Upper North Shore Regional Sediment Management Study

January, 2021

Prepared for:
MA Department of Conservation & Recreation

Prepared by:
Applied Coastal Research and Engineering, Inc.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

USGS MAP


7.5 X 15 MINUTE SERIES (TOPOGRAPHIC)
Salisbury Plains
Seabrook Beach
SEABROOK
SALISBURY
Salisbury
Salisbury Beach
Browns Point
Rings Island
ATLANTIC OCEAN
Plum Island
JOPPA FLATS
Woodbridge Island
Plumbush
Pine Island
NEWBURY
Old Town Hill
Newbury Old Town
Kents Island
KENTS ISLAND WILDLIFE MANAGEMENT AREA
PARKER RIVER NATIONAL WILDLIFE REFUGE
PLUM ISLAND
SCALE 1:25 000
CONTOUR INTERVAL 3 METERS
NEWBURYPORT, MASS. – N. H.
42070-G7-TM-025
1987

1.0 PROJECT OVERVIEW

1.1 Introduction

The Massachusetts Department of Conservation and Recreation (DCR) contracted Applied Coastal Research and Engineering, Inc. (Applied Coastal) to perform a regional sediment management study along the upper North Shore of Massachusetts, including the municipalities of Salisbury, Newbury, and Newburyport (Project Area; Figure 1.1). This study provides a comprehensive look at long-term coastal processes that shape both the open coast and the barrier beach areas within the Merrimack River entrance. The assessment of coastal processes serves as the basis for developing management strategies for erosion control, coastal protection, beneficial re-use of compatible dredge material on public beaches, beach management, and coastal resiliency for the public beaches in the three communities within the study area.

It should be noted that the shoreline in the vicinity of the Merrimack River entrance consists of a broad range of both public and private properties In addition, much of the public beach in both Salisbury (Figure 1.2) and Plum Island (Figure 1.3) represents a relatively narrow strip of land along the Atlantic Ocean shoreline, with private properties immediately landward of this beach area. Ultimately, to improve coastal resiliency along this barrier beach system, management will require significant coordination and cooperation between federal, state, town, and private entities.

Figure 1.1 Aerial map of the project area, showing limits of open ocean shoreline modeling (solid yellow line) and the inlet area modeled using the combined hydrodynamics and wave model (dashed box). Town boundaries also are provided.

Figure 1.2. Beachfront ownership in Salisbury as delineated by Massachusetts GIS tax parcels. The state owns Salisbury beachfront, however the shoreline behind the dune is privately owned starting at Atlantic Ave up to the Massachusetts and New Hampshire border.

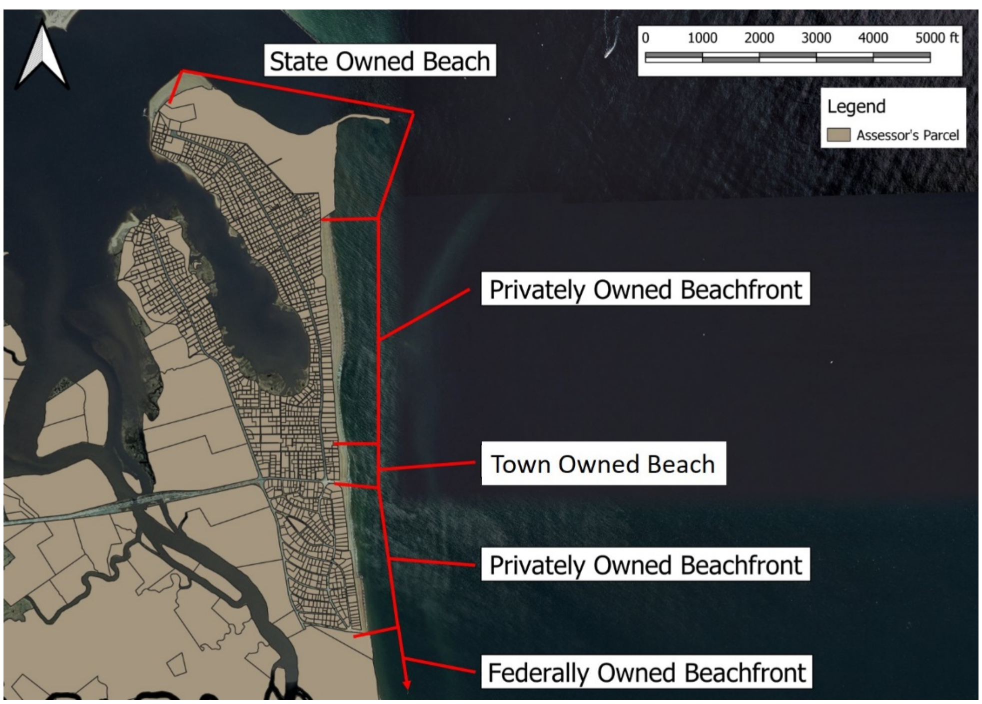

Figure 1.3. Distribution of beachfront ownership along Plum Island. Reservation Terrace at the northern end of Plum Island is state owned, with private ownership just to the south for all but eight parcels north of Center Island Groin that are owned by the Town of Newbury. Parker National Wildlife Refuge exists to the south, and is federally owned.

The Merrimack River/Great Marsh system is similar to many barrier beach/salt marsh complexes throughout the northeastern United States. The fronting beach system is composed of the glacially-derived sediments that are available in the nearshore region. For Salisbury and Plum Island, these sediments consist of a mixture of sand, coarse sand, and gravel. The influence of daily coastal processes, episodic storm events, and ongoing relative sea-level rise continues to reshape the shoreline and the salt marsh system landward of the beach. Sediment derived from the Merrimack River, updrift shorelines, and the nearshore region continue to supply sediments to the beach and dune system. However, the influence of the Merrimack River entrance, as well as anthropogenic alterations to the tidal inlet system and adjacent shorelines has altered natural sediment migration patterns. The general south-directed littoral drift causes beach material to migrate toward Plum Island Sound to the south. In addition, episodic storms (e.g. the “No Name Storm” in 1991 and “Winter Storm Riley” in 2018) can cause significant migration of beach material, both depositing and removing large volumes of beach sand in a single event. Over the past several decades, beach erosion caused by significant nor’easters have prompted emergency shore protection efforts to protect dwellings along the barrier beach system. Overall, these efforts provide some temporary relief to affected properties; however, long-term planning efforts are needed to adapt to ongoing coastal erosion along the Salisbury, Newbury, and Newburyport ocean shoreline. Although storm-driven erosion events have necessitated implementation of emergency storm protection in some areas, it should be noted that long-term shoreline change along shorelines to the north and south of the Merrimack River entrance have been relatively modest, ranging from stable (i.e. no change or slightly accretional) to around 2 feet per year of erosion. Therefore, under historical conditions, proper management of available sand resources trapped within the Merrimack River entrance may have been sufficient to maintain the existing shoreline over the next several decades.

Further in the future, it is anticipated that the rate of sea-level rise will increase. As a result, the high water shoreline will migrate landward at an increased rate, as the barrier beach system equilibrates to a higher water level. This increase in observed shoreline erosion will require additional material to offset this impact, which likely will exceed the sediment supply available from the Merrimack River. With this in mind, long-term future management considerations should include the full range of potential options ranging from maintaining the position of the beach to potentially evaluating managed retreat in certain cases. It is understood that barrier beach systems are dynamic and maintaining the overall feature in a fixed position can be a challenging and costly endeavor. Assuming that sea-level rise accelerates in the future, maintaining the beach system will become more costly and problematic over time. Therefore, long-term planning (i.e. 30-to-50 years into the future) may need more careful consideration of alternatives that allow the shoreline to naturally migrate landward to some extent.

For over 100 years, the Merrimack River entrance has been armored with jetties in a manner that alters the natural sediment transport pathways in the vicinity of the tidal inlet. Long-term management of the navigation channel by the U.S. Army Corps of Engineers (USACE) has led to a net loss of sediment to the nearshore littoral system, which directly impacts the stability of the regional barrier beach system. While corrective actions may be difficult to implement, the influence of removing significant volumes of sediment from the littoral system has had a profound impact along the adjacent shorelines. It is anticipated that the towns directly influenced by the stabilized Merrimack River entrance and USACE will coordinate efforts necessary to rectify long-term sediment losses to adjacent beaches, which would substantially improve the overall resiliency of the existing barrier beach system.

1.2 Study Purpose and Overview

This study is aimed at understanding the variety of coastal and inlet processes that govern the Merrimack River and barrier island complex, and to offer potential shorter-term response strategies available to landowners including municipalities of Salisbury, Newbury, and Newburyport. Management of the barrier beach, coastal dune, and salt marsh system needs consider the effects of significant storm events on the system. Overall, this effort is aimed at management goals over the next 10-to-20-year planning time horizon for the Upper North Shore Coastal Complex: sustaining the beach and dune as an attractive public resource and enhancing the dune system to provide coastal resiliency.

A number of previous studies have been performed to evaluate regional coastal processes and to assess potential responses to ongoing coastal erosion concerns. Overall, these studies provide a general understanding of sediment transport pathways, and the data provided by these previous studies proved invaluable to the in-depth understanding of coastal processes contained in this report. Data related to regional coastal processes was compiled including contemporary shoreline and bathymetric surveys (inclusive of the Merrimack River area within the study limits), grain size testing data, natural resource characterizations, sediment transport and wave studies, shoreline monitoring reports, coastal infrastructure inventory and assessment reports, and other pertinent documents/data related to local coastal and estuarine sediment transport processes. Much of the recent coastal processes studies within the region have been performed by university researchers from either Boston University or the Virginia Institute of Marine Studies.

As a result of ongoing coastal erosion, as well as significant development along the barrier beach shoreline within the study area, the regional shoreline from the New Hampshire border to Ipswich has been the subject of several coastal processes assessments. Most recently, United States Army Corps of Engineers (USACE) has performed work in the area related to their Regional Sediment Management (RSM) program. Data collection performed as part of USACE work, specifically tidal information, was able to be utilized for this study. Other information related to shoreline change, FEMA repetitive loss, beach management plans, and limited survey data also was available to help inform both the coastal processes analysis and shore protection alternatives evaluation.

Each of the three communities have begun (or completed) the development of a beach management plan. In general, these plans address management strategies for each community aimed at guiding sustainable development, as well as preparing for future sea level rise impacts. Relevant to this study, the management plans provide steps to take in response to certain events, specifically related to storm-driven damage. For example, the Salisbury Beach management plan outlines specific actions to take if certain public infrastructure (e.g., benches, dunes, etc.) are damaged. This is important to ensure storm response and short-term functioning of public resources. However, the overall goal of these management plans is to provide reactive repairs to infrastructure associated with storm damage, rather than long-term proactive efforts needed to restore the beach system to historic levels required to provide upland protection. The long-term shore protection measures outlined in this report can work in conjunction with the existing beach management plans to ensure both preemptive measures (proactive) and emergency protocols (reactive) are in place.

Once data compilation was complete, a series of numerical coastal processes models were developed to provide a more thorough understanding of coastal processes along the study shoreline. Specifically, the ocean-facing beach areas are dominated by wave-driven sediment transport processes; therefore, a spectral wave model combined with an alongshore sediment transport model can be utilized effectively to assess performance of shoreline management strategies (e.g. beach nourishment and modifications to existing coastal engineering structures) in these areas. In the vicinity of the Merrimack River entrance, the sediment transport patterns are driven by both tidal currents and waves. In this area, a time-dependent analysis of both tidal currents with freshwater inflow and ocean waves was needed. The Coastal Modeling System (CMS) developed by USACE was utilized to perform the analysis in the vicinity of the inlet. The generalized limit of the two modeling approaches is shown in Figure 1.1 and is further described as follows:

- *Sediment Transport along the Open Ocean Shoreline* - To properly evaluate natural forces influencing nearshore sediment movement along the ocean-facing beaches, an analysis of coastal processes (primarily waves) governing beach sediment transport was performed.

Spectral wave refraction modeling was used to determine how nearshore bathymetry modifies the wave climate along the open ocean beaches of Salisbury, Newburyport, and Newbury. Since this area incorporates the effects of both locally generated wind waves and swell generated offshore in the open North Atlantic Ocean, wave transformation modeling required incorporation of both components. Wave information used to drive the wave refraction model was developed from locally available wind information (NOAA buoy data), as well as available NOAA and USACE data sets for this portion of the North Atlantic Ocean. Information from the wave modeling was incorporated into a one-line shoreline change model. For the sediment transport/shoreline change model, appropriate nearshore wave climate, grain size, and historic shoreline change data were required to accurately simulate sediment transport. Since the purpose of the sediment transport study was to focus on changes to the nearshore regions in the contemporary time-frame, shoreline data used to validate the modeling effort focused on a recent time period where high-quality shoreline data was available (2005 to 2015). Once calibrated, the shoreline change model was used to assess sediment transport pathways and delineate littoral cells, determine future migration of the shoreline, delineate sources and sinks at the limits of the delineated littoral cells, and evaluate alternative shore protection strategies.

- *Sediment Transport along the Merrimack River Entrance Shoreline* – The combination of tidal currents and waves within the entrance channel to the Merrimack River requires a time-dependent analysis of coastal processes to quantify sediment transport patterns along the shorelines immediately west of the two jetties. This time-dependent approach incorporated typical tides and freshwater inflow through several tidal cycles combined with time-varying wave conditions to drive sediment transport. The Coastal Modeling System (CMS), developed by USACE, was utilized to perform the analysis in the vicinity of the inlet. An additional CMS model was developed for the northern end of Plum Island with results from the inlet model, to understand flow around the bypass bar. Due to the computational requirements of this type of modeling, an evaluation of 'typical' conditions was performed to quantify sediment transport pathways. Similar to the open ocean shoreline analysis, the modeling analysis within the Merrimack River entrance provided quantitative information regarding sediment transport pathways to support the evaluation of alternative shore protection measures.

The two-phased modeling approach described above, which incorporated different tools to assess the ocean-facing and interior Merrimack River shorelines, provided the most defensible approach for assessing shoreline stabilization methods for each of these areas. Overall, the modeling tools were used to evaluate several shoreline stabilization alternatives at each site. Understanding that the 'practicability' of an alternative (i.e. an evaluation ensuring that an alternative is available and capable of being done after taking into consideration cost, existing technology, and logistics in light of overall project purposes) is critical in ranking the viability of alternatives. In addition, potential environmental impacts associated with any alternative also need to be considered within the context of practicability, as potential options that either cannot be permitted or would require substantial mitigation to offset impacts likely would be deemed unacceptable. A broad-based alternatives analysis was performed for a full range of potential shoreline stabilization responses and summarized in a rating matrix. As well as evaluating the influence of each measure in stabilizing the shoreline, the effectiveness of each alternative was assessed based on relative sea-level rise projections over the next 50 years.

Following prioritization of the management alternatives for public beaches, more detailed conceptual designs were developed for the highest rated alternatives. As part of this conceptual design process, typical cross-sections were developed and overall environmental impacts (i.e. overall project 'footprint' and types of resource areas impacted) were quantified. These conceptual designs were developed to determine approximate environmental impacts based on project scale and provide a typical cross-section of the design, as appropriate. For the prioritized alternatives, the report also provides identification and description of further analyses that will be needed if a decision is made to move forward with detailed design and permitting.

Sand Nourishment Projects for the Public Beaches in the Region: Project development tasks included the determination of possible sand sources including sand from local dredging projects (i.e. beneficial re-use of beach compatible dredged material) or upland sources. Steps in the development process included existing conditions surveys performed by others; development of alternate layouts for sand placement to provide various levels of storm damage protection; volume calculations for each alternative; analyses of environmental impacts of proposed work on existing beach and dune resources and associated cost estimates. Costs estimates included a complete range of potential sources, including navigational dredge projects and upland sources from around the region.

Modification/Repair to Groins and Jetties: As part of the initial modeling analysis, potential alternatives for modifying structures were developed to optimize coastal protection. Understanding the generalized concept of structure modification and modeling of the prioritized structure modifications included addition of new groins, as appropriate, as well as modifying the South Jetty to improve sediment bypassing. It should be understood *a priori* that the potential for modification to the federal jetty structures would require substantial backing from USACE which may be challenging due to recent jetty improvements.

Nearshore versus Onshore Sand Placement: Based on the patterns of sediment movement identified in the modeling effort, specific locations were identified for placement of nearshore nourishment that will give the greatest benefit for feeding the public beach.

Publicly Owned Coastal Engineering Structures: The report provides generalized design recommendations that may improve the current protection provided by publicly owned coastal engineering structures on public beaches in the project area, including repairs, rehabilitation and placement of nourishment seaward of the structure.

1.3 Description of Project Area

The Project Area contains an ocean-facing barrier beach coast comprised of paraglacial sediments in the western Gulf of Maine with tides in the range of 2.7 m (Hein et al., 2016, Figure 1.4). This barrier beach system is bifurcated at the Merrimack River Inlet, located at the northern end of Plum Island. Plum Island extends south for 11 miles. Developed areas of the island constitute the village of Plum Island, with public beaches, businesses and private residences. The village surrounds a body of water known as "the Basin," and lies wholly within Newburyport and Newbury. The island's pristine largest section is managed by the United States Fish and Wildlife Service as the Parker River National Wildlife Refuge. Plum Island is accessed by one road running from Newburyport to the north of the island on a causeway and drawbridge over the Plum Island River.

Plum Island was built from a variety of sediment sources, including glacial-fluvial sediment discharged by the Merrimack River and nearshore marine deposits. Its evolution was strongly influenced by the combination of global eustatic sea-level rise, and regional glacio- and hydro-isostatic adjustments (Hein et al., 2014, 2012). Plum Island stabilized in its modern position about 3,000-4,000 years ago, coinciding with the shoaling and closure of a central tidal inlet. Following closure, Plum Island has undergone 3000 years of aggradation, elongation, and progradation (Hein et al., 2012). The southern two thirds Newburyport Harbor in Newburyport is about 2.5 miles long and stretches from the mouth of the Merrimack River to the U.S. Route 1 Bridge. It is four miles south of the Massachusetts/New Hampshire state line. The harbor is home base for charter excursion and sport fishing boats, as well as many recreational craft.

At the northern end of Plum Island the Merrimack River Inlet once freely migrated across a 2.5-km long section of the coast through spit elongation, inlet migration, and ebb-delta breaching (FitzGerald and

Montello, 1993). These processes alternately built and eroded the northeast sector of the island and created a significant navigational hazard. In December of 1839 three destructive storms cut a channel through Salisbury Beach at the mouth of the Merrimack River, creating an island and two inlets into the harbor. Eventually the original channel closed, creating the current Merrimack River Inlet orientation. As the southern extent of the inlet expanded northward, it formed the cove now referred to as the Basin. This new, slender arm of land, which continued to increase in area, was called New Point and retained that designation for many years (Weare, 1996).

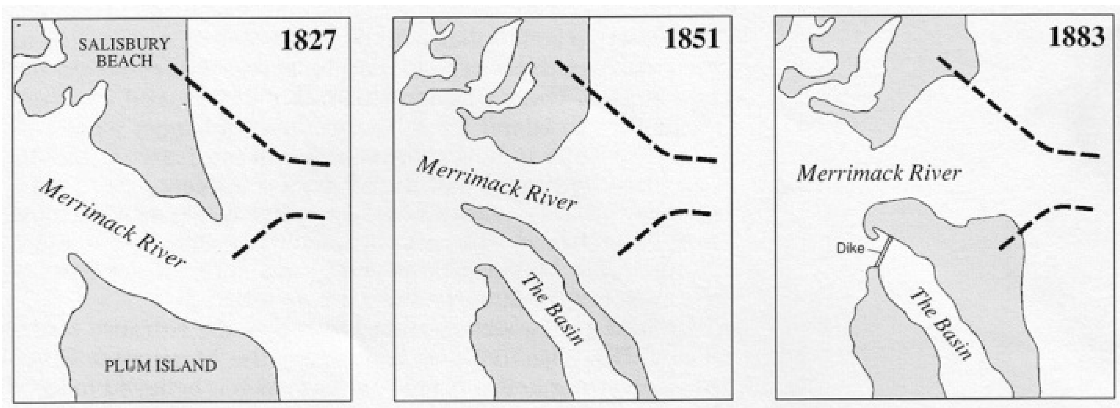

Figure 1.4 Three maps, based on surveys by USACE in 1827, 1851 and 1883, show the changing contours at the mouth of the Merrimack River in relation to the present-day jetties indicated by dotted lines. The views represent the high-water marks on both the Plum Island and the Salisbury shores (Weare, 1996).

USACE initiated the Newburyport Harbor Project in 1881 and completed the work in 1900. In 1914, the north jetty was extended to improve navigation of the inlet. Additional repairs were then required in 1932 for both jetties, and then again in 1938. As it is designed, north jetty extends from Salisbury Beach in Salisbury and is 4,118 feet long. The south jetty extends from Plum Island Point in Newburyport and is 2,445 feet long. A three-mile-long channel extending from the Atlantic Ocean, through the harbor entrance, upstream to the Route 1 Bridge. From the Atlantic Ocean through the entrance to the harbor, the channel is 12 feet deep and 400 feet wide. From the harbor entrance to the Route 1 Bridge, the channel is nine feet deep and 200 feet wide.

The Merrimack River Inlet affects sediment transport within the littoral system that includes the coastal dunes of Salisbury, Newbury, and Newburyport. The jetties have a long history of repair due to breaches occurring between the beach and jetty, allowing flow to pass over top. According to Newburyport town records, the jetties were repaired in between 1966 and 1969, when 70,000 tons of stone were added (Nicastro, 2011). Following multiple severe winter storms (Tropical Storm Irene, Hurricane Sandy, Winter Storm Nemo), the first 600 feet of the South Jetty was repaired again in 2013 with the placement of 12,000 tons of rock (USACE 2013). Two years later in 2015 the North Jetty was repaired to design conditions. Review of reports and analysis of morphology changes and management alternatives are discussed in Section 2.3.

Figure 1.5 High tide image of the unraveled jetties in 2009, prior to rehabilitation by USACE.

Figure 1.6 A September 2011 image of the north and south jetties prior to jetty rehabilitation.

1.4 Executive Summary

Applied Coastal Research and Engineering, Inc. (Applied Coastal) performed a regional sediment management study along the upper North Shore of Massachusetts for the Massachusetts Department of Conservation and Recreation (DCR). The regional study included the municipalities of Salisbury, Newbury, and Newburyport. This study provides a comprehensive look at long-term coastal processes that shape both the open coast and the barrier beach areas within the Merrimack River entrance. The assessment of coastal processes serves as the basis for developing management strategies for erosion control, coastal protection, beneficial re-use of compatible dredge material on public beaches, beach management, and coastal resiliency for the public beaches in the three communities within the study area. To accomplish these goals, the study consists of the following components:

- A review of previous studies and available data, including coordination with any ongoing studies
- Coastal modeling and analysis for the east-facing open coast shoreline, as well as the Merrimack River entrance shoreline
- Broad-based analysis of potential shore protection alternatives and more detailed analysis of alternatives deemed most appropriate for long-term coastal resiliency
- Development of maintenance and monitoring approaches for public beaches within the study area

The report begins with a review of existing literature and historical documentation. Some important components of the review included geological reports and articles, to better understand the larger scale morphological changes. For example, review of the literature gave some insight into the fluvial and coastal processes that shaped the inlet. These processes substantially modify the northeastern section of the island and create a navigational hazard. The impacts of coastal processes are amplified during major storm events. For example, in December of 1839, three destructive storms cut a channel through Salisbury Beach at the mouth of the Merrimack River, creating an island and two inlets into the harbor. Eventually the original channel closed, forming the existing Merrimack River Inlet orientation.

The position of the Merrimack River Inlet was stabilized in the beginning of the 20th century with the construction of a pair of stone jetties. The jetties have been rehabilitated several times, only to weaken structurally over time. Fluctuations in the integrity of the jetties, primarily following significant storm events, were found to have a tremendous influence in sediment transport patterns in the region. Reservation Terrace, located at the northern end of Plum Island is significantly influenced by the southern jetty. This section of shoreline fluctuates between periods of erosion and accretion, with LiDAR data showing erosion rates on the order of 50 to 70 feet per year following a recent jetty rehabilitation project in 2013. Another critical area that historically has experienced drastic changes in shoreline width is the so-called “erosion hotspot” located adjacent to the center island groin. There are several theories as to why that section of shoreline faces serious erosion, however the literature mostly agrees that the hotspot is related to openings in a bypass bar situated 800 to 2,000 feet offshore depending on the locations. These critical sections of shoreline are discussed in further detail in the full report.

Once existing literature and historical records were reviewed, data were assembled to use in modeling efforts. A topographical map was developed using several sources, including LiDAR data from Army Corps surveys and NOAA bathymetric surveys offshore (see report Appendix C). Tide data were collected from a 2018 United States Army Corps report, to use as boundary condition data for the CMS flow model. Wave data were generated from a USACE WIS hindcast station offshore. Further information regarding the collection and use of the data can be found in the report.

Following data collection, Applied Coastal calibrated a combination of numerical models to ultimately estimate sediment transport rates and test a variety of alternatives. Models used in the study included:

- SWAN (Simulating Waves Nearshore): SWAN is able to simulate wave refraction and shoaling induced by changes in bathymetry and by wave interactions with currents. The model includes a wave breaking model based on water depth and wave steepness. Model output includes significant wave height H_s, peak period T_p, and wave direction.
- One-line Shoreline Model: Shoreline evolution modeling was performed using a “one-line” longshore transport computer code. So called “one-line” models simulate the evolution of a shoreline through time, at one specific contour level, e.g. the beach berm crest or mean water level, based on the assumption that the nearshore bathymetry (to the depth of closure used to define the active extent of the beach profile) can be adequately represented by straight and parallel contours.
- CMS (Coastal Modeling System): The CMS numerical modeling package that was used for this study was developed by USACE Coastal Hydraulics Laboratory (CHL). The present hydrodynamic analysis of the inlet was undertaken to evaluate the flow in and around the inlet, in addition to associated sediment transport patterns.

An important observation made during the modeling process was the existence of a gyre-like feature that forms within the inlet during a flood tide (Figure 1.7). The gyre was only apparent in existing conditions with the jetty rehabilitated. Lowering of the jetty to pre-rehabilitation conditions (pre - 2013) disrupted the gyre formation, and modified flow within the inlet. Modifications of the jetty that would disrupt the gyre formation were then considered in the alternative’s analysis.

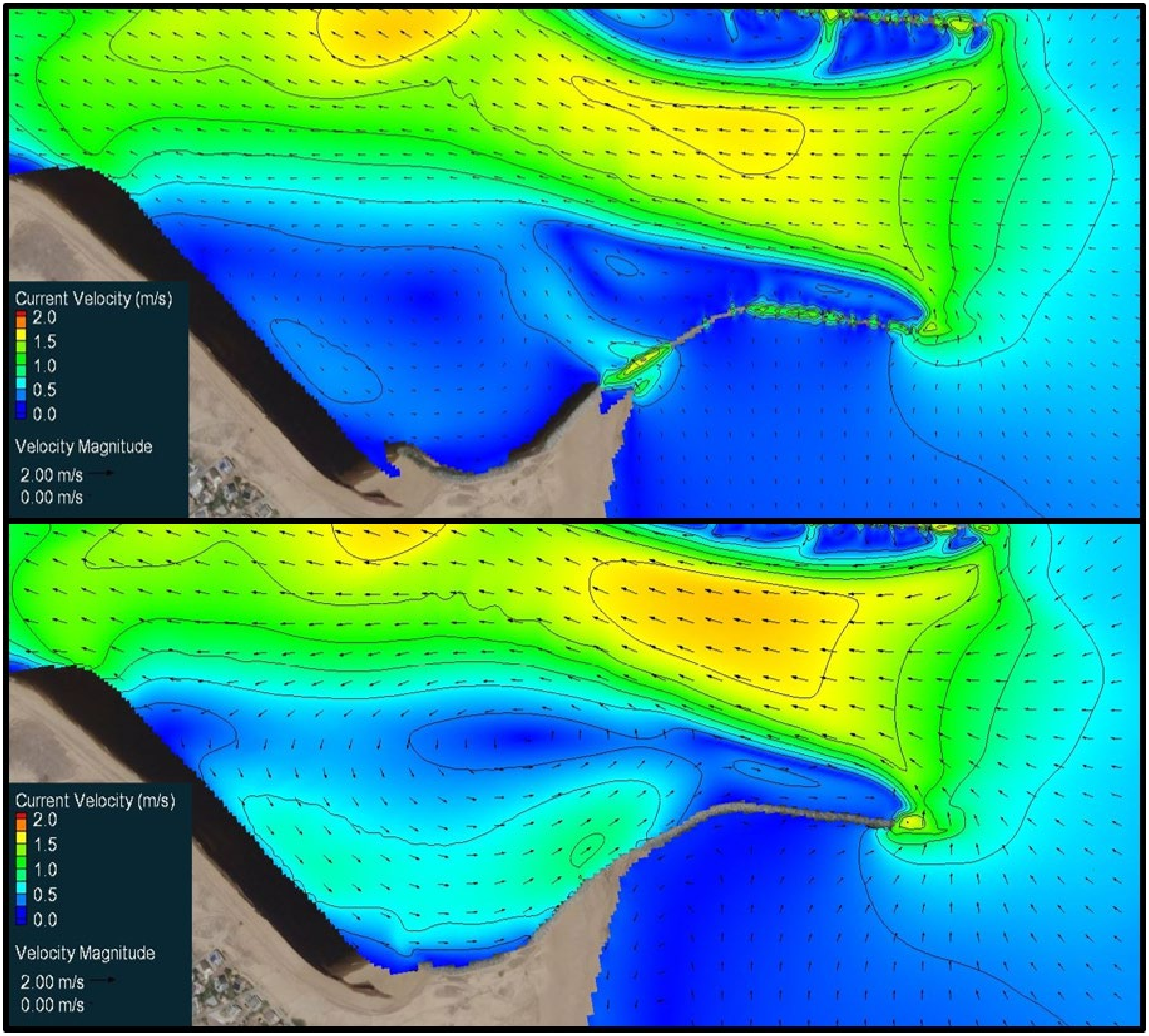

Figure 1.7 CMS Flow results showing the influence the structural condition of the jetties have upon flows into the Merrimack River. The figure shows the same simulation time step at peak flood tide with 2014 bathymetry for both model cases. The elevation data of the jetty in the simulation for the upper plot was edited to include LiDAR (2010) of the jetty prior to USACE rehabilitation in 2013. A circulation gyre develops along Reservation Terrace with currents approaching 0.85 m/s (2.8 ft/s) when the jetty prevents flow through the structure.

Applied Coastal divided the region into three areas to organize and test alternatives. These regions were selected and bounded based on geographic and man-made barriers (e.g., the jetties). The first region analyzed in the study was Salisbury beach. Historical shoreline change data for Salisbury indicate relatively stable conditions, with erosion rates around 1-3 feet per year. Erosion of this magnitude could be offset with a regular nourishment schedule using a sediment supply from the inlet.

The second region that alternatives were developed for is the Reservation Terrace shoreline. This shoreline of approximately 1,500 feet in length features drastic changes in shoreline position. Applied Coastal determined that with the fluctuations in the structural integrity of the jetty, regular nourishing of the shoreline would not be a stable solution. Therefore, several structural options were considered, with a weir jetty selected by Applied Coastal as most appropriate.

The final region that was considered was the inhabited, east-facing portion of Plum Island (northernmost 2.5 – 3 km). The northern section of this shoreline is presently accreting, but conditions can change with deterioration of the south jetty following a major storm event. This portion of shoreline is also heavily dependent on the status of a bypass bar, that has been bolstered with several dredging disposals the past several decades. It was determined that most of this shoreline can be maintained with regular nourishments every few years with material from the inlet, and emergency nourishments for the hotspot when necessary. Modeled nourishment results can be found for Salisbury and Plum Island in Figure 1.8 and Figure 1.9 respectively. The regional alternative analysis is summarized in the alternatives matrix provided in Appendix C.

Figure 1.8 Modeled position of the Scenario 4 berm relative to the 2005 and 2015 shorelines following a 15 year simulation for Salisbury Beach.

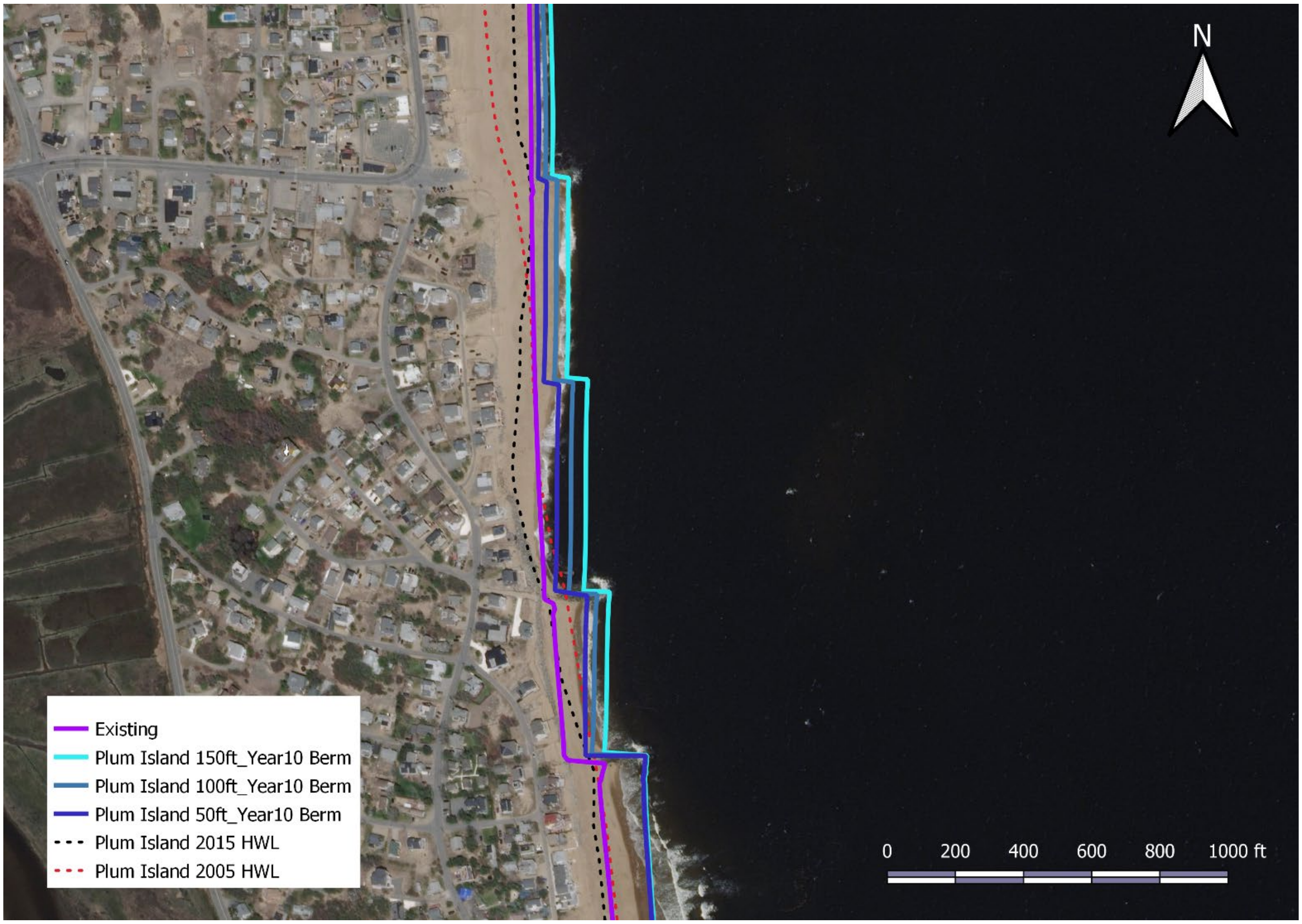

Figure 1.9 Modeled position of the berm for each scenario after 10 years relative to the 2005 and 2015 shorelines for Plum Island.

2.0 HISTORICAL PERSPECTIVE

The Merrimack River Inlet has been studied on several occasions to both understand the coastal morphology, processes, and potential shoreline management responses. Preliminary analysis of shoreline change dates back to the 1940's (Nichols, 1941), with some more in depth morphology studies beginning in the 1960's and 1970's (Hubbard, 1975; McIntire and Morgan, 1962; Wentworth, 1969). Some USACE engineering reports date back to the 1800's, but do not provide detailed quantitative analyses of local coastal processes. Only in the past 30 years have remote sensing (e.g., satellite imagery) and other surveying techniques provided high resolution data to perform large scale shoreline change analysis on a more frequent basis (1-3 years). Due to the significant influence of storms on shoreline processes, more frequent survey information is critical to ensure a complete understanding of coastal processes that will inform future shoreline management decisions. Both geomorphology and engineering studies have been reviewed for relevant information as described below. The purpose of this review was to identify important long-term processes and characteristics relevant to the project area.

2.1 Morphology of Plum Island

The Merrimack River entrance features a tidal inlet bypass bar, a system which has received ample attention in the scientific literature (FitzGerald et al., 2000). Some previous works have defined cycles of natural tidal inlets is on the order of 4-8 years from the preliminary building of the bypass bar to the final step of welding to the shoreline (Fitzgerald, 1984). Periodic cycles of accretion and erosion downdrift of the bypass bar are dependent on the timing of the bypassing cycle (Gaudiano and Kana, 2001). The hardening of an inlet with jetties (e.g., Merrimack River Inlet), alters the mechanisms of the bypass bar system and its cycle, therefore influencing downdrift erosion and accretion patterns.

Fallon (2016) provides a comprehensive analysis of shoreline change patterns downdrift of the bypass bar. The author compares the Merrimack River Inlet system to similar structured, mixed-energy tidal inlets. Hubbard (1979) suggested that erosion patterns at the Merrimack River Inlet ebb tidal bar are cyclical, and the bar facilitates the existence of a downdrift erosion hotspot. Similar cyclical erosion patterns have been linked to tidal inlet processes influenced by jetties with documented erosion hotspots (Fallon, 2016). For example, a similar cyclical pattern of breaching, migration, and welding over a 40-year time frame was observed at Ocean City Inlet in Maryland. Also, a similar jetty at Guadiana Estuary had a hotspot 1.5 times further downdrift from the jetties, indicating a relationship between the jetty length and location of the erosion hotspot. Fallon (2016) developed a conceptual model of the bypass bar system end with associated erosional and accretional impacts to the shoreline.

Historically, the Plum Island Beach shoreline has remained relatively stable, with a long-term erosion rate of only 0.3 ± 2.0 ft/yr (0.09 ± 0.6 m/yr) (Thieler, 2013). However, there are some cases of periodic short term erosion and accretion with rapid changes in the beach high-water line (Fallon, 2016). The most apparent of these short-term shorelines change features is an erosion hotspot, typically 1,000 to 2,600 feet (300-800 meters) in alongshore length, that migrates along the northern end of Plum Island. This section has been an ongoing problem for Plum Island residents, with recorded observations of the hotspot going back to the 1960's (Hubbard, 1975; Wentworth, 1969). The studies mentioned in this section that characterize morphology at Plum Island were primarily qualitative studies that mostly looked to define the large-scale processes rather than understand the mechanics and provide responses. Further detail regarding 'hotspot' erosion as it applies to shoreline management is discussed in Section 3.4.

The location of the erosional hotspot has been observed to migrate with the southern end of the aforementioned bypass bar. The bypass bar extends southward from the ebb tidal delta (Figure 2.1) that formed as a result of the ebb-dominated flow leaving the inlet. This bypass bar is typical of the types of shoals that form when alongshore transport is dominantly from one direction; in this case, the dominant waves transport sand from north to south. Therefore, the position of the ebb tidal delta becomes skewed towards the south, rather than appearing as the more balanced idealized case represented in Figure 2.1. The offshore bypass bar or ebb tidal delta at the Merrimack River entrance is positioned roughly 1,500 to 1,800 feet offshore, due to the stabilization of the tidal channel by jetties that "jet" (i.e., fast-moving intrusion of water that features increased velocities due to the constriction of flow) sandy material further offshore, and extends approximately 1.2 to 1.5 miles (2-2.5 km) south of the southern jetty. The southern end of the bypass bar extends towards a nearshore bar than runs along the remaining stretch of the Plum Island shoreline, and sits approximately 300 to 600 feet offshore. The size of the bar was bolstered due to a shift in location of dredging disposal from offshore to the nearshore just south of the inlet in the 1980s.

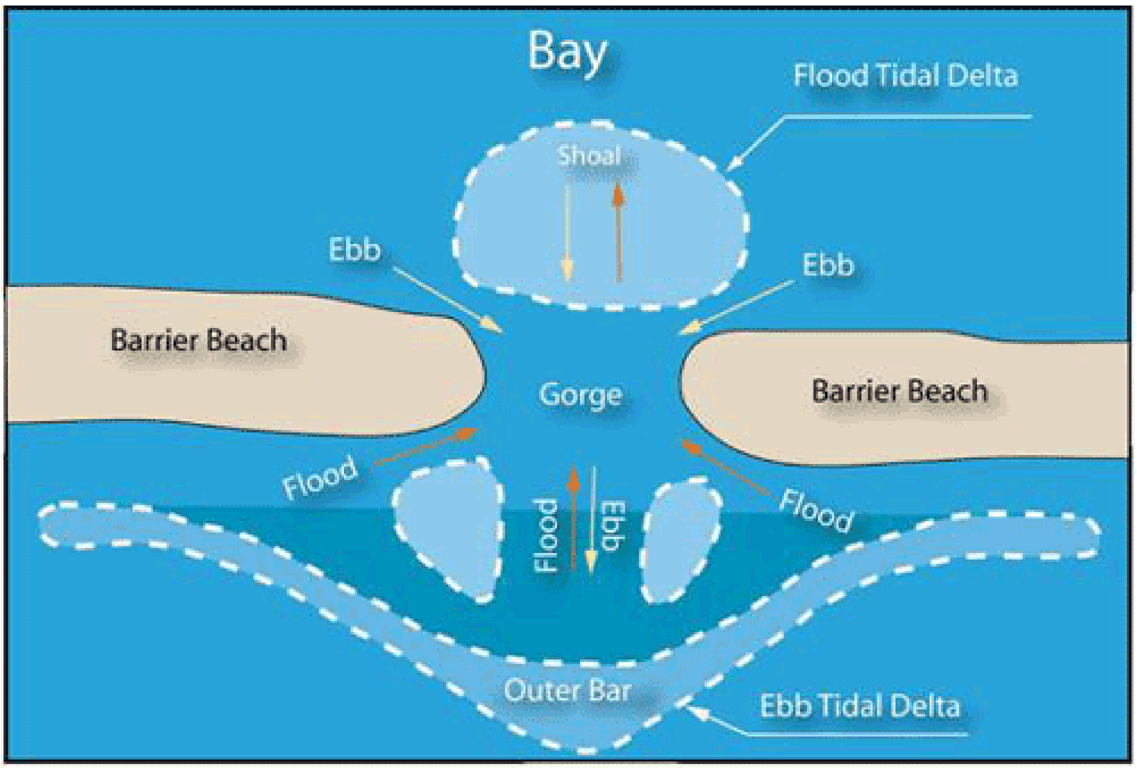

Figure 2.1 Idealized diagram of a tidal inlet showing the various channels and shoals that form as a result of both tidal currents and waves.

It should be noted that the bypass bar represents a large-scale offshore feature which is different from the seasonal beach bar that forms in the nearshore area due to changes in the local wave climate. In general, the milder wave climate during the summer months tends to build the beach, as sand is transported from the offshore area towards the beach. However, the steeper winter waves tend to transport beach material offshore, which causes not only narrowing of the beach, but also formation of a nearshore beach bar. This seasonal variation in the beach and nearshore beach profile characteristics is shown in Figure 2.2.

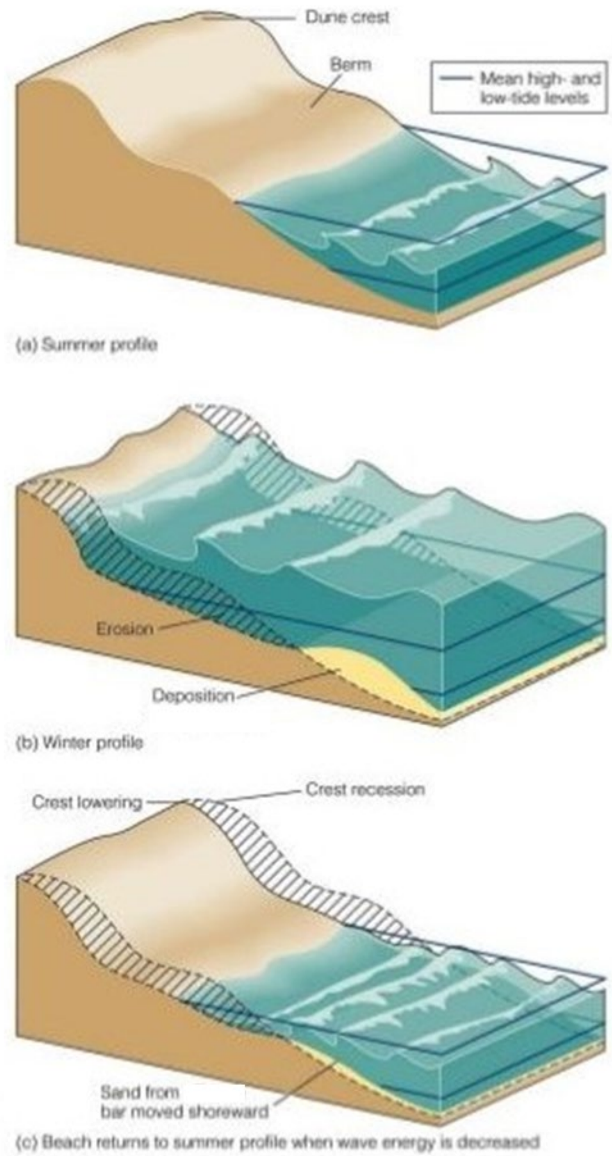

Figure 2.2 Comparison of beach profile changes from summer (calmer months) to winter (higher wave energy months). Note the beach width typically widens in the summer and the sand that is transported offshore in the winter months is stored in a shore-parallel offshore bar.

Along Plum Island, there have been some local suggestions regarding mechanical manipulation of the nearshore winter bar, where the concept of dredging this bar to place the material along the upper beach face to provide added winter protection has been discussed. This manipulation of the natural nearshore bar system likely would cause adverse impacts to the overall stability of the beach system, as loss of the nearshore bar would lead to higher wave heights at the shoreline and the placement along the upper beach face would be short-lived since the profile would not be in equilibrium. Overall, this type of manipulation would not provide meaningful shore protection, even for a single winter storm event, and would lead to more rapid long-term erosion of the beach along Plum Island.

From the early 1980's through the early 2000's, USACE deposited dredge spoils in a nearshore placement site along the bypass bar. At the time, it was believed that this sediment would migrate onshore and provide protection. During this time, USACE placed just under one million cubic yards of sediment at this nearshore location. This placement had a tremendous role in shaping the coastal processes in the region as it amplified the impact of the bypass bar on wave refraction, and therefore transport along the shoreline behind it. However, there is no definitive evidence that the sediment placed along the offshore edge of the bypass bar supplied sand onshore. Effectively, this nearshore placement strategy actually removed that material from the littoral system. Instead, that sediment has likely migrated south along the offshore side of the bypass bar. Based on information from other nearshore placement sites (e.g. Canaveral and Jupiter Island in Florida), little evidence exists that this strategy is directly beneficial to the stability of adjacent shorelines. Contrary to some of these aforementioned theories, dredged material placed directly on the beach as nourishment is the only proven management strategy that benefits downdrift shorelines impacted by armored tidal inlets.

The transport further offshore along the bypass bar acts independently from nearshore seasonal cross-shore transport. As described above, there is an exchange of sediment between the summer berm (onshore) and the winter bar (offshore). Smaller, shorter period waves that are typical in the summer generate a net landward force that pushes sand up on to the beach in the form of a berm. During the winter, longer period storm waves generate a net seaward force that deposits sediment in an offshore bar location, in this case, a few hundred feet offshore (Figure 2.3). This cross-shore exchange of sediment is unique from bypass bar processes that are ongoing, as a result of both nearshore placement and the natural ebb tidal delta formation south of the inlet. This feature is generally further offshore of the seasonal bar system, as shown schematically in Figure 2.3.

Applied Coastal also employed existing literature of sediment transport pathways, in addition to modeled flow patterns in the project area (further discussed in Section 4.3) to determine where sediment is likely moving on a larger scale. While there are some north and south components of transport throughout the year, the general net transport in this region is south directed (Figure 2.4). However, because of the presence of the bypass bar, there is some redirection of flow patterns that alter transport patterns to the north. Sediment also moves both into and out of the inlet, as the material transfers between the ebb shoal and inlet throat. Finally, sediment moves to the south along the bypass bar, until it reaches the break where it is either redirected offshore by currents, or sent south towards Parker River National Wildlife Refuge. Modeling of sediment transport and quantification of alongshore transport are further discussed in Section 4.2.

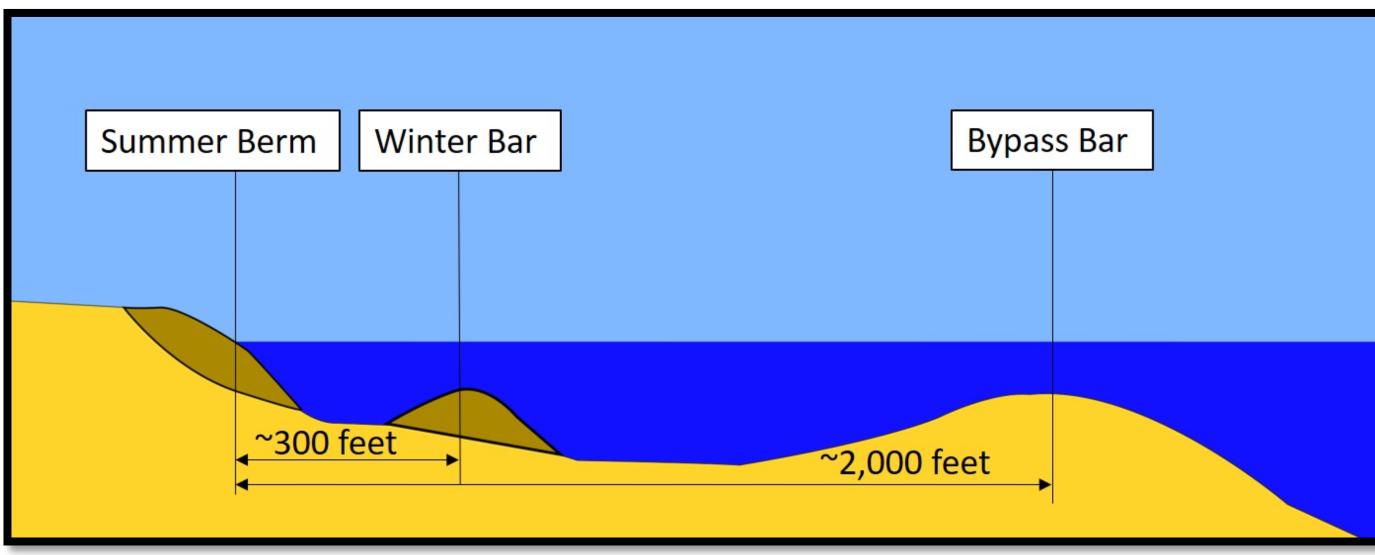

Figure 2.3 Approximate relative locations of the summer berm, winter bar, and bypass bar at the northern end of Plum Island. The bypass bar varies in distance from the shoreline, and sits just 800-900 feet offshore at the southern end. Note the position and size of the features are not to scale.