5.3.1 Bypass Bar Flow Modifications

To effectively quantify the influence of the ebb shoal on circulation and sediment transport behind the shoal, a high-resolution CMS Flow model was developed, with 13 foot (4 meter) grid resolution in regions of interest. Several alternatives were analyzed to determine a solution to the heavy erosion located south of the center groin at the northern end of the Island. To mitigate some of the effects the ebb shoal has on erosion hotspots around center island, Applied Coastal included several modifications of the ebb shoal in the modeling. Similar alternatives were modeled and recommended in USACE 2018 report (Li et al., 2018). Although positive alterations of flow were indicated by the modeling efforts, the reductions to alongshore currents were not significant enough to pursue further. A short summary of each alternative is provided below.

Relief Channel Dredging

Several alternatives to dredge "relief channels" in the ebb shoal were analyzed with a CMS Flow model. Each channel was roughly 250,000 square feet and was dredged to the seaward depth of the channel behind the ebb shoal it was relieving. The shape of each designed channel was rectangular, with an extension off the onshore end to help redirect flow. The goal of the alternative was to allow water to exit the channel behind the ebb shoal during an ebbing tide event with significant wave heights greater than 3 feet (1 meter) in the nearshore. The channels provided some reduction in observed currents according to the model results (0.07 feet/s ~ 2 cm/s; Figure 5.13), but the reductions were insignificant relative to the anticipated cost of dredging.

Dredge Southern End of Bypass Bar

A second modification to the ebb shoal was considered to reduce currents existing in the channel behind the shoal. The CMS Flow model was modified with the southernmost tip (8,000 feet) of the shoal dredged to a depth of 15.75 feet (approximate channel depth). The removal of the southern portion of the ebb shoal again provided some reduction in currents according to the model results (0.16 feet/s ~ 5 cm/s), however the reduction accounted for was insignificant relative to the scale and anticipated cost of the dredging project.

Fill Southern Bar Break

An alternative in which the bar breaks were filled in and the channel running alongshore was sealed off near center island with 80,000 cubic yards of material, provided minimal reduction of the alongshore current running behind the ebb shoal. Although sediment transport was not modeled for this scenario, it is expected that any attempt at filling in the bar breaks along tail of the ebb shoal would rapidly erode. Therefore, an alternative that includes a nourishment on the beach at the location of the hotspot would be preferred.

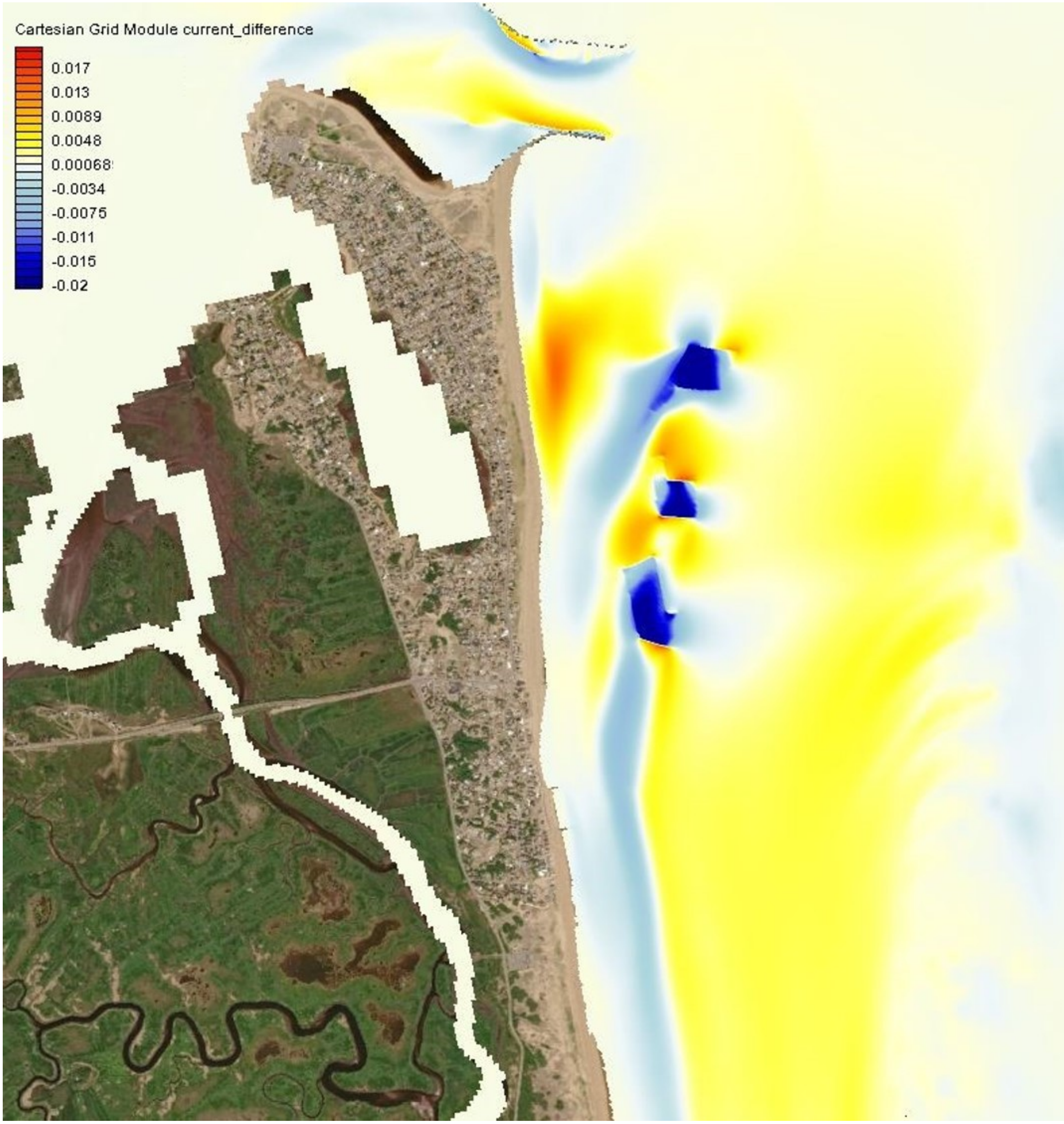

Figure 5.13 Difference in current velocity (m/s) for a single timestep between the relief channel dredging scenario and the existing conditions scenario.

5.3.2 Plum Island Nourishment

Plum Island, located south of the Merrimack River inlet exhibits relatively stable long-term transport patterns with significant short-term variability. The short-term variability is apparent in the northern 1.5 to 2 miles (2.5 – 3 km) of shoreline, where a divergent net transport pattern generates an erosion hotspot. Improved understanding of these transport patterns is crucial to making sound management decisions in the area. Although studying the bypass bar is important to making long-term management decisions, many properties are in need of protection now. To try to alleviate future risk to the exposed shoreline, Applied Coastal believes a nourishment would be a possible solution to protect some of the properties along the erosion hotspot. Based on repetitive loss records for Plum Island, the focal point of the majority of damage to Plum Island is located on either side of center groin. These locations are in-line with recent locations of the erosion hotspot, indicating that the increased exposure during storms waves is problematic for these properties. A nourished shoreline would provide sufficient width to better predict some of these properties.

Applied Coastal considered three beach width nourishment alternatives for the Plum Island coastline: 50 feet, 100 ft, and 150 feet (Figure 5.14). The areas were selected based on the location of repetitive loss data, to provide better protection of properties that have been damaged in the past, and extend northward 2,000 feet from the southernmost jetty. Each nourishment was designed to raise the berm elevation to 11 feet NAVD88. Dimensions of the nourishment were selected based on the likely availability of resources based on cost and typical dredging volumes. Figure 5.15 shows the approximate extents of shoreline recommended for nourishment. Modeling results indicate that a 2,000-foot nourishment provides sufficient length for protection.

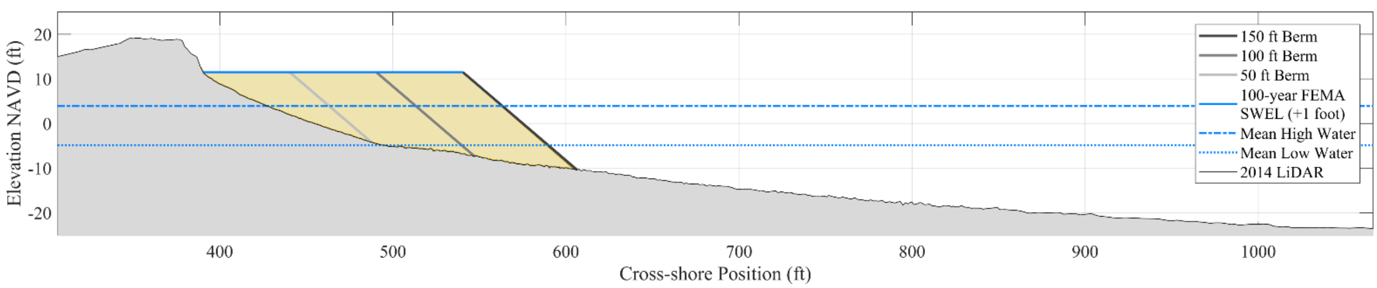

Figure 5.14 Profile view of each nourishment alternative (150, 100, and 50-foot berms). Each berm is designed to an elevation of 11 feet NAVD88, or one foot above the FEMA 100 year still water elevation. Most properties along the shoreline sit at an elevation of 17-20 feet NAVD88.

Figure 5.15 Approximate extents of shoreline considered for nourishment along the Plum Island shoreline. The general footprint of the recommended nourishment location was Final dimensions of any nourishment design are dependent on the availability of nourishment material and funding.

Nourishments are typically designed for a lifespan, at which point management can decide whether or not the funding is available to replenish the beach. Model runs for each fill scenario were executed for a simulated 15-year period. Similar metrics of percent fill remaining was used to evaluate the Plum Island nourishment alternative. Based on results of the shoreline modeling, the nourishments are able to maintain 30% of their fill between 6 and 16 years. A comparison of fill performance for the four scenarios is included in Figure 5.16, showing percent fill remaining after each modeled year. It is seen that the 50 ft wide berm rapidly loses fill from the template, whereas the 100- and 150-foot berms remain relatively stable. Table 5.2 compares the dimensions and relative performances of each alternative.

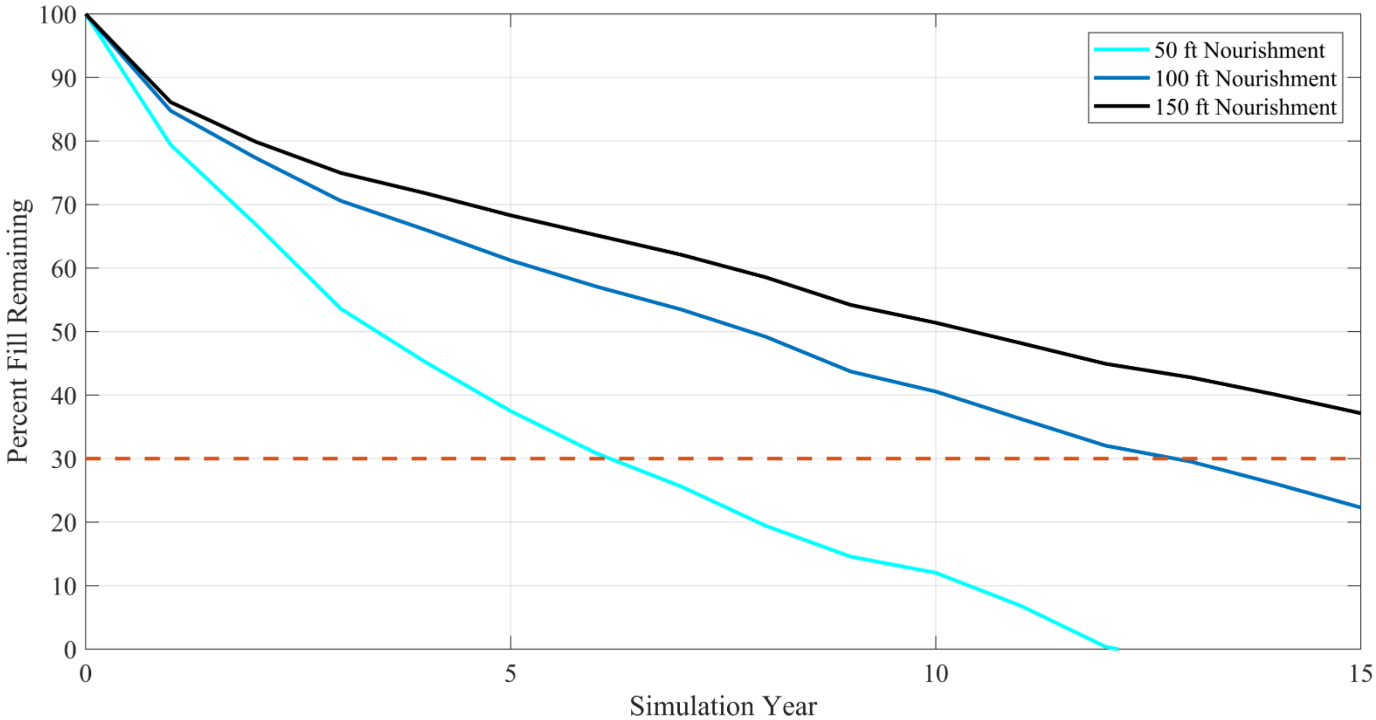

Figure 5.16 Performance comparison between Plum Island nourishment options after 15 years.

Table 5.2 Modeled beach fill scenarios for Plum Island

scenario	Volume (yd^3)	berm width (ft)	fill length (ft)	Year of 30 % Fill Remaining
1	70,000	50	2,000	6.1
2	95,000	100	2,000	12.4
3	120,000	150	2,000	15.8

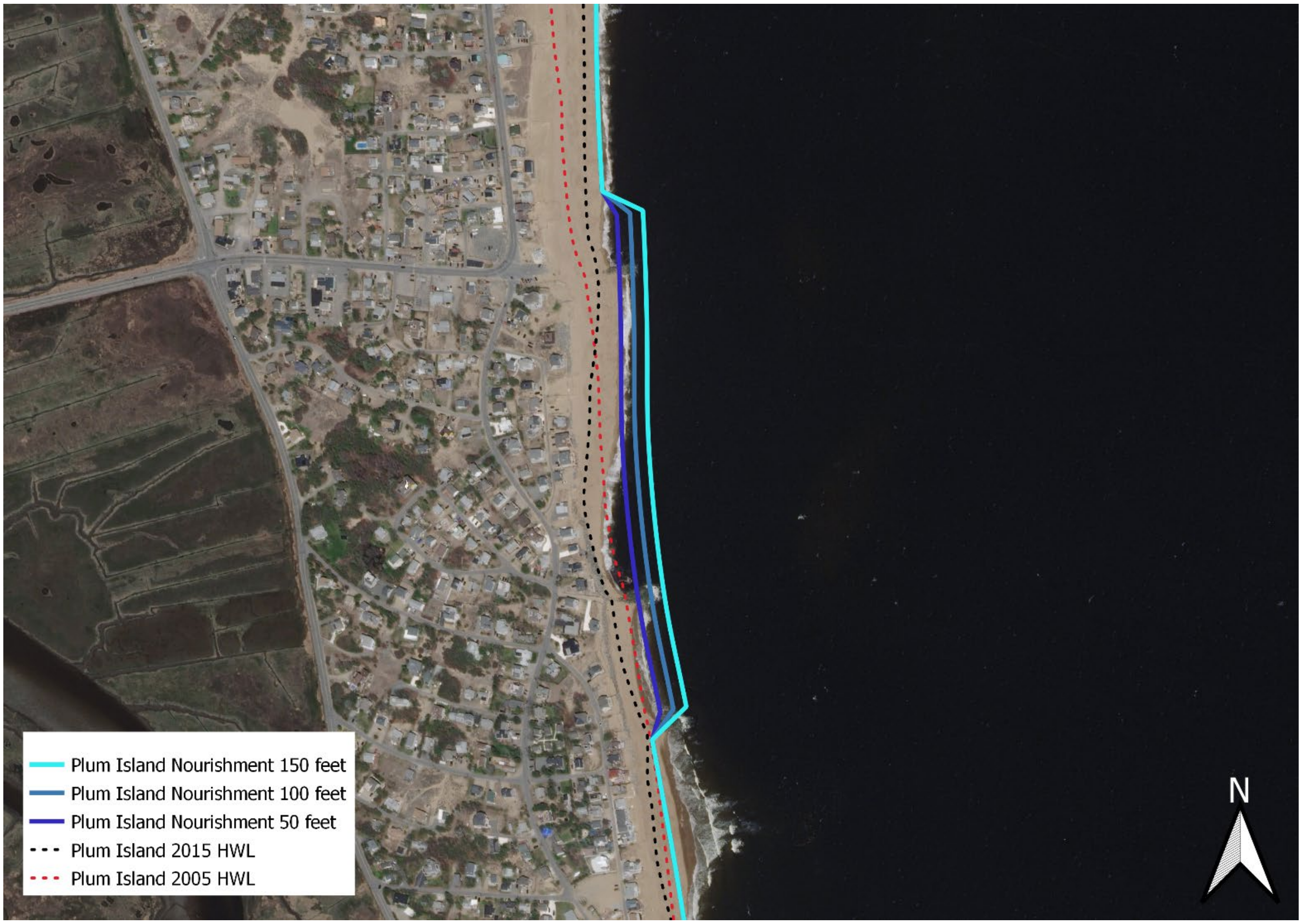

Figure 5.17. Modeled position of the Scenario 4 berm after 15 years relative to the 2005 and 2015 shorelines.

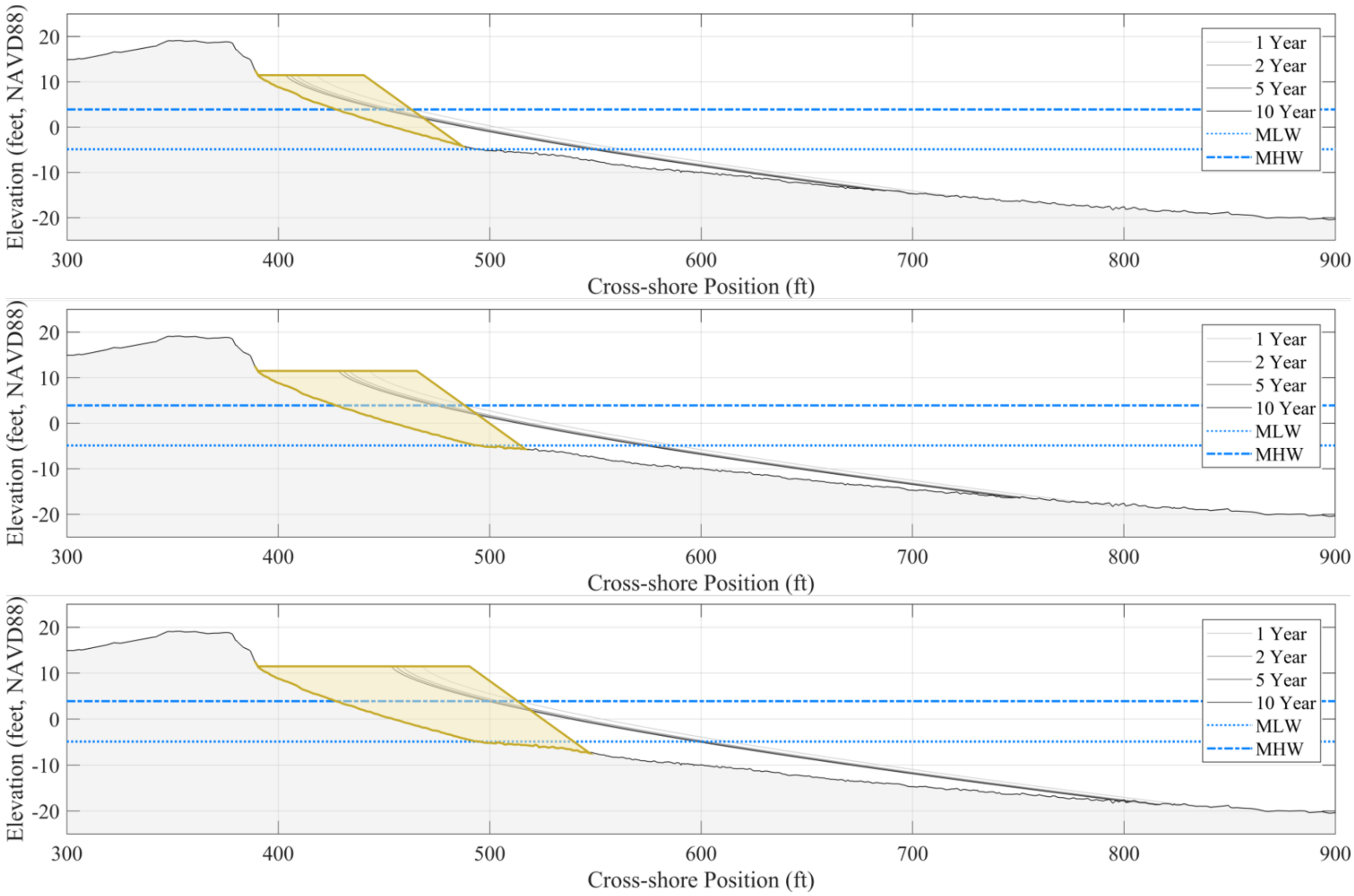

Figure 5.18. Comparison of 50 (top), 100 (middle), and 150 (bottom) foot berm shoreline positions along a transect (2014 LiDAR) crossing the erosion hotspot transect location of Plum Island.

5.3.3 Groin Modifications

Another potential solution to the erosion hotspot located near center island would be to reduce the groin spacing by including another groin 700 feet to the south of Center Island Groin. However, environmental regulations generally prohibit construction of new permanent coastal engineering structures on a barrier beach. Since the alongshore sediment transport model had already been developed, which included the influence of the existing groin field, a straight-forward analysis of a modified groin could be performed to quantify the influence of additional structures. This exercise provided an initial evaluation of how groin modifications would influence local sediment transport and beach stability.

Reducing groin spacing would diminish alongshore currents moving between groins, resulting in decreased sediment transport within groin compartments. A similar effect on a larger scale is apparent with the log spiral shape of crenulate bays, that form between two headlands. The shape and orientation of the log spiral shoreline is dependent primarily upon the spacing of the two fixed endpoints (e.g., headlands, groins) and the incident wave direction. The closer the two endpoints are stationed, the less pronounced crenulate shape the shoreline forms. A May 2018 aerial photo (Figure 5.19) shows the crenulate shape of the shoreline just south of the Center Island Groin. The groin compartment to the south is spaced about a third of the distance of the crenulate shaped compartment and presents a much wider beach.

To assess groin modification alternatives, Applied Coastal used the one-line model developed for Plum Island to compare modeled shoreline change scenarios with the groin to those without. The positions of the groins were optimized to most effectively retain sediment. Each structural scenario was run with and without nourishment. The results of each scenario are included in Table 5.3 and example results for the single groin scenario are found in Figure 5.20. It is important to recognize that any structural modifications to groins with an included nourishment, would require maintaining these structures by filling the groin compartment to entrapment to ensure no downdrift impacts.

Table 5.3 Shoreline change along the hotspot transect for Plum Island groin modifications*.

Scenario	No Nourishment	50 ft Berm	100 ft Berm	150 ft Berm
Existing	-33.2	13.4	49.6	97.4
Single New Groin	-9.3	28.4	88.6	137.6
Two New Groins	-8.1	29.8	90.0	138.1

*Shoreline change measured as distance in feet from the 2015 shoreline over a 10-year period.

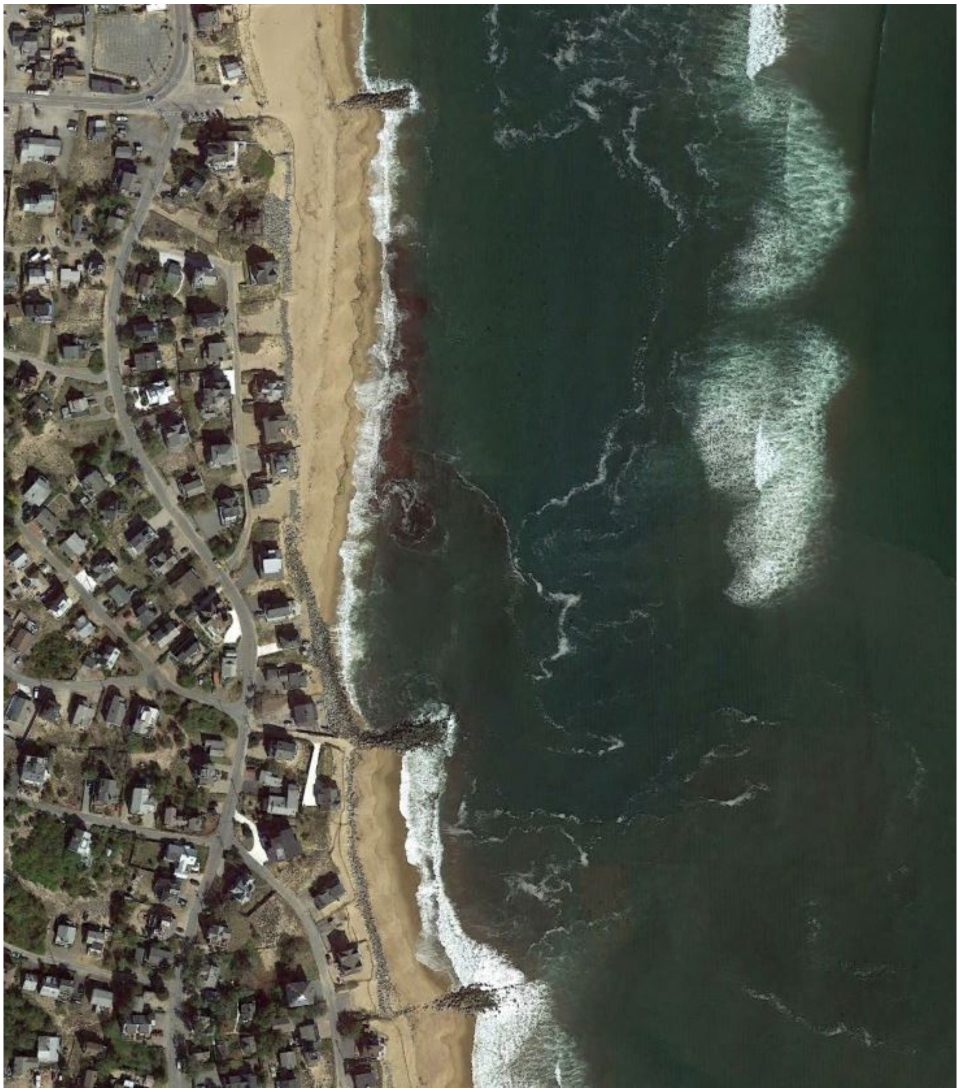

Figure 5.19. May 2018 aerial photograph of the Plum Island shoreline located just south of the Center Island Groin. The log spiral shape of the shoreline between the two northern groins is apparent, and is in stark contrast to the wider beach in the groin compartment to the south.

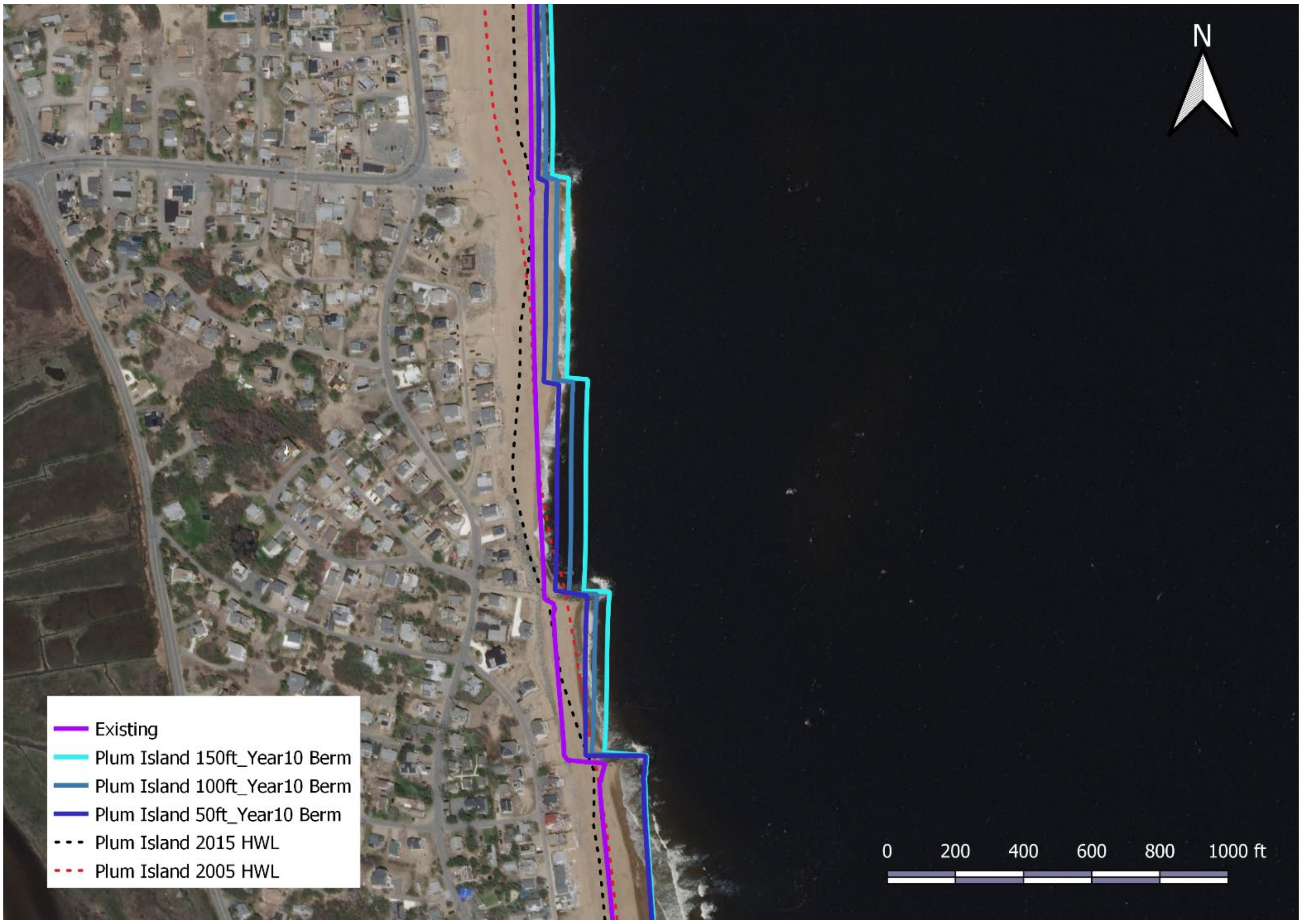

Figure 5.20. Modeled position of the berm for each scenario after 10 years relative to the 2005 and 2015 shorelines.

6.0 FUTURE CONSIDERATIONS

There are three critical locations along the Upper North Shore project area that Applied Coastal prepared alternatives for: Salisbury Beach, Reservation Terrace, and Plum Island. Each region has its own unique geomorphic features and coastal process that govern the alternatives outline in this report. For example, in the case of beach nourishment for the various sites, Salisbury Beach has several miles of developed shoreline which would primarily benefit from a lengthier nourishment to increase the height and extend the berm seaward to provide general storm wave energy dissipation over the entire beach length. Reservation Terrace consists of a much shorter shoreline in the interior of the inlet, where a lower berm nourishment coupled with a structural improvement to reduce the erosive gyre formation just offshore would suffice. Finally, Plum Island, which has a prominent erosional hotspot that migrates along a portion of the shoreline, would benefit from a shorter in length, but wider nourishment to try to stabilize the erosion hotspot. Again, structural enhancements to this nourishment likely would be warranted to maintain an appropriate berm width in the area of highest observed erosion rates. Several designs from Section 5 are outlined below that can aid stakeholders in making management decisions for their respective beaches. These management options were designed for existing conditions, and might change in the future depending on how sea level rise adjusts moving forward.

Salisbury Beach and State Reservation

Sediment management along the Salisbury Beach Shore has not been consistent, as recent nourishments have been small (< 10,000 cubic yards) other than a 40,000 cubic yard nourishment in 2010. As a result of long-term shoreline erosion along this beach, a significant sediment deficit exists along the coastal region, with the most pronounced effects toward the southern section along Atlantic Avenue. From the perspective of local sediment management, beach nourishment programs that can initially restore the regional sediment deficit will provide the basis for a shoreline that can be maintained by the Town with reasonable financial resources. Based on the numerical modeling analysis completed for this report, 110,000 cubic yard beach nourishment along Salisbury Beach (Table 6.1) will maintain just over half of its volume after 10 years. The nourishment will raise the berm to one foot above the 100-year maximum still water elevation. The modeled shoreline for scenario 4 after 15 years is included below in Figure 6.1.

Another mechanism to provide relief following significant storm events would be to construct the aforementioned SSA from the 2008 Beach Management Plan to provide relief to sections of shoreline following storm events. The originally proposed placement of the SSA likely is not viable from a regulatory perspective, as the imported sand would likely merge into the existing dune system, preventing this material from being excavated and placed in areas of need. Rather, a modified version of the SSA, with a significantly smaller volume, could be placed on a portion of the parking area away from the dune system. In addition, this stockpile would only be replenished if material were readily available, understanding that any material placed in the SSA needs to be "double-handled" (i.e. initially moved and stockpiled in the SSA, and then excavated and trucked to the area of need). Readily available material could include an affordable local upland source, or locally dredged material.

This emergency sand supply would be important for stretches of State Reservation Beach that do not receive nourishment as part of the larger-scale ocean facing beach project described above, notably at the inner end of the jetty. However, it is important to take into account SSA management considerations including storage and environmental considerations. For example, the SSA would have to be stored on the parking lot, to prevent merging with the dunes. However, placement on the parking lot would take away from parking spots that generate revenue for the state park in the summer months. A possible solution to the storage issue would be to store the sediment in the off-season between October and April, and mobilize most of the supply while only retaining 2,000-to-3,000 cubic yards, if deemed necessary.

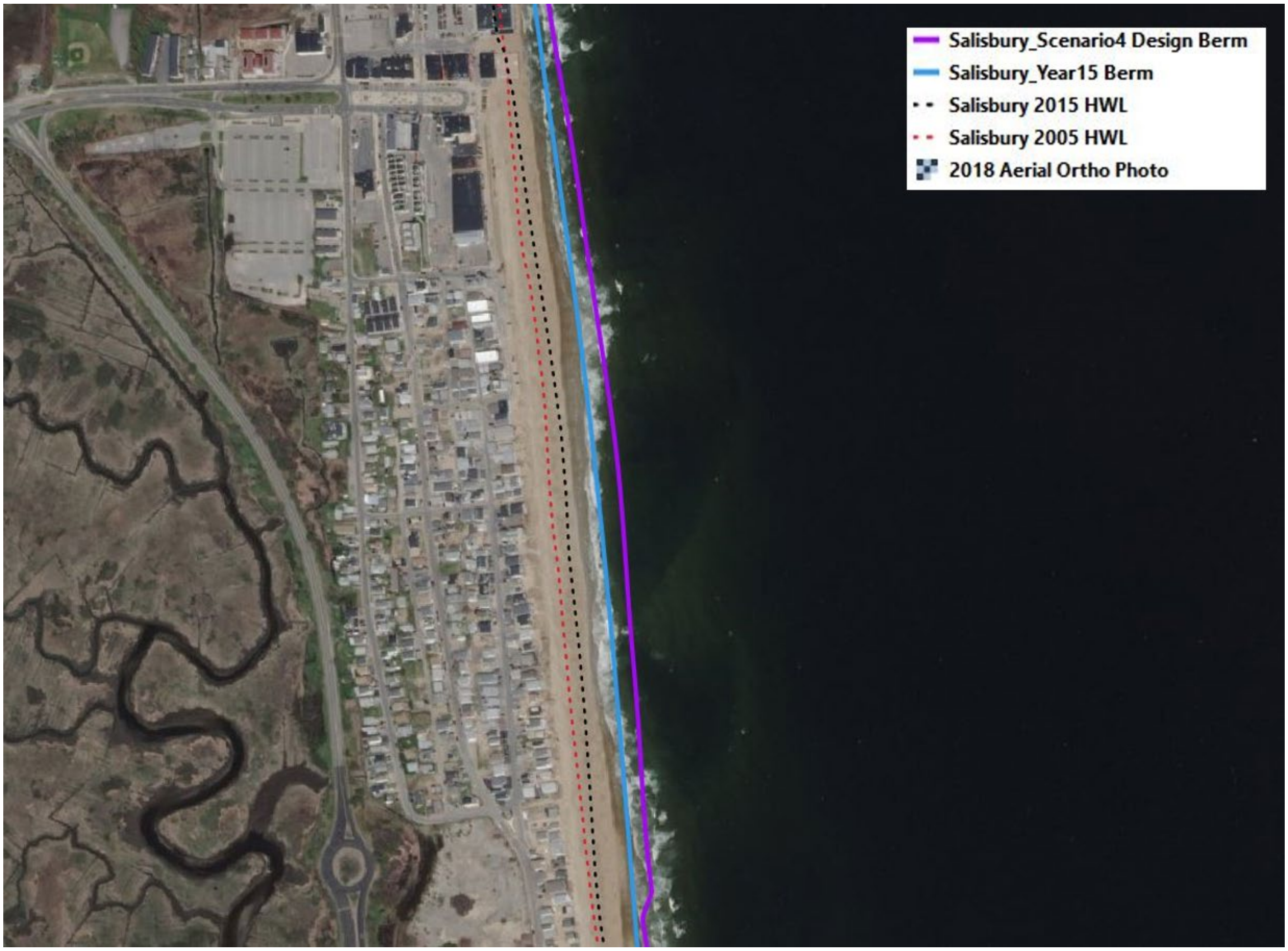

Figure 6.1. Closeup image of the Scenario 4 berm position after 15 years just south of the Salisbury Music Hall along Atlantic Avenue.

Reservation Terrace

To return the position of the shoreline to its historic location, a relatively small beach nourishment inside the inlet is the preferred alternative (Table 6.1), coupled with the design of either a weir along the southern jetty or an extension of the southern jetty as a breakwater. Either structural adjustment would function to break up the gyre that forms during a flooding tide and prolong the life of the nourishment. Each design would face permitting challenges, the weir scenario likely being the easier option. However, if this process was driven by the local sponsor rather than USACE, the onerous federal Section 408 would be required to demonstrate that modification to USACE structure would have no adverse impacts to the functionality of the authorized navigation project. Through a more complete design process, the potential adverse impacts associated with each of these structural alternatives would need to be evaluated to determine its effect on adjacent beaches and nearshore areas.

Based on both historical shoreline change information and the numerical modeling analysis, it is clear that the weir design would allow sediment to leak across the jetty from south-to-north. This loss of sediment south of the jetty would result in some minor erosion, but provide some stability to the Reservation Terrace shoreline. The design process of the weir would optimize the flow entering the inlet to break-up the gyre formation, while also minimizing sediment losses south of the jetty. Once the structural design is in place, it is recommended that an additional nourishment plan be formulated to provide material to a shoreline that has experienced net erosion following construction of the 1970 sand dike.

As shown in Table 6.1, no costs were developed for structural alternatives for Reservation Terrace, as the preferred alternative incorporating the weir jetty modification will require further optimization through USACE.

Plum Island

The preferred alternative for Plum Island is a beach nourishment project adjacent to the Center Island Groin. It is anticipated that the long-term stabilization of this shoreline will require nourishment to protect the existing development. The nourishment would extend 2,000 feet in length, with a berm width of 150 feet.

From a coastal engineering perspective, the spacing of the existing groins is not ideal and allows alongshore currents to erode sediment from inside the groin compartment. Inclusion of one or two new groin structures, 125 feet to either side of the Center Island Groin, would help hold the nourishment in place by reducing the spacing between groins, allow a reduced berm width of 100 feet, and reduce the frequency of maintenance nourishment. However, environmental regulations generally prohibit the construction of new permanent coastal engineering structures on a barrier beach system. For this reason, no costs were developed for additional groins in the vicinity of the Center Island Groin. It is also important to note that inclusion of new structures with the nourishment design would potentially modify the supply of sediment to downdrift beaches, necessitating that the structures be filled to entrapment in perpetuity. This would require a long-term, potentially cost-prohibitive, commitment from the project proponent, unless it could be demonstrated that the structure could naturally bypass sediment.

Nourishment alternatives for the study area are summarized in Table 6.1.

Table 6.1 Proposed nourishment alternatives for the upper north shore coastline.

Area	Total fill volume (cu. yd.)	Length of fill template (feet)	Width of template (feet)	Estimated cost ($36/cubic yard)*	Estimated Number of Truck Trips (Based on Average of 22 Cubic Yards per Truck)
Salisbury Beach	95,000	9,000	50/30 (Tapered width)	$3,420,000	4,319
Reservation Terrace	20,000	1,000	50	$720,000	909
Plum Island (Center Island)	120,000	2,000	150	$4,320,000	5,455

*These options include the nourishments alone without the structural cost included

6.1 Sediment Sources

To provide adequate sediment for the preferred beach nourishment alternatives, available offshore resources might be required to supplement dredged material and make the effort more cost-effective. Due to the scale of the nourishment project options, hydraulic placement by dredge appears to be the most effective means of delivery. However, depending on the final volumes required and availability of offshore material, the hydraulic placement could be supplemented with upland sources delivered by truck.

Figure 6.2 illustrates alternative locations to the channel maintenance dredging as potential sediment sources for managing the upper north shore coastline. These sources of nearshore sand are unpermitted, but have been considered in recent management studies as sources (Tyler and Beck, 2018). There likely are significant environmental and potentially hydrodynamic concerns that may make the shoal in the interior of the Merrimack River entrance challenging to utilize as a source of nourishment material. The shoaled area south of the south jetty is a more viable option, as much of this material has accreted since construction of the jetty system and it is in a high wave energy area that reduces its value as a fisheries resource.

Recent jetty reconstruction allowed for significant accretion to occur along the south side of the south jetty. If no adjustments are made to the south jetty, a sediment bypassing alternative may be attractive for long-term management of littoral sediments along Reservation Terrace. Sediment would be removed from the northern end of Plum Island (south of the south jetty) and placed on Reservation Terrace. Figure 6.2 shows the approximate locations in which sediment would either by bypassed or back-passed. The material would be deposited along the Reservation Terrace shoreline to maintain a particular shoreline distance. Approximate volumes would depend on the shoreline locations for both sites. Additional back-passing may be required if the jetty were to allow sediment to pass through.

Although not substantial, periodic excavation of the material accreting along the spit at the northern end of Plum Island would reduce the requirement for channel maintenance dredging in this region and provide a source of beach quality material. An in-depth evaluation of potential volumes of beach quality materials was beyond the scope of the present study; however, generalized estimates of available material can be approximated by the area and type of deposit. In addition, the longevity of any nourishment project along Reservation Terrace is limited if the issues related to the nearshore gyre current are not addressed.

Alternatively, Massachusetts Coastal Zone Management (MCZM) mapped locations of offshore sandy material in 2015 to identify potential borrow resource sites as part of the Massachusetts Ocean Management Plan (OMP) development (MCZM, 2015). Subsequently, MCZM funded consultants to perform additional geotechnical analyses (APTIM, 2018), where this work discovered several regions that are within 2 miles of the Merrimack River Inlet that have more than 10 feet (3 meters) of sand depth (Figure 6.3). Further maps developed by APTIM to show potential offshore sand resource locations are included in Appendix A. These locations could be considered if larger nourishment programs are permitted for the Salisbury or Plum Island, as logistics for nourishment project on the scale of 100,000 cubic yards are complex if upland sources are pursued. Although offshore mining has several environmental impacts (e.g., disturbance of natural habitat, wave refraction), these downsides might be less significant than some of the implications of an upland source. The transportation of sediment from upland sources would have serious environmental and societal implications. For example, upland nourishments would require thousands of truck trips that consume large quantities of fuel, potentially damage roads, and generate noise during all of the trips.

Assessment of offshore borrow sites will require monitoring for marine fisheries resources, and should include outreach to local fishing fleets to identify preferred borrow areas.

Figure 6.2 Aerial photograph of the upper north shore study area showing potential sand borrow sources to provide material to the Reservation Terrace shoreline.

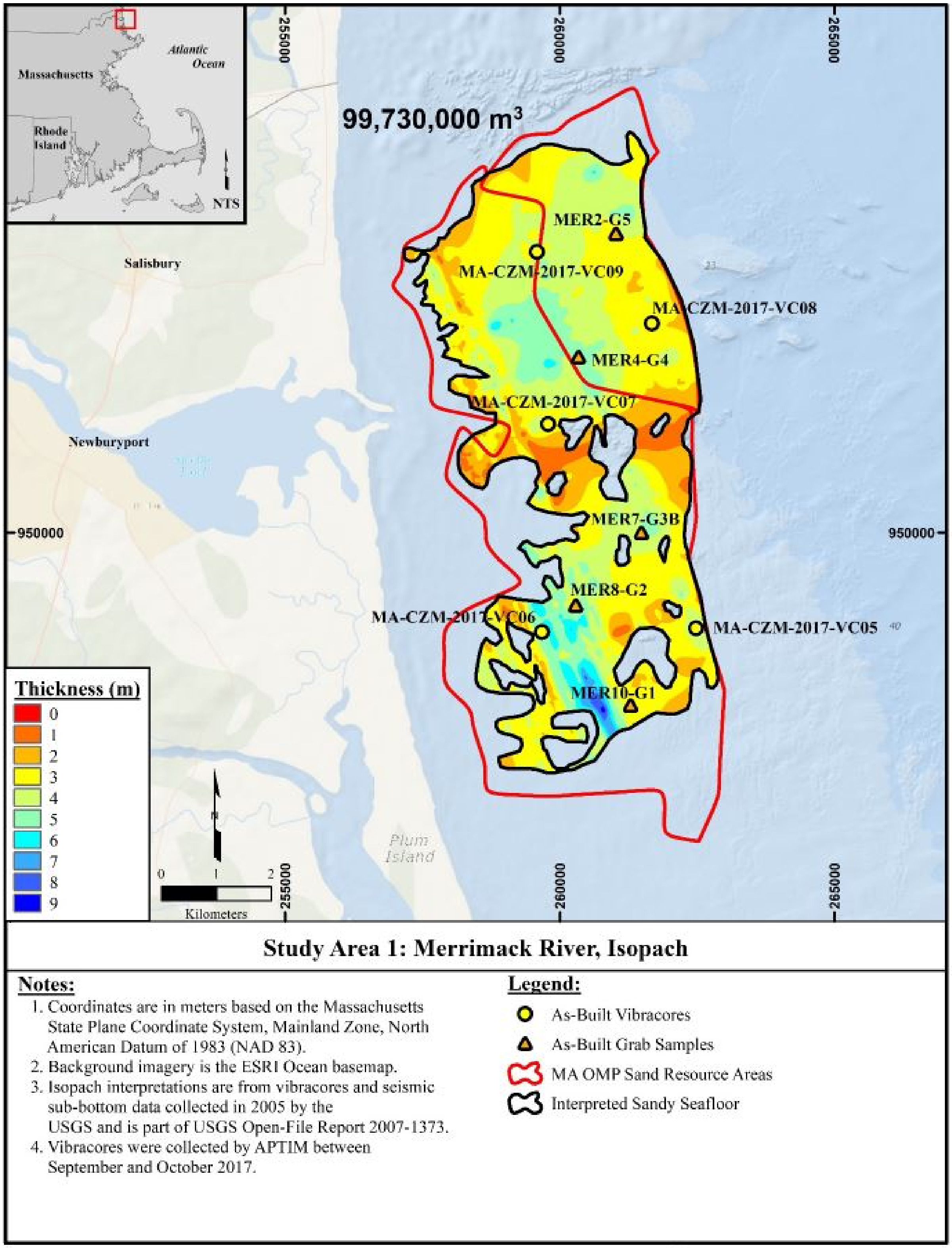

Figure 6.3 APTIM (2018) mapped locations of sediment samples and interpolated regions of sandy material. Some thicker layers of sandy material exist a few miles offshore of the Merrimack River Inlet.

6.2 Permitting

Some of the potential borrow sites and beach placement locations have existing permits to perform work. These permits were used for the 2010 nourishment project that provided Salisbury beach with 40,000 cubic yards along Atlantic Avenue and Plum Island with 120,000 cubic yards near Center Groin. Moving forward, it is recommended that the three municipalities utilize the results of this assessment to develop a comprehensive plan for developing and maintaining a single set of regulatory permits for the entire upper north shore region. This overall plan would seek permits for several offshore and nearshore sites to be utilized as needed to maintain the integrity of the littoral system along this shoreline. In addition, permits should be sought to allow for beach nourishment along the Upper North Shore coastline sections described as preferred alternative nourishment locations. For both the borrow site and beach nourishment aspects of the environmental permitting process, a number of regulatory “triggers” will be exceeded that will require significant coordination with the various regulatory agencies that oversee actions in the coastal zone. In general, the following permit filings are likely to be required by state and federal permits to move forward with each of the projects:

- Environmental Notification Form to MEPA, which may trigger additional regulatory review
- Due to the scale of nourishment proposed, a mandatory Environmental Impact Report (EIR) will be required. If utilizing an offshore borrow source, the EIR process may be quite onerous.
- Notice of Intent filed locally (also reviewed by Massachusetts DEP)
- Water Quality Certification if dredging is required
- Chapter 91 License (for structural elements) and Chapter 91 Permit (for beach nourishment)
- USACE permit application (the overall management approach will require an individual permit)
- MA Coastal Zone Management coastal consistency filing (as part of USACE process)
- MESA filing to address potential impacts to endangered or threatened species
- DCR Construction Access Permit

As part of the regulatory permitting process, coordination with various agencies will be required to ensure the process moves forward in an efficient manner. Known environmental concerns associated with borrow site excavation and beach placement/excavation include marine fisheries, endangered and/or threatened bird species, and potential physical impacts to coastal resource areas.

To support the beach nourishment design and the environmental regulatory process, a number of data collection efforts will be required. For the various potential offshore borrow sites, further geophysical analyses and geotechnical sampling will be needed to determine compatibility of these sites with the native beach. Geophysical analyses also will indicate the surficial sediment characteristics, the depth of the sand deposit, and the existence of archeological resources. Biological evaluation of the potential borrow sites and beach nourishment sites also would be required to determine the existing conditions or the habitat quality at these sites. Fauna and shellfish surveys would be performed at each borrow site, as well as within the anticipated equilibrated ‘footprint’ of the beach nourishment projects. Initial physical and biological sampling can be utilized to ‘screen’ various sites and provide information to the environmental regulatory agencies needed to guide management decisions. While the level of analysis required to support a comprehensive coastal management plan for the north shore may appear onerous, it likely is more cost-effective to pursue one set of environmental permits for the entire stretch of shoreline, rather than having a piecemeal approach that likely does not address the entire coast and is more expensive in the long-term.

It has been over 30 years since an offshore borrow site was permitted in Massachusetts that was not directly linked to a navigation project. With this in mind, potential use of offshore borrow material should only be sought if the regulatory mind-set has shifted, as all states south of Massachusetts along the East and Gulf Coasts of the U.S. routinely perform beach nourishment from offshore borrow sites. Since the major ‘road block’ is at the federal level (i.e. USACE permitting process), the permitting process should be initiated with the federal regulators first to determine what would be needed to move these types of critical shore protection projects forward.

Alternatively, the Towns should consider working with USACE to ensure that sediment from inlet dredging is placed on beaches in need. In the long-term it is quite possible that placement of this material in an alternate manner between each of the three preferred nourishment locations may provide the necessary volume to maintain these projects.

6.3 Recommended Monitoring Plan

Long-term monitoring of the beach system to both the north and south of the Merrimack River entrance is critical for assessing (a) future shore protection and/or beach nourishment needs, (b) evaluation of ongoing “hot spot” erosion, and (c) assessment of storm impacts to the beach system. It should be noted that ongoing monitoring and maintenance plans are critical for complying with FEMA requirements associated with potential storm-related reimbursement for episodic beach nourishment erosion.

Existing Beach Monitoring Efforts

DCR has already been performing baseline beach surveys along the Salisbury Beach and Plum Island, where shore-perpendicular transects spaced at approximate 500-ft alongshore intervals have been surveyed three times since the summer/fall of 2017. The monitoring protocol for this effort utilized an RTK-GPS for the survey and include events done in the spring and fall season. To date, transects have been surveyed within the vicinity of Center Groin, along the Atlantic Ocean facing coast of Salisbury Beach, and along the Reservation Terrace shoreline. Beach transects extended from the MLW elevation landward to a point approximately 600 feet above MHW, with measurements taken at every noticeable break in elevation. Elevations along each transect were reported in the NAVD88 vertical datum.

The survey protocol developed to date provides a general framework for evaluating beach erosion and accretion trends; however, site-specific monitoring protocol could provide beneficial information for the more dynamic portions of the shoreline. Therefore, the existing monitoring protocol is likely sufficient for Salisbury Beach. The two more rapidly changing areas, Plum Island in the vicinity of Center Groin and Reservation Terrace, would likely benefit from increased spatial analysis including the following:

- Rather than 500-ft alongshore spacing of transects, better spatial resolution of the Plum Island “hot spot” and the Reservation Terrace area could be achieved with alongshore transect spacing of 150 feet. This would allow more in-depth analysis of profile response to the more rapid alterations to the shoreline. This more detailed shoreline transect survey could be performed annually, preferably in the spring to represent “worst-case” beach conditions relative to the winter profile.
- The RTK-GPS survey equipment also can be utilized to trace the observed high-water shoreline based upon the observed “wrack” line at the time of the survey. To ensure this line is consistent between surveys, a comparison of the recorded elevation of the observed wrack line would need to accompany the survey results. This analysis performed on an annual basis would provide more detailed information regarding alongshore variability of shoreline shape, which is critical for assessing the impact of erosional “hot spots”. Similar to the closely spaced shore-perpendicular transect survey describe above, the high-water shoreline survey could be performed annually, preferably in the spring to represent “worst-case” beach conditions relative to the winter profile.

Beach Nourishment Monitoring Protocol

Although, as of the release of this report, a nourishment project is not in place, it is important to consider the necessary maintenance and monitoring that must be included. Since the purpose of the beach nourishment program is to reestablish the local sediment supply and provide storm protection for the shoreline, an evaluation of long-term nourishment needs will be required to assist DCR or other project proponents with future nourishment maintenance. An essential aspect to this project will be monitoring the performance of fill placed for the purpose of beach nourishment. This monitoring information will aid in determining:

- The percent fill remaining within the design template
- Accretion or erosion along adjacent beaches (either to the north or south of the project)
- The longshore variability in beach width indicative of potential "hot spot" erosion
- Future nourishment need required to maintain any nourishment for shore protection and the sediment supply

The rapid introduction of a large volume of sediment to the nearshore area would result in the material moving both alongshore and cross-shore to reach equilibrium with the waves and currents in the area. Monitoring would provide a means to measure the shoreline change and shifting of the nourishment fill. This can be determined by measuring the elevation along a series of shore perpendicular control transects (or cross-sections) along the length of the fill, as well as performing an RTK-GPS survey of the observed high-water line. For the alternative nourishment designs within this report, monitoring protocol similar to the one employed by DCR currently would be adequate. Survey transects at approximately 80 locations in Salisbury and 45 locations on Plum Island spaced 200 feet along the beach, could be employed for the monitoring effort of the nourishment alternatives described in the report. Surveys would be conducted from the landward edge of the primary dune and extend offshore. The actual distance that each transect runs offshore would need to be determined by *in situ* water depth. A pre-construction survey would be performed immediately preceding the nourishment project. In the first-year post-construction, typical regulatory requirements ask for surveys to be performed quarterly. The post-construction survey would be performed as soon as is practical after the completion of the nourishment project and would extend offshore to -15 ft NAVD88; well offshore of the proposed equilibrated nourishment toe. The remaining surveys in the first year would be wading surveys out to the -5 ft contour. The second-year post-construction would see two surveys performed: the first survey (12 months post construction) would again be to the -15 ft contour and the second survey (18 months post construction) would be a wading survey to -5 ft. Starting in the third-year post-construction, surveys would be conducted once annually out to -15 feet.

To ensure consistency between surveys, permanent benchmarks and/or markers would be installed in appropriate locations along the shoreline for the purpose of future beach measurements. The elevations along the transects would be plotted to determine changes in the fill volume. The cross-sections could also be used to determine performance of the nourishment within the original design template. In addition, RTK-GPS surveys would be performed using a backpack unit along the observed high-water line. These surveys of the high-water line would be performed immediately following construction, and would take place on the same schedule as the cross-shore transects discussed above. Shorelines plotted from this data set would help identify changes in the alongshore position of the erosion "hot spot", as well as the spreading of nourishment in the alongshore direction.

Monitoring reports would be prepared one (1), three (3), five (5), and seven (7) years after completion of the nourishment project. These reports would include a summary of all data collected, information regarding the wave climate and storm activity, volume change over time, and an evaluation of shoreline change. In this manner, the performance of the beach nourishment would be evaluated relative to design predictions. The monitoring information would provide useful data needed to assess future renourishment requirements of both the Salisbury and Plum Island shoreline. Copies of the monitoring reports will be provided to each of the towns, DCR, MCZM, and the U.S. Army Corps of Engineers. A more detailed site-specific monitoring and maintenance plan can be developed upon the finalization of nourishment project design.

7.0 CONCLUSION

This report summarizes a study completed along the upper North Shore of Massachusetts by Applied Coastal for Massachusetts DCR. The study includes a review of existing literature, in addition to coastal modeling to develop an array of alternatives that stakeholders may employ to better manage the shoreline. Some of the key findings include a recent decline in dredging events (i.e., one in the past 20 years), and a resulting loss of material in the system as most of the sand was placed either offshore or along the bypass bar. This removal of sediment from the system has resulted in a net erosion shoreline change for most of both Salisbury and Plum Island’s shoreline.

Other findings from the review and modeling include the existence a strong gyre-like system offshore of Reservation Terrace that is strengthened by a sealed jetty. These fast-moving currents are able to mobilize and transport sediment out of the inlet throat towards a spit that has formed within the channel. Some sort of structural modifications would be necessary to disrupt strong alongshore currents within the inlet before any nourishment project could be effective along Reservation Terrace. Finally, sediment transport processes at the northern end of Plum Island are tied to the bypass bar feature offshore. It provides important protection from storm waves for most of the inhabited sections of coastline, but leaves other sections exposed at critical breaks in the bar that focus both currents and wave energy. This exposed section of shoreline is considered an erosion hotspot, and the relative position is tied to the location of the southern end of the bypass bar. Proper management for this section of shoreline would require more frequent nourishments in addition to regular monitoring.

Due to the broad range of both public and private properties along this section of coastline (e.g., the towns, homeowners, DCR, and USACE), a coordination and cooperation between federal, state, town, and private entities must exist to implement any future design alternatives. Under existing conditions with relatively small erosion rates for most of the shoreline, shore protection can be managed with sediment dredged from the inlet every few years. In the future, changes in sea level rise and the bypass bar will result in changes to management requirements and techniques. While mitigation of shoreline erosion is possible with nourishment in the near future, the aforementioned changes mentioned here could present scenarios in which managed retreat becomes a potential course. An updated study that includes compiled monitoring for the upper north shore every few decades would be an effective way for stakeholders to evaluate and reconsider existing management practices.

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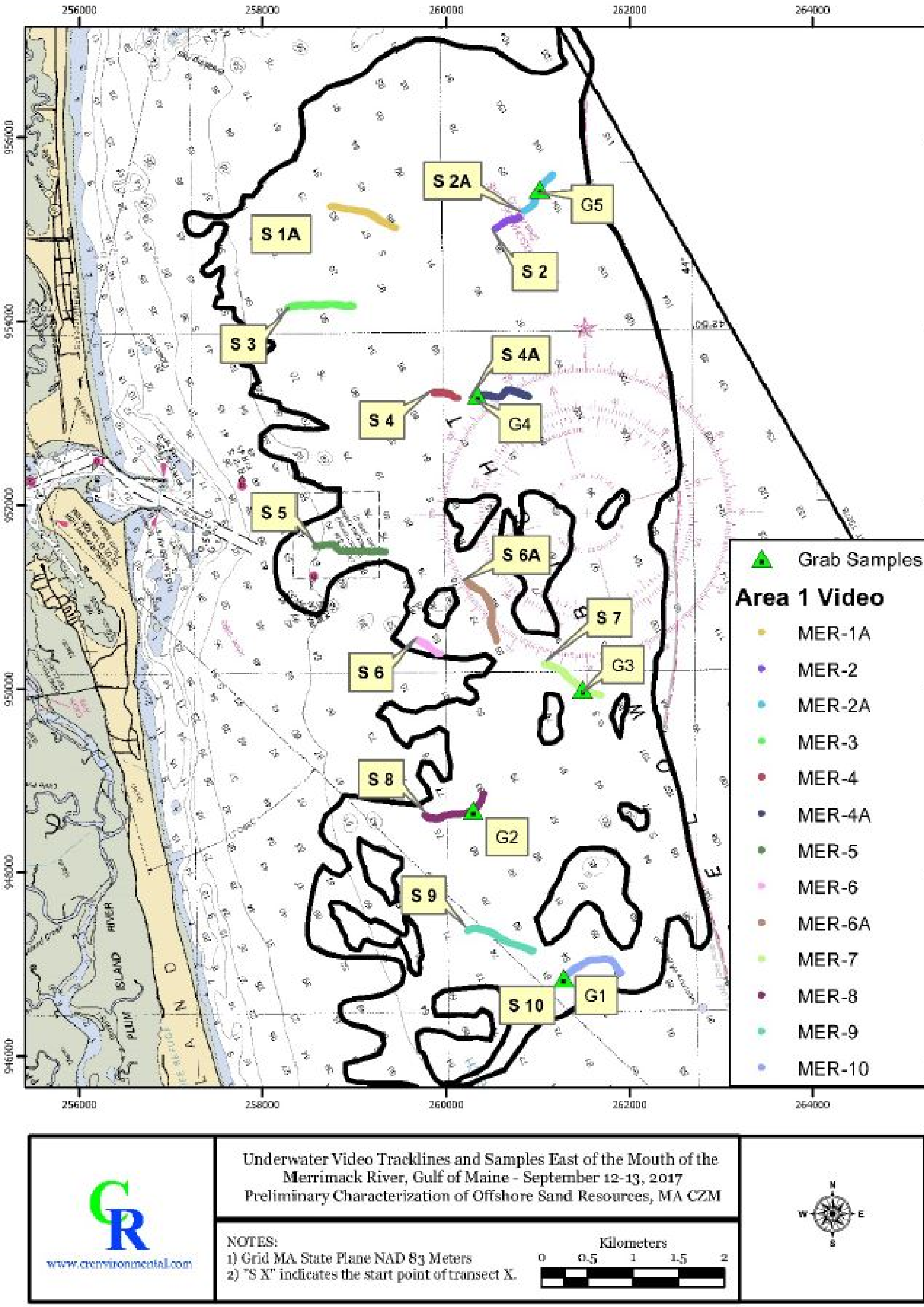
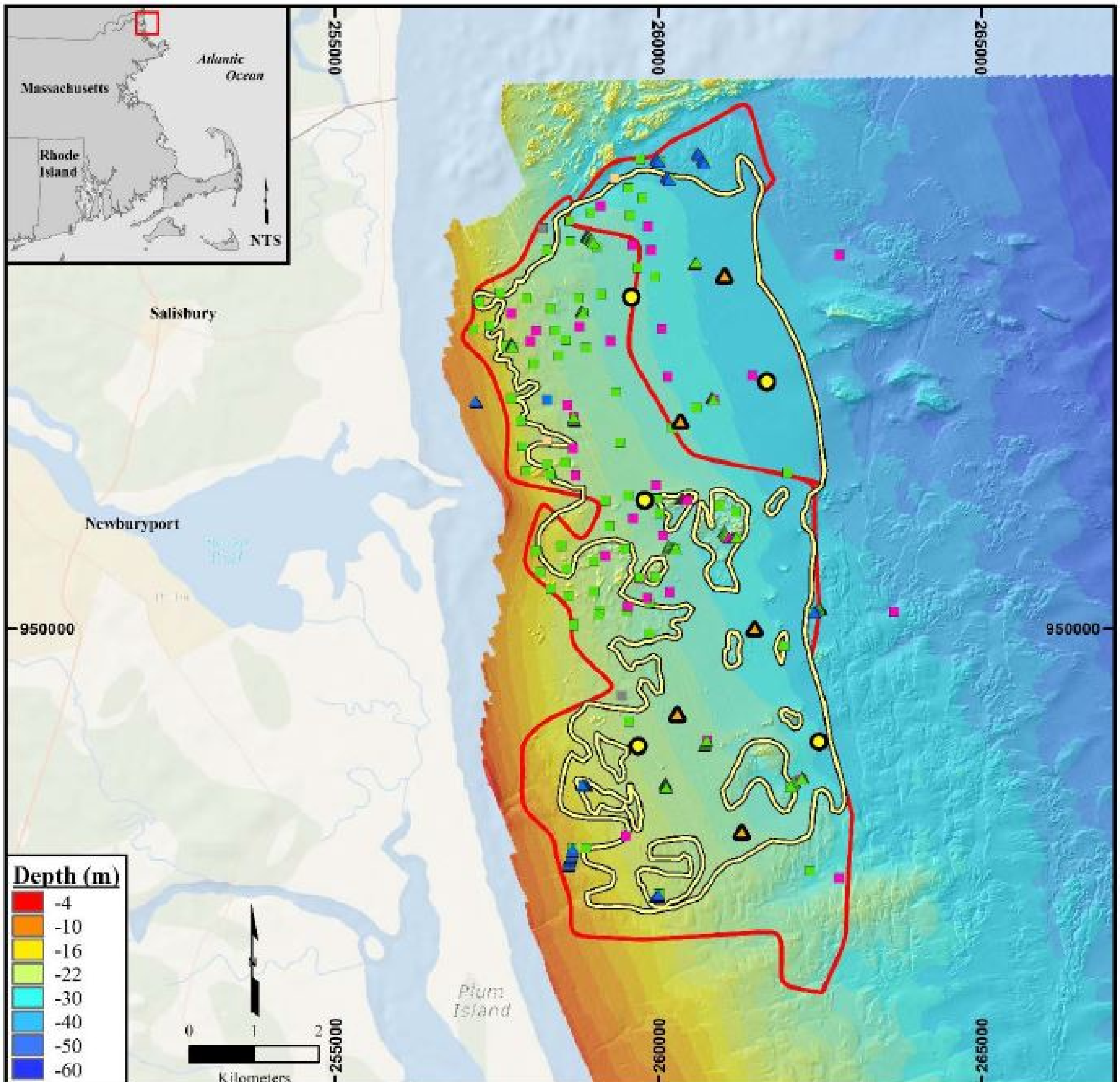
8.0 APPENDIX

Appendix A: Potential Borrow Site Locations (APTIM, 2018)





Study Area 1: Merrimack River, Historic Bathymetry

Notes:

1. Coordinates are in meters based on the Massachusetts State Plane Coordinate System, Mainland Zone, North American Datum of 1983 (NAD 83).
2. Background imagery is the ESRI Ocean basemap.
3. Surface grab sample data are from the U.S. Geological Survey sample database.
4. Bathymetry surface and bottom photograph data are from the U.S. Geological Survey Open-File Report 2007-1373.

Legend:

- Planned Vibracores
- Planned Grab Samples
- MA OMP Sand Resource Areas
- Interpreted Sandy Seafloor

Seafloor Classification Photographs

- Sand
- FG Sand
- Hardbottom/Rock

Surface Grab Samples

- Clayey Silt
- Gravel
- Sand
- Sandy Silt
- Silty Sand

Appendix B: Potential Design Matrix

(See Next Page)

Region	ALTERNATIVE	ADVANTAGES	DISADVANTAGES
Salisbury Beach and State Reservation	Salisbury Beach Nourishment	• Would effectively protect properties from storm damage, without creating any permanent structures • Introduces new sediment to the system that will provide future protection to the beach where nourishment is placed, as well as downdrift beaches • Provides additional recreational space to further generate revenue	• Large volume of sediment will be costly to construct • Potential temporary environmental impacts to the nearshore area within the nourishment 'footprint' • Maintenance of the nourishment will be required and could be costly, depending on frequency of major storms
	Emergency Sand Source (SSA)	• Emergency storm response • Sand nourishment/restoration of critical dune areas • Repairing/Maintaining public access ways and other access structures located along the State Reservation	• Sand in the stockpile could be allocated towards pre-emptive storm protection measures and not have volume needed to maintain storm protection, especially for major storm events • Limited volume available to be stored on parking area (i.e., SSA would become resource area if placed on the existing dune and storage/placement in the paved parking area could greatly reduce capacity).
Reservation Terrace	Weir Jetty	• Prevents gyre formation during flooding (incoming) tidal flows • Reduction in alongshore velocities	• Increase infilling of the inlet, potentially requiring more frequent navigation dredging • Sand losses along beach immediately south of the jetty
	Offshore Breakwater	• Provide storm protection for homes situated along Reservation Terrace • Relocates the gyre further into the inlet and reduces erosion along the Reservation Terrace shoreline	• Expensive to construct • Environmental permitting of hard structures would be difficult • Increase in tidal currents along the south jetty
	Beach Nourishment	• Would protect properties from storm damage, without creating any permanent structures • Introduces new sediment to the system that will provide future protection to downdrift beaches • Provides additional recreational space	• Potential environmental impacts • Expensive with a relatively short design-life due to the tidal currents in this area that will rapidly erode nourishment material placed • Potential increase in navigation dredging requirements as rapidly eroded material from Reservation Terrace settles in the navigation channel
Plum Island Beach	Bypass Bar Modifications	• Provides negligible reduction in velocity of alongshore currents travelling in the channel behind the bypass bar • Dredged material could be used as storm protection onshore in the form of beach nourishment	• Expensive • Environmental impacts could be significant due to alterations in tidal current, wave, and sediment transport patterns in the nearshore area • Would expose portions of the Plum Island shoreline to larger waves that propagate across the deeper dredged areas
	Plum Island Beach Nourishment	• Would protect properties behind the erosion hotspot from storm damage, without creating any permanent structures • Introduces new sediment to the system that will provide protection to the beach where nourishment is placed, as well as to downdrift beaches. • Provides additional recreational space	• Large volume of sediment will be costly (depending on the source) • Potential temporary environmental impacts to the nearshore area within the nourishment 'footprint' • Maintenance of the nourishment will be required and could be costly, depending on frequency of major storms
	Groin Modifications	• Reduce alongshore sediment transport to potentially minimize erosion hotspot impacts	• Environmental regulations generally prohibit construction of new permanent coastal engineering structures on a barrier beach. • High cost of maintaining the structures "filled to entrapment" in perpetuity to ensure no downdrift impact results from construction

Appendix C: Data Sources

Data Type	Data Source	Data Location
Wave	• WIS 63045 Station	http://wis.usace.army.mil/
Tidal	• United States Army Corps of Engineers (USACE) 2018 Survey (Li et al., 2018)	By Request
LiDAR	• 2010 USACE Topobathy LiDAR • 2011 USACE Topobathy LiDAR • 2014 USACE Topobathy LiDAR • 2015 USACE Topobathy LiDAR	https://coast.noaa.gov/dataviewer/#/lidar/search/
Bathymetry	• NOS Historical Hydrographic Surveys	https://maps.ngdc.noaa.gov/viewers/bathymetry/
Additional Resources	• Town Beach Management Plans • Municipal Vulnerability Plans	By Request