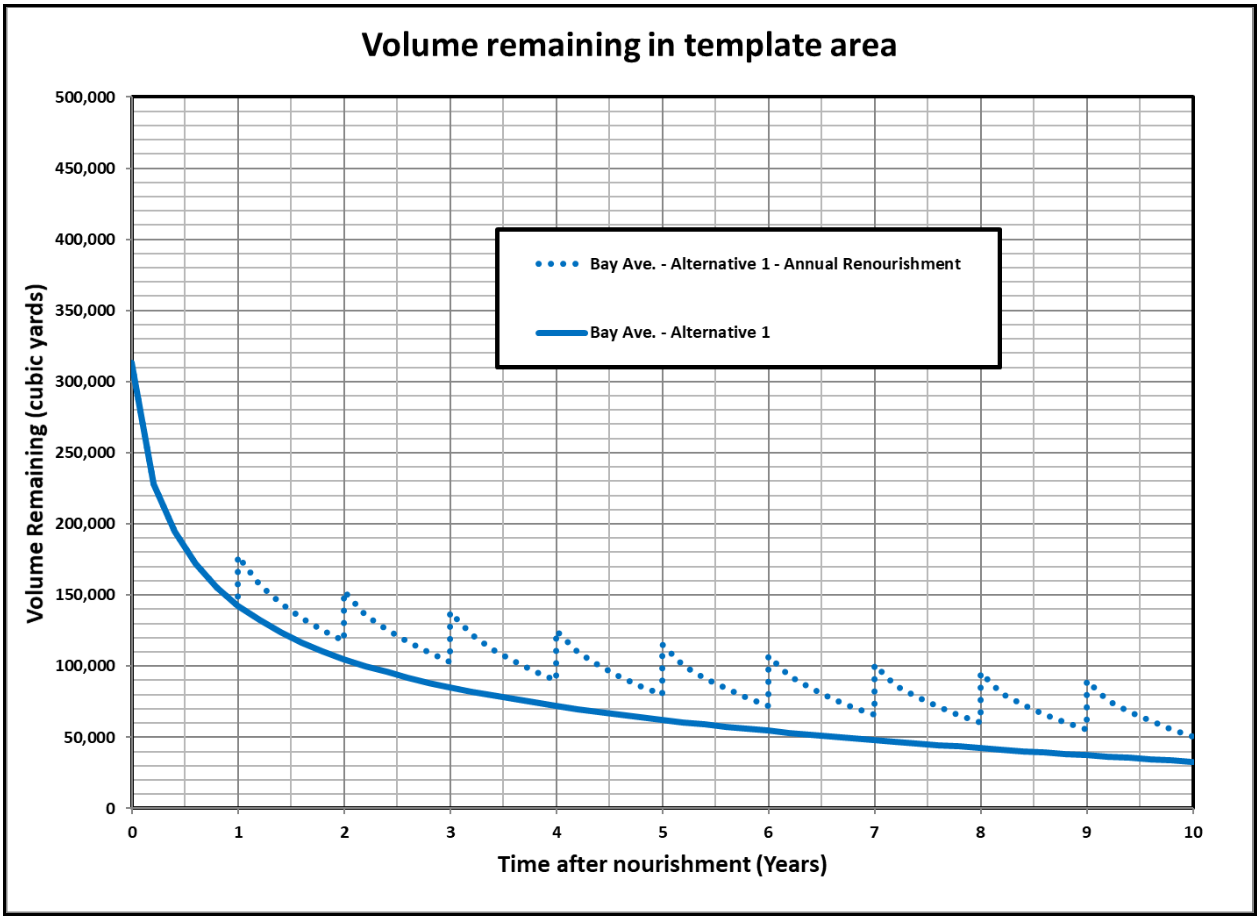

Figure D-41. Service life estimate for Bay Ave/Gurnet Rd – Alt 1 assuming annual renourishment of 30,000 cubic yards dredged from Green Harbor.

Figure D-42 shows the width of the beach berm over time for the three Bay Ave. and Gurnet Rd. nourishment alternatives. As with the service life estimates, the berm width decreases rapidly during the first year following construction. By year 2 the berm widths for all alternatives are estimated to be 30 ft.

Impacts of the three (3) Bay Ave/Gurnet Rd nourishment alternatives on rates of wave overtopping were also evaluated. Calculations summarized in Table D-14 indicate that existing rates of wave overtopping decrease from north to south along the Bay Ave. and Gurnet Rd. Beaches, with damaging overtopping occurring during a 10-yr storm event and greater. Beach profile data for the 10-yr storm scenarios from XBeach and XBeach-G were used to evaluate changes in overtopping rates for each alternative. The calculations showed a 100% reduction in wave overtopping for all three (3) alternatives indicating no damage to buildings from overtopping during a 10-yr storm event.

Over time as additional storms and longshore spreading act to reshape the nourishment, the elevation of the beach in front of the seawalls will lower and the risk of overtopping will increase. To quantify the critical beach elevation at which damaging wave overtopping starts to occur, additional calculations were performed for the Bay Ave. and Gurnet Rd. Beaches. For the 10-yr and 50-yr storms, damaging overtopping will begin to occur when the beach drops to an elevation of 3.5 ft and 4.5 ft NAVD88, respectively. For Bay Ave/Gurnet Rd – Alt 1 the berm would have to lower 3.5 to 4.5 ft to reach the critical elevation. Because the starting berm elevations for Bay Ave/Gurnet Rd – Alt 2 and Alt 3 are higher, the beach would have to lower between 5 and 7.5 ft to reach the critical elevation for damaging wave overtopping.

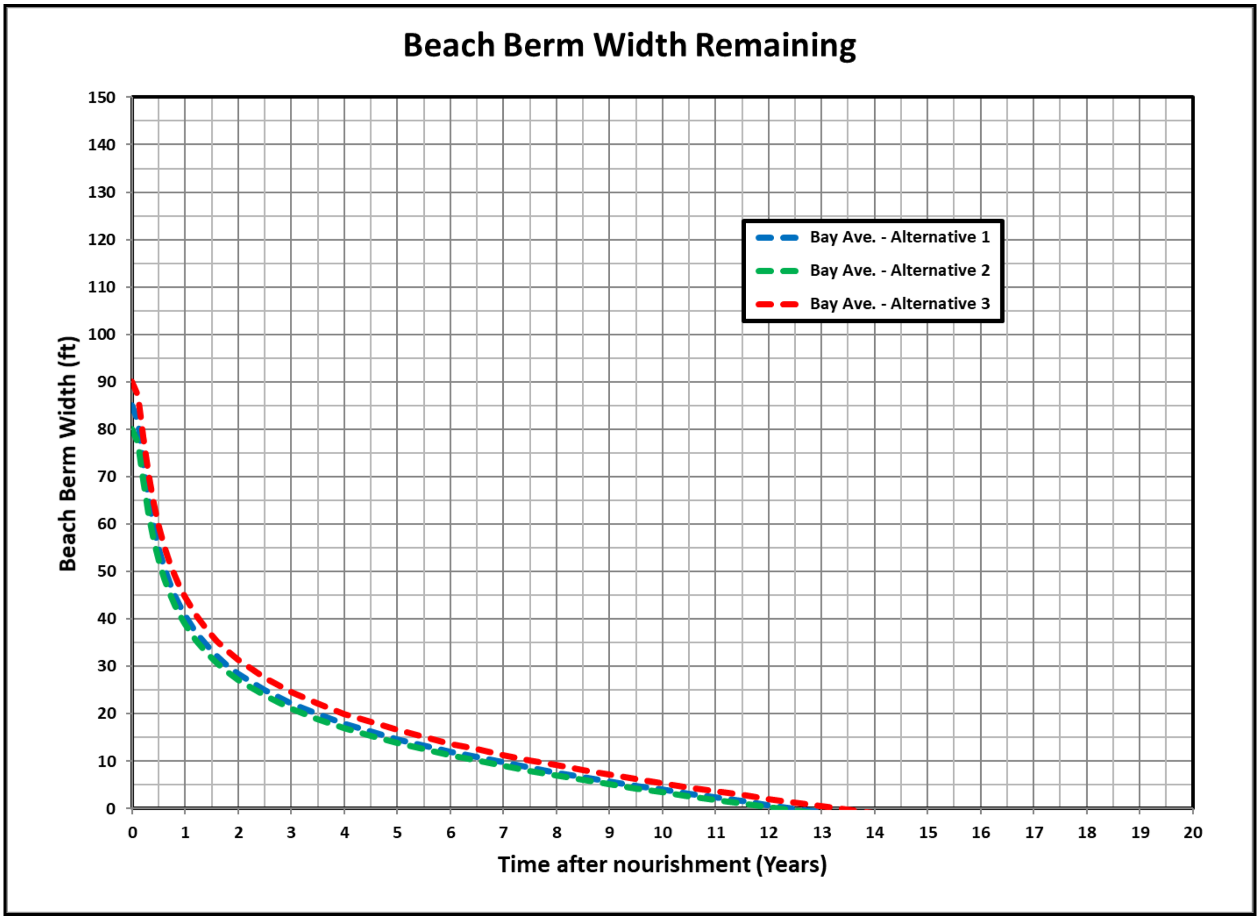

Figure D-42. Berm width over time for beach nourishment alternatives at Bay Ave. and Gurnet Rd. Beaches.

Costs associated with the Bay Ave. and Gurnet Rd. Beach alternatives are summarized in Table D-16. The costs include the purchase of sand purchase, trucking, and spreading following the design template. Projected costs over the next 30 years are also provided assuming renourishment every 5 years for Alt 1, every 3.75 years for Alt 2 and every 3.3 years for Alt 3 when 80% of the volume is lost from the original footprint.

Table D-16. Costs Associated with Nourishment Alternatives at Bay Ave. and Gurnet Rd. Beaches.

Resiliency Alternative	Initial Construction Cost	Costs Over Next 30 Years
Bay Ave/Gurnet Rd – Alt 1	$9.40 million	$53.24 million
Bay Ave/Gurnet Rd – Alt 2	$15.33 million	$76.65 million
Bay Ave/Gurnet Rd – Alt 3	$15.83 million	$70.53 million

Managed Retreat

Managed retreat from the shoreline at Bay Ave. and Gurnet Rd. Beaches was considered as an option for the long-term to reduce coastal vulnerability. Preliminary results from the MC-FRM model show that all of Bay Ave. and portions of Gurnet Rd. Beach will have a 100% probability of flooding by 2050 (Figures D-13). While the model data indicate flood pathways from the ocean as well as Green Harbor and Duxbury Bay, the most vulnerable properties will be those closest to the ocean that will experience damaging wave overtopping in combination with flooding (Figures D-43 and D-44). The 2020 assessor's database shows property values for the first row of homes most affected by coastal flooding and wave overtopping to be $36.08 million along Bay Ave. and $47.30 million at Gurnet Rd. The annual tax revenue for the Town of Marshfield from these property owners is $975,089; for the Town of Duxbury the annual tax revenue is $705,984. To pursue this alternative over the next 30 years, close coordination between the towns and affected property owners would be required, and federal and/or state monies would be needed to help the town with property acquisitions.

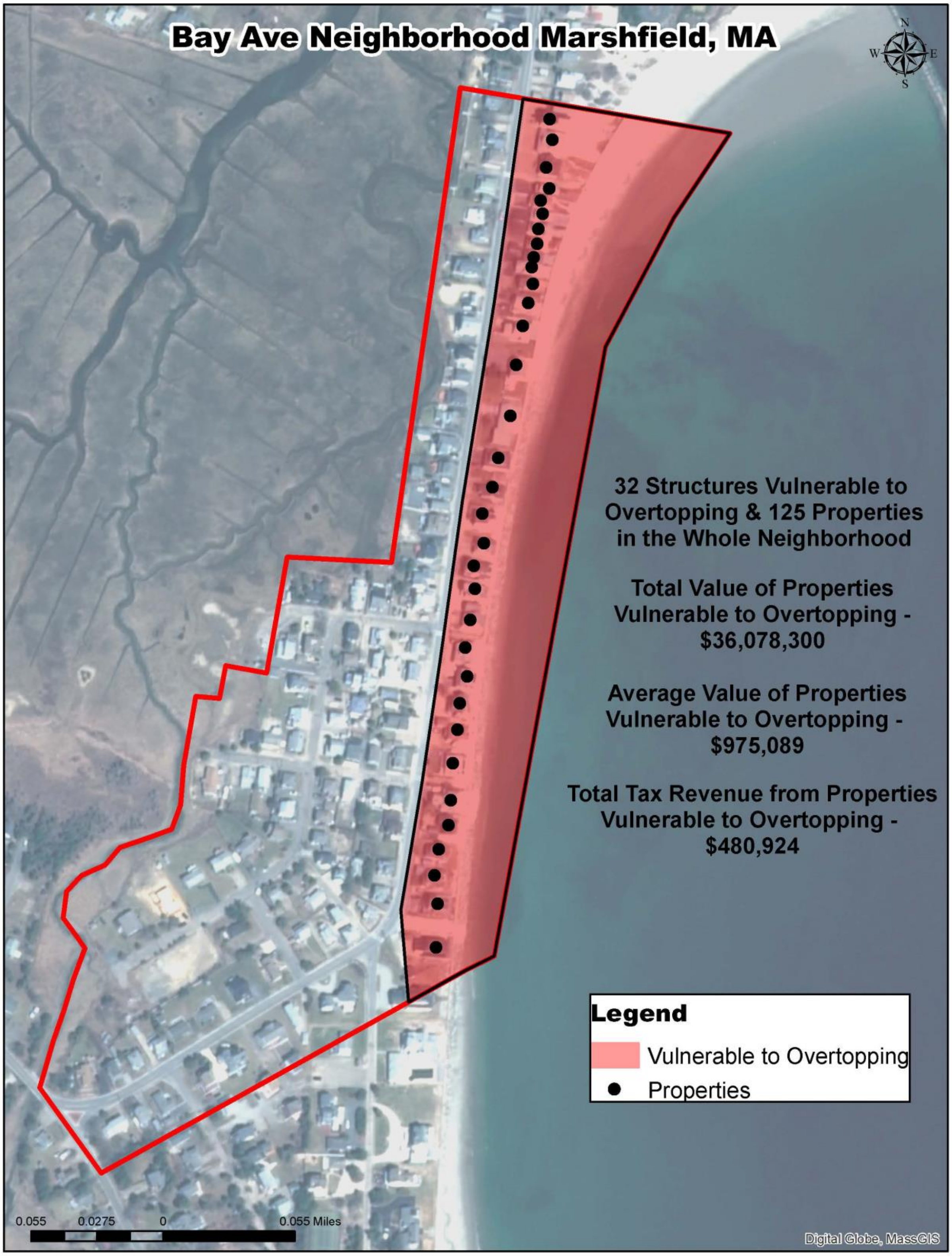

Figure D-43. Bay Ave. area showing properties vulnerable to flooding and overtopping with potential costs for managed retreat.

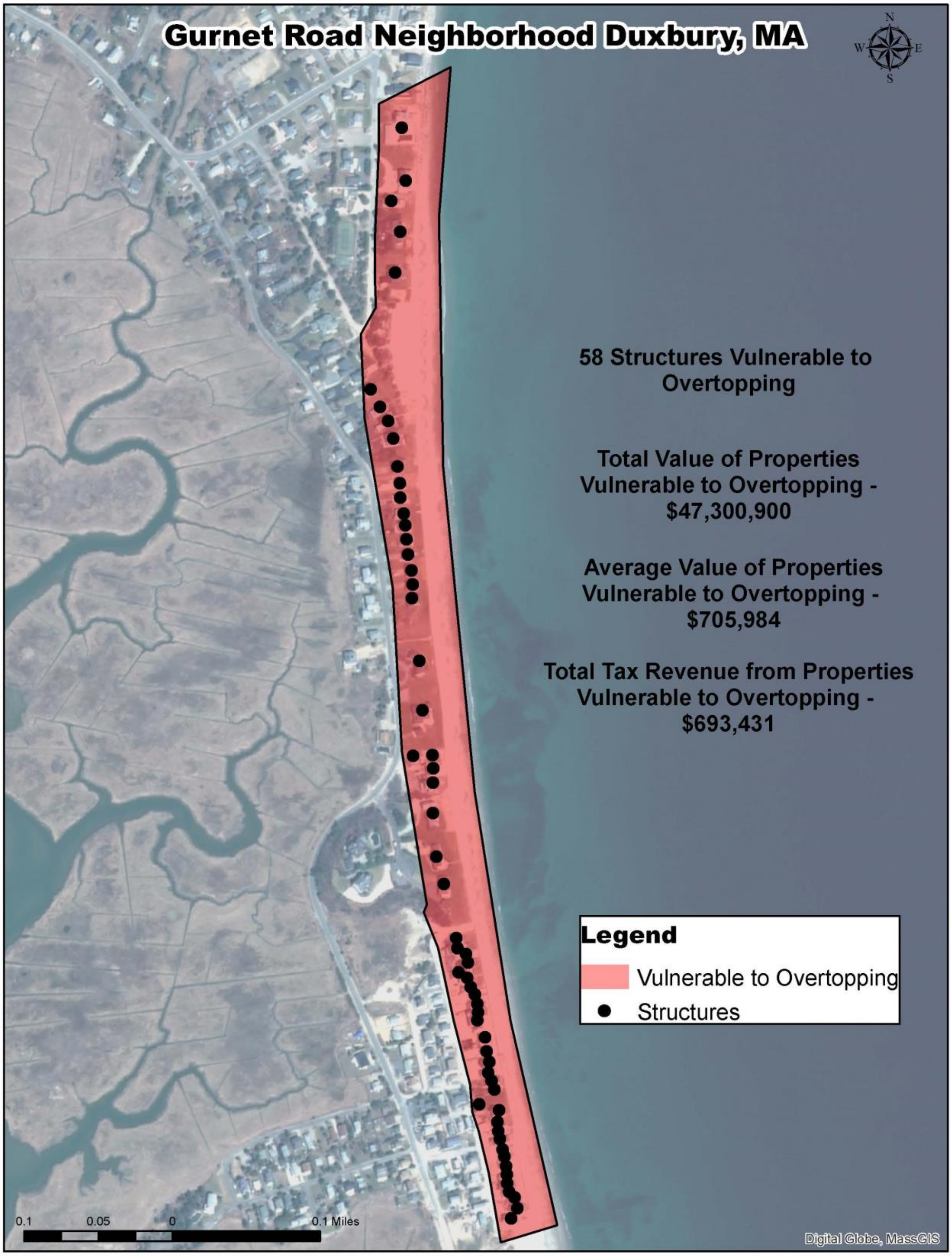

Figure D-44. Gurnet Rd. area showing properties vulnerable to flooding and overtopping with potential costs for managed retreat.

3.10 Site Specific Selection of Resiliency Alternatives

The preceding assessment was utilized to select the most appropriate alternatives for building shoreline resiliency at key locations along the Marshfield and Duxbury shoreline. While emphasis was placed on identification of soft engineering approaches for increasing shoreline resiliency, depending on the beach, it was not always feasible to identify appropriate soft engineering solutions. For these beaches, further investigation and engineering design will be needed by the Towns before proceeding with final plans and permitting for enhanced shore protection and improved resiliency. The remaining locations where soft engineering solutions were identified as viable alternatives were carried through to the next phase of the analysis to evaluate environmental impacts so that a preferred alternative could be selected. Table D-17 provides a summary of alternatives considered for each beach and identifies the sites carried forward to the assessment of impacts.

Table D-17. Summary of Resiliency Alternatives Considered for Beaches in Marshfield and Duxbury Showing Locations Where Beach and/or Dune Nourishment was Carried Through to the Assessment of Impacts.

Beach	*Status Quo*	Enhance/ Enlarge Existing Structures	Beach Nourishment	Dune Nourishment	Nearshore Boulder Field	Managed Retreat	Further Design Needed	Carried Through to Assessment of Impacts
Rexhame Public	√	NA	√	√	X	√	X	√
Rexhame	√	√	X	X	√	√	√	X
Winslow Ave.	√	NA	X	√	X	√	X	√
Fieldston	√	√	√	√	X	√	X	√
Sunrise	√	√	√	√	X	√	X	√
Ocean Bluff	√	√	X	X	√	√	√	X
Hewitt's Point	√	√	X	X	√	√	√	X
Brant Rock	√	√	X	X	√	√	√	X
South Brant Rock	√	√	X	X	√	√	√	X
Blackman's Point	√	NA	X	X	√	√	X	X
Blue Fish Cove	√	√	X	X	√	√	√	X
Green Harbor	√	NA	X	X	X	√	X	X
Bay Ave.	√	√	√	√	X	√	X	√
Gurnet Rd.	√	√	√	√	X	√	X	√

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