MANAGEMENT PLAN FOR

THE DELAWARE BAY BEACHES

FINAL REPORT • MARCH 2010

PREPARED FOR:

DELAWARE DEPARTMENT OF NATURAL RESOURCES AND ENVIRONMENTAL CONTROL
DIVISION OF SOIL AND WATER CONSERVATION
SHORELINE AND WATERWAY MANAGEMENT SECTION
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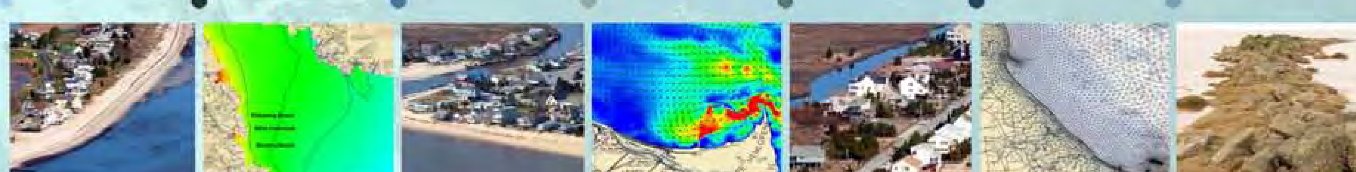

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03144-BD-10

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FOR

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Delaware Department of Natural Resources and Environmental Control
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89 Kings Highway
Dover, Delaware 19901

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1. Executive Summary

The beaches along the western shore of Delaware Bay have long experienced varying levels of shoreline erosion due to intermittent storm events and the resultant wind, wave, and water level forces acting on the beach system. In the past, beach nourishment projects and shoreline protection structures were implemented on an as-needed basis. The State of Delaware determined there is a need to develop a long-term beach management plan and associated cost analysis. The goal of the plan is a cost-effective strategy for the future management of the Bay beaches

PBS&J was tasked by DNREC's Shoreline and Waterway Management Section to develop a ten-year beach management plan for the communities of Pickering Beach, Kitts Hummock, Bowers Beach, South Bowers Beach, Slaughter Beach, Primehook Beach and Broadkill Beach (see Figure 1.1). The study incorporates existing literature and data, previous historical analyses, coastal processes modeling, conceptual beach nourishment designs, and cost estimates and schedules.

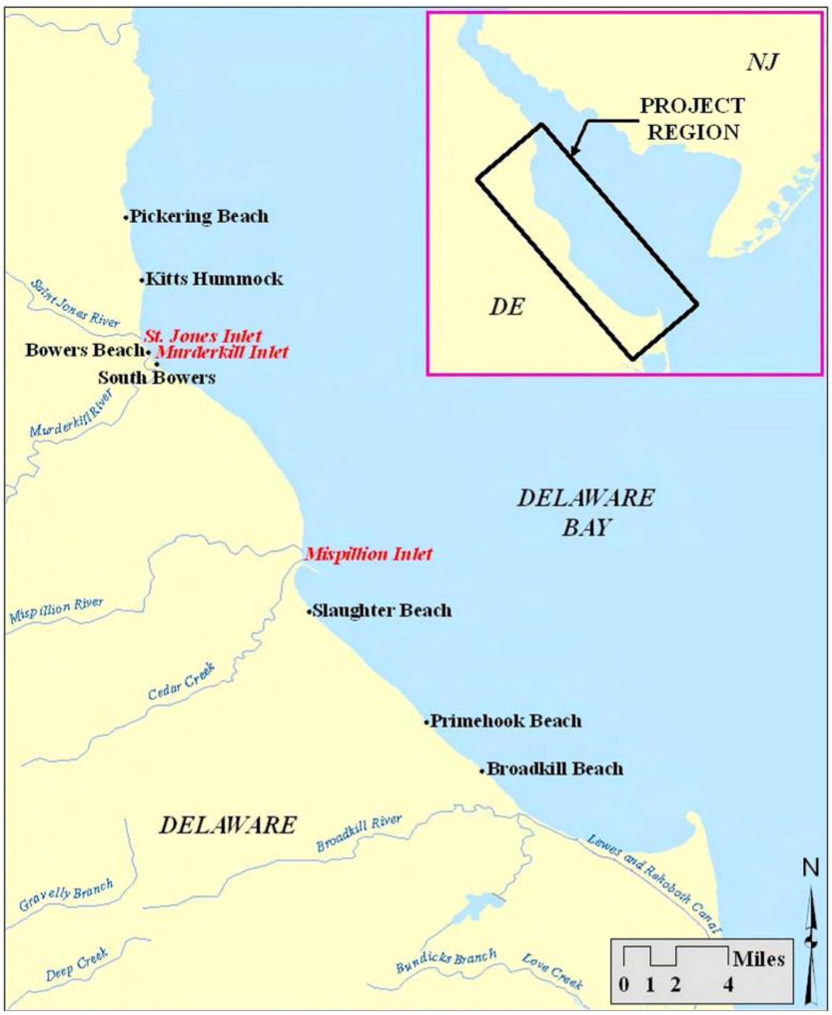


Figure 1.1 Overall map of the Delaware Bay communities.

Delaware Bay Beach System

The beach communities are located along the western shore of Delaware Bay. The orientation of the shoreline generally faces the northeast, but with divergences along the reaches. The shoreline is punctuated by several tidal inlets, some with jetties that influence the short and long-term sediment transport processes. The continued shoreline retreat of the barrier beaches fronting the wetland systems, such as in the vicinity of Fowler Beach, has added stress to the adjacent shorelines. The approximate lineal length* of the communities is:

Pickering Beach	0.6 miles
Kitts Hummock	1.1 miles
Bowers Beach	0.7 miles
South Bowers	0.7 miles
Slaughter Beach	2.8 miles
Primehook Beach	1.5 miles
Broadkill Beach	4.7 miles
Total approximate length	12.1 miles
Total approximate reach length	30.2 miles

*Length estimates were measured and estimated from existing published maps of the areas.

The influences of ocean waves, bay currents and seasonal wind/wave events have an effect on the direction and volume of transport of beach material and shape of the beaches. In general, the lower – southeastern portion – of the Delaware Bay coast can be influenced by the incoming ocean waves that are altered by local water depths, but the area is also influenced by the seasonal wind/wave patterns. The areas external to the direct influence of ocean waves respond seasonally to the local wind/fetch-wave and water level conditions.

The daily influences of "normal" waves and fluctuations of water levels provide the background for the shape of the beach and the on-going movements of sand in the beach system. These movements of the beach sand include shore parallel transport in each direction, onshore and offshore transport and on occasions wind transport of the sand. The "abnormal" waves and water levels are associated with storms. In particular, storm surge can override a low tide and significantly raise the actual water level above the predicted high tide. This elevated water level can allow the storm waves to significantly erode the beach, and during certain storm events, overtop the beach and dune and flood properties. This overtopping of the beach and dune can overwash the beach and dune sand landward onto lots and streets and into the adjacent wetland systems.

The impact of manmade structures, primarily for maintenance of navigation, has influenced the shape and orientation of the Delaware Bay coastal shoreline. In particular, the Murderkill River inlet and the Mispillion River inlet jetties have influenced the alignments and locations of their respective inlet drainages. In addition, the jetties have also influenced the adjacent beaches and the sand transport processes in and around the inlets. Other structures, such as the shore-parallel experimental breakwaters at Kitts Hummock, have not had an overtly noticeable effect on the beach shape. In other communities, as a result of changes in the beach, groins were constructed perpendicular to the shoreline. Their effect on the beach is localized.

The natural resources attendant to these beach communities is very diverse. They include significant numbers of resident shore birds, major migratory bird populations that use the nearby wetlands and beaches, beach-spawning horseshoe crabs and a host of native crabs, fish, micro- and macro-invertebrates and a diversity of vegetative species, both wetlands and upland. Many of the communities are backed by significant inland wetland systems. Satellite and aerial photographic images reveal that the typical Delaware Bay coastline consists of a relatively narrow band of beach fronting wetlands. The beach communities occupy this narrow strand of sand between the Bay and the wetland and upland ecosystems landward of the beach.

Delaware Bay 10 Year Strategic Beach Management Plan – Synopsis of Plan Elements

The proposed management plan addresses the impacts of beach erosion caused by wave attack and storm surge. The plan provides recommendations to protect and enhance the beach and dune system in each of the communities included in the study. These recommendations are intended for planning purposes at this stage. The specific site conditions at each community will be investigated during the design and permitting phases and will result in a more detailed design. In addition, the plan is not intended to address flooding issues resulting from inland drainage conveyance or storage concerns.

Beach Management Plan Conceptual Designs

The design of a beach nourishment project is based on the geometry of the shoreline and localized historical erosion rates (historic erosion losses) in conjunction with the amount of protection desired from a return period storm event (storm protection). Various beach fill design alternatives were considered within the development of this plan. It should be noted that these conceptual designs are for purposes of estimating costs and are not intended for construction. Three levels of protection were evaluated to provide a range of projects to be considered from an economic, environmental and local sponsor perspective. The three project beach fill designs for each community include:

1. Strategic Fill Placement – The Strategic Placement scenario consists of concentrating the placement of fill along the specific locations of greatest need in each community. This alternative is largely based on the previous shore protection activities conducted by DNREC, and is the minimum level of protection that would be recommended.
2. 5 Year Level of Protection - The 5 Year Scenario is based on restoring 5 years of estimated shoreline losses and providing protection from a storm event with a 5-year return period.

3. 10 Year Level of Protection - The 10 Year Scenario is based on restoring 10 years of estimated shoreline losses and providing protection from a storm event with a 10-year return period.

These three beach fill conceptual designs include a template to provide a long term 10 year level of protection, a template to provide a 5 year level of protection, and a template to provide strategic protection through placement in areas of greatest need. Cost estimates for each project scenario were developed based on the most recent and accurate pricing possible. In addition, improvements and changes to existing shore protection structures were considered at each community and presented in the full report.

Data and Analyses

Historical data was gathered from a variety of sources, including DNREC staff and files, University of Delaware researchers, and U.S. Army Corps of Engineers staff and files. This information serves as a backdrop for the plan, and yields vital details concerning previous management activities, long-term environmental conditions and forces acting on the beach system and other relevant items. The development of the beach management plan included a review of previous historical analyses related to wave conditions and sediment transport. Three new numerical coastal process models encompassing bay circulation, wave propagation, and beach morphology provided a conceptual understanding of sediment transport trends in the areas of concern. The historical analyses and modeling results, combined with local insight and experience, provided the basis for the development of the beach management plan concepts.

Beach Nourishment

The primary shore protection recommendation presented in the management plan is beach fill placement or beach nourishment tailored to the needs of each community. The primary function of a beach nourishment project is to restore a natural resource and provide protection to upland infrastructure and resources from erosion caused by wave action and storm surge. Figure 1.2 shows how storms can impact the shoreline and cause damage to upland infrastructure. During higher water levels and increased wave heights, the beach berm, which acts as a protective buffer, is eroded. However, note the accretion in the nearshore zone also caused by the storm or high energy event. The “beach” includes the nearshore features (bars and shoals), the beach berm and the dune complex. Each of these three beach components are addressed in the conceptual designs individually developed for each of the beach communities.

Beach nourishment involves placing sand along the shoreline and extending the width of the beach and in some cases raising the initial height, thereby increasing the buffer of protection. The amount of protection provided by a nourishment project is not an absolute measure, due to the uncertainties in the frequency of storm events that may be encountered over the project lifespan. Scheduled maintenance (renourishment) is needed to maintain the desired level of protection. Typical features found in beach nourishment projects include a berm and dune (Figure 1.2). Figure 1.3 illustrates a general example of the pre-project condition, post-construction profile (cross-section), and the intended equilibrated project design configuration. The berm is the primary feature of a beach nourishment project, and provides additional beach width to dissipate wave energy. A dune is typically included in the design of a beach nourishment project and includes less sand volume than the berm. However, it provides additional height to the beach to help prevent storm surge overtopping.

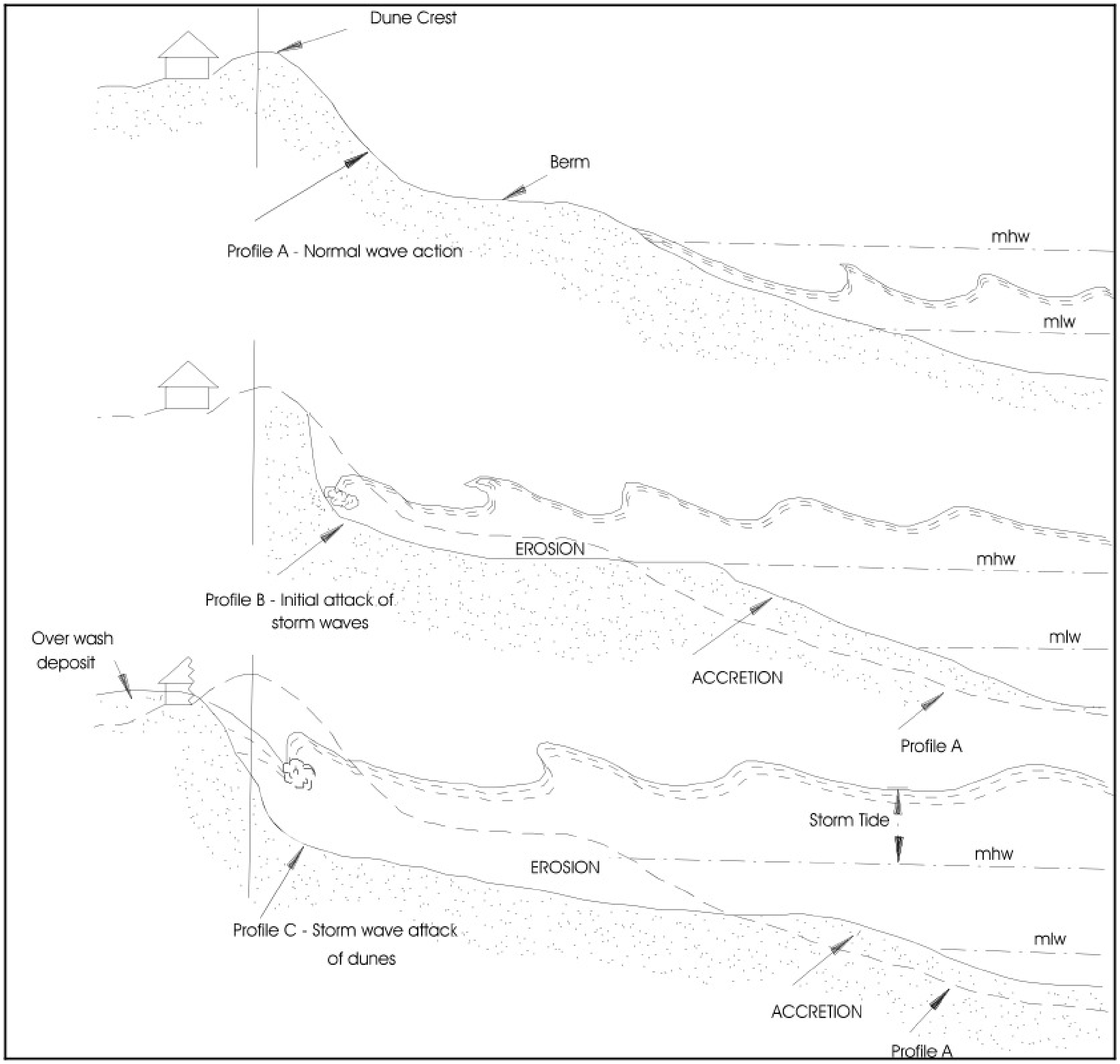


Figure 1.2 Example of storm impacts to shoreline and upland areas (CEM Figure V-4-1).

Dune vegetation occurs naturally along the Delaware Bay coastline, and provides additional protection against the effects of wind and waves. When dunes are artificially constructed, planting dune grasses can help anchor the placed sand, as well as potentially accumulate windblown sand. Cape American beach grass is a pioneer species in dune formation, due to its extensive root and rhizome system. It should be planted along the top and down the face of the constructed dunes to increase the stability of the dune and assist the dune in providing additional protection to upland structures.

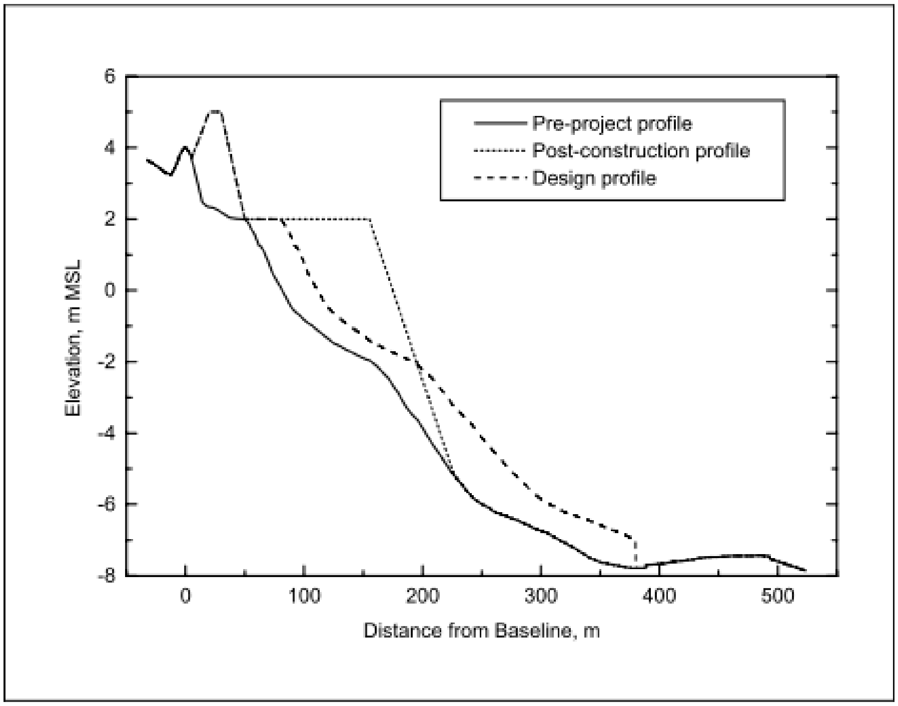


Figure 1.3 Conceptual example of pre-project, post-construction, and design beach profiles (CEM Figure V-4-2).

Beach Management Implementation Framework

The proposed management plan is considered the first step in a multi phase process to implement the plan. Following the approval and adoption of the plan and establishing a long-term funding source the projected schedule of work includes the following activities:

- Geotechnical investigations. Limited data are available on the exact locations and extents of sand sources that could be used for nourishment projects. In order to prepare permit applications, design documents, and bid documents, a more detailed geotechnical study will be required to locate and characterize the sources of sand that will be used for each community. This work should be performed as one study that will cover the needs of all seven communities. The cost of performing this work has been included in the attached tables and has been prorated over each community based on the relative amount of sand that community needs. These investigations are expected to take approximately 1 year to complete.

- Final design and permitting. Once the detailed geotechnical study is completed and specific sources of sand have been identified, final design and permitting work can proceed. The design of each project will depend on the nature of the sand source.

The cost of performing this work has been included in the attached tables and has been prorated over each community based on the relative amount of sand that community needs. Design and permitting work are expected to take about 1½ to 2 years to complete.

- Sand placement. We have assumed that all work will be performed in two main groups; a north region that will include Pickering Beach, Kitts Hummock, Bowers Beach, and South Bowers Beach, and a south region that will include Slaughter Beach, Primehook Beach and Broadkill Beach. This grouping can help minimize the large mobilization/demobilization costs associated with this type of project. The inclusion of adjacent communities can also help make these projects suitable and attractive to local, relatively small commercial dredging firms. The goal is to obtain reasonable, competitive prices. Sand placement was estimated to take 1 year to complete for each region.

In addition to the above items, the proposed long term beach management plan includes the following post construction activities:

- Environmental permit monitoring. Once initial construction has been completed, it is likely that the permit terms for each project will require some type of follow up monitoring of project impacts and/or various performance measures. An allowance for these costs has been included for the three years following the initial completion of each project.

- Beach surveys. To assist with design and permitting leading up to initial construction and to properly assess the performance of each project, annual beach surveys should be performed in each community. An allowance for these costs has been included for each project.

- Periodic maintenance or follow up nourishments. Each project will require maintenance. Projected maintenance costs for each option have been included based on the assumption that 60% of the volume of sand initially placed will need to be restored at the end of the "design life" of the alternative. The frequency and level of maintenance will depend on how often storms impact the area, how severe the storms are, and the relative size of the initial beach nourishment project (e.g., the 10 year scenario should require less maintenance than the 5 year and strategic beach fill placement scenarios under the same storm conditions).

Cost Projections

Cost projections and a schedule were developed for each community. Long range planning provides opportunities for employing regional approaches to beach management and encourages coordination among communities to lower costs and provide long term solutions to beach erosion. For the purposes of this management plan, the long range planning timeframe used was 10 years. The long range cost projections for the three project scenarios are provided for each community.

Combining as many projects as practical is an effective means for minimizing these costs. For the purposes of this plan, it was assumed that work would be grouped into two regions and performed under two contracts. The north region includes the communities of Pickering Beach, Kitts Hummock, Bowers Beach and South Bowers Beach. The south region includes Slaughter Beach, Primehook Beach and Broadkill Beach. If work is to be performed as individual contracts, costs would need to be increased to reflect mobilization and demobilization costs for each project.

Construction cost estimates were developed based on discussions with contractors, available cost information from other relevant projects in this region and the project team's experience with similar relatively small beach restoration projects.

Costs for design, permitting, geotechnical investigation, post-project performance, and physical/biological monitoring are presented in tabular form for each community within the main body of the plan. Construction costs are estimated for each of the three project scenarios and include mobilization and demobilization, sand placement, and dune plantings.

1. <u>Mobilization/demobilization costs</u>. One of the largest costs associated with beach nourishment projects is the cost of mobilizing and demobilizing a dredge to pump sand from an offshore source onto the beach. These costs typically range from $450,000 per project for a relatively small dredge (e.g., 14 in hydraulic dredge with a draft of 4 ft) to over $1 million for larger dredges suitable for work in deeper water.

   For these projects, mobilization/demobilization costs were estimated to be $750,000 for the north region and $650,000 for the south region. This is based on an initial mobilization/demobilization cost of $450,000 plus $100,000 to move to each additional community. The mobilization and demobilization costs assume the pumping distance is 1 to 2 mi and that no special problems or restrictions exist for dredging. The cost for intermediate work at each beach such as laying and removing pipe are also included in mobilization. The mobilization and demobilization cost is spread out evenly among the four northern communities and the three southern communities.

2. <u>Sand placement costs</u>. A unit cost of $7/cy reflects relative estimates for excavation, delivery distances, and the estimated placement quantities for sand. The unit volume for the berm represents the area of the template with a full width berm. A unit volume equal to half of the full berm is used in estimating volume in the taper.

3. <u>Dune plant costs</u>. A unit cost of $1.09/planting unit reflects relative estimates for plants and the labor to install them. The basic planting scheme used for each community assumes 11 or 12 rows of plants planted on 18 in centers with one planting unit in each hole. One planting unit equals two plants.

Funding

The various strategies listed do not include a funding source for the initial projects undertaken under this long term beach management plan. The development of a long term funding program and commitment will be essential to meet the goals set forth in the long term beach management plan. There is also no funding mechanism for the emergency placement of sand if one or more major storms strike the area above the level of protection criteria discussed. These types of events generally cause damage along an entire coastline. The Federal Emergency Management Agency (FEMA) recognizes engineered and maintained beaches as public infrastructure which may be eligible for public recovery funds provided that sufficient damage occurs to warrant a federal disaster declaration. This type of funding could help with recovery from a major storm event. Regardless, if the state is attempting to achieve and maintain a uniform level of protection, there may be a need to set aside additional funding to deal with emergencies.

Delaware Bay Beach Community Management Plans

The following sections outline the proposed alternative actions for long term management of each of the Delaware Bay Beach Communities. Table 1.1, at the end of this section, details the estimated costs for each community and each conceptual design.

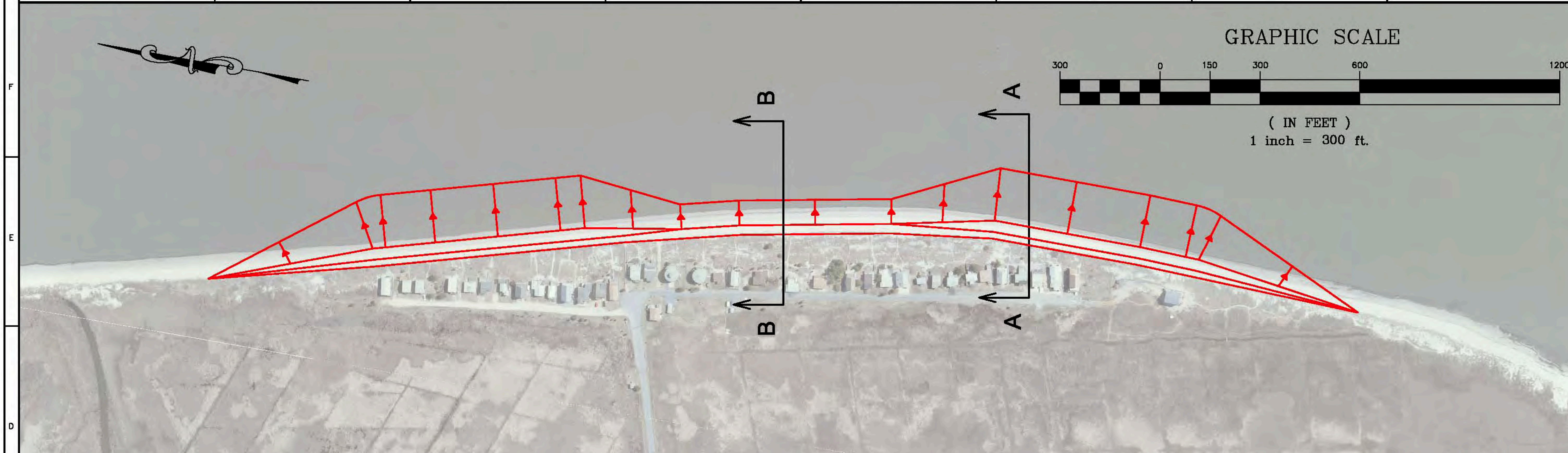
Pickering Beach

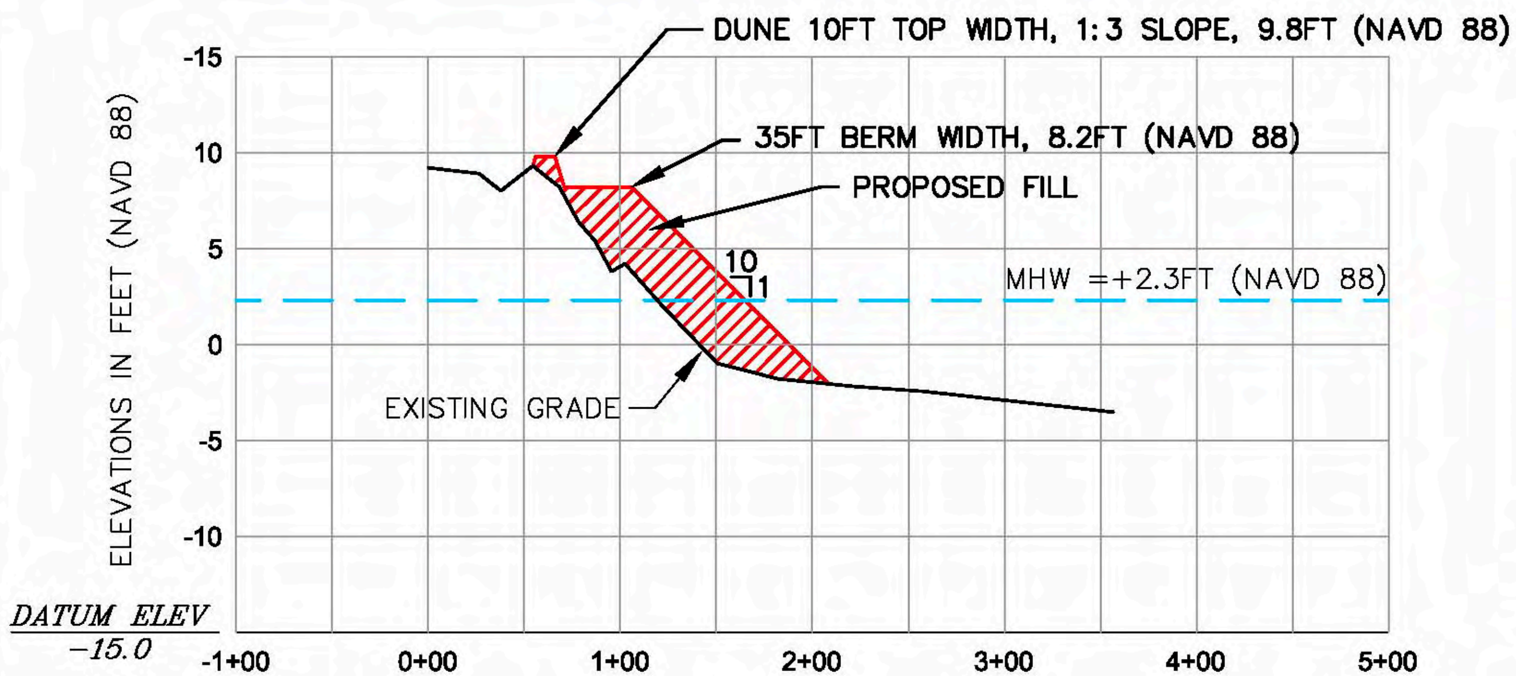
Pickering Beach, measuring about 3,500 ft in length, is located approximately 29 mi from the mouth of the Delaware Bay. It occupies a narrow barrier of sand bordered by Delaware Bay and a back barrier marsh. Observation of past beach fill behavior suggests that the dominant transport direction is northward in the north half of the community and southward in the southern half, with the central curve in the shoreline acting as a nodal point. Beach nourishment and the installation of shore protection structures have been conducted at Pickering Beach since 1962. A total of 255,750 cy of beach material have been placed to date. A portion of the floating tire breakwater installed by the Corps as part of the Section 54 Demonstration program in 1978 still exists, but resides on the bottom. Unless aesthetic reasons dictate action, removal of the remnants of the tire breakwater is not recommended as part of the overall shore protection strategy.

The Strategic Placement scenario (Figure 1.4) consists of two beach fill segments, northern and southern, with a dune feature along each section. The total project spans 3,500 ft of shoreline, with a maximum berm width of 35 ft at an elevation of +8.2 ft NAVD88. This requires an initial fill volume of 37,100 cy of material, with a maintenance placement of 22,260 cy every four years thereafter. The slope of the dune should be planted with 21,500 units of beach grass. The initial placement will cost an estimated $470,635, while the total ten year plan costs approximately $1,120,102.

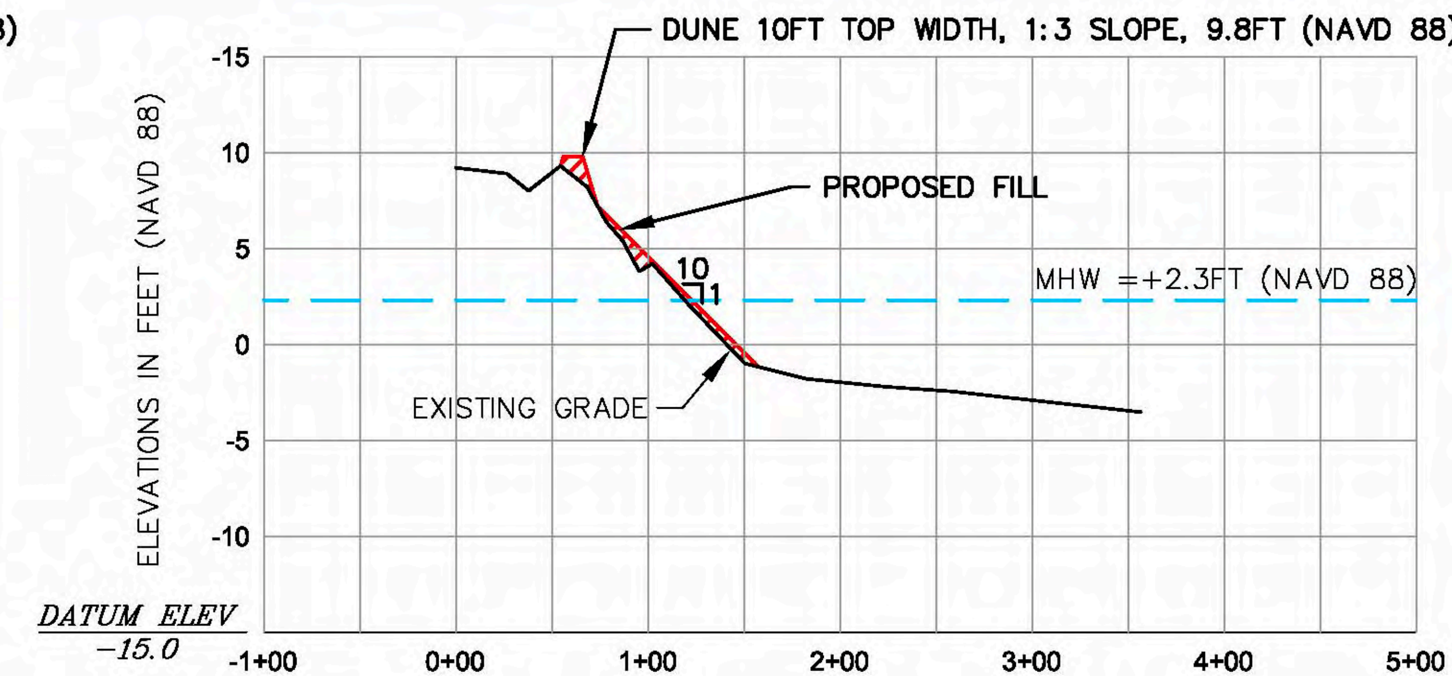
The 5 Year Scenario project (Figure 1.5) consists of a uniform dune and berm, spanning 3,500 ft of shoreline, with a maximum berm width of 35 ft at an elevation of +8.2 ft NAVD88. This requires an initial fill volume of 51,500 cy of material, with a maintenance placement of 30,900 cy every five years thereafter. The slope of the dune should be planted with 21,500 units of beach grass. The initial placement will cost an estimated $571,435, while the total ten year plan costs approximately $1,246,382.

The 10 Year Scenario project (Figure 1.6) consists of a uniform dune and berm, spanning 3,500 ft of shoreline, with a maximum berm width of 115 ft at an elevation of +8.2 ft NAVD88. This requires an initial fill volume of 138,500 cy of material, with a maintenance placement of 83,100 cy every ten years thereafter. The slope of the dune should be planted with 21,500 units of beach grass. The initial placement will cost an estimated $1,180,435, while the total ten year plan costs approximately $1,416,582.





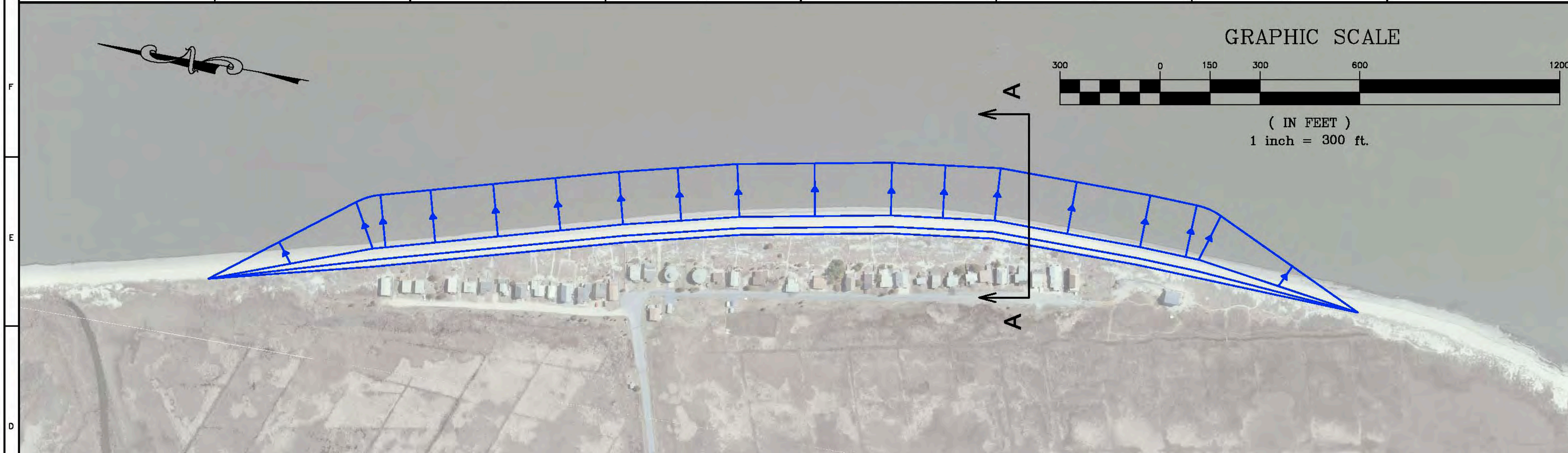
TYPICAL CROSS SECTION A-A

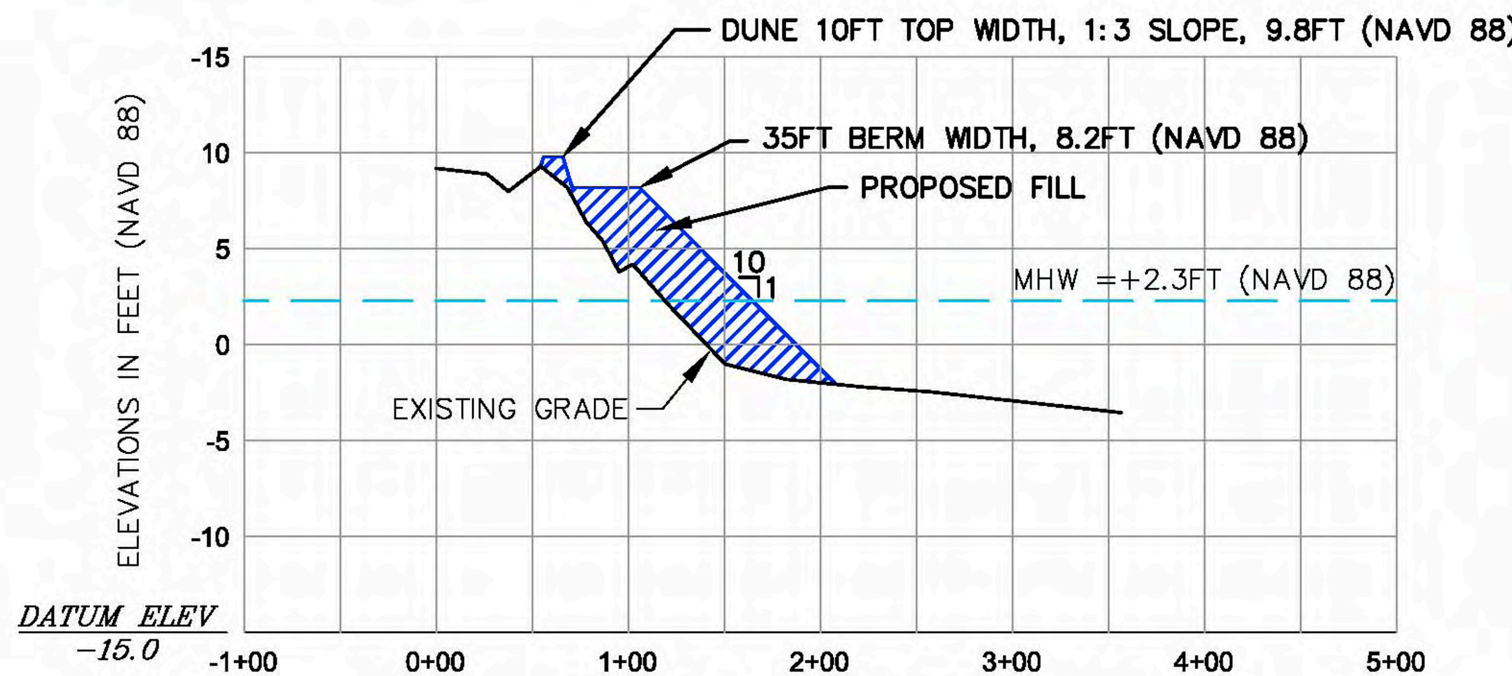


TYPICAL CROSS SECTION B-B

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: **DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL**	PROJECT: **PICKERING BEACH**	TASK: **STRATEGIC FILL PLACEMENT**	**FIGURE 1.4**

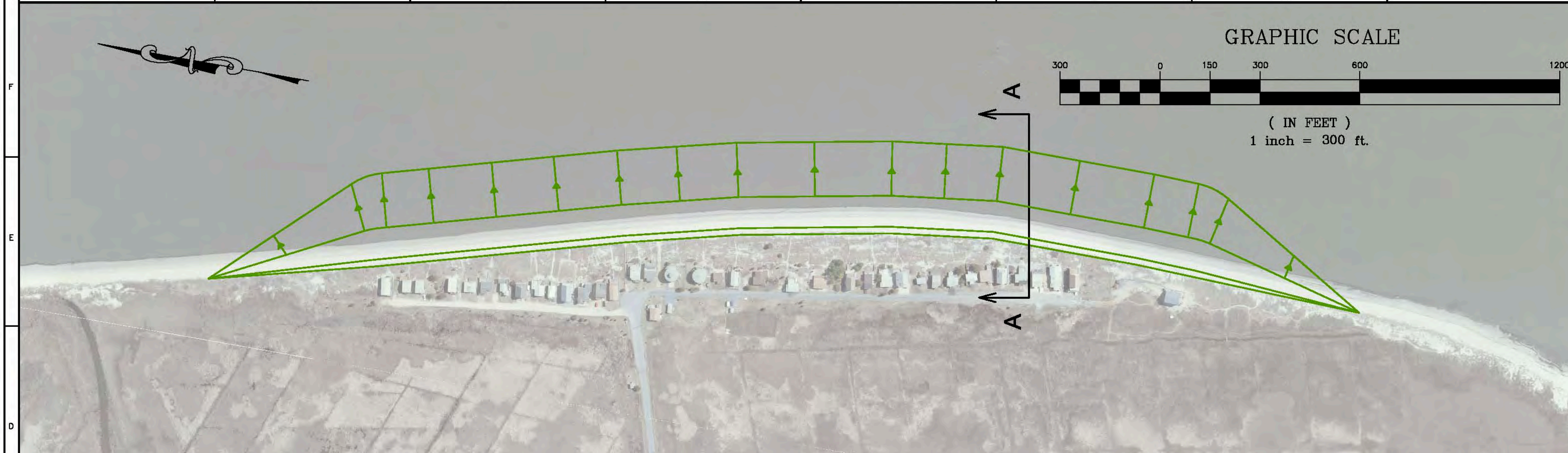


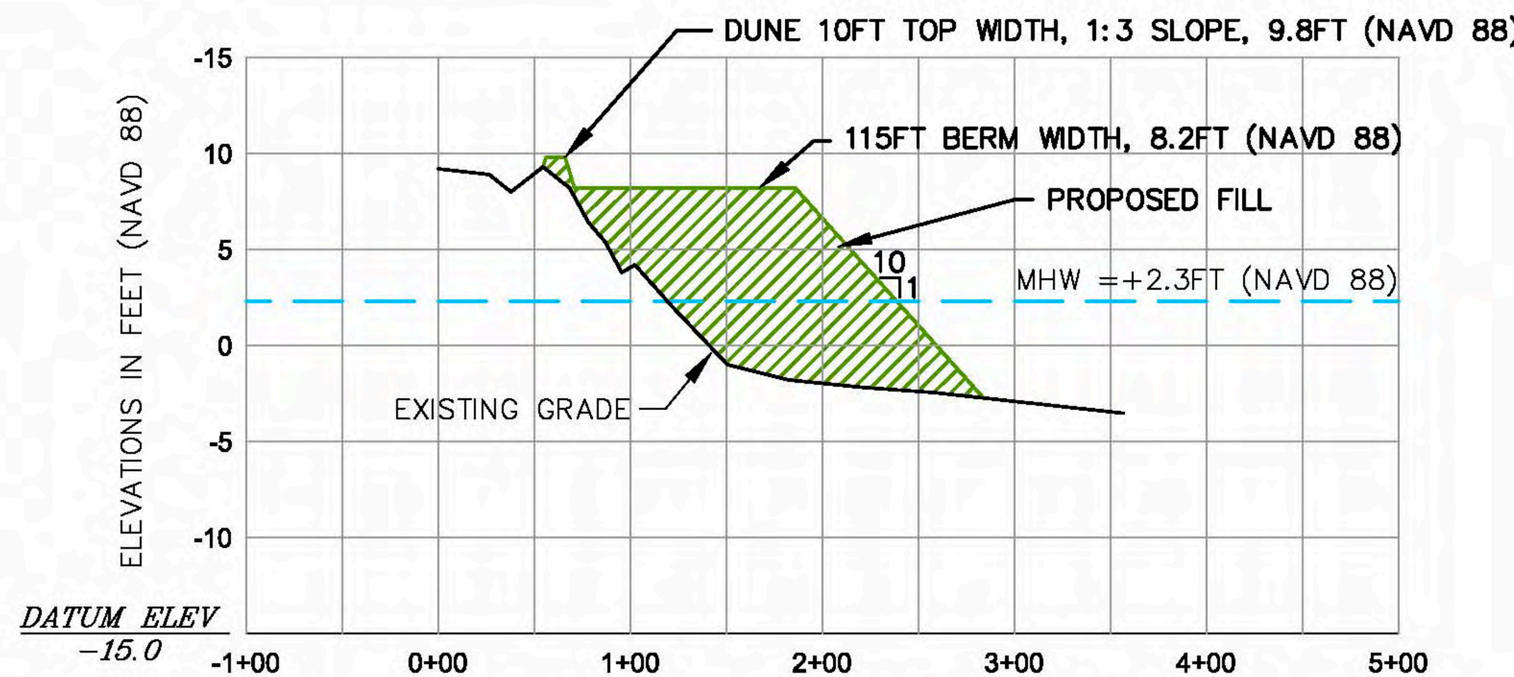


TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: PICKERING BEACH	TASK: 5 YEAR SCENARIO	FIGURE 1.5





TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ

CLIENT:
DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL

PROJECT:
PICKERING BEACH

TASK:
10 YEAR SCENARIO

FIGURE 1.6

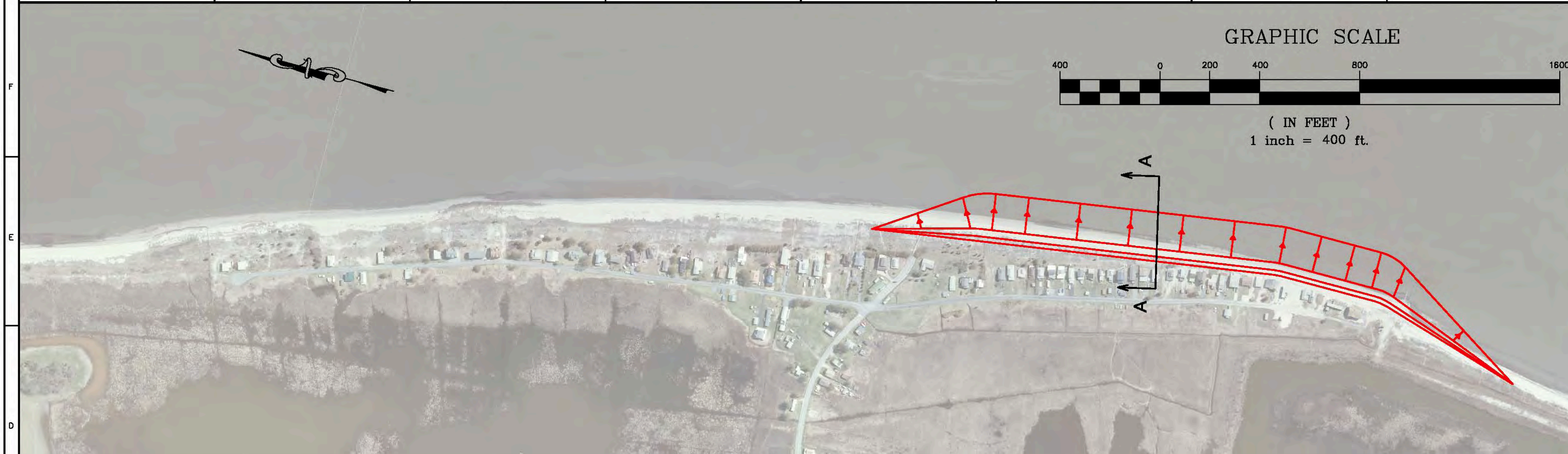
Kitts Hummock

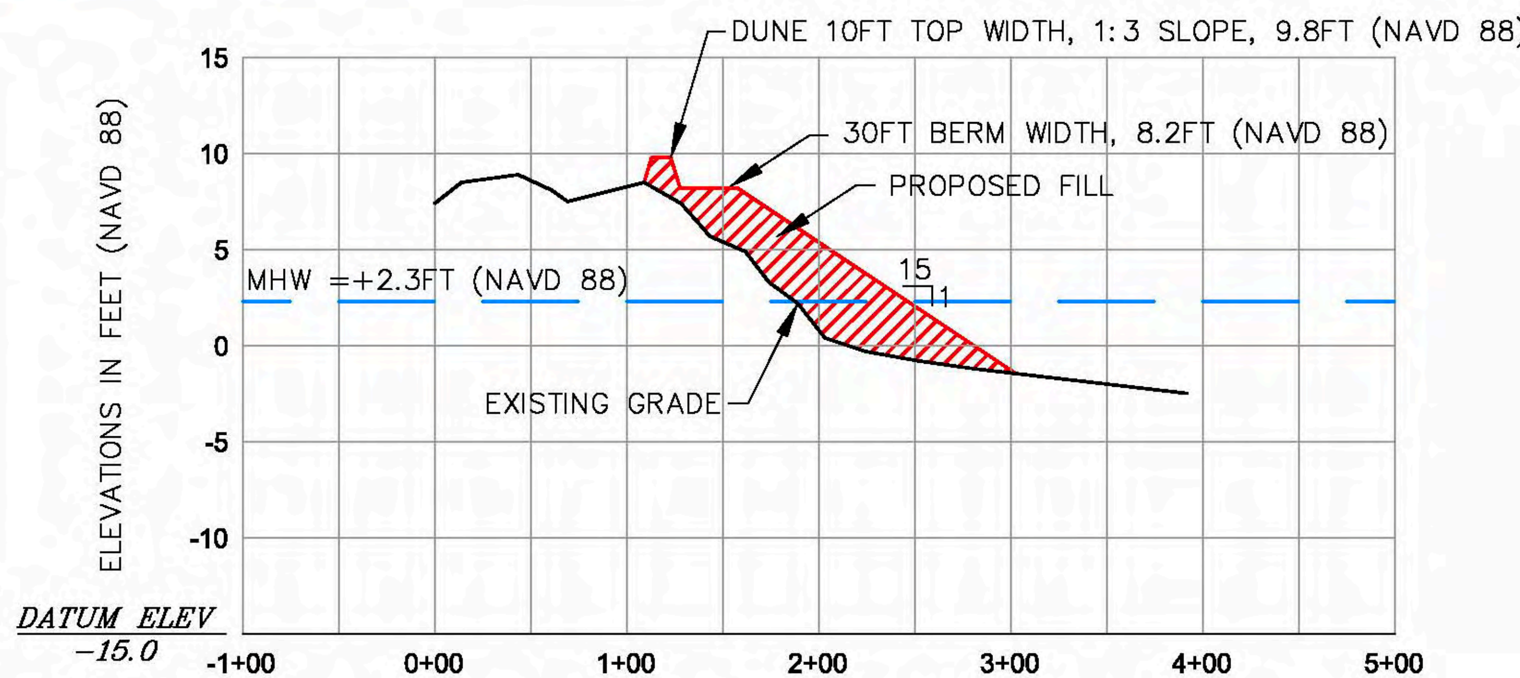
Kitts Hummock, measuring about 6,000 ft in length, is located approximately 27 mi from the mouth of the Delaware Bay, and is bordered to the west by a 1,600 ft wide tidal marsh. Observation of past beach fill behavior suggests that the dominant sediment transport direction is northerly. There is a component of southerly transport at the southern end of Kitts Hummock as noted at the terminal groin/drainage structure. The groin is retaining sand with an erosional offset of the shoreline on the south side of the structure. Beach nourishment events and the installation of shore protection structures have occurred at Kitts Hummock since 1961. A total of 310,130 cy of material has been placed to date. Three breakwaters were constructed by the Corps in 1978, approximately 700 ft offshore. Each breakwater was constructed using a different material: nylon sandbags, concrete boxes, and rip rap stone. Currently, the concrete box and riprap mound structures remain offshore. Removal or modification of the structures is not recommended.

The Strategic Placement scenario (Figure 1.7) consists of a beach fill and dune feature along the southern 3,700 ft of the community, with a berm width of 30 ft at an elevation of +8.2 ft NAVD88. This requires an initial fill volume of 42,300 cy of material, with a maintenance placement of 25,380 cy every four years thereafter. The slope of the dune should be planted with 39,000 units of beach grass. The initial placement will cost an estimated $503,765, and the total ten year plan costs approximately $1,121,796.

The 5 Year Scenario project (Figure 1.8) consists of a uniform dune and berm, spanning 5,800 ft of shoreline, with a maximum berm width of 30 ft at an elevation of +8.2 ft NAVD88. This requires an initial fill volume of 101,200 cy of material, with a maintenance placement of 60,720 cy every five years thereafter. The slope of the dune should be planted with 21,500 units of beach grass. The initial placement will cost an estimated $988,410. The total ten year plan costs approximately $1,956,321..

The 10 Year Scenario project (Figure 1.9) consists of a uniform dune and berm, spanning 5,800 ft of shoreline, with a maximum berm width of 75 ft at an elevation of +8.2 ft NAVD88. This requires an initial fill volume of 196,600 cy of material, with a maintenance placement of 117,960 cy every ten years thereafter. The slope of the dune should be planted with 39,000 units of beach grass. The initial placement will cost an estimated $1,656,210. The total ten year plan costs approximately $1,976,581.

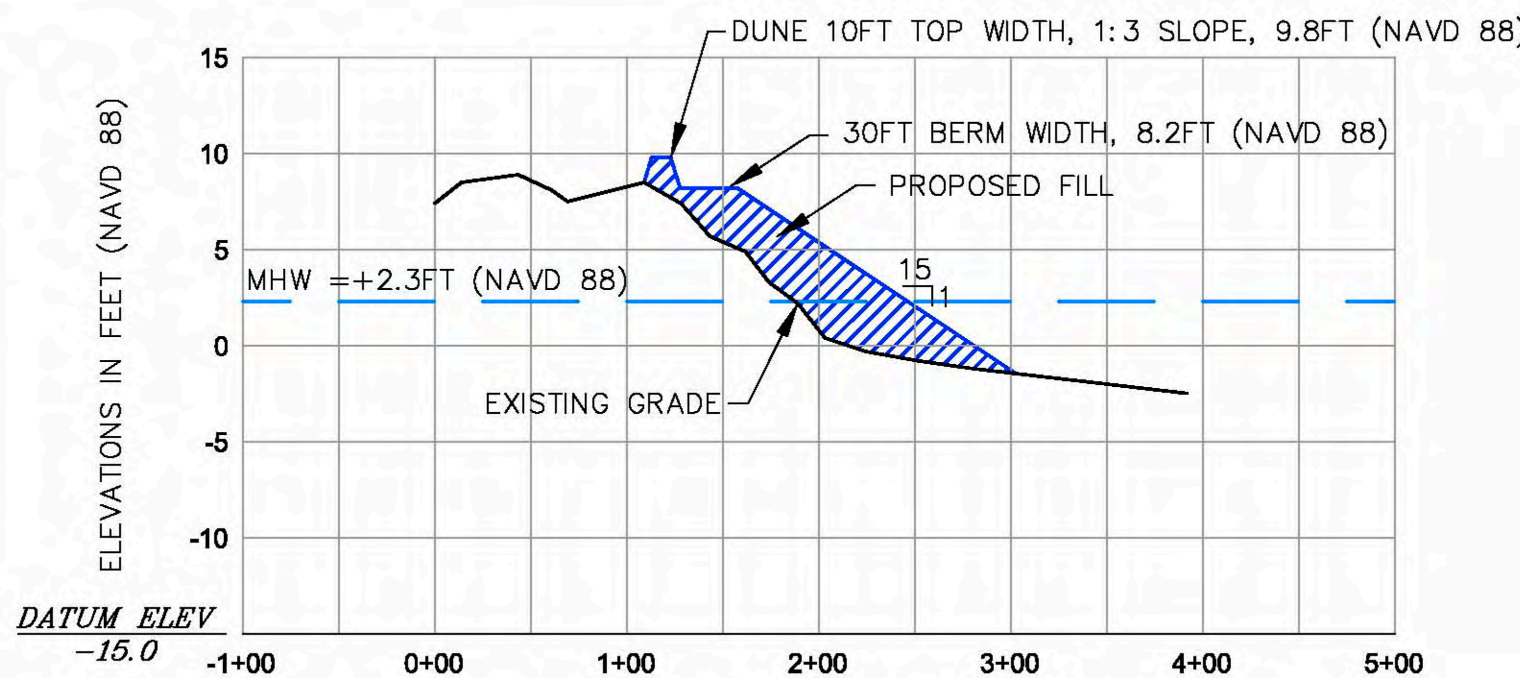




TYPICAL CROSS-SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: KITTS HUMMOCK	TASK: STRATEGIC FILL PLACEMENT	FIGURE 1.7



TYPICAL CROSS-SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

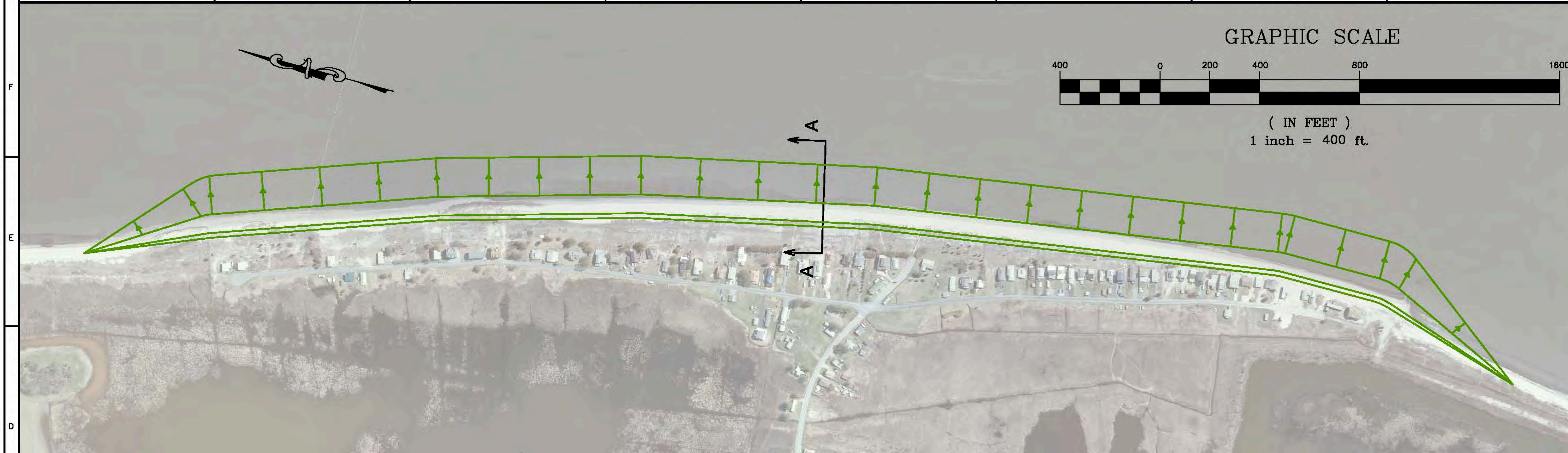
PBSJ

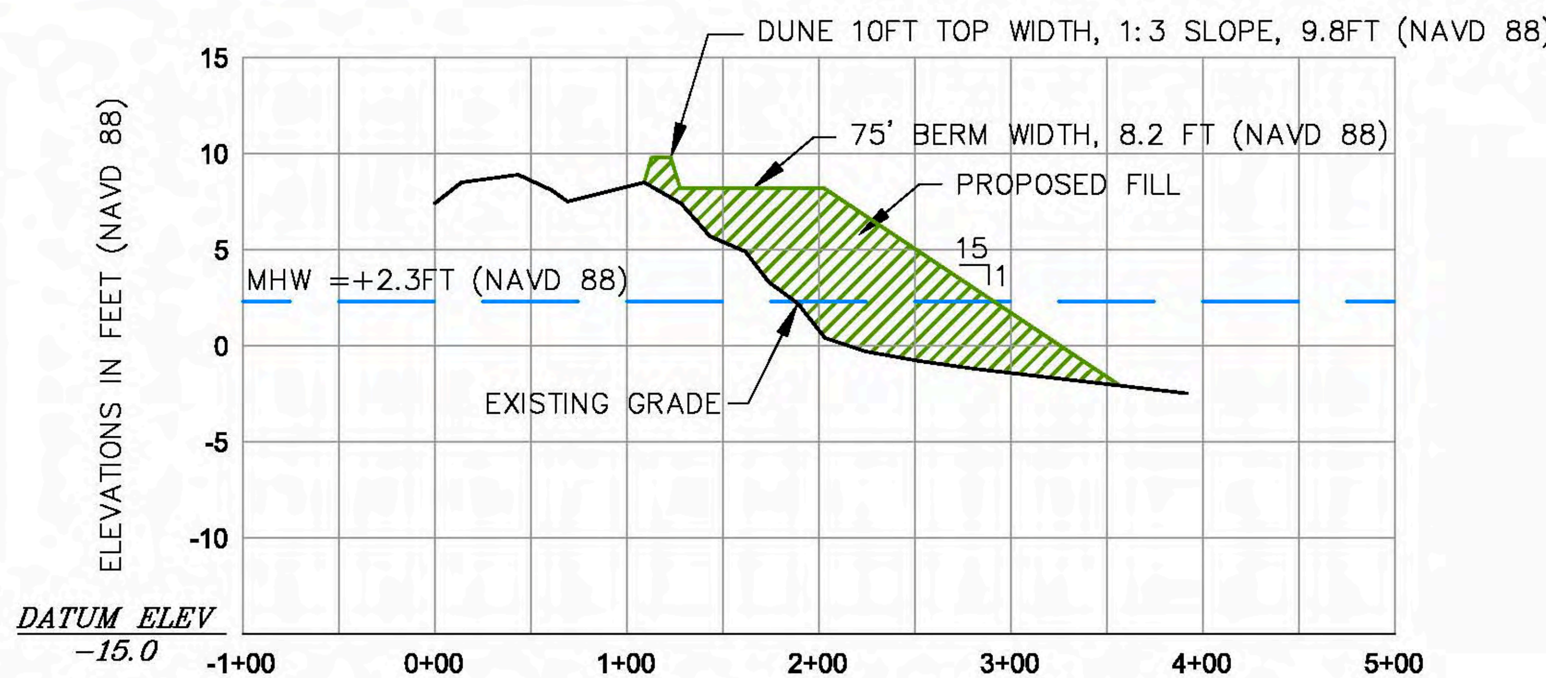
CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL

PROJECT: **KITTS HUMMOCK**

TASK: **5 YEAR SCENARIO**

FIGURE 1.8





VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

TYPICAL CROSS-SECTION A-A

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: KITTS HUMMOCK	TASK: 10 YEAR SCENARIO	FIGURE 1.9

Bowers Beach

Bowers Beach, measuring about 3,500 ft in length, is located approximately 24 mi from the mouth of the Delaware Bay, bordered by wetlands and is located between the St. Jones River Inlet (unstructured) and the Murderkill River Inlet (structured). Observation of past beach fill behavior suggests that the dominant transport direction is northward in the north half of the community and southward in the southern half. The first beach nourishment was conducted at Bowers Beach in 1962. A total of 294,065 cy of material has been placed to date. A terminal groin and jetty were constructed with large, concrete filled sandbags at the north and south ends of the community, respectively, in 1976. The northern groin is retaining sand with an erosional offset of the shoreline on the north side of the structure. In 2009, improvements were implemented to the south jetty that included lengthening and adding height. No modifications to the northern groin are recommended.

The Strategic Placement scenario (Figure 1.10) consists of a beach fill and dune feature along the southern 1,550 ft of the community, with a berm width of 20 ft at an elevation of +8.2 ft NAVD88. This requires an initial fill volume of 18,450 cy of material, with a maintenance placement of 11,070 cy every four years thereafter. The slope of the dune should be planted with 14,000 units of beach grass. The initial placement will cost an estimated $331,910. The total cost over ten years is approximately $756,859.

The 5 Year Scenario project (Figure 1.11) consists of a uniform dune and berm, spanning 3,200 ft of shoreline, with a maximum berm width of 20 ft at an elevation of +8.2 ft NAVD88. This requires an initial fill volume of 39,600 cy of material, with a maintenance placement of 23,760 cy every five years thereafter. The slope of the dune should be planted with 25,000 units of beach grass. The initial placement will cost an estimated $491,950. The total ten year plan costs approximately $1,002,299.

The 10 Year Scenario project (Figure 1.12) consists of a uniform dune and berm, spanning 3,200 ft of shoreline, with a maximum berm width of 60 ft at an elevation of +8.2 ft NAVD88. This requires an initial fill volume of 76,000 cy of material, with a maintenance placement of 45,600 cy every ten years thereafter. The slope of the dune should be planted with 25,000 units of beach grass. The initial placement will cost an estimated $746,750. The total ten year plan costs approximately $894,449.

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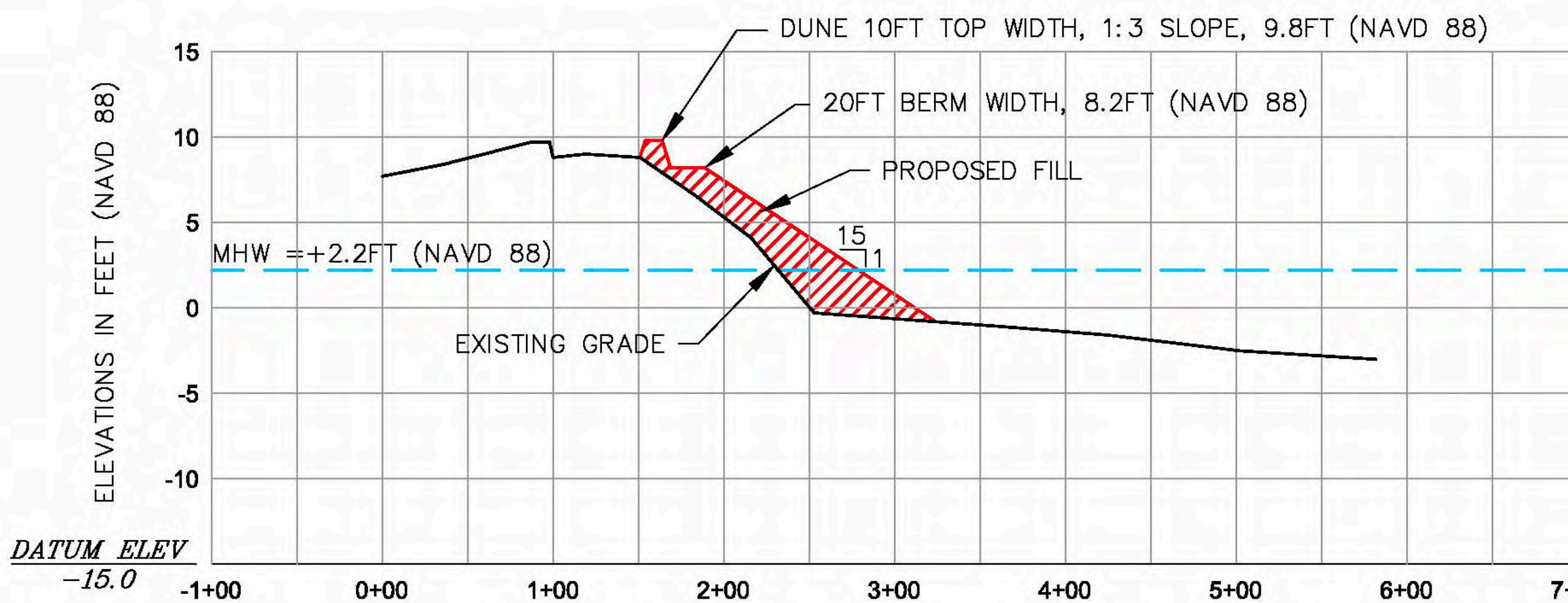
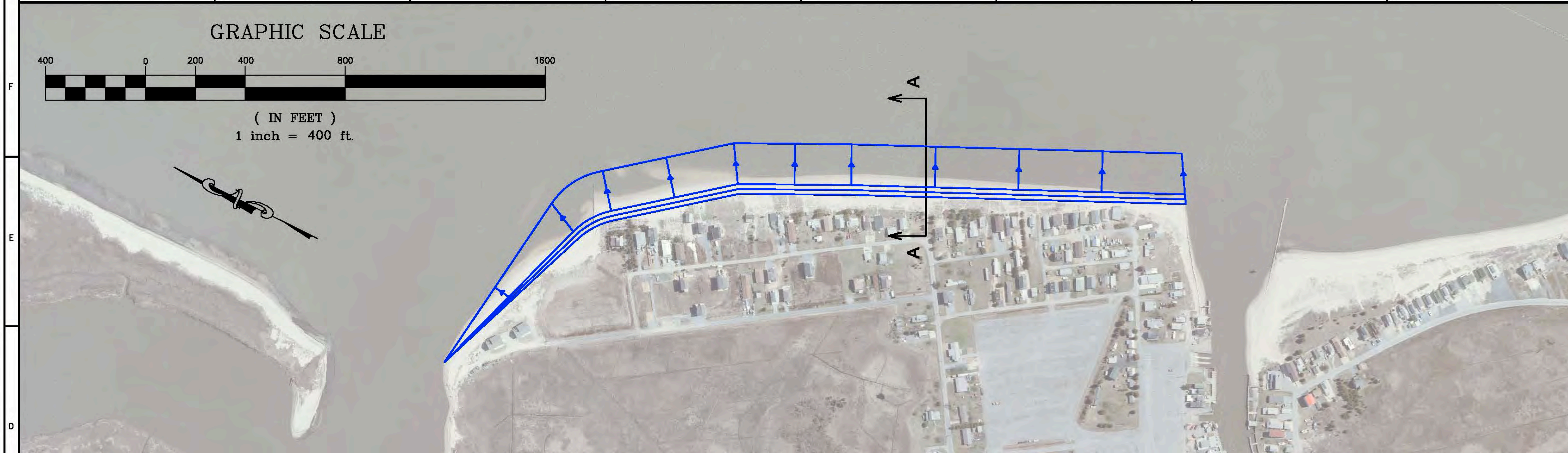
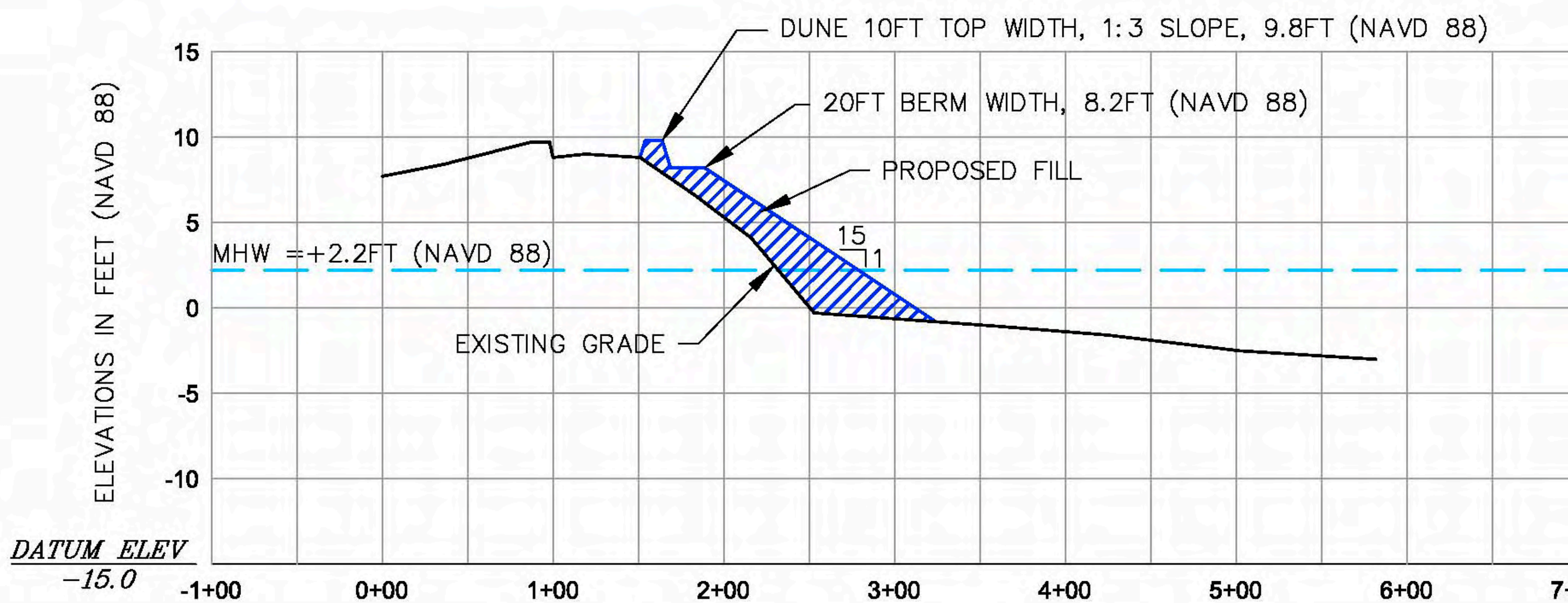


TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: BOWERS BEACH	TASK: STRATEGIC FILL PLACEMENT	FIGURE 1.10

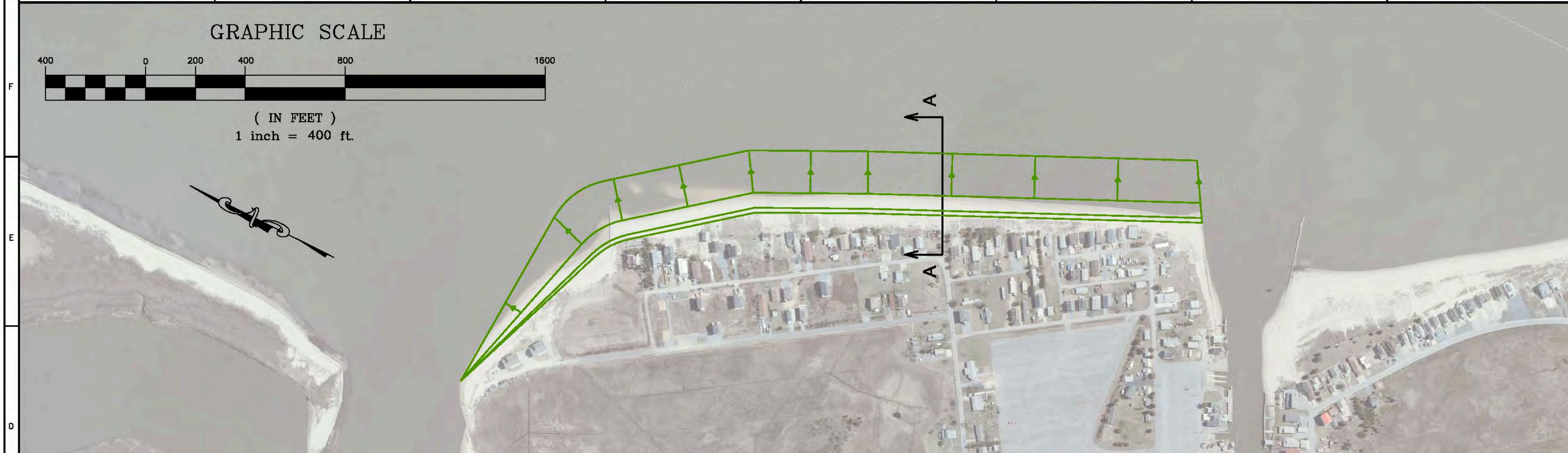


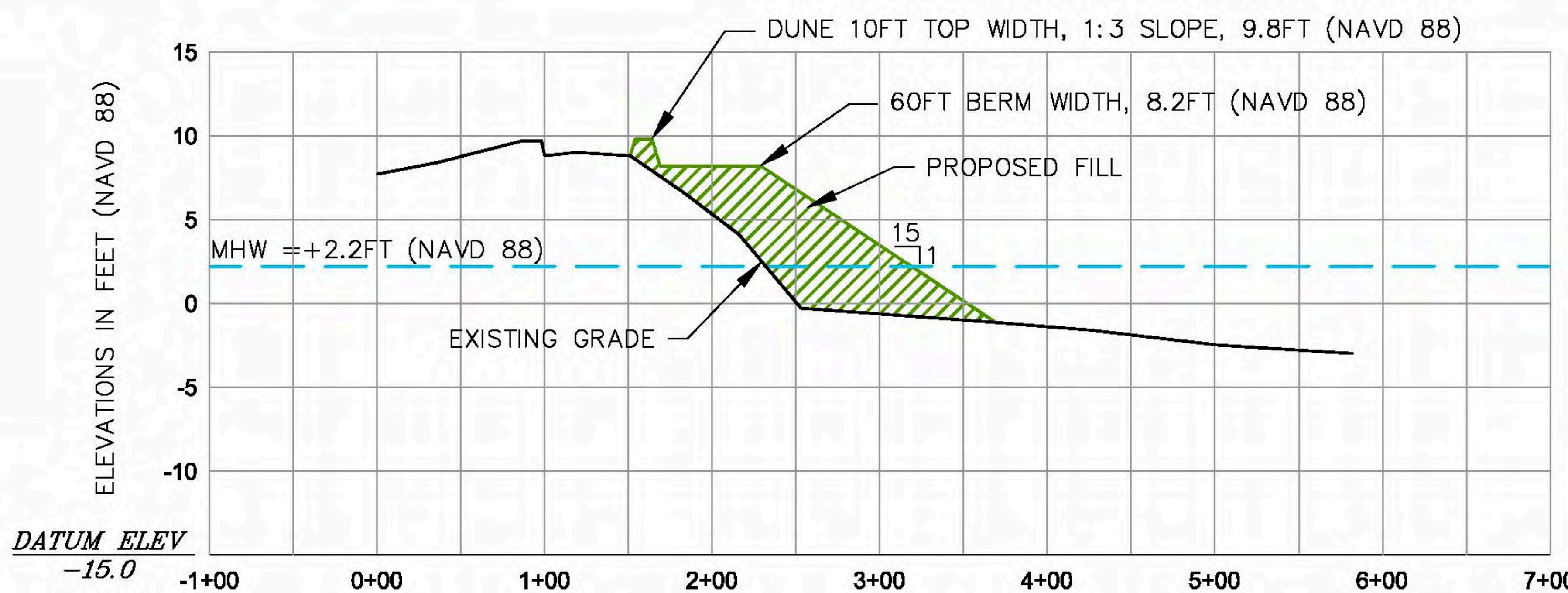


TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: **BOWERS BEACH**	TASK: **5 YEAR SCENARIO**	**FIGURE 1.11**





TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT:	PROJECT:	TASK:	
	DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	BOWERS BEACH	10 YEAR SCENARIO	FIGURE 1.12

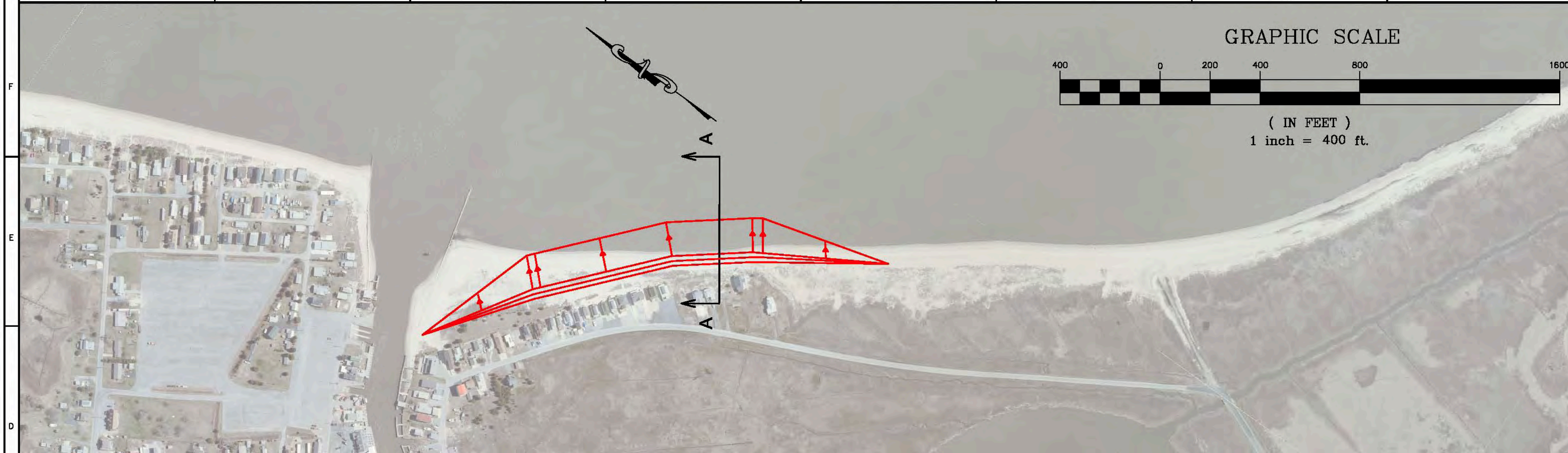
South Bowers

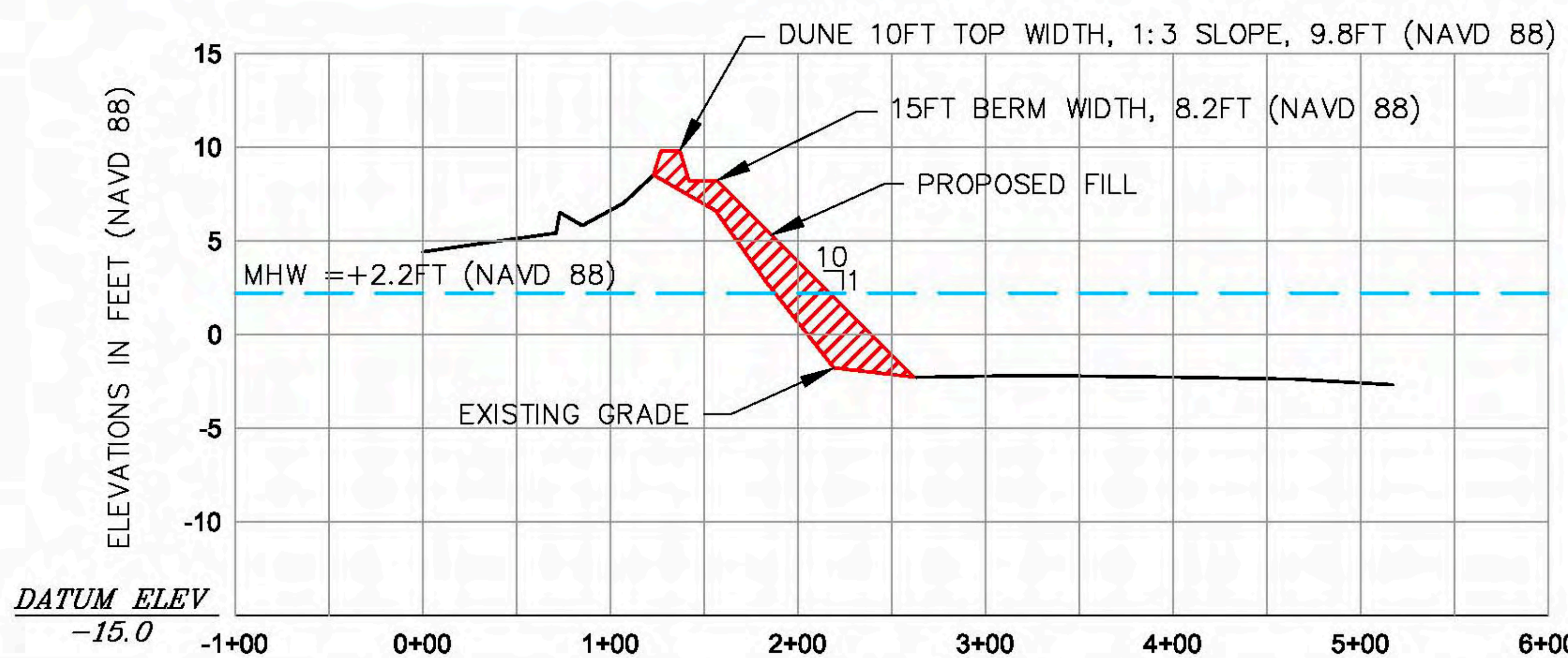
South Bowers, measuring about 3,500 feet in length, is located on a sand and gravel barrier beach bordering on an extensive back barrier marsh across the Murderkill Inlet south of Bowers Beach. The northern portion of the beach, bordered by the south jetty at the Murderkill River is wide and the houses are set back a good distance from the shoreline. The homes to the south are built much closer to the shoreline and are more vulnerable to the effects of erosion and storms. Observation of past beach fill behavior suggests that the dominant transport direction is northerly. Beach nourishment events and the installation of shore protection structures have been conducted at South Bowers Beach since 1961. A total of 96,900 cy of material has been placed to date. A jetty was constructed along the southern shoreline of the Murderkill Inlet in 1976. The portion of the jetty along the inlet shoreline has been subject to sand transport over the jetty burying the western/landward end of the structure. This transport has created a sand shoal just inside the inlet shoreline. The jetty should be rehabilitated to return the functions of maintaining sand on the beach and reducing the volume of sand entering the Murderkill River. Sand tightening of the jetty and raising the height is recommended.

The Strategic Placement scenario (Figure 1.13) consists of a beach fill and dune feature concentrated along the southern portion the community tapering towards the north jetty for a distance of 1,700 ft, with a berm width of 15 ft at an elevation of +8.2 ft NAVD88. This requires an initial fill volume of 12,200 cy of material, with a maintenance placement of 7,320 cy every four years thereafter. The slope of the dune should be planted with 20,500 units of beach grass. The initial placement will cost an estimated $295,245. The total ten year plan costs approximately $910,599.

The 5 Year Scenario project (Figure 1.14) consists of a uniform dune and berm tapering towards the northern jetty, spanning 2,800 ft of shoreline, with a maximum berm width of 15 ft at an elevation of +8.2 ft NAVD88. This requires an initial fill volume of 23,800 cy of material, with a maintenance placement of 14,280 cy every five years thereafter. The slope of the dune should be planted with 22,500 units of beach grass. The initial placement will cost an estimated $478,625, while the total ten year plan costs approximately $1,298,935.

The 10 Year Scenario project (Figure 1.15) consists of a uniform dune and berm tapering towards the northern jetty, spanning 2,800 ft of shoreline, with a maximum berm width of 65 ft at an elevation of +8.2 ft NAVD88. This requires an initial fill volume of 65,800 cy of material, with a maintenance placement of 39,480 cy every ten years thereafter. The slope of the dune should be planted with 22,500 units of beach grass. The initial placement will cost an estimated $772,625. The total ten year plan costs approximately $1,045,535.

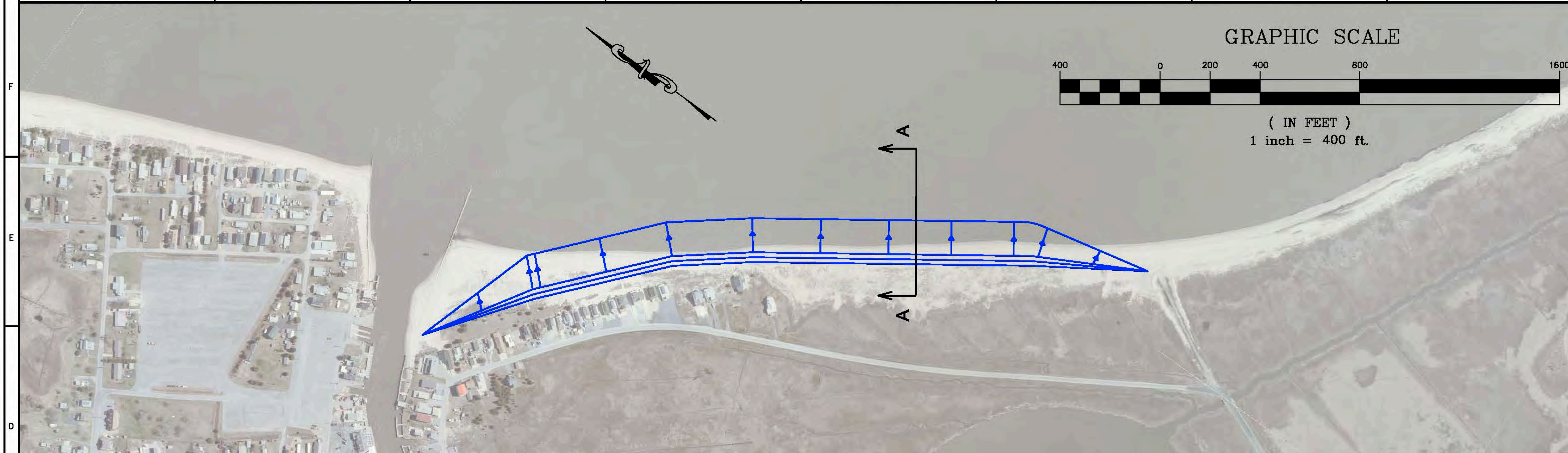


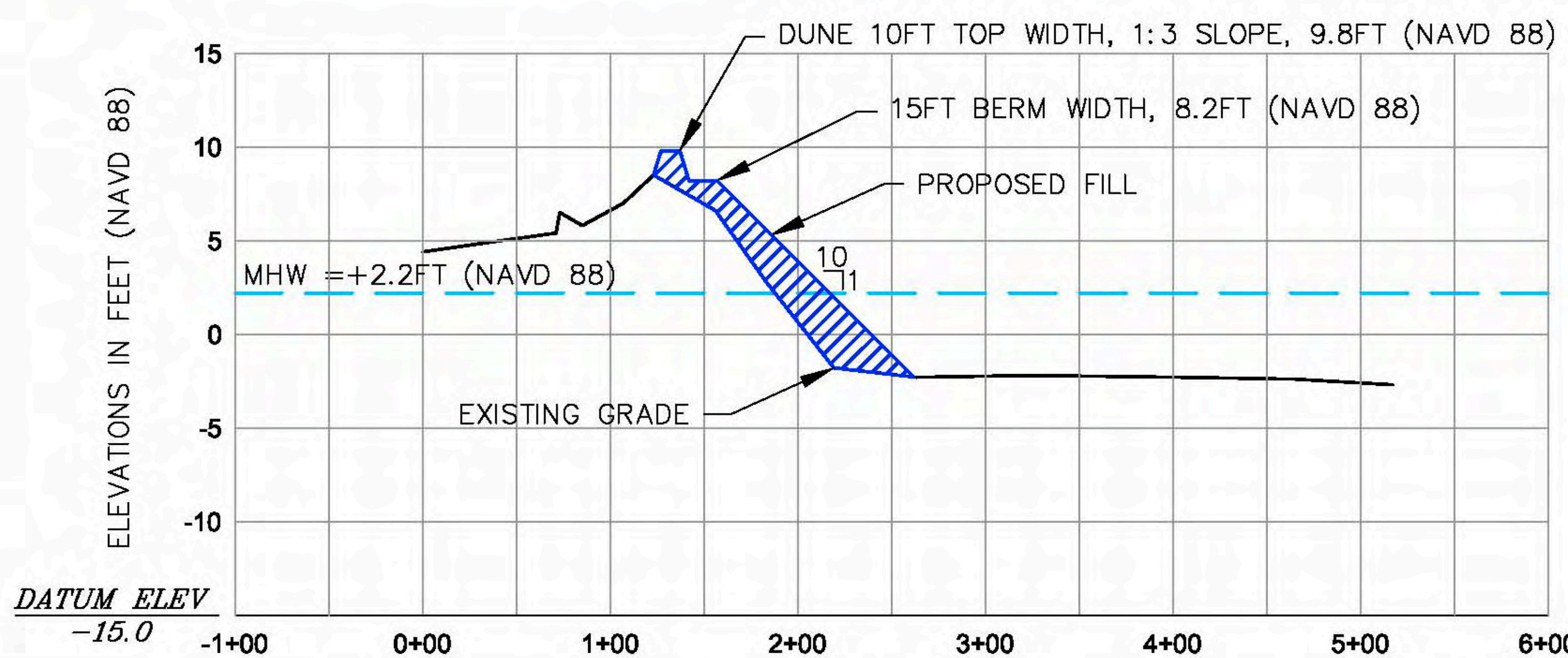


TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: SOUTH BOWERS	TASK: STRATEGIC FILL PLACEMENT	FIGURE 1.13

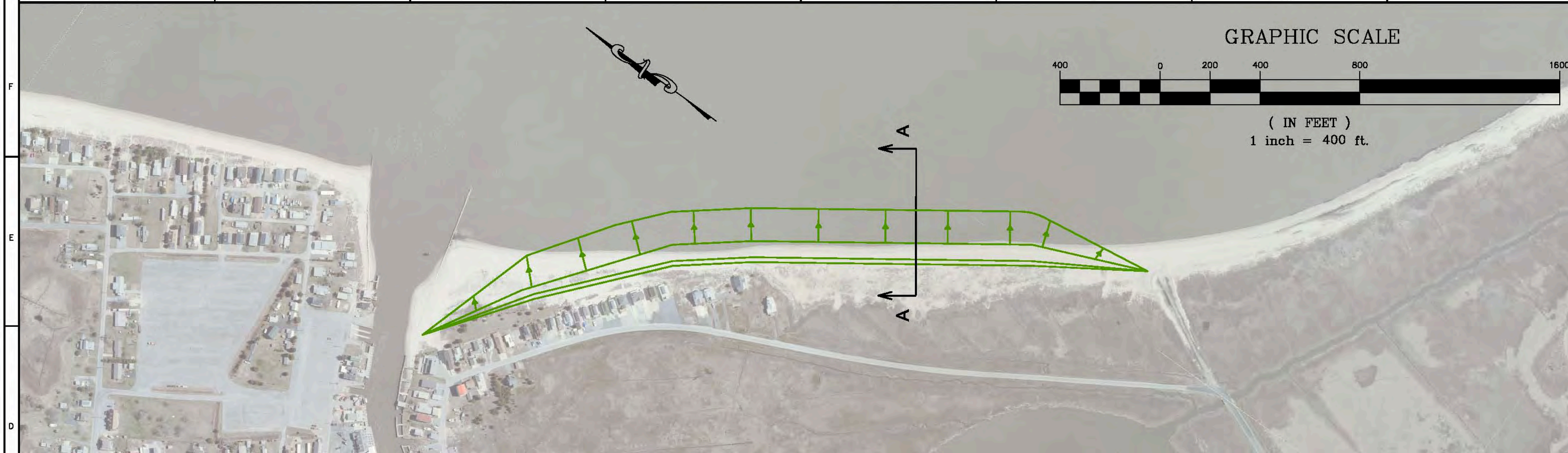


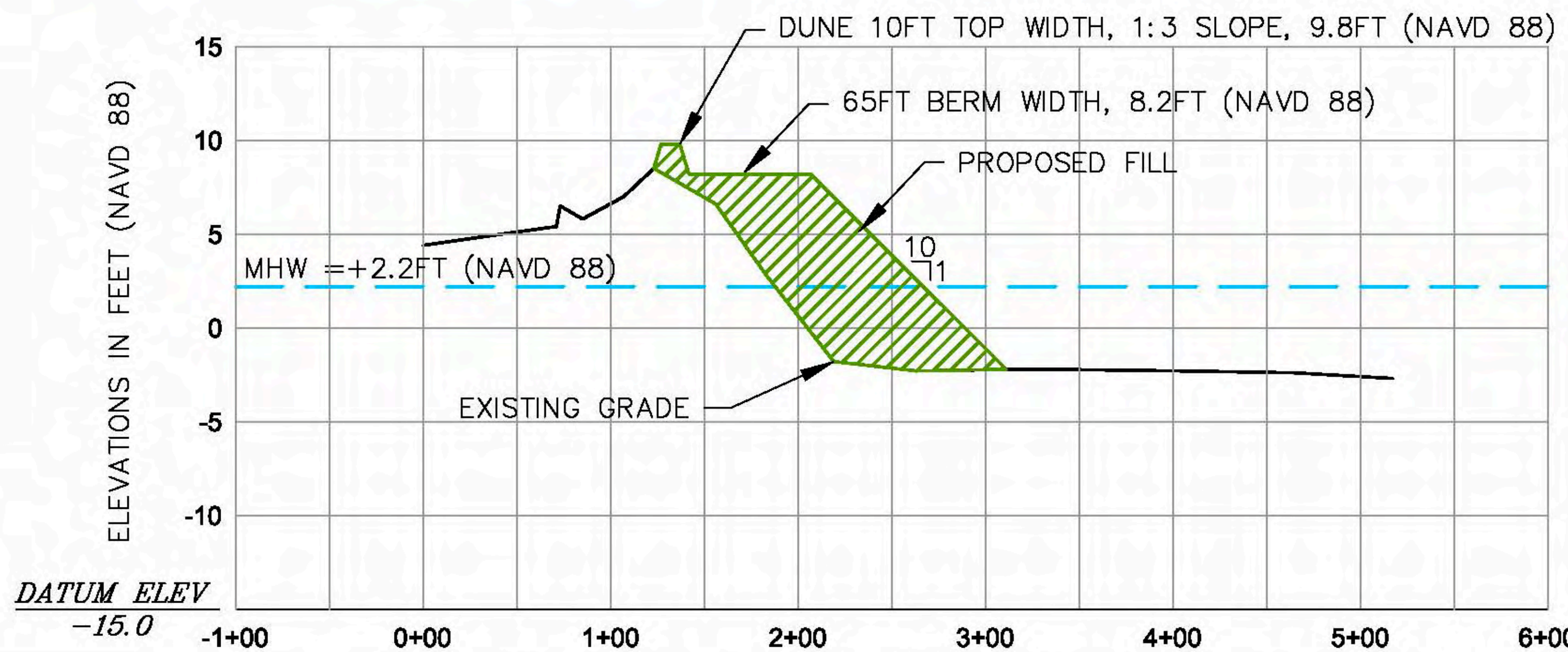


TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: **SOUTH BOWERS**	TASK: **5 YEAR SCENARIO**	**FIGURE 1.14**





TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: **DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL**	PROJECT: **SOUTH BOWERS**	TASK: **10 YEAR SCENARIO**	**FIGURE 1.15**

Slaughter Beach

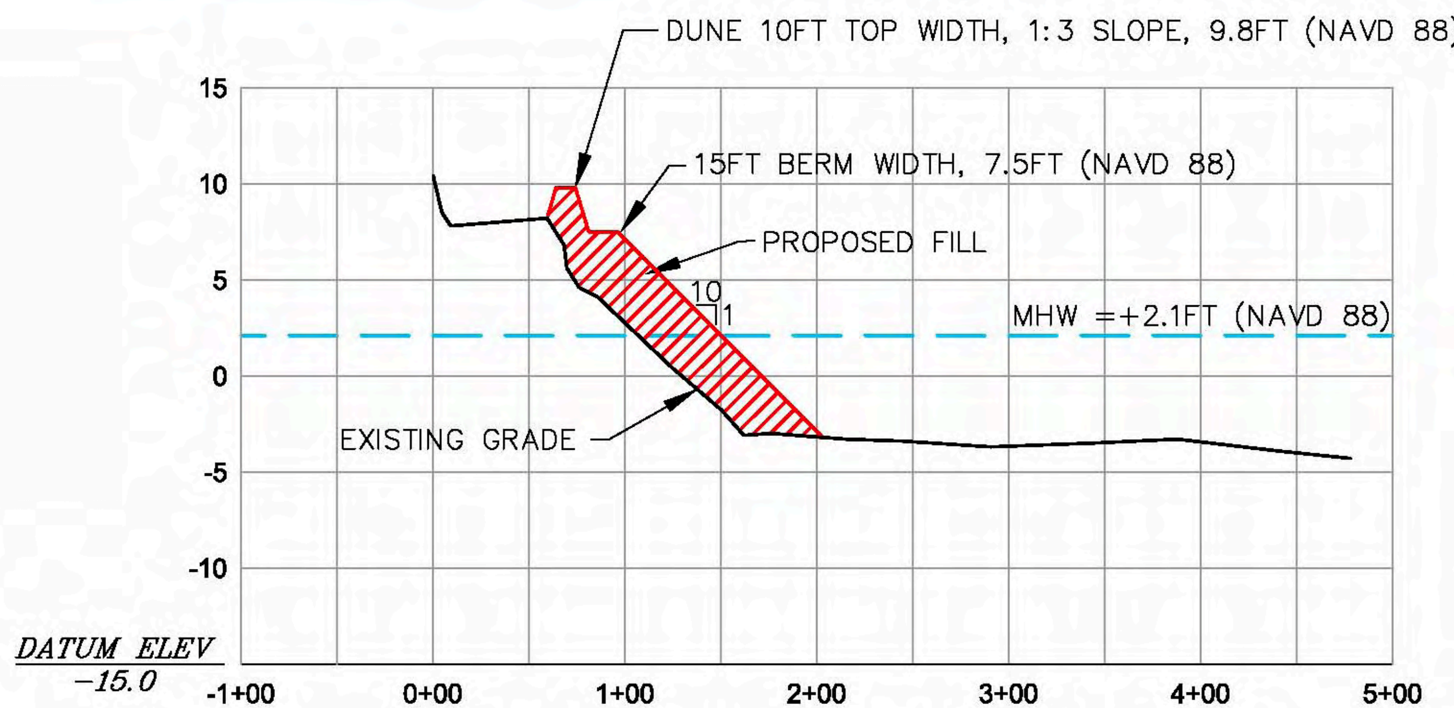
Slaughter Beach, measuring about 14,800 feet in length, is 2 mi south of Mispillion Inlet and approximately 14 miles from the mouth of Delaware Bay. It is bordered by wetlands to the southwest and Delaware Bay to the northeast. Observations of past beach fill behavior, along with previous research, suggest that the dominant transport direction is northerly, and the greatest need for beach fill is at the southern end of the community. The observed northerly transport at Slaughter Beach is evident from the accretion of sand along the northern shoreline and accumulation of detritus along the northern portions of the community. The northern end of the community is somewhat sheltered by the Mispillion Inlet jetties. Beach nourishment events and the installation of shore protection structures have been conducted at Slaughter Beach since 1958. A total of 899,300 cy of material has been placed to date.

The Mispillion Inlet, located approximately 3,500 ft north of Slaughter Beach, is hardened with jetties that extend over 3,000 ft into Delaware Bay. The jetties are in a deteriorated condition and are very porous. The jetties have had a considerable effect on the shape of the shoreline at Slaughter Beach due to their configuration. The 2008 study completed by Moffat and Nichol concluded that restoration of the south jetty would have negligible impact on the circulation and accumulation of detritus on Slaughter Beach. Monitoring is recommended for the jetties in order to continue to evaluate performance and the interaction with any proposed sand placement.

The Strategic Placement scenario (Figure 1.16) consists of a beach fill and dune feature concentrated along the southern 2,500 ft of the community, with a berm width of 15 ft at an elevation of +7.5 ft NAVD88. This requires an initial fill volume of 36,500 cy of material, with a maintenance placement of 21,900 cy every four years thereafter. The slope of the dune should be planted with 27,500 units of beach grass. The initial placement will cost an estimated $499,975, while the total ten year plan costs approximately $1,342,478.

The 5 Year Scenario project (Figure 1.17) consists of a uniform dune and berm spanning 14,500 ft of shoreline, with a maximum berm width of 15 ft at an elevation of +7.5 ft NAVD88. This requires an initial fill volume of 252,500 cy of material, with a maintenance placement of 151,500 cy every five years thereafter. The slope of the dune should be planted with 120,000 units of beach grass. The initial placement will cost an estimated $2,112,800, while the total ten year plan costs approximately $4,107,503.

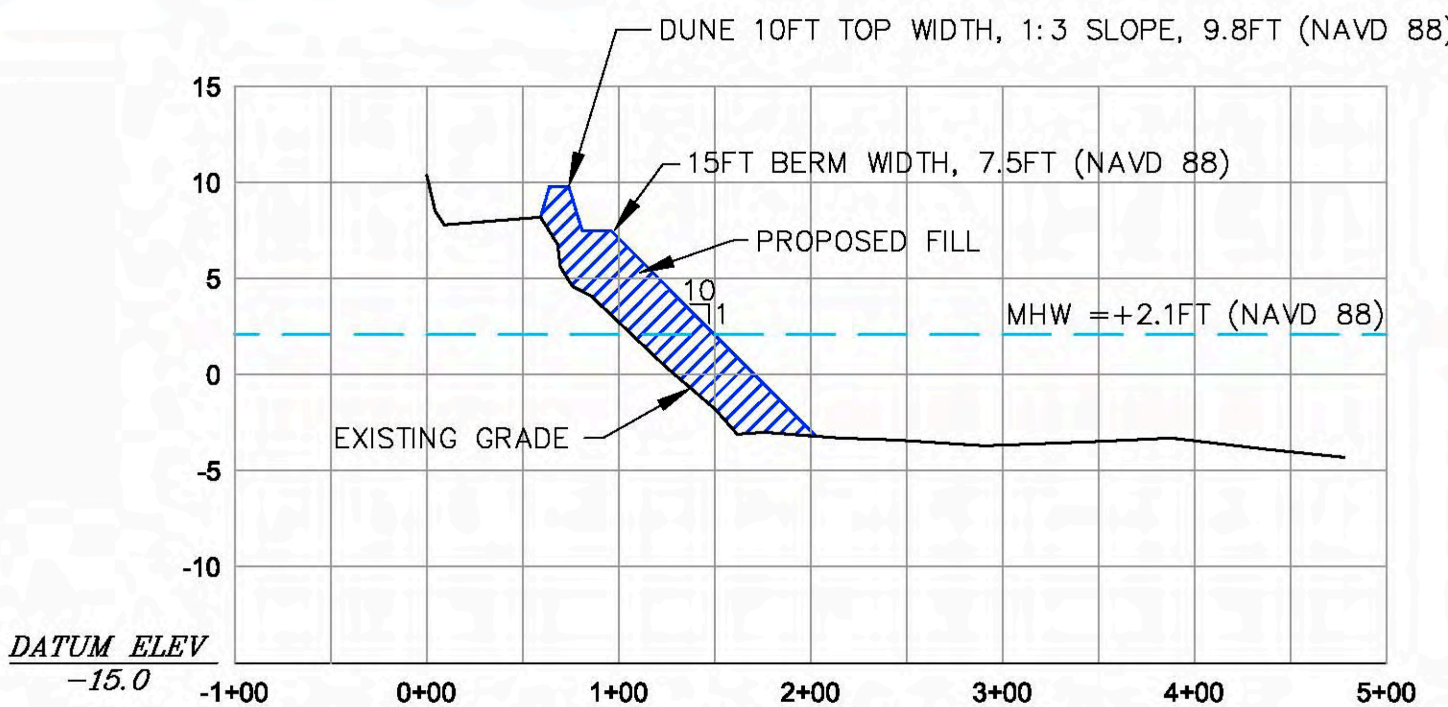
The 10 Year Scenario project (Figure 1.18) consists of a uniform dune and berm spanning 14,500 ft of shoreline, with a maximum berm width of 55 ft at an elevation of +7.5 ft NAVD88. This requires an initial fill volume of 476,500 cy of material, with a maintenance placement of 285,900 cy every ten years thereafter. The slope of the dune should be planted with 120,000 units of beach grass. The initial placement will cost an estimated $3,680,800, while the total ten year plan costs approximately $4,260,503.



TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

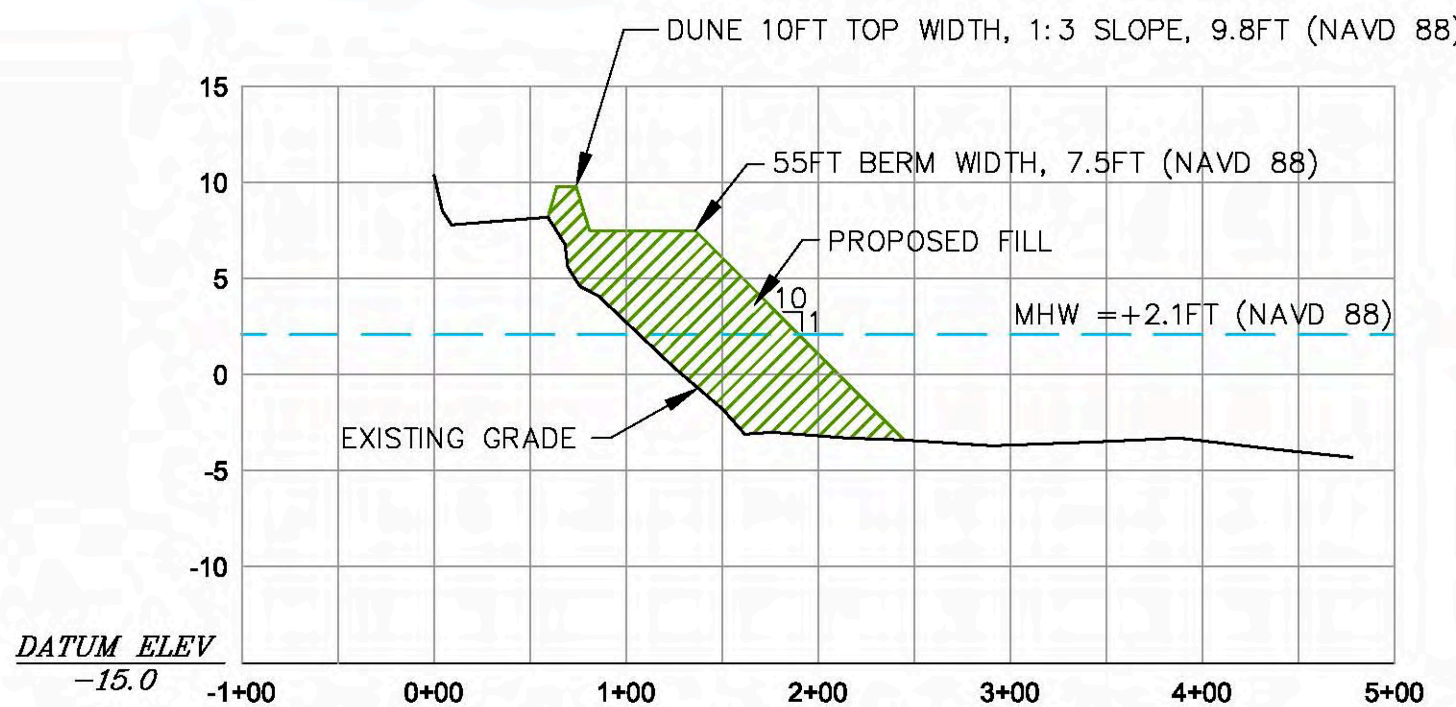
PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: SLAUGHTER BEACH	TASK: STRATEGIC FILL PLACEMENT	FIGURE 1.16



TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: **SLAUGHTER BEACH**	TASK: **5 YEAR SCENARIO**	**FIGURE 1.17**



TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ

CLIENT:
DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL

PROJECT:
SLAUGHTER BEACH

TASK:
10 YEAR SCENARIO

FIGURE 1.18

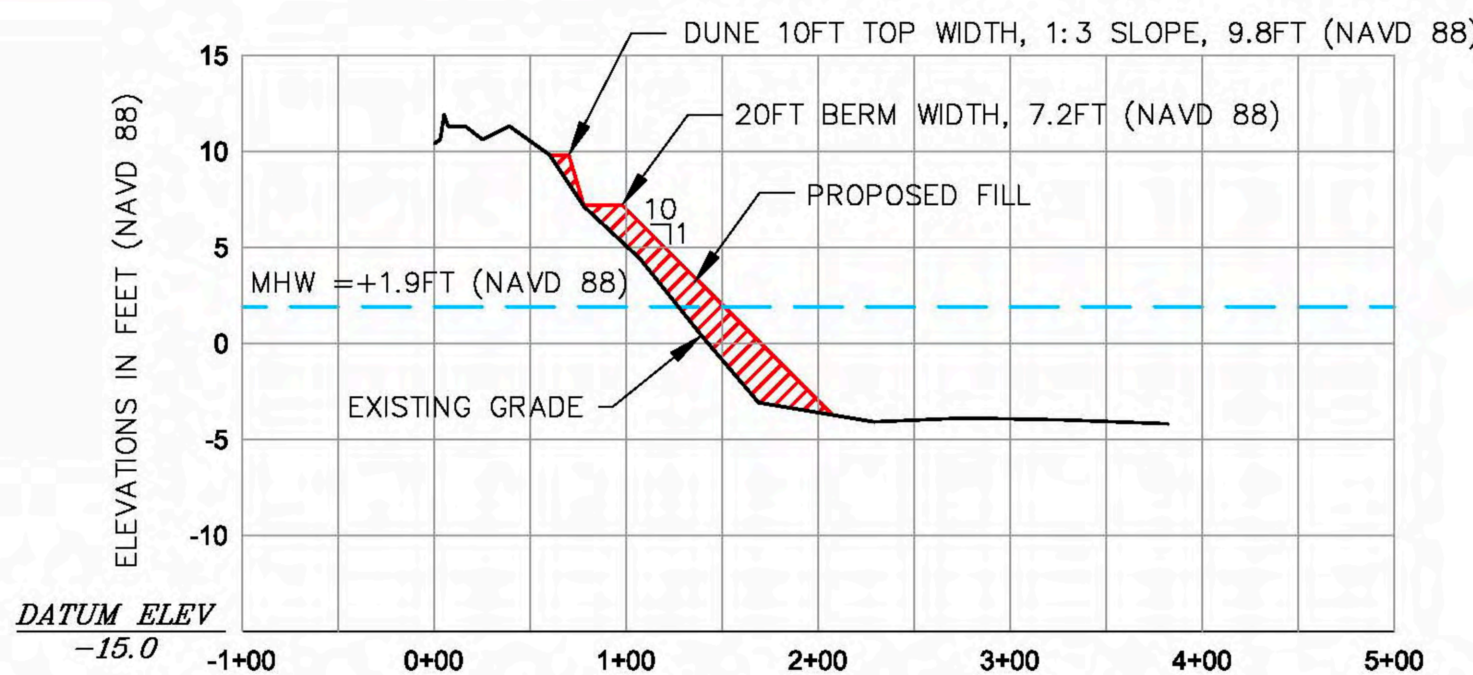
Primehook Beach

Primehook Beach, measuring about 7,900 ft in length, is located approximately 10 miles from the mouth of Delaware Bay. The beach shoreline is characterized by broad, low dunes, a beach berm that is cuspate in the mid and southern section of the beach and a complex series of diagonal and shore parallel sand bars. The community is bordered to the west by 1-2 mi of marsh, and a broad subtidal flat extends almost 1 mi offshore. Local observations suggest that the northern 1/3 of the community has the greatest need for shore protection. Approximately 20,200 cy of material were placed in 1962. In April 2008, the thirteen northernmost lots were filled with 1,700 tons of sand.

The Strategic Placement scenario (Figure 1.19) consists of a beach fill and dune feature concentrated along the northern 2,800 ft of the community, with a berm width of 20 ft at an elevation of +7.2 ft NAVD88. This requires an initial fill volume of 24,000 cy of material, with a maintenance placement of 14,400 cy every four years thereafter. The slope of the dune should be planted with 31,500 units of beach grass. The initial placement is estimated at $416,835, and the total ten year plan is estimated to cost $984,924.

The 5 Year Scenario project (Figure 1.20) consists of a uniform dune and berm spanning 7,500 ft of shoreline, with a maximum berm width of 20 ft at an elevation of +7.2 ft NAVD88. This requires an initial fill volume of 71,000 cy of material, with a maintenance placement of 36,600 cy every five years thereafter. The slope of the dune should be planted with 70,000 units of beach grass. The initial placement is estimated to cost $787,800, and the total ten year plan is estimated to cost $1,623,289.

The 10 Year Scenario project (Figure 1.21) consists of a uniform dune and berm spanning 7,500 ft of shoreline, with a maximum berm width of 55 ft at an elevation of +7.2 ft NAVD88. This requires an initial fill volume of 176,000 cy of material, with a maintenance placement of 105,600 cy every ten years thereafter. The slope of the dune should be planted with 70,000 units of beach grass. The initial placement is estimated to cost $1,522,800, and the total ten year plan is estimated to cost $1,775,589.



TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

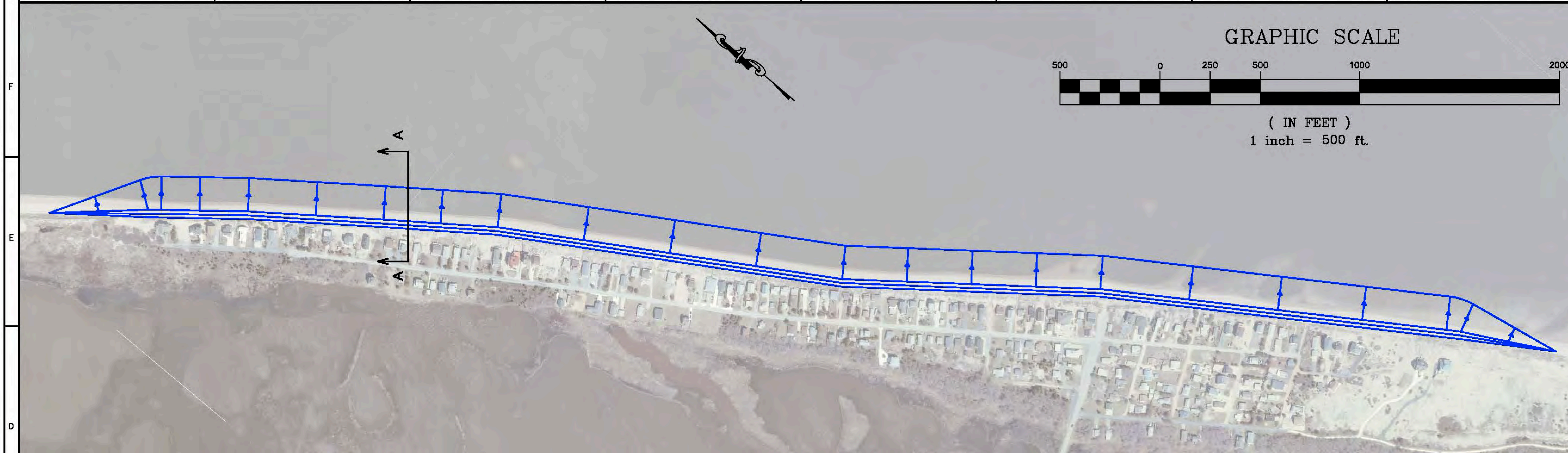
PBSJ

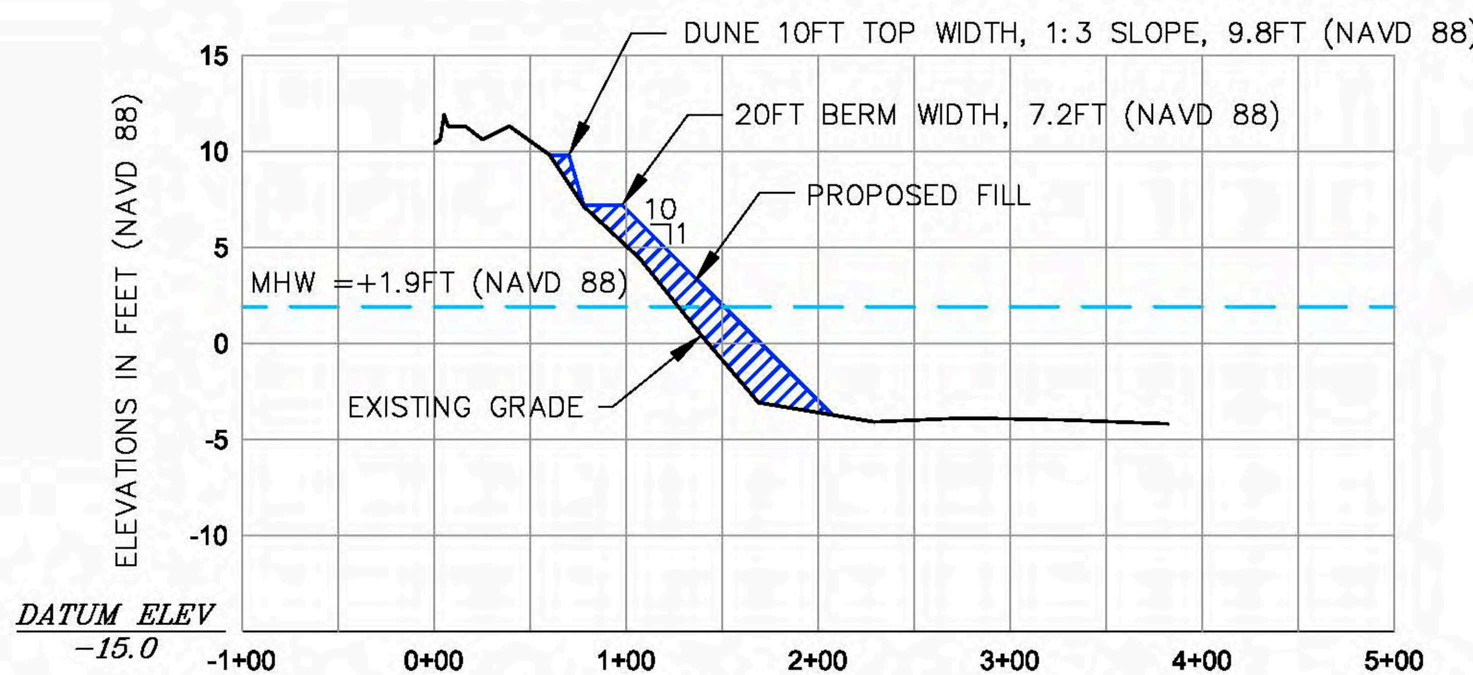
CLIENT:
DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL

PROJECT:
PRIMEHOOK BEACH

TASK:
STRATEGIC FILL PLACEMENT

FIGURE 1.19

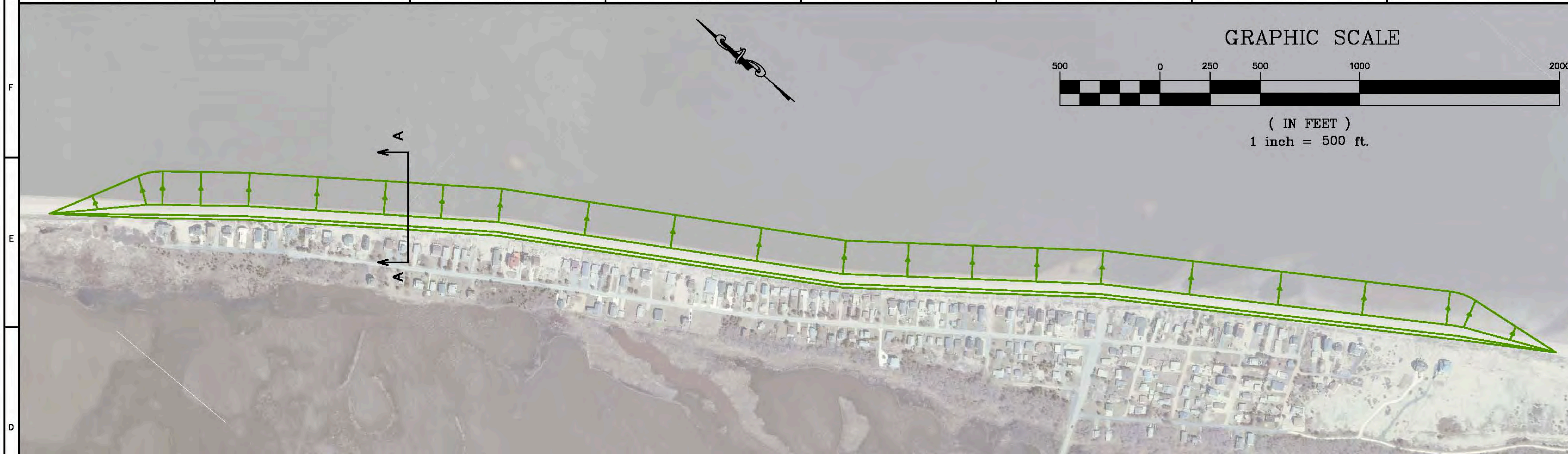


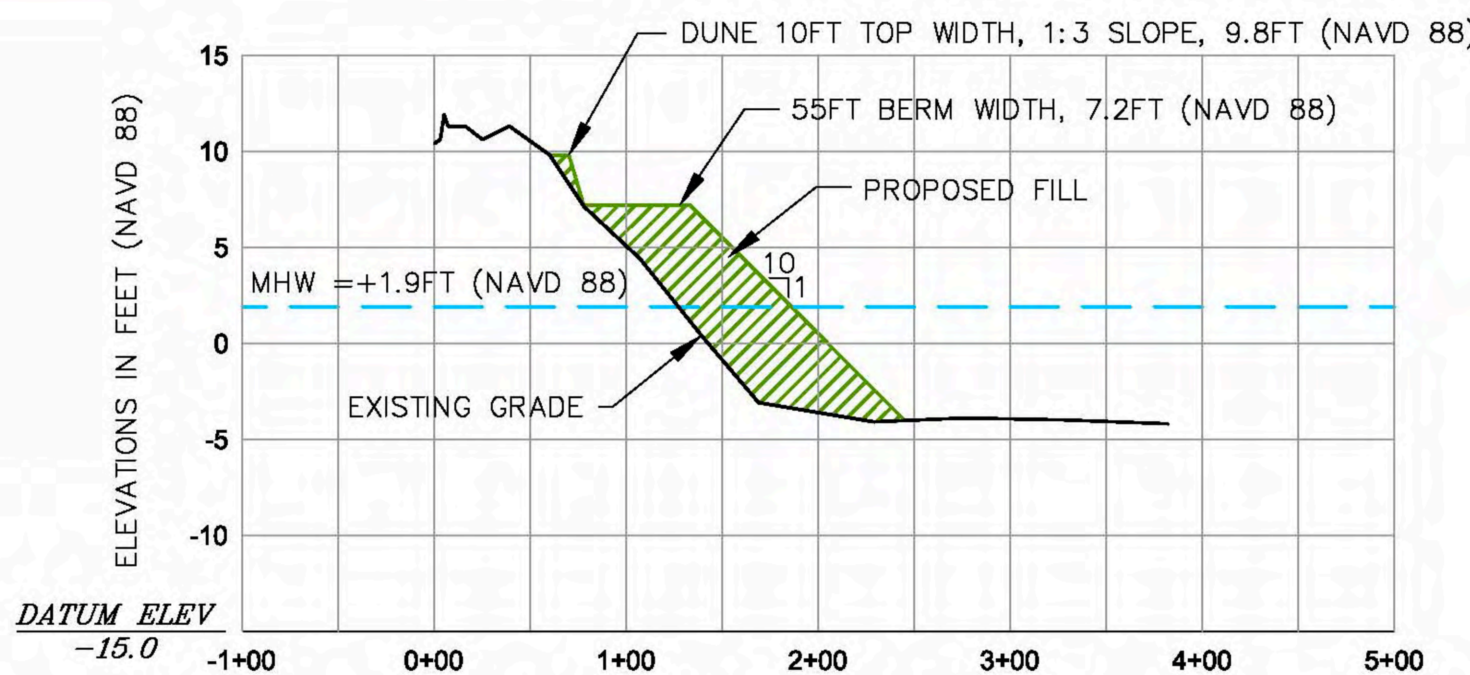


TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: PRIMEHOOK BEACH	TASK: 5 YEAR SCENARIO	FIGURE 1.20





TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: **PRIMEHOOK BEACH**	TASK: **10 YEAR SCENARIO**	**FIGURE 1.21**

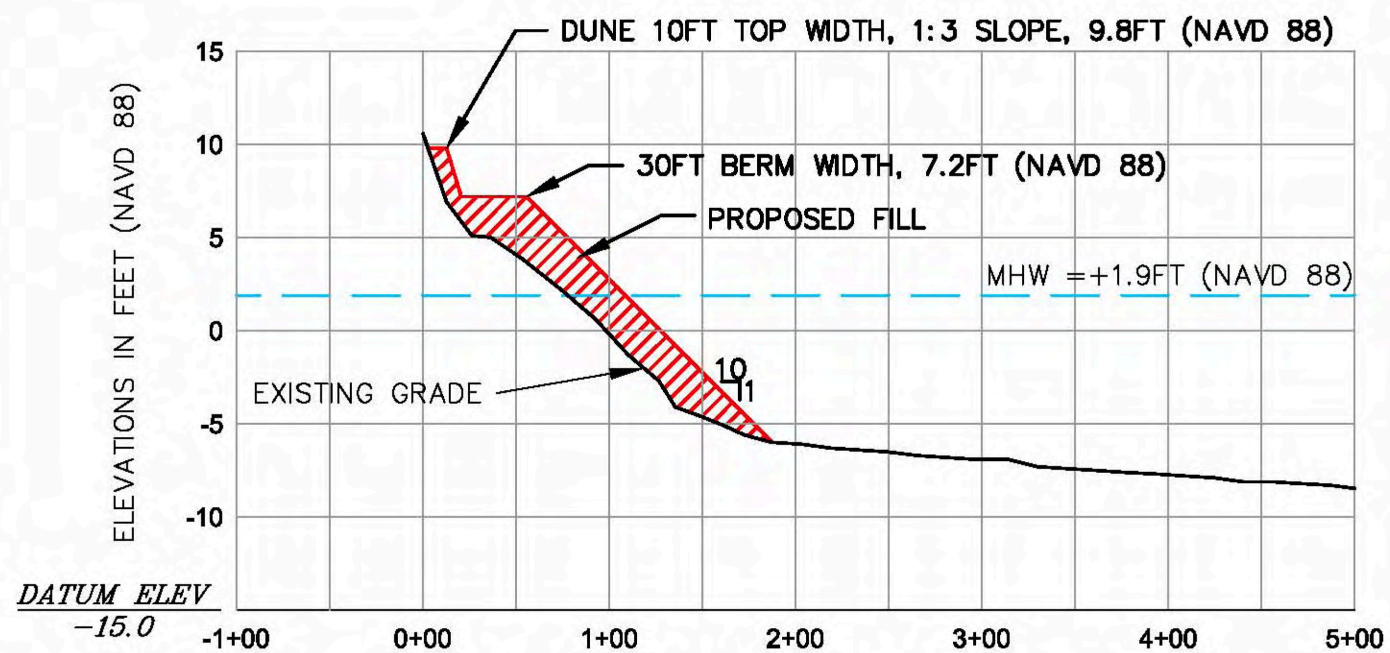
Broadkill Beach

Broadkill Beach, measuring 24,800 feet, is located approximately 3 mi northwest of Lewes and 7 mi northwest of the mouth of Delaware Bay. The beach occupies a strip of land measuring 300 ft to 1,000 ft in width, situated between expansive marsh and the Delaware Bay. Observation of past beach fill behavior suggests that the dominant transport direction is northward in the north half of the community and southward in the southern half, with a nodal point at Route 16 (Broadkill Road). Broadkill Beach has been receiving nourishment since 1957. Approximately 1,150,600 cy of material has been placed to date. In the 1950s, a series of five groins were built at Washington, Adams, North Carolina, Georgia, and Alabama Avenues. In 1964, a concrete rubble revetment was construction from North Carolina Avenue to approximately 700 ft north of Alabama Avenue. The groins do not appear to have a significant effect on the shoreline. Since construction, these groins have created a slight offset in beach width, but their influence on the shoreline is limited. Since the structures are not adversely affecting the shoreline, neither removal nor structure modifications are recommended as a shore protection strategy. Deterioration of the structures that could cause personal injury would require reassessment and a response plan.

The Strategic Placement scenario (Figure 1.22) consists of a beach fill and dune feature concentrated along the middle 6,700 ft of the community, with a berm width of 30 ft at an elevation of +7.2 ft NAVD88. This requires an initial fill volume of 99,700 cy of material, with a maintenance placement of 60,000 cy every four years thereafter. The slope of the dune should be planted with 65,000 units of beach grass. The initial placement will cost an estimated $983,250, and the total ten year plan costs approximately $2,216,869.

The 5 Year Scenario project (Figure 1.23) consists of a uniform dune and berm spanning 16,000 ft of shoreline, with a maximum berm width of 30 ft at an elevation of +7.2 ft NAVD88. This requires an initial fill volume of 264,500 cy of material, with a maintenance placement of 162,000 cy every five years thereafter. The slope of the dune should be planted with 150,000 units of beach grass. The initial placement will cost an estimated $2,229,500, and the total ten year plan is estimated to cost $4,295,279.

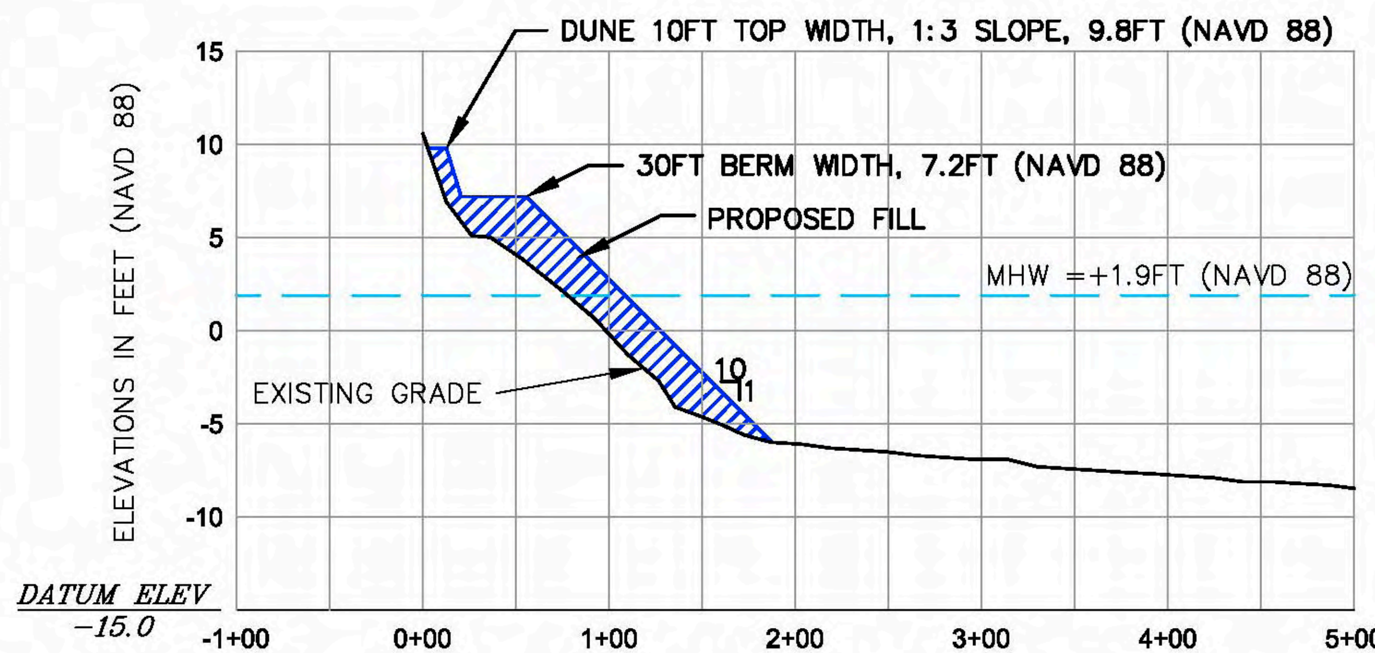
The 10 Year Scenario project (Figure 1.24) consists of a uniform dune and berm spanning 16,000 ft of shoreline, with a maximum berm width of 70 ft at an elevation of +7.2 ft NAVD88. This requires an initial fill volume of 528,000 cy of material, with a maintenance placement of 324,000 cy every ten years thereafter. The slope of the dune should be planted with 150,000 units of beach grass. The initial placement will cost an estimated $4,074,000, and the total ten year plan estimated cost is $4,674,379.



TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

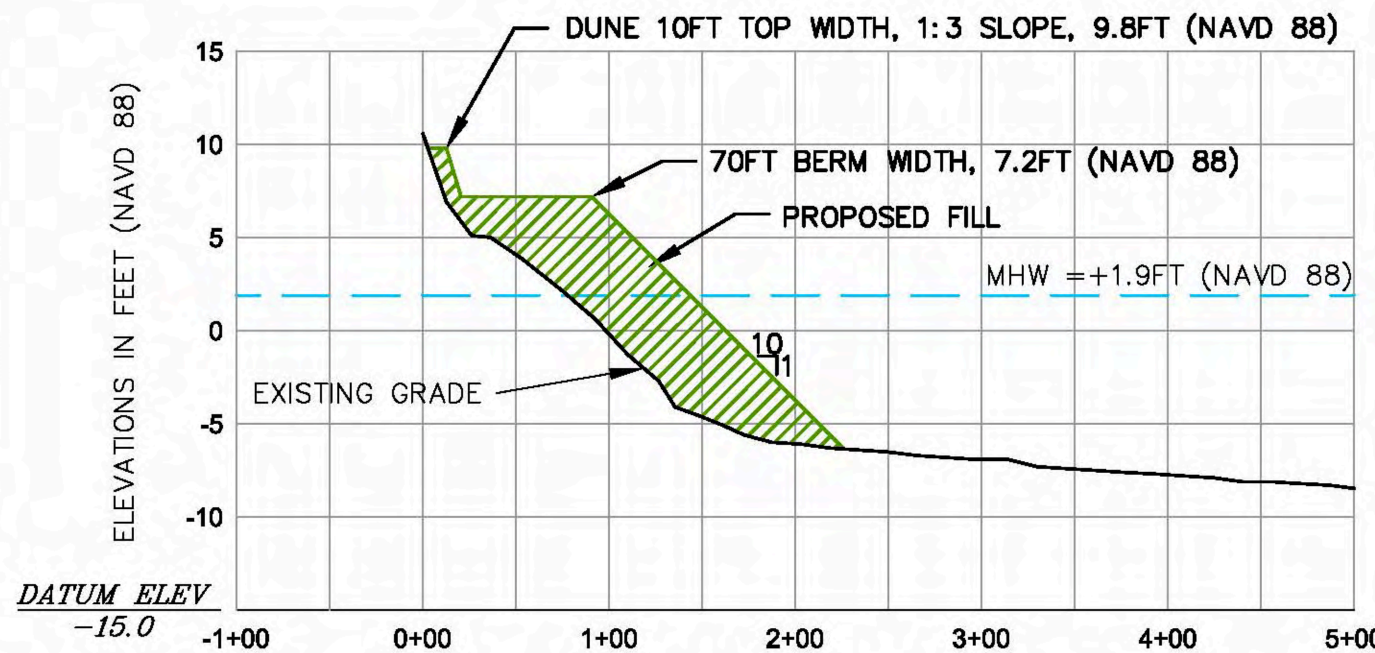
PBSJ	CLIENT: **DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL**	PROJECT: **BROADKILL BEACH**	TASK: **STRATEGIC FILL PLACEMENT**	**FIGURE 1.22**



TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: BROADKILL BEACH	TASK: 5 YEAR SCENARIO	FIGURE 1.23



TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: BROADKILL BEACH	TASK: 10 YEAR SCENARIO	FIGURE 1.24

Summary

In summary, this plan outlines a regionalized beach management and funding program for the seven designated coastal communities of the Delaware Bay region. The principal goals of this plan are to:

1. Present a management plan that addresses beach erosion and provides shore protection from wave attack and storm surge to the beach and dune system. The plan is not intended to address flooding issues resulting from inland drainage conveyance or storage concerns.
2. Provide DNREC with a planning document with a ten-year outlook to allow for proactive management of the beaches.
3. Examine sand movement pathways and develop predicted sand needs for each community over a ten year time frame.
    a. Evaluate specific forces or circumstances that have historically caused significant erosion.
    b. Estimate the quantity of sand needed for the design life of each project.
4. Extend the life of beach nourishment projects and provide a quantifiable level of protection for storm impacts and historical losses by designing projects with the appropriate beach fill templates. It should be noted that these conceptual designs are for purposes of estimating costs and are not intended for construction.
5. Encourage regionalized approaches to, and reduce equipment mobilization and demobilization costs of, beach projects that take advantage of geographic coordination and sequencing of projects.

The plan provides a great deal of background information concerning the history, processes, and other factors that need to be considered in developing and applying a 10-year management plan for these beaches. This information was applied to present three management plan scenarios for each of the seven communities.

Construction costs and schedule are estimated for each of the three project scenarios and include mobilization and demobilization, sand placement, and dune plantings. Costs for design, permitting, geotechnical investigation, post-project performance, and physical/biological monitoring are presented. A summary of the entire plan is presented in Table 1.1. The construction of the initial beach nourishment and total ten year costs are provided.

Table 1.1 Summary of Construction Costs for the Plan

	Beach Fill Scenarios	Initial Placement Cost	Total Cost Over 10 Years
Pickering Beach	Strategic	$470,635	$1,120,102
	5 Year	$571,435	$1,246,382
	10 Year	$1,180,435	$1,416,582
Kitts Hummock	Strategic	$503,765	$1,121,796
	5 Year	$988,410	$1,956,321
	10 Year	$1,656,210	$1,976,581
Bowers Beach	Strategic	$331,910	$756,859
	5 Year	$491,950	$1,002,299
	10 Year	$746,750	$894,449
South Bowers	Strategic	$295,245	$910,599
	5 Year	$478,625	$1,298,935
	10 Year	$772,625	$1,045,535
Slaughter Beach	Strategic	$499,975	$1,342,478
	5 Year	$2,112,800	$4,107,503
	10 Year	$3,680,800	$4,260,503
Primehook Beach	Strategic	$416,835	$984,924
	5 Year	$787,800	$1,623,289
	10 Year	$1,522,800	$1,775,589
Broadkill Beach	Strategic	$983,250	$2,216,869
	5 Year	$2,229,500	$4,295,279
	10 Year	$4,074,000	$4,674,379

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2. Preface

This report presents a regionalized beach management/nourishment and funding plan for seven coastal communities of the Delaware Bay region. These seven communities consist of Pickering Beach, Kitts Hummock, Bowers Beach, South Bowers, Slaughter Beach, Primehook Beach, and Broadkill Beach. The plan emphasizes a resilient community approach by appropriately using shoreline restoration and maintenance to reduce infrastructure damage due to storms. The focus of the plan is on beach enhancement, shore protection, and environmental concerns for each area in order to develop a comprehensive shore protection strategy and its associated long-term cost basis.

This plan was generated through interviews with those knowledgeable about Delaware's coastline, literature review, analysis of existing studies, evaluation of past project performance, wave, circulation, and erosion modeling, engineering recommendations, and cost/schedule estimation. The emphasis for each area was to provide a technically based set of alternatives for improving the present shore protection strategies.

3. Introduction

The beach communities included in this plan are located along the western shore of Delaware Bay. The shoreline generally faces northeast, with local deviations along specific reaches. The shoreline is demarcated by several river inlets, some of which are hardened with jetties that influence short and long term sediment transport patterns. Figure 3.1 provides an overall map of the locations of the communities and inlets. The rivers that significantly influence the Delaware Bay coastline are also shown.

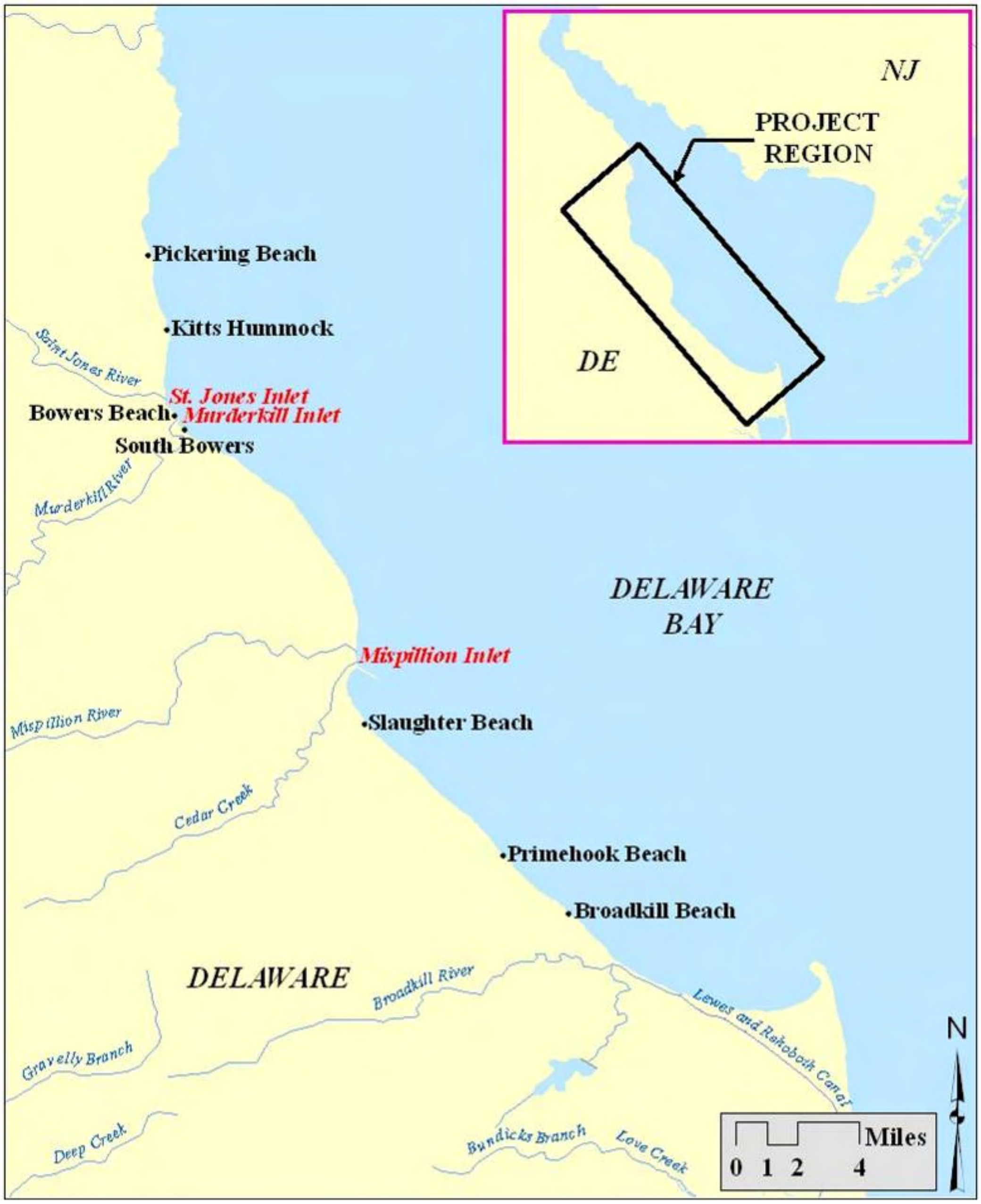


Figure 3.1 Overall map of Delaware Bay communities.

The approximate lengths* of the sandy beach within each community are as follows:

Table 3.1 Approximate length of the sandy beach fronting each community.

Pickering Beach	0.50 mi
Kitts Hummock	0.94 mi
Bowers Beach	0.61 mi
South Bowers	0.33 mi
Slaughter Beach	3.05 mi
Primehook Beach	1.29 mi
Broadkill Beach	3.10 mi
Total approximate length	**9.80 mi**

*Lengths were estimated from DNREC's 2007 aerial of the shoreline. The lengths represent the sandy beach in front of the communities, measured from 100 ft north and south of the homes.

The influences of ocean waves, bay currents and seasonal storm events have a strong effect on the direction and volume of transport of beach material and the resultant beach planform. The areas external to the direct influence of ocean waves from South Bowers to North Pickering Beach respond seasonally to the local wind-generated wave conditions. In general, the lower southeastern portion of the Delaware Bay coast from Slaughter Beach to Cape Henlopen is influenced by incoming ocean waves as well as seasonal wind-generated waves.

The impact of manmade structures, primarily for maintenance of navigation, has influenced the shape and orientation of the Delaware Bay shoreline. In particular, the Murderkill River inlet and the Mispillion River inlet jetties have influenced the position/alignment of the adjacent shorelines and the configuration of the adjacent offshore areas. Other structures, such as the shore-parallel experimental breakwaters at Kitts Hummock, have had much lesser effects on local beach planforms.

The natural resources of these beach communities are very diverse. They include significant numbers of resident shore birds, large migratory bird populations that use the nearby wetlands and beaches, beach-spawning horseshoe crabs, a host of native crabs, fish, micro- and macro-invertebrates and a diversity of vegetation, both wetland and upland species.

3.1 Purpose and Goals of Plan

The purpose of this plan is to develop a regionalized beach management and funding program for seven coastal communities of the Delaware Bay region. The plan emphasizes a resilient community approach by appropriately using beach nourishment and maintenance to reduce infrastructure damage due to storms. The focus of the plan is on beach enhancement, shore protection, and environmental concerns for each area in order to develop a comprehensive shore protection strategy and its associated long-term cost basis. Specific goals of the plan include:

1. Present a management plan that addresses beach erosion and provides shore protection from wave attack and storm surge to the beach and dune system. The plan is not intended to address flooding issues resulting from inland drainage conveyance or storage concerns.
2. Provide DNREC with a ten-year outlook to allow for proactive management of the beaches.
3. Examine sand movement pathways and develop predicted sand needs for each community over a ten year time frame.
    a. Evaluate specific forces or circumstances that have historically caused significant erosion.
    b. Estimate the quantity of sand needed for the design life of each project.
4. Extend the life of beach nourishment projects and provide a quantifiable level of protection for storm impacts and historical losses by designing projects with the appropriate construction templates.
5. Encourage regionalized approaches to, and reduce equipment mobilization and demobilization costs of, beach projects that take advantage of geographic coordination and sequencing of projects.

3.2 Study Methodology

In order to gain an understanding of the Delaware Bay beaches in this area, a series of data collection and analysis tasks were carried out. Effort was taken to utilize existing historical data and studies when possible, bolstered by new and updated analysis to verify and/or revise the past conclusions and recommendations. These efforts are summarized below.

Local community meetings. Two sets of meetings were held with each local community. The first was held between July and September 2008. These meetings were a forum for community members to express their concerns and desires as they relate to the future management of the Bay beaches. The second set of meetings, held in April 2009, served as an opportunity to update the local communities on the progress of the plan development and for the communities to provide additional information that may be useful for the plan.

DNREC staff and archives. A kickoff meeting and archives search was held the week of

February 9, 2009 to familiarize the PBS&J and DNREC staff involved in this project, develop a plan for completion of the study, and begin the data collection effort. DNREC staff, including Tony Pratt, Maria Sadler, Chuck Williams, Dan Brower, Mike Powell, and Allen MacDonald, provided documents and information on the history of DNREC's involvement in the management of the Bay beaches. Information gathered from the DNREC office included digital beach survey data, permitting documents, previous structure construction and sand placement documentation, beach fill plans and specifications, and relevant research papers covering environmental issues, Delaware policy, geology/morphology of the Bay, history of the Bay, and information about the natural resources of the Bay beaches.

U.S. Army Corps of Engineers. During a visit to the Philadelphia District of the U. S. Army Corps of Engineers (USACE) on February 11, 2009, Jeff Gebert provided information and insight on current and authorized USACE work along Delaware Bay. In addition, an extensive list of relevant literature was gathered from the USACE library.

University of Delaware faculty/researchers. On February 10, 2009, PBS&J staff members met with Dr. Evelyn Maurmeyer (UD), Dr. Wendy Carey (Delaware Sea Grant), and Hilary Stevens (UD). They accompanied PBS&J staff on a tour of the beaches, providing valuable insight on the history of the beaches and their management, and the biological communities that are important to the Bay. They provided PBS&J staff with a list of relevant research papers as well as a list of scientists who work, or have worked, in our area of interest.

Tour of beach areas. A tour of the beach communities with DNREC and UD staff on February 10, 2009 provided an understanding of the issues particular to each area including sediment type, shoreline orientation, biological communities, and shoreline development, to name a few.

Follow-up phone calls. Additional information was gathered from environmental scientists, engineers, and geologists from University of Delaware and other sections within DNREC through teleconferences. These contacts provided additional literature, mostly related to horseshoe crab nesting and shorebird foraging.

Aerial photography. Oblique aerial photographs were taken in April 2009 going north from Lewes to Kitts Hummock and then going south back to Lewes. All photos were taken using a 21 MP Canon EOS 1DS Mark III.

Coastal environment characterization. Available data and past studies were analyzed to determine the dominant physical conditions and forcings that influence shoreline evolution in Delaware Bay, including wind, waves, tidal circulation, and storm events. These factors were used in the development of the design beach templates for each community.

Historical analysis. Data and conclusions from previous studies and reports were used as the basis for estimates of historical shoreline erosion rates as well as longshore transport rates and directions for each community.

Wave and circulation modeling. Planning-level models were developed to examine wave transformation and tidal circulation in Delaware Bay for a variety of normal and extreme conditions. The model results were used to supplement the results of previous historical studies in developing design beach templates and optimizing nourishment placement.

Beach fill template design and optimization. A beach erosion model was used to estimate berm erosion due to a design storm. The resulting eroded volume combined with historic erosion rates was used to develop conceptual design beach fill templates for several life expectancy periods. Modeling results, historical longshore transport estimates, and local knowledge gained from previous beach fill behavior was used to develop a fill placement strategy using a “feeder beach” method.

4. Literature Review and Data Collection

4.1 Existing Studies

Existing historical data, reports, and other information related to the coastal communities of Delaware Bay were acquired from DNREC, USACE, and University of Delaware files. This information was used to obtain an understanding of the physical processes and biological communities in the coastal regions of Delaware Bay. These reports are referenced throughout this plan; a list of literature is provided in Section 9: References.

Information gathered for each community included state and federal permit applications and final permits, which included project drawings, correspondence between DNREC and the permitting agencies, bid documents, and contract documents as available. The information gathered from these documents was fairly complete but details were often missing regarding sand source, placement method, and/or specific placement location. Specific resource studies were available for some beaches, including sand source studies and historical resource identification studies.

Important information and data on biological communities was obtained through discussions with University of Delaware and DNREC biologists. Horseshoe crab nesting density has been systematically surveyed since 1999, giving a picture of nesting trends in relation to beach nourishment events over time. A recently-completed PhD thesis provided information on the ability of Sabellarid worms to recolonize after sand placement events.

The USACE provided detailed information on the federally-mandated projects along Delaware Bay, particularly the Broadkill Beach project. They also provided background information on the morphology and geology of Delaware Bay and assessments of the Low-Cost Shore Protection Project.

Studies performed by the University of Delaware (Maurmeyer, 1978 and French, 1990) provided information on historical shoreline change rates, coastal environment characterization, and estimates of longshore sediment transport. This data was crucial in evaluating past management practices and developing new designs and strategies for the bay beaches.

4.2 Existing Data

The following provides a catalog of the data compilation effort completed in support of this study. Available data includes hydrodynamic data, aerial photographs, and published research articles from various sources, including government, private, and academic entities.

Current measurements (ADCP) at Fowler Beach (University of Delaware)
November 3-11, 2008
Binary RDI format + delimited text

High-resolution digital coastline shapefile (NOAA National Geophysical Data Center)
GEODAS format, Geographic NAD83 datum

Delaware Bay, Delaware River, and Atlantic Ocean bathymetry (NOAA)
Various surveys compiled
XYZ delimited text, Geographic NAD83 datum

Digital Elevation Models, New Jersey and Delaware (USGS)
New Jersey – 30 m resolution, 1998; UTM-18 datum, NAVD88 (m)
Delaware – 30 m resolution, 1993; UTM-18 datum, NAVD88 (m)

Aerial Photography (Delaware DataMIL)
1937, 1954, 1961, 1968, 1992, 1997, 2002, 2006, 2007
MrSID format, County or Quad separated

Navigational Charts (NOAA)
Raster images

Measured directional wave data (NOAA NDBC)
44009 – May 1993 to October 1998 (Atlantic Ocean)
44054 – February 2007 to January 2008 (Delaware Bay south)
44055 – June 2007 to January 2008 (Delaware Bay north)

Hindcast wave data (USACE)
WIS Stations 152, 154 (Atlantic Ocean)
1980 to 1999

Wind data (NOAA NDBC)
44009 – 1984 to 2008 (Atlantic Ocean)
BRND1 – 2006 to 2008 (Delaware Bay south)

Verified tide levels and datums (NOAA Tides and Currents)
Cape May, NJ
Ship John Shoal, NJ
Philadelphia, PA
Delaware City, DE

Reedy Point, DE
Brandywine Shoal Light, NJ
Lewes, DE

Beach profile data (DNREC)
Delaware's bay shoreline, Pickering Beach to Broadkill Beach
Varied dates and locations, 1995 to 2009
XYZ delimited text, DE State Plane NAD83, NAVD88 (ft)

Beach structure / nourishment project data (DNREC)
Dates, fill volumes, project lengths, costs, etc. where available
1940s to present

Horseshoe Crab Nesting Data (DNREC)
Horseshoe crab nesting density data
1999 to 2008

5. Characterization of Delaware Bay Beaches

5.1 Introduction

A comprehensive management plan requires an understanding of the factors involved, including physical characteristics and environmental resources, local and federal funding and political considerations. The following sections describe various aspects pertinent to the development of a beach management strategy. The majority of presented information and data has been compiled from previous studies and reports.

The coastal environment is characterized by the set of physical characteristics and forcing conditions that drive the hydrodynamics and sediment transport in the region. These include currents, wind, waves, astronomical tides and river flows. An understanding of these parameters is necessary to perform analysis on circulation and beach morphology. These analyses are a crucial component in the development of design beach templates and strategies.

An understanding of the geologic history and morphology of the Delaware Bay beaches provides insight into how the sandy beaches were formed and where potential sources of beach-quality sediment may be located.

Delaware Bay is well-known for its importance as a flight stopover area for migratory shorebirds, which make their stop in Delaware to feed on horseshoe crab eggs that are laid on the Bay beaches each summer. Their presence, in addition to that of other species of concern, makes the protection of the beaches particularly important. An understanding of the important natural communities that use the Delaware Bay beaches and nearshore as habitat is important in designing beach projects that cause minimal impact and provide quality habitat. Because of its importance as habitat, the shoreline consists of a number of state, federal, and private protected areas. Varying levels of use are permitted in each area, but they are all significant to the management of the bay beaches.

The Delaware Department of Natural Resources and Environmental Control and the USACE have been involved in the management of the Delaware Bay beaches since the 1950s. Through enactment of legislation to protect the beach and direct involvement with project construction, they both have significantly affected the condition and management of the beaches today.

5.2 Coastal Environment

5.2.1 Tides

Tides in Delaware Bay and the adjacent Atlantic Ocean are semidiurnal, exhibiting two high and two low tides per day. Some amplitude modulation exists, meaning tide elevations can vary significantly between two successive tides. Due to the funnel-like geometry of Delaware Bay, tidal ranges up the bay and in the Delaware River are typically larger than those at the bay mouth. The head of tide is located at Trenton, NJ, roughly 125 mi (200 km) upstream from the Atlantic Ocean. Table 5.1 outlines tidal characteristics at several locations in the estuary.

Table 5.1 Tidal characteristics at several locations in the Delaware Bay estuary.

Location	MHW (ft NAVD88)	MLW (ft NAVD88)	Range (MHW-MLW, ft)
Lewes, DE	1.6	-2.5	4.1
Cape May, NJ	2.0	-2.9	4.8
Reedy Point, DE	2.6	-2.8	5.3
Philadelphia, PA	3.0	-3.0	6.0

5.2.2 Wind

Maurmeyer (1978) described the wind environment of the Delaware Bay region, using data and analysis from several sources. Annually, the prevailing wind direction is from the northwest. However, the strongest winds originate in the northeast, typically caused by winter nor'easter storms. Figure 5.1 is wind roses for annual as well as seasonal time periods. During winter, northwesterly winds are by far the prevailing condition. In springtime, there is significant input from the northeast and south. South and southwest winds are most common during summer, while northwest and northeast dominate in autumn. Figure 5.2 is a wind rose for data from Brandywine Shoal Light, covering the period between March 1, 2006 and December 31, 2008. The directional distribution in this data is similar to that seen in Figure 5.1. The maximum recorded wind speed over the ~2 yr time period is 55 mph (24.8 m/s), and the average speed is 15 mph (6.7 m/s).

Table 5.2 (Maurmeyer, 1978) outlines wind speed statistics for the region. The mean annual wind speed is 11 mph (4.9 m/s), and the highest average wind speed occurs during the winter. Gale force or greater winds (greater than 47 mph (20.8 m/s)) occur 0.3% of the time annually, most often in winter. Table 5.3 lists the extreme return period sustained wind speeds from the Offshore & Coastal Technology, Inc. (OCTI) 1994 Delaware Bay hindcast. Numbers are taken from the Kitts Hummock hindcast location for both nor'easters and hurricanes, but other areas in the region are nearly identical. A sustained gale force wind event has an approximate 10 yr recurrence interval.

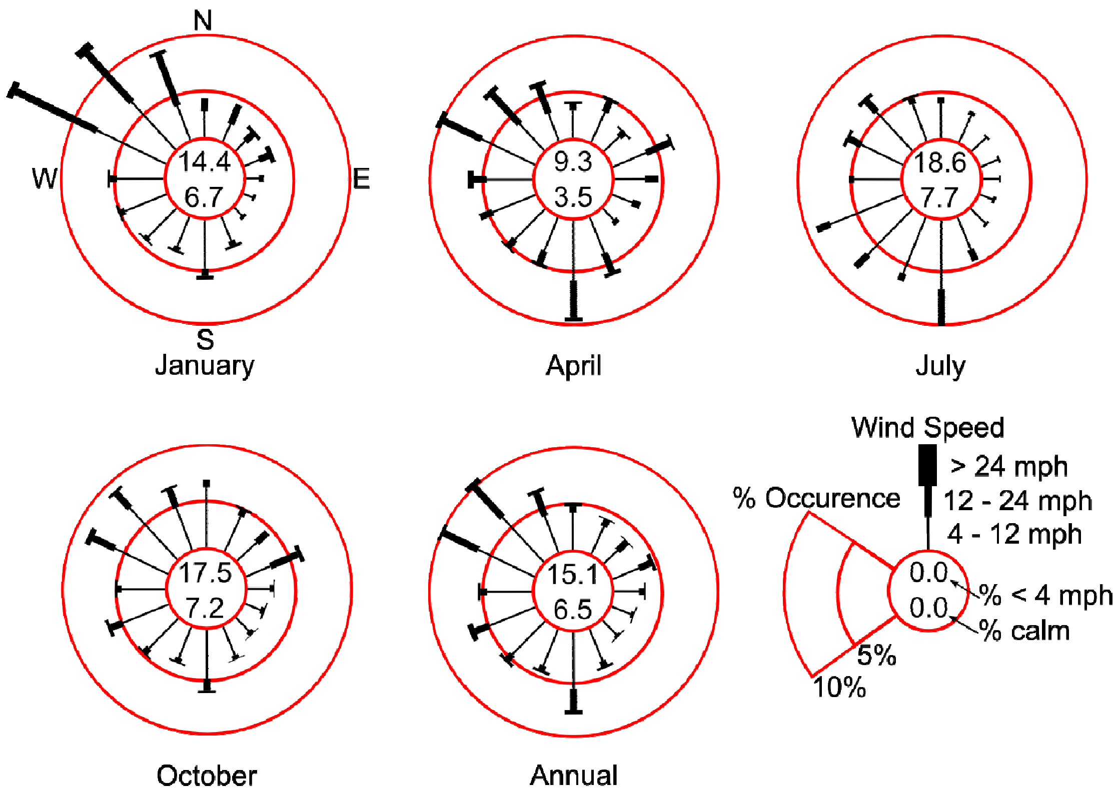


Figure 5.1 Wind roses for the Delaware Bay region (Maurmeyer, 1978).

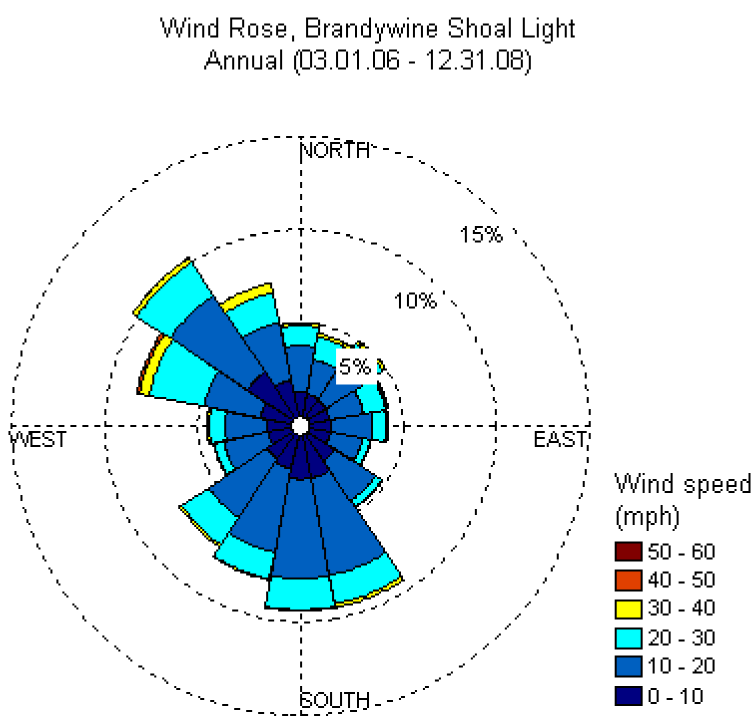


Figure 5.2 Wind rose for Brandywine Shoal Light, March 1, 2006 to December 31, 2008.

Table 5.2 Wind speed characteristics in Delaware Bay (Maurmeyer, 1978).

Time Period	Mean wind speed (mph)	Gale force occurrence % (% > 46.5 mph)
January	12.8	0.7
April	11.9	0.3
July	8.1	0.1
October	10.5	0.2
Annual	11.0	0.3

Table 5.3 Extreme wind speed recurrences (OCTI 1994).

Recurrence Interval (yr)	Wind Speed (mph)
5	40.7
10	46.1
25	52.3
50	56.8
100	61.3
250	67.1
500	71.6

5.2.3 Waves

Waves in Delaware Bay are predominantly generated by local winds; swell from the Atlantic Ocean has a limited influence only on the southernmost bay beaches from Broadkill to Slaughter Beach. Figure 5.4 illustrates wave roses for Delaware Bay from Maurmeyer (1978).

The distribution of wave occurrences corresponds fairly well with the wind distributions shown in Figure 5.1; the majority of waves originate from the north and northwest on an annual basis, and most waves are less than 1.6 ft in height. NOAA maintains a directional wave buoy (Buoy 44054) offshore of Broadkill Beach, and archived data is available for the period of February 6, 2007 to January 29, 2008 (Figure 5.3). Figure 5.5 presents wave roses of this data set.

Figure 5.3 Locations of NOAA Buoys 44009 and 44054.

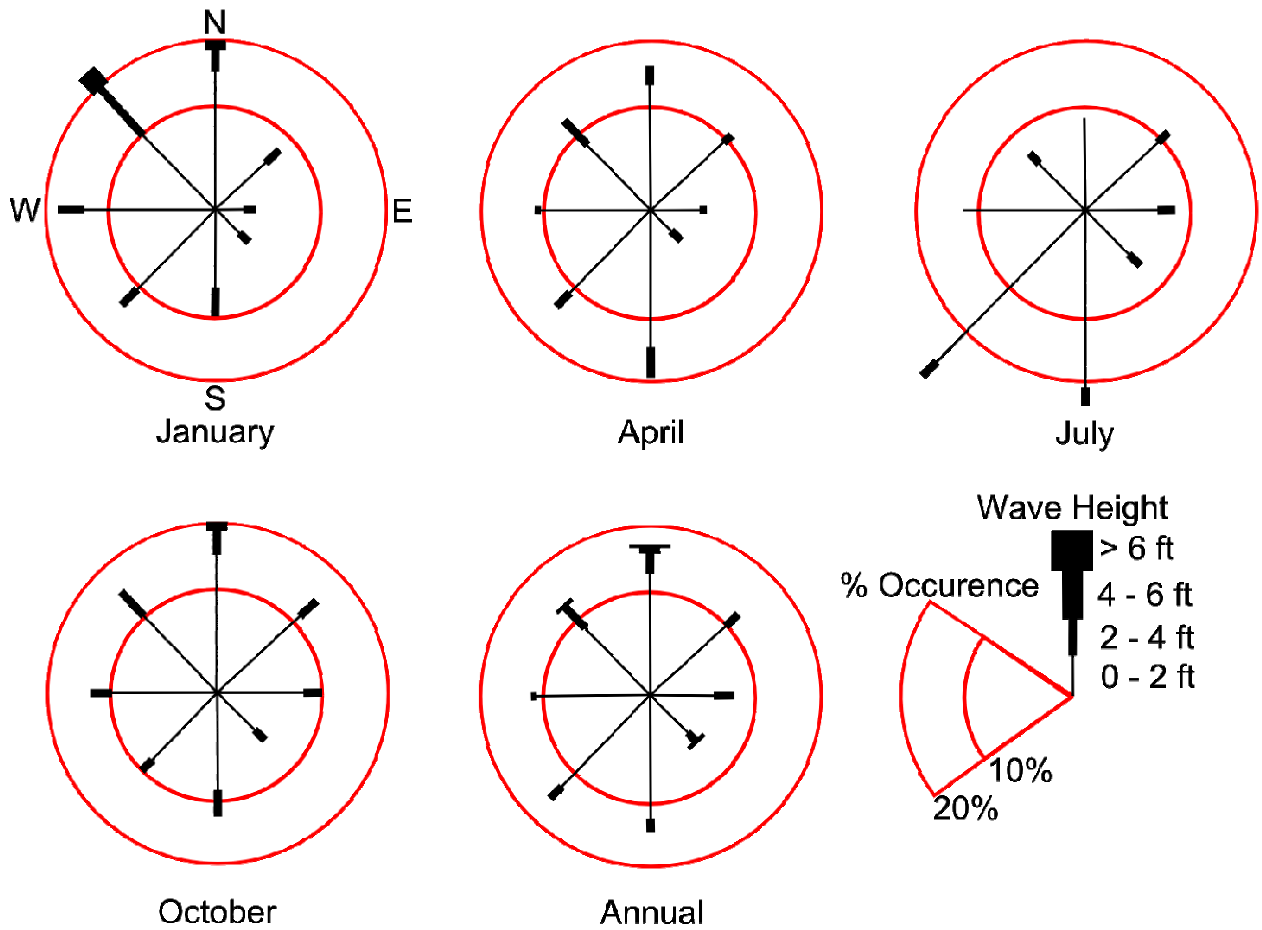


Figure 5.4 Wave roses for Delaware Bay (from Maurmeyer, 1978).

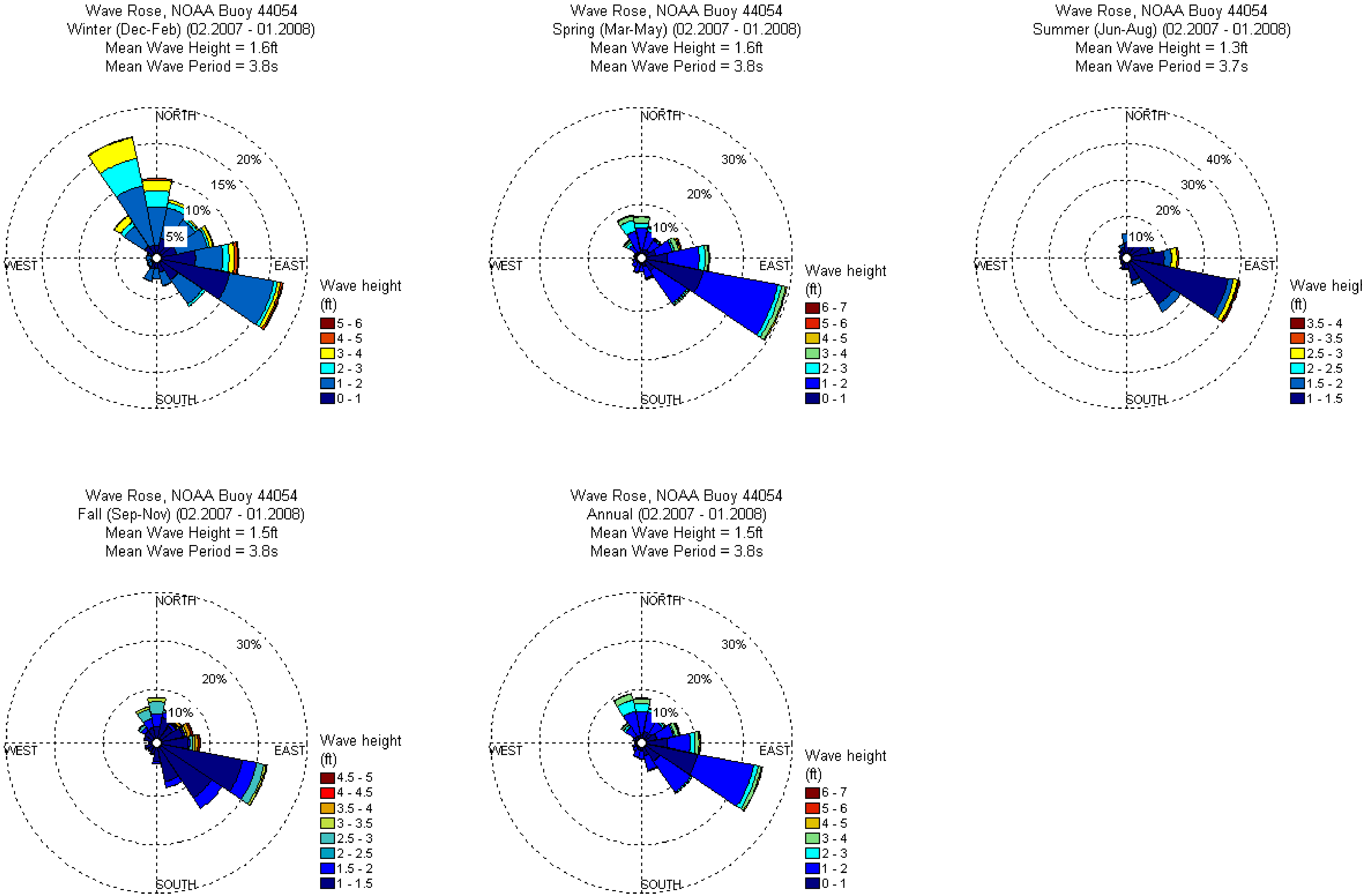


Figure 5.5 Wave roses for NOAA Buoy 44054.

The mean annual wave height during this period is 1.5 ft, with a maximum value of 6.6 ft. The winter season exhibits a strong northwesterly influence, likely due to waves generated during high wind events. Based on the dominance of the east-southeasterly direction of wave height during all seasons, as well as the buoy's proximity to the mouth of Delaware Bay, it appears that there is a significant amount of wave energy from the Atlantic Ocean propagating to the buoy's location.

Table 5.4 presents extreme wave height statistics taken from OCTI's 1994 Delaware Bay hindcast for the combined population of hurricanes and nor'easters. As expected, the predicted wave heights diminish up the bay; Lewes would likely see a 17.4 ft wave during a 100 yr return period event, while Reedy Point would experience a 10 ft wave. Directionality was not taken into account in this study.

Table 5.4 Extreme wave heights and recurrence intervals, in feet (OCTI, 1994).

	Return Period (yr)						
Location	5	10	25	50	100	250	500
Kitts Hummock	6.6	7.9	9.5	10.5	11.8	13.1	14.1
Bowers Beach	6.6	7.5	8.9	9.8	10.5	11.8	12.8
Mispillion S	7.5	9.2	10.8	11.8	13.1	14.4	15.7
Broadkill Beach	7.9	8.9	10.2	11.2	12.1	13.5	14.4
Lewes	10.2	12.1	14.4	16.1	17.4	19.7	21.3

Figure 5.6 illustrates wind roses for NOAA Buoy 44009, located in the Atlantic Ocean offshore of the Delaware coast. Directional wave data was available for the period of May 1993 to November 1998. Similar to Buoy 44054, the predominant wave direction is from the south-southeast, with the winter season exhibiting some influence from the northwest. Mean wave height is highest in the winter (4.9 ft) and lowest in the summer (3.0 ft); annually the average is 3.9 ft.

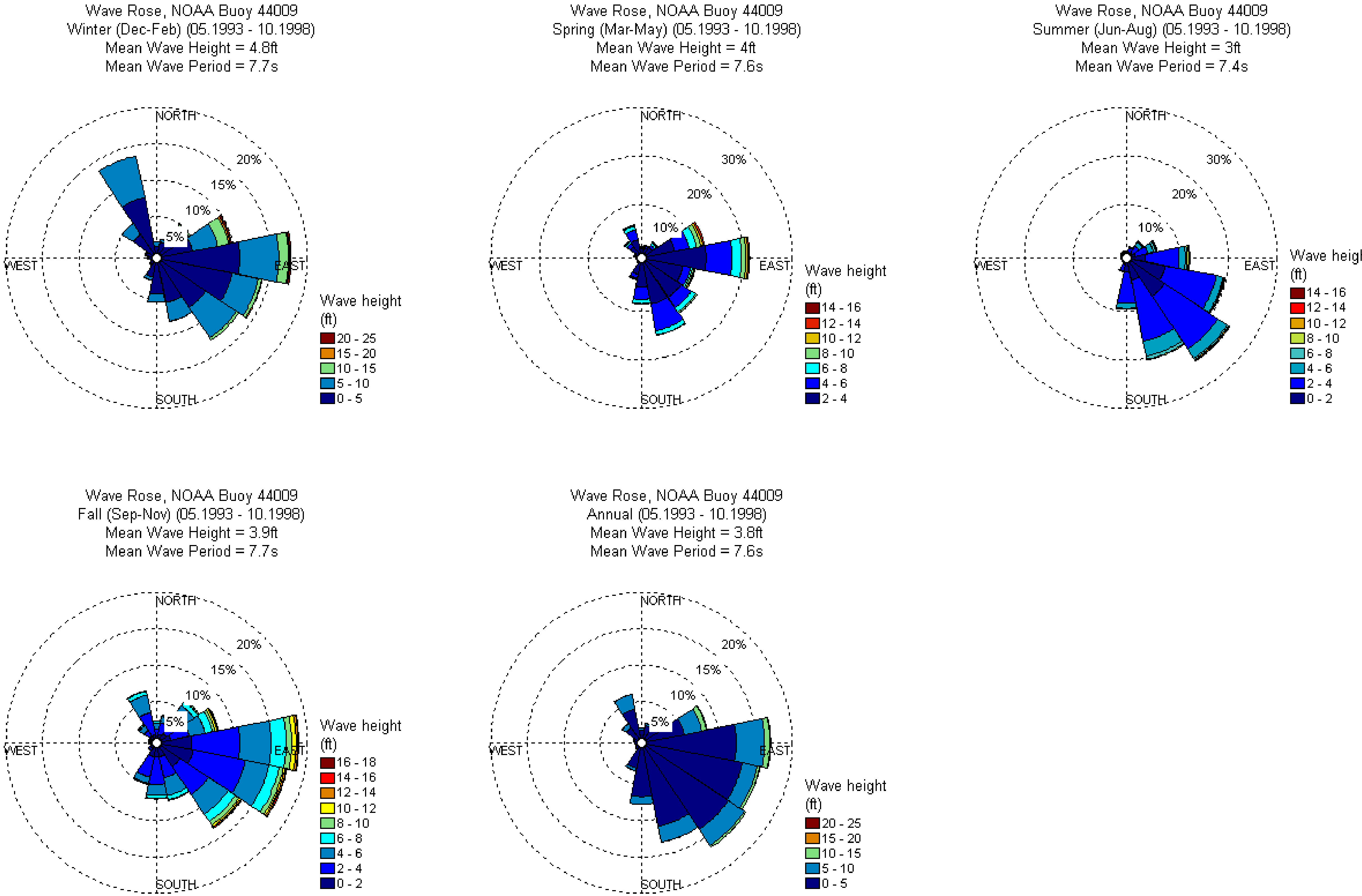


Figure 5.6 Wave roses for NOAA Buoy 44009.

5.2.4 Major Storm Events

In recent history, influential storms influencing Delaware Bay beaches include nor'easters in March 1962, December 1974, January 1992, January 1998, February 1998, and May 2008 and a hurricane in September 1985. These storms caused varying levels of structural damage along the Bay shoreline. Between 1923 and 1974, there was an average of 0.8 storms per year that caused significant damage to the coastal zone of Delaware (Delaware Coastal Management Program, 1977). According to this study, which covered the time period between 1923 and 1974, the average storm tide lasted 40 hours, with the longest duration being 96 hours, during the Ash Wednesday Storm of 1962. This storm also had the highest tide level, reaching 7.9 ft above MSL (7.5 ft NAVD88) at Lewes Harbor. Note that this level corresponds approximately to a 75 yr return period event according to OCTI's hindcast in the next section. The average storm tide level was 5 ft above MSL (4.6 ft NAVD88) for this period. The Mother's Day Storm of 2008 is the most significant nor'easter in recent memory, bringing a peak storm surge of 5.2 ft NAVD88 to Lewes Harbor.

5.2.5 Storm Event Frequency-of-Occurrence / Return Period

An important aspect of coastal management is the understanding of storm frequency-of-occurrence for a given area. There are various techniques to determine storm frequency-of-occurrence. Largely, these techniques rely on historic data to calculate (through probabilistic and statistical methods) site-specific storm frequency relationships. In general, these techniques utilize various parameters that define a given storm event (wind speed and direction, surge elevation, wave height and period, barometric pressure) in order to develop recurrence relationships (return periods).

Coastal protection projects are typically designed to provide a certain level of protection against a specific return period event, and the project is designed based on the maximum storm surge associated with that event's frequency-of-occurrence. One such relationship is shown in Figure 5.7, demonstrating the stage-frequency relationship, up to a 200-year return period storm, for Lewes, DE.

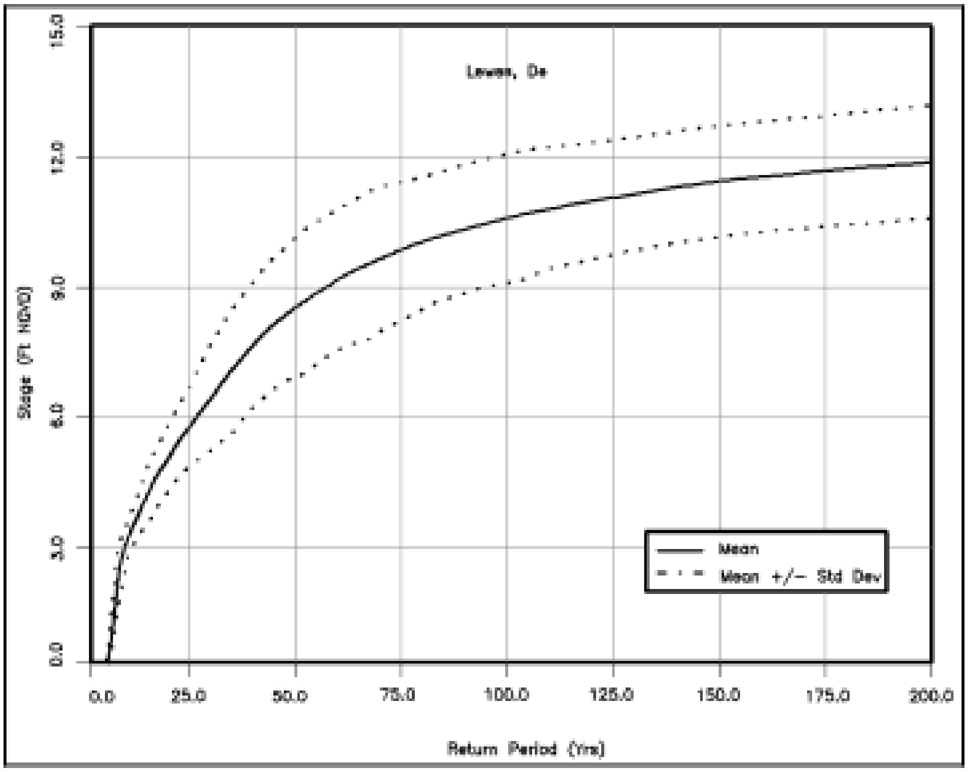


Figure 5.7 Stage-frequency relationship along the coast of Delaware (CEM Figure II-5-27).

It is important to note that return periods can vary within a small geographic area. As stated above, the storm frequency-of-occurrence is largely based on historic data. Depending on these records, a given storm event may represent varying return periods for different coastal locations. In the case of coastal Delaware, return periods for the same magnitude storm surge can differ between the Atlantic Ocean and Delaware Bay coastlines. Other factors also contribute to variations in return periods, such as storm duration, approach angle, and the orientation of the coastline. Therefore, it is not unusual for the same storm surge elevation to vary in its frequency-of-occurrence at different locations along the coastline of Delaware Bay, as will be shown in subsequent sections.

5.2.6 Storm Surge

Delaware Bay is vulnerable to extremes in tide elevations, most commonly caused by nor'easters and hurricanes. Table 5.5 outlines storm surge statistics as calculated by OCTI (1994). These values are the combined influence of storm surge and astronomical tide. The original report referenced the elevations to MLW; here, they are referenced to NAVD88, which is about 2.5 ft above MLW for the lower Delaware Bay region. For reference, the 2008 Mother's Day Storm produced a peak tidal elevation at Lewes of 5.2 ft NAVD88.

Table 5.5 Extreme water levels and recurrence intervals, in feet NAVD88 (OCTI, 1994).

	Return Period (yr)						
Location	**5**	**10**	**25**	**50**	**100**	**250**	**500**
Reedy Point	4.3	5.2	6.6	7.5	8.5	9.8	10.8
Bowers Beach	4.6	5.9	7.2	8.2	9.2	10.5	11.5
Broadkill Beach	3.9	5.2	6.2	7.2	8.2	9.2	10.2
Lewes	3.9	4.9	6.2	7.2	7.9	9.2	10.2

5.2.7 Currents and Circulation

Circulation within Delaware Bay is influenced by astronomical tides, wind, freshwater inflows, and, to a lesser extent, waves. Maurmeyer (1978) presented estimates of the mid-channel ebb and flood current magnitudes, which range from over 3.3 ft/s at the bay mouth to around 1.3 ft/s near the St. Jones River. Ebb currents are stronger than flood currents due to freshwater inflow from the Delaware River. Figure 5.8 presents these current velocities at several locations along Delaware Bay.

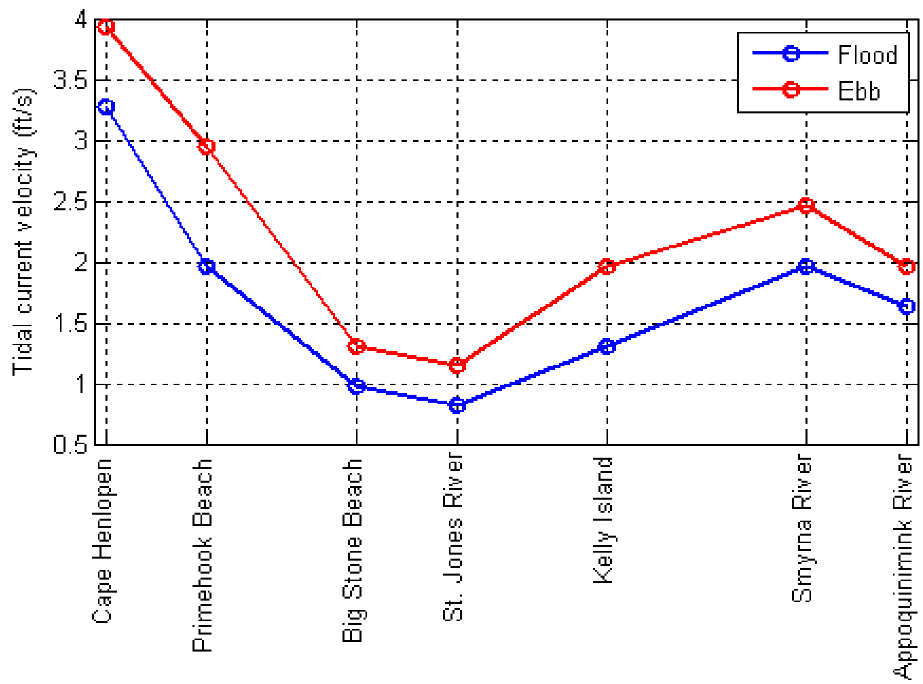


Figure 5.8 Mid-channel ebb and flood currents in Delaware Bay (Maurmeyer, 1978).

A series of field investigations were undertaken by the University of Delaware between July 1976 and September 1977, during which currents at a number of Delaware Bay beaches were measured. This data is presented in Table 5.6. Southerly transport appears to be the dominant longshore current direction.

Table 5.6 Measured current velocities at Delaware Bay beaches (Maurmeyer, 1978).

Location	Date	Longshore current velocity (ft/s)	Direction
Pickering Beach	9-28-76	0.8	south
	6-8-77	0.3	south
Kitts Hummock	9-29-76	0.8	north
	7-14-77	0.8	south
	9-28-77	0.5	south
South Bowers	7-14-76	0.3	south
	10-5-76	0.4	south
	10-12-76	0.4	north
	1-10-77	0.3	south
Slaughter Beach	10-5-76	0.5	south
Fowler Beach	7-13-76	0.4	south
	12-17-76	0.3	south
	6-29-77	0.3	south
	9-28-77	0.5	south
Primehook Beach	10-5-76	0.6	south
Broadkill Beach	7-13-76	0.3	south
	3-21-77	0.5	northwest
Lewes Beach	12-20-76	0.1	northwest
	3-21-77	0.2	northwest

Data is available from an Acoustic Doppler Current Profiler (ADCP) deployed by the University of Delaware at Fowler Beach. The data covers approximately one week in the beginning of November 2008. Figure 5.9 shows a time series of the depth-averaged velocity measurements recorded by this instrument; a positive value indicates a northerly direction. This data shows a slightly southerly average velocity of less than 0.1 ft/s, with identical peak northerly and southerly velocities of 2.1 ft/s.

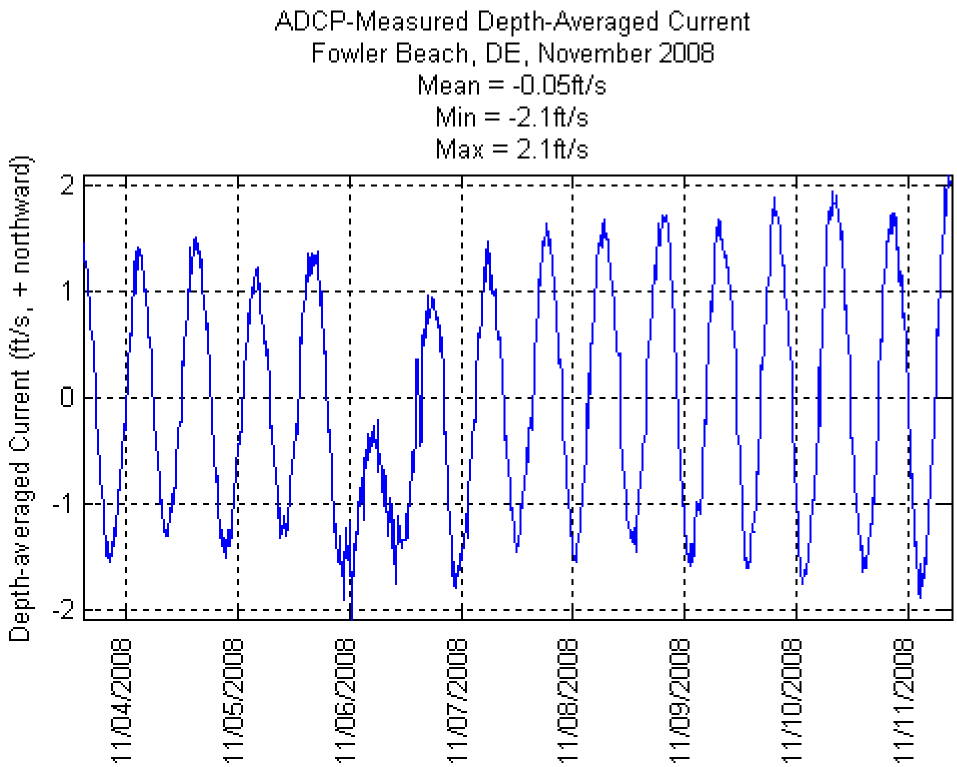


Figure 5.9 Current measurements at Fowler Beach, November 2008 (University of Delaware).

5.3 Geologic History and General Morphology

The Delaware Bay coastline has been shaped by geological processes that began approximately 17,000 years ago. Due to a much lower sea level at that time, Delaware Bay was a narrow freshwater river. As ice sheets to the north melted, sea level rose, and about 11,000 years ago, the Delaware Bay estuary began to form. Relative sea level has continued to rise at a rate of approximately 1.0 ft per century for the past 70 years (Drew, 1981).

Delaware Bay is 47 mi long and 27 mi wide measured at the widest point. The greatest depth is 150 ft (with a mean depth of 31 ft) (Maley, 1981). Due to the relatively short fetch over the surface of the Bay, wave energy along the Delaware Bay shoreline is fairly low (Maley, 1981). Waves in Delaware Bay generally average less than 2.0 ft in height (more than 80% of the time) but can reach heights of greater than 6 ft (less than 2% of the time) (Drew, 1981). Littoral drift and storm overwash are the dominant morphologic processes that affect and maintain the shoreline (Maley, 1981).

The shorelines of Delaware Bay have historically received sediment from five sources (Drew, 1981). The first is material eroded from sediments that are exposed as a series of headlands that separate ancient streams. At areas of high elevation between the ancient river valleys, Pleistocene material is close to the surface and may provide sediment to the beaches. This source accounts for most of the coarse-grained material supplied to the beaches (Maurmeyer, 1978). At former valleys, thick layers of marsh and lagoonal muds cause subsidence and high erosion rates. The second source is longshore transport from adjacent beaches, which is influenced by incident wave direction, coastal morphology, wind fetch, and adjacent shore protection projects and/or structures. Along the area of concern, southward transport (17.0 - 51.0 yd^3/day) is greater than northward transport (10.0 - 14.0 yd^3/day); therefore, the net sediment transport direction is from north to south (Drew, 1981).

Historically, a third source of sediment was the ocean coast. In the past, material would travel around Cape Henlopen and northward through Primehook. However, construction of the breakwaters in Breakwater Harbor has essentially cut off this supply of material (Drew, 1981). The Broadkill Beach shoreline was supplied with sand transported around Cape Henlopen, forming a spit at Broadkill Beach which modified the outlet location of the Broadkill River (Figure 5.10).

Offshore shoals within the Bay, including linear sand shoals and ebb tidal deltas, provide a fourth source of material. Shoals from ebb tidal delta contribute significant amounts of sand and gravel to the beach, especially at Slaughter Beach. Many of these shoals are located at the mouth of relict inlets such as offshore of Slaughter Beach, Broadkill Beach, and Primehook Beach. Finally, a small amount of material may be eroded inland and carried to the coast by streams and rivers.

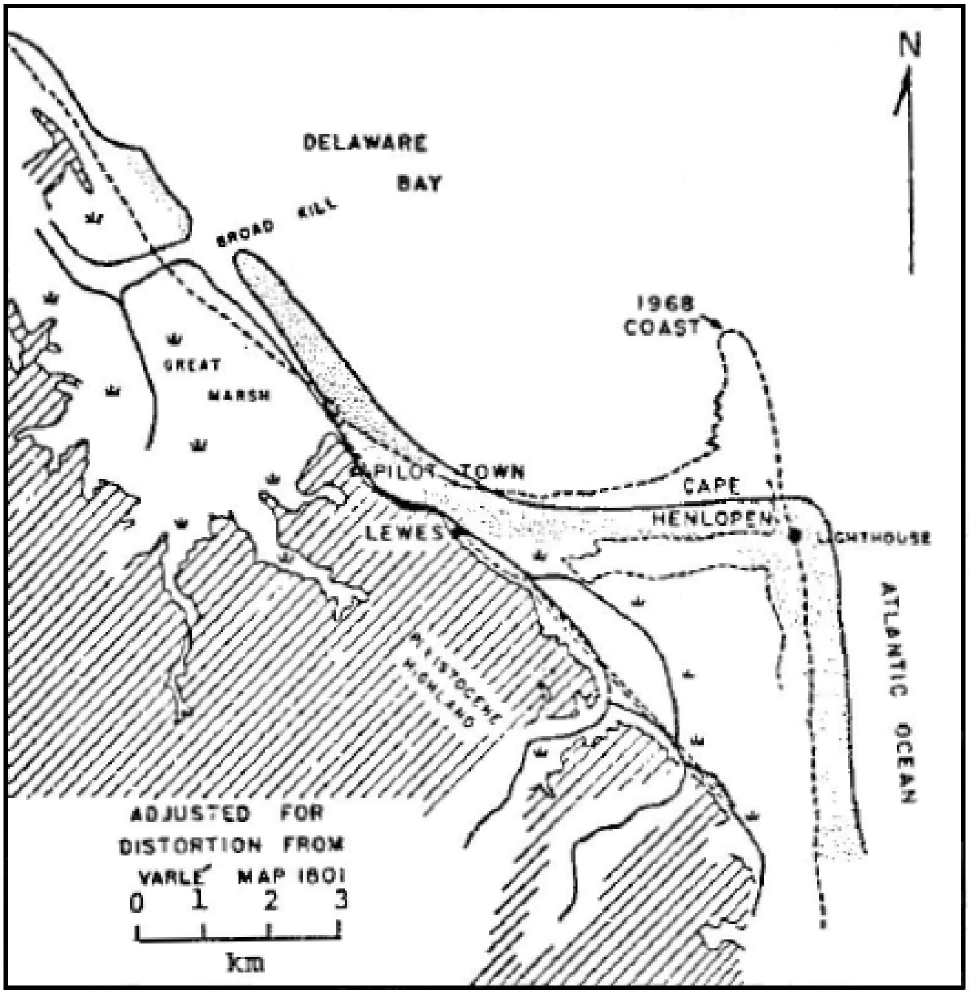


Figure 5.10 History of Cape Henlopen spit (Maurmeyer, 1978).

Most of the Delaware Bay shoreline between Pickering Beach and Broadkill Beach is characterized by broad marshes with a narrow barrier of sand along the beach (Kraft et al., 1976). The barrier is widest and most well-developed near the mouth of the bay south of Primehook, becoming less prevalent to the north. The sediments along the southern portion of the Bay are fine-grained and well-sorted (Maurmeyer, 1978) while the northern portion is composed of locally derived, coarse sands and gravels (Maurmeyer, 1978; Kraft and Others, 1979).

The nearshore zone of Delaware Bay is characterized by broad, shallow, tidal flats. Up to 35% of the bay area is represented by these flats, which are covered by less than 4 m of water (Weil 1981). Along the southwestern shoreline, subtidal flats are mostly sandy, with mud locally important in some areas; toward the northwest, subtidal flats become muddier (Weil, 1976).

5.4 Adjacent Land Uses

The Delaware Bay shoreline is comprised of many acres of protected lands. Consideration of these areas regarding the potential impact of implementing recommended shore protection strategies is important. Communication with resource managers and stakeholders in necessary to meet varying needs. Figure 5.11 shows approximate locations and a brief description of each of these protected lands follows below.

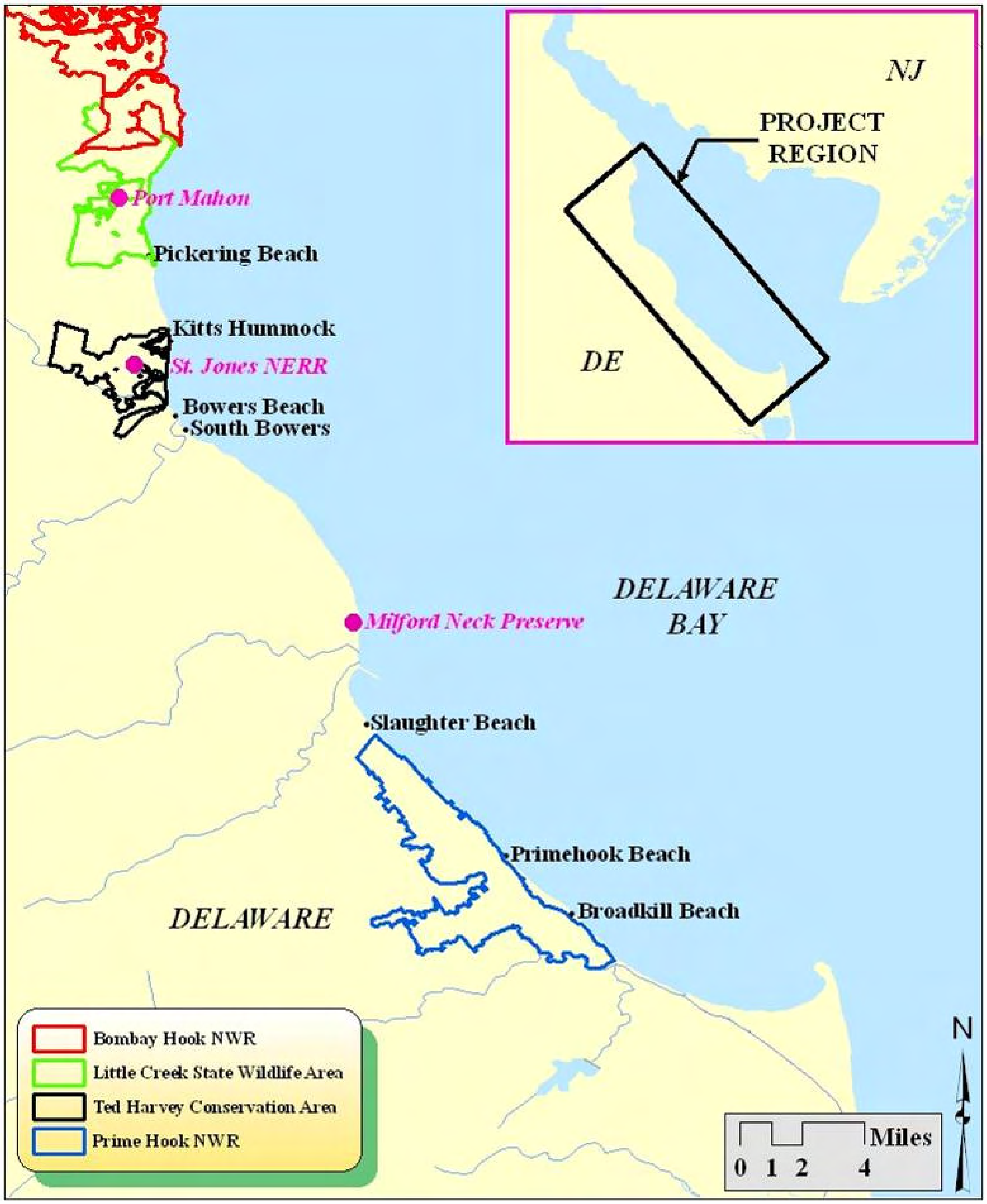


Figure 5.11 Protected lands in relation to the Delaware Bay communities.

St. Jones Reserve (Delaware National Estuarine Research Reserve). The St. Jones Reserve is located on the north shore of the St. Jones River and includes a portion of Delaware Bay. The Reserve is characterized by tidal water, salt marshes, and open water including creek, river, and bay areas, buffered by wooded areas, farmlands, and meadows. Within the Reserve's boundaries, 698.5 acres of tidal marshes, upland fields, woodlots, and croplands were purchased or protected by the Delaware National Estuarine Research Reserve in 1991-1992 but the remaining majority is privately owned.

Ted Harvey Conservation Area (DNREC). To the east of the St. Jones Reserve is the Ted Harvey Conservation Area, which is owned and managed by DNREC's Division of Fish and Wildlife. It consists of 2,019 acres of land, including portions of the Delaware Bay shoreline.

Prime Hook National Wildlife Refuge (U.S. Fish and Wildlife Service). Primehook National Wildlife Refuge, established in 1963 under the authority of the Migratory Bird Conservation Act, stretches from Slaughter Beach to the Broadkill River and protects more than 10,000 acres of mostly fresh and saltwater wetlands. The primary objective of the Refuge is to provide habitat and protection for waterfowl, waterbirds, and other migratory birds, and endangered species.

Milford Neck Preserve (The Nature Conservancy). The Nature Conservancy acquired the Milford Neck Preserve in 1990 and began converting former agricultural fields into native coastal deciduous forests. With assistance from the Delaware Department of Fish and Wildlife and Delaware Wild Lands, Inc., the Conservancy established the 10,000 acre Milford Neck Conservation Area in 1998. This tract of land, characterized by beaches and dunes, marshlands, upland forests, and agricultural lands, is an important migratory shorebird feeding ground for which Delaware is famous.

Port Mahon (The Nature Conservancy). Port Mahon preserve lies within a large conservation area that includes Bombay Hook National Wildlife Refuge and Little Creek State Wildlife Area. The Conservancy obtained the 341 acre tract of land in 1990 and manages it as a natural area with controlled public use. Like Milford Neck Preserve, this area is an important feeding ground for migratory shorebirds.

Bombay Hook National Wildlife Refuge (U.S. Fish and Wildlife Service). Bombay Hook NWR, established in 1937, comprises 15,978 acres, most of which is tidal salt marsh. As one of the largest expanses of nearly unaltered salt marsh, it serves as a refuge and breeding ground for migrating shorebirds and other wildlife.

Little Creek State Wildlife Area (DNREC). The Little Creek State Wildlife Area consists of 3,897 acres of marshlands and impounded ponds and is known for its attraction of migratory shorebirds.

Public Use Easements. As part of the State's beach erosion control program, DNREC has acquired easements to several Delaware Bay beaches. The easements are established prior to initial sand placement on a stretch of beach and are perpetual. The primary purpose of the easements is to allow construction equipment access to the beach when necessary. However, they also provide for expanded public access to the shoreline in areas where the beach and dune are constructed and maintained using public funds.

5.5 Environmental Resources and Permitting Considerations

This section addresses the existing conditions and important biological species resident along the entire Delaware Bay shoreline. The discussion below is an overview of environmental considerations that will need to be taken into account when permitting projects along the shoreline and is not intended to provide the level of detail that will be required as part of the process of filing actual environmental permitting applications.

5.5.1 Environmental Setting

The beaches of Delaware Bay serve as an important breeding ground for horseshoe crabs and the largest staging area for shorebirds in the Atlantic (Atlantic State Marine Fisheries Commission). This coastline has been designated as a globally important bird area by the National Audubon Society and the American Bird Conservancy. For this reason, appropriate protection of this shoreline is particularly important to create and maintain the sandy beach habitat.

5.5.2 Horseshoe crabs

Throughout their range from Maine to the Yucatan Peninsula, horseshoe crabs provide an important food source for migrating shorebirds, finfish, and Atlantic loggerhead turtles. Because of their important role in the continued existence of dependent species, as well as their use in the biomedical industry and as bait in the American eel and conch pot fisheries, horseshoe crabs are managed regionally by the Atlantic States Marine Fisheries Commission (ASMFC) and on a statewide basis. The Delaware Division of Fish and Wildlife has been monitoring horseshoe crab nesting density for the past ten years. Some of the data from this monitoring work is presented in Table 5.7.

Table 5.7 Index of female spawning horseshoe crab abundance, expressed as the mean number of female crabs per yd^2 per night (adapted from Michels et al., 2009).

Beach	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Pickering		3.95	1.94	2.03	1.96	1.96	1.76	1.78	1.96	2.38
Kitts Hummock	2.57	3.09	2.81	1.76	1.85	1.48	1.70	2.06	1.72	1.47
North Bowers	1.05	1.41	1.24	1.45	1.17	0.60	0.72	0.90	1.33	0.43
South Bowers		1.10	1.00	1.35	0.56	0.57	0.75	0.86	1.55	0.68
Slaughter	1.94	1.59	1.31	0.87	1.97	1.82	0.81	1.24	1.48	1.32
Primehook	0.72	0.23	0.53	0.71	0.56	0.91	0.78	0.87	1.33	1.10
Broadkill	0.38	0.07	.014	0.16	0.25	0.20	0.23	0.14	0.22	0.66

Sandy beaches and nearshore, shallow water, intertidal, and subtidal flats are considered essential horseshoe crab habitat for spawning as well as development of juveniles. Nesting occurs on low-energy beaches between March and July, with a peak during May and June (Schuster and Botton, 1985). Egg development is dependent on temperature, moisture and oxygen content of the nest environment (Schrading et al., 1998).

Based on our literature search, the following is a summary of beach characteristics important to horseshoe crabs.

Grain size. Grain size plays an important role in egg development. The beaches of Delaware Bay are characterized by very coarse sand and cobbles. Sediment grain size determines the drainage of a beach, which in turn affects interstitial oxygen content (Gordon, 1960; Brafield, 1964; Eagle, 1983 in Penn and Brockmann, 1994). In addition to affecting moisture content on the beach, fine-grained sediments could decrease porosity and increase density, making the sediment resistant to wave action and more difficult to penetrate for egg deposition (Smith et al., 2002). Sediment sizes appropriate for spawning in Delaware Bay range from 0.35 mm to 2 mm (Botton et al., 1994; Smith et al., 2002).

Depth of sand. Adult horseshoe crabs are sensitive to hydrogen sulfide because it affects the development of eggs. In order for crabs to successfully nest on a beach underlain by marsh, there should be a minimum of 8 in of sand cover, but 16 in is optimal (pers. comm. Michels).

Beach slope. Slope has been determined to be an important orientation cue for nesting horseshoe crabs. Crabs that are not able to orient themselves to the water become stranded and desiccate on the beach. Botton and Loveland (1987) found that a slope of 6 degrees seaward (approximately 1V:10H) allowed both sighted and blinded crabs to orient to the shoreline. Any slope shallower than this caused crabs to have trouble finding their way back to the water line.

Location of borrow areas. Juvenile horseshoe crabs spend their first one to three years in nearshore shallow habitats. Borrow areas should be located sufficiently offshore so as to avoid impacts to this important nursery habitat (Schrading et al., 1998).

Timing. To protect spawning horseshoe crabs, time restrictions have been placed on certain beach-related activities. Beach nourishment projects are not permitted during the peak horseshoe crab nesting and shorebird foraging season between April 15 and August 30. The grouping of beach nourishment projects together may also cause ecological problems. Although building beaches regionally is desirable from a financial standpoint, there is concern from staff with the Delaware Coastal Management Program that placing sand on multiple beaches in the same year could cause disruption to nesting crabs over too large an area on the beach and juvenile crabs in the nearshore.

The northernmost four beaches (Pickering Beach, Kitts Hummock, Bowers Beach, and South Bowers) are the most important nesting habitat of the seven beaches considered in this plan. There may be an advantage to staggering full-scale beach nourishment at these four beaches. Based on discussions with staff members with the Coastal Management Program, it has also been suggested that these beaches be nourished as close to the beginning of the dredging season (April 15) as possible so that sediments have a chance to settle prior to nesting season.

5.5.3 Shorebirds

Delaware Bay serves as a primary feeding, resting, and staging area for an estimated 425,000 to 1,000,000 federally-protected migratory shorebirds during May and June every year (Wander and Dunne 1981; Myers 1981, 1986; Burger 1986; Myers et al. 1987; Clark et al. 1993 in Botton et al. 1994). Red knots (*Calidris canutus rufa*), ruddy turnstones (*Arenaria interpres*), sanderlings (*Calidris alba*), semipalmated sandpipers (*Calidris pusilla*), dunlins (*Calidris alpina*) and short-billed dowitchers (*Limnodromus griseus*) make an annual migration between wintering grounds in South America and breeding grounds in the Arctic. During their short stop in Delaware Bay, shorebirds must gain 50% of their body mass in order to successfully continue on their migration to their Arctic breeding grounds. For reference, red knots require an average daily intake of 18,000 horseshoe crab eggs to gain that mass (Andres, 2003). Red knot populations are declining drastically and are being considered for federal listing.

Although crab eggs are buried at a sufficient depth to avoid predation by shorebirds, which have relatively short beaks, wave action and digging by other nesting crabs uncovers enough eggs for foraging shorebirds. Birds gather at the water line and around shoreline discontinuities that tend to accumulate eggs (Botton et al., 1994). Shorebirds do not appear to be dependent on beach characteristics other than through the success of horseshoe crab nesting.

Table 5.8 Maximum counts of shorebirds made on spring aerial surveys of Delaware Bay beaches, 1986-2002 (Niles and Clark, unpublished data, Delaware Bay Shorebird-Horseshoe Crab Assessment Report).

	Ruddy Turnstone	Red Knot	Sanderling	Semipalmated Sandpiper	Dunlin	Dowitcher spp.
1986	88,234	58,156	16,193	285,802	8,054	166
1987	68,958	38,790	28,625	93,600	8,630	1,748
1988	58,390	34,750	41,055	177,110	2,030	2,980
1989	108,120	95,490	6,252	86,712	2,300	265
1990	32,301	45,860	5,378	48,185	2,875	1,130
1991	42,020	27,280	5,305	68,300	3,480	1,136
1992	53,930	25,595	7,330	42,630	11,245	6,335
1993	64,985	44,000	10,390	91,080	4,875	2,875
1994	80,795	52,055	9,955	95,180	12,165	5,045
1995	70,370	38,600	10,130	81,235	6,385	3,675
1996	47,115	19,445	8,355	41,190	8,740	8,330
1997	69,340	41,855	15,455	74,825	4,880	3,955
1998	101,660	50,360	23,520	67,745	16,305	6,830
1999	87,605	49,805	10,005	83,695	31,345	11,415
2000	69,000	43,145	20,815	100,635	39,935	10,185
2001	86,365	36,125	21,830	188,925	45,080	13,375
2002	64,690	31,695	13,835	51,320	32,305	13,000

5.5.4 Northern Diamondback Terrapins

Diamandback terrapins, which are protected by law in Delaware and are candidates for federal protection, are a year-round resident of the Delaware Estuary. They are generally found along Spartina marshes and adjacent nearshore bay waters. Females nest on land, often on or near beaches, during early June through mid-July. Terrapins are active from April to October and hibernate in the winter. The timing restrictions that have been placed on dredging to protect horseshoe crabs and shorebirds will offer protection to diamondback terrapins as well.

5.5.5 Sabellarid worms

Sabellarid worms (*Sabellaria vulgaris*), a tube-building polychaete, are found along the Mid-Atlantic coast. This species takes different forms throughout its range but the building of ‘reefs’ seems to be a unique characteristic of the Delaware Bay populations (Miller, 2002). More specifically, Sabellaria colonies seem to be limited to the southern portion of the western Delaware Bay shoreline. Brown (2009) found colonies at Broadkill, Primehook, and Slaughter. In addition, recent offshore mapping efforts have revealed widespread sabellarid coverage throughout the bay, indicating that their existence is not just limited to the nearshore regions. By cementing sand grains, these worms create bundles that extend 20 cm or more above the substratum to which they are attached. The ‘reef’ structures provide shelter to various invertebrate species and larvae of commercially important fish species.

Settlement of Sabellarid larvae occurs from spring to fall. It is assumed that up to 99% of intertidal worms die during the winter months due to low water temperatures. Subtidal adults appear to have higher survival rates and are likely the main contributor of the spring larvae. Larvae are attracted to existing structures so the presence of these structures promotes additional colony growth during the spring settlement.

Brown (2009) observed colonies over a seven-year time frame and through beach nourishment events at both Broadkill and Slaughter Beaches. The colonies were observed 2-3 years after burial by sand and the recovery time seemed to be closely linked with the re-exposure of beach protection structures and previously existing reefs. While beach nourishment seemed to be detrimental in the short-term due to the loss of habitat the reefs were more structurally stable upon re-emergence indicating the resiliency of the sabellarid colonies. In addition, if protective measures are not implemented to prevent shoreline erosion, long term adverse impacts to this habitat may result due to loss of essential sediment in an already sediment starved system. Another impact observed in the winter months (unrelated to beach nourishment) is icing that can be destructive to the nearshore and shallow colonies.

Due to the ephemeral nature of the sabellaria communities in Delaware Bay, particularly in the intertidal zone, mitigation has not been required in the past. However, recently the National Marine Fisheries Service has voiced concern over the potential loss of this fish habitat. Miller (2002) performed a pre-construction baseline monitoring study at Broadkill Beach and has suggested the following potential mitigation strategies, should the resource agencies determine that mitigation is necessary.

- Place suitable substratum, large rock in groins or jetties or cobble-sized gravel on sand beaches at the MLW elevation during the summer months following shoreline restoration.
- Remove the current reef masses to new shoreline locations to reconstruct or re-seed reefs via enhanced larval settlement.
- Reestablish reefs by placing colonized rocks from an extensive source population.

5.5.6 Sea Turtles

Several species of federally-listed sea turtles have been observed in Delaware Bay, including the loggerhead, Kemp's Ridley, and green sea turtle. They live in the bay, which serves as feeding grounds, between May and November, and migrate to warmer waters during the winter months. Best management practices should be employed when dredging occurs during the time period in which sea turtles are present in the bay.

5.5.7 Shortnose Sturgeon

The shortnose sturgeon is listed as endangered under the Endangered Species Act of 1973. This species of fish inhabit upstream waters in the Delaware water. It is possible, but unlikely, that beach projects and their associated dredging in Delaware Bay will impact this species.

5.5.8 Sandbar Shark

The offshore habitat along the lower Delaware Bay is considered "Habitat Areas of Particular Concern" by the National Marine Fisheries Service. There is a potential for impacts to shark pups and their food source in nursery areas along the coastline, particularly from Broadkill Beach to Slaughter Beach if sand is placed between 3 and 13 ft deep. In order to protect this habitat, sand placement during the period from May 1 through September 15 must be completed in accordance with a list of conservation measures. However, the environmental window for horseshoe crabs closely aligns with this restriction so sand placement likely would not be permissible during this time frame.

5.6 Beach-Related Legislation

5.6.1 The Beach Preservation Act

The Delaware Legislature passed the Beach Preservation Act in 1972 in an effort to protect beaches and the resources they provide. The purposes of the legislation are to enhance, preserve and protect the public and private beaches of the state, to mitigate beach erosion, and to create civil and criminal penalties for acts that are destructive to beaches. In addition to giving DNREC the authority to protect the beaches, the legislation created a Beach Preservation Fund, which provides money to help cover the costs of shoreline protection.

The Beach Preservation Act gives the Department the authority to adopt rules and regulations. Under the Regulations Governing Beach Protection and the Use of Beaches, the Department has established and adopted a mapped Building Line which runs parallel to the coast. The building line along the Delaware Bay shoreline lies 75 ft landward of the 7 ft elevation contour between Primehook and Pickering Beach, and 100 ft landward of the 7 ft elevation contour for the rest of the Bay shoreline. Any construction, modification, or reconstruction of a structure seaward of the building line is prohibited without a permit or letter of approval from the Department. In addition, a letter of approval is required prior to any construction, reconstruction, or modification of a structure, or any alteration, digging, mining, moving, removal, or deposition of beach or other materials landward of the building line and in the area defined as the beach.

5.6.2 Delaware's Coastal Management Program

Delaware's Coastal Management Program was implemented in 1979 to regulate development along the shoreline. Under this program, a system of standards, guidelines, and controls to manage coastal land and water uses was developed to ensure a rational decision-making process in relation to coastal development. The program protects the beaches through reviews of federal and state projects to ensure consistency with coastal policies, special area management planning, assistance to state and local governments for local land use planning, and other special projects. This program receives financial assistance from the federal government.

5.6.3 The Coastal Zone Act

The Coastal Zone Act was enacted in 1971 to control industrial development in the coastal zone for the purpose of protecting the environment and maintaining the coast as an area primarily for recreation. This act prohibits heavy industry and bulk product transfer facilities from locating in coastal areas.

5.6.4 The Subaqueous Lands Act

The Subaqueous Lands Act regulates the use of subaqueous lands, which includes non-tidal streams, lakes, ponds, and tidal waters seaward of the mean high water line. As it relates to beach projects, this Act requires permits to deposit material on or remove material from submerged lands, and to construct, modify, repair, or reconstruct any structure on submerged lands.

5.7 History of DNREC Involvement in Management of the Beaches

In 1934, the Delaware Highway Commission was delegated responsibility for beach lands management. Between the 1930s and 1950s, beach management consisted of dealing with specific erosion problems along the Bay and Atlantic coasts, with no long-term or broad-scale planning. Nourishment of the Delaware Bay beaches began in the 1950s. The Department of Natural Resources and Environmental Control took on responsibility for the beaches in the 1970s. At that time, the State bought a dredge to do work in five tidal creeks. DNREC saw an opportunity to use the dredge for work in other areas and began dredging operations in Delaware Bay for beach nourishment. A basic fill template was applied to nourish the Bay beaches. The design of this fill template may have come from the Corps or the Highway Commission but the specific source is unknown. The actual volume placed within each fill template varied based on the specific shore protection need at the time, sediment availability, weather, and other factors.

In the 1970s and early 1980s, DNREC was placing material on beaches every few years. Since then, there have been two recent changes. The first is that the bay beach communities have grown and more expensive homes have been built. The second is that the window for dredging has been narrowed to prohibit work from April 15 through August 30 in response to increased concerns over environmental issues (shorebirds and horseshoe crabs). This forced dredging operations to the winter when water conditions are often too rough to conduct dredging with a small dredge. In 2000, one of the state's dredges sank off of Broadkill Beach and the Coast Guard had to rescue staff off of the dredge at night. The combination of environmental restrictions and the safety concerns associated with dredging in the winter months resulted in a relatively narrow timeframe for dredging (in the late winter before April 15 and in the fall after August 30).

In 2004/2005, the state stopped dredging and now outsources this work to private contractors. There are presently no local dredges; the closest dredge companies are in the Norfolk area. Small commercial dredges typically have a draft of about 4 ft; this is much deeper than the 2 ft draft the state's dredge had. This has resulted in increased costs and reduced flexibility, especially for mobilization and demobilization.

5.8 History of Corps Involvement in Management of the Beaches

The US Army Corps of Engineers, Philadelphia District, is responsible for maintaining the bigger river channels, including the Delaware River Main Channel and the Mispillion River, the Murderkill River, the Broadkill River, and Port Mahon.

Delaware River Main Channel Deepening. The Federal project, which has had appropriated funds from Congress since Fiscal Year 1999, involves the deepening of the existing Delaware River Navigation Channel from -40 ft MLW to -45 ft MLW. The State of Pennsylvania and Port of Philadelphia are the local sponsors. Initial construction will dredge approximately 16.4 million cubic yards (cy) of material with placement of approximately 12.3 million cy of sand, silt, and clay slated for disposal in federal upland Confined Disposal Facilities in New Jersey and Delaware.

Of the total material dredged, an estimated 2.5 million cy of primarily good quality sand is slated for beneficial use at Kelly Island, Delaware for wetland restoration and protection. Another 1.6 million cy of good quality sand is slated for placement along Delaware Bay beaches. The annual maintenance dredging volume will be approximately 4.3 million cy with approximately 350,000 cy of maintenance dredged material slated for placement every five years.

Hopper and hydraulic pipeline dredges will perform the work with a bucket dredge to be used for removal of rock. Pre-construction biological monitoring has been established to gather baseline data that the Corps, DNREC, and other state and federal resource agencies can use to document that construction does not impact the natural resources of the region. Data is being collected on oysters, horseshoe crabs, shorebirds, blue crabs and Sabellaria worms. The monitoring will continue during and after project construction.

The next step for this project is to go through the DNREC permitting process. A variety of local environmental groups have expressed concerns and/or opposition to this project and this may affect how quickly the permitting and ultimately construction can proceed.

Broadkill Beach Nourishment. This Federal project, which is currently unfunded, would involve construction of a beach nourishment project along 14,600 ft of shoreline at Broadkill Beach. The proposed design includes a 100 ft wide berm with an elevation of 7.2 ft NAVD88 and a dune with an elevation of 15.2 ft NAVD88. This plan also includes dune grass, dune fencing and suitable advance beach fill with periodic nourishment every five years to maintain the integrity of the design.

Mispillion River. The Mispillion River is authorized at 60 ft wide and 7 ft (MLLW) deep. It was last dredged by the Corps in FY 2002, and the 14,000 cy of material that was removed was placed in the breached area of Conch Bar Island. A 2008 survey showed 4 ft controlling depth but there is currently no funding for the project.

Figure 5.12 Mispillion Inlet, with Slaughter Beach to the south. (Wayne Lasch, April 17, 2009).

Murderkill River. The Murderkill River, last dredged by the Corps in 2002, is authorized for a channel depth of 7 ft (MLW) and a width of 60 ft in Delaware Bay. The controlling depth, identified by a July 2007 channel exam survey, is 3.1 ft (MLW) but no additional dredging will be completed until funding is available.

Port Mahon. This project involves the construction of a 5,200 ft long beachfill, the raising of State Road 89 for a distance of 7,500 ft and placement of riprap along a 1,200 ft length of the road to protect wetlands. The project also includes the restoration of 21.4 acres of degraded wetland habitat west of the road for the purposes of flood and coastal storm damage reduction and ecosystem restoration. A Limited Reevaluation Report was completed and approved in May 2006 but there is currently no source of funding.

6. Coastal Littoral Processes

6.1 Historical Analysis

6.1.1 Introduction

A number of studies have been performed that investigate both the evolution of Delaware Bay's beaches over time and those forces that influence this evolution. The most exhaustive of these are: *Geomorphology and Evolution of Transgressive Estuarine Washover Barriers Along the Western Shore of Delaware Bay* (Maurmeyer, 1978); *Historical Shoreline Changes in Response to Environmental Conditions in West Delaware Bay* (French, 1990); and *Delaware Bay Coastline – New Jersey and Delaware – Reconnaissance Study* (USACE, 1991).

The study by Maurmeyer (1978) includes analysis of shoreline change rates from 1841 through 1968, annual and seasonal longshore transport rates based on wave measurements and calculated energy flux, and longshore transport direction inferred from field investigations. French (1990) performed a shoreline evolution analysis for multiple transects at each beach along the Delaware Bay coast encompassing the period of 1842 through 1977, using surveyed shorelines and aerial photography. The USACE Reconnaissance Report (1991) contains data on shoreline change rates with the influence of beach fill removed.

6.1.2 Longshore Sediment Transport

Maurmeyer (1978) calculated potential longshore sediment transport rates for the beaches along Delaware's bay coastline using measured wave data and an energy flux formulation. Figure 6.1 presents the annual littoral drift rose from this analysis. The angles along the plot correspond to the outward azimuth of the shoreline. The beaches along the western shore of the bay have an azimuth between 0° and 95°; thus, all locations experience a net southerly drift on an annual basis, according to this analysis. Southerly transport is dominant in all seasons but summer. Table 6.1 presents the littoral drift estimates in tabular form for each location of interest. The average southerly transport rate is 8,800 yd^3/yr.

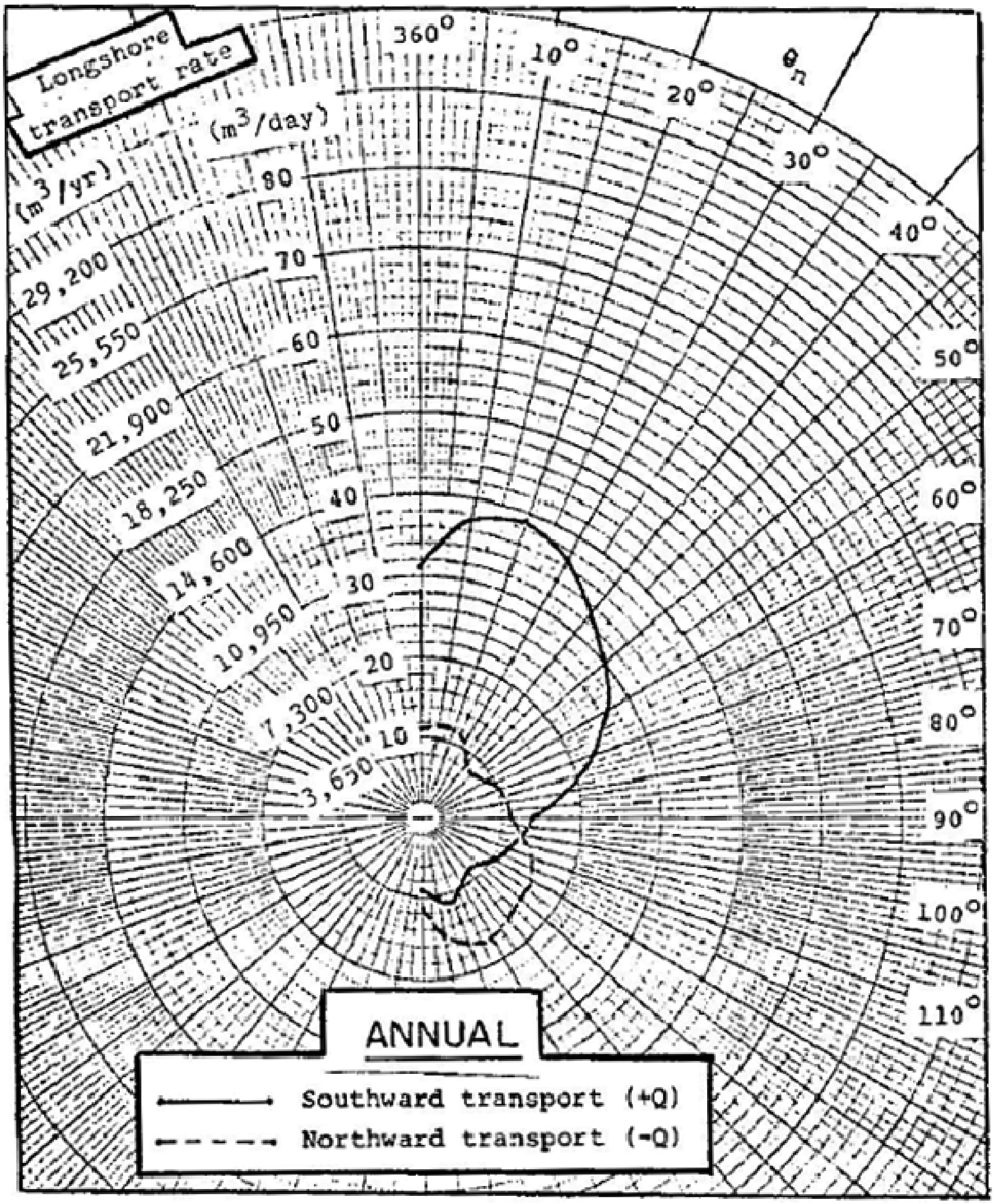


Figure 6.1 Annual littoral drift rose; western shore of Delaware Bay (Maurmeyer, 1978).

Table 6.1 Littoral drift estimates for Delaware Bay beaches (Maurmeyer, 1978).

Location	Shoreline azimuth (°N)	Total southerly transport (yd^3/yr)	Total northerly transport (yd^3/yr)	Gross transport (yd^3/yr)	Net transport (+ southerly) (yd^3/yr)
Pickering Beach	82	8,100	5,000	13,100	+3,100
Kitts Hummock (N)	75	9,700	5,000	14,700	+4,700
Kitts Hummock (S)	95	6,300	5,400	11,700	+900
Bowers	65	11,900	4,800	16,700	+7,100
South Bowers (N)	53	13,600	4,200	17,800	+9,400
South Bowers (S)	40	16,000	4,200	20,200	+11,800
Slaughter Beach (N)	60	13,000	4,400	17,400	+8,600
Slaughter Beach (S)	48	14,500	4,100	18,600	+10,400
Fowler Beach	45	15,000	4,100	19,100	+10,900
Primehook Beach	55	13,600	4,200	17,800	+9,400
Broadkill Beach (N)	47	14,800	4,100	18,900	+10,700
Broadkill Beach (S)	50	14,400	3,900	18,300	+10,500
Lewes (W)	26	18,200	5,400	23,600	+12,800
Lewes (E)	7	17,100	5,600	22,700	+11,500

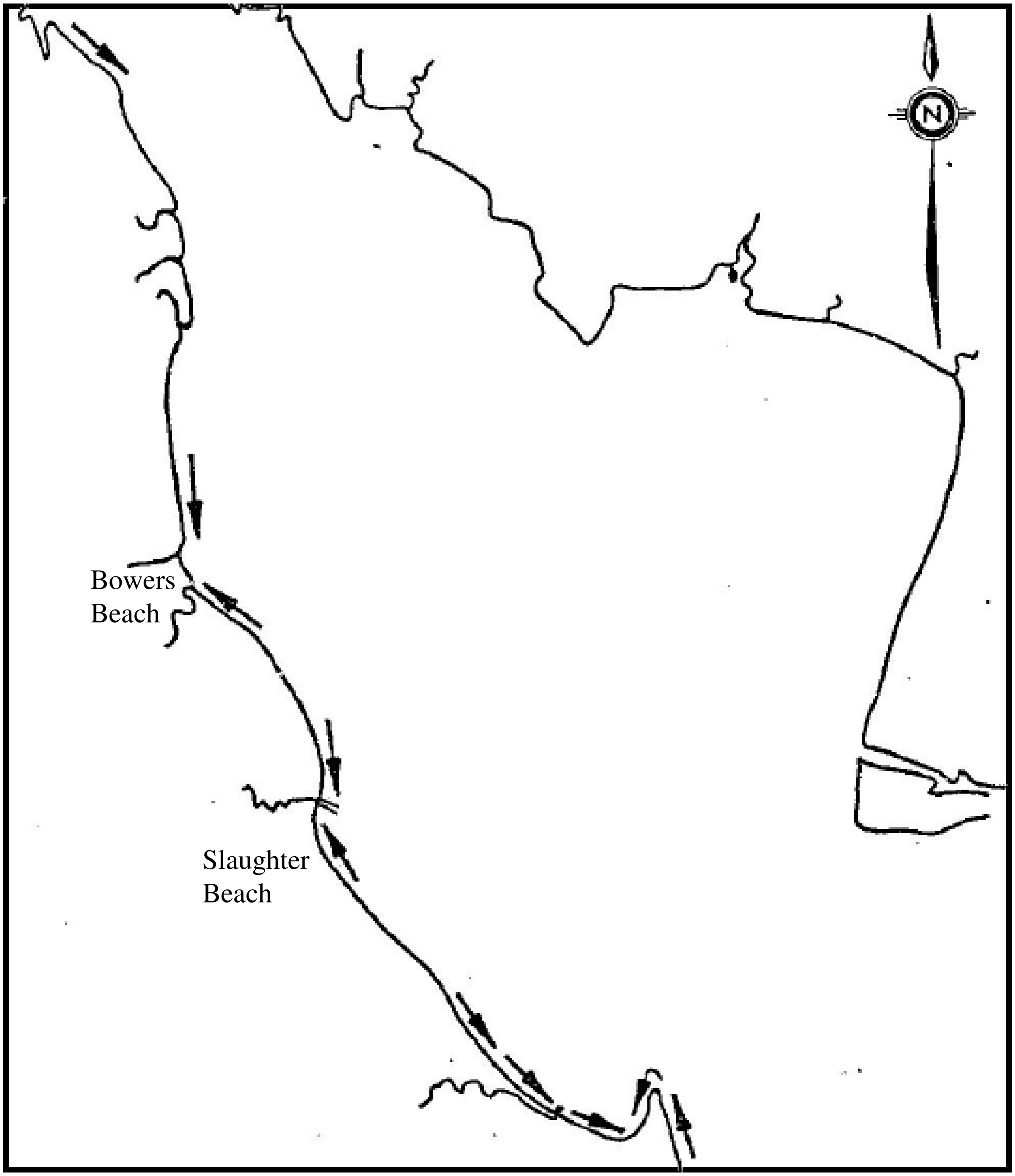


Figure 6.2 Observed longshore sediment transport directions (from Maurmeyer, 1978).

In Figure 6.2, the directions of observed longshore transport rates are depicted. These estimations were deduced from field investigations, using evidence such as sand accretion on structures, growth of spits and shore-parallel features, inlet migration, and orientation of shoals and sediment deposits. The overall trend of southerly transport is evident from these observations; exceptions include northerly transport at Slaughter Beach and South Bowers. In the field investigations, sand accumulation was apparent on the south sides of groins at Broadkill Beach, evidence of the northerly transport during summer months.

6.1.3 Observed Longshore Sediment Transport Patterns

Based on field visits, review of available data, assessment of historic aerials and discussions with DNREC staff the following are our general observations of longshore sediment transport patterns in each community. This information was used to help determine location and placement of fill for each scenario.

Pickering Beach
Sediment transport seems to be north and south with a nodal point at the middle of the community. Aerial photos provide evidence of sand spits forming at the northern and southern ends of the community. Past beach fill projects have focused on the northern and southern ends. These projects may have resulted from the increased need for shore protection due to the orientation of the shoreline as compared to the alignment of development.

Kitts Hummock
Observation of past beach fill behavior suggests that the dominant transport direction is northerly. However, the groin located at the southern end of the community shows an offset on the north side, suggesting southern transport. This discrepancy in observed sediment transport may be due to seasonal fluctuations in meteorological conditions affecting the shoreline. In addition, the developed area along Kitts Hummock has received several sand placement projects resulting in the shoreline position being maintained seaward of adjacent unprotected shorelines. This may also be due to the orientation of the shoreline and alignment of development, as well as the lower elevations that exist along this area. The southern third of the community seems to have the greatest need for shore protection and has received the majority of the sand placement.

Bowers Beach
Sediment transport seems to be north and south with a nodal point at the middle of the project area. Past beach fill projects have primarily placed sand in the middle of the community and spreading was observed both north and south. The greatest need for shore protection has been from the entrance road south to the jetty. This is likely due to the influence of the jetty and inlet on sediment transport processes.

South Bowers
Observation of past beach fill behavior suggests that the dominant transport direction is northerly. Beach fill projects have largely consisted of placing sediment from the dredging of the Murderkill River. The southern third of the community seems to have the greatest need for shore protection. This is likely due to the orientation of shoreline and alignment of development.

Slaughter Beach
Observation of past beach fill behavior suggests that the dominant transport direction is northerly, and the greatest need for beach fill is at the southern end of the community. The influence of the jetties of the Mispillion Inlet is evident along the northern shoreline and may be dictating sediment transport patterns in the community.

Primehook Beach
Local observations suggest that the northern third of the community has the greatest need for shore protection. Examination of historic aerials suggests that the dominant transport direction was northerly prior to the construction of the breakwaters. Recently, the dominant transport direction may be southerly due to the influence of the breakwaters and the advancement of Cape Henlopen. Relic offshore ebb shoals may contribute sediment to the beach and influence transport patterns.

Broadkill Beach
Observation of past beach fill behavior suggests that the dominant transport direction is northward in the north half of the community and southward in the southern half, with the nodal point at Route 16 (Broadkill Road). Similar to Primehook, the construction of the breakwaters and advancement of Cape Henlopen may have impacted sediment transport. Field observations revealed sand accumulation on the south sides of groins located in the northern portion of the community, evidence of the northerly transport.

6.1.4 Shoreline Change Rates

The USACE (1991) estimated shoreline change rates for the Delaware Bay beaches based on available shoreline and beach profile data. An attempt was made to filter out the effects of beach fill projects and quantify the actual dynamics without human interference. These rates are presented for the beaches of interest in Table 6.2. The beaches of interest all exhibit a trend of shoreline recession, ranging from 1 ft/yr at Slaughter Beach to 12 ft/yr between Broadkill Beach and Roosevelt Inlet.

Table 6.2 Delaware Bay shoreline change rates (USACE, 1991).

Location	Shoreline Recession (ft/yr)
Pickering Beach	-4.9
Bowers Beach	-2.0
South Bowers	-7.9
Slaughter Beach	-2.0
Slaughter Beach to Fowler Beach	-1.0 to -4.9
Broadkill Beach	-3.0
Broadkill Beach to Roosevelt Inlet:	
South of Broadkill	-3.9 to -5.9
Central	-8.9 to -12.1
West of inlet; pre-cutoff of jetties	-0 to -1.0
West of inlet; post-cutoff of jetties	-5.9 to -7.9
Lewes (near Roosevelt Inlet)	-3.0

French (1990) used aerial photography and topographic surveys to measure shoreline change rates at 1000 ft intervals along the west shore Delaware Bay beaches from 1882 to 1977. The mean change rates and error ranges for each beach for the long-term period of 1882 to 1977 are presented in Table 6.3. A positive rate indicates accretion; negative is erosion or recession. Figure 6.3 illustrates the long-term rate of change along the study area.

Table 6.3 Delaware Bay shoreline change rates, 1882 to 1977 (French, 1991).

Location	Mean Shoreline Change Rate (ft/yr)	Highest Transect Loss (ft/yr)	Lowest Transect Loss (ft/yr)
Kitts Hummock	-4.3	-5.6	-3.3
Bowers Beach / South Bowers Beach	-3.0	-3.6	-1.6
Big Stone Beach	-3.6	-4.6	-3.3
Mispillion Inlet	+3.0	-2.3	+9.2
Slaughter Beach	+1.0	0.0	+2.0
Primehook Beach	+1.3	-0.3	+2.3
Broadkill Beach (north)	+6.6	+1.6	+9.8
Broadkill Beach (south)	-4.6	-5.2	-3.3
Roosevelt Inlet	-3.3	-4.6	-2.0
Lewes Beach / Breakwater Harbor	+1.3	-0.7	+3.0
Port Mahon	-20.3	-30.2	-10.5

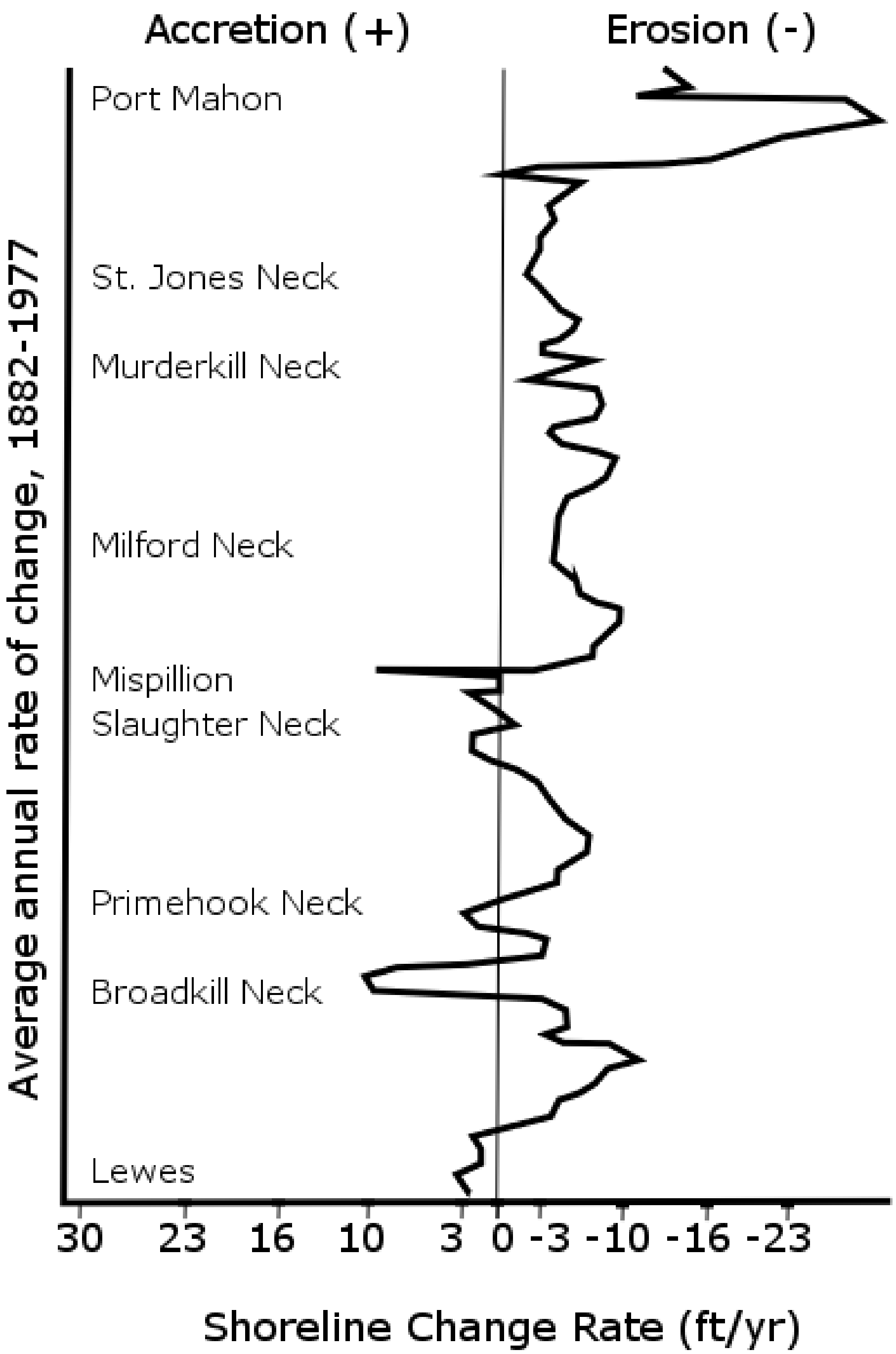


Figure 6.3 Long-term erosion/accretion rates in Delaware Bay (French, 1990).

Over the period of 1882 to 1977, the majority of the western shore of Delaware Bay experienced net shoreline recession. Exceptions to this are Lewes Beach and Broadkill Beach, and the area between Slaughter Beach and Mispillion Inlet. Average change rates varied from losses of over 20 ft/yr at Port Mahon to gains of 10 ft/yr in northern Broadkill Beach.

6.1.5 Historic Beach Fill Placement Analysis

Beach fill events have been conducted along the bay beaches since the late 1950s. To date, a total of over 3 million cy of material has been placed. Table 6.4 provides the data available regarding the beach fill history for each community.

Table 6.4 Record of beach fill events for each community

	Year	Volume (cy)
Pickering Beach	1962	39,600
	1969	5,000
	1978	85,200
	1979	7,400
	1986	36,000
	1990	55,400
	2001	27,150
Kitts Hummock	1961	80,000
	1962	30,600
	1969	12,000
	1973	3,000
	1974	46,500
	1979	74,000
	1988	15,780
	1996	32,850
	2008	15,000
Bowers Beach	1962	35,500
	1968	18,000
	1969	6,500
	1972	21,200
	1973	15,800
	1974	28,800
	1985	35,700
	1986	13,700
	1988	51,700
	1994	12,000
	1998	55,165
	2009	9,000

	Year	Volume (cy)
South Bowers	1961	20,000
	1962	10,000
	1969	4,000
	1974	4,000
	1975	15,000
	1976	9,400
	1984	17,000
	1989	8,000
	1992	2,000
	1997	7,500
Slaughter Beach	1958	49,000
	1961	165,000
	1962	56,600
	1976	179,500
	1976	277,700
	1979	20,000
	1985	26,200
	1985	10,300
	2005	115,000
Primehook Beach	1962	20,200
Broadkill Beach	1957	76,800
	1961	120,000
	1962	180,000
	1973	118,000
	1975	295,000
	1976	60,000
	1981	127,700
	1987	52,600
	1988	28,500
	1993	67,000
	1996	25,000
	2005	152,000

Due to the lack of beach profile survey data to analyze volume change, these data can only be used to estimate the general historic demand required to maintain these beaches. This analysis does not take into account the vulnerability of infrastructure, length of project nor actual erosion losses; rather, it provides an estimate of sand demand based solely on historic placement events. Records provided limited information regarding the length of a project. Table 6.5 provides the historic demand in total and for placement events since the 1970s. The fill placement records provided greater detail (placement volume, location, length, etc.) starting in the 1970s and were evaluated to make a comparison to the total historic demands.

Table 6.5 Historic demand based on placement events.

	Historic Demand (cy/yr)	
Community	**Total**	**1970s - Present**
Pickering Beach	5,862	8,000
Kitts Hummock	7,482	6,056
Bowers Beach	6,257	6,326
South Bowers	2,483	2,409
Slaughter Beach	17,006	17,623
*Primehook Beach	20,626	25,090
Broadkill Beach	23,970	28,931

*Only one placement event was recorded, average of Slaughter and Broadkill was used.

6.2 Planning Level Hydrodynamic Modeling

6.2.1 Introduction

As part of this overall management plan, a planning level hydrodynamic modeling effort was undertaken, using the ADCIRC model (Luettich & Westerink, 2006) and the Surface Water Modeling System (SMS) graphical interface developed by Aquaveo. ADCIRC is a two-dimensional, depth-integrated, finite-element circulation model, capable of simulating the hydrodynamics of water bodies ranging from lakes and rivers to entire ocean basins. It has the ability to simulate wetting and drying of model elements, bottom friction, Coriolis forcing, wind stresses, and other effects. It allows for a variety of boundary conditions, including normal inflow and outflow, uniform water level variations, and spatially-varying tidal constituent forcing.

The goal of this modeling effort was to develop a working circulation model of Delaware Bay in order to gain a better understanding of the roles that wind, tidal circulation, upstream inflows, and storm surges play in determining the dominant current circulation patterns along the western shore of Delaware Bay. The model is also used to confirm observations from past research efforts. These patterns can be an indicator of the major pathways, sources, and sinks of beach sediment under average, operational, and extreme conditions. Examination of net flow directions and areas of current acceleration/deceleration in the model results are combined with local observations of past beach fill behavior to develop strategic beach fill placement options. Appendix A presents detailed information on the hydrodynamic modeling that was performed for this study.

6.2.2 Modeling Conclusions

The ADCIRC model was used to simulate the residual circulation patterns of three physical scenarios: 1) operational conditions with measured wind, inflow, and tide conditions; 2) average conditions with mean wind, flow, and predicted tide levels; and 3) the 2008 Mother's Day Storm. Examining the net flow patterns and magnitudes for these circumstances offered insight into the pathways that dominate water movement, and likely sediment transport, along the western shore of Delaware Bay during both normal and extreme events.

Operational conditions were a 20 day 'snapshot' of actual, recorded wind, flow, and water levels. This simulation was used to calibrate the model as well as investigate the circulation patterns that arise during everyday or 'operational' physical conditions. Under operational conditions the dominant nearshore net flow was in a south/southeasterly direction, towards the mouth of the bay. Exceptions to this trend were a northerly flow offshore of Bowers Beach and Slaughter Beach and a northwesterly current towards Mispillion Inlet (Figure 6.4). These patterns correlate well with the observed longshore sediment transport directions found in Maurmeyer (1978), shown here in Figure 6.2, and local observations found through this investigation.

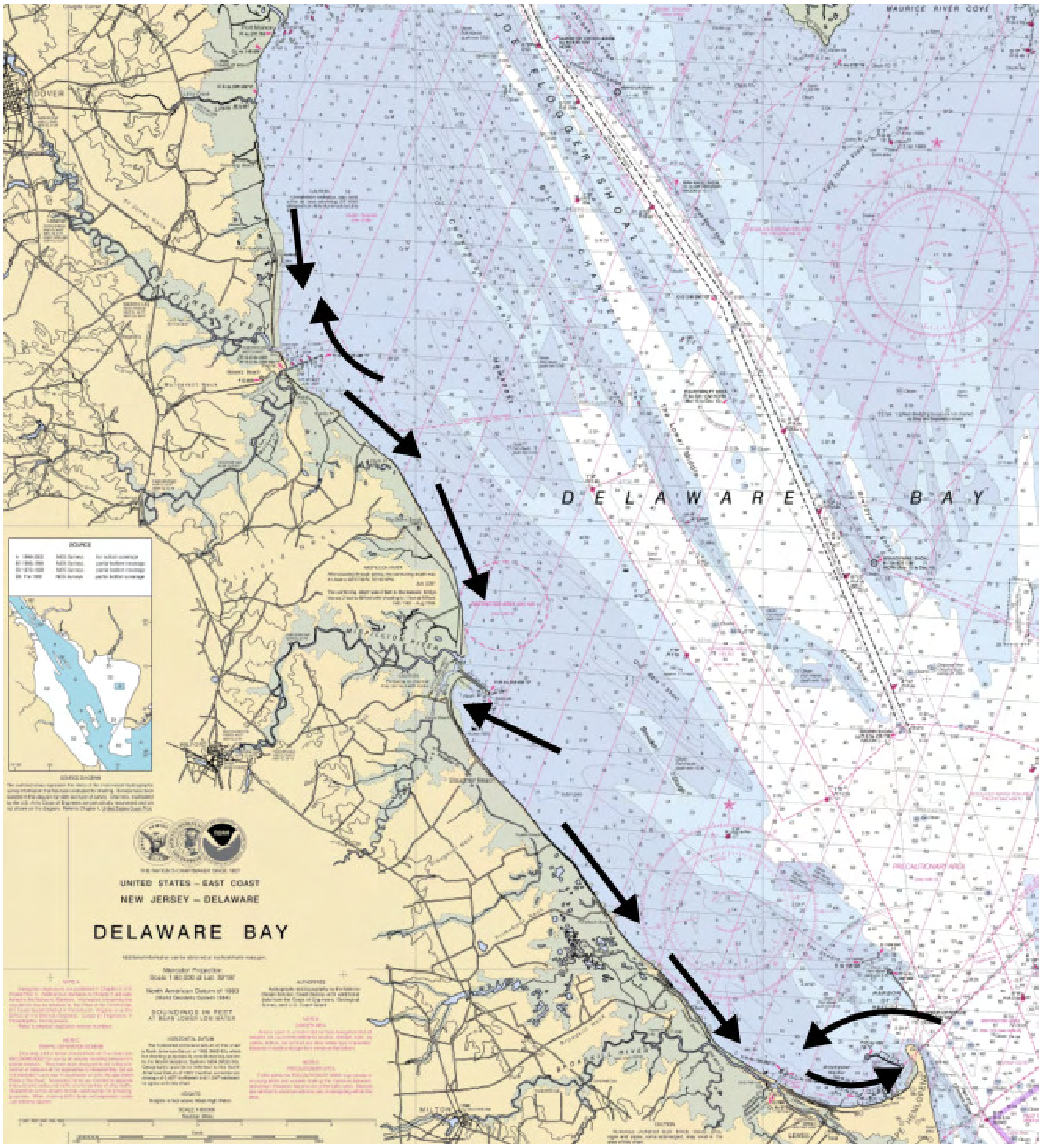


Figure 6.4 Prevailing current patterns along Delaware Bay beaches; operational conditions.

Also simulated were average conditions that are representative of predicted tidal fluctuations combined with mean conditions for river inflow and wind. This simulation was used to gain insight on how prevailing physical conditions create circulation patterns in Delaware Bay; these average conditions show the dominant patterns that emerge over larger time scales. With average forcing conditions applied (with a prevailing NW wind), the net alongshore circulation was uniformly southeasterly towards the mouth of the bay at all beaches of interest. The exception to this was a westerly flow entering the bay just north of Cape Henlopen. Figure 6.5 illustrates these flow patterns. These patterns agree with the longshore transport directions calculated in Maurmeyer (1978) and discussed in Section 6.1.2 (Table 6.1); each location along Delaware's bay coast was calculated to have a net southerly sediment transport.

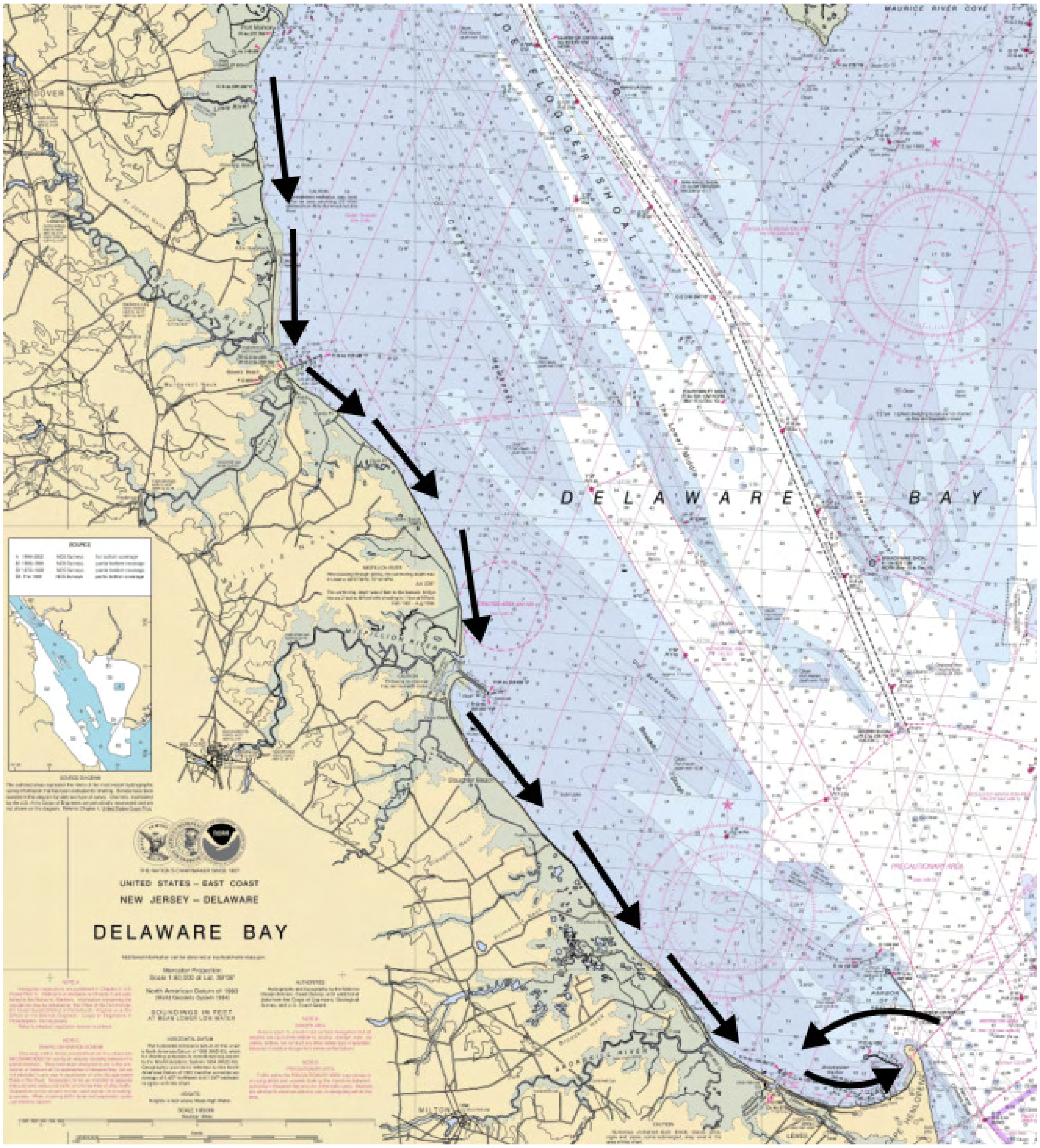


Figure 6.5 Prevailing current patterns along Delaware Bay beaches; average conditions.

A simulation was also conducted to model the time period of the 2008 Mother's Day Storm (extreme conditions). This was a significant and destructive nor'easter for the Delaware Bay region. A recreation of this event was utilized to examine circulation patterns during extreme events, and serves as a tool to investigate potential sediment sources and sinks during such a storm event.

The 2008 Mother's Day Storm was a significant event for the Delaware Bay beaches. Strong northeast winds amplified the surge on the western shore of the bay, and the bay's funnel shape caused the maximum surge elevation to increase in the upstream direction. The model estimated surges ranging from 6.2 ft NAVD88 at Lewes to 9.2 ft NAVD88 at

Pickering Beach, with some river basins experiencing local water level focusing up to 10.5 ft NAVD88.

Figure 6.6 presents the net circulation patterns during the storm peak. Offshore of the bay beaches, the net circulation direction was southerly; however, patterns varied in the nearshore. Certain beaches, most notably Fowler Beach and Broadkill Beach, experienced high net offshore flow, possibly indicating barrier breach locations where flood waters that initially overwashed the dune system concentrated and returned to the bay. These localized breaches can have impacts long after the storm, with continued saltwater intrusion possible due to normal tidal movement through the newly-created channel. In many flooded areas, especially the river basins, the net circulation is directed landward, implying that more water is being pushed upland during the storm than is flowing back to the bay. This suggests that sediment transported onshore through rivers and barrier overwash may remain trapped in the coastal back bays. Essentially, these back bays may become sinks of sediment that was once on the beach, and this material is unlikely to return to the beach face quickly enough to offset critical beach erosion caused by the storm. These modeling results are consistent with documented and observed morphologic processes (littoral drift and storm overwash) that affect and maintain the bay beaches (Maley, 1981).

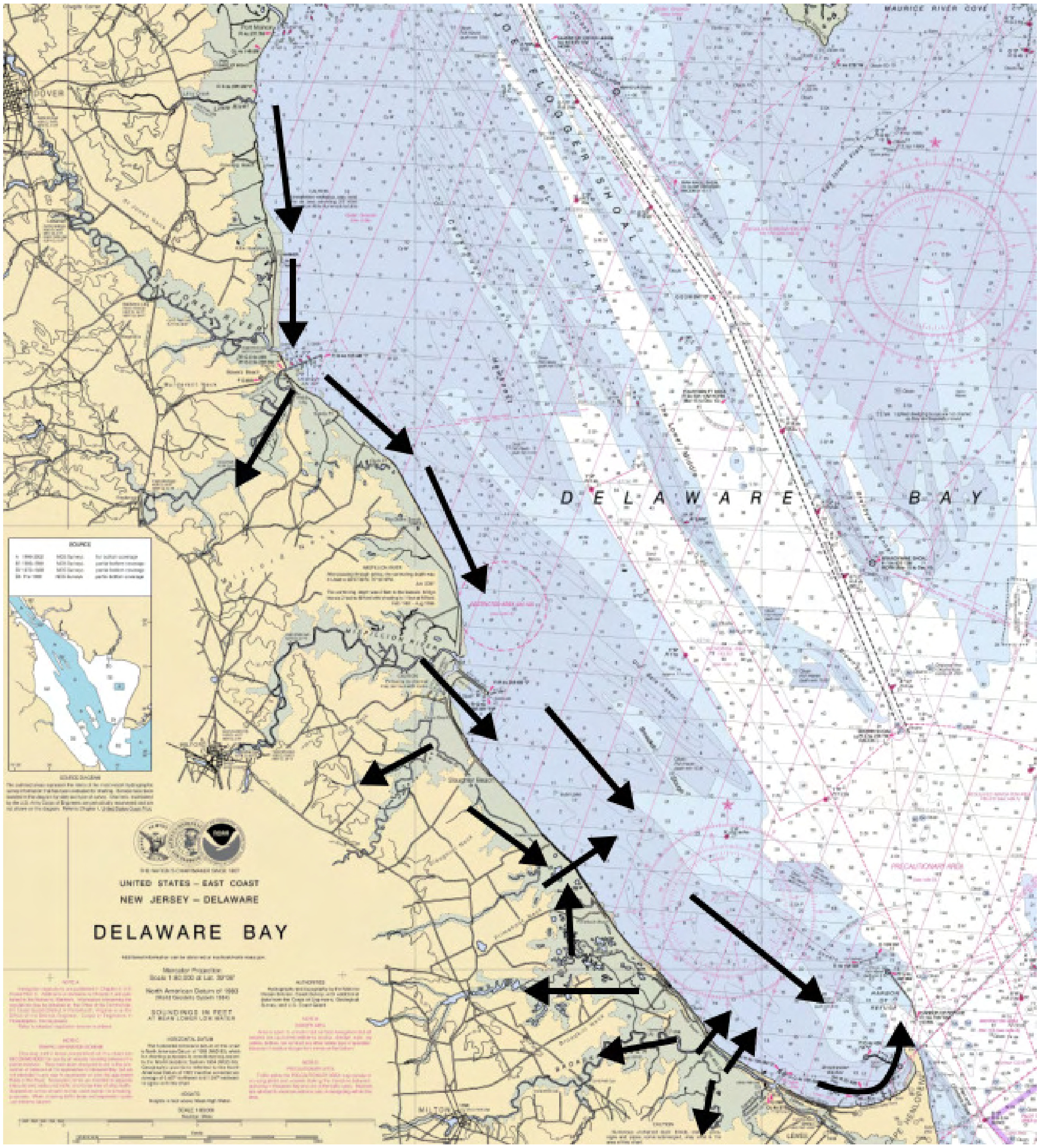


Figure 6.6 Prevailing current patterns along Delaware Bay beaches; 2008 Mother's Day Storm.

In summary, three physical scenarios were used to simulate the residual circulation patterns in Delaware Bay. These simulations offered insight into the pathways that dominate water movement, and likely sediment transport, along the western shore of Delaware Bay during both normal and extreme events. Results indicate that under both operational and average conditions, dominant nearshore net flow was in a southerly direction, towards the mouth of the bay. These patterns agree with the potential longshore transport directions calculated by Maurmeyer (1978). Limited areas experienced northerly nearshore net flows during operational conditions and were consistent with observations of sediment transport patterns made by Maurmeyer (1978) and during this investigation. A simulation was also conducted to model the time period of the 2008 Mother's Day Storm in order to investigate circulation during an extreme event. The offshore net circulation direction was southerly; however, patterns varied in the nearshore, indicating high net offshore flows where barrier breach locations exist. This suggests that the back bays/estuaries may become sediment sinks during extreme events.

6.3 Wave Modeling

6.3.1 Introduction

In support of the ADCIRC circulation model described above, a wave development and propagation model was created using the STWAVE model (USACE) and the SMS graphical interface. STWAVE is a steady-state spectral wave propagation model that incorporates wave refraction, wind wave growth, shoaling, and breaking. This wave model will assist in determining the predominant directions and pathways of hydrodynamic and sediment transport along the Delaware Bay coastline under both offshore wave dominated and local wind wave dominated scenarios. Appendix A presents detailed information on the wave modeling that was performed for this study.

6.3.2 Modeling Conclusions

Ten wave condition scenarios were examined to gain an understanding of the variations in wave height and direction at each bay beach location. These scenarios include conditions with and without the influence of offshore waves for annual, winter, spring, summer and fall conditions. Wave height correlates with the energy available to initiate and maintain sediment transport, while the direction dictates where the sediment is transported.

Results of the wave modeling demonstrate the variability of seasonal conditions affecting the bay beaches. As would be expected, the winter conditions produce the largest wave heights and provide the greatest potential for sediment transport. Appendix A provides the full results of the wave modeling, including seasonal wave conditions. Table 6.6 provides the annual wave heights and potential transport directions for the beaches along Delaware's bay coastline with and without the offshore wave influence. Wave heights are approximate, based on the variation at each location. Figures 6.7 and 6.8, respectively, illustrate the wave height field under average annual conditions with and without the influence of offshore waves. With offshore waves included in the simulation, wave heights generally decrease up-bay, with Kitts Hummock and Pickering Beach showing a slight increase likely due to their orientation to the mouth of the bay. Localized areas of wave focusing were observed at Slaughter Beach and Broadkill Beach. Transport potential varies along the coastline from a southwesterly to a northwesterly direction up-bay with a transition observed near Slaughter Beach. Without offshore waves, local wind wave heights are relatively small (≤ 0.7 ft) and show a prevailing southerly transport potential. Comparing Figures 6.7 and 6.8 demonstrates that offshore waves will generally dominate conditions along the bay beaches.

Table 6.6 Wave heights and potential transport directions; annual conditions.

Location	Wave height (w/ off. waves) (ft)	Transport direction (w/ off. waves)	Wave height (wind waves only) (ft)	Transport direction (wind waves only)
Pickering Beach	2.1	NW	0.3	S
Kitts Hummock	1.6	NW	0.3	S
Bowers Beach	1.5	NW	0.3	S
South Bowers	1.3	NW	0.5	S
Slaughter Beach	2.0	NW/SW	0.5	S
Primehook Beach	2.0	SW	0.7	S
Broadkill Beach	2.3	SW	0.5	S

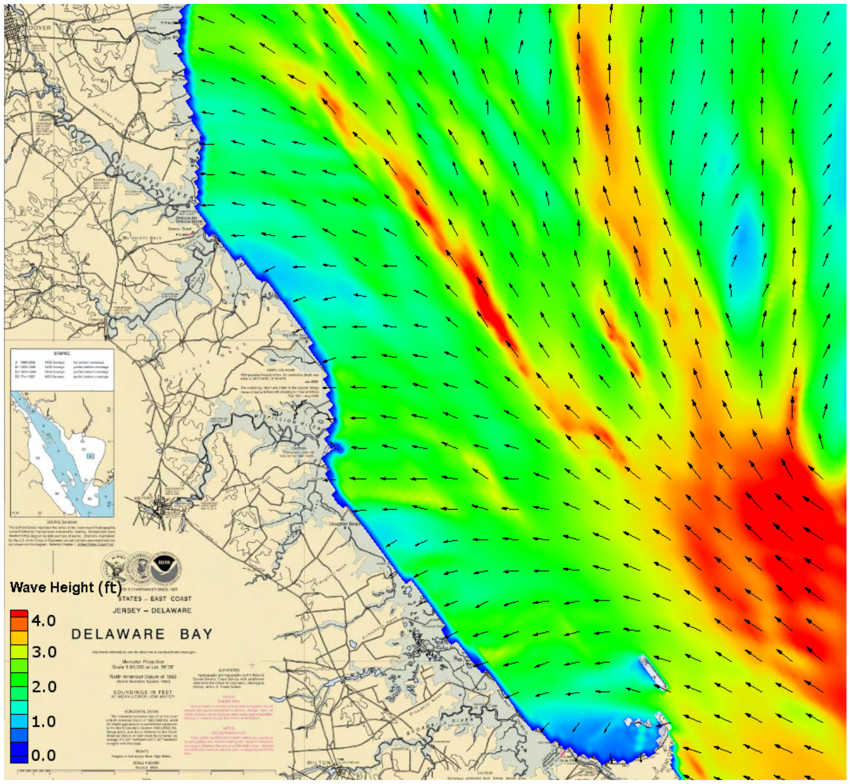


Figure 6.7 Wave heights during average annual conditions; with offshore wave influence.

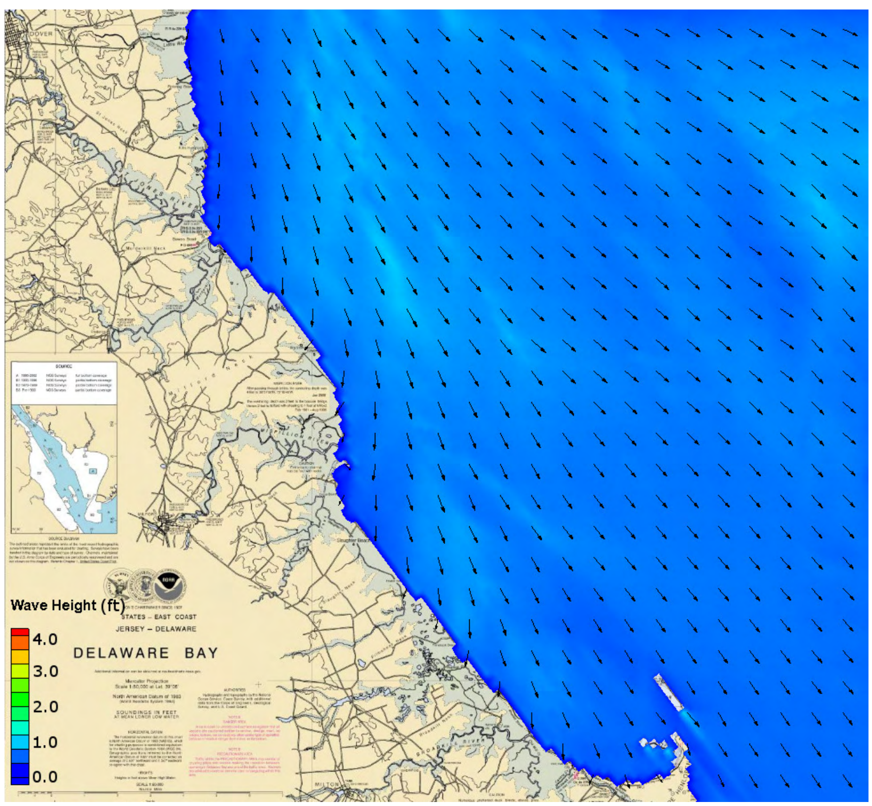


Figure 6.8 Wave heights during average annual conditions; without offshore wave influence.

These results were compared to the circulation model as well as past estimations and observations of longshore transport to assist in developing strategic beach fill placement options. Results of the wave modeling show a southerly transport potential for Slaughter, Primehook and Broadkill beaches. These results agree with the circulation modeling, potential longshore transport directions calculated by Maurmeyer (1978), and local observations, with the exception of observed northerly transport in Broadkill Beach. With offshore waves included, the wave modeling results provide a northwesterly potential for sediment transport for South Bowers, Bowers, Kitts Hummock and Pickering beaches. This is consistent with past beach fill behavior and may offer some explanation of localized northerly transport observations.

6.4 Design Beach Width Determination

6.4.1 Introduction

In order to establish an appropriate placement volume for each project, it is essential to determine the width of the desired berm (design berm) after the constructed beach fill (construction berm) equilibrates to the local environmental conditions. There are two major components to a design berm; the first is the width necessary to protect upland areas from the design storm, and the second is the width needed to account for historical loss rates over the design life of the project.

For this study, a design berm was created for each community. Three basic scenarios were developed for each community based on localized historical loss rates and providing protection from storm events with specific return periods. The three scenarios were selected to provide a reasonable range of costs and benefits for each community. The three scenarios are as follows:

1. Provide targeted beach nourishment at specific locations within each community based on modeling results and observations of past beach fill evolution to minimize volume placement and allow natural forces to distribute fill material.
2. Restore 5 years of estimated shoreline losses and provide protection from a storm event with a 5-year return period.
3. Restore 10 years of estimated shoreline losses and provide protection from a storm event with a 10-year return period.

In addition to the design berm, the design template for each community includes a dune feature at the intersection of the new berm and the existing grade. This dune feature has an elevation of 9.8 ft NAVD88, a crest width of 10 ft, and a side slope of 1V:3H down to the berm or existing grade. This dune elevation was developed from design plans of previous fill projects as well as erosion modeling efforts.

The following sections describe how each of these scenarios was developed.

6.4.2 Storm Protection Berm

To determine the minimum width necessary for storm protection, a modeling effort was undertaken utilizing SBEACH, a coastal model developed by the USACE. SBEACH is a short-timescale cross-shore sediment transport model that simulates beach profile evolution due to wave attack and storm surge. For each community, a measured beach profile from available data was chosen as the representative condition in the SBEACH model. Effort was taken to choose profiles that were not measured too close to fill projects that could skew the validity of the profile as a representation of normal conditions.

From each representative profile, multiple nourished profiles were constructed, with berm widths ranging from 0 ft to 33 ft and foreshore slopes corresponding to the foreshore of the existing beach. The nourished profiles in SBEACH should be representative of natural conditions. They are meant to be an equilibrated berm, not a design berm; this is why the foreshore slopes of the new profiles mirror those of existing conditions.

Berm elevations were set to a height consistent with the stage of a fifty year storm event as estimated by OCTI (1994) and at elevations approximately consistent with past fill placement projects. It is important to note that this elevation does not constitute protection at a fifty year storm level as it does not account for wave setup. Sediment grain sizes were taken from Maurmeyer (1978); samples at each community along the beach face and berm were averaged to yield an effective grain diameter. Many beach profiles did not extend deeper than an elevation of -3 ft NAVD88, so the apparent offshore slope was extended in SBEACH to move the model boundary sufficiently far away from the beach face.

Wave conditions in SBEACH were a randomized time series based on the wave heights from OCTI (1994); wave period was estimated using the relationship $T = 3.86\sqrt{H_s}$, where T is wave period in seconds and H_s is significant wave height in meters. The applied water level in SBEACH was a 96 hr composite of a predicted spring tide and a modified storm surge residual water level from the 2008 Mother's Day Storm. The storm surge was aligned with peak high tide and scaled so that the total maximum water level was equal to that of the desired return period event.

Table 6.7 outlines the beach profile parameters input to SBEACH for each community. Figure 6.9 shows the native profiles and range of nourished profiles for each community. Table 6.8 lists the parameters of the 5 yr and 10 yr storms for each community. Figure 6.10 illustrates the water level hydrographs for each storm surge elevation.

Table 6.7 Beach profile parameters input to SBEACH.

	Pickering Beach	Kitts Hummock	Bowers Beach	South Bowers	Slaughter Beach	Primehook Beach	Broadkill Beach
Dune width (ft)	10	10	10	10	10	10	10
Dune height (ft NAVD88)	9.8	9.8	9.8	9.8	9.8	9.8	9.8
Dune slope (V:H)	1:3	1:3	1:3	1:3	1:3	1:3	1:3
Berm range (ft)	0 to 33	0 to 33	0 to 33	0 to 33	0 to 33	0 to 33	0 to 33
Berm elevation (ft NAVD88)	8.2	8.2	8.2	8.2	7.5	7.2	7.2
Foreshore slope (V:H)	1:9	1:11	1:10	1:8	1:9	1:9	1:12
Median grain size (d_{50}, mm)	0.723	0.550	0.586	0.586	0.809	0.758	0.627

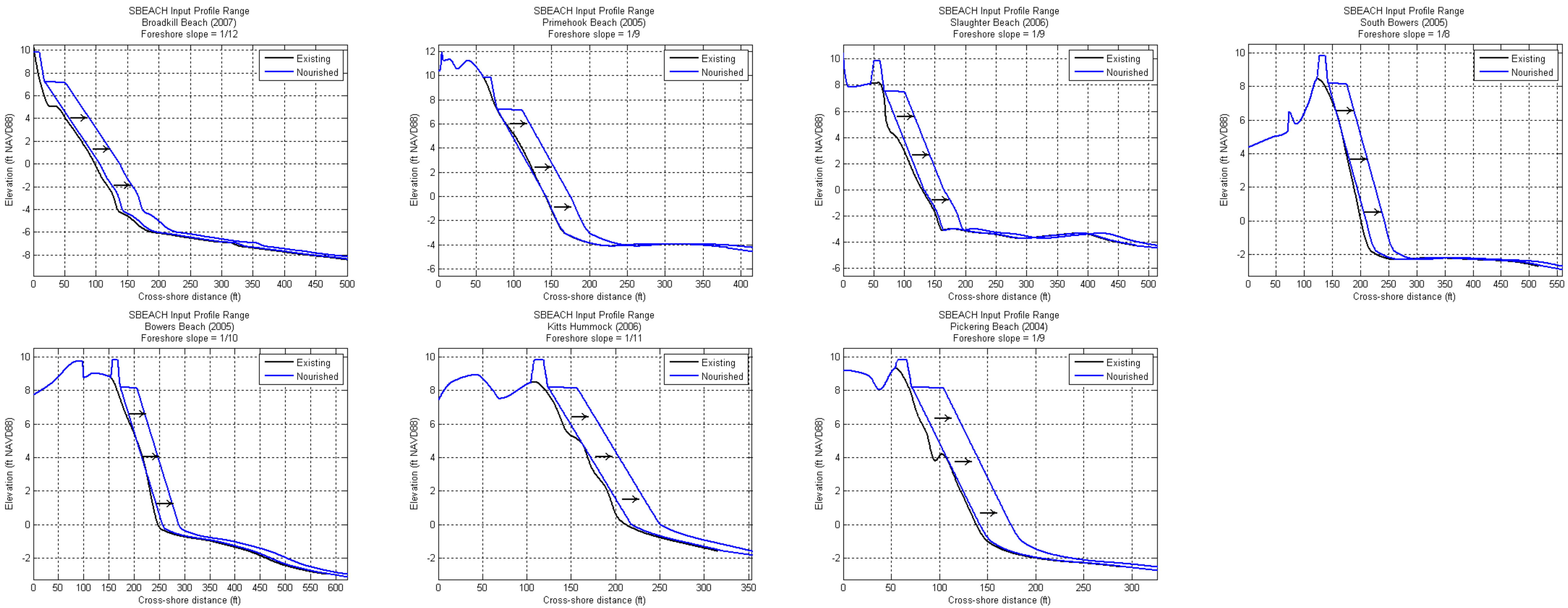


Figure 6.9 SBEACH input profiles ranges for each community.

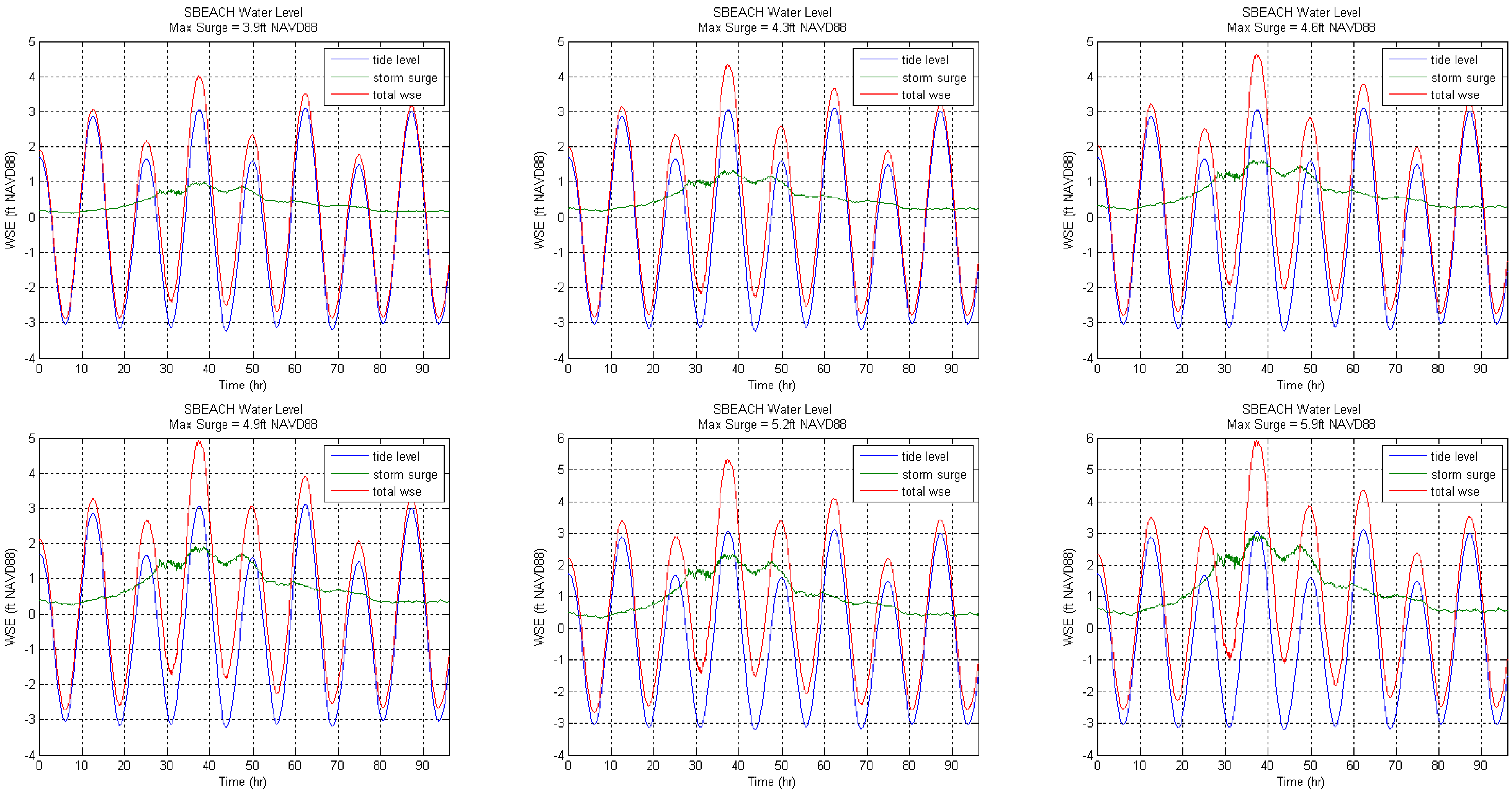


Figure 6.10 Storm surge hydrographs used in SBEACH model runs.

Table 6.8 Storm parameters for each community, 5 yr and 10yr return periods.

Location	5 yr storm			10 yr storm		
	Wave height (ft)	Wave period (s)	Peak WSE (ft NAVD88)	Wave height (ft)	Wave period (s)	Peak WSE (ft NAVD88)
Pickering Beach	6.6	5.5	4.9	7.9	6.0	5.9
Kitts Hummock	6.6	5.5	4.9	7.9	6.0	5.9
Bowers Beach	6.6	5.5	4.6	7.5	5.9	5.9
South Bowers	6.6	5.5	4.6	7.5	5.9	5.9
Slaughter Beach	7.5	5.9	4.3	9.2	6.5	5.2
Primehook Beach	7.9	6.0	3.9	8.9	6.3	5.2
Broadkill Beach	7.9	6.0	3.9	8.9	6.3	5.2

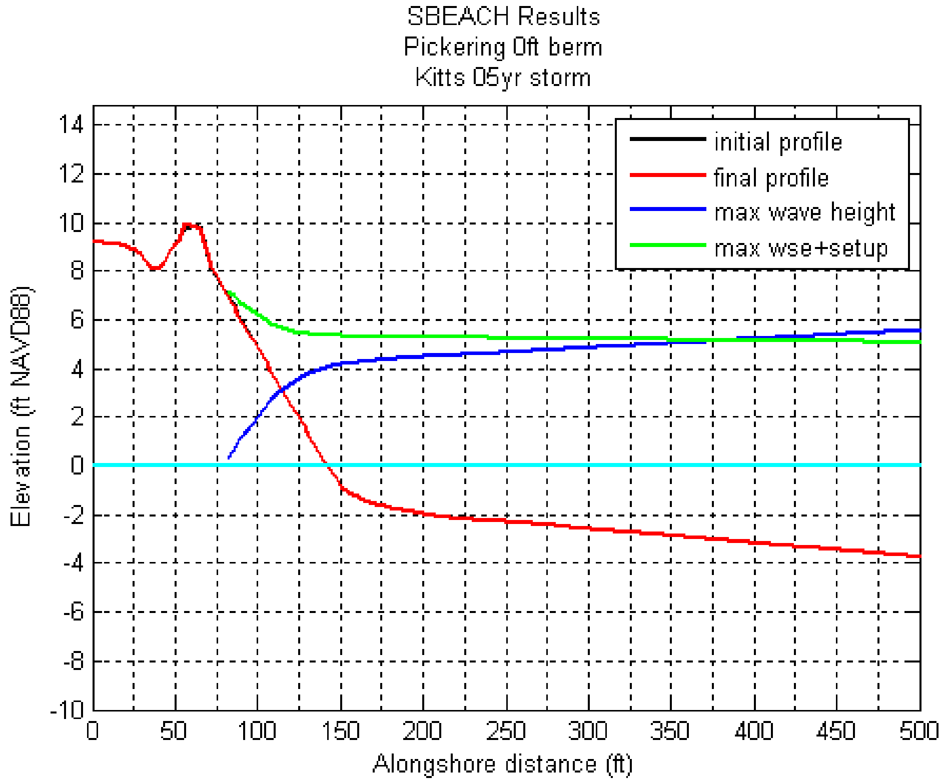
SBEACH simulations were performed by running each potential berm size versus the 5 yr and 10 yr storm events for each community. The results were examined to determine the berm width necessary to protect the upland area from erosion during each storm event. For all communities, the design dune feature and sloping foreshore was shown to provide protection against a 5 yr storm. It is important to note that this determination does not include any historic losses, as will be discussed in the next section. To protect against a 10 yr event, berm widths ranging from 7 ft to 20 ft were necessary in addition to the dune.

Figures 6.11 to 6.17 illustrate the SBEACH model results for the recommended berm widths in each community. The black line is the initial profile with the nourished berm, the red line is the beach profile after the storm simulation, the green line is the maximum water surface elevation (including wave setup) during the simulation, and the dark blue line represents the maximum wave height during the simulation.

6.4.3 Historical Loss Rates / Advance Fill

Accounting for background shoreline recession when determining a design berm is usually a source of significant uncertainty. In Delaware Bay, shoreline data is sparse and irregular in both space and time. The primary sources of historical shoreline change rates for the region are French (1990) and the USACE (1991). The beaches of interest all exhibit a trend of shoreline recession and values from these publications were similar. Due to the lack of consistent beach profile data to calculate a recent shoreline recession rate, the largest estimated recession rate from these publications was used in each community. Once determined, the rate was multiplied by the expected project lifetime to determine the necessary berm component to account for historical recession on both a 5 yr and 10 yr time frame. This conservative approach to determining advance fill also serves to mitigate for losses due to the alongshore diffusion of sediment typical of beach fill projects of this size.

The storm protection and advance fill components were then added together, resulting in the total berm width required for each scenario. Table 6.9 outlines the storm berms, historic loss rates, and total design berm widths proposed for each community. In addition to the dune feature, design berm widths for a 5 yr scenario range from 10 ft in Slaughter Beach to 39 ft in South Bowers. Design berm widths for a 10 yr scenario range from 36 ft in Primehook Beach to 98 ft in South Bowers.



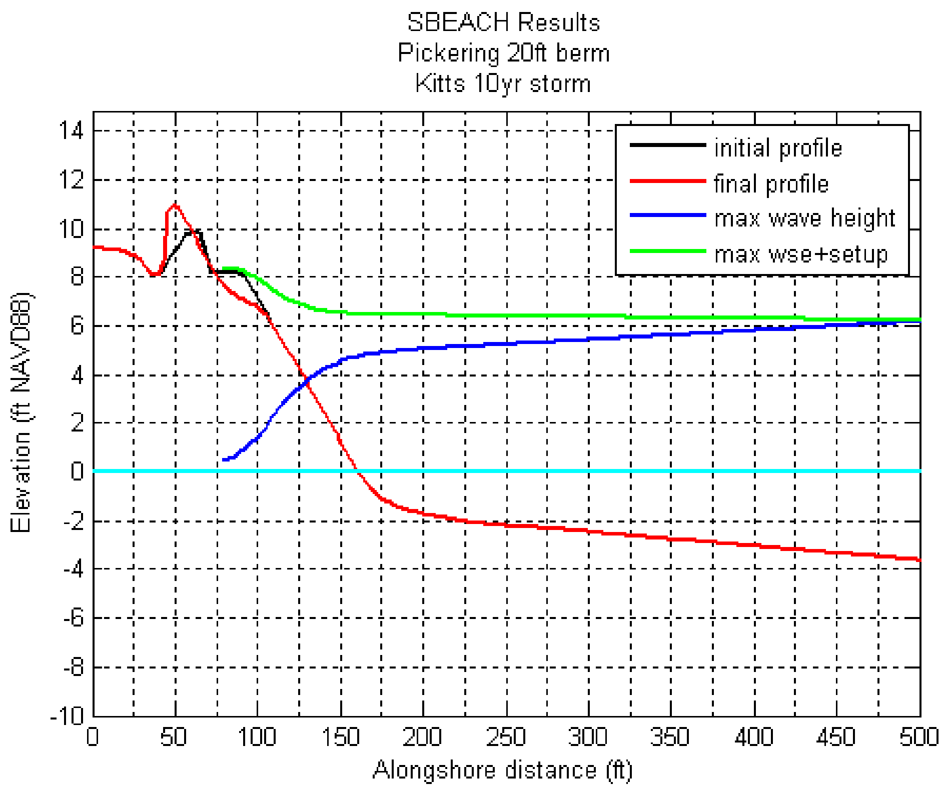


Figure 6.11 Pickering Beach SBREACH results. The dune itself provides sufficient protection against a 5 yr storm (top); the dune plus a 20 ft berm protects against a 10 yr storm (bottom).

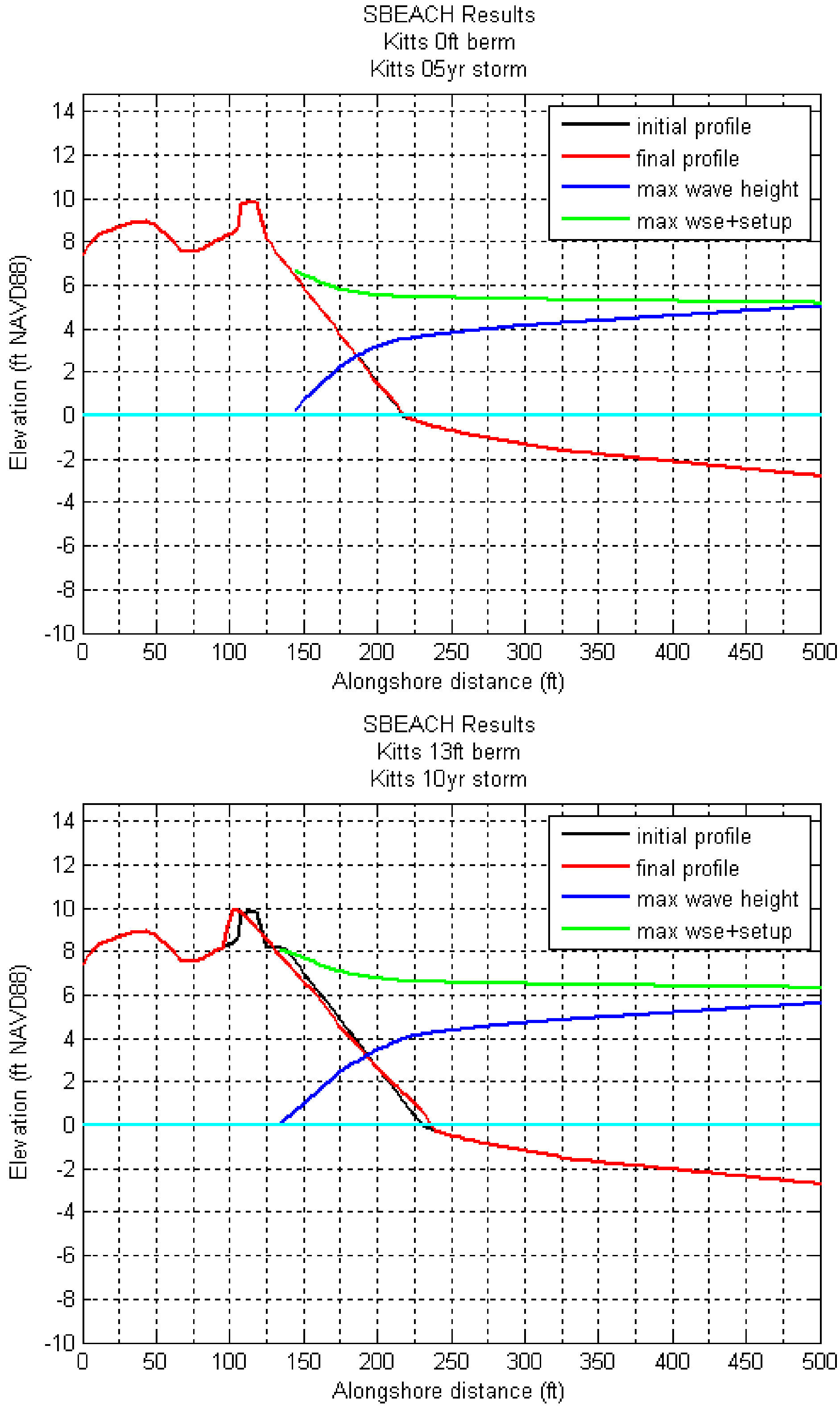


Figure 6.12 Kitts Hummock SBEACH results. The dune itself provides sufficient protection against a 5 yr storm (top); the dune plus a 13 ft berm protects against a 10 yr storm (bottom).

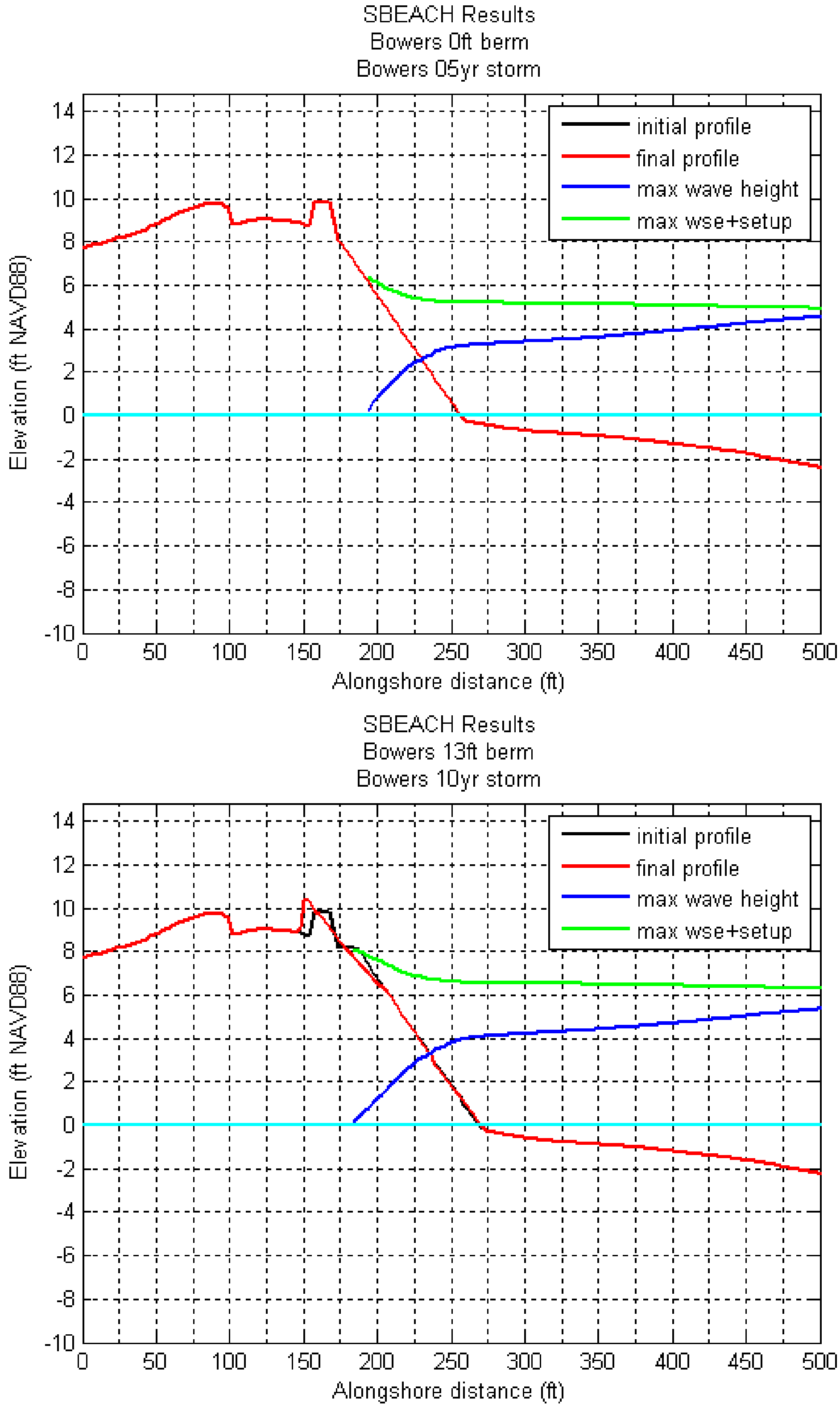


Figure 6.13 Bowers Beach SBEACH results. The dune itself provides sufficient protection against a 5 yr storm (top); the dune plus a 13 ft berm protects against a 10 yr storm (bottom).

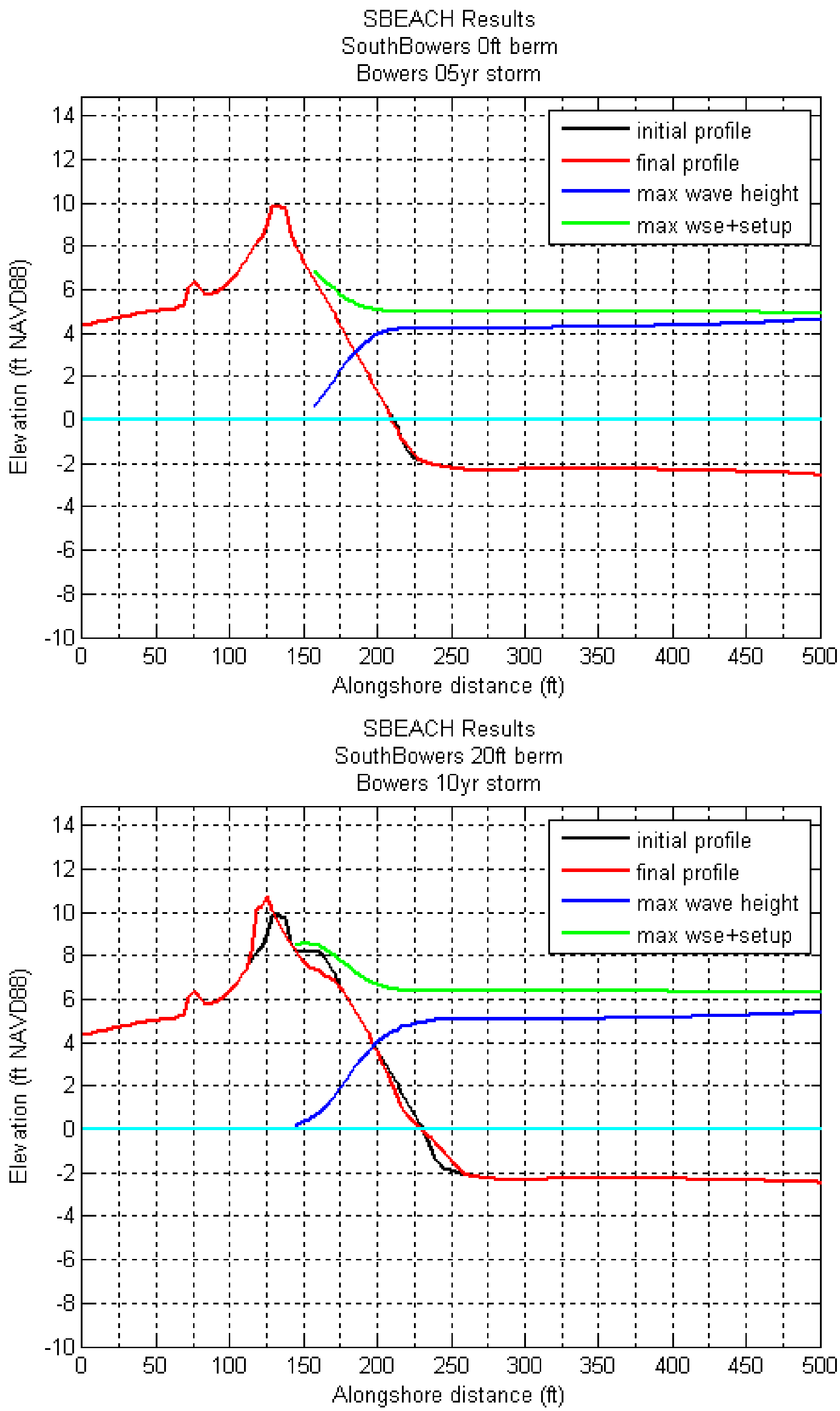


Figure 6.14 South Bowers SBEACH results. The dune itself provides sufficient protection against a 5 yr storm (top); the dune plus a 20 ft berm protects against a 10 yr storm (bottom).

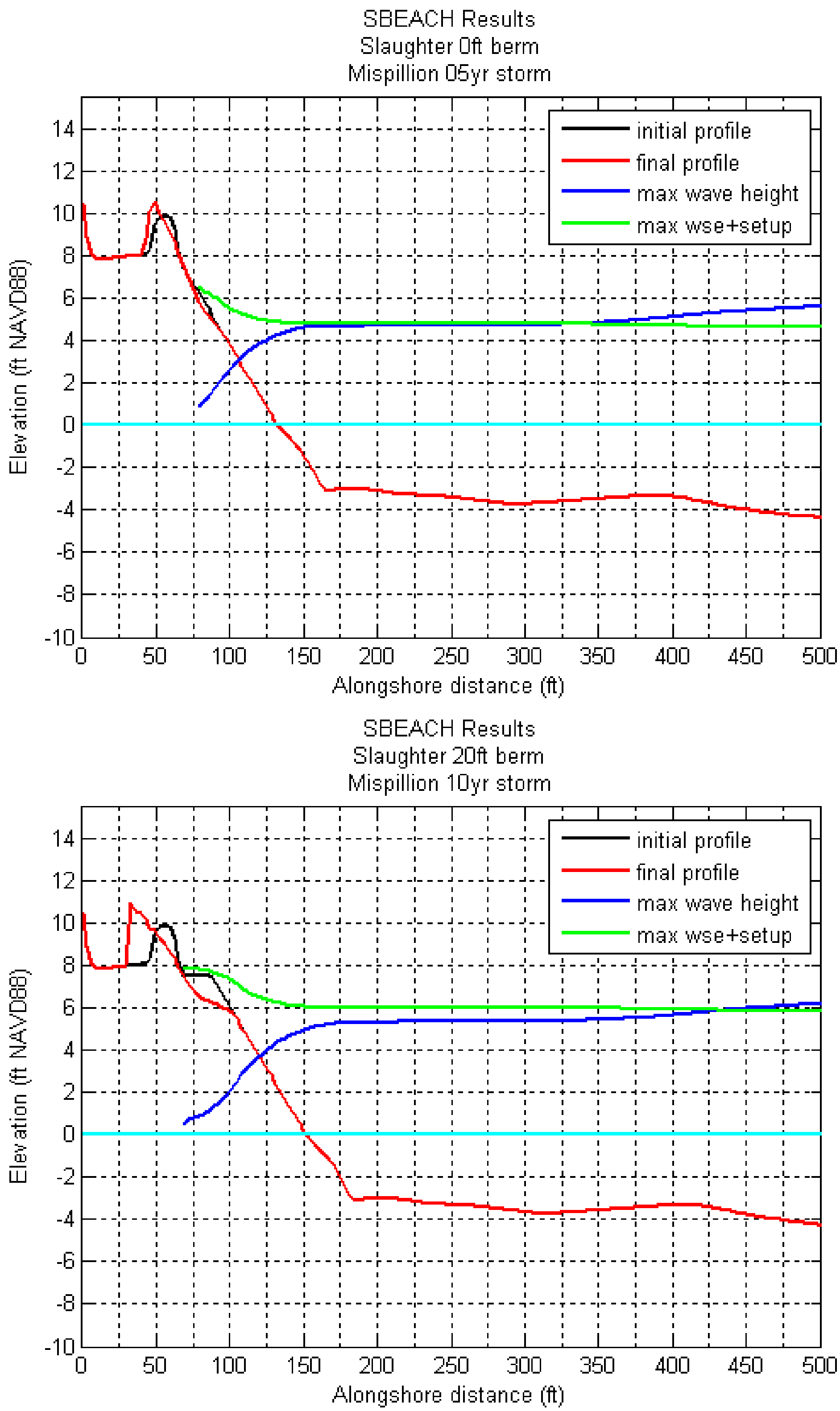
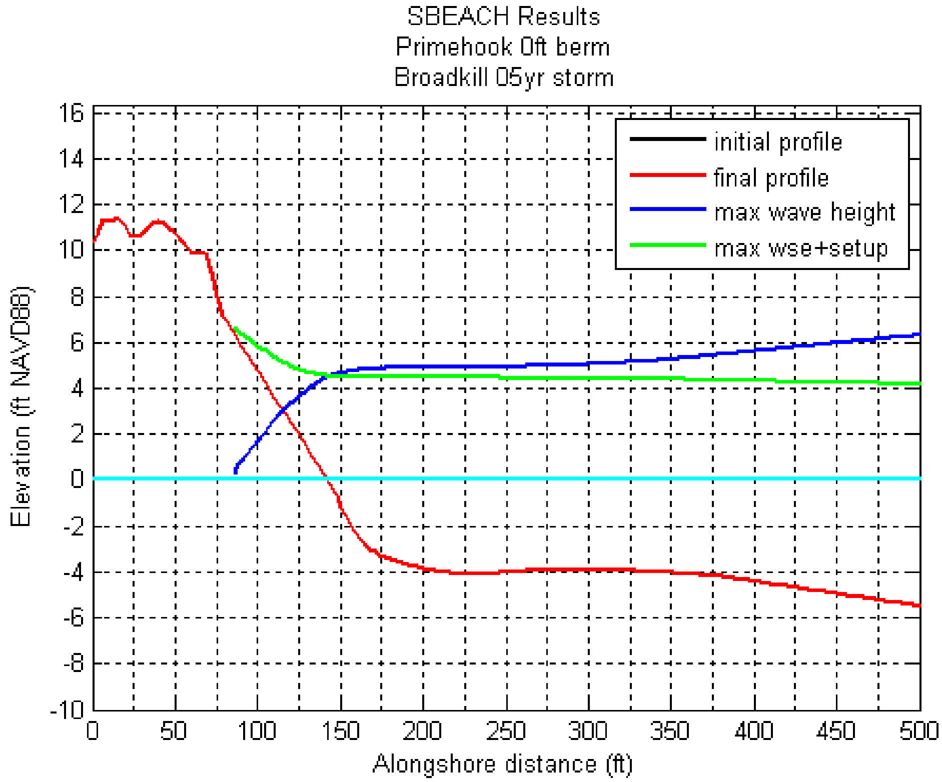


Figure 6.15 Slaughter Beach SBEACH results. The dune itself provides sufficient protection against a 5 yr storm (top); the dune plus a 20 ft berm protects against a 10 yr storm (bottom).



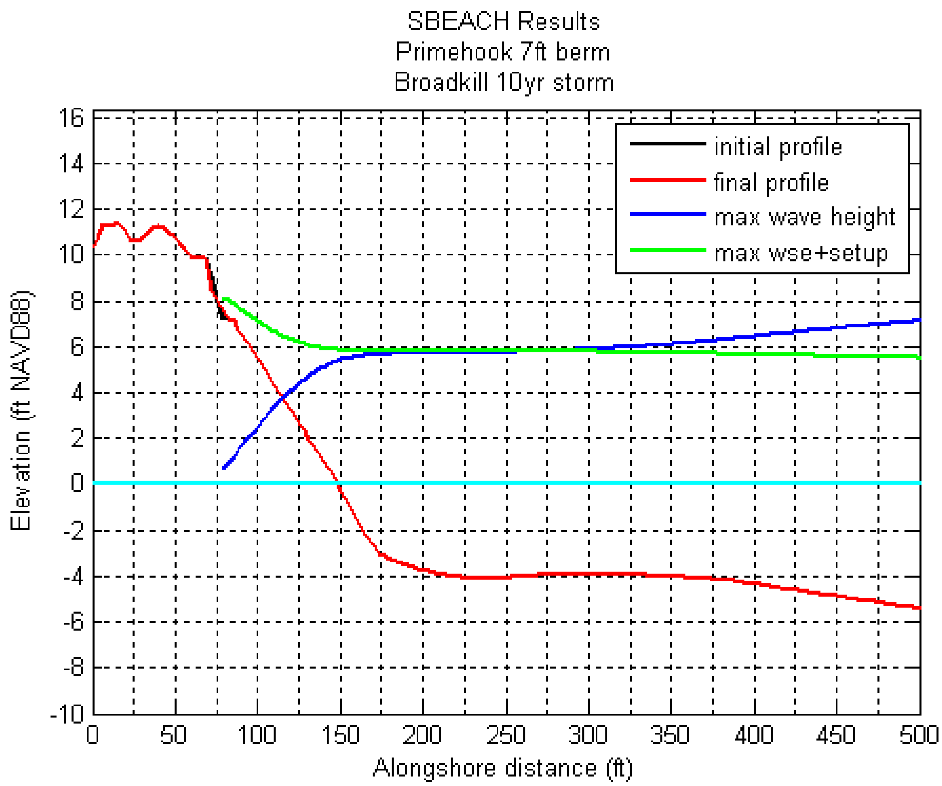
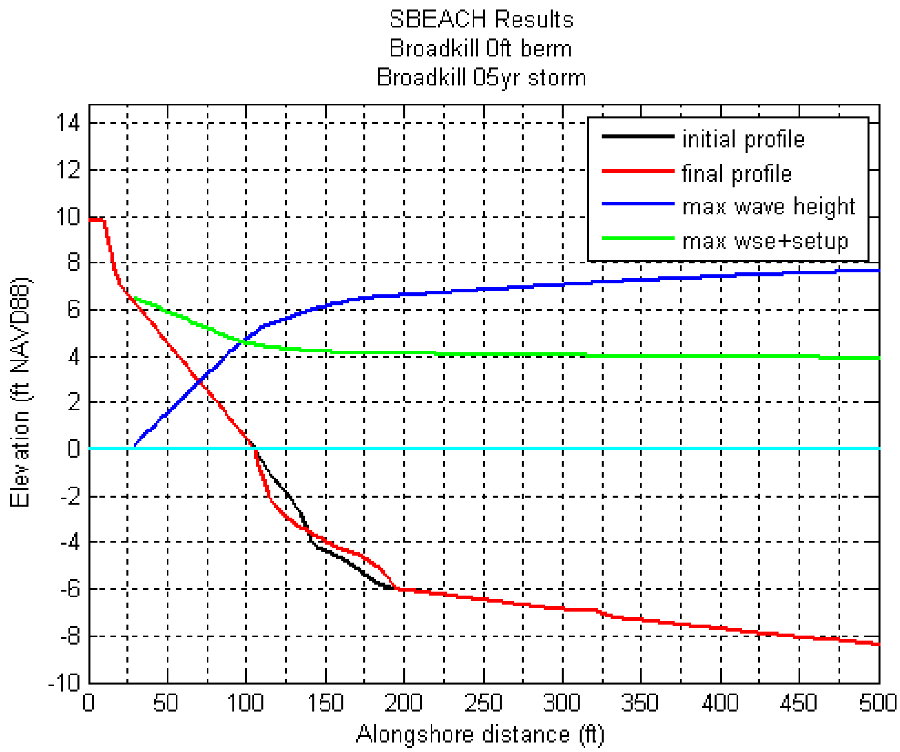


Figure 6.16 Primehook Beach SBEACH results. The dune itself provides sufficient protection against a 5 yr storm (top); the dune plus a 7 ft berm protects against a 10 yr storm (bottom).



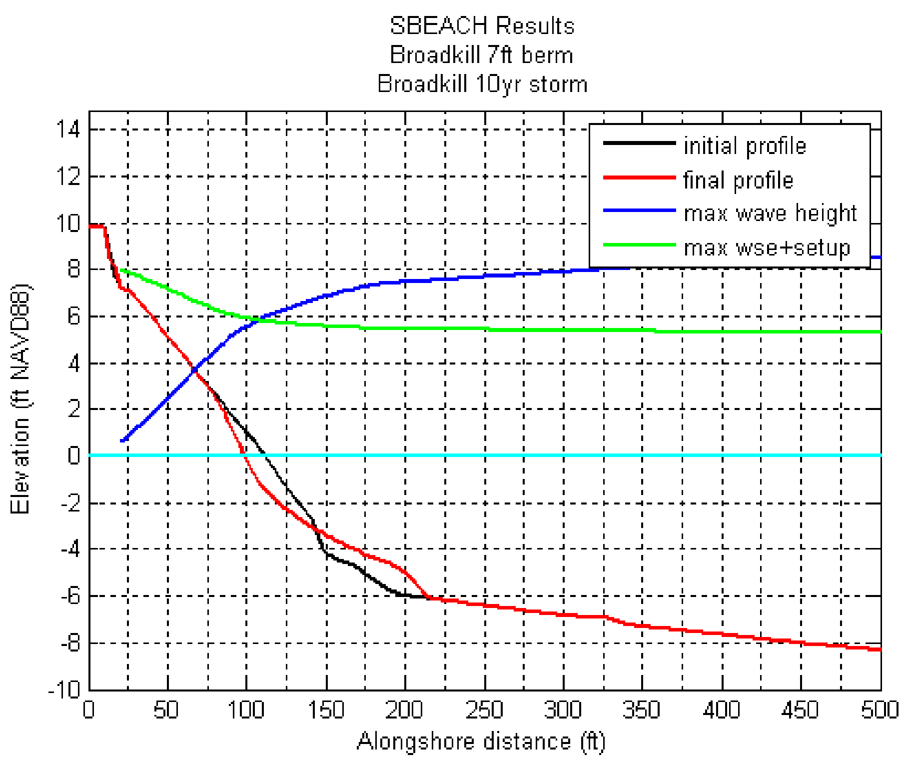


Figure 6.17 Broadkill Beach SBEACH results. The dune itself provides sufficient protection against a 5 yr storm (top); the design dune plus a 7 ft berm protects against a 10 yr storm (bottom).

Table 6.9 Design berm components for each community template.

	Pickering Beach	Kitts Hummock	Bowers Beach	South Bowers	Slaughter Beach	Primehook Beach	Broadkill Beach
5yr storm berm width (ft)	0	0	0	0	0	0	0
10yr storm berm width (ft)	20	13	13	20	20	7	7
Dune width (ft)	10	10	10	10	10	10	10
Dune height (ft NAVD88)	9.8	9.8	9.8	9.8	9.8	9.8	9.8
Dune slope (V:H)	1:3	1:3	1:3	1:3	1:3	1:3	1:3
Berm height (ft NAVD88)	8.2	8.2	8.2	8.2	7.5	7.2	7.2
Foreshore slope (V:H)	1:9	1:11	1:10	1:8	1:9	1:9	1:12
d_{50} (mm)	0.723	0.550	0.586	0.586	0.809	0.758	0.627
Hist. loss rate (ft/yr)	-4.9	-4.3	-3.0	-3.0	-2.0	-3.0	-4.6
(source)	USACE	French	French	French	USACE	USACE	French
5yr loss (ft)	25	21	15	15	10	15	23
10yr loss (ft)	49	43	30	30	20	30	46
5yr total berm width (ft)	25	21	15	15	10	15	23
10yr total berm width (ft)	69	56	43	50	39	36	53

6.4.4 Placement Volume Estimation

When a volume of sand is placed on a beach during a nourishment project, the cross-section of the placement experiences a morphological change as the placed sediment adjusts to the local environmental conditions. This is known as profile equilibration, and it occurs over a relatively short timeframe after material is placed. The design berm widths determined in the previous section represent the width of berm after profile equilibration. Using the equilibrium beach profile theory developed in Dean (2002), the desired equilibrated berm width can be related to a unit volume of placed sediment (i.e., this approach helps determine the amount of sand that should be placed during construction to achieve the desired equilibrium profile); this relationship is highly dependent on the relationship between the grain sizes of the native and placed material.

Table 6.10 outlines the equations for calculating the placed volume requirement necessary for a given equilibrium berm width. Figure 6.18 illustrates the relationship between grain size and the sediment scale parameter in Dean's equations. The depth of closure was estimated to be 8.2 ft, based on typical incident wave conditions, submerged profile characteristics, and resultant unit volume placements. Using this method, a unit volume placement was estimated for each community that would result in the desired equilibrium berm width. In lieu of a detailed sediment borrow area analysis, fill material was assumed to be the same size as native material. If this is not the case at the time of project execution, fill volumes must be adjusted accordingly. Note that the volume required for dune construction is not accounted for with this method and must be estimated separately.

Table 6.10 Parameters used in calculating unit volume placement for given beach width.

Name	Symbol	Units	Source
Depth of closure	h_*	ft	estimated
Berm elevation	B	ft	prescribed
Median diameter of native sediment (d_{50})	D_N	mm	prescribed
Median diameter of fill sediment (d_{50})	D_F	mm	prescribed
Profile scale factor of native sediment	A_N	--	Figure 6.58
Profile scale factor of fill sediment	A_F	--	Figure 6.58
Length of active profile	W_*	ft	$W_* = \left(h_*/A_N\right)^{3/2}$
Equilibrium berm width	Δy_0	ft	prescribed
Profile intersection parameter	P	--	$P = \frac{\Delta y_0}{W_*} + \left(\frac{A_N}{A_F}\right)^{3/2} - 1$
Unit volume placement	V	ft^3/ft	$if\ P < 0:\ \frac{V}{BW_*} = \frac{\Delta y_0}{W_*} + \frac{3}{5}\frac{h_*}{B}\left(\frac{\Delta y_0}{W_*}\right)^{5/3} \frac{1}{\left(1-\left(\frac{A_N}{A_F}\right)^{3/2}\right)^{2/3}}$ $if\ P > 0:\ \frac{V}{BW_*} = \frac{\Delta y_0}{W_*} + \frac{3}{5}\frac{h_*}{B}\left\{\left[\frac{\Delta y_0}{W_*} + \left(\frac{A_N}{A_F}\right)^{3/2}\right]^{5/3} - \left(\frac{A_N}{A_F}\right)^{3/2}\right\}$

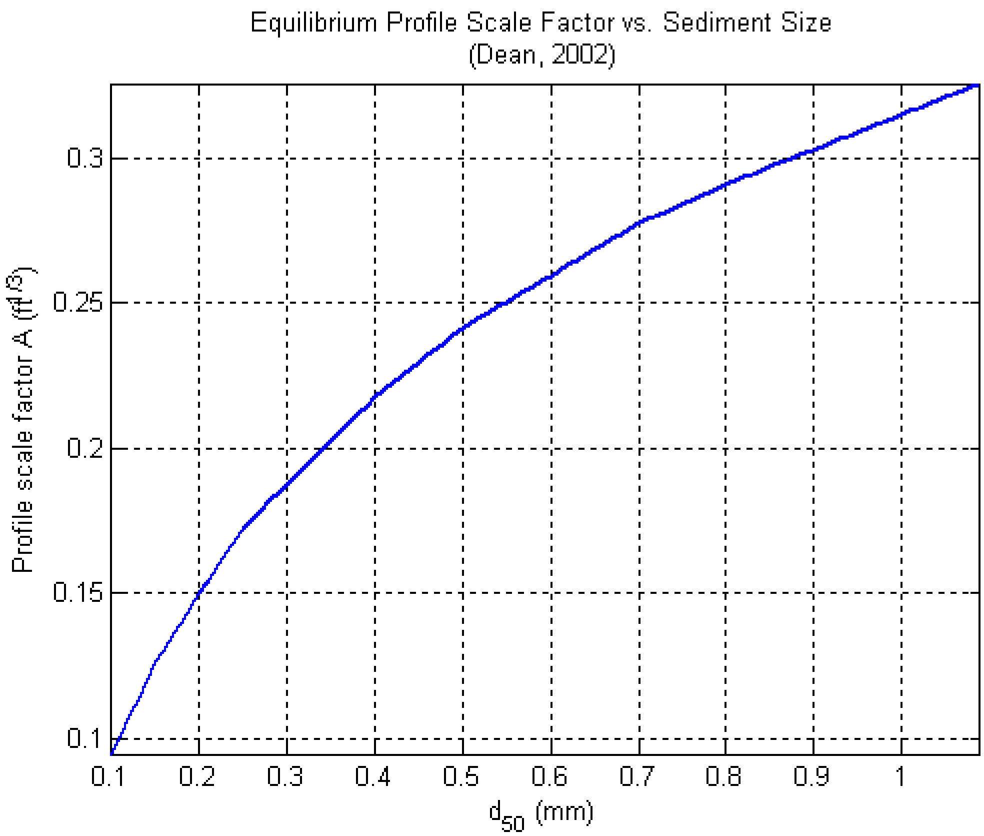


Figure 6.18 Equilibrium beach profile scale factor versus sediment grain size (Dean, 2002).

Table 6.11 presents the unit volume placements necessary to create the design berm in each community using the method of Dean (2002), as well as the unit dune volumes assuming a simple trapezoidal shape from crest to berm elevation. Note that units have been converted from metric to English.

Table 6.11 Unit volume placements for each design berm; equilibrium profile method (Dean 2002).

	5 yr Design Project			10 yr Design Project		
	Berm width (ft)	**Unit volume (berm) (cy/ft)**	**Unit volume (dune) (cy/ft)**	**Berm width (ft)**	**Unit volume (berm) (cy/ft)**	**Unit volume (dune) (cy/ft)**
Pickering Beach	25	16	0.9	69	45	0.9
Kitts Hummock	21	14	0.9	56	36	0.9
Bowers Beach	15	10	0.9	43	27	0.9
South Bowers	15	9	0.9	50	32	0.9
Slaughter Beach	10	6	1.42	39	24	1.42
Primehook Beach	15	9	1.72	36	22	1.72
Broadkill Beach	23	14	1.72	52	32	1.72

Unit volume placements for the 5 yr design vary between 6 cy/ft in Slaughter Beach and 16 cy/ft in Pickering Beach. For the 10 yr design, volume placements range from 22 cy/ft in Primehook Beach to 45 cy/ft in Pickering Beach. Unit volumes for the dune feature range from 0.9 cy/ft to 1.72 cy/ft, depending on the design berm elevation.

7. Beach Management Plan

7.1 Overview

This plan outlines a regionalized beach management and funding program for the seven designated coastal communities of the Delaware Bay region.

As was discussed in previous sections of this document, the principal goals of this plan are to:

1. Present a management plan that addresses beach erosion and provides shore protection from wave attack and storm surge to the beach and dune system. The plan is not intended to address flooding issues resulting from inland drainage conveyance or storage concerns.
2. Provide DNREC with a ten-year outlook to allow for proactive management of the beaches.
3. Examine sand movement pathways and develop predicted sand needs for each community over a ten year time frame.
    a. Evaluate specific forces or circumstances that have historically caused significant erosion.
    b. Estimate the quantity of sand needed for the design life of each project.
4. Extend the life of beach nourishment projects and provide a quantifiable level of protection for storm impacts and historical losses by designing projects with the appropriate construction templates.
5. Encourage regionalized approaches to, and reduce equipment mobilization and demobilization costs of, beach projects that take advantage of geographic coordination and sequencing of projects.

Sections 1 through 6 of this document provide a great deal of background information concerning the history, processes, and other factors that need to be considered in developing and applying a 10-year management plan for these beaches. This section, along with Section 8, applies this information to present three management plan scenarios for each of the seven communities.

Before presenting the management plan scenarios for each community, the following general information is provided as a backdrop for all of the management plans.

7.1.1 Beach Fill / Nourishment Projects

The primary function of a beach nourishment project is to provide protection to upland infrastructure from erosion induced by wave action and storm surge. Figure 7.1 shows how storms can impact the shoreline and cause damage to upland infrastructure. Through higher water levels and increased wave heights, the natural berm, which acts as a protective buffer, is eroded.

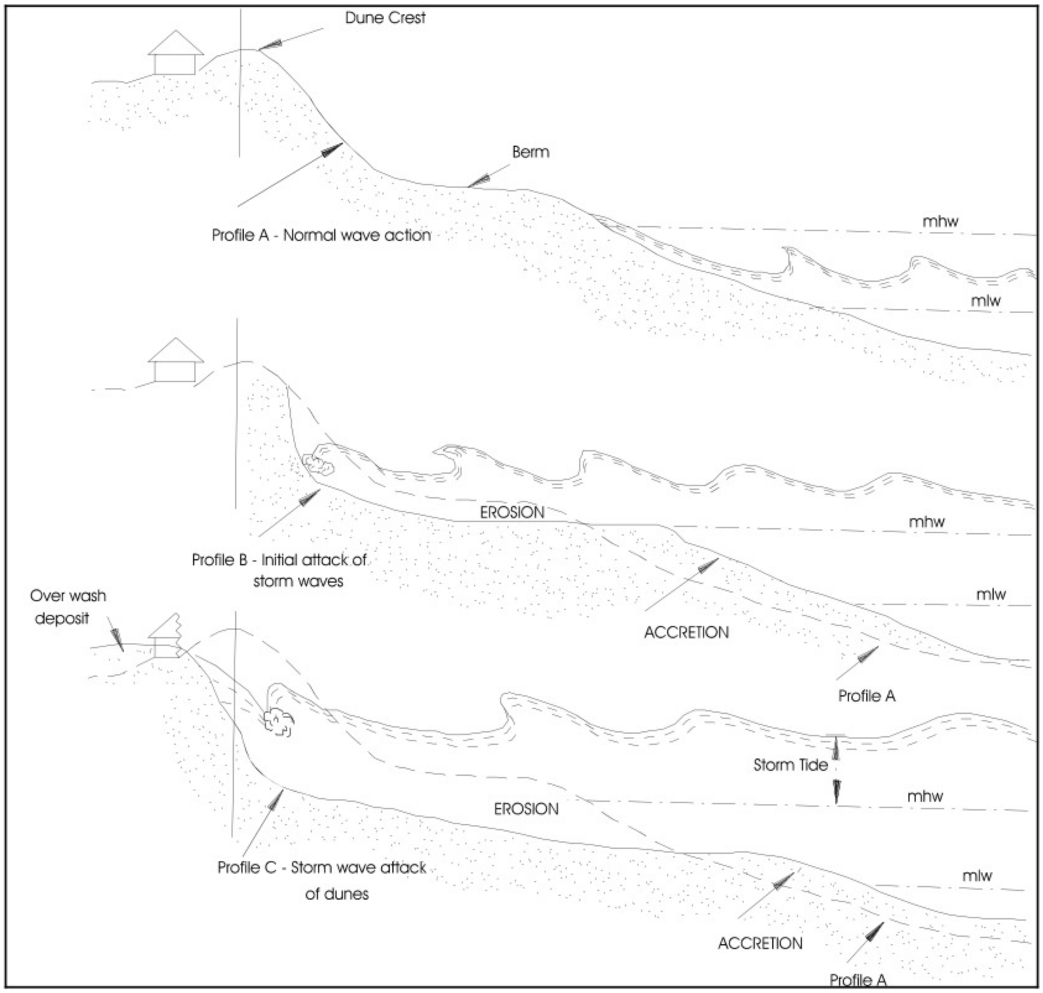


Figure 7.1 Example of storm impacts to shoreline and upland areas (CEM Figure V-4-1).

Beach nourishment involves placing sand along the shoreline and extending the width of the beach, thereby increasing the buffer of protection. The amount of protection provided by a nourishment project is not an absolute measure, due to the uncertainties in the frequency of storm events that may be encountered over the project lifespan. Scheduled maintenance (renourishment) is needed in order to maintain the desired level of protection. Typical features found in beach nourishment projects include a berm and dune (Figure 7.1). Figure 7.2 illustrates a general example of the pre-project condition, post-construction profile (cross-section), and the intended equilibrated project design configuration. The berm is the primary feature of a beach nourishment project, and provides additional beach width to dissipate wave energy. A dune is typically included in the design of a beach nourishment project and includes less sand volume than the berm; however, it provides additional height to the beach to help prevent storm surge overtopping.

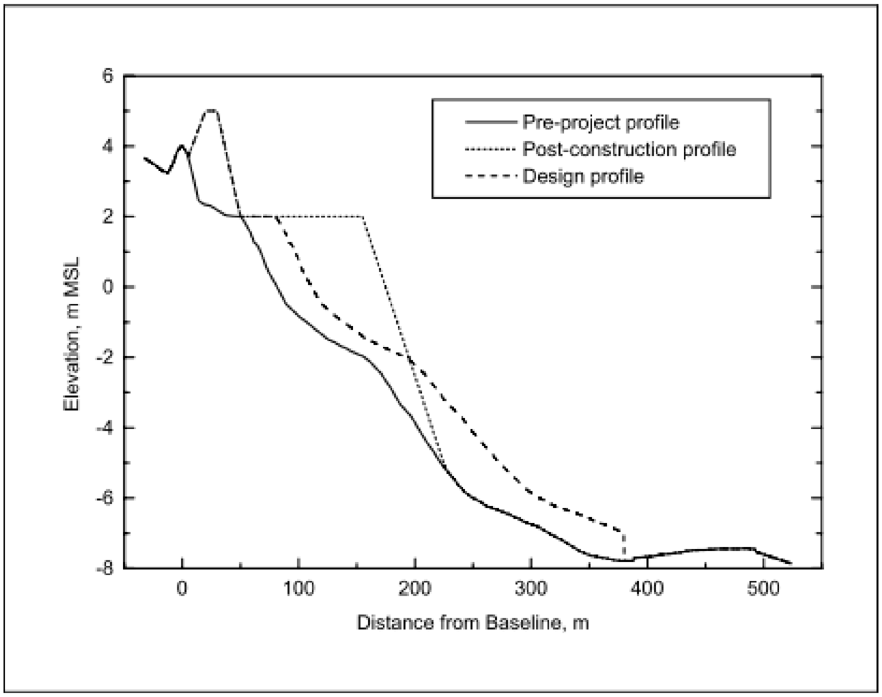


Figure 7.2 Conceptual example of pre-project, post-construction, and design beach profile (CEM Figure V-4-2).

Dune vegetation occurs naturally along the Delaware Bay coastline, and provides additional protection against the effects of wind and waves. When dunes are artificially constructed, planting dune grasses can help anchor the placed sand, as well as potentially accumulate additional sand. Cape American beachgrass is a pioneer species in dune formation, due to its extensive root and rhizome system. It should be planted along the top and down the face of the constructed dunes to increase the stability of the dune and provide additional protection to upland structures.

The design of a beach nourishment project is largely based on the geometry of the shoreline and localized historical erosion rates in conjunction with the amount of protection desired from a return period storm event. Various beach fill design alternatives were considered within the development of this plan. Three levels of protection were evaluated in order to provide a range of projects to be considered from an economic, environmental and local sponsor perspective. The three project beach fill designs include:

1. Strategic Fill Placement
2. 5 Year Level of Protection
3. 10 Year Level of Protection

It should be noted that the beach profiles and fill templates are generalized for each beach, and do not represent final design projects or construction templates. In some cases, fill template tapers on each end of the project may require the securing of additional easements. In addition, local infrastructure (e.g. stormwater outfall pipes) is not accounted for in this analysis and would have to be quantified in any final design template. These factors could result in extra time and costs not accounted for herein.

7.1.2 Long Range Budget Plan Timeframe

A budget and schedule has been developed for each community. Long range planning provides opportunities for employing regional approaches to beach management and encourages coordination among local governments to lower costs and provide long term solutions to beach erosion. For the purposes of this management plan, the long range planning timeframe used was 10 years. The long range budget plan for the three project scenarios is provided for each community.

7.1.3 General Environmental Permitting Issues

Natural Resources. The beaches of Delaware Bay serve as important nesting grounds for the horseshoe crab and foraging grounds for a variety of Federally-protected bird species. As such, nourishment of these beaches is an important method of protecting habitat. Future work in identifying sediment sources and constructing specific beach projects will require further attention to the needs of the communities that utilize the beach.

The nearshore environment provides important habitat for a number of commercially important fish species, the sandbar shark, and juvenile sea turtles. While this does not directly impact the initial design of beach projects, it will be important as borrow areas are delineated and construction methods are determined.

Historical Resources. Historic resource surveys have been completed offshore of a number of the communities during permitting of past projects. Consideration of the location of potential resources will be important during permitting. More specific details of these surveys are included in each community section.

7.1.4 Emergency Funding

The various strategies listed do not include a funding source or mechanism for the emergency placement of sand if one or more major storms strike the area outside the level of protection criteria discussed. These types of events generally cause damage along an entire coastline. The Federal Emergency Management Agency (FEMA) recognizes engineered and maintained beaches as public infrastructure which may be eligible for public recovery funds provided that sufficient damage occurs to warrant a federal disaster declaration. This type of funding could help with recovery from a major storm event. Regardless, if the state is attempting to achieve and maintain a uniform level of protection, there may be a need to set aside additional funding to deal with these emergencies.

7.1.5 Overall Schedule

The projected schedule of work includes the following activities:

- Geotechnical investigations. As has been discussed in the preceding sections, very limited data are available on the exact locations and extents of sand sources that could be used for nourishment projects. In order to prepare permit applications, design documents, and bid documents, a more detailed geotechnical study will be required to locate and characterize the sources of sand that will be used for each community. This work should be performed as one study that will cover the needs of all seven communities. The cost of performing this work has been included in the attached tables and has been prorated over each community based on the relative amount of sand that community needs.

These investigations are expected to take about 1 year to complete.

- Design and permitting. Once the detailed geotechnical study is completed and specific sources of sand have been identified, final design and permitting work can proceed. The design of each project will depend on the nature of the sand source. As with the cost of the geotechnical study, the cost of performing this work has been included in the attached tables and has been prorated over each community based on the relative amount of sand that community needs.

Design and permitting work are expected to take about 1½ to 2 years to complete.

- Sand placement. We have assumed that all work will be performed in two main groups; a north region that will include Pickering Beach, Kitts Hummock, Bowers Beach, and South Bowers Beach, and a south region that will include Slaughter Beach, Primehook Beach and Broadkill Beach. As is discussed below in the construction cost section, this has been done to help minimize the large mobilization/demobilization costs associated with this type of project. This grouping is also intended to help make these projects suitable and attractive to local, relatively small commercial dredging firms and thereby obtain competitive prices.

The type of equipment operated by the small dredging firms that typically compete for work in the Delaware Bay region is a 14 in hydraulic suction dredge. These dredges typically require about 4 ft of water to operate in and have the capability of pumping from 2,500 cy to 5,000 cy of sand per day (based on 24 hour operations). Based on the expected state and federal permit terms and available window for safe dredging operations, sand placement work for each region is expected to require one year.

In addition to the above items, the schedule also includes the following post construction activities:

- Environmental permit monitoring. Once initial construction has been completed, it is likely that the permit terms for each project will require some type of follow up monitoring of project impacts and/or various performance measures. An allowance for these costs has been included for the three years following the initial completion of each project.

- Beach surveys. To assist with design and permitting leading up to initial construction and to properly assess the performance of each project, annual beach surveys should be performed in each community. An allowance for these costs has been included for each project.

Periodic maintenance or follow up nourishments. Each project will require maintenance. Projected maintenance costs for each option have been included based on the assumption that 60% of the volume of sand initially placed will need to be restored at the end of the "design life" of the alternative. The frequency and level of maintenance will depend on how often storms impact the area, how severe the storms are, and the relative size of the initial beach nourishment project (e.g., the 10 year scenario should require less maintenance than the 5 year and strategic beach fill placement scenarios under the same storm conditions).

7.1.6 Construction Cost Estimates

Construction cost estimates have been developed based on discussions with contractors, available cost information from other relevant projects in this region and our project team's experience with similar relatively small beach restoration projects.

Local dredging contractors. The following contractors were contacted during the course of this project:

Barnegat Bay Dredging Harvey Cedars, NJ Contact person: John Fullerton Telephone: 609-494-5913	Norfolk Dredging Chesapeake, VA Contact person: Mike Haverty Telephone: 757-547-9391
Cottrell Contracting Chesapeake, VA Contact person: Ben Cottrell Telephone: 757-547-9611	Southwind Construction Evansville, IN Contact person: Steve Bassett Telephone: 812-867-7220

Mobile Dredging Chester, PA Contact person: Bill Daisy Telephone: 610-497-9500	

Costs for design, permitting, geotechnical investigation, post-project performance, and physical/biological monitoring are presented in tabular form for each community. Construction costs are estimated for each of the three project scenarios and include mobilization and demobilization, sand placement, and dune plantings.

4. Mobilization/demobilization costs. One of the largest costs associated with beach nourishment projects is the cost of mobilizing and demobilizing a dredge to pump sand from an offshore source onto the beach. These costs typically range from $450,000 per project for a relatively small (e.g., 14 in hydraulic dredge with a draft of 4 ft) to over $1 million for larger dredges suitable for work in deeper water.

Combining as many projects as practical is an effective means for minimizing these costs. For the purposes of this plan, it was assumed that work would be grouped into two regions and performed under two contracts. If work is to be performed as individual contracts, costs would need to be increased to reflect the need for mobilizing and demobilizing for each project.

For these projects, mobilization/demobilization costs were estimated to be $750,000 for the north region and $650,000 for the south region. This is based on an initial mobilization/demobilization cost of $450,000 plus $100,000 to move to each additional community. The mobilization and demobilization costs assume the pumping distance is 1 to 2 mi and that no special problems or restrictions exist for dredging, and include the cost for intermediate work at each beach such as laying and removing pipe. The mobilization and demobilization cost is spread out evenly among the four northern communities and the three southern communities.

5. Sand placement costs. A unit cost of $7/cy reflects relative estimates for excavation, delivery distances, and placement quantities for sand. The unit volume for the berm represents the area of the template with a full width berm. A unit volume equal to half of the full berm is used in estimating volume in the taper.

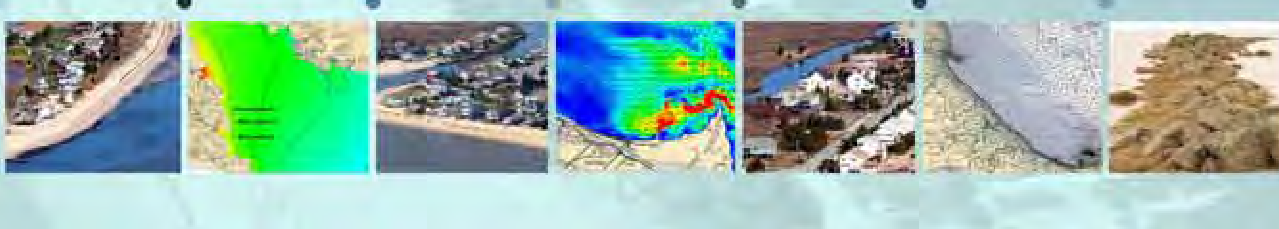
6. Dune plant costs. A unit cost of $1.09/planting unit reflects relative estimates for plants and the labor to install them. The basic planting scheme used for each community assumes 11 or 12 rows of plants planted on 18 in centers with one planting unit in each hole. One planting unit equals two plants.

Pickering Beach

MANAGEMENT PLAN FOR

THE DELAWARE BAY BEACHES

FINAL REPORT • MARCH 2010



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7.2 Pickering Beach

7.2.1 Background

Pickering Beach is located approximately 25 mi from the mouth of the Delaware Bay and occupies a narrow barrier of sand bordered by Delaware Bay and a back barrier marsh. It lies generally in a north-south direction, with a shoreline azimuth of 82°N. The community is situated on a curve in the shoreline, but houses were generally built in a straight line. As a result, houses at the north and south ends of the community are located much closer to the shoreline than those in the middle of the community. The USACE estimated that the shoreline erosion rate is approximately 4.9 ft/yr (Table 6.2).

The beach measures approximately 3,000 ft in length and is narrow in width (Wethe et al., 1983). Beach sand is supplied by erosion of ancient land forms that sit bayward of the community. The beach sediments in this area are primarily fine to coarse sands (Department of the Army, 1981). During a site visit in January 2008, it was also noted that the swash zone contained medium to small gravel. There is a small vegetated dune along the back of the beach.

Maurmeyer (1978) calculated a net transport rate in the southerly direction of 3,100 yd^3/yr (Table 6.1). Observation of past beach fill behavior suggests that the dominant transport direction is northward in the north half of the community and southward in the southern half, with the curve in the shoreline acting as a nodal point. This trend is partially reflected in the results of the circulation model for operational conditions (Figure 1.17 of the Modeling Report) where flow is mostly directed away from the shore with an area of weak currents in the center of the community. South of this spot, the current accelerates and has a slight southerly direction. North of it, flow is stronger with a slightly northward direction. This reversal of flow from the center of the community was considered in the design of the placement for Pickering Beach. Under average conditions, the circulation modeling exhibits a southerly flow direction which correlates with the calculated net transport direction.

In the wave model, there is more wave energy on the north side of the town than on the south side with the annual potential transport direction directed northward due to the influence of the offshore waves. This is consistent with past beach fill behavior and may offer some explanation of localized northerly transport observations. In addition, the wave model demonstrated the seasonal variability of wave heights and potential transport direction. These results were compared to the circulation model as well as past estimations and observations of longshore transport potential to assist in developing beach fill placement options.

Figure 7.3 2007 Aerial of Pickering Beach (Delaware DataMIL)

Shore Protection History. Beach nourishment events and the installation of shore protection structures have been conducted at Pickering Beach since 1962. A total of 255,750 cy of material have been placed to date. Table 7.1 provides the data available regarding the beach nourishment and shore protection history for Pickering Beach. The fill template typically used for past projects at this beach consists of a berm with a height elevation of 9.0 ft NAVD88 and a foreshore slope of 1V:15H (Figure 7.4).

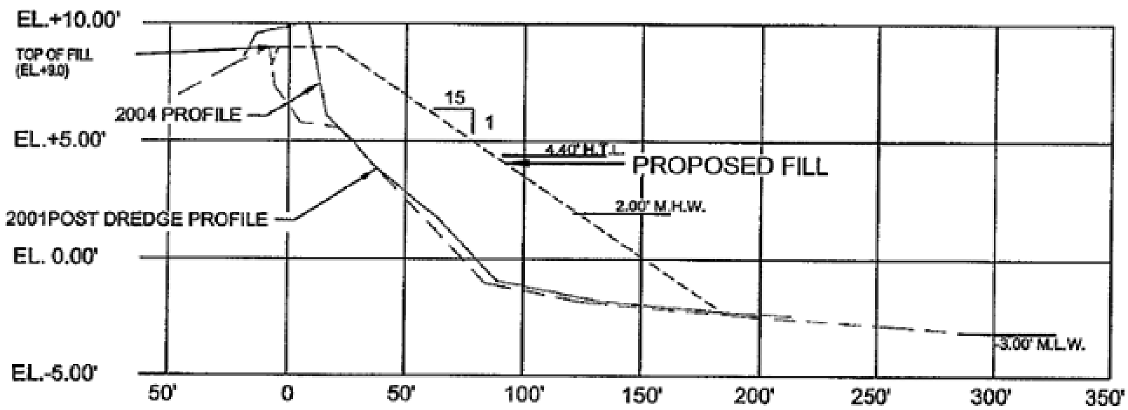


Figure 7.4 Typical fill template for past projects at Pickering Beach, vertical datum NAVD88 (from 2005 permit application).

Table 7.1 Pickering Beach Shore Protection History.

Year	Volume (cy)	Length (ft)	Location	Method	Sediment Source	Structure
1962	39,600	2,800	N/A	Truck-haul	N/A	
1969	5,000	N/A	N/A	Truck-haul	N/A	
1978	85,200	1600	1+00N through 16+00S	Hydraulic Dredge	N/A	
1978	Structure	400	800ft. offshore			Tire breakwater
1978	Structure	400	800ft. offshore			Tire breakwater
1979	7,400	400	0+00 through 4+00N	N/A	N/A	
1986	36,000	2500	10+00N through 15+00S	N/A	N/A	
1990	55,400	2400	10+00N through 14+00S	Hydraulic Dredge	Offshore	
2001	27,150	1100	North end of community	Hydraulic Dredge	Offshore	

N/A = Information not available. The information for this table was gathered from DNREC records and state and federal permitting documents.

Existing Structures. Some portion of the floating tire breakwater installed by the Corps as part of the Section 54 Demonstration program in 1978 still exists offshore of Pickering Beach (Figure 7.5). In a 1989 report on the status of the structure, the Corps indicated that no obvious accretion was occurring on the shoreline due to the existence of this structure. The neutral performance of the structure was determined to be likely due to the short length of the structure compared to the distance offshore, a significant long wave period which is not dissipated by the short length of the structure, and the limited volume of sand in the littoral zone. A small accumulation of sand has occurred in the lee of the structure.

Recommendation: The structure is not presently adversely affecting the shoreline. A closer inspection of the tires and the connections between the tires should be conducted to determine the condition of the structure. Removal would be recommended if the inspection revealed that the structure would likely break apart during a storm event which would result in the tires being deposited on the shoreline and in the marsh. Unless aesthetic reasons dictate action, removal would not be required as part of the overall shore protection strategy for this shoreline. Monitoring is recommended in order to continue to evaluate performance and the interaction with any proposed sand placement.

Figure 7.5 Remainder of tire breakwater, installed by the Corps in 1978.

7.2.2 Management Plan Alternatives

No Action

Landward migration of the shoreline would likely continue if no action is taken at this community. Of greatest concern is the shoreline that is located on the outer ends of the community. Infrastructure including recreational beach, utilities, roadways, and private homes could be damaged or lost during high energy coastal storms. Continued erosion would also decrease the available acreage of nesting beach for use by horseshoe crabs; this would negatively impact both the horseshoe crab population and the populations of shorebirds that rely on the horseshoe crabs.

Strategic Fill Placement

This scenario consists of concentrating the placement of fill along the specific locations of greatest need in each community. This alternative is largely based on the previous shore protection activities conducted by DNREC (Table 7.1) and is the minimum level of protection that would be recommended. Based on a review of previous studies, historic aerials, longshore transport estimates, and local knowledge gained from previous beach fill behavior, the recommended design components of this scenario include the components listed below. Due to the observed and modeled erosion patterns at the site, the strategic placement event has been designed to protect the most vulnerable portions of the beach located at the north and south ends of the community.

- Two beach fill segments, northern and southern, with a dune feature along each section. These segments are shown in Figure 7.6.
- As is shown in Figure 7.6, the northern beach fill berm has a gradual taper of 450 ft from the northern project limit and extends seaward to a width of 35 ft at an elevation of +8.2 ft NAVD88. It then extends 600 ft roughly parallel to the shoreline with a seaward slope of 1V:10H. It then has a gradual taper of 200 ft. back to the shoreline.
- The southern beach fill berm has a gradual taper of 300 ft from the northern end and extends seaward to a width of 35 ft at an elevation of +8.2 ft NAVD88. It then extends for 700 ft roughly parallel to the shoreline with a seaward slope of 1V:10H. It then has a gradual taper of 450 ft back to the shoreline.
- A dune feature with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H extending throughout the project area including the central 600 ft where the project consists solely of the dune feature.
- A total initial volume of 37,100 cubic yards of sand fill.
- Maintaining the beach with periodic nourishment through the placement of 22,260 cubic yards every 4 years. This volume is based on historic erosion losses and historic placement volumes.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a spacing of 18 in by 18 in and a minimum of 11 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the

back of the top of the dune and continue the entire length of the project. The minimum number of planting units necessary is 21,500.

5 Year Scenario

This scenario is based on restoring 5 years of estimated shoreline losses and providing protection from a storm event with a 5-year return period.

There are two components considered in determining the required level of protection for this scenario; the first is the width of beach necessary to protect upland infrastructure from a 5 yr return period storm, and the second is the width of beach needed to account for 5 years of historical losses. The recommended design components include the components listed below. The inclusion of a berm in the central portion of the community is meant to act as a feeder beach to the northern and southern beaches. As the central portion of the beach erodes it will supply sand to the adjacent beaches where the observed and calculated erosion is the greatest.

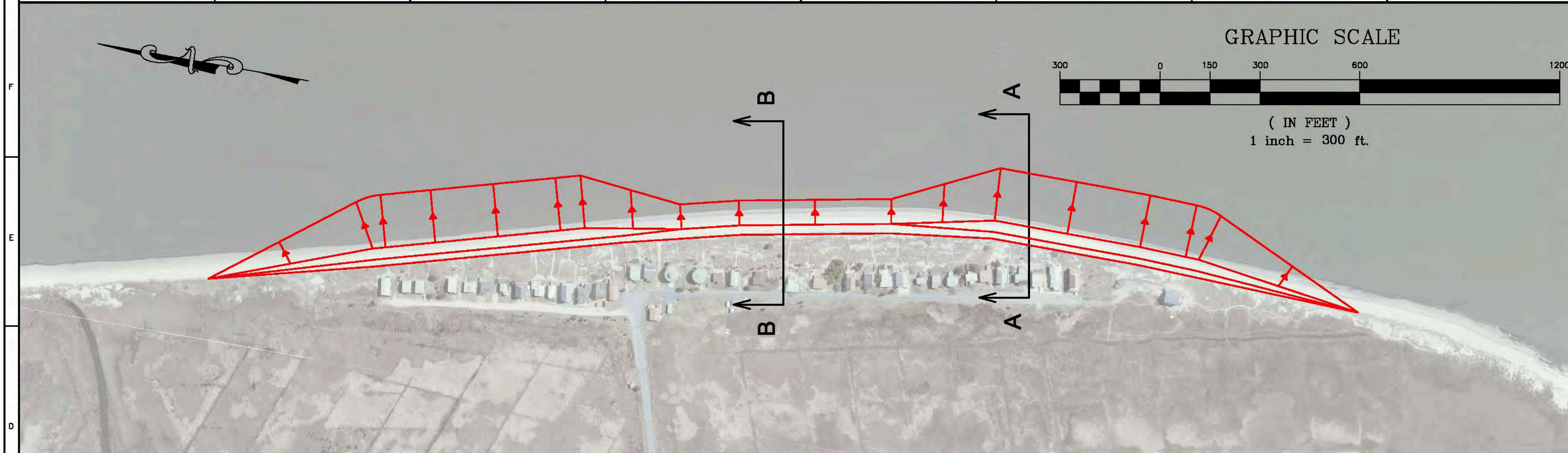
- A berm extending seaward 35 ft from the toe of the constructed dune at an elevation of +8.2 ft NAVD88 with a seaward slope of 1V:10H along the entire community for a length of 3,500 linear ft including tapering ends of 500 ft each.
- A dune feature throughout the project area with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H.
- A total initial volume of 51,500 cubic yards of sand where this fill volume includes initial design fill requirements and advanced nourishment.
- Maintaining the beach with periodic nourishment through the placement of 30,900 cubic yards every 5 years. This volume is based on historic erosion losses and historic placement volumes.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a spacing of 18 in by 18 in and a minimum of 11 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the back of the top of the dune and continue the length of the project. The minimum number of planting units necessary is 21,500.

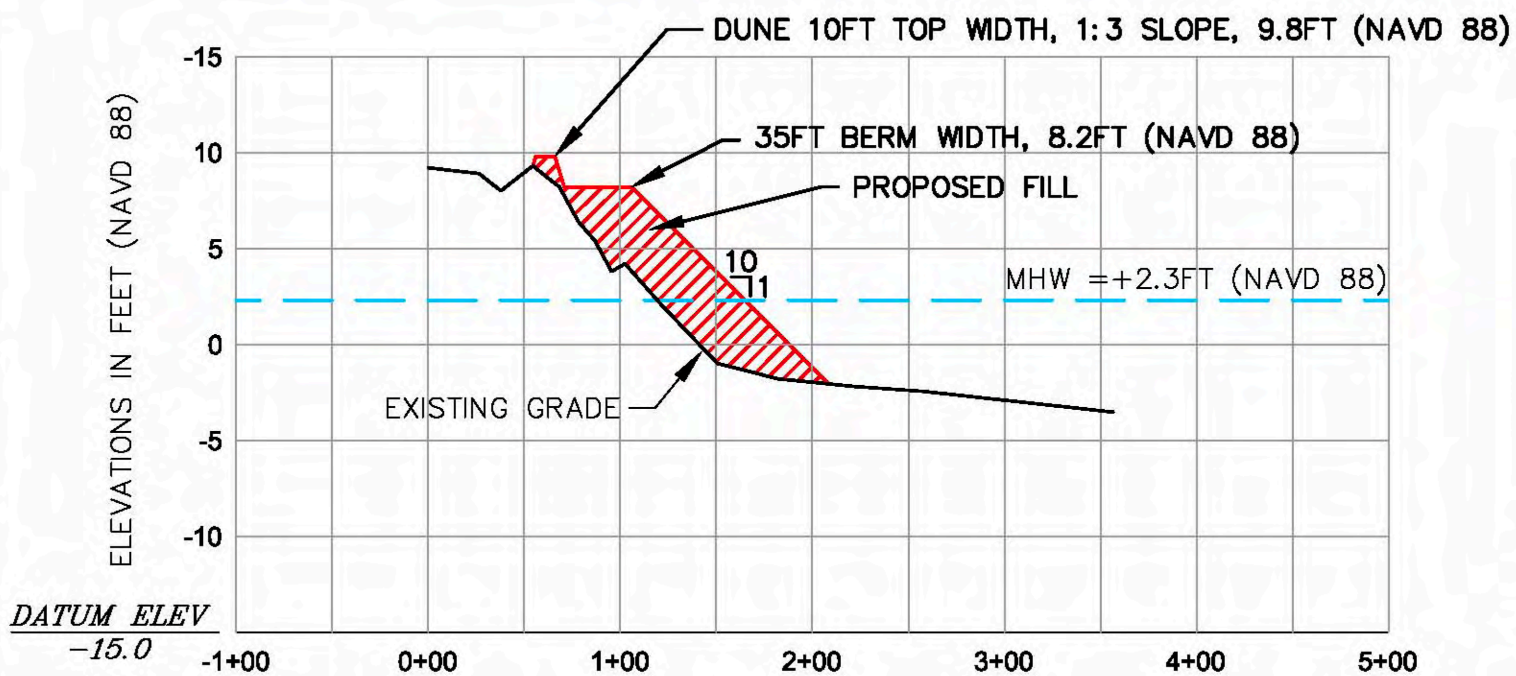
10 Year Scenario

This scenario is based on restoring 10 years of estimated shoreline losses and providing protection from a storm event with a 10-year return period.

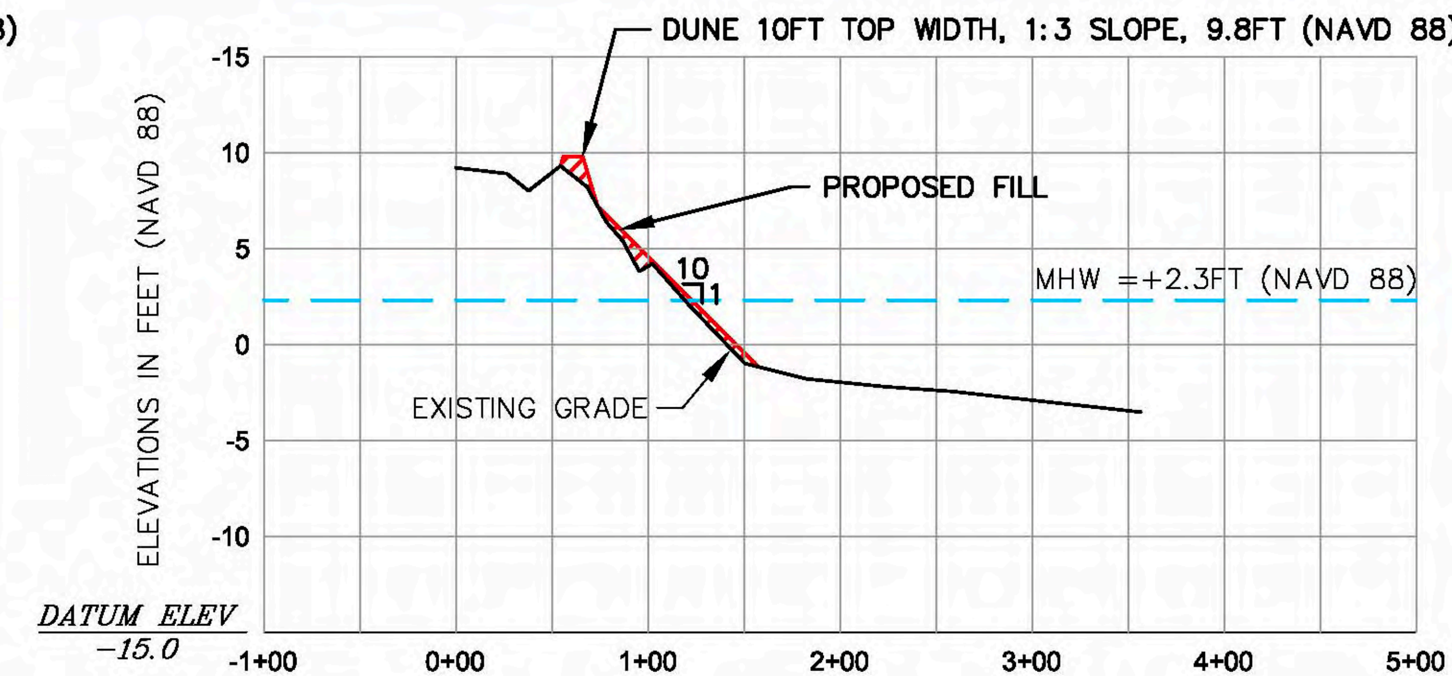
As is discussed in detail in Section 6.4, there are two components considered in determining the required level of protection for this scenario; the first is the width of beach necessary to protect upland infrastructure from a 10 yr return period storm, and the second is the width of beach needed to account for 10 years of historical losses. The recommended design components include the components listed below. The inclusion of a berm in the central portion of the community is meant to act as a feeder beach to the northern and southern beaches. As the central portion of the beach erodes it will supply sand to the adjacent beaches where the observed and calculated erosion is the greatest.

- A berm extending seaward 115 ft from the toe of the constructed dune at an elevation of +8.2 ft NAVD88 with a seaward slope of 1V:10H along the entire community for a length of 3,500 linear ft including tapering ends of 500 ft each.
- A dune feature throughout the project area with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H.
- A total initial volume of 138,500 cubic yards of sand where this fill volume includes initial design fill requirements and advanced nourishment.
- Maintaining the beach with periodic nourishment through the placement of 83,100 cubic yards every 10 years. This volume is based on historic erosion losses and historic placement volumes.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a spacing of 18 in by 18 in and a minimum of 11 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the back of the top of the dune and continue the length of the project. The minimum number of planting units necessary is 21,500.





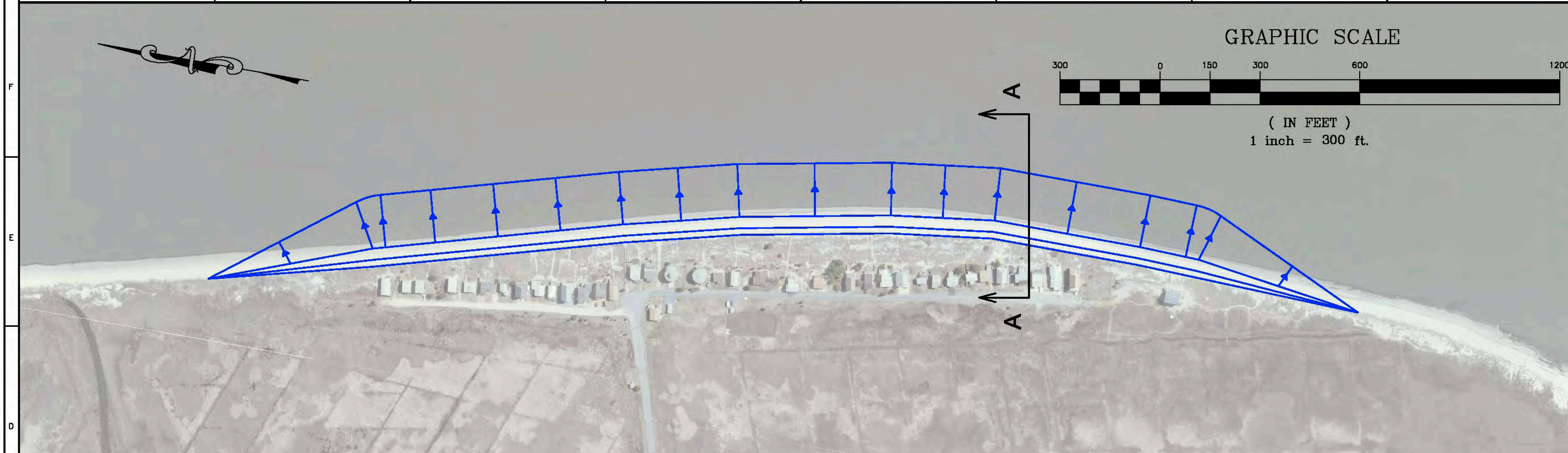
TYPICAL CROSS SECTION A-A

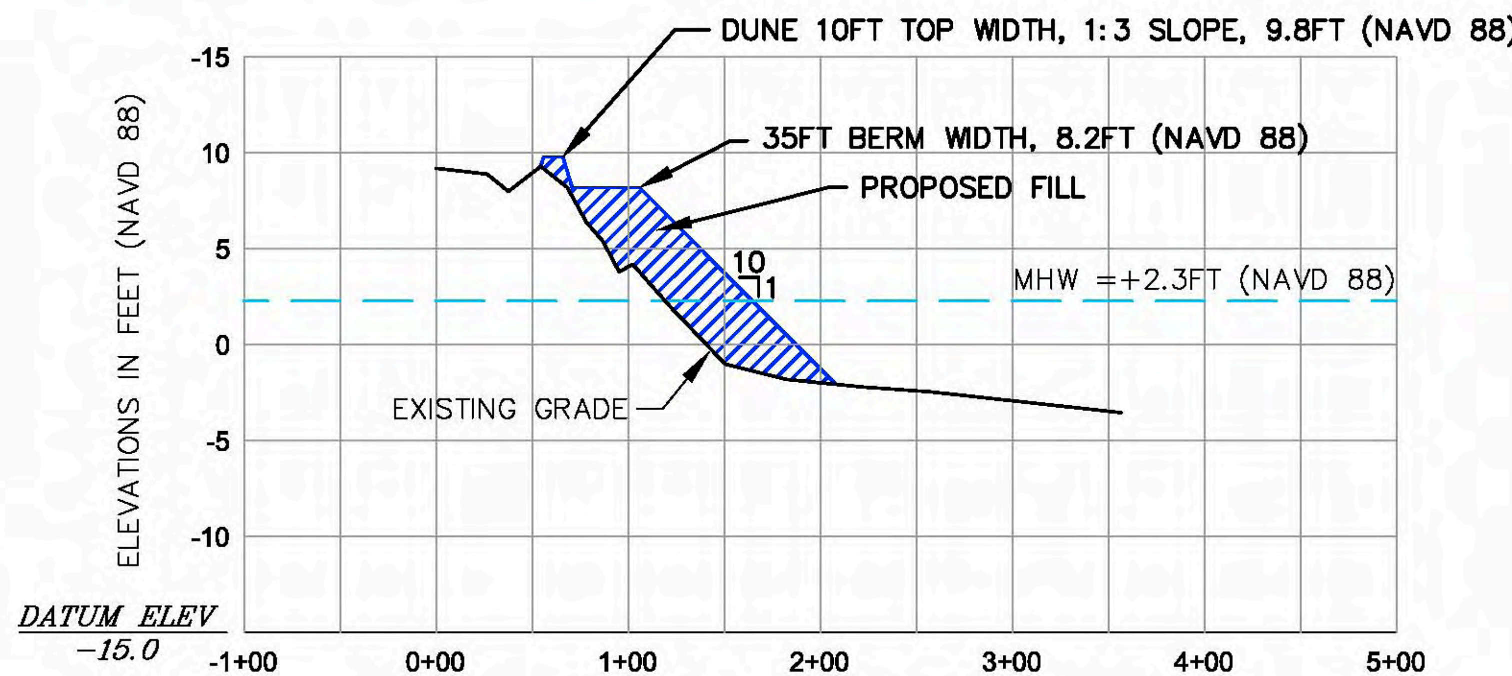


TYPICAL CROSS SECTION B-B

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: PICKERING BEACH	TASK: STRATEGIC FILL PLACEMENT	FIGURE 7.6

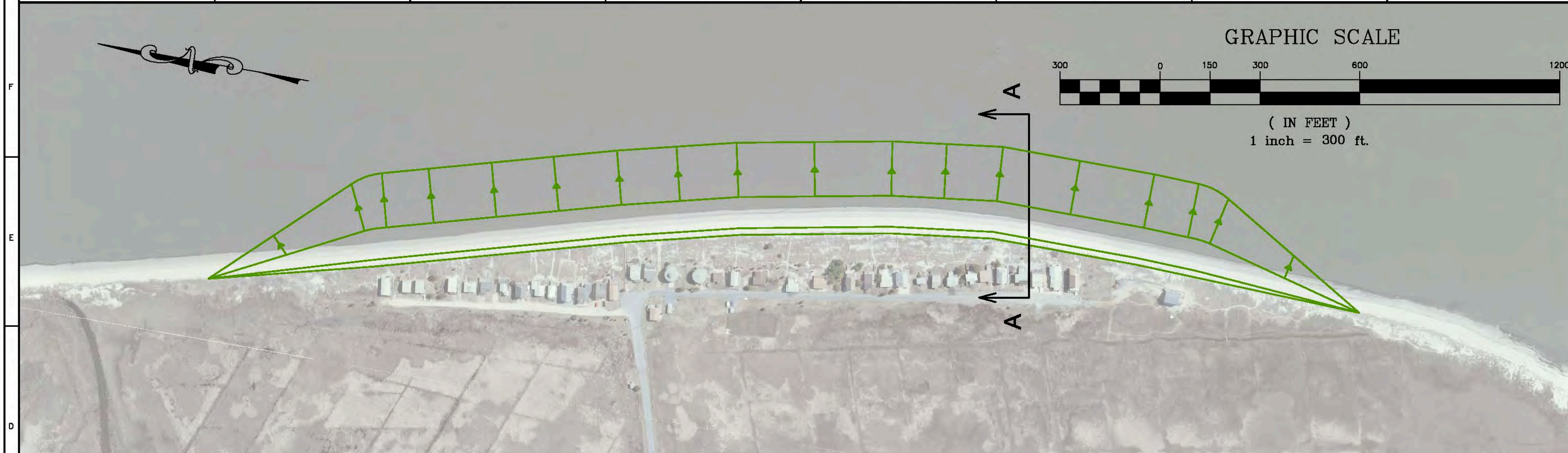


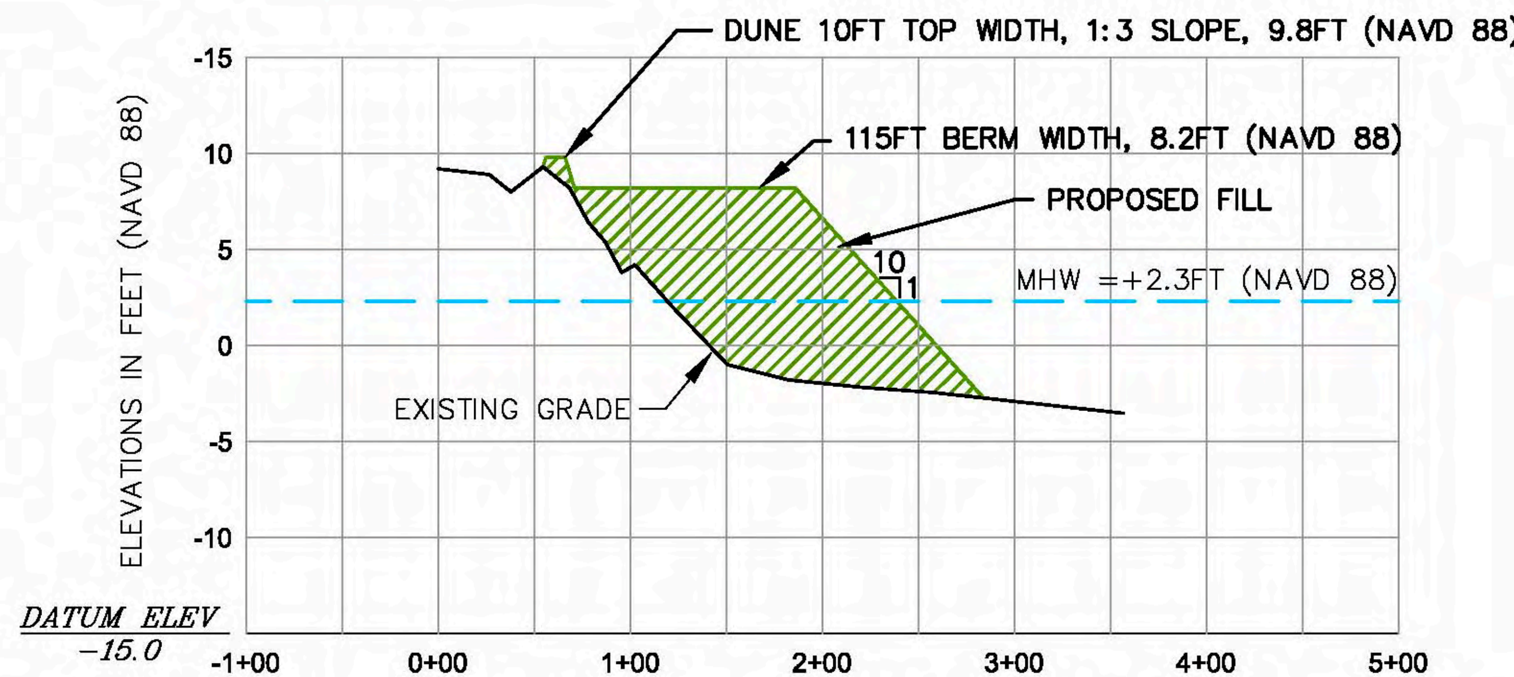


TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: PICKERING BEACH	TASK: 5 YEAR SCENARIO	FIGURE 7.7





TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: **DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL**	PROJECT: **PICKERING BEACH**	TASK: **10 YEAR SCENARIO**	**FIGURE 7.8**

Potential sediment sources

Wethe et al. (1982) investigated sand sources within 3,500 ft of the Pickering Beach shoreline located in water depths of less than 10 ft deep. Suitable sand sources were identified, but are located under an overburden of mud and unsuitable sands. The author notes that the sands underneath the overburden contain a higher percentage of fines than the native beach sediments. Below the overburden and to a depth of -20.8 ft NAVD88, the area contains 1.7 million cy of sand. In order to dredge the sand, 0.7 million cy of overburden would need to be removed. The overburden was found to be the thinnest closest to shore (approximately 1000 ft offshore) with a thickness ranging from 0.7 ft to 2.1 ft. The overburden increases further offshore to thicknesses of 9.9 ft at 3,500 ft offshore. Figure 7.9 depicts the locations of the sand sources with an overburden of less than 5 ft. Sand was extracted from this source for use in the 1978, 1990, and 2001 beach nourishment projects.

A recent (2008) benthic mapping study of potential sand sources near Kitts Hummock and Bowers Beach was completed by Bart Wilson of DNREC. Preliminary results of this effort conclude that a volume of 900,000 cy of beach-quality sediment is available between Kitts Hummock and Clark Point, after accounting for overburden and depth limitations. Sand was mostly found in deep deposits in the nearshore, with fines and silts further offshore. Further investigation into this sand source is necessary to determine more accurate volumes and better assess the feasibility of extraction and suitability for nourishment projects.

For future projects, this sand source should be investigated to determine the volume of remaining sand that could be extracted. Future projects will require a minimum water depth of at least 4 ft to accommodate typical commercial dredging equipment. Future sand search investigations should extend the limits of this study to locate additional sand sources within 2 mi of the Pickering Beach shoreline.

Removal of sediments from spits that have developed at the mouths of ditches approximately 0.6 mi north and south of the intersection of Pickering Beach Road and Sandpiper Drive should also be investigated. The sand in these spits appears to be sand transported from the Pickering Beach shoreline. These locations could provide an easily accessible source of beach compatible sand. Visual assessments of aerial photography indicate that the potential volumes of sand located at these sites would likely be relatively small.

Sand derived from upland sources such as local sand and gravel operations are also available for purchase and placement on this beach. However, sand from these sources will continue to be relatively expensive and best suited to use for relatively small emergency projects.

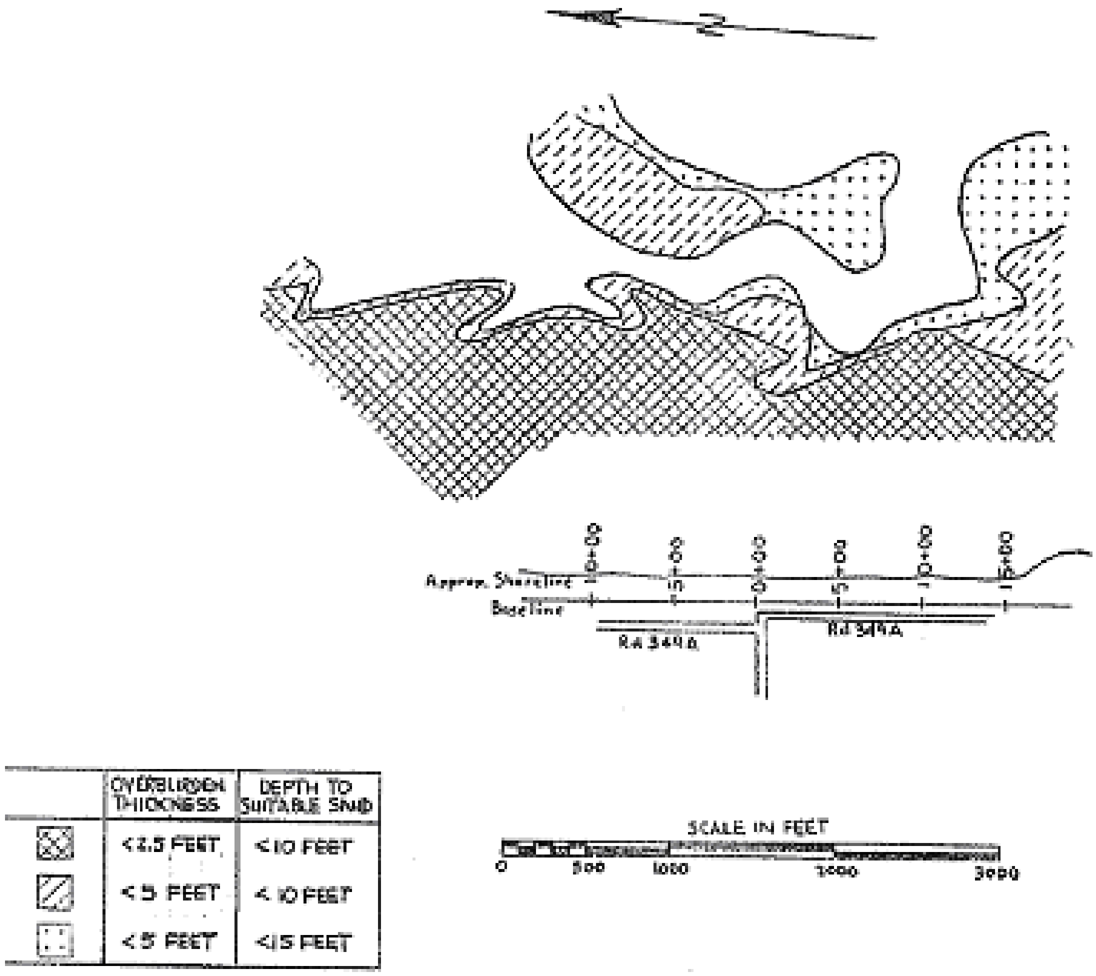


Figure 7.9 Pickering Beach sand source locations (Wethe et al., 1983).

Historical Resources

A remote sensing survey of a 1500 ft by 3000 ft area located approximately 1000 ft east of the mean low water line at Pickering Beach indicated the presence of three anomalies, one of which may be of historical significance (Watts, 1985). The anomaly that showed potential signatures of a historic resource was located at the southeast corner (75° 24' 03''W, 39° 08' 06''N) of the study area, covering an area of approximately 36,000 square ft in approximately 5 ft of water. The other two anomalies, which were located in the northeast (75° 24' 03''W, 39° 08' 26''N) and southwest (75° 24' 15''W, 39° 08' 05''N) corners of the study area, are unlikely to be of historical significance (Watts, 1985).

Construction Cost Estimate

Construction costs are estimated for each of the three project scenarios in Table 7.2 and include mobilization and demobilization, sand placement, and dune plantings. Costs for design, permitting, geotechnical investigation, post-project performance, and physical/biological monitoring are presented in Table 7.3.

Table 7.2 Pickering Beach Shore Protection Construction Cost Estimate

Pickering Beach Construction Cost Estimate Details						
Strategic Placement Scenario						
	Length	**Unit Volume**	**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*			0.25	lump sum	$750,000	$187,500
Berm Taper	1,600 ft	8 cy/ft	12,800	cy	$7.00	$89,600
Berm	1,300 ft	16 cy/ft	20,800	cy	$7.00	$145,600
Dune	3,500 ft	1 cy/ft	3,500	cy	$7.00	$24,500
Plant Units			21,500	each	$1.09	$23,435
		Total Volume	**37,100**	**cy**		**$470,635**
5 Year Scenario						
	Length	**Unit Volume**	**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*			0.25	lump sum	$750,000	$187,500
Berm Taper	1,000 ft	8 cy/ft	8,000	cy	$7.00	$56,000
Berm	2,500 ft	16 cy/ft	40,000	cy	$7.00	$280,000
Dune	3,500 ft	1 cy/ft	3,500	cy	$7.00	$24,500
Plant Units			21,500	each	$1.09	$23,435
		Total Volume	**51,500**	**cy**		**$571,435**
10 Year Scenario						
	Length	**Unit Volume**	**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*			0.25	lump sum	$750,000	$187,500
Berm Taper	1,000 ft	22.5 cy/ft	22,500	cy	$7.00	$157,500
Berm	2,500 ft	45 cy/ft	112,500	cy	$7.00	$787,500
Dune	3,500 ft	1 cy/ft	3,500	cy	$7.00	$24,500
Plant Units			21,500	each	$1.09	$23,435
		Total Volume	**138,500**	**cy**		**$1,180,435**

* Mob/Demob costs are based on this project being performed as part of a regional beach nourishment project that includes the nearby communities of Kitts Humock, Bowers Beach, and South Bowers Beach. Performing this work as a separate contract would increase the estimated mob/demob costs to $450,000.

Long Range Budget Plan

Table 7.3 Pickering Beach Shore Protection Long Range Budget Plan

	Strategic Fill Placement	Budget Estimate										
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
	*Geotechnical Investigation	$34,098										$34,098
	*Design/Permitting	$17,049										$17,049
	Construction					$470,635				$343,320		$813,955
	Env. Permit Monitoring					$35,000	$35,000	$35,000		$35,000	$35,000	$175,000
	Beach Surveys	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$80,000
	Sub Total	$59,147	$8,000	$8,000	$8,000	$513,635	$43,000	$43,000	$8,000	$386,320	$43,000	**$1,120,102**
	5 Year Scenario	**Budget Estimate**										
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
	*Geotechnical Investigation	$34,098										$34,098
Pickering Beach	*Design/Permitting	$17,049										$17,049
	Construction					$571,435					$403,800	$975,235
	Env. Permit Monitoring					$35,000	$35,000	$35,000			$35,000	$140,000
	Beach Surveys	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$80,000
	Sub Total	$59,147	$8,000	$8,000	$8,000	$614,435	$43,000	$43,000	$8,000	$8,000	$446,800	**$1,246,382**
	10 Year Scenario	**Budget Estimate**										
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
	*Geotechnical Investigation	$34,098										$34,098
	*Design/Permitting	$17,049										$17,049
	Construction					$1,180,435						$1,180,435
	Env. Permit Monitoring					$35,000	$35,000	$35,000				$105,000
	Beach Surveys	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$80,000
	Sub Total	$59,147	$8,000	$8,000	$8,000	$1,223,435	$43,000	$43,000	$8,000	$8,000	$8,000	**$1,416,582**

***Notes: The costs for these items are proportional to total volume placed for all of the seven communities included in this management plan.**
Renourishment costs are based on restoring 60% of initial volume placed to restore historic losses.
Costs are based on work being performed on a regional basis.
Costs are in July 2009 dollars.

MANAGEMENT PLAN FOR

THE DELAWARE BAY BEACHES

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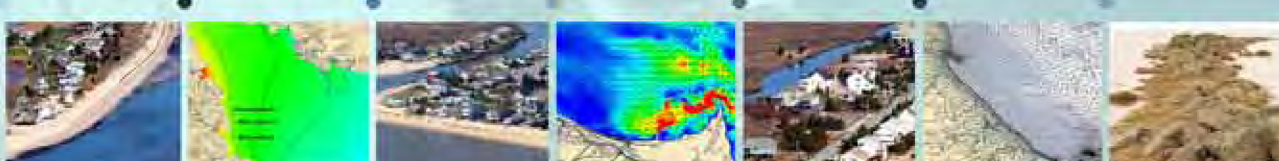


Kitts Hummock

12023-BD-09

7.3 Kitts Hummock

7.3.1 Background

Kitts Hummock is located approximately 24 mi from the mouth of the Delaware Bay. The beach measures about 4,500 ft in length. Kitts Hummock is bordered to the west by a 1,600 ft wide tidal marsh and then Pleistocene highlands (Drew, 1981). Kitts Hummock lies in a north-south direction with shoreline azimuths of 75°N in the northern portion and 95°N in the southern portion. The mean erosion rate at Kitts Hummock was calculated at 4.3 ft/yr and ranged from 3.3 ft/yr to 5.6 ft/yr (French, 1990).

Beach material at Kitts Hummock consists of granular soils ranging from medium- to fine-grained sands to fine gravel (Department of the Army, 1981). This description of the sediments concurs with Wethe et al.'s visual assessment in 1983 that the beach contained gravelly medium to coarse sand along the berm and gravelly to muddy sediments along the low water line.

Maurmeyer (1978) calculated transport rates that vary drastically along the shoreline in this area where the net transport direction is southerly at a rate of 4,700 yd^3/yr in the northern portion of the community and 900 yd^3/yr in the southern portion of the community (Table 6.1). The results of the circulation modeling correlate well with the calculated net transport direction. Circulation modeling results for operational and average conditions at the site also exhibit a trend of southerly flow (Figure 1.17 of the Modeling Report).

Wave model results indicate an annual potential transport direction northward due to the influence of the offshore waves. These results were compared to the circulation model as well as past estimations and observations of longshore transport potential to assist in developing beach fill placement options. These results are consistent with past beach fill behavior and may offer some explanation of localized northerly transport observations. However, the results do not agree with calculated sediment transport rates and the circulation model. This may be due to the seasonal variability of wave heights and potential transport direction presented in the wave modeling scenarios. A more refined modeling effort in conjunction with a data collection effort to better calibrate the model would better resolve the actual conditions at Kitts Hummock than the modeling effort that was undertaken for the purposes of this study.

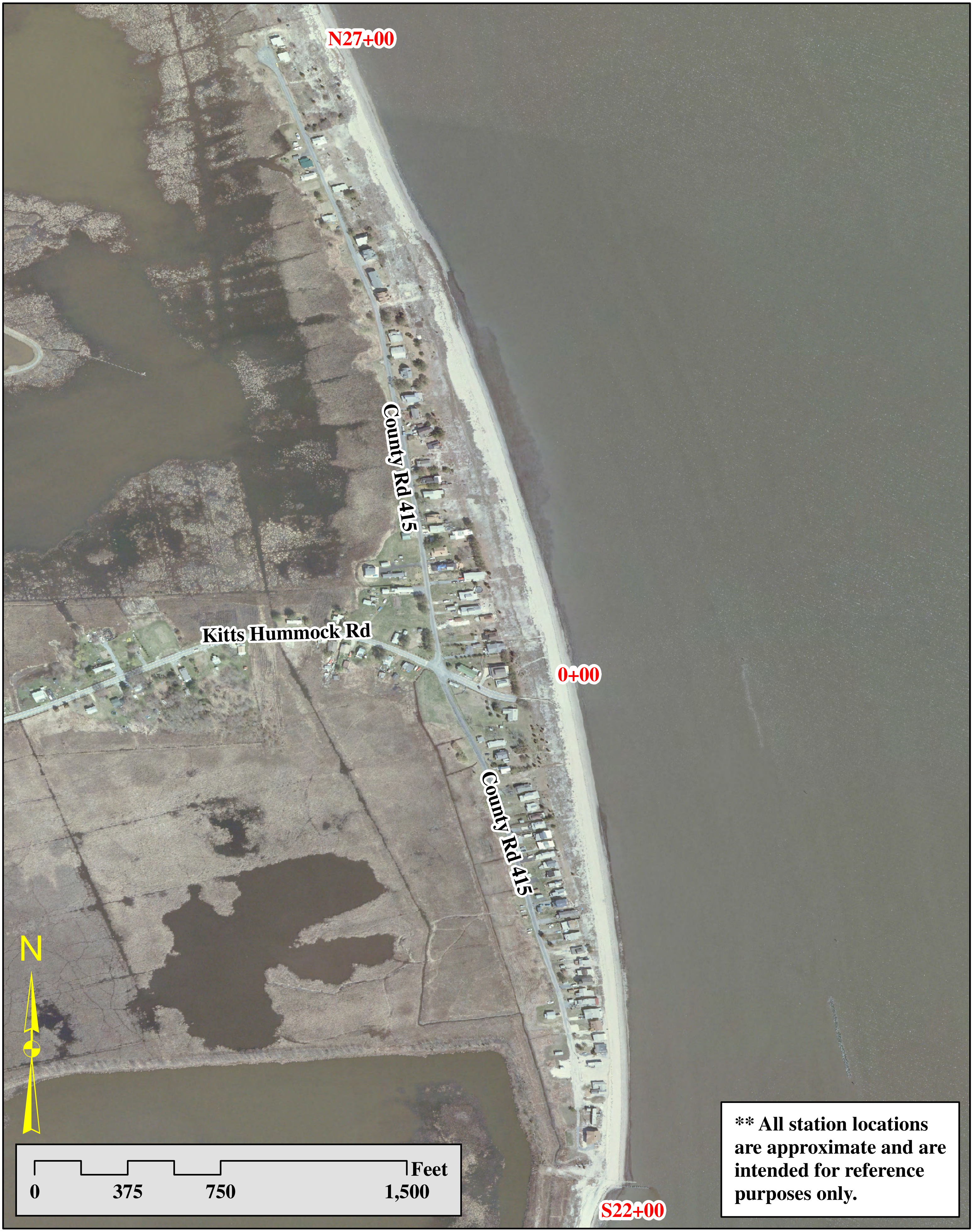


Figure 7.10 2007 Aerial of Kitts Hummock (Delaware DataMIL)

Shore Protection History. Beach nourishment events and the installation of shore protection structures have occurred at Kitts Hummock since 1961. A total of 310,130 cy of material has been placed to date. Table 7.4 provides the data available regarding the beach nourishment and shore protection history for Kitts Hummock. The fill template typically used for past projects at this beach consists of a berm with a height of 9.2 ft NAVD88 and a foreshore slope of 1V:15H (Figure 7.11).

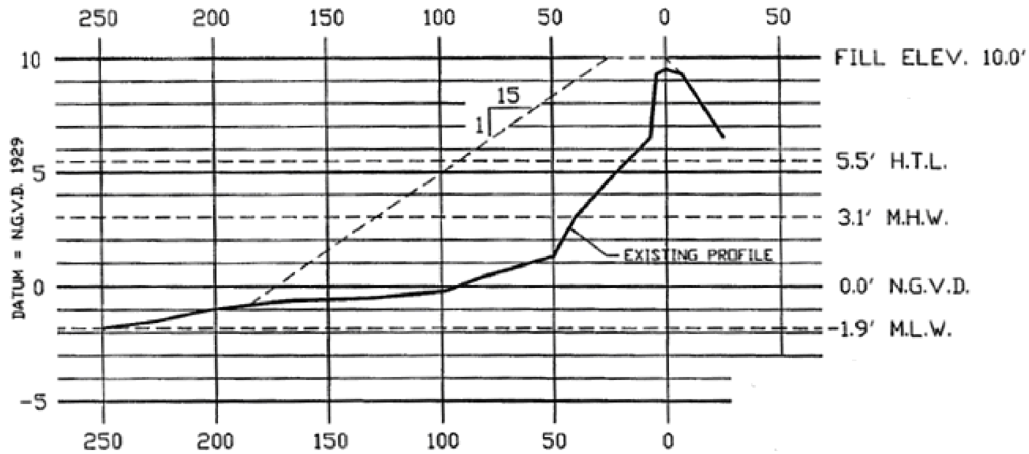


Figure 7.11 Typical fill template for past projects at Kitts Hummock, vertical datum NGVD 1929 (from 1995 Corps permit application).

Table 7.4 Kitts Hummock Shore Protection History.

Year	Volume (cy)	Length (ft)	Location	Method	Sediment Source	Structure
1961	80,000	4250	N/A	N/A	N/A	
1962	30,600	4850	N/A	Truck-haul	Upland	
1969	12,000	N/A	N/A	Truck-haul	Upland	
1973	3,000	1600	Southern portion	Truck-haul	Upland	
1974	46,500	1700	N/A	Hydraulic dredge	1000' x 100', 1800' offshore	
1978	Structure	330	700 ft from shoreline			Rubble-mound breakwater
1978	Structure	330	700 ft from shoreline			Concrete-box breakwater
1978	Structure	336	700 ft from shoreline			Nylon sandbag breakwater
1979	74,000	5000	16+00S to 27+00N	Hydraulic dredge	Offshore	
1987	Structure	180				Terminal grout sandbag groin
1988	15,780	1000	N/A	Hydraulic dredge	N/A	
1996	32,850	1000	11+00S to 23+00S	Hydraulic dredge	1000' X 400', 1200' offshore	
2006	200	700	N/A	Truck-haul	Tilcon Pit	
2006	200	700	N/A	Truck-haul	Tilcon Pit	
2008	15,000	1400	N/A	Truck-haul	Tilcon Pit	

N/A = Information not available. The information for this table was gathered from DNREC records and state and federal permitting documents.

Existing Structures. Three breakwaters were constructed by the Corps in 1978 approximately 700 ft offshore of Kitts Hummock. Each breakwater was constructed using a different material: nylon sandbags, concrete boxes, and stone (rubble-mound). The nylon-sandbag breakwater was deemed non-functional by the Corps in 1989 due to significant subsidence.

Currently, the concrete box and rubble mound structures remain offshore (Figures 7.13 and 7.14). The ends of the structures are marked with steel I-beam pilings with signs warning boaters. The structures are submerged at high tide. The concrete box and rubble-mound breakwaters do not appear to have a significant effect on the shoreline. The neutral performance of the structures is likely due to their short lengths compared to the distance offshore, a long significant wave period which is not dissipated by the short length of the structure, and the limited volume of sand in the littoral zone. The concrete structure has deteriorated since installation. Some of the concrete boxes have broken lips and sides and the structure has subsided into the underlying sediments.

A terminal groin was constructed in 1987 approximately 200 ft south of the community's southern most home using grout filled sandbags (Figure 7.15). The groin acts as a barrier to southerly sediment transport and thereby helps to maintain sand on the beach. Since constructed, the groin has induced a slight offset in the beach south of the structure.

An outfall pipe is located just south of this terminal groin. This structure was not constructed as a shore protection structure, as it is located downdrift of the terminal groin. The outfall pipe only retains a limited volume of sand due to the proximity of the terminal groin. In the absence of the terminal groin, the outfall pipe may have a greater affect on the beach.

> **Recommendation**: Due to the limited amount of sand in the littoral zone and the short distance of the breakwaters offshore, modifications of the structures to lengthen or raise the crest elevation would likely have little effect. Since the structures are not adversely affecting the shoreline, neither removal nor structure modification are recommended or needed.
>
> With the addition of sand onto the beach through a nourishment program, the capacity of the terminal groin will soon be reached. At that time, sand will begin bypassing the structure. The crest elevation of the structure would need to be raised and potentially lengthened to increase the effectiveness of this structure. This idea should be examined and assessed relative to the potential losses of the downdrift beach that would likely occur. Monitoring is recommended for the breakwater and groin in order to continue to evaluate their performance and their interactions with any proposed sand placement.

Figure 7.12 Aerial photograph of Kitts Hummock (Wayne Lasch, April 17, 2009).

Figure 7.13 Concrete box breakwater constructed by the Corps in 1979

(Wayne Lasch, April 17, 2009).

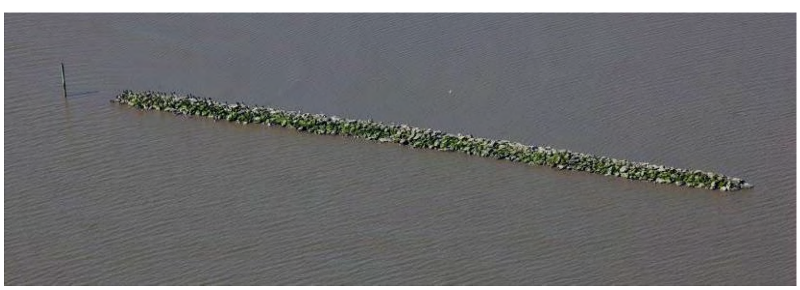


Figure 7.14 Concrete sand bag breakwater constructed by the Corps in 1979

(Wayne Lasch, April 17, 2009).

Figure 7.15 Terminal groin and an outfall structure at the south end of Kitts Hummock.

7.3.2 Management Plan Alternatives

The main area of concern is the southern 600 to 1,000 ft, as the beach landform curves westward toward the marsh and pinches the upland at this end. Those houses in this zone are the most susceptible to storm impact and infrastructure damage. Evidence of the need to protect this end is the structure designed to capture sand at this end. Of lesser concern is the north end where the beach does curve back towards the homes but there is a significant amount of land.

No Action

Landward migration of the shoreline would likely continue if no action is taken at this community. Of greatest concern is the southernmost area of the shoreline located within 1000 ft north of the groin. As a result, infrastructure including, recreational beach, utilities, roadways, and private homes could be damaged or lost during high energy coastal storms. Continued erosion would also decrease the available acreage of nesting beach for use by horseshoe crabs; this would negatively impact both the horseshoe crab population and the populations of shorebirds that rely on the horseshoe crabs.

Strategic Fill Placement

This scenario consists of concentrating the placement of fill along the specific locations of greatest need in each community. This alternative is largely based on the previous shore protection activities conducted by DNREC (Table 7.4) and is the minimum level of protection that would be recommended. Based on a review of previous studies, historic aerials, longshore transport estimates, and local knowledge gained from previous beach fill behavior, the recommended design components of this scenario include:.

- As shown in Figure 7.16, a berm extending seaward 30 ft from the toe of the constructed dune at an elevation of +8.2 ft NAVD88 with a seaward slope of 1V:15H along 2,700 linear ft including gradually tapering ends of 500 ft each. The location of the berm is along the southern portion of the shoreline.
- A dune feature throughout the project area with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H.
- A total initial volume of 42,300 cubic yards of sand.
- Maintaining the beach with periodic nourishment through the placement of 25,380 cubic yards every 4 years. This volume is based on historic erosion losses and historic placement volumes.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a spacing of 18 in by 18 in and a minimum of 11 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the back of the top of the dune and continue the entire length of the project. The minimum number of planting units necessary is 18,500.

5 Year Scenario

This scenario is based on restoring 5 years of estimated shoreline losses and providing protection from a storm event with a 5-year return period.

There are two major components considered in determining the required level of protection for this scenario; the first is the width of beach necessary to protect upland infrastructure from a 5 yr return period storm, and the second is the width of beach needed to account for 5 years of historical losses. The recommended design components include:

- As shown in Figure 7.17, a berm extending seaward 30 ft from the toe of the constructed dune at an elevation of +8.2 ft NAVD88 with a seaward slope of 1V:15H along the entire community for a length of 5,800 linear ft including gradually tapering ends of 500 ft each.
- A dune feature throughout the project area with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H.
- A total initial volume of 101,200 cubic yards of sand where this fill volume includes initial design fill requirements and advanced nourishment.
- Maintaining the beach with periodic nourishment through the placement of 60,720 cubic yards every 5 years. This volume is based on historic erosion losses and historic placement volumes.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a spacing of 18 in by 18 in and a minimum of 11 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the back of the top of the dune and continue the entire length of the project. The minimum number of planting units necessary is 39,000.

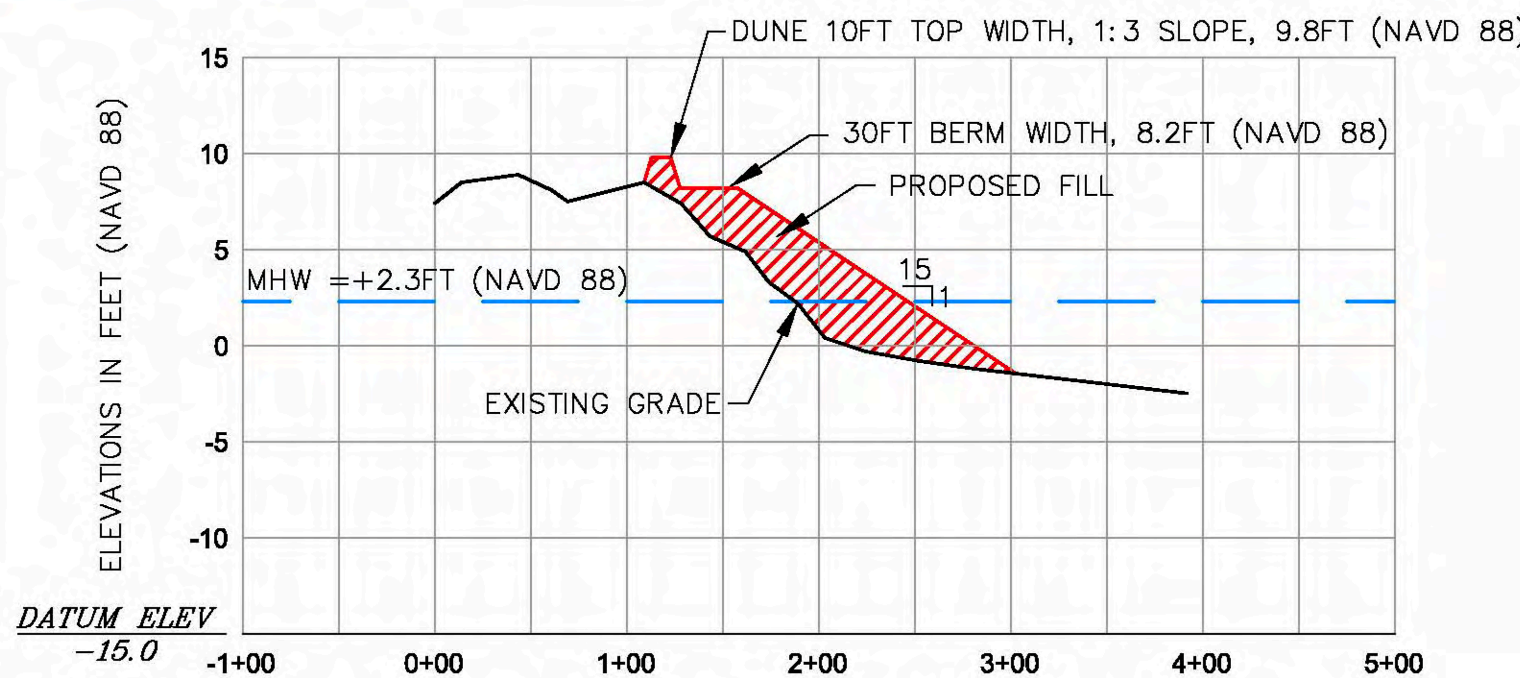
10 Year Scenario

This scenario is based on restoring 10 years of estimated shoreline losses and providing protection from a storm event with a 10-year return period.

As is discussed in detail in Section 6.4, there are two major components considered in determining the required level of protection for this scenario; the first is the width of beach necessary to protect upland infrastructure from a 10 yr return period storm, and the second is the width of beach needed to account for 10 years of historical losses. The recommended design components include:

- A berm extending seaward 75 ft from the toe of the constructed dune at an elevation of +8.2 ft NAVD88 with a seaward slope of 1V:15H along the entire community for a length of 5,800 linear ft including tapering ends of 500 ft each.
- A dune feature throughout the project area with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H.

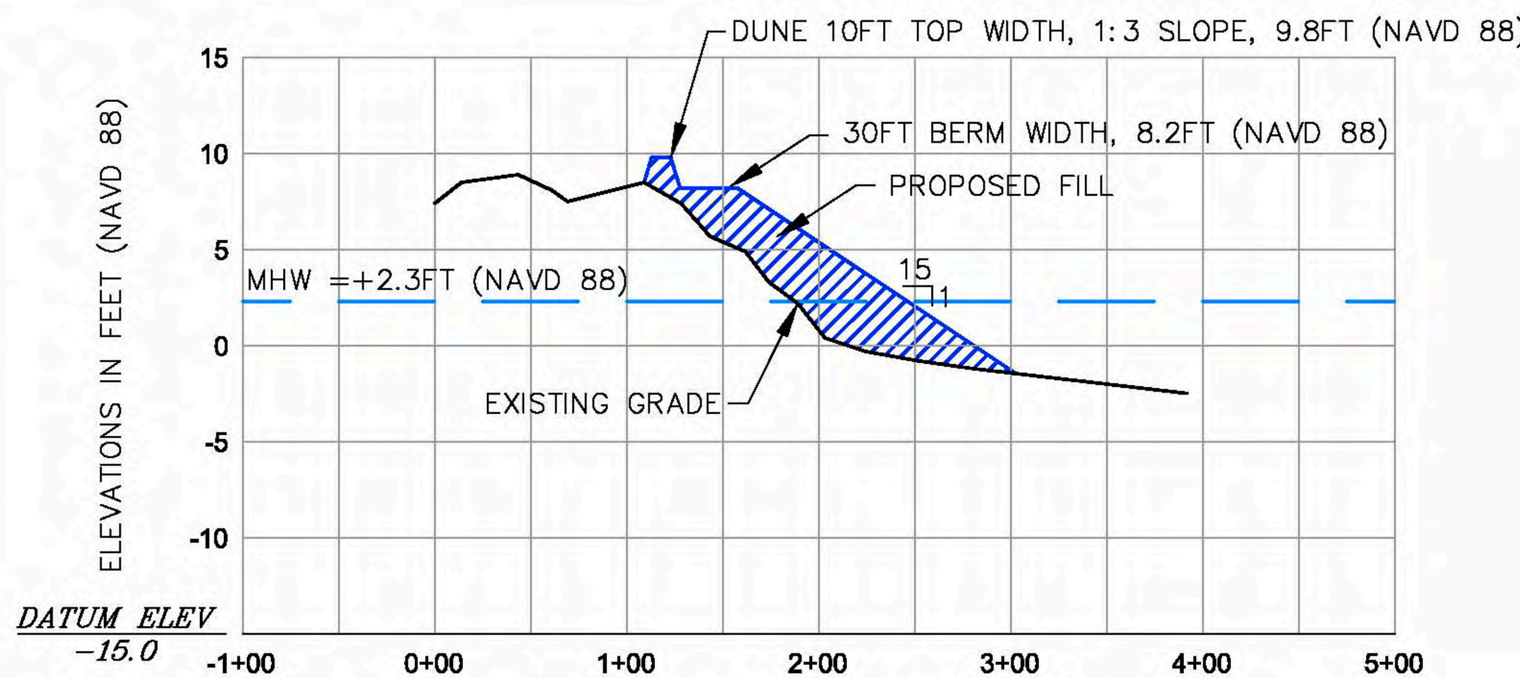
- A total initial volume of 196,600 cubic yards of sand where this fill volume includes initial design fill requirements and advanced nourishment.
- Maintaining the beach with periodic nourishment through the placement of 117,960 cubic yards every 10 years. This volume is based on historic erosion losses and historic placement volumes.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a spacing of 18 in by 18 in and a minimum of 11 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the back of the top of the dune and continue the entire length of the project. The minimum number of planting units necessary is 39,000.



TYPICAL CROSS-SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

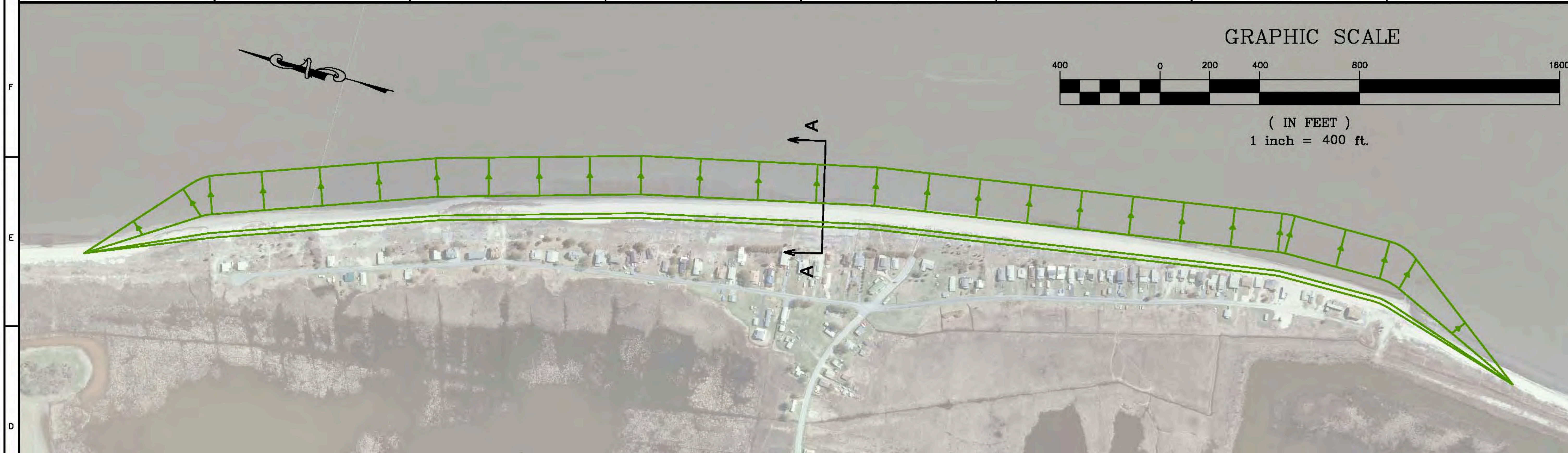
PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: KITTS HUMMOCK	TASK: STRATEGIC FILL PLACEMENT	FIGURE 7.16

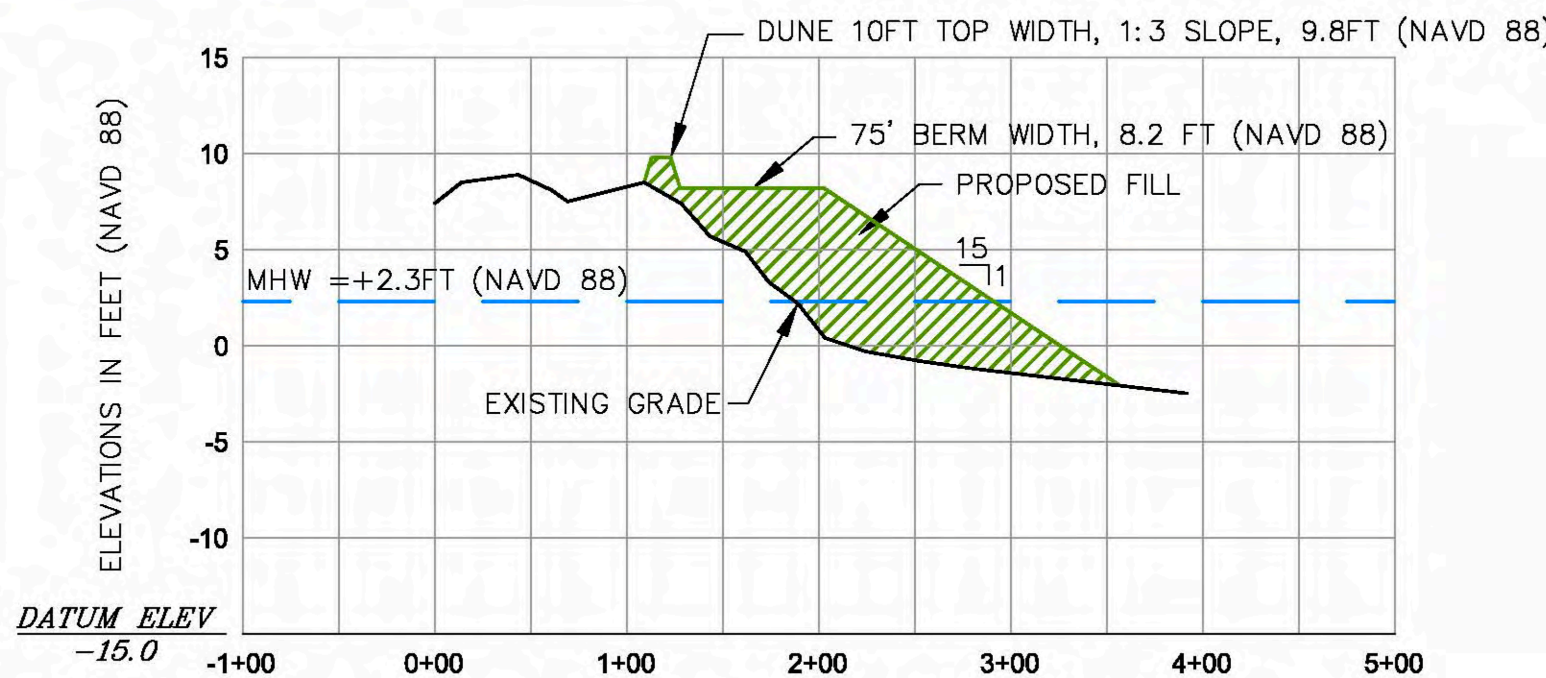


TYPICAL CROSS-SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: KITTS HUMMOCK	TASK: 5 YEAR SCENARIO	FIGURE 7.17





TYPICAL CROSS-SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ

CLIENT:
DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL

PROJECT:
KITTS HUMMOCK

TASK:
10 YEAR SCENARIO

FIGURE 7.18

Potential sediment sources

Wethe et al (1983) investigated sand sources within 3,500 ft of the Kitts Hummock shoreline located in water depths of less than 10 ft deep. Suitable sand sources were identified, but are located under an overburden of mud, silt, and peat. The author notes that the sands underneath the overburden contain a higher percentage of fines than the native beach sediments. Below the overburden and to a depth of -20.8 ft NAVD88, the area contains 900,000 cy of sand; however only 400,000 cy are estimated to be suitable for beach nourishment. To dredge the sand, 1.1 million cy of overburden would need to be removed. The overburden was found to be the thinnest closest to shore (approximately 1000 ft offshore) with a thickness ranging from 4.8 ft to 12 ft. The overburden increases further offshore to thicknesses of 7.3 ft to 15.5 ft at 3,500 ft offshore. Figure 7.19 depicts the locations of the sand sources with an overburden less than 7.5 ft. Sand was dredged from this source for use in the 1974 and 1979 beach nourishment projects. Additional use of this area may have occurred, but records containing the sand source locations for other projects are ambiguous.

For future projects, this sand source should be investigated to determine the volume of remaining sand that could be extracted. Future projects would be limited by a minimum water depth of at least 4 ft necessary for operation of the dredge equipment. Future sand search investigations should extend the limits of this study to find additional sand sources within 2 mi of the Kitts Hummock shoreline.

A recent (2008) benthic mapping study of potential sand sources near Kitts Hummock and Bowers Beach was completed by Bart Wilson of DNREC. Preliminary results of this effort conclude that a volume of 900,000 cy of beach-quality sediment is available between Kitts Hummock and Clark Point, after accounting for overburden and depth limitations. Sand was mostly found in deep deposits in the nearshore, with fines and silts further offshore. Further investigation into this sand source is necessary to determine more accurate volumes and better assess the feasibility of extraction and suitability for nourishment projects.

Sand derived from upland sources such as local sand and gravel operations are also available for purchase and placement on this beach. However, sand from these sources will continue to be relatively expensive and best suited to use for relatively small emergency projects.

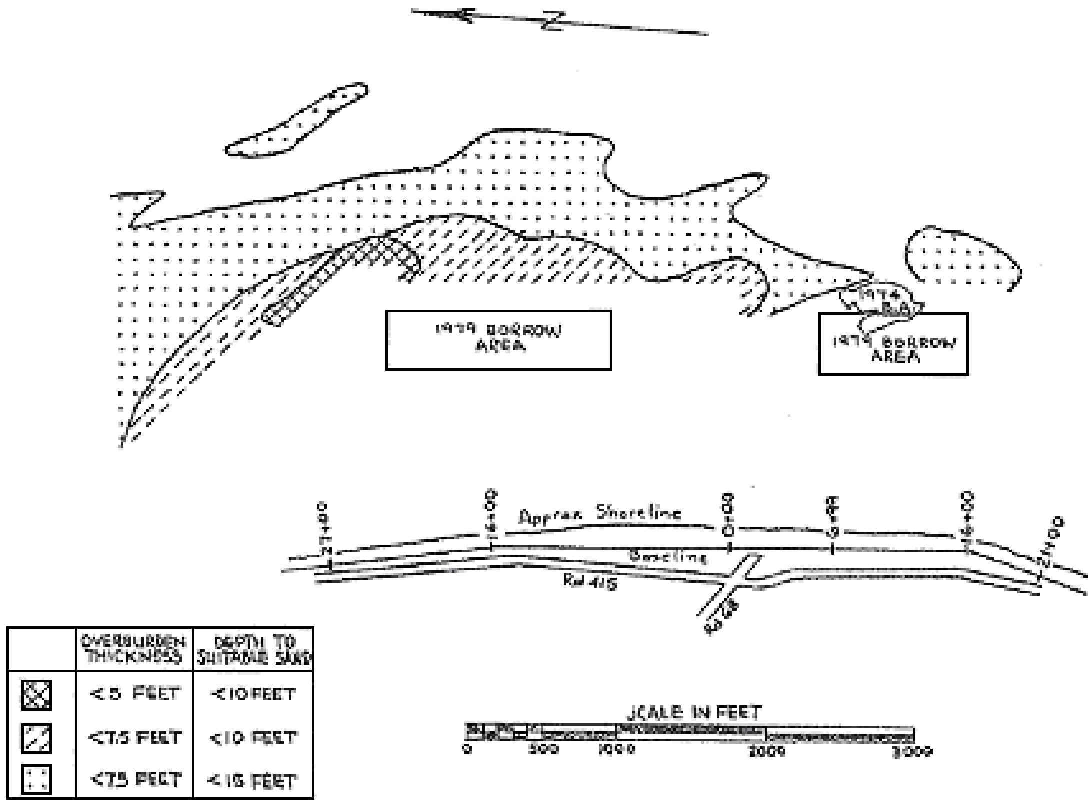


Figure 7.19 Kitts Hummock sand source locations (Wethe et al., 1983).

Historical Resources

A remote sensing survey of an area measuring 1500 ft by 5000 ft and located approximately 1000 ft east of the Mean Low Water Line indicated that two of three anomalies may represent historical resources (Watts, 1985). The first anomaly was located in the southwest corner (75° 23’ 50’’W, 39° 06’ 05’’N) and was detectable over an area of approximately 38,000 square ft in a water depth of 7 ft. The second, located in the lower south central section of the study area (75° 23’ 42’’W, 39° 06’ 03’’N), was detectable over an area of 16,500 square ft in a water depth of 7 ft. The third anomaly was located in the south central portion (75° 23’ 41’’W, 39° 06’ 08’’N) but is unlikely to be of historical significance (Watts, 1985).

Construction Cost Estimate

Construction costs are estimated for each of the three project scenarios in Table 7.5 and include mobilization and demobilization, sand placement, and dune plantings. Costs for design, permitting, geotechnical investigation, post-project performance, and physical/biological monitoring are presented in Table 7.6.

Table 7.5 Kitts Hummock Beach Shore Protection Construction Cost Estimate

Kitts Hummock Construction Cost Estimate Details						
Strategic Placement Scenario						
	Length	**Unit Volume**	**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*			0.25	lump sum	$750,000	$187,500
Berm Taper	1,000 ft	9 cy/ft	9,000	cy	$7.00	$63,000
Berm	1,700 ft	18 cy/ft	30,600	cy	$7.00	$214,200
Dune	2,700 ft	1 cy/ft	2,700	cy	$7.00	$18,900
Plant Units			18,500	each	$1.09	$20,165
		Total Volume	**42,300**	**cy**		**$503,765**
5 Year Scenario						
	Length	**Unit Volume**	**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*			0.25	lump sum	$750,000	$187,500
Berm Taper	1,000 ft	9 cy/ft	9,000	cy	$7.00	$63,000
Berm	4,800 ft	18 cy/ft	86,400	cy	$7.00	$604,800
Dune	5,800 ft	1 cy/ft	5,800	cy	$7.00	$40,600
Plant Units			39,000	each	$1.09	$42,510
Allowance for Structure Modification						$50,000
		Total Volume	**101,200**	**cy**		**$988,410**
****						
	Length	**Unit Volume**	**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*			0.25	lump sum	$750,000	$187,500
Berm Taper	1,000 ft	18 cy/ft	18,000	cy	$7.00	$126,000
Berm	4,800 ft	36 cy/ft	172,800	cy	$7.00	$1,209,600
Dune	5,800 ft	1 cy/ft	5,800	cy	$7.00	$40,600
Plant Units			39,000	each	$1.09	$42,510
Allowance for Structure Modification						$50,000
		Total Volume	**196,600**	**cy**		**$1,656,210**

***** Mob/Demob costs are based on this project being performed as part of a regional beach nourishment project that includes the nearby communities of Pickering Beach, Bowers Beach, and South Bowers Beach. Performing this work as a separate contract would increase the estimated mob/demob costs to $450,000.

Long Range Budget Plan

Table 7.6 Kitts Hummock Beach Shore Protection Long Range Budget Plan

	Strategic Fill Placement	Budget Estimate										Total
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
Kitts Hummock Beach	*Geotechnical Investigation	$56,914										$56,914
	*Design/Permitting	$28,457										$28,457
	Construction					$503,765				$365,160		$868,925
	Env. Permit Monitoring					$17,500	$17,500	$17,500		$17,500	$17,500	$87,500
	Beach Surveys	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$80,000
	Sub Total	$93,371	$8,000	$8,000	$8,000	$529,265	$25,500	$25,500	$8,000	$390,660	$25,500	**$1,121,796**
	5 Year Scenario	**Budget Estimate**										
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
	*Geotechnical Investigation	$56,914										$56,914
	*Design/Permitting	$28,457										$28,457
	Construction					$988,410					$612,540	$1,600,950
	Env. Permit Monitoring					$35,000	$35,000	$35,000			$35,000	$140,000
	Beach Surveys	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$80,000
	Structure Modification					$50,000						$50,000
	Sub Total	$93,371	$8,000	$8,000	$8,000	$1,081,410	$43,000	$43,000	$8,000	$8,000	$655,540	**$1,956,321**
	10 Year Scenario	**Budget Estimate**										
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
	*Geotechnical Investigation	$56,914										$56,914
	*Design/Permitting	$28,457										$28,457
	Construction					$1,656,210						$1,656,210
	Env. Permit Monitoring					$35,000	$35,000	$35,000				$105,000
	Beach Surveys	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$80,000
	Structure Modification					$50,000						$50,000
	Sub Total	$93,371	$8,000	$8,000	$8,000	$1,749,210	$43,000	$43,000	$8,000	$8,000	$8,000	**$1,976,581**

***Notes: The costs for these items are proportional to total volume placed for all of the seven communities included in this management plan**
Renourishment costs are based on restoring 60% of initial volume placed to restore historic losses
Costs are based on work being performed on a regional basis
Costs shown are in July 2009 prices.

MANAGEMENT PLAN FOR

THE DELAWARE BAY BEACHES

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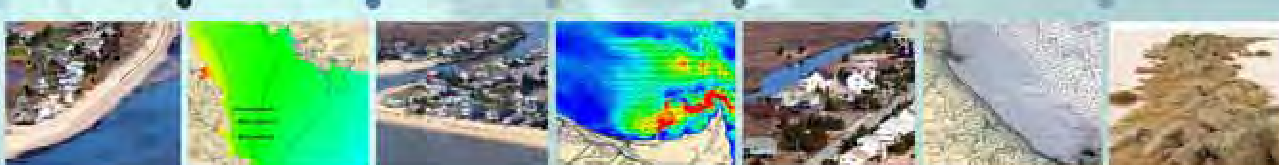


Bowers Beach

12023-B0-09

7.4 Bowers Beach

7.4.1 Background

Bowers Beach is bordered to the north and west by wetlands and is located between the St. Jones River Inlet (unstructured) and the Murderkill River Inlet (structured). Bowers Beach has a shoreline azimuth of 65°N. Bowers Beach lies above an upland pre-Holocene sediment deposit. The beach soils consist of fine to medium sand with some fine gravel and the dune consists of fine to medium sands (Department of the Army, 1981). This description of the sediments concurs with Wethe et al.'s visual assessment in 1982 that the beach contained gravelly, fine to coarse sand along the berm and slightly gravelly to fine sand along the low water line. Bowers Beach is a low-lying area that is subject to frequent flooding during storms and at spring high tides (Wethe, 1984). The well-compacted nature of the underlying Pleistocene sediments makes the beach more resistant to erosion than other Bay beaches. The USACE (1991) calculated an erosion rate of 2 ft/yr for Bowers Beach. Flooding occurs frequently due to 1) the proximity to rivers; 2) the mosquito ditch system, which provides inland access to floodwaters that would otherwise be confined; 3) beach erosion which lowers the height of the beach; and 4) strong winds that 'pile up' water inland and hold it there until wind direction changes (Friedlander et al., 1977).

Maurmeyer (1978) calculated a net sediment transport rate of 7,100 yd^3/yr in the southerly direction with a sediment transport rate of 11,900 yd^3/yr to the south and 4,800 yd^3/yr to the north. These results were compared to the circulation and wave model as well as past estimations and observations of longshore transport potential to assist in developing beach fill placement options. Observation of past beach fill behavior suggests that the dominant transport direction is northward in the north half of the community and southward in the southern half. Circulation modeling results show that under operational conditions, net flow is mostly offshore, with the weakest residual current at the center of town. Currents increase north and south of this location. The patterns of current direction indicate that the north side of town exhibits a slight northerly flow, while the south side exhibits a slight southerly flow. Under average and storm conditions, the currents exhibit a southerly flow throughout the community.

Wave model results indicate slightly more wave energy on the north side of the town than on the south side with the annual potential transport direction directed northward due to the influence of the offshore waves. The variation in wave energy may be due to sheltering provided by the coastline to the south. However, the influence of the northern groin and southern jetty on the modeling results is not clear. A more refined wave modeling effort in conjunction with a data collection effort would better resolve the conditions at Bowers and may be considered in future phases.

Figure 7.20 2007 Aerial of Bowers Beach (Delaware DataMIL)

Shore Protection History. The first beach nourishment was conducted at Bowers Beach in 1962. A total of 294,065 cy of material has been placed to date and a number of shore protection structures have been constructed. Table 7.7 provides the data available regarding the beach nourishment and shore protection history for Bowers Beach. The fill template used for past project at Bowers consists of a berm with a height of 9.2 ft NAVD88 and a foreshore slope of 1V:15H (Figure 7.21).

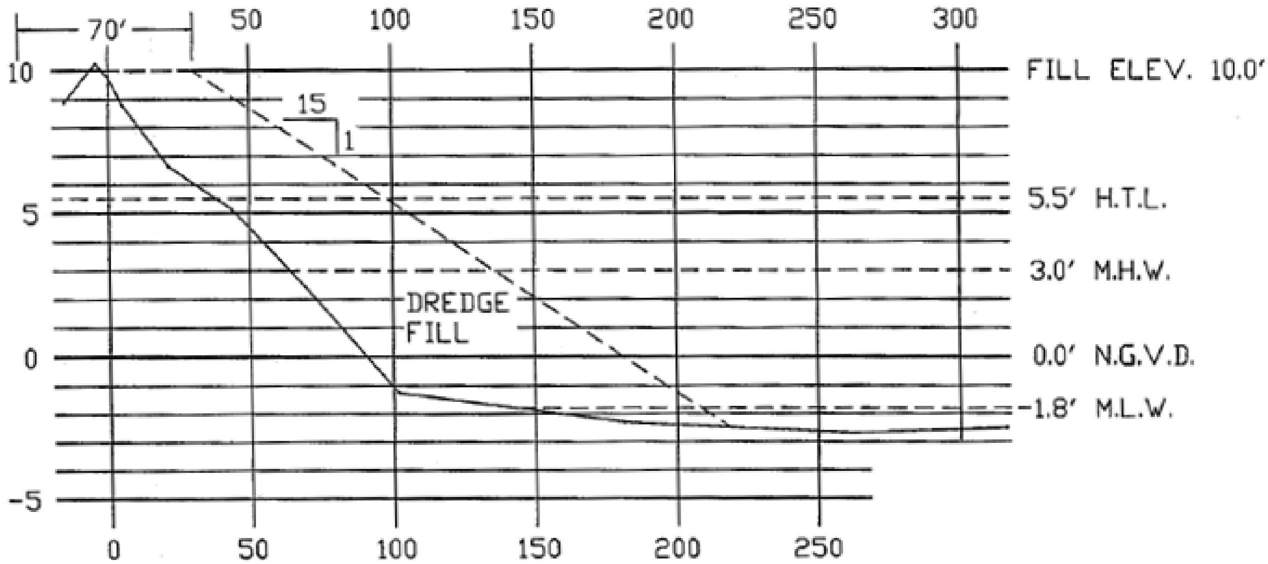


Figure 7.21 Typical fill template for past projects at Bowers Beach (from 1997 Corps permit application).

Table 7.7 Bowers Beach Shore Protection History.

Year	Volume (cy)	Length (ft)	Location	Method	Sediment Source	Structure
1962	35,500	N/A	N/A	Truck-haul	N/A	
1968	18,000	N/A	N/A	Hydraulic dredge	N/A	
1969	6,500	N/A	N/A	Truck-haul	N/A	
1972	21,200	N/A	N/A	Hydraulic dredge	N/A	
1973	15,800	1400	N/A	Hydraulic dredge	N/A	
1974	28,800	1000	N/A	Hydraulic dredge	N/A	
1976	Structure	900	South end			Sand-filled bag groin
1976	Structure	400	North end			Sand-filled bag groin
1985	35,700	N/A	N/A	Truck-haul	Upland	
1986	13,700	600	N/A	Hydraulic dredge	1000' offshore	
1986	Structure	213	26+50			Sand-filled bag groin
1988	51,700	N/A	N/A	Hydraulic dredge	N/A	
1988	Structure	320	South end			Grout-filled bag groin
1988	Structure	290	North end			Grout-filled bag groin
1994	12,000	500	N/A	Hydraulic dredge	N/A	
1998	55,165	N/A	N/A	Hydraulic dredge	N/A	
2009	Structure	130	N/A			Grout-filled bag groin
2009	1,000	400	N/A	Truck-haul	N/A	
2009	9,000	N/A	N/A	Truck-haul	N/A	

N/A = Information not available. The information for this table was gathered from DNREC records and state and federal permitting documents.

Existing Structures. A terminal groin was constructed approximately 50 ft north of the northern most home, originally with sand filled bags in 1976 and then reinforced with grout filled bags in 1988 (Figure 7.23). The northern groin is retaining sand at the expense of the erosional offset of the shoreline on the north side of the structure.

A jetty was constructed along the northern shoreline of the Murderkill Inlet originally with sand filled bags in 1976 and then reinforced with grout filled bags in 1988 (Figure 7.24). The total length of the structure is approximately 550 ft. The jetty extends approximately 100 ft into the Bay. In 2009 improvements were implemented to the jetty that included lengthening and adding height.

> **Recommendation**: No modifications to the terminal groin and jetty are recommended at this time. The cost estimates provided herein do not include budgets for modification of the groin or jetty. Monitoring is recommended for the groin and jetty in order to continue to evaluate performance and the interaction with any proposed sand placement.

Figure 7.22 Aerial photograph of Bowers Beach (Wayne Lasch, April 17, 2009).

Figure 7.23 North terminal sandbag groin.

Gary Anderson, January 9, 2008.

Figure 7.24 North jetty at Murderkill Inlet, looking inland.

Gary Anderson, January 9, 2008.

7.4.2 Management Plan Alternatives

No Action

The groin and jetty have provided some stability to the shoreline, however the beaches continue to require periodic fill placement to maintain the shoreline position. Therefore, landward migration of the shoreline would likely continue if no action is taken at this community. As a result, infrastructure including, recreational beach, utilities, roadways, and private homes could be damaged or lost during high energy coastal storms. Continued erosion would also decrease the available acreage of nesting beach for use by horseshoe crabs; this would negatively impact both the horseshoe crab population and the populations of shorebirds that rely on the horseshoe crabs.

Strategic Fill Placement

This scenario consists of concentrating the placement of fill along the specific locations of greatest need in each community. This alternative is largely based on the previous shore protection activities conducted by DNREC (Table 7.7) and is the minimum level of protection that would be recommended. Based on a review of previous studies, historic aerials, longshore transport estimates, and local knowledge gained from previous beach fill behavior, the recommended design components of this scenario include:

- As shown in Figure 7.25, a berm extending seaward 20 ft from the toe of the constructed dune at an elevation of +8.2 ft NAVD88 with a seaward slope of 1V:15H along 1,550 linear ft including gradually tapering the northern project limit for 500 ft. The location of this berm is along the southern portion of the shoreline.
- A dune feature throughout the project area with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H.
- A total initial volume of 18,450 cubic yards of sand.
- Maintaining the beach with periodic nourishment through the placement of 11,070 cubic yards every 4 years. This volume is based on historic erosion losses and historic placement volumes.
- Monitor the beach offset north of the terminal groin.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a spacing of 18 in by 18 in and a minimum of 11 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the back of the top of the dune and continue the entire length of the project. The minimum number of planting units necessary is 14,000.

5 Year Scenario

This scenario is based on restoring 5 years of estimated shoreline losses and providing protection from a storm event with a 5-year return period.

There are two components considered in determining the required level of protection for this scenario; the first is the width of beach necessary to protect upland infrastructure from a 5 yr return period storm, and the second is the width of beach needed to account for 5 years of historical losses. The recommended design components include:

- As shown in Figure 7.26, a berm extending seaward 20 ft from the toe of the constructed dune at an elevation of +8.2 ft NAVD88 with a seaward slope of 1V:15H along the entire community for a length of 3,200 linear ft including gradually tapering the northern project limit for 800 ft.
- A dune feature throughout the project area with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H.
- A total initial volume of 39,600 cubic yards of sand where this fill volume includes initial design fill requirements and advanced nourishment.
- Maintaining the beach with periodic nourishment through the placement of 23,760 cubic yards every 5 years. This volume is based on historic erosion losses and historic placement volumes.
- Monitor the beach offset north of the terminal groin.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a spacing of 18 in by 18 in and a minimum of 11 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the back of the top of the dune and continue the entire length of the project. The minimum number of planting units necessary is 25,000.

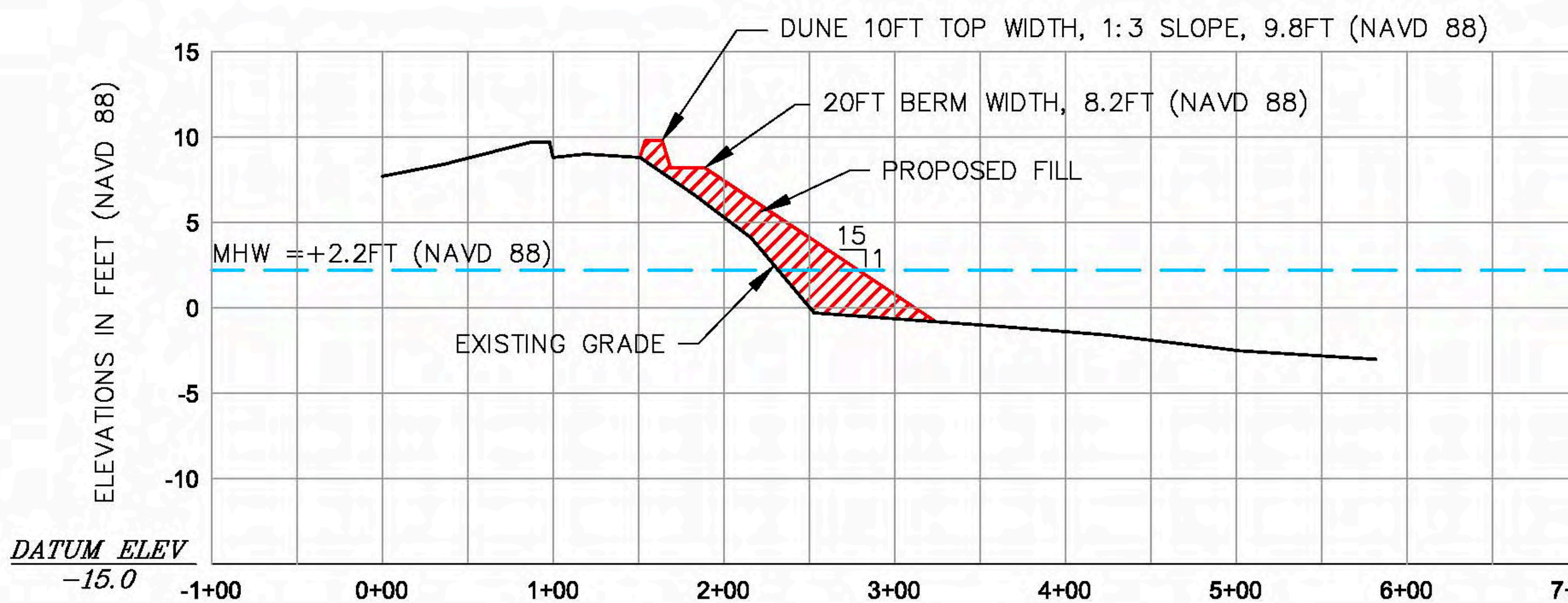
10 Year Scenario

This scenario is based on restoring 10 years of estimated shoreline losses and providing protection from a storm event with a 10-year return period.

As is discussed in detail in Section 6.4, there are two components considered in determining the required level of protection for this scenario; the first is the width of beach necessary to protect upland infrastructure from a 10 yr return period storm, and the second is the width of beach needed to account for 10 years of historical losses. The recommended design components include:

- As shown in Figure 7.27, a berm extending seaward 60 ft from the toe of the constructed dune at an elevation of +8.2 ft NAVD88 with a seaward slope of 1V:15H along the entire community for a length of 3,200 linear ft including gradually tapering the northern project limit for 800 ft.
- A dune feature throughout the project area with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H.
- A total initial volume of 76,000 cubic yards of sand where this fill volume includes initial design fill requirements and advanced nourishment.
- Maintaining the beach with periodic nourishment through the placement of 45,600 cubic yards every 10 years. This volume is based on historic erosion losses and historic placement volumes.

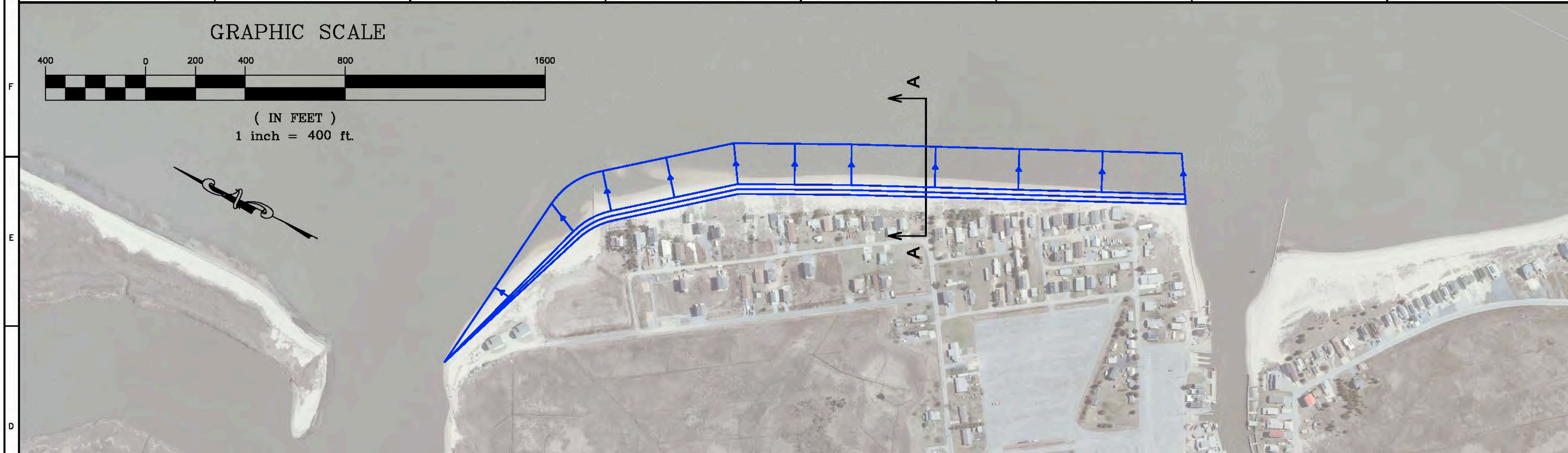
- Monitor the beach offset north of the terminal groin.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a spacing of 18 in by 18 in and a minimum of 11 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the back of the top of the dune and continue the entire length of the project. The minimum number of planting units necessary is 25,000.

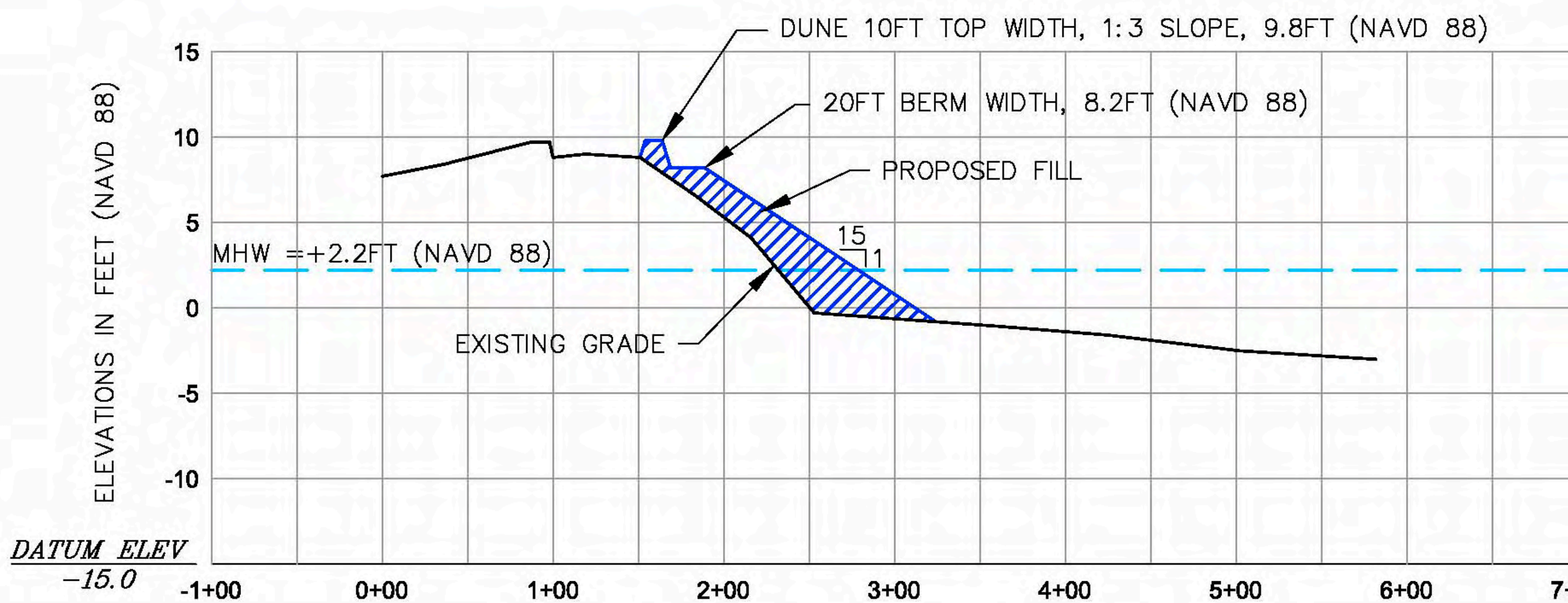


TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: BOWERS BEACH	TASK: STRATEGIC FILL PLACEMENT	FIGURE 7.25

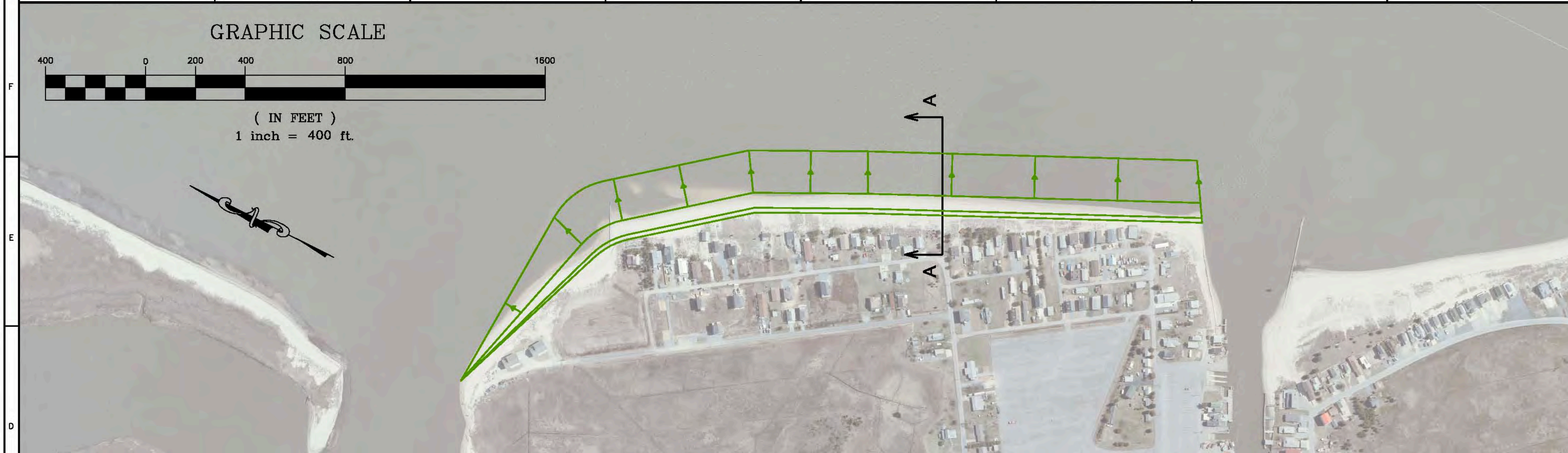


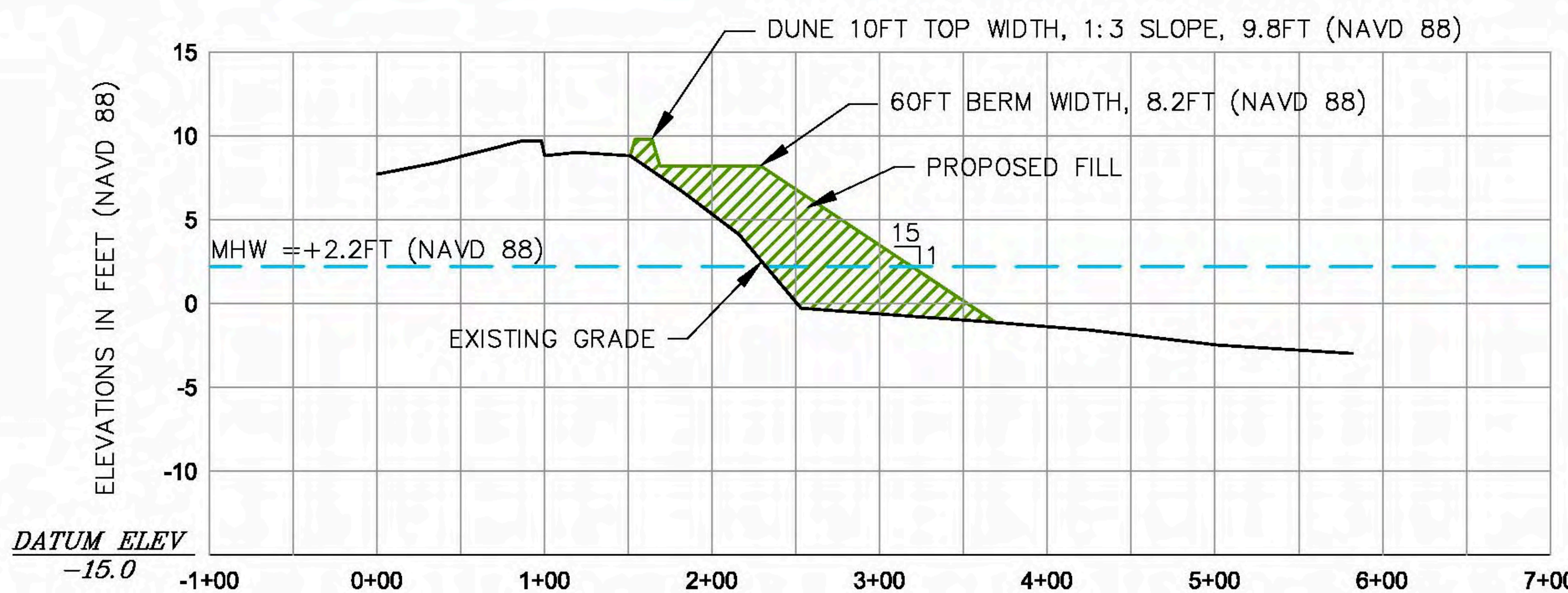


TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: BOWERS BEACH	TASK: 5 YEAR SCENARIO	FIGURE 7.26





TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: BOWERS BEACH	TASK: 10 YEAR SCENARIO	FIGURE 7.27

Potential sediment sources

Wethe et al (1982) investigated sand sources within 3,500 ft of the Bowers Beach shoreline located in water depths of less than 7 ft deep for use in nourishment projects for Bowers and South Bowers Beaches. These sources were determined to have too high a fines content to be considered ideal for beach nourishment (Wethe 1984). Even though these sources are not ideal, they may be used as a sand source but would require a large volume to be placed due to the winnowing out of the fines over time. This source may also be used as part of a feeder beach; however, studies should be developed to look at transport of these fines and the affect they have on navigation. Below the overburden and to a depth of -10 ft NAVD88, the area contains 1.2 million cy of sand. The location of this area is in the vicinity of cores BW-2 and BW-4 shown in Figure 7.28. In order to dredge the sand, up to a 5 ft thick layer of unsuitable sand overburden would need to be removed. This area may have been used for prior projects, but records containing the sand source locations for projects are not fully delineated.

For future projects, sand sources will need to be identified and may include the sand sources off of Kitts Hummock which is located less than 3 mi from Bowers Beach. Future projects will require a minimum water depth of at least 4 ft to accommodate typical commercial dredging equipment. Future sand search investigations should extend the limits of this study to find additional sand sources within 2 mi of the Bowers Beach shoreline.

The area directly offshore of the entrance to the Saint Jones River channel is a potential sand source that has been utilized previously. Depending on the volume extracted previously and how quickly the borrow area fills in this source may be available for future projects. Backpassing of material that has 'leaked' through the jetty into the Murderkill River may also provide some locally derived sediments.

A recent (2008) benthic mapping study of potential sand sources near Kitts Hummock and Bowers Beach was completed by Bart Wilson of DNREC. Preliminary results of this effort conclude that a volume of 900,000 cy of beach-quality sediment is available between Kitts Hummock and Clark Point, after accounting for overburden and depth limitations. Sand was mostly found in deep deposits in the nearshore, with fines and silts further offshore. Further investigation into this sand source is necessary to determine more accurate volumes and better assess the feasibility of extraction and suitability for nourishment projects.

Sand derived from upland sources such as local sand and gravel operations are also available for purchase and placement on this beach. However, sand from these sources will continue to be relatively expensive and best suited to use for relatively small emergency projects.

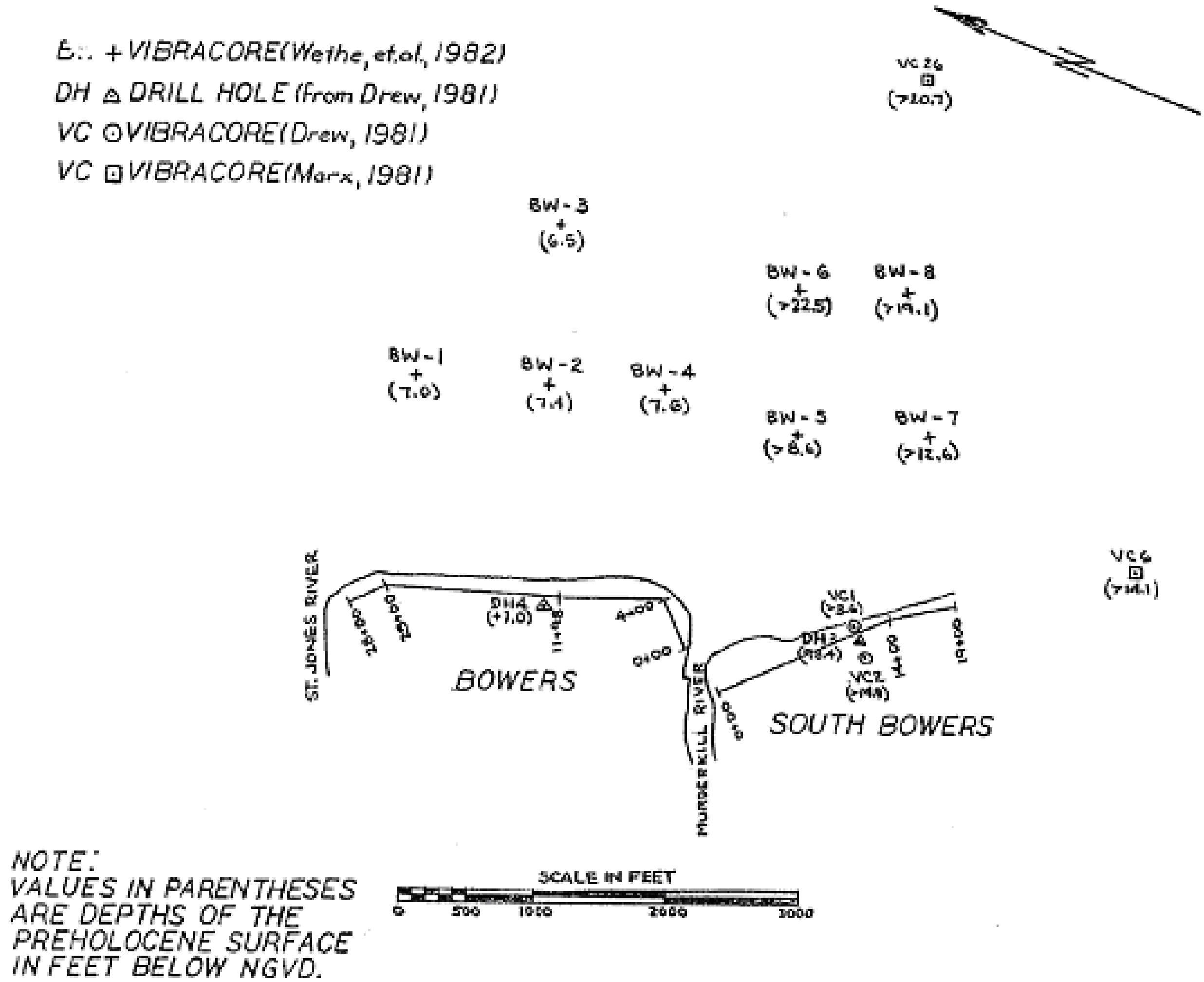


Figure 7.28 Core locations for Bowers and South Bowers Beach (Wethe, 1982).

Historical Resources

A remote sensing survey of an area measuring 1500 ft by 3000 ft, located approximately 1000 ft northeast of the mean low water line indicated one anomaly. This anomaly, located in the northwest corner (75° 23' 49''W, 39° 04' 02''N), is not likely to be of historical significance.

Construction Cost Estimate

Construction costs are estimated for each of the three project scenarios in Table 7.8 and include mobilization and demobilization, sand placement, and dune plantings. Costs for design, permitting, geotechnical investigation, post-project performance, and physical/biological monitoring are presented in Table 7.9.

Table 7.8 Bowers Beach Shore Protection Construction Cost Estimate

Bowers Beach Construction Cost Estimate Details									
Strategic Placement Scenario									
	Length		**Unit Volume**		**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*					0.25	lump sum	$750,000	$187,500
Berm Taper	500	ft	6.5	cy/ft	3,250	cy	$7.00	$22,750
Berm	1,050	ft	13	cy/ft	13,650	cy	$7.00	$95,550
Dune	1,550	ft	1	cy/ft	1,550	cy	$7.00	$10,850
Plant Units					14,000	each	$1.09	$15,260
			Total Volume		**18,450**	**cy**		**$331,910**
5 Year Scenario								
	Length		**Unit Volume**		**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*					0.25	lump sum	$750,000	$187,500
Berm Taper	800	ft	6.5	cy/ft	5,200	cy	$7.00	$36,400
Berm	2,400	ft	13	cy/ft	31,200	cy	$7.00	$218,400
Dune	3,200	ft	1	cy/ft	3,200	cy	$7.00	$22,400
Plant Units					25,000	each	$1.09	$27,250
			Total Volume		**39,600**	**cy**		**$491,950**
10 Year Scenario								
	Length		**Unit Volume**		**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*					0.25	lump sum	$750,000	$187,500
Berm Taper	800	ft	13	cy/ft	10,400	cy	$7.00	$72,800
Berm	2,400	ft	26	cy/ft	62,400	cy	$7.00	$436,800
Dune	3,200	ft	1	cy/ft	3,200	cy	$7.00	$22,400
Plant Units					25,000	each	$1.09	$27,250
			Total Volume		**76,000**	**cy**		**$746,750**

* Mob/Demob costs are based on this project being performed as part of a regional beach nourishment project that includes the nearby communities of Pickering Beach, Kitts Hummock, and South Bowers Beach. Performing this work as a separate contract would increase the estimated mob/demob costs to $450,000.

Long Range Budget Plan

Table 7.9 Bowers Beach Shore Protection Long Range Budget Plan

	Strategic Fill Placement	Budget Estimate										
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
	***Geotechnical Investigation**	$23,466										$23,466
	***Design/Permitting**	$11,733										$11,733
	Construction					$331,910				$242,250		$574,160
	Env. Permit Monitoring					$17,500	$17,500	$17,500		$17,500	$17,500	$87,500
	Beach Survey	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$60,000
	Sub Total	$41,199	$6,000	$6,000	$6,000	$355,410	$23,500	$23,500	$6,000	$265,750	$23,500	**$756,859**
	5 Year Scenario	**Budget Estimate**										
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
	***Geotechnical Investigation**	$23,466										$23,466
Bowers Beach	***Design/Permitting**	$11,733										$11,733
	Construction					$491,950					$345,150	$837,100
	Env. Permit Monitoring					$17,500	$17,500	$17,500			$17,500	$70,000
	Beach Survey	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$60,000
	Sub Total	$41,199	$6,000	$6,000	$6,000	$515,450	$23,500	$23,500	$6,000	$6,000	$368,650	**$1,002,299**
	10 Year Scenario	**Budget Estimate**										
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
	***Geotechnical Investigation**	$23,466										$23,466
	***Design/Permitting**	$11,733										$11,733
	Construction					$746,750						$746,750
	Env. Permit Monitoring					$17,500	$17,500	$17,500				$52,500
	Beach Survey	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$60,000
	Sub Total	$41,199	$6,000	$6,000	$6,000	$770,250	$23,500	$23,500	$6,000	$6,000	$6,000	**$894,449**

***Notes: The costs for these items are proportional to total volume placed for all of the seven communities included in this management plan**
Renourishment costs are based on restoring 60% of initial volume placed to restore historic losses
Costs are based on work being performed on a regional basis
Costs shown are in July 2009 prices.

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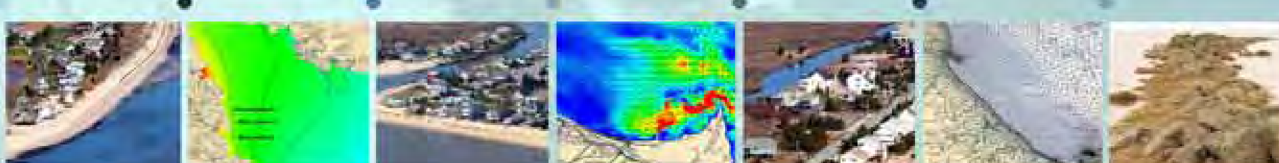


South Bowers

12023-BD-09

7.5 South Bowers

7.5.1 Background

South Bowers is located on a sand and gravel barrier beach bordering on an extensive back barrier marsh. The barrier is approximately 230 ft wide with a fairly low maximum height. The wide, low nature of South Bowers Beach is characteristic of a washover-dominated system (Maurmeyer, 1978). South Bowers Beach has shoreline azimuths of 53°N at the northern portion and 40°N at the southern portion. A wide expanse of relict marsh deposits sits offshore of South Bowers, which results in a very gentle slope. Wethe et al.'s visual assessment in 1982 states that the beach contained gravelly, fine to coarse sand along the berm and slightly gravelly to fine sand along the low water line.

The northern portion of the beach, bordered by the south jetty at the Murderkill River is wide and the houses are set back a good distance from the shoreline. However, the homes to the south are built much closer to the shoreline and are more vulnerable to the effects of erosion and storms. The average erosion rate calculated by French (1991) at South Bowers Beach is 3.0 ft/yr (Table 6.3).

Maurmeyer calculated a southerly annual net transport direction at a rate of 9,400 yd^3/yr and 11,800 yd^3/yr along the northern and southern portions of South Bowers Beach (Table 6.1). Observation of past beach fill behavior suggests that the dominant transport direction is northerly. Nearshore residual currents from the circulation modeling exercise suggest a slight southerly direction in the nearshore, but there is a consistent northerly flow just offshore which may be the dominating factor long-term. There is less net current on the north side of town adjacent to the jetty; this could be a factor in the observed accretion at this location. Similar to Bowers Beach, this variation in transport direction may be due to sheltering provided by the coastline to the south and/or due to the seasonal variability that exists along this region of coastline.

Wave model results indicate annual potential transport direction northward due to the influence of the offshore waves. In addition, the wave model demonstrated the seasonal variability of wave heights and potential transport direction. During fall conditions the wave model showed a southerly trend due to the offshore wave approach and local wind direction; however, the influence of the jetty on modeling results is not clear. The jetty and inlet likely have an influence on the local littoral processes. A more refined wave modeling effort in conjunction with a data collection effort would better resolve the influence of the jetty.

Figure 7.29 2007 Aerial of South Bowers (Delaware DataMIL)

Shore Protection History. Beach nourishment events and the installation of shore protection structures have been conducted at South Bowers Beach since 1961. A total of 96,900 cy of material has been placed to date. Table 7.10 provides the data available regarding the beach nourishment and shore protection history for South Bowers Beach. The fill template used at this beach for past projects consists of a berm height of 9.2 ft NAVD88.

Table 7.10 South Bowers Shore Protection History.

Year	Volume (cy)	Length (ft)	Location	Method	Sediment Source	Structure
1961	20,000	N/A	N/A	N/A	N/A	
1962	10,000	N/A	N/A	Truck-haul	N/A	
1969	4,000	N/A	N/A	Truck-haul	N/A	
1974	4,000	830	N/A	Truck-haul	N/A	
1975	15,000	1000	N/A	Hydraulic dredge	N/A	
1976	9,400	N/A	N/A	Hydraulic dredge	N/A	
1976	Structure	325	South end			Sand-filled bag groin
1976	Structure	325	South end			Sand-filled bag groin
1984	17,000	N/A	6+00 through 15+00	Hydraulic dredge	Murderkill River channel	
1988	Structure	625				Grout-filled bag groin
1989	8,000	N/A	N/A	Hydraulic dredge	N/A	
1992	2,000	N/A	N/A	Hydraulic dredge	N/A	
1997	7,500	500	N/A	Hydraulic dredge	N/A	

N/A = Information not available. The information for this table was gathered from DNREC records and state and federal permitting documents.

Existing Structures. A jetty was constructed along the southern shoreline of the Murderkill Inlet, originally with sand filled bags in 1976 and then reinforced with grout filled bags in 1988. The total length of the visible structure is approximately 300 ft. The jetty extends approximately 150 ft into the bay. Over time, the portion of the jetty along the inlet shoreline has been subject to sand transport over the jetty, effectively burying the western end of the structure and creating a sand shoal just inside the inlet shoreline. The sand shoal could pose a hazard to navigation as it grows larger.

> **Recommendation:** The jetty should be rehabilitated to return the functions of maintaining sand on the beach and reducing the volume of sand entering the Murderkill River. Sand tightening of the jetty and raising the height is recommended. The structure would better retain sand on the beach and keep sand from entering the Murderkill River. Monitoring is recommended for the jetty in order to continue to evaluate performance and the interaction with any proposed sand placement. In addition, sand that is located in the shoal, just north of the structure, should be excavated and placed on South Bowers Beach.

Figure 7.30 Aerial photograph of South Bowers Beach (Wayne Lasch, April 17, 2009).

7.5.2 Management Plan Alternatives

No Action

Landward migration of the shoreline would likely continue if no action is taken at this community. As a result, infrastructure including, recreational beach, utilities, roadways, and private homes could be damaged or lost during high energy coastal storms. Continued erosion would also decrease the available acreage of nesting beach for use by horseshoe crabs; this would negatively impact both the horseshoe crab population and the populations of shorebirds that rely on the horseshoe crabs.

Backpassing

Backpassing, the movement of sand from an accretional area of the beach to an eroding area, is a management alternative for South Bowers that would be best utilized when emergency infusions of sand are needed. The sand fillet located south of the jetty could provide a volume of sand to be placed on the downdrift beaches of greatest need. If this alternative were undertaken, then close monitoring of the borrow site and placement site should be performed to better understand the local sediment pathways and determine if any detrimental effects due to excavation of sand on the beach have occurred.

Strategic Fill Placement

This scenario consists of concentrating the placement of fill along the specific locations of greatest need in each community. This alternative is largely based on the previous shore protection activities conducted by DNREC (Table 7.10) and is the minimum level of protection that would be recommended. Based on a review of previous studies, historic aerials, longshore transport estimates, and local knowledge gained from previous beach fill behavior, the recommended design components of this scenario include:

- As shown in Figure 7.31, a beach fill concentrated on the southern end of the community with a berm extending seaward 15 ft from the toe of the constructed dune at an elevation of +8.2 ft NAVD88 along the entire community including a gradual taper at the northern project limit for 800 ft and a gradual taper at southern project limit for 500 ft.
- A dune feature throughout the project area with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H.
- A total initial volume of 12,200 cubic yards of sand.
- Maintaining the beach with periodic nourishment through the placement of 7,320 cubic yards every 4 years. This volume is based on historic erosion losses and historic placement volumes.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a spacing of 18 in by 18 in and a minimum of 11 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the back of the top of the dune and continue the entire length of the project. The minimum number of planting units necessary is 20,500.

5 Year Scenario

This scenario is based on restoring 5 years of estimated shoreline losses and providing protection from a storm event with a 5-year return period.

There are two components considered in determining the required level of protection for this scenario; the first is the width of beach necessary to protect upland infrastructure from a 5 yr return period storm, and the second is the width of beach needed to account for 5 years of historical losses. While a shorter project length could be considered for this scenario, the proposed project length was determined based on the historically high erosion rates for this community and concerns that, by not maximizing the project length, performance of the beachfill project may be compromised. The recommended design components include:

- As shown in Figure 7.32, a beach fill along the entire community with a berm extending seaward 15 ft from the toe of the constructed dune at an elevation of +8.2 ft NAVD88 along the entire community including a gradual taper at the northern project limit for 900 ft and a gradual taper at southern project limit for 500 ft.

- A dune feature throughout the project area with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H.
- A total initial volume of 23,800 cubic yards of sand where this fill volume includes initial design fill requirements and advanced nourishment.
- Maintaining the beach with periodic nourishment through the placement of 14,280 cubic yards every 5 years. This volume is based on historic erosion losses and historic placement volumes.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a spacing of 18 in by 18 in and a minimum of 11 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the back of the top of the dune and continue the entire length of the project. The minimum number of planting units necessary is 22,500.

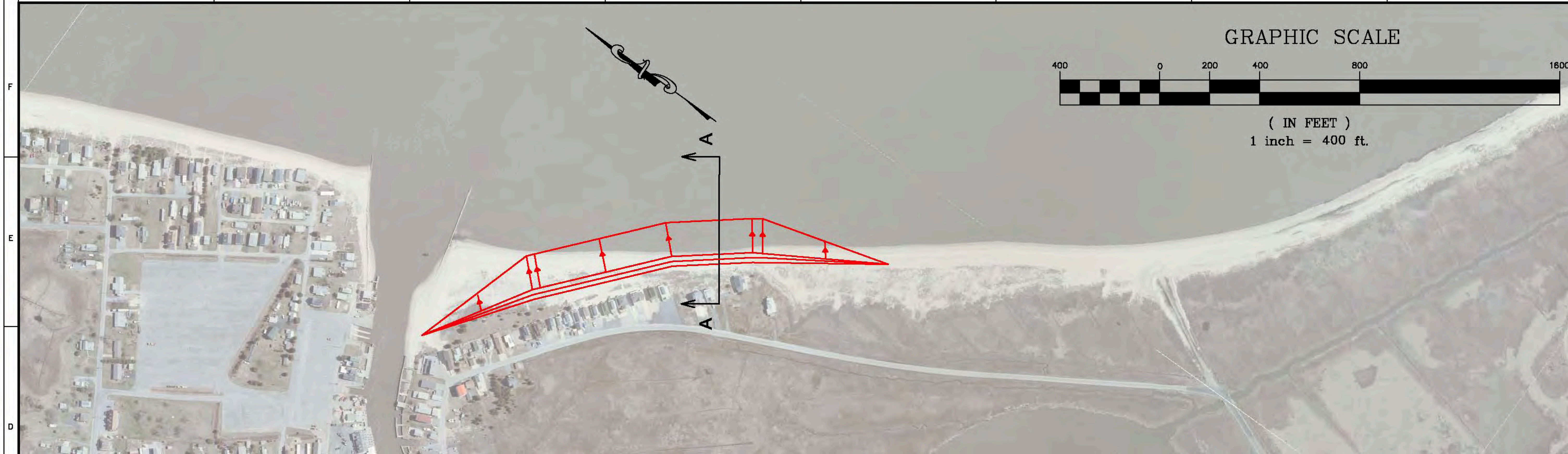
10 Year Scenario

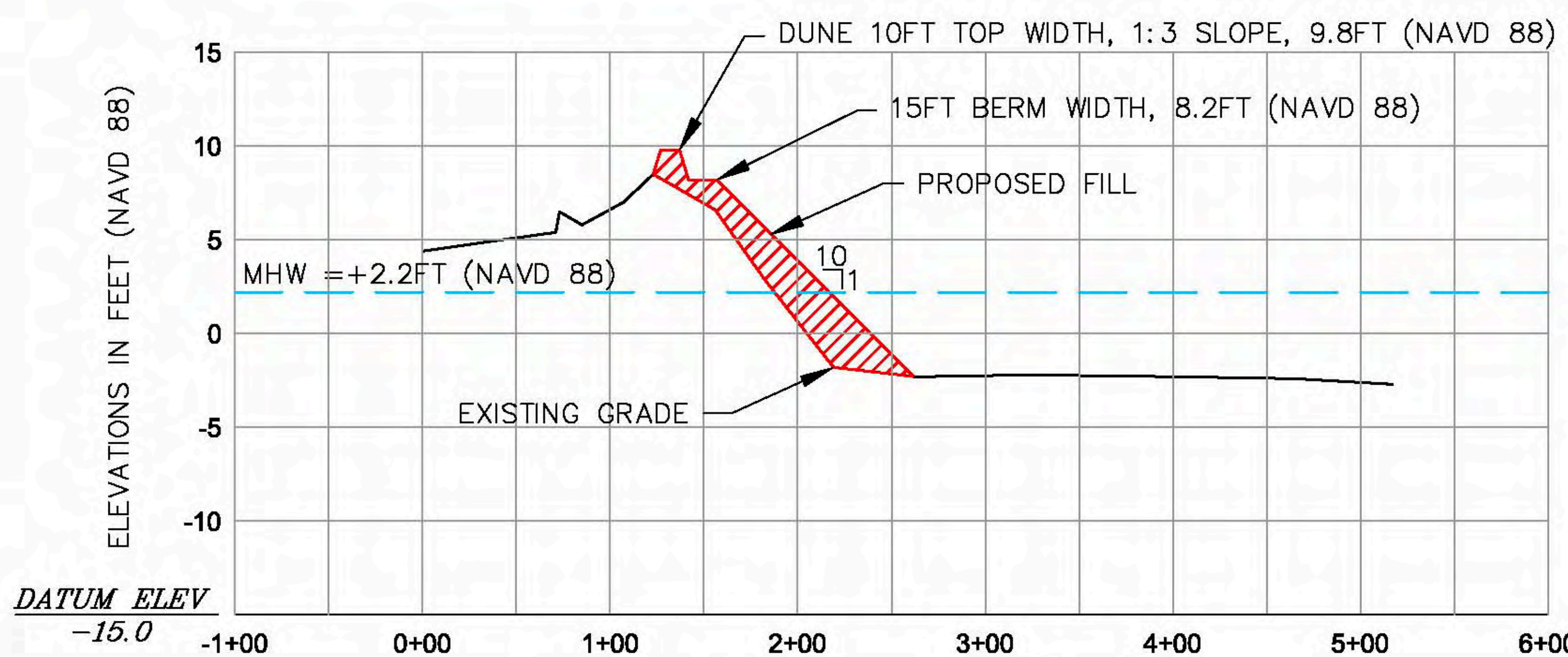
This scenario is based on restoring 10 years of estimated shoreline losses and providing protection from a storm event with a 10-year return period.

As is discussed in detail in Section 6.4, there are two components considered in determining the required level of protection for this scenario; the first is the width of beach necessary to protect upland infrastructure from a 10 yr return period storm, and the second is the width of beach needed to account for 10 years of historical losses. While a shorter project length could be considered for this scenario, the proposed project length was determined based on the historically high erosion rates for this community and concerns that, by not maximizing the project length, performance of the beachfill project may be compromised. The recommended design components include:

- As shown in Figure 7.33, a beach fill along the entire community with a berm extending seaward 65 ft from the toe of the constructed dune at an elevation of +8.2 ft NAVD88 along the entire community including a gradual taper at the northern project limit for 900 ft and a gradual taper at southern project limit for 500 ft.

- A dune feature throughout the project area with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H.
- A total initial volume of 65,800 cubic yards of sand where this fill volume includes initial design fill requirements and advanced nourishment.
- Maintaining the beach with periodic nourishment through the placement of 39,480 cubic yards every 10 years. This volume is based on historic erosion losses and historic placement volumes.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a spacing of 18 in by 18 in and a minimum of 11 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the back of the top of the dune and continue the entire length of the project. The minimum number of planting units necessary is 22,500.

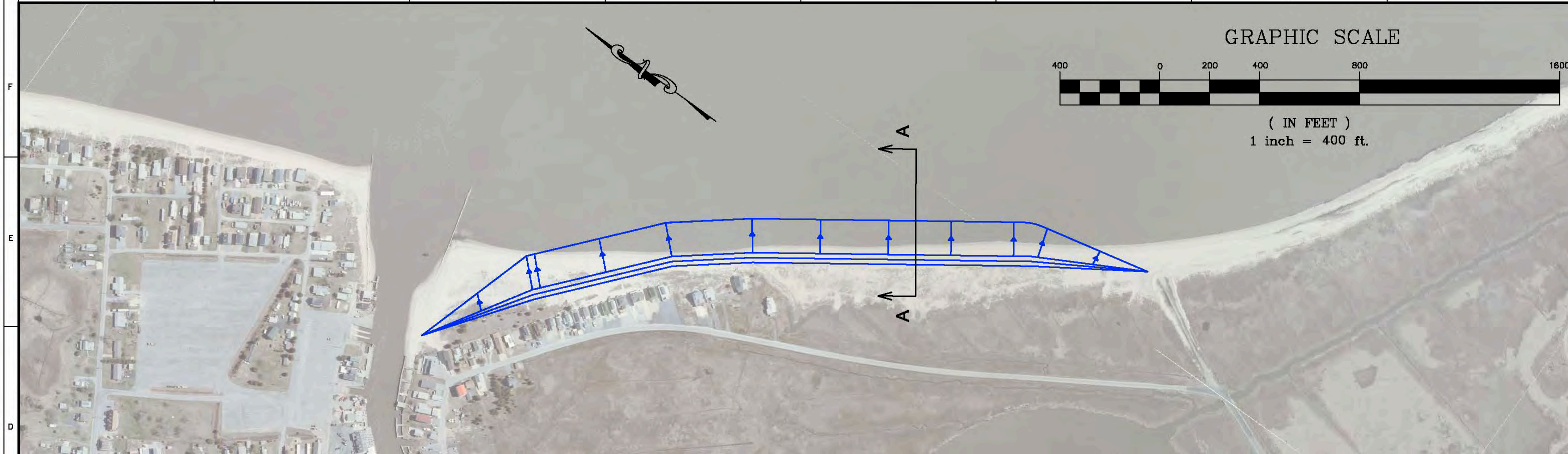


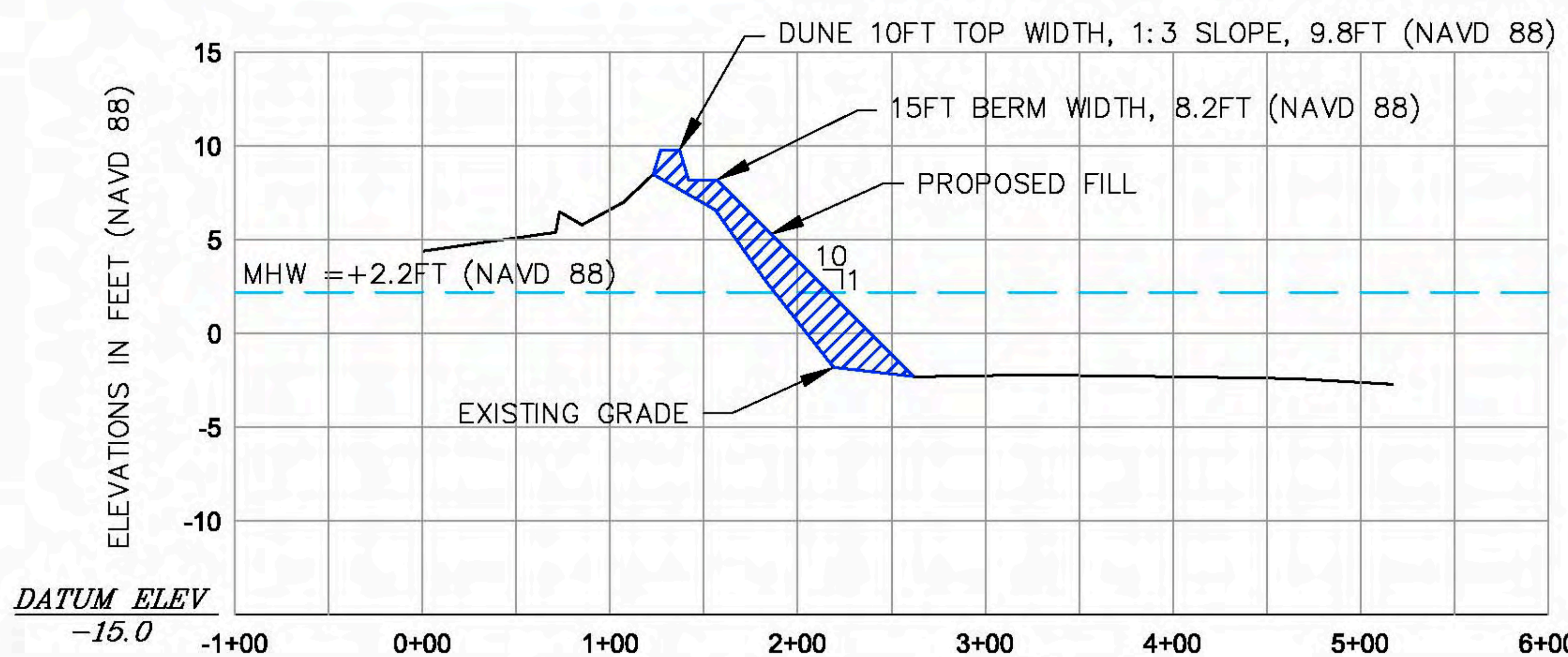


TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: SOUTH BOWERS	TASK: STRATEGIC FILL PLACEMENT	FIGURE 7.31

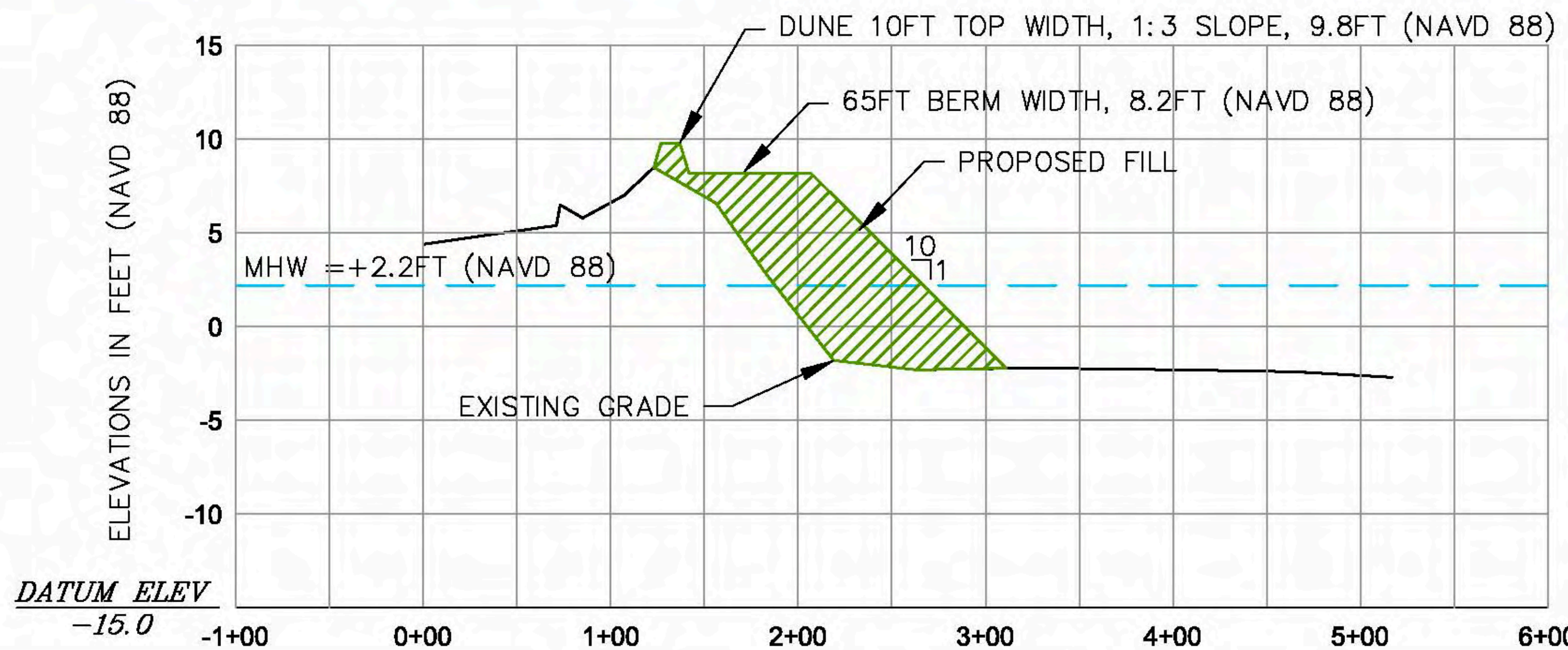




TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: **SOUTH BOWERS**	TASK: **5 YEAR SCENARIO**	**FIGURE 7.32**



TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: SOUTH BOWERS	TASK: 10 YEAR SCENARIO	FIGURE 7.33

Potential sediment sources

Wethe et al (1982) investigated sand sources within 3,500 ft of the Bowers Beach shoreline located in water depths of less than 7 ft for use in nourishment projects for Bowers and South Bowers Beaches. These sources were determined to have too high a fines content to be considered ideal for beach nourishment (Wethe 1984). Even though these sources are not ideal, they may be used as a sand source but would require a large volume to be placed due to the winnowing out of the fines over time. Below the overburden and to a depth of -10 ft NAVD88, the area contains 1.2 million cy of sand. The location of this area is in the vicinity of cores BW-2 and BW-4 shown on Figure 7.34. In order to dredge the sand, up to a 5 ft thick layer of unsuitable sand overburden would need to be removed. This area may have been used for prior projects, but records containing the sand source locations for projects are limited.

For future projects, sand sources will need to be identified and may include the sand sources off of Kitts Hummock which is located less than 3 mi from South Bowers Beach. Future projects will require a minimum water depth of at least 4 ft to accommodate typical commercial dredging equipment. Future sand search investigations should extend the limits of this study to find additional sand sources within 2 mi of the South Bowers Beach shoreline.

The waters directly offshore of the entrance to the Saint Jones River channel are a potential sand source that has been utilized previously. Depending on the volume extracted previously and how quickly the borrow area has filled in, this source may be available for future projects.

A recent (2008) benthic mapping study of potential sand sources near Kitts Hummock and Bowers Beach was completed by Bart Wilson of DNREC. Preliminary results of this effort conclude that a volume of 900,000 cy of beach-quality sediment is available between Kitts Hummock and Clark Point, after accounting for overburden and depth limitations. Sand was mostly found in deep deposits in the nearshore, with fines and silts further offshore. Further investigation into this sand source is necessary to determine more accurate volumes and better assess the feasibility of extraction and suitability for nourishment projects.

Sand derived from upland sources such as local sand and gravel operations are also available for purchase and placement on this beach. However, sand from these sources will continue to be relatively expensive and best suited to use for relatively small emergency projects.

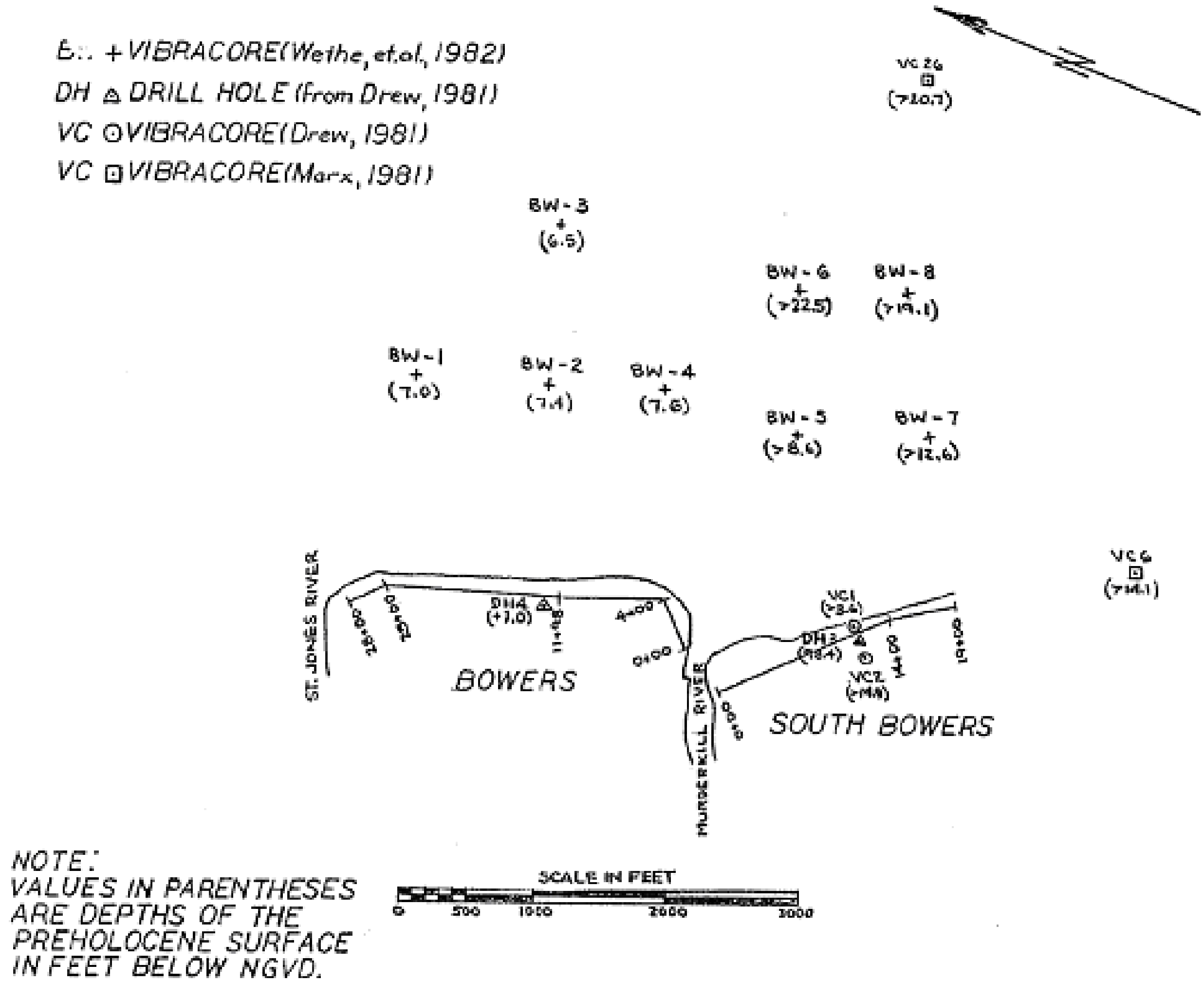


Figure 7.34 Core locations for Bowers and South Bowers Beach (Wethe, 1982).

Construction Cost Estimate

Construction costs are estimated for each of the three project scenarios in Table 7.11 and include mobilization and demobilization, sand placement, and dune plantings. Costs for design, permitting, geotechnical investigation, post-project performance, and physical/biological monitoring are presented in Table 7.12.

Table 7.11 South Bowers Beach Shore Protection Construction Cost Estimate

South Bowers Beach Construction Cost Estimate Details									
Strategic Placement Scenario									
	Length		**Unit Volume**		**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*					0.25	lump sum	$750,000	$187,500
Berm Taper	1,300	ft	5	cy/ft	6,500	cy	$7.00	$45,500
Berm	400	ft	10	cy/ft	4,000	cy	$7.00	$28,000
Dune	1,700	ft	1	cy/ft	1,700	cy	$7.00	$11,900
Plant Units					20,500	each	$1.09	$22,345
			Total Volume		**12,200**	**cy**		**$295,245**
5 Year Scenario								
	Length		**Unit Volume**		**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*					0.25	lump sum	$750,000	$187,500
Berm Taper	1,400	ft	5	cy/ft	7,000	cy	$7.00	$49,000
Berm	1,400	ft	10	cy/ft	14,000	cy	$7.00	$98,000
Dune	2,800	ft	1	cy/ft	2,800	cy	$7.00	$19,600
Plant Units					22,500	each	$1.09	$24,525
Allowance for Structure Modification								$100,000
			Total Volume		**23,800**	**cy**		**$478,625**
10 Year Scenario								
	Length		**Unit Volume**		**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*					0.25	lump sum	$750,000	$187,500
Berm Taper	1,400	ft	15	cy/ft	21,000	cy	$7.00	$147,000
Berm	1,400	ft	30	cy/ft	42,000	cy	$7.00	$294,000
Dune	2,800	ft	1	cy/ft	2,800	cy	$7.00	$19,600
Plant Units					22,500	each	$1.09	$24,525
Allowance for Structure Modification								$100,000
			Total Volume		**65,800**	**cy**		**$772,625**

* Mob/Demob costs are based on this project being performed as part of a regional beach nourishment project that includes the nearby communities of Pickering Beach, Kitts Humock and Bowers Beach. Performing this work as a separate contract would increase the estimated mob/demob costs to $450,000.

Long Range Budget Plan

Table 7.12 South Bowers Beach Shore Protection Long Range Budget Plan

	Strategic Fill Placement	Budget Estimate										
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
	*Geotechnical Investigation	$46,940										$46,940
	*Design/Permitting	$23,470										$23,470
	Construction					$295,245				$407,444		$702,689
	Env. Permit Monitoring					$17,500	$17,500	$17,500		$17,500	$17,500	$87,500
	Beach Survey	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$50,000
	Sub Total	$75,410	$5,000	$5,000	$5,000	$317,745	$22,500	$22,500	$5,000	$429,944	$22,500	**$910,599**
	5 Year Scenario	**Budget Estimate**										
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
	*Geotechnical Investigation	$46,940										$46,940
	*Design/Permitting	$23,470										$23,470
South Bowers Beach	Construction					$478,625					$529,900	$1,008,525
	Env. Permit Monitoring					$17,500	$17,500	$17,500			$17,500	$70,000
	Beach Survey	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$50,000
	Structure Modification					$100,000						$100,000
	Sub Total	$75,410	$5,000	$5,000	$5,000	$601,125	$22,500	$22,500	$5,000	$5,000	$552,400	**$1,298,935**
	10 Year Scenario	**Budget Estimate**										
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
	*Geotechnical Investigation	$46,940										$46,940
	*Design/Permitting	$23,470										$23,470
	Construction					$772,625						$772,625
	Env. Permit Monitoring					$17,500	$17,500	$17,500				$52,500
	Beach Survey	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$50,000
	Structure Modification					$100,000						$100,000
	Sub Total	$75,410	$5,000	$5,000	$5,000	$895,125	$22,500	$22,500	$5,000	$5,000	$5,000	**$1,045,535**

***Notes: The costs for these items are proportional to total volume placed for all of the seven communities included in this management plan**

Renourishment costs are based on restoring 60% of initial volume placed to restore historic losses

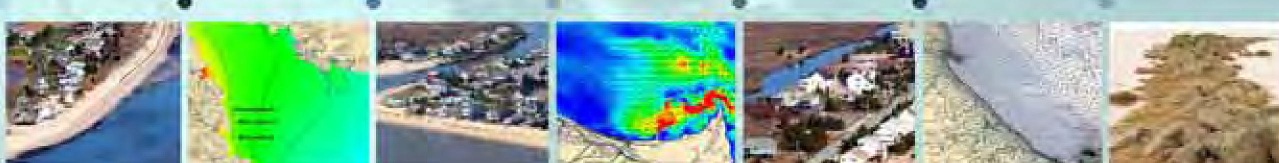
Costs are based on work being performed on a regional basis

Costs shown are in July 2009 prices.

MANAGEMENT PLAN FOR

THE DELAWARE BAY BEACHES

FINAL REPORT • MARCH 2010



Slaughter Beach

12023-BD-09

7.6 Slaughter Beach

7.6.1 Background

Slaughter Beach is located 7 mi east of Milford and 2 mi south of Mispillion Inlet, and has shoreline azimuths of 60°N at the northern end and 48°N at the southern end. It is bordered by wetlands to the southwest and Delaware Bay to the northeast. Slaughter Beach lies on a barrier beach that ranges in width from 360 ft to 500 ft. The soils consist primarily of fine and medium sands.

Observations of past beach fill behavior, along with previous research, suggest that the dominant transport direction is northerly, and the greatest need for beach fill is at the southern end of the community. The observed northerly transport at Slaughter Beach is evident from the accretion of the shoreline and accumulation of detritus along the northern portions of the community. In addition, the Mispillion Inlet is protected by 3,000 foot long jetties extending into the bay. These structures have an effect on the Slaughter Beach shoreline by influencing incoming waves and providing shelter to the northern shoreline of Slaughter Beach.

Just away from shore, circulation model results indicate a net northerly flow direction from Fowler Beach to the Inlet. Annual wave model results suggest a slight northern transport direction, but is variable based on seasonal conditions. Localized wave focusing was observed particularly during winter conditions at Slaughter Beach due to the presence of larger waves in the vicinity. These results were utilized to assist in developing beach fill placement options.

Figure 7.35 2007 Aerial of Slaughter Beach (Delaware DataMIL)

Shore Protection History. Beach nourishment events and the installation of shore protection structures have been conducted at Slaughter Beach since 1958. A total of 899,300 cy of material has been placed to date. Table 7.13 provides more detail regarding the shore protection history for Slaughter Beach. The fill template used at this beach for past projects consists of a berm with a height of 8.0 ft NAVD88 and a foreshore slope of 1V:10H (Figure 7.36).

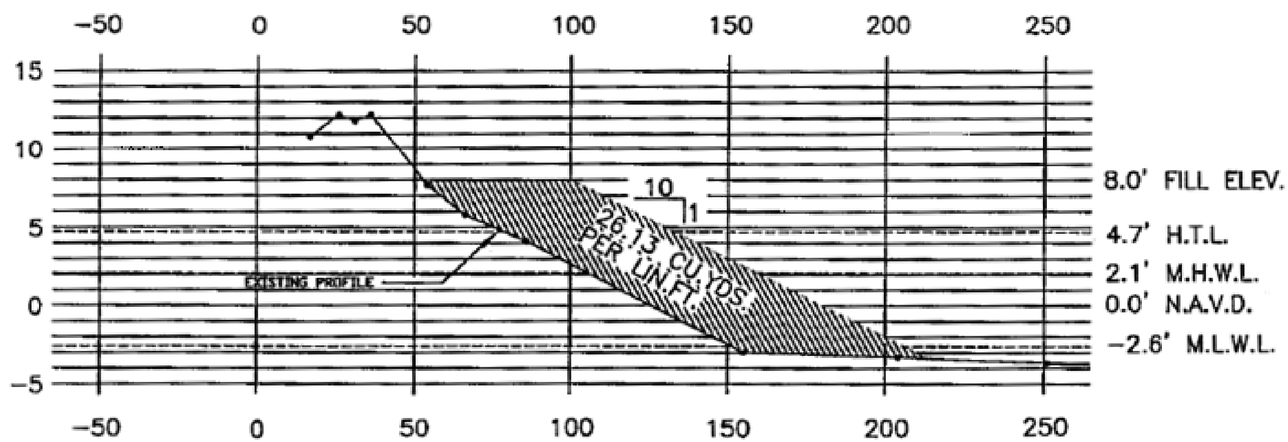


Figure 7.36 Typical fill section for previous projects at Slaughter Beach, vertical datum NAVD88 (taken from 2001 Corps permit application).

Table 7.13 Slaughter Beach Shore Protection History.

Year	Volume (cy)	Length (ft)	Location	Method	Sediment Source	Structure
1940-1957	Structure	100-200				Series of timber groins
1958	49,000	N/A	N/A	Truck-haul	Upland	
1961	165,000	N/A	N/A	Hydraulic dredge	N/A	
1962	56,600	N/A	N/A	Truck-haul	N/A	
1975	179,500	4,700	N/A	Hydraulic dredge	Offshore	
1976	277,700	9,600	N/A	Hydraulic dredge	Offshore	
1976	Structure	325				Sand-filled bag groin
1979	20,000	N/A	N/A	Backpassing	N/A	“Perched beach”
1985	26,200	1,700	N/A	Hydraulic dredge	N/A	
1985	10,300	N/A	N/A	Hydraulic dredge	N/A	
2002	N/A	N/A	N/A	Hydraulic dredge	N/A	
2005	115,000	4,400	S0+00 through S44+00	Hydraulic dredge	Approximately 1,600 ft offshore	

N/A = Information not available. The information for this table was gathered from DNREC records and state and federal permitting documents.

In 1979, the Corps constructed a ‘perched beach’ at the south end of the community. The structure consisted of three different types of material on which the raised beach ‘perched’: concrete boxes, wood sheet piling, and large nylon sandbags. The structure was then backpassed with 20,000 cy of material. Weggel (1987) assessed the effectiveness of the perched beach and determined that the beach planform adjusted in the presence of the perched beach such that the shoreline accreted downdrift of the perched beach and eroded updrift of the perched beach. He concluded that the design did not retain the sand placed but may have slowed the erosion rate in the area.

Figure 7.37 Aerial photograph of Slaughter Beach (Wayne Lasch, April 17, 2009).

Existing Structures. The Mispillion Inlet, located approximately 3,500 ft north of Slaughter Beach, is hardened with jetties that extend over 3,000 ft into Delaware Bay. The jetties are in a deteriorated condition and are very porous. The jetties have had a considerable effect on the shape of the shoreline at Slaughter Beach due to their configuration. The jetties modify incoming waves and shelter the northern end of Slaughter Beach. This creates a current that carries sediment and detritus to the north. Marsh detritus travels down the Mispillion River, through the gaps in the southern jetty, and settles on the beach south of the jetties.

> **Recommendation:** The 2008 study completed by Moffat and Nichol concluded that restoration of the south jetty would have negligible impact on the circulation and accumulation of detritus on Slaughter Beach. Monitoring is recommended for the jetties in order to continue to evaluate performance and the interaction with any proposed sand placement.

7.6.2 Management Plan Alternatives

No Action

Landward migration of the shoreline would likely continue if no action is taken at this community. As a result, infrastructure including, recreational beach, utilities, roadways, and private homes could be damaged or lost during high energy coastal storms. Continued erosion would also decrease the available acreage of nesting beach for use by horseshoe crabs; this would negatively impact both the horseshoe crab population and the populations of shorebirds that rely on the horseshoe crabs. The southern 2,500 feet of the shoreline is of particular concern where development is the closest to the Bay waters and the beach is the narrowest.

Strategic Fill Placement

This scenario consists of concentrating the placement of fill along the specific locations of greatest need in each community. The area of greatest need for Slaughter Beach is the southern 2,500 feet of shoreline. This alternative is largely based on the previous shore protection activities conducted by DNREC (Table 7.13) and is the minimum level of protection that would be recommended. Based on a review of previous studies, historic aerials, longshore transport estimates, and local knowledge gained from previous beach fill behavior, the recommended design components of this scenario include:

- As shown in Figure 7.38, a berm extending seaward 15 ft from the toe of the constructed dune at an elevation of +7.5 ft NAVD88 with a seaward slope of 1V:10H for a length of 2,500 linear ft including gradually tapering the project limits for 500 ft. The location of this fill is concentrated at the southern end of the community.
- A dune feature throughout the project area with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H.
- A total initial volume of 36,500 cubic yards of sand where this fill volume includes initial design fill requirements and advanced nourishment.
- Maintaining the beach with periodic nourishment through the placement of 21,900 cubic yards every 4 years. This volume is based on historic erosion losses and historic placement volumes.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a spacing of 18 in by 18 in and a minimum of 11 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the back of the top of the dune and continue the entire length of the project. The minimum number of planting units necessary is 27,500.

5 Year Scenario

This scenario is based on restoring 5 years of estimated shoreline losses and providing protection from a storm event with a 5-year return period.

There are two components considered in determining the required level of protection for this scenario; the first is the width of beach necessary to protect upland infrastructure from a 5 yr return period storm, and the second is the width of beach needed to account for 5 years of historical losses. The recommended design components include:

- As shown in Figure 7.39, a berm extending seaward 15 ft from the toe of the constructed dune at an elevation of +7.5 ft NAVD88 with a seaward slope of 1V:10H along the entire community for a length of 14,500 ft including gradually tapering the project limits for 500 ft.
- A dune feature throughout the project area with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H.
- A total initial volume of 252,500 cubic yards of sand where this fill volume includes initial design fill requirements and advanced nourishment.
- Maintaining the beach with periodic nourishment through the placement of 151,500 cubic yards every 5 years. This volume is based on historic erosion losses and historic placement volumes.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a spacing of 18 in by 18 in and a minimum of 11 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the back of the top of the dune and continue the entire length of the project. The minimum number of planting units necessary is 120,000.

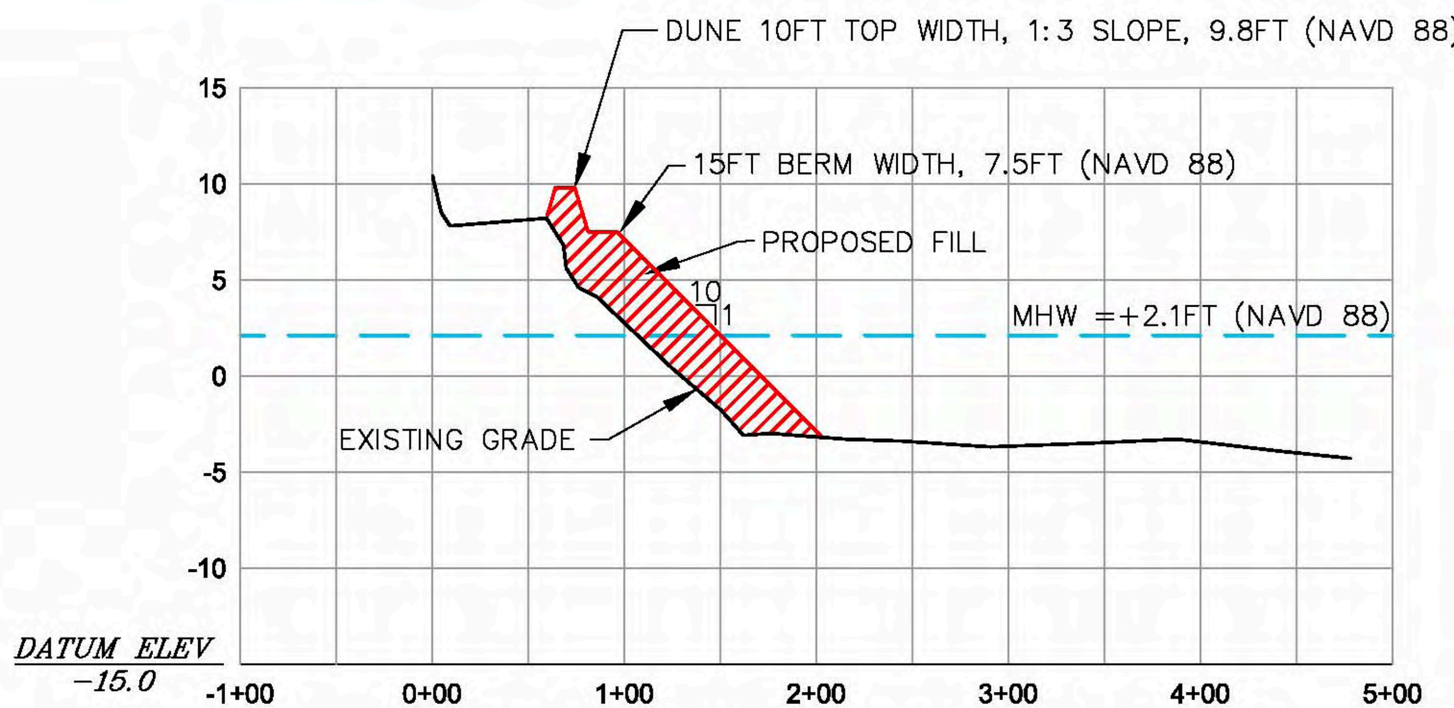
10 Year Scenario

This scenario is based on restoring 10 years of estimated shoreline losses and providing protection from a storm event with a 10-year return period.

As is discussed in detail in Section 6.4, there are two components considered in determining the required level of protection for this scenario; the first is the width of beach necessary to protect upland infrastructure from a 10 yr return period storm, and the second is the width of beach needed to account for 10 years of historical losses. The recommended design components include:

- As shown in Figure 7.40, a berm extending seaward 55 ft from the toe of the constructed dune at an elevation of +7.5 ft NAVD88 with a seaward slope of 1V:10H along the entire community for a length of 14,500 linear ft including gradually tapering the project limits for 500 ft.
- A dune feature throughout the project area with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H.
- A total initial volume of 476,500 cubic yards of sand where this fill volume includes initial design fill requirements and advanced nourishment.
- Maintaining the beach with periodic nourishment through the placement of 285,900 cubic yards every 10 years. This volume is based on historic erosion losses and historic placement volumes.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a

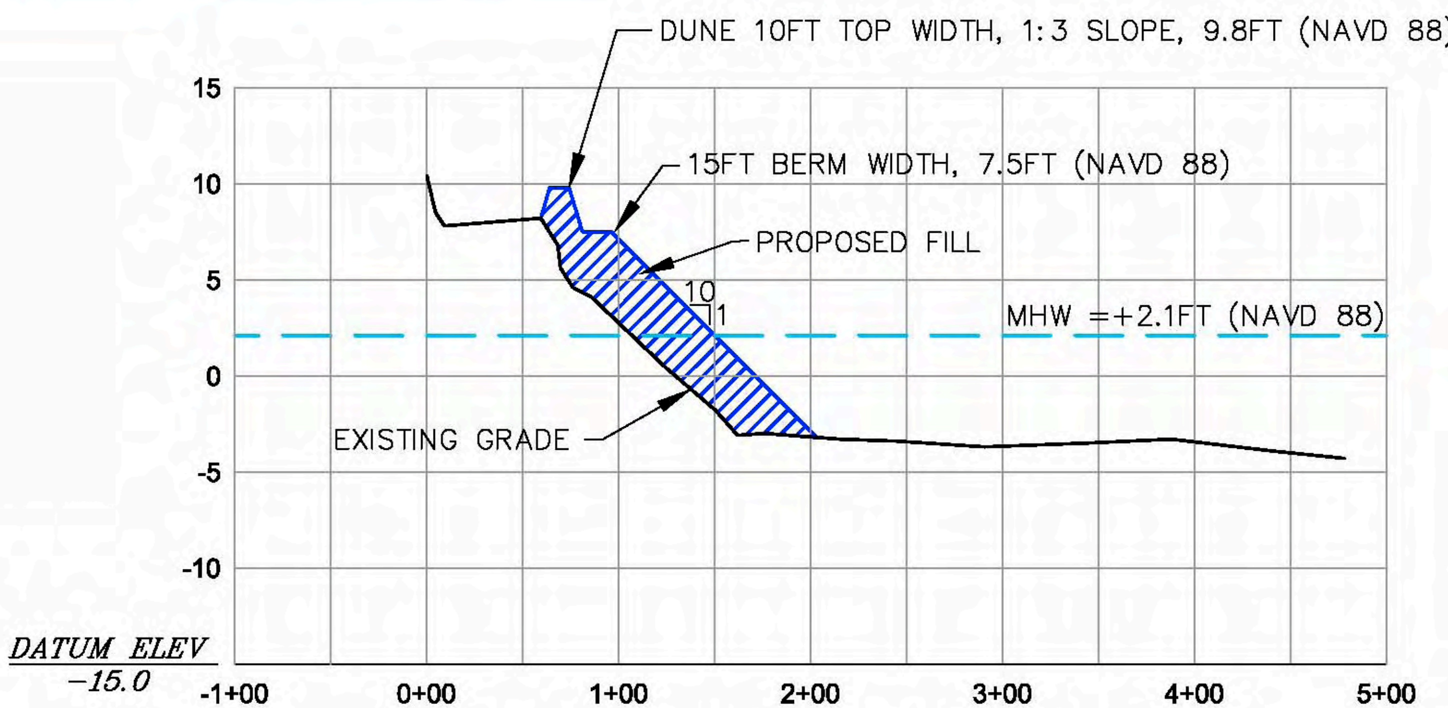
spacing of 18 in by 18 in and a minimum of 11 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the back of the top of the dune and continue the entire length of the project. The minimum number of planting units necessary is 120,000.



TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

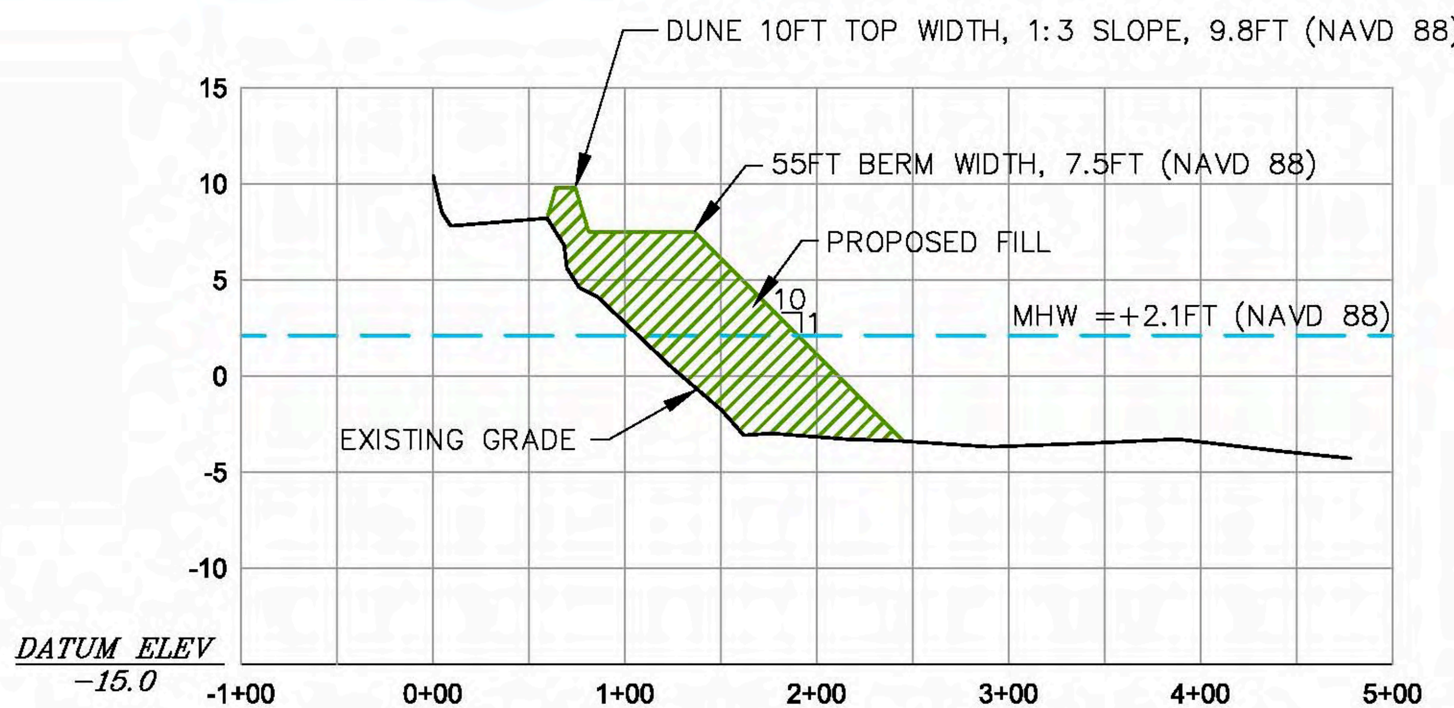
PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: SLAUGHTER BEACH	TASK: STRATEGIC FILL PLACEMENT	FIGURE 7.38



TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: **SLAUGHTER BEACH**	TASK: **5 YEAR SCENARIO**	**FIGURE 7.39**



TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: **SLAUGHTER BEACH**	TASK: **10 YEAR SCENARIO**	**FIGURE 7.40**

Potential sediment sources

Wethe et al. (1982) investigated sand sources within 3,500 ft of the Slaughter Beach shoreline located in water depths less than 10 ft deep. Suitable sand sources were identified, but are located under an overburden of muddy shelly sand, silty clay, and peat. Below the overburden and to a depth of -20.8 ft NAVD88, the area contains 1.7 million cy of sand. In order to dredge the sand, 1.2 million cy of overburden would need to be removed. The overburden thickness is not consistent throughout the area and measures from less than 1 ft in some locations to over 9 ft in other locations. Figure 7.41 depicts the locations of the sand sources with an overburden of less than 5 ft. Borrow areas for the 1962, 1975, and 1976 nourishment projects are located in this area. Additional use of this area may have occurred, but records containing the sand source locations for other projects are limited.

For future projects, this sand source should be investigated to determine the volume of remaining sand that could be extracted. Future projects will require a minimum water depth of at least 4 ft to accommodate typical commercial dredging equipment. Future sand search investigations should extend the limits of this study to find additional sand sources within 2 mi of the Slaughter Beach shoreline.

Sand derived from upland sources such as local sand and gravel operations are also available for purchase and placement on this beach. However, sand from these sources will continue to be relatively expensive and best suited to use for relatively small emergency projects.

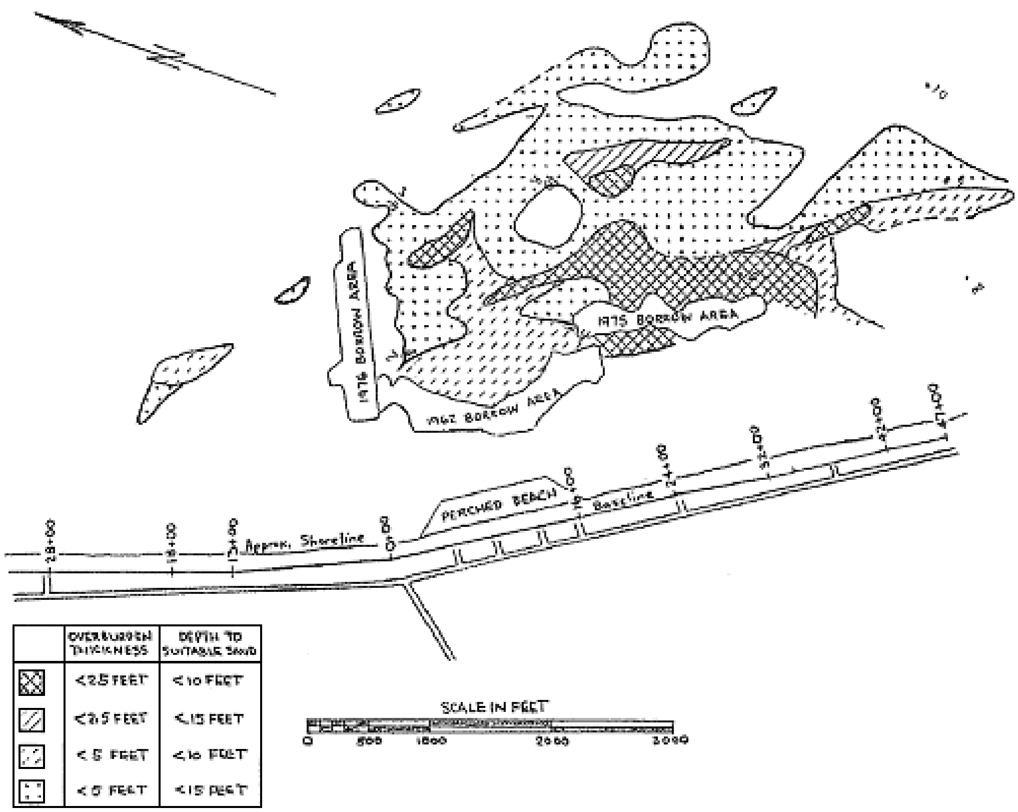


Figure 7.41 Slaughter Beach sand source locations (Wethe et al., 1983).

Natural Resources

In addition to providing habitat to the species discussed in Section 7.1.3, the nearshore zone at Slaughter Beach also serves as habitat for Sabellarid worm communities. Because these communities are relatively common and at least partially ephemeral, the preliminary designs provided in this document do not avoid or minimize potential impacts to these communities. As projects are finalized, designed, and permitted, more detailed consideration should be given to whether mitigating any impacts to these worm communities will be necessary.

Historical Resources

A remote sensing survey of an area measuring 2,000 ft by 5,000 ft and located approximately 1,000 ft southeast of the Mean Low Water Line indicated that no objects of historical significance are present (Koski-Karell, 1984). Background research of the Slaughter Beach area in general indicates that there are four sites that may be found to be historically significant in the future. These include the original site of the Mispillion Lighthouse, the present location of the Mispillion Lighthouse, Fort Saulsbury, and a shipwreck on the eastern shore of the Mispillion River.

Construction Cost Estimate

Construction costs are estimated for each of the three project scenarios in Table 7.14 and include mobilization and demobilization, sand placement, and dune plantings. Costs for design, permitting, geotechnical investigation, post-project performance, and physical/biological monitoring are presented in Table 7.15.

Table 7.14 Slaughter Beach Shore Protection Construction Cost Estimate

Slaughter Beach Construction Cost Estimate Details									
Strategic Placement Scenario									
	Length		**Unit Volume**		**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*					0.33	lump sum	$650,000	$214,500
Berm Taper	1,000	ft	8.5	cy/ft	8,500	cy	$7.00	$59,500
Berm	1,500	ft	17	cy/ft	25,500	cy	$7.00	$178,500
Dune	2,500	ft	1	cy/ft	2,500	cy	$7.00	$17,500
Plant Units					27,500	each	$1.09	$29,975
			Total Volume		**36,500**	**cy**		**$499,975**
5 Year Scenario								
	Length		**Unit Volume**		**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*					0.33	lump sum	$650,000	$214,500
Berm Taper	1,000	ft	8.5	cy/ft	8,500	cy	$7.00	$59,500
Berm	13,500	ft	17	cy/ft	229,500	cy	$7.00	$1,606,500
Dune	14,500	ft	1	cy/ft	14,500	cy	$7.00	$101,500
Plant Units					120,000	each	$1.09	$130,800
			Total Volume		**252,500**	**cy**		**$2,112,800**
10 Year Scenario								
	Length		**Unit Volume**		**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*					0.33	lump sum	$650,000	$214,500
Berm Taper	1,000	ft	16.5	cy/ft	16,500	cy	$7.00	$115,500
Berm	13,500	ft	33	cy/ft	445,500	cy	$7.00	$3,118,500
Dune	14,500	ft	1	cy/ft	14,500	cy	$7.00	$101,500
Plant Units					120,000	each	$1.09	$130,800
			Total Volume		**476,500**	**cy**		**$3,680,800**

* Mob/Demob costs are based on this project being performed as part of a regional beach nourishment project that includes the nearby communities of Primehook Beach and Broadkill Beach. Performing this work as a separate contract would increase the estimated mob/demob costs to $450,000.

Long Range Budget Plan

Table 7.15 Slaughter Beach Shore Protection Long Range Budget Plan

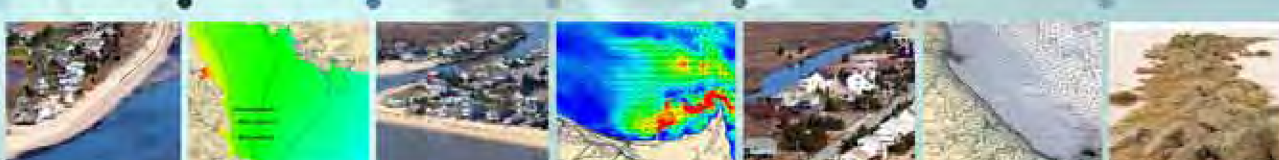
	Strategic Fill Placement	**Budget Estimate**										
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
	***Geotechnical Investigation**	$139,802										$139,802
	***Design/Permitting**	$69,901										$69,901
	Construction				$499,975				$367,800			$867,775
	Env. Permit Monitoring				$17,500	$17,500	$17,500		$17,500	$17,500	$17,500	$122,500
	Beach Survey	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$160,000
	Sub Total	$225,703	$16,000	$16,000	$533,475	$33,500	$33,500	$16,000	$401,300	$33,500	$33,500	**$1,342,478**
	5 Year Scenario	**Budget Estimate**										
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
	***Geotechnical Investigation**	$139,802										$139,802
Slaughter Beach	***Design/Permitting**	$69,901										$69,901
	Construction				$2,112,800					$1,275,000		$3,387,800
	Env. Permit Monitoring				$70,000	$70,000	$70,000			$70,000	$70,000	$350,000
	Beach Survey	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$160,000
	Sub Total	$225,703	$16,000	$16,000	$2,198,800	$86,000	$86,000	$16,000	$16,000	$1,361,000	$86,000	**$4,107,503**
	10 Year Scenario	**Budget Estimate**										
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
	***Geotechnical Investigation**	$139,802										$139,802
	***Design/Permitting**	$69,901										$69,901
	Construction				$3,680,800							$3,680,800
	Env. Permit Monitoring				$70,000	$70,000	$70,000					$210,000
	Beach Survey	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$160,000
	Sub Total	$225,703	$16,000	$16,000	$3,766,800	$86,000	$86,000	$16,000	$16,000	$16,000	$16,000	**$4,260,503**

***Notes: The costs for these items are proportional to total volume placed for all of the seven communities included in this management plan**
Renourishment costs are based on restoring 60% of initial volume placed to restore historic losses
Costs are based on work being performed on a regional basis
Costs shown are in July 2009 prices.

MANAGEMENT PLAN FOR

THE DELAWARE BAY BEACHES

FINAL REPORT • MARCH 2010



Primehook Beach

12023-BD-09

7.7 Primehook Beach

7.7.1 Background

Primehook Beach consists of approximately 4,000 ft of shoreline characterized by broad, low dunes with a shoreline azimuth of 55°N. The community is bordered to the west by 1-2 mi of marsh, and a broad subtidal flat extends almost 1 mi offshore. The beach here shows a cuspate form with oblique, but nearshore, perpendicular bars and shoals. The beach measure approximately 16,000 ft in length and is narrow in width. The community is situated along the straight shoreline with the northern shoreline being the narrowest with homes located the closest to the beach. The development density drops dramatically at the southern end of the community where single family homes are located on large parcels of land with a broad vegetated beach.

Maurmeyer (1978) calculated a net transport rate in the southerly direction of 9,400 yd^3/yr (Table 6.1). Local observations suggest that the northern 1/3 of the community has the greatest need for shore protection. Modeling of currents show a net southerly flow during average and operational conditions; results also highlight a 'hotspot' in the northern 1/3 of the community, consistent with the local observation that this is an area of greatest need. South of the hotspot, the currents decrease in magnitude until the center of the community, at which point the strength of the currents increases in a southerly direction towards Broadkill Beach. Wave model results indicate an annual potential transport direction southward due to the influence of the offshore waves and Cape Henlopen. These results were compared to the circulation model as well as past estimations and observations of longshore transport potential to assist in developing beach fill placement options. The results are consistent with the circulation model findings and local observations.

Figure 7.42 2007 Aerial of Primehook Beach (Delaware DataMIL)

Shore Protection History. Approximately 20,200 cy of material were placed in 1962. In April 2008, the thirteen northernmost lots were filled with 1,700 tons of sand. No other known projects have taken place at Primehook Beach.

Existing Structures. No structures are present at this location.

Figure 7.43 Extensive Sabellarid communities were visible at Primehook Beach (February 2009).

Figure 7.44 Aerial photograph of Primehook Beach (Wayne Lasch, April 17, 2009).

7.7.2 Management Plan Alternatives

No Action

Landward migration of the shoreline would likely continue if no action is taken at this community. As a result, infrastructure including, recreational beach, utilities, roadways, and private homes could be damaged or lost during high energy coastal storms. Continued erosion would also decrease the available acreage of nesting beach for use by horseshoe crabs; this would negatively impact both the horseshoe crab population and the populations of shorebirds that rely on the horseshoe crabs.

Strategic Fill Placement

This scenario consists of concentrating the placement of fill along the specific locations of greatest need in each community. This alternative is the minimum level of protection that would be recommended. Based on a review of previous studies, historic aerials, longshore transport estimates, and local knowledge gained from previous beach fill behavior, the recommended design components of this scenario include:

- As shown in Figure 7.45, a berm extending seaward 20 ft from the toe of the constructed dune at an elevation of +7.2 ft NAVD88 with a seaward slope of 1V:10H for a length of 2,800 linear ft including gradually tapering the project limits for 500 ft. The location of this fill is concentrated on the northern end of the community.
- A dune feature throughout the project area with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H.
- A total initial volume of 24,000 cubic yards of sand where this fill volume includes initial design fill requirements and advanced nourishment.
- Maintaining the beach with periodic nourishment through the placement of 14,400 cubic yards every 4 years. This volume is based on historic erosion losses and historic placement volumes.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a spacing of 18 in by 18 in and a minimum of 11 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the back of the top of the dune and continue the entire length of the project. The minimum number of planting units necessary is 31,500.

5 Year Scenario

This scenario is based on restoring 5 years of estimated shoreline losses and providing protection from a storm event with a 5-year return period.

There are two components considered in determining the required level of protection for this scenario; the first is the width of beach necessary to protect upland infrastructure from a 5 yr return period storm, and the second is the width of beach needed to account for 5 years of historical losses. The recommended design components include:

- As shown in Figure 7.46, a berm extending seaward 20 ft from the toe of the constructed dune at an elevation of +7.2 ft NAVD88 with a seaward slope of 1V:10H along the entire community for a length of 7,500 linear ft including gradually tapering the project limits for 500 ft.
- A dune feature throughout the project area with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H.
- A total initial volume of 71,000 cubic yards of sand where this fill volume includes initial design fill requirements and advanced nourishment.
- Maintaining the beach with periodic nourishment through the placement of 36,600 cubic yards every 5 years. This volume is based on historic erosion losses and historic placement volumes.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a spacing of 18 in by 18 in and a minimum of 11 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the back of the top of the dune and continue the entire length of the project. The minimum number of planting units necessary is 70,000.

10 Year Scenario

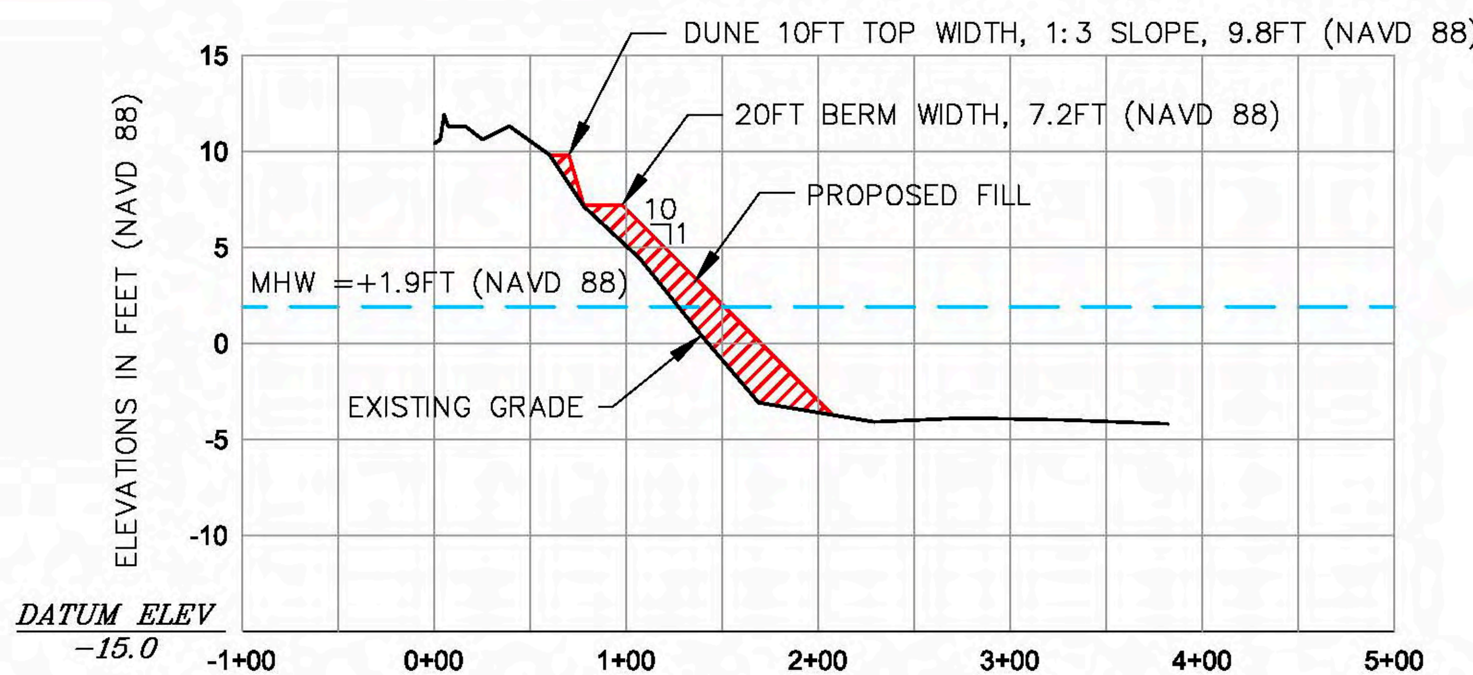
This scenario is based on restoring 10 years of estimated shoreline losses and providing protection from a storm event with a 10-year return period.

As is discussed in detail in Section 6.4, there are two components considered in determining the required level of protection for this scenario; the first is the width of beach necessary to protect upland infrastructure from a 10 yr return period storm, and the second is the width of beach needed to account for 10 years of historical losses. The recommended design components include:

- As shown in Figure 7.47, a berm extending seaward 55 ft from the toe of the constructed dune at an elevation of +7.2 ft NAVD88 with a seaward slope of 1V:10H along the entire community for a length of 7,500 linear ft including gradually tapering the project limits for 500 ft.
- A dune feature throughout the project area with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H.
- A total initial volume of 176,000 cubic yards of sand where this fill volume includes

initial design fill requirements and advanced nourishment.

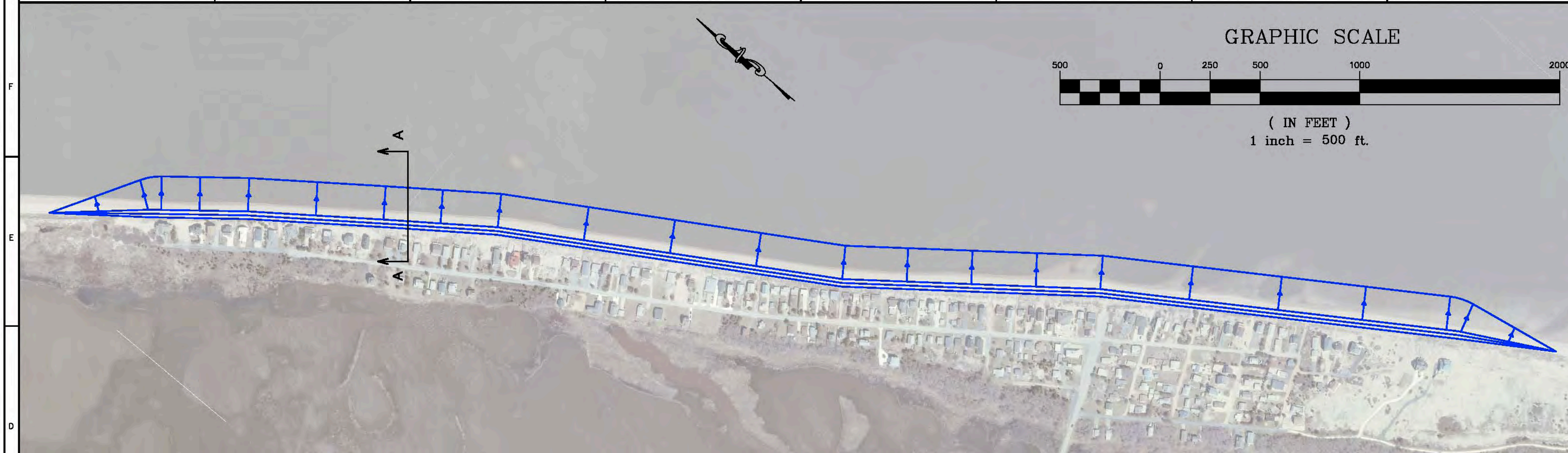
- Maintaining the beach with periodic nourishment through the placement of 105,600 cubic yards every 10 years. This volume is based on historic erosion losses and historic placement volumes.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a spacing of 18 in by 18 in and a minimum of 11 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the back of the top of the dune and continue the entire length of the project. The minimum number of planting units necessary is 70,000.

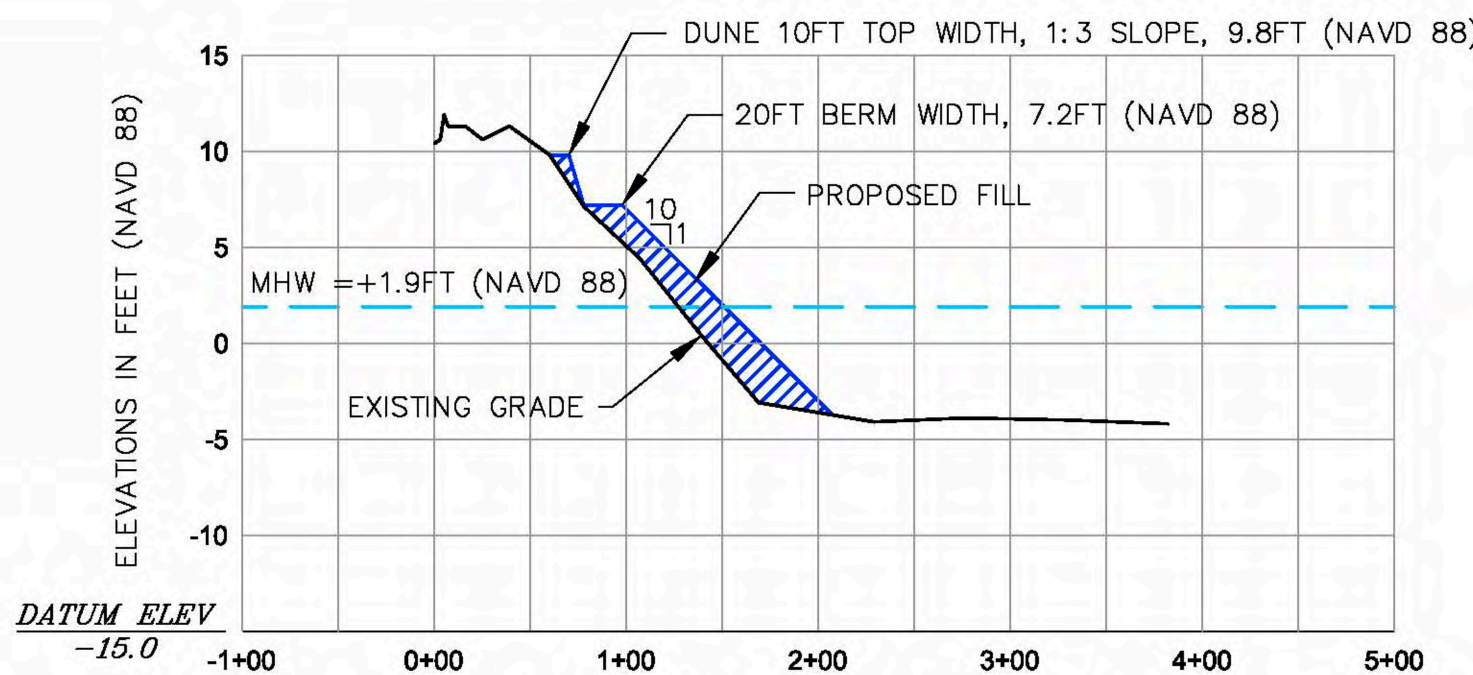


TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: **PRIMEHOOK BEACH**	TASK: **STRATEGIC FILL PLACEMENT**	**FIGURE 7.45**



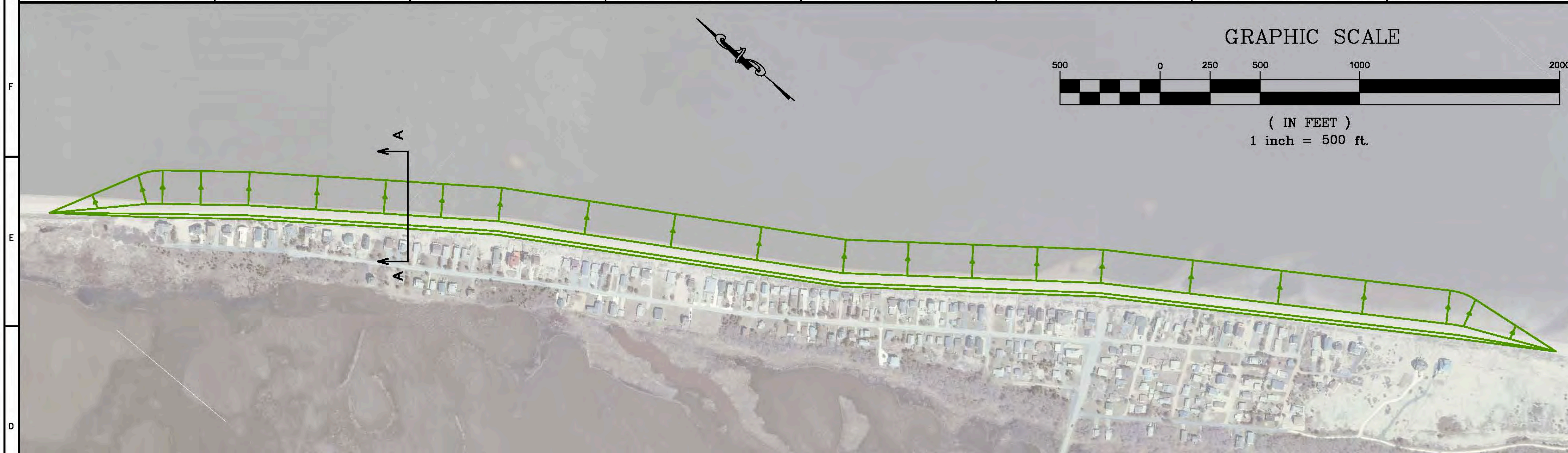


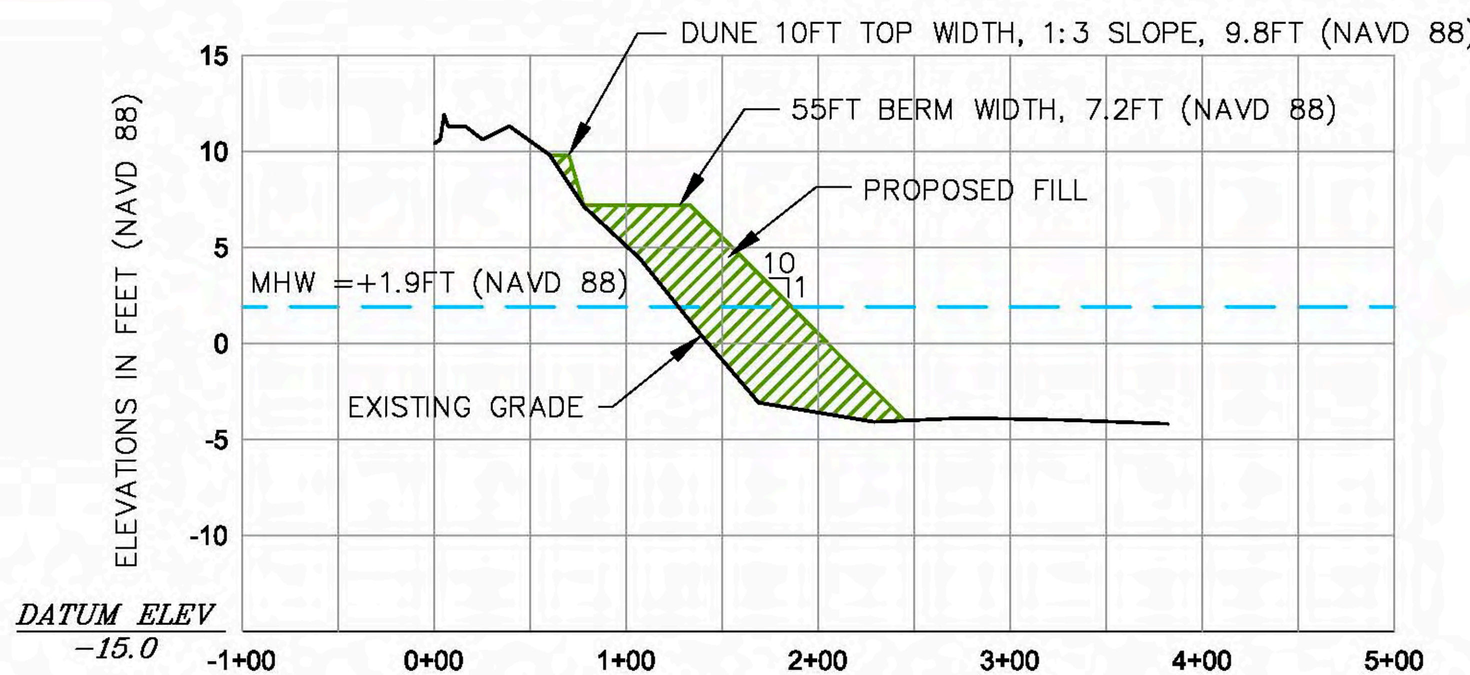
TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: PRIMEHOOK BEACH	TASK: 5 YEAR SCENARIO

FIGURE 7.46





TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: PRIMEHOOK BEACH	TASK: 10 YEAR SCENARIO	FIGURE 7.47

Potential sediment sources

No published sand searches have been performed offshore of Primehook Beach. A sand search study should be undertaken to identify compatible sources of sand that are located within 2 mi of the Primehook Beach shoreline. Due to the proximity to Primehook Beach, sand sources offshore of Broadkill Beach, located just over 2 mi from Primehook Beach, should be investigated for compatibility and use on Primehook Beach.

Sand derived from upland sources such as local sand and gravel operations are also available for purchase and placement on this beach. However, sand from these sources will continue to be relatively expensive and best suited to use for relatively small emergency projects.

Natural Resources

In addition to providing habitat to the species discussed in Section 7.1.3, the nearshore zone at Broadkill Beach also serves as habitat for Sabellarid worm communities. The Sabellarid worm communities build substantial “reef” structures at Broadkill. Because these communities are relatively common and at least partially ephemeral, the preliminary designs provided in this document do not avoid or minimize potential impacts to these communities. As projects are finalized, designed, and permitted, more detailed consideration should be given to whether mitigating any impacts to these worm communities will be necessary.

Construction Cost Estimate

Construction costs are estimated for each of the three project scenarios in Table 7.16 and include mobilization and demobilization, sand placement, and dune plantings. Costs for design, permitting, geotechnical investigation, post-project performance, and physical/biological monitoring are presented in Table 7.17.

Table 7.16 Primehook Beach Shore Protection Construction Cost Estimate

Primehook Beach Construction Cost Estimate Details						
Strategic Placement Scenario						
	Length	**Unit Volume**	**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*			0.33	lump sum	$650,000	$214,500
Berm Taper	1,000 ft	4 cy/ft	4,000	cy	$7.00	$28,000
Berm	1,800 ft	8 cy/ft	14,400	cy	$7.00	$100,800
Dune	2,800 ft	2 cy/ft	5,600	cy	$7.00	$39,200
Plant Units			31,500	each	$1.09	$34,335
		Total Volume	**24,000**	**cy**		**$416,835**
5 Year Scenario						
	Length	**Unit Volume**	**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*			0.33	lump sum	$650,000	$214,500
Berm Taper	1,000 ft	4 cy/ft	4,000	cy	$7.00	$28,000
Berm	6,500 ft	8 cy/ft	52,000	cy	$7.00	$364,000
Dune	7,500 ft	2 cy/ft	15,000	cy	$7.00	$105,000
Plant Units			70,000	each	$1.09	$76,300
		Total Volume	**71,000**	**cy**		**$787,800**
10 Year Scenario						
	Length	**Unit Volume**	**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*			0.33	lump sum	$650,000	$214,500
Berm Taper	1,000 ft	11.5 cy/ft	11,500	cy	$7.00	$80,500
Berm	6,500 ft	23 cy/ft	149,500	cy	$7.00	$1,046,500
Dune	7,500 ft	2 cy/ft	15,000	cy	$7.00	$105,000
Plant Units			70,000	each	$1.09	$76,300
		Total Volume	**176,000**	**cy**		**$1,522,800**

* Mob/Demob costs are based on this project being performed as part of a regional beach nourishment project that includes the nearby communities of Slaughter Beach and Broadkill Beach. Performing this work as a separate contract would increase the estimated mob/demob costs to $450,000.

Long Range Budget Plan

Table 7.17 Primehook Beach Shore Protection Long Range Budget Plan

	Strategic Fill Placement	Budget Estimate										
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
	*Geotechnical Investigation	$45,193										$45,193
	*Design/Permitting	$22,596										$22,596
	Construction				$416,835				$315,300			$732,135
	Env. Permit Monitoring				$17,500	$17,500	$17,500		$17,500	$17,500	$17,500	$105,000
	Beach Survey	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$80,000
	Sub Total	$75,789	$8,000	$8,000	$442,335	$25,500	$25,500	$8,000	$340,800	$25,500	$25,500	**$984,924**
	5 Year Scenario	**Budget Estimate**										
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
	*Geotechnical Investigation	$45,193										$45,193
Primehook Beach	*Design/Permitting	$22,596										$22,596
	Construction				$787,800					$512,700		$1,300,500
	Env. Permit Monitoring				$35,000	$35,000	$35,000			$35,000	$35,000	$175,000
	Beach Survey	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$80,000
	Sub Total	$75,789	$8,000	$8,000	$830,800	$43,000	$43,000	$8,000	$8,000	$555,700	$43,000	**$1,623,289**
	10 Year Scenario	**Budget Estimate**										
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
	*Geotechnical Investigation	$45,193										$45,193
	*Design/Permitting	$22,596										$22,596
	Construction				$1,522,800							$1,522,800
	Env. Permit Monitoring				$35,000	$35,000	$35,000					$105,000
	Beach Surveys	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$80,000
	Sub Total	$75,789	$8,000	$8,000	$1,565,800	$43,000	$43,000	$8,000	$8,000	$8,000	$8,000	**$1,775,589**

***Notes: The costs for these items are proportional to total volume placed for all of the seven communities included in this management plan**

Renourishment costs are based on restoring 60% of initial volume placed to restore historic losses

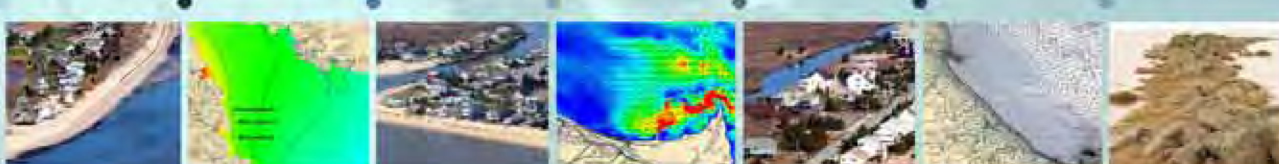
Costs are based on work being performed on a regional basis

Costs shown are in July 2009 prices.

MANAGEMENT PLAN FOR

THE DELAWARE BAY BEACHES

FINAL REPORT • MARCH 2010



Broadkill Beach

12023-B0-09

7.8 Broadkill Beach

7.8.1 Background

Broadkill Beach is located approximately 3 mi northwest of Lewes and 7 mi northwest of the mouth of Delaware Bay with shoreline azimuths of 47°N at the northern portion of the community and 50°N at the southern portion. It extends along 6,000 ft of shoreline and occupies a strip of land measuring 300 ft to 1,000 ft in width situated between expansive marsh and the Delaware Bay. The Broadkill River flows through the marsh to the beach barrier at the southern end of the community. The beach primarily consists of fine to medium sands. The USACE (1996) conducted testing of the native beach sands and found the mean grain size to be 0.374 mm.

Maurmeyer (1978) calculated a net sediment transport direction to the south at a rate of 10,700 yd^3/yr and 10,500 yd^3/yr in the northern and southern reaches, respectively (Table 6.1). The USACE (1991) calculated the average annual erosion rate at Broadkill at 3.0 ft/yr (Table 6.2), although French (1991) found that the northern portion of the community was accreting sand at an annual rate of 6.6 ft/yr and the southern portion was eroding at a rate of 4.6 ft/yr (Table 6.3). Observation of past beach fill behavior suggests that the dominant transport direction is northward in the north half of the community and southward in the southern half, with a nodal point at Route 16 (Broadkill Road). Circulation modeling suggests that net flows during storms have a slight northerly component, but generally the currents are southerly during operational and average conditions.

Annual wave model results suggest a southerly transport direction. In addition, wave modeling results show that the north side of town has increased wave heights compared to the south side when offshore waves are present suggesting wave focusing along this portion of shoreline. The presence of Cape Henlopen and the breakwaters has an effect on Broadkill Beach by influencing incoming waves and providing sheltering. These results were utilized to assist in developing beach fill placement options.

Figure 7.48 2007 Aerial of Broadkill Beach (Delaware DataMIL)

Shore Protection History. Broadkill Beach has been receiving sediment since 1957. A total of 1,150,600 cy of material has been placed to date. Table 7.18 provides more detail regarding the shore protection history for Broadkill Beach.

Table 7.18 Broadkill Beach Shore Protection History.

Year	Volume (cy)	Length (ft)	Location	Method	Sediment Source	Structure
1908	Structure	1263				Timber and stone jetty
1950	Structure	196				Timber groin
1950	Structure	196				Timber groin
1950	Structure	199				Timber groin
1954	Structure	195				Timber and stone groin
1954	Structure	186				Timber groin
1957	76,800	1500	N7+50 to S7+50	N/A	N/A	
1961	120,000	1900	N19+00 to N12+00 and N2+00 to S14+00	Hydraulic dredge	N/A	
1962	180,000	N/A	N/A	143,000 by hydraulic dredge	N/A	
1964	Structure					Rubble mound groin
1964	Structure					Rubble mound groin
1964	Structure					Rubble mound revetment
1973	118,000	4500	N27+00 to S18+00	Hydraulic dredge	N/A	
1975	295,000	6100	S18+00 to S79+00	Hydraulic dredge	N/A	
1976	60,000	2200	N25+00 to N4+00	Hydraulic dredge	N/A	
1981	127,700	2900	N28+00 to S1+00	Hydraulic dredge	N/A	
1987	52,600	2700	N17+00 to N3+00 and S8+00 to S21+00	Hydraulic dredge	N/A	
1988	28,500	1400	N24+00 to N16+00 and S25+00 to S31+00	N/A	N/A	
1993	67,000	N/A	S25+00 to S34+00	Hydraulic dredge	N/A	
1996	25,000	N/A	N/A	Hydraulic dredge	N/A	
2005	152,000	5700	N/A	Cutter Head Dredge	N/A	

N/A = Information not available. The information for this table was gathered from DNREC records and state and federal permitting documents.

Figure 7.49 Aerial photograph of Broadkill Beach (Wayne Lasch, April 17, 2009).

Figure 7.50 Groin covered in Sabellarid colonies at Broadkill Beach.

Existing Structures. In the 1950s, a series of five groins were built at Washington, Adams, North Carolina, Georgia, and Alabama Avenues. In 1964 a concrete rubble revetment was constructed from North Carolina Avenue to approximately 700 ft just north of Alabama Avenue. The groins do not appear to have a significant effect on the shoreline. Since construction these groins have created a slight offset in beach width, but their influence on the shoreline is limited. The poor performance of the structures is likely due to their short length, poor condition (high permeability) and the limited volume of sand in the littoral zone. The timber and rubble groins have deteriorated since installation.

> **Recommendation**: With the addition of sand onto the beach through a nourishment program, the capacity of the groins may be reached, however due to their poor condition this is unlikely. The crest elevation would need to be raised and sand tightening on the structures completed to ensure improved performance. Since the structures are not adversely affecting the shoreline, neither removal nor structure modifications are recommended as a shore protection strategy. Monitoring is recommended of the groins in order to continue to evaluate performance and the interaction with any proposed sand placement.

Figure 7.51 Aerial photograph of homes on beach at Broadkill Beach (Wayne Lasch, April 17, 2009).

Figure 7.52 Photograph of A-frame house from beach (February 2009).

Figure 7.53 Groin at Broadkill Beach (Wayne Lasch, April 17, 2009).

7.8.2 Management Plan Alternatives

No Action

Landward migration of the shoreline would likely continue if no action is taken at this community. As a result, infrastructure including, recreational beach, utilities, roadways, and private homes could be damaged or lost during high energy coastal storms. Continued erosion would also decrease the available acreage of nesting beach for use by horseshoe crabs; this would negatively impact both the horseshoe crab population and the populations of shorebirds that rely on the horseshoe crabs.

Strategic Fill Placement

This scenario consists of concentrating the placement of fill along the specific locations of greatest need in each community. This alternative is largely based on the previous shore protection activities conducted by DNREC (Table 7.18) and is the minimum level of protection that would be recommended. Based on a review of previous studies, historic aerials, longshore transport estimates, and local knowledge gained from previous beach fill behavior, the recommended design components of this scenario include:

- As shown in Figure 7.54, a berm extending seaward 30 ft from the toe of the constructed dune at an elevation of +7.2 ft NAVD88 with a seaward slope of 1V:10H for a length of 6,700 linear ft including tapering the project limits for 500 ft. This fill is concentrated on the center shoreline of the community.
- A dune feature throughout the project area with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H.
- A total initial volume of 99,700 cubic yards of sand where this fill volume includes initial design fill requirements and advanced nourishment.
- Maintaining the beach with periodic nourishment through the placement of 60,000 cubic yards every 4 years. This volume is based on historic erosion losses and historic placement volumes.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a spacing of 18 in by 18 in and a minimum of 12 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the back of the top of the dune and continue the entire length of the project. The minimum number of planting units necessary is 65,000.

5 Year Scenario

This scenario is based on restoring 5 years of estimated shoreline losses and providing protection from a storm event with a 5-year return period.

There are two components considered in determining the required level of protection for this scenario; the first is the width of beach necessary to protect upland infrastructure from a 5 yr return period storm, and the second is the width of beach needed to account for 5 years of historical losses. The recommended design components include:

- As shown in Figure 7.55, a berm extending seaward 30 ft from the toe of the constructed dune at an elevation of +7.2 ft NAVD88 with a seaward slope of 1V:10H along the entire community for a length of 16,000 linear ft including gradually tapering the project limits for 500 ft.
- A dune feature throughout the project area with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H.
- A total initial volume of 264,500 cubic yards of sand where this fill volume includes initial design fill requirements and advanced nourishment.
- Maintaining the beach with periodic nourishment through the placement of 162,000 cubic yards every 5 years. This volume is based on historic erosion losses and historic placement volumes.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a spacing of 18 in by 18 in and a minimum of 12 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the back of the top of the dune and continue the entire length of the project. The minimum number of planting units necessary is 150,000.

10 Year Scenario

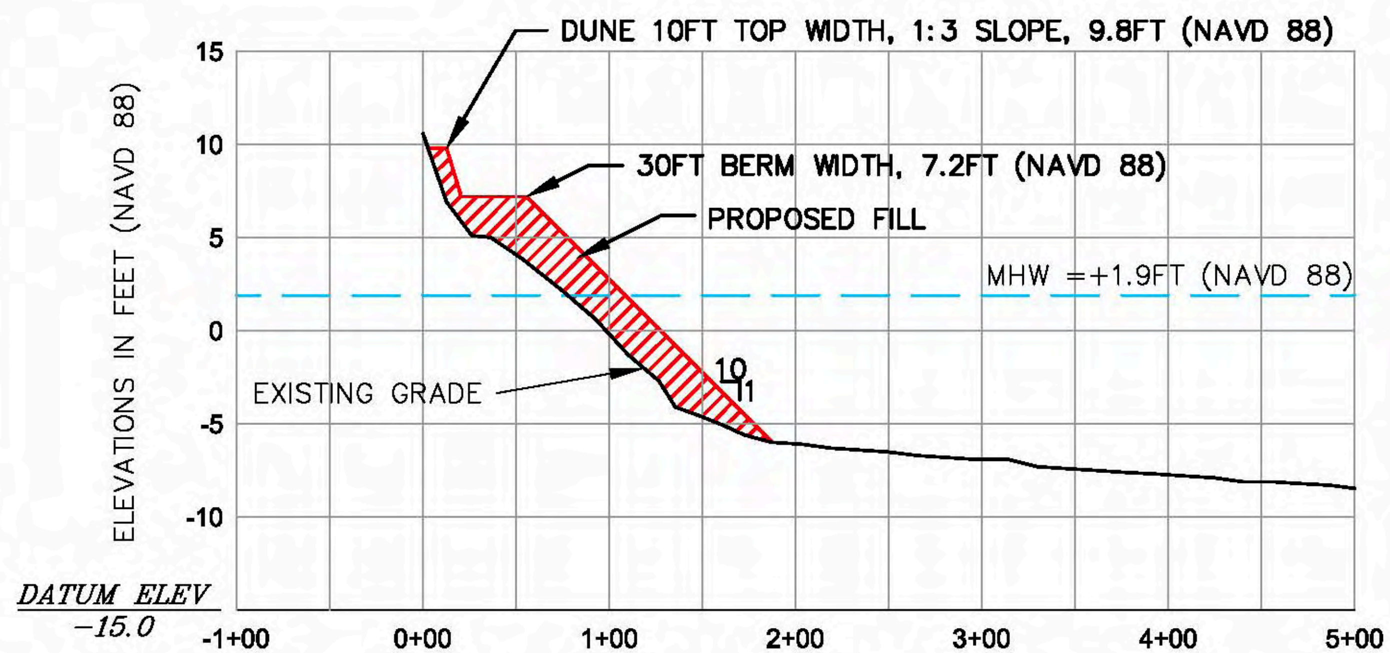
This scenario is based on restoring 10 years of estimated shoreline losses and providing protection from a storm event with a 10-year return period.

As is discussed in detail in Section 6.4, there are two components considered in determining the required level of protection for this scenario; the first is the width of beach necessary to protect upland infrastructure from a 10 yr return period storm, and the second is the width of beach needed to account for 10 years of historical losses. The recommended design components include:

- As shown in Figure 7.56, a berm extending seaward 70 ft from the toe of the constructed dune at an elevation of +7.2 ft NAVD88 with a seaward slope of 1V:10H along the entire community for a length of 16,000 linear ft including gradually tapering the project limits for 500 ft.
- A dune feature throughout the project area with a crest elevation of +9.8 NAVD88, a top width of 10 ft and side slopes of 1V:3H.
- A total initial volume of 528,000 cubic yards of sand where this fill volume includes

initial design fill requirements and advanced nourishment.

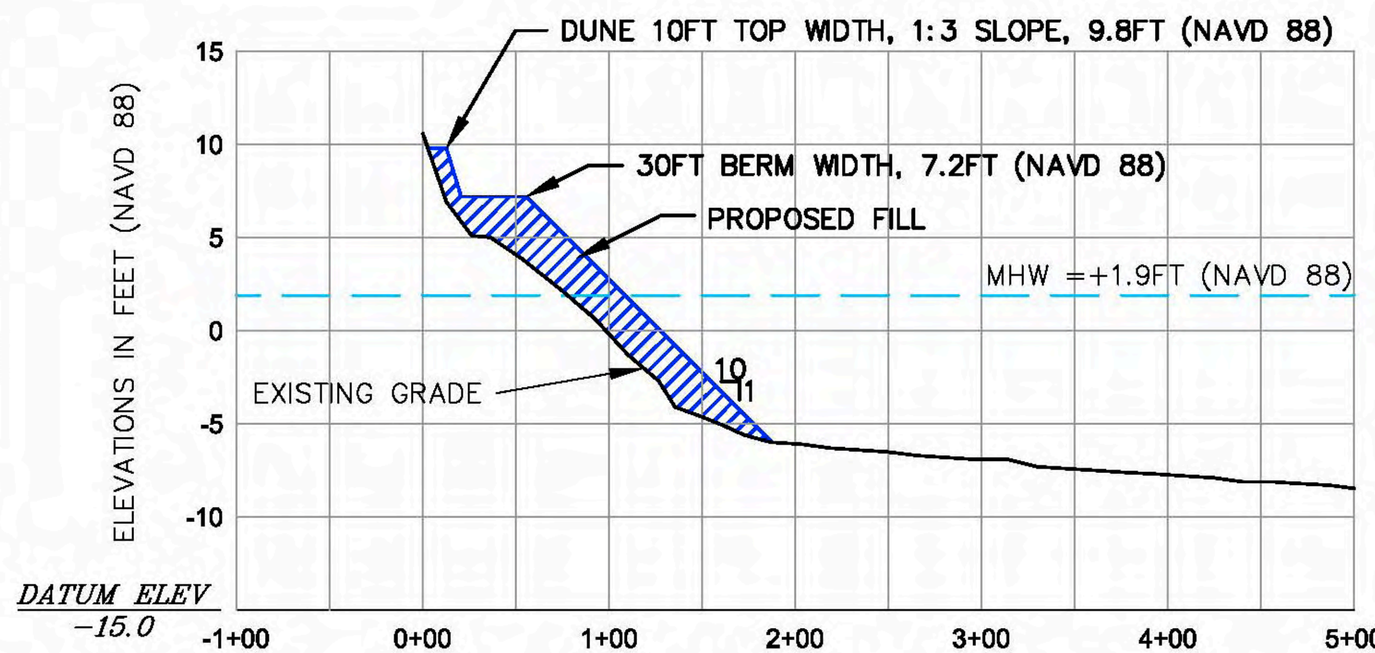
- Maintaining the beach with periodic nourishment through the placement of 324,000 cubic yards every 10 years. This volume is based on historic erosion losses and historic placement volumes.
- Planting Cape American Beach Grass (*Ammophila breveligulata*) on the dune at a spacing of 18 in by 18 in and a minimum of 12 rows with two plants (one planting unit) per hole. The planting area would cover a 15 foot wide strip of beach starting from the back of the top of the dune and continue the entire length of the project. The minimum number of planting units necessary is 150,000.



TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

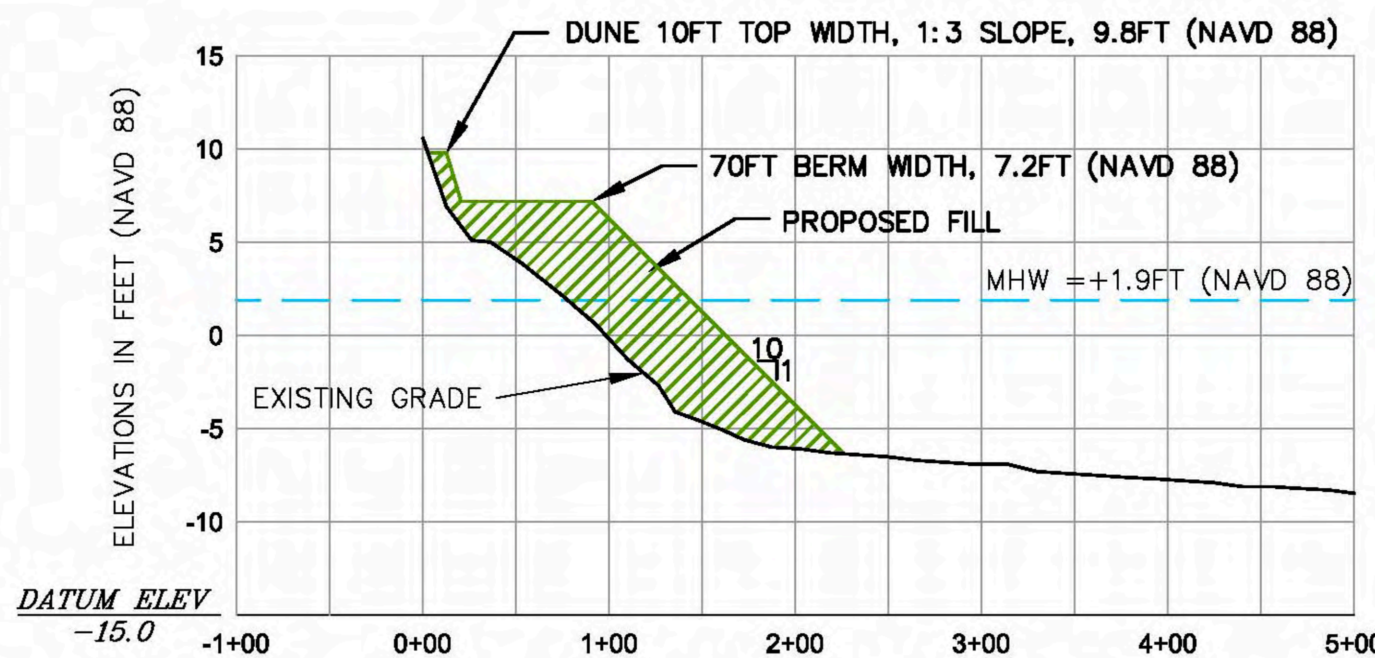
PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: BROADKILL BEACH	TASK: STRATEGIC FILL PLACEMENT	FIGURE 7.54



TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: **DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL**	PROJECT: **BROADKILL BEACH**	TASK: **5 YEAR SCENARIO**	**FIGURE 7.55**



TYPICAL CROSS SECTION A-A

VERTICAL SCALE: 1" = 10'
HORIZONTAL SCALE: 1" = 100'

PBSJ	CLIENT: DELAWARE DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENTAL CONTROL	PROJECT: BROADKILL BEACH	TASK: 10 YEAR SCENARIO	FIGURE 7.56

Potential sediment sources

Wethe et al (1982) investigated sand sources within 3,500 ft of the Broadkill Beach shoreline located in water depths less than 14 ft deep. Suitable sand sources were identified, but are located under an overburden of mud and medium sands. Below an overburden and to a depth of -20.8 ft NAVD88, the area contains 2.4 million cy of sand. In order to dredge the sand, 1.4 million cy of overburden would need to be removed. The thickness of overburden is generally 2.5 to 5 ft. In some locations the overburden thickness reaches 10 ft. Figure 7.57 depicts the locations of the sand sources with an overburden of less than 5 ft. Sand was extracted from this identified source for use in the 1961, 1973, 1975, 1976, and 1981 beach nourishment projects. This area may have been used for other projects, but records containing the sand source locations for projects are limited.

For future projects, this sand source should be investigated to determine the volume of remaining sand that could be extracted. Future projects will require a minimum water depth of at least 4 ft to accommodate typical commercial dredging equipment. Future sand search investigations should extend the limits of this study to find additional sand sources within 2 mi of the Broadkill Beach shoreline.

A shoal located offshore of the northern end of the community contains 300,000 cy of sands coarser than the native beach and is not covered by an overburden (USACE 1991). Wethe, et al. (1982) states that removal of sediments from these shoals may increase erosion rates along the northern shoreline of Broadkill Beach. Further investigation on the impact of removing sediments from this location should be undertaken.

The Corps conducted sand search studies as a part of the feasibility study for Broadkill Beach and identified two areas with sufficient sand quality and volume for the Federal project. Both areas are located in water depths of 9 to 13 ft. The northern site is approximately 312 acres and lays 1.5 to 2.5 mi offshore. The southern site is approximately 349 acres and lays 0.5 to 2.5 mi offshore. Figure 7.58 depicts the location of these areas.

Sand derived from upland sources such as local sand and gravel operations are also available for purchase and placement on this beach. However, sand from these sources will continue to be relatively expensive and best suited to use for relatively small emergency projects.

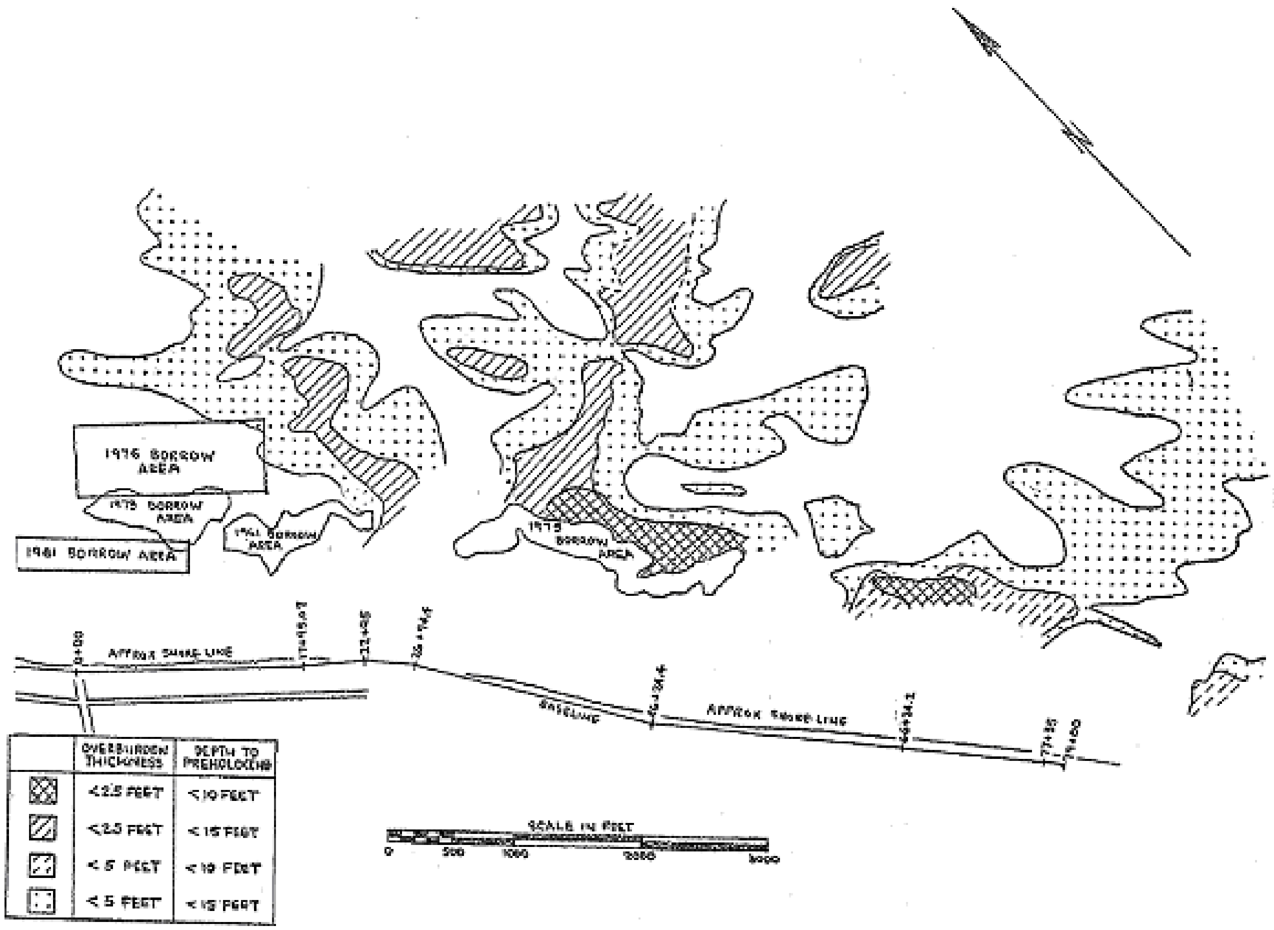


Figure 7.57 Broadkill Beach sand source locations identified by Wethe et al (Wethe et al, 1982).

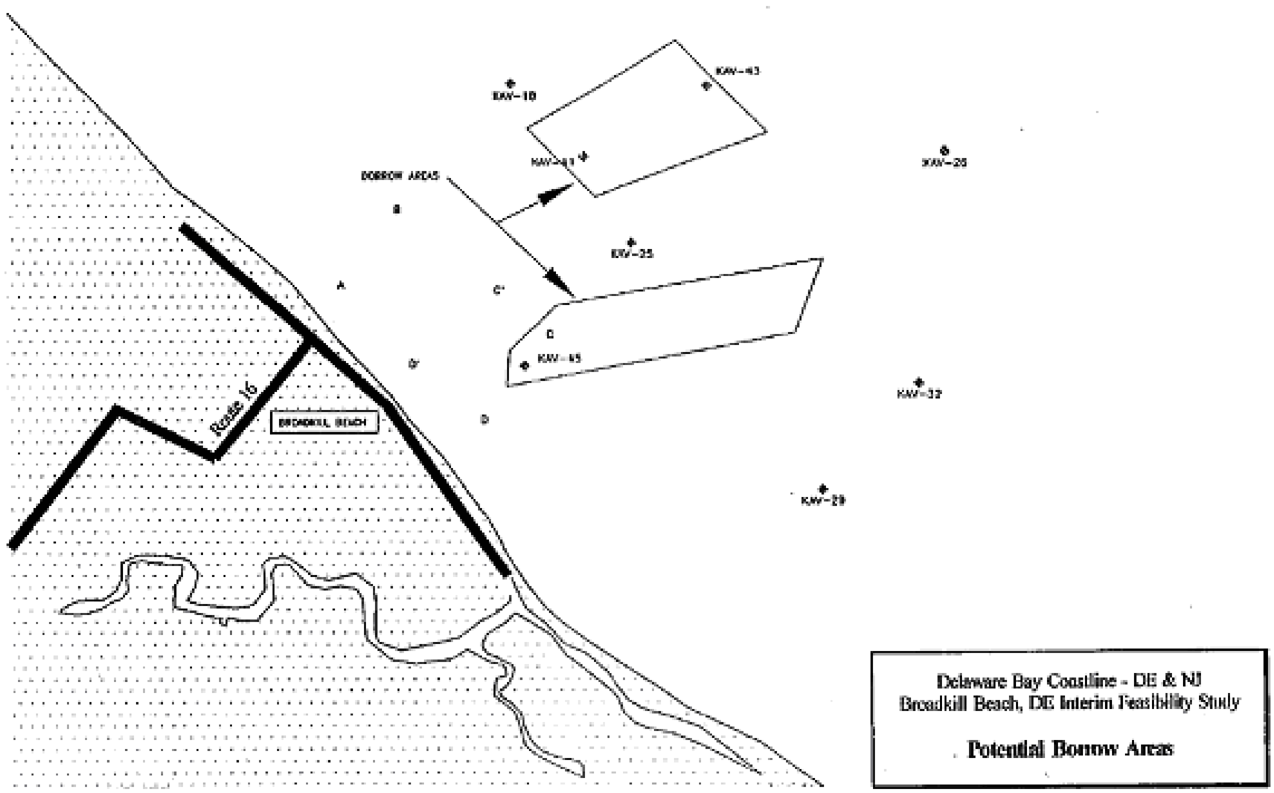


Figure 7.58 Broadkill Beach sand source locations identified by the USACE (USACE, 1996).

Natural Resources

In addition to providing habitat for the species discussed in Section 7.1.3, the nearshore zone at Broadkill Beach also serves as habitat for Sabellarid worm communities. Because these communities are relatively common and at least partially ephemeral, the preliminary designs provided in this document do not avoid or minimize potential impacts to these communities. As projects are finalized, designed, and permitted, more detailed consideration should be given to whether mitigating any impacts to these worm communities will be necessary.

Historical Resources

A remote sensing survey of an area measuring 1,500 ft by 8,000 ft and located approximately 1,000 ft east of the mean low water line indicated that three of four anomalies may represent historical resources (Watts, 1985). The first anomaly was located in the northeast corner (75° 11’ 57’’W, 38° 49’ 39’’N) and covered an area of approximately 1,900 square ft in a water depth of 6 ft. The second, located in the northwest corner (75° 12’ 26’’W, 38° 49’ 42’’N), covered an area of 57,500 square ft in a depth of 5.5 ft. The third anomaly was also located in the northwest corner (75° 12’ 30’’W, 38° 49’ 51’’N) in a depth of 6 ft and covering an area of approximately 48,000 square ft. These three anomalies have the potential to be historical resources. The final anomaly, which is likely not of historical significance, is located in the southern portion (75° 12’ 15’’W, 38° 49’ 41’’N) in a water depth of 4.5 ft.

Construction Cost Estimate

Construction costs are estimated for each of the three project scenarios in Table 7.19 and include mobilization and demobilization, sand placement, and dune plantings. Costs for design, permitting, geotechnical investigation, post-project performance, and physical/biological monitoring are presented in Table 7.20.

Table 7.19 Broadkill Beach Shore Protection Construction Cost Estimate

Broadkill Beach Construction Cost Estimate Details									
Strategic Placement Scenario									
	Length		**Unit Volume**		**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*					0.33	lump sum	$650,000	$214,500
Berm Taper	1,000	ft	7.5	cy/ft	7,500	cy	$7.00	$52,500
Berm	5,700	ft	15	cy/ft	85,500	cy	$7.00	$598,500
Dune	6,700	ft	1	cy/ft	6,700	cy	$7.00	$46,900
Plant Units					65,000	each	$1.09	$70,850
			Total Volume		**99,700**	**cy**		**$983,250**
5 Year Scenario								
	Length		**Unit Volume**		**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*					0.33	lump sum	$650,000	$214,500
Berm Taper	1,000	ft	7.5	cy/ft	7,500	cy	$7.00	$52,500
Berm	15,000	ft	15	cy/ft	225,000	cy	$7.00	$1,575,000
Dune	16,000	ft	2	cy/ft	32,000	cy	$7.00	$224,000
Plant Units					150,000	each	$1.09	$163,500
			Total Volume		**264,500**	**cy**		**$2,229,500**
10 Year Scenario								
	Length		**Unit Volume**		**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Mob/Demob*					0.33	lump sum	$650,000	$214,500
Berm Taper	1,000	ft	16	cy/ft	16,000	cy	$7.00	$112,000
Berm	15,000	ft	32	cy/ft	480,000	cy	$7.00	$3,360,000
Dune	16,000	ft	2	cy/ft	32,000	cy	$7.00	$224,000
Plant Units					150,000	each	$1.09	$163,500
			Total Volume		**528,000**	**cy**		**$4,074,000**

***** Mob/Demob costs are based on this project being performed as part of a regional beach nourishment project that includes the nearby communities of Slaughter Beach and Primehook Beach. Performing this work as a separate contract would increase the estimated mob/demob costs to $450,000.

Long Range Budget Plan

Table 7.20 Broadkill Beach Shore Protection Long Range Budget Plan

	Strategic Fill Placement	**Budget Estimate**										
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
	***Geotechnical Investigation**	$153,586										$153,586
	***Design/Permitting**	$76,793										$76,793
	Construction				$983,250				$633,240			$1,616,490
	Env. Permit Monitoring				$35,000	$35,000	$35,000		$35,000	$35,000	$35,000	$210,000
	Beach Survey	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$160,000
	Sub Total	$246,379	$16,000	$16,000	$1,034,250	$51,000	$51,000	$16,000	$684,240	$51,000	$51,000	**$2,216,869**
	5 Year Scenario	**Budget Estimate**										
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
	***Geotechnical Investigation**	$153,586										$153,586
Broadkill Beach	***Design/Permitting**	$76,793										$76,793
	Construction				$2,229,500					$1,325,400		$3,554,900
	Env. Permit Monitoring				$70,000	$70,000	$70,000			$70,000	$70,000	$350,000
	Beach Survey	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$160,000
	Sub Total	$246,379	$16,000	$16,000	$2,315,500	$86,000	$86,000	$16,000	$16,000	$1,411,400	$86,000	**$4,295,279**
	10 Year Scenario	**Budget Estimate**										
	Project Element	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
	***Geotechnical Investigation**	$153,586										$153,586
	***Design/Permitting**	$76,793										$76,793
	Construction				$4,074,000							$4,074,000
	Env. Permit Monitoring				$70,000	$70,000	$70,000					$210,000
	Beach Survey	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$160,000
	Sub Total	$246,379	$16,000	$16,000	$4,160,000	$86,000	$86,000	$16,000	$16,000	$16,000	$16,000	**$4,674,379**

***Notes: The costs for these items are proportional to total volume placed for all of the seven communities included in this management plan**

Renourishment costs are based on restoring 60% of initial volume placed to restore historic losses

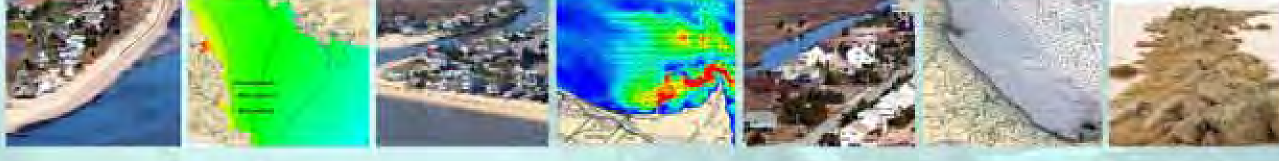
Costs are based on work being performed on a regional basis

Costs shown are in July 2009 prices.

MANAGEMENT PLAN FOR

THE DELAWARE BAY BEACHES

FINAL REPORT • MARCH 2010



Regional Management and Long Range Budget Plan

12023-BD-09

8. Regional Management Approaches and Overall Long Range Budget Plan

This section provides tables that summarize the management alternatives presented in Section 7 for each of the seven communities. These tables include a long range budget plan with estimated costs for each alternative over the next ten years.

As was discussed in Sections 6 and 7, three alternatives were selected to provide a reasonable range of costs and benefits for each community. The three scenarios are as follows:

1. Provide targeted beach nourishment at specific locations within each community.
2. Restore 5 years of estimated shoreline losses and provide protection from a storm event with a 5-year return period.
3. Restore 10 years of estimated shoreline losses and provide protection from a storm event with a 10-year return period.

8.1 Regional Management Approaches

Each of the three alternatives examined for the seven communities includes several activities that must be performed on a regional basis before any sand placement work can begin. These include:

1. Geotechnical investigations. As has been discussed in the preceding sections, very limited data are available on the exact locations and extents of sand sources that could be used for nourishment projects. In order to prepare permit applications, design documents, and bid documents, a more detailed geotechnical study will be required to locate and characterize the sources of sand that will be used for each community. This work should be performed as one study that will cover the needs of all seven communities. The cost of performing this work has been included in the attached tables and has been prorated over each community based on the relative amount of sand that community needs.
2. Design and permitting. Once the detailed geotechnical study is completed and specific sources of sand have been identified, final design and permitting work can proceed. The design of each project will depend on the nature of the sand source. As with the cost of the geotechnical study, the cost of performing this work has been included in the attached tables and has been prorated over each community based on the relative amount of sand that community needs.

Each alternative also includes the following post construction activities. These activities should also be performed on a regional basis:

1. Environmental permit monitoring. Once initial construction has been completed, it is likely that the permit terms for each project will require some type of follow up monitoring of project impacts and/or various performance measures. An allowance for these costs has been included for the three years following the initial completion of each

project.

2. Beach surveys. To assist with design and permitting leading up to initial construction and to properly assess the performance of each project, annual beach surveys should be performed in each community. An allowance for these costs has been included for each project.
3. Periodic maintenance or follow up nourishments. Each project will require maintenance. Projected maintenance costs for each option have been included based on the assumption that 60% of the volume of sand initially placed will need to be restored at the end of the "design life" of the alternative. The frequency and level of maintenance will depend on how often storms impact the area, how severe the storms are, and the relative size of the initial beach nourishment project (e.g., the 10 year scenario should require less maintenance than the 5 year and strategic beach fill placement scenarios under the same storm conditions).

One of the largest costs associated with beach nourishment projects is the cost of mobilizing and demobilizing a dredge to pump sand from an offshore source onto the beach. These costs typically range from $500,000 per project for a relatively small dredge (e.g., 14 in hydraulic dredge with a draft of 4 ft) to over $1 million for larger dredges suitable for work in deeper water.

Combining as many projects as practical is an effective means for minimizing these costs. For the purposes of this plan, it was assumed that work would be grouped into two regions and performed under two contracts. If work is to be performed as individual contracts, costs would need to be increased to reflect the need for mobilizing and demobilizing for each project.

8.2 Regional Sediment Management

Developing and maintaining an accurate inventory of suitable regional sand sources will greatly benefit all of the management options for these communities. This regional inventory should include both offshore and upland sand sources. Offshore sand sources will usually be more cost effective for relatively large projects, especially when there is sufficient lead time for permitting and construction activities. Upland sand sources will usually be better suited for smaller projects, especially when dealing with emergency situations.

Offshore Sand Sources. As mentioned above, developing an up-to-date inventory of offshore sand resources is one of the first steps needed to implement any of the options discussed in this management plan. This inventory will need to be periodically updated as work proceeds and project needs and/or environmental conditions change.

Upland Sand Sources. In 1987, the South-East Area Sand Inventory Project (SEASIP) investigated upland sand sources in close proximity to the Delaware Atlantic beaches. The study focused on the geographic region located east of Route 113, south of Indian River Bay, and north of the Delaware-Maryland state line. Nine borrow pits were visited and evaluated. Eight of these pits were determined to have the potential for excellent to fair beach compatible sand. Only one of these pits is located north of Highway 1 with the remaining pits located in south

Delaware south of the Indian River Bay. This pit, Howard Ritter & Sons, located the closest to the Delaware Bay beaches was identified as having excellent potential for extracting beach quality sand. Additionally, using geologic sampling, the study identified areas where further investigation would likely yield suitable sands. While this study specifically searched for sand sources to nourish the Atlantic coast beaches, the findings are applicable for Delaware Bay beaches as well.

8.3 Long range budget plans

The following tables present the long range budget plans for each community and scenario.

Table 8.1 Strategic Fill Placement Shore Protection - Long Range Budget Plan

	Strategic Fill Placement		Budget Estimate										
	Community Name	Project Element	FY10/11	FY11/12	FY12/13	FY13/14	FY14/15	FY15/16	FY16/17	FY17/18	FY18/19	FY19/20	Total
North Reach	Pickering Beach	*Geotechnical Investigation	$34,098										$34,098
		*Design/Permitting	$17,049										$17,049
		Construction					$470,635				$343,320		$813,955
		Env. Permit Monitoring					$35,000	$35,000	$35,000		$35,000	$35,000	$175,000
		Beach Survey	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$80,000
		Sub Total	$59,147	$8,000	$8,000	$8,000	$513,635	$43,000	$43,000	$8,000	$386,320	$43,000	**$1,120,102**
	Kitts Hummock	*Geotechnical Investigation	$56,914										$56,914
		*Design/Permitting	$28,457										$28,457
		Construction					$503,765				$365,160		$868,925
		Env. Permit Monitoring					$17,500	$17,500	$17,500		$17,500	$17,500	$87,500
		*Monitoring	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$80,000
		Sub Total	$93,371	$8,000	$8,000	$8,000	$529,265	$25,500	$25,500	$8,000	$390,660	$25,500	**$1,121,796**
	Bowers Beach	*Geotechnical Investigation	$23,466										$23,466
		*Design/Permitting	$11,733										$11,733
		Construction					$331,910				$242,250		$574,160
		Env. Permit Monitoring					$17,500	$17,500	$17,500		$17,500	$17,500	$87,500
		Monitoring	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$60,000
		Sub Total	$41,199	$6,000	$6,000	$6,000	$355,410	$23,500	$23,500	$6,000	$265,750	$23,500	**$756,859**
	South Bowers	*Geotechnical Investigation	$46,940										$46,940
		*Design/Permitting	$23,470										$23,470
		Construction					$295,245				$407,444		$702,689
		Env. Permit Monitoring					$17,500	$17,500	$17,500		$17,500	$17,500	$87,500
		Monitoring	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$50,000
		Sub Total	$75,410	$5,000	$5,000	$5,000	$317,745	$22,500	$22,500	$5,000	$429,944	$22,500	**$910,599**
	North Reach Total		$269,127	$27,000	$27,000	$27,000	$1,716,055	$114,500	$114,500	$27,000	$1,472,674	$114,500	**$3,909,356**
South Reach	Slaughter Beach	*Geotechnical Investigation	$139,802										$139,802
		*Design/Permitting	$69,901										$69,901
		Construction				$499,975				$367,800			$867,775
		Env. Permit Monitoring				$17,500	$17,500	$17,500		$17,500	$17,500	$17,500	$105,000
		*Monitoring	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$160,000
		Sub Total	$225,703	$16,000	$16,000	$533,475	$33,500	$33,500	$16,000	$401,300	$33,500	$33,500	**$1,342,478**
	Primehook Beach	*Geotechnical Investigation	$45,193										$45,193
		*Design/Permitting	$22,596										$22,596
		Construction				$416,835				$315,300			$732,135
		Env. Permit Monitoring				$17,500	$17,500	$17,500		$17,500	$17,500	$17,500	$105,000
		Monitoring	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$80,000
		Sub Total	$75,789	$8,000	$8,000	$442,335	$25,500	$25,500	$8,000	$340,800	$25,500	$25,500	**$984,924**
	Broadkill Beach	*Geotechnical Investigation	$153,586										$153,586
		*Design/Permitting	$76,793										$76,793
		Construction				$983,250				$633,240			$1,616,490
		Env. Permit Monitoring				$35,000	$35,000	$35,000		$35,000	$35,000	$35,000	$210,000
		Monitoring	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$160,000
		Sub Total	$246,379	$16,000	$16,000	$1,034,250	$51,000	$51,000	$16,000	$684,240	$51,000	$51,000	**$2,216,869**
	South Reach Total		$547,871	$40,000	$40,000	$2,010,060	$110,000	$110,000	$40,000	$1,426,340	$110,000	$110,000	**$4,544,271**
	Strategic Fill Placement Total		**$816,998**	**$67,000**	**$67,000**	**$2,037,060**	**$1,826,055**	**$224,500**	**$154,500**	**$1,453,340**	**$1,582,674**	**$224,500**	**$8,453,627**

***Notes: The costs for these items are proportional to total volume placed for all of the seven communities included in this management plan.**
Renourishment costs are based on restoring 60% of initial volume placed to restore historic losses.
Costs are based on work being performed on a regional basis.
Costs shown are in July 2009 prices.

Table 8.2 Five (5) Year Scenario – Long Range Budget Plan

	5 Year Scenario		Budget Estimate										
	Community Name	**Project Element**	**FY10/11**	**FY11/12**	**FY12/13**	**FY13/14**	**FY14/15**	**FY15/16**	**FY16/17**	**FY17/18**	**FY18/19**	**FY19/20**	**Total**
North Reach	Pickering Beach	*Geotechnical Investigation	$34,098										$34,098
		*Design/Permitting	$17,049										$17,049
		Construction					$571,435					$403,800	$975,235
		Env. Permit Monitoring					$35,000	$35,000	35000			$35,000	$140,000
		Beach Survey	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$80,000
		Sub Total	$59,147	$8,000	$8,000	$8,000	$614,435	$43,000	$43,000	$8,000	$8,000	$446,800	**$1,246,382**
	Kitts Hummock	*Geotechnical Investigation	$56,914										$56,914
		*Design/Permitting	$28,457										$28,457
		Construction					$988,410					$612,540	$1,600,950
		Env. Permit Monitoring					$35,000	$35,000	$35,000			$35,000	$140,000
		Beach Survey	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$80,000
		Structure Modification					$50,000						$50,000
		Sub Total	$93,371	$8,000	$8,000	$8,000	$1,081,410	$43,000	$43,000	$8,000	$8,000	$655,540	**$1,956,321**
	Bowers Beach	*Geotechnical Investigation	$23,466										$23,466
		*Design/Permitting	$11,733										$11,733
		Construction					$491,950					$345,150	$837,100
		Env. Permit Monitoring					$17,500	$17,500	$17,500			$17,500	$70,000
		Beach Survey	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$60,000
		Sub Total	$41,199	$6,000	$6,000	$6,000	$515,450	$23,500	$23,500	$6,000	$6,000	$368,650	**$1,002,299**
	South Bowers	*Geotechnical Investigation	$46,940										$46,940
		*Design/Permitting	$23,470										$23,470
		Construction					$478,625					$529,900	$1,008,525
		Env. Permit Monitoring					$17,500	$17,500	$17,500			$17,500	$70,000
		Beach Survey	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$50,000
		Structure Modification					$100,000						$100,000
		Sub Total	$75,410	$5,000	$5,000	$5,000	$601,125	$22,500	$22,500	$5,000	$5,000	$552,400	**$1,298,935**
	North Reach Total		$269,127	$27,000	$27,000	$27,000	$2,812,420	$132,000	$132,000	$27,000	$27,000	$2,023,390	**$5,503,937**
South Reach	Slaughter Beach	*Geotechnical Investigation	$139,802										$139,802
		*Design/Permitting	$69,901										$69,901
		Construction				$2,112,800					$1,275,000		$3,387,800
		Env. Permit Monitoring				$70,000	$70,000	$70,000			$70,000	$70,000	$350,000
		Beach Survey	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$160,000
		Sub Total	$225,703	$16,000	$16,000	$2,198,800	$86,000	$86,000	$16,000	$16,000	$1,361,000	$86,000	**$4,107,503**
	Primehook Beach	*Geotechnical Investigation	$45,193										$45,193
		*Design/Permitting	$22,596										$22,596
		Construction				$787,800					$512,700		$1,300,500
		Env. Permit Monitoring				$35,000	$35,000	$35,000			$35,000	$35,000	$175,000
		Beach Survey	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$80,000
		Sub Total	$75,789	$8,000	$8,000	$830,800	$43,000	$43,000	$8,000	$8,000	$555,700	$43,000	**$1,623,289**
	Broadkill Beach	*Geotechnical Investigation	$153,586										$153,586
		*Design/Permitting	$76,793										$76,793
		Construction				$2,229,500					$1,325,400		$3,554,900
		Env. Permit Monitoring				$70,000	$70,000	$70,000			$70,000	$70,000	$350,000
		Beach Survey	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$160,000
		Sub Total	$246,379	$16,000	$16,000	$2,315,500	$86,000	$86,000	$16,000	$16,000	$1,411,400	$86,000	**$4,295,279**
	South Reach Total		$547,871	$40,000	$40,000	$5,345,100	$215,000	$215,000	$40,000	$40,000	$3,328,100	$215,000	**$10,026,071**
	5 Year Scenario Total		**$816,998**	**$67,000**	**$67,000**	**$5,372,100**	**$3,027,420**	**$347,000**	**$172,000**	**$67,000**	**$3,355,100**	**$2,238,390**	**$15,530,008**

***Notes: The costs for these items are proportional to total volume placed for all of the seven communities included in this management plan.**
Renourishment costs are based on restoring 60% of initial volume placed to restore historic losses.
Costs are based on work being performed on a regional basis.
Costs shown are in July 2009 prices.

Table 8.3 Ten (10) Year Scenario – Long Range Budget Plan

	10 Year Scenario		Budget Estimate										
	Community Name	Project Element	FY10/11	FY11/12	FY12/13	FY13/14	FY14/15	FY15/16	FY16/17	FY17/18	FY18/19	FY19/20	Total
North Reach	Pickering Beach	*Geotechnical Investigation	$34,098										$34,098
		*Design/Permitting	$17,049										$17,049
		Construction					$1,180,435						$1,180,435
		Env. Permit Monitoring					$35,000	$35,000	$35,000				$105,000
		Beach Survey	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$80,000
		Sub Total	$59,147	$8,000	$8,000	$8,000	$1,223,435	$43,000	$43,000	$8,000	$8,000	$8,000	**$1,416,582**
	Kitts Hummock	*Geotechnical Investigation	$56,914										$56,914
		*Design/Permitting	$28,457										$28,457
		Construction					$1,656,210						$1,656,210
		Env. Permit Monitoring					$35,000	$35,000	$35,000				$105,000
		Beach Survey	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$80,000
		Structure Modification					$50,000						$50,000
		Sub Total	$93,371	$8,000	$8,000	$8,000	$1,749,210	$43,000	$43,000	$8,000	$8,000	$8,000	**$1,976,581**
	Bowers Beach	*Geotechnical Investigation	$23,466										$23,466
		*Design/Permitting	$11,733										$11,733
		Construction					$746,750						$746,750
		Env. Permit Monitoring					$17,500	$17,500	$17,500				$52,500
		Beach Survey	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$60,000
		Sub Total	$41,199	$6,000	$6,000	$6,000	$770,250	$23,500	$23,500	$6,000	$6,000	$6,000	**$894,449**
	South Bowers	*Geotechnical Investigation	$46,940										$46,940
		*Design/Permitting	$23,470										$23,470
		Construction					$772,625						$772,625
		Env. Permit Monitoring					$17,500	$17,500	$17,500				$52,500
		Beach Survey	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$50,000
		Structure Modification					$100,000						$100,000
		Sub Total	$75,410	$5,000	$5,000	$5,000	$895,125	$22,500	$22,500	$5,000	$5,000	$5,000	**$1,045,535**
	North Reach Total		$269,127	$27,000	$27,000	$27,000	$4,638,020	$132,000	$132,000	$27,000	$27,000	$27,000	**$5,333,147**
South Reach	Slaughter Beach	*Geotechnical Investigation	$139,802										$139,802
		*Design/Permitting	$69,901										$69,901
		Construction				$3,680,800							$3,680,800
		Env. Permit Monitoring				$70,000	$70,000	$70,000					$210,000
		Beach Survey	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$160,000
		Sub Total	$225,703	$16,000	$16,000	$3,766,800	$86,000	$86,000	$16,000	$16,000	$16,000	$16,000	**$4,260,503**
	Primehook Beach	*Geotechnical Investigation	$45,193										$45,193
		*Design/Permitting	$22,596										$22,596
		Construction				$1,522,800							$1,522,800
		Env. Permit Monitoring				$35,000	$35,000	$35,000					$105,000
		Beach Survey	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$80,000
		Sub Total	$75,789	$8,000	$8,000	$1,565,800	$43,000	$43,000	$8,000	$8,000	$8,000	$8,000	**$1,775,589**
	Broadkill Beach	*Geotechnical Investigation	$153,586										$153,586
		*Design/Permitting	$76,793										$76,793
		Construction				$4,074,000							$4,074,000
		Env. Permit Monitoring				$70,000	$70,000	$70,000					$210,000
		Beach Survey	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$160,000
		Sub Total	$246,379	$16,000	$16,000	$4,160,000	$86,000	$86,000	$16,000	$16,000	$16,000	$16,000	**$4,674,379**
	South Reach Total		$547,871	$40,000	$40,000	$9,492,600	$215,000	$215,000	$40,000	$40,000	$40,000	$40,000	**$10,710,471**
	10 Year Scenario Total		**$816,998**	**$67,000**	**$67,000**	**$9,519,600**	**$4,853,020**	**$347,000**	**$172,000**	**$67,000**	**$67,000**	**$67,000**	**$16,043,618**

***Notes: The costs for these items are proportional to total volume placed for all of the seven communities included in this management plan.**
Renourishment costs are based on restoring 60% of initial volume placed to restore historic losses.
Costs are based on work being performed on a regional basis.
Costs shown are in July 2009 prices.

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Appendix A:
Planning Level Hydrodynamic and Wave Modeling Report

Planning Level Hydrodynamic and Wave Modeling

for

The Delaware Bay Beaches

Prepared for:

Delaware Department of Natural Resources and Environmental Control
Division of Soil and Water Conservation
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DECEMBER 2009

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1. Planning Level Hydrodynamic Modeling

1.1 Introduction

As part of this overall management plan, a planning level hydrodynamic modeling effort was undertaken, using the ADCIRC model (Luettich & Westerink, 2006) and the Surface Water Modeling System (SMS) graphical interface developed by Aquaveo. ADCIRC is a two-dimensional, depth-integrated, finite-element circulation model, capable of simulating the hydrodynamics of water bodies ranging from lakes and rivers to entire ocean basins. It has the ability to simulate wetting and drying of model elements, bottom friction, Coriolis forcing, wind stresses, and other effects. It allows for a variety of boundary conditions, including normal inflow and outflow, uniform water level variations, and spatially-varying tidal constituent forcing.

The goal of this modeling effort was to develop a working circulation model of Delaware Bay in order to gain a better understanding of the roles that wind, tidal circulation, upstream inflows, and storm surges play in determining the dominant current circulation patterns along the western shore of Delaware Bay. The model is also used to confirm observations from past research efforts. These patterns can be an indicator of the major pathways, sources, and sinks of beach sediment under average, operational, and extreme conditions. Examination of net flow directions and areas of current acceleration/deceleration in the model results are combined with local observations of past beach fill behavior to develop strategic beach fill placement options; this is discussed in detail in subsequent sections of this report.

1.2 Data Sources

The model was assembled using existing available data and no new field data was collected. Key information necessary to build a hydrodynamic model that incorporates flooding scenarios includes desired boundaries (forcing and non-forcing), bathymetry, and topography.

NOAA navigational charts were used to visually relate areas of interest to the model grid. NOAA's National Geophysical Data Center (NGDC) developed a digitized coastline for the entire world, from which the coastline of the area of interest can be extracted using the GEODAS utility. Bathymetry from offshore in the Atlantic Ocean north to Trenton, NJ was acquired from NOAA's NOS Hydrographic Survey Database. This data is a compilation of a multiple surveys. Topography was obtained in the form of USGS Digital Elevation Models (DEMs) for the states of Delaware and New Jersey. DEMs for both states have a resolution of 30 m; the New Jersey data is from 1998, and the Delaware data is from 1993.

NOAA's Tides and Currents website serves as a database for both predicted and observed tide levels at multiple locations in the United States; there are several in and around Delaware Bay and the Delaware River. NOAA's National Data Buoy Center (NDBC) maintains a record of current and historical meteorological data, including wind and atmospheric pressure, for several stations in this region. The USGS National Water Information System catalogs streamflow information including stage height and discharge rates. The ADCIRC model includes a utility to access predicted tide constituent phases and amplitudes for the entire northern Atlantic Ocean; this can be used to construct a spatially-varying tidal boundary for any period of time.

1.3 Model Grid Development

In order to be able to independently vary the boundary condition forcings of the model, the grid extent must be sufficiently large. In the case of Delaware Bay, the astronomical tide from the ocean has effects as far upstream as Trenton, NJ. Thus, the model must extend to this area so that the upstream inflow can be set independent of the downstream tidal boundary. The offshore tidal boundary should be significantly far away from the areas of interest to minimize the effects on these areas from any computational abnormalities at the boundary. It is also helpful if the boundary corresponds to an area where real physical data collection has taken or is taking place. The NDBC maintains Buoy 44009, which is approximately 40 km southeast of the mouth of Delaware Bay. This allows for a sufficient distance between the boundary and the Bay beaches and provides real measurements at the boundary. This boundary location allows the geometry of the bay, especially its entrance to influence hydrodynamic calculations in the model as it would in reality.

This model allows for flooding and drying of elements, so the coastline is not sufficient as a closed model boundary. Using the DEM data as a guide, the +4 m NAVD88 contour was chosen as the upland model extent. This allows for propagation of flooding that may be expected from a 500 year return period event as estimated by OCTI (1994). Flooding is accounted for as far north as New Castle, DE.

With model boundaries and topography in place, a computational grid can be formed. This procedure requires a balance between adequate grid resolution and reasonable computational time in order to accurately model the dynamics of the areas of interest while being able to perform a sufficient number of model runs for calibration and analysis during the project timeframe. The ADCIRC model allows for varying grid spacing within the domain, which expedites this process. The element resolution varies from 120 to 400 m along the western Delaware Bay shoreline to 5 km at the open ocean boundary. Figure 1.1 shows the model boundaries overlaid on NOAA navigational charts. Figure 1.2 illustrates the computational grid of the entire model domain, while Figure 1.3 shows a closer view of the western shore of Delaware Bay. Figure 1.4 illustrates the bathymetry and topography in the model.

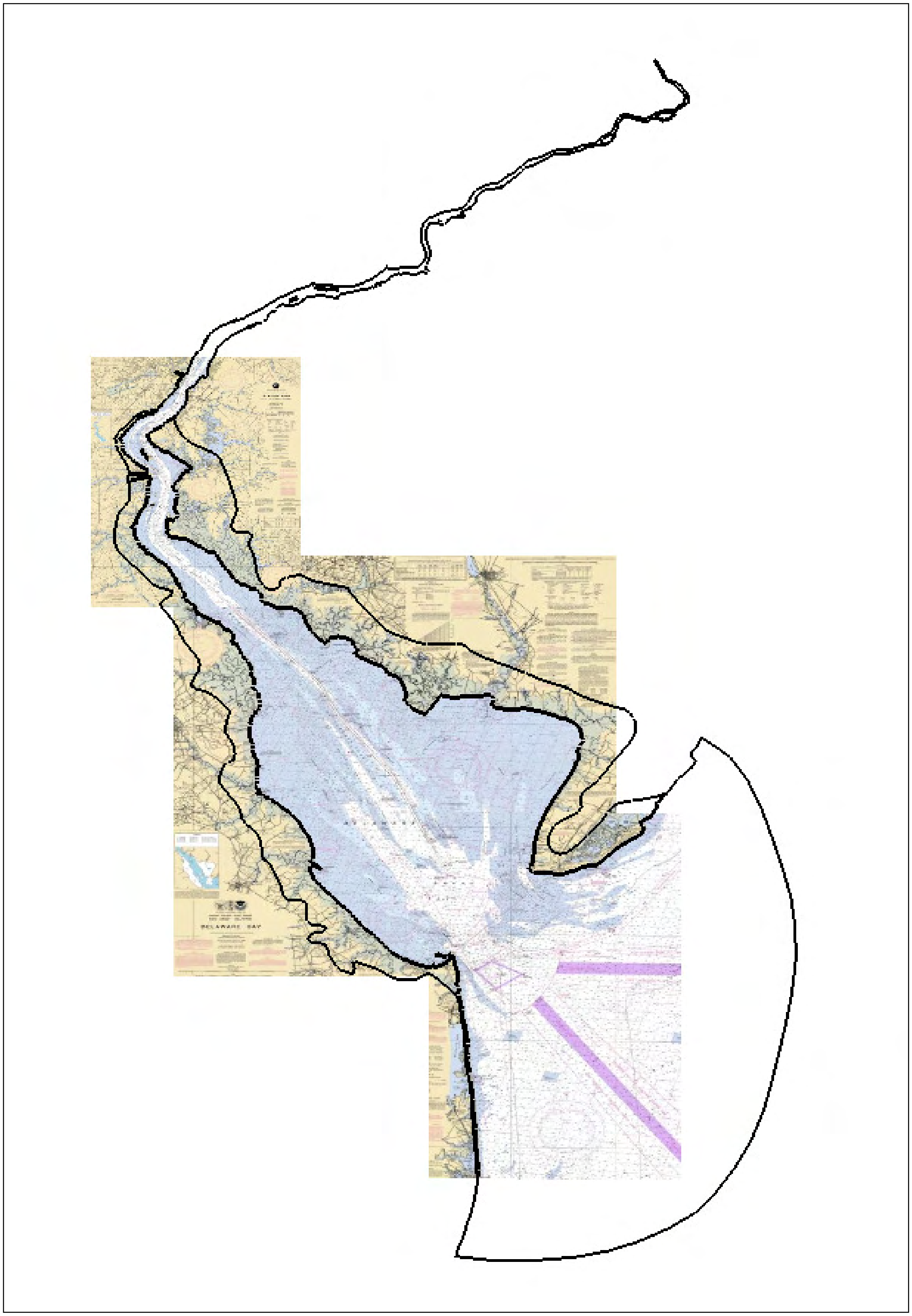

Figure 1.1 Computational boundaries of the ADCIRC model.

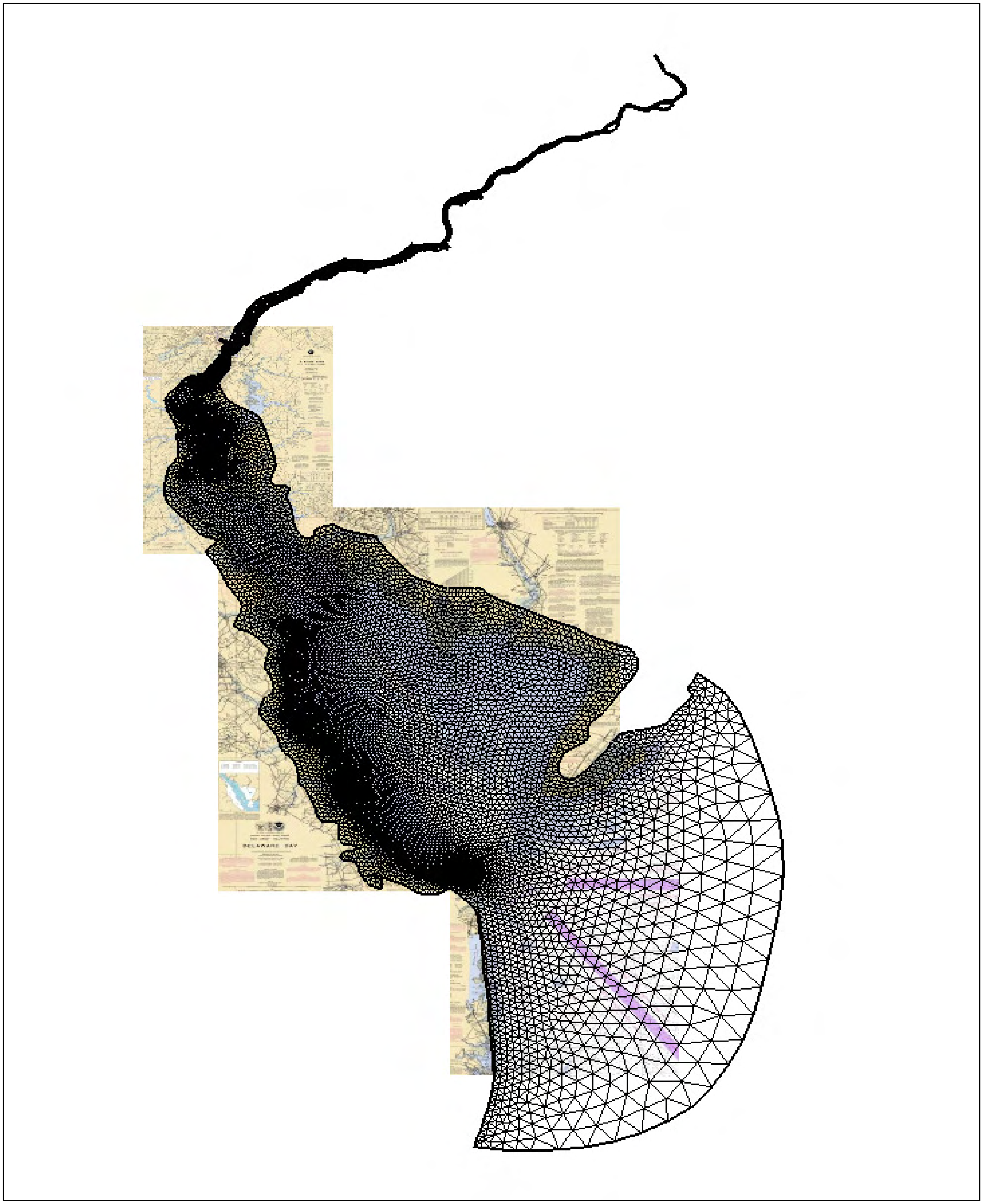

Figure 1.2 ADCIRC model element resolution.

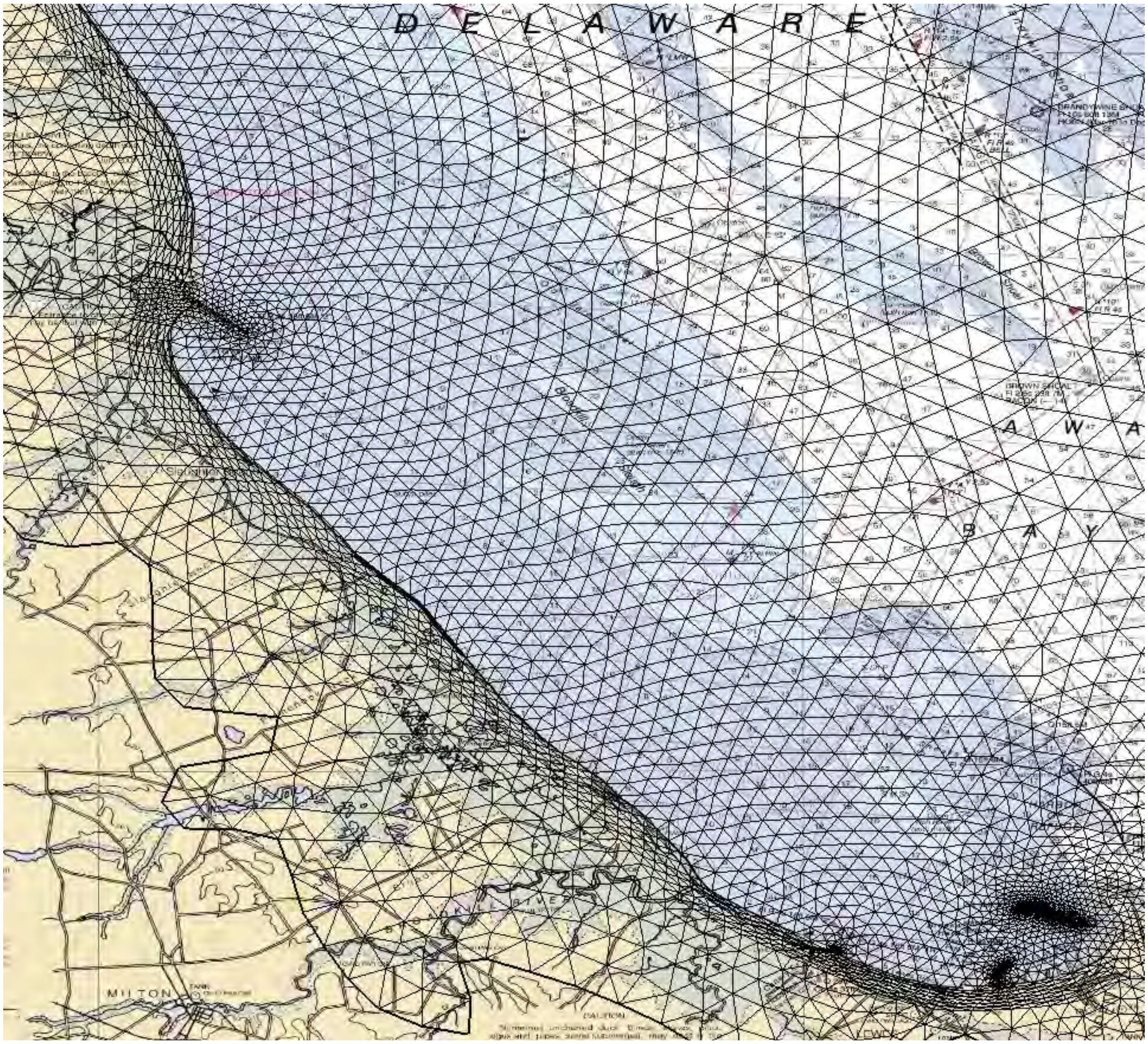

Figure 1.3 ADCIRC model element resolution along western shore of Delaware Bay.

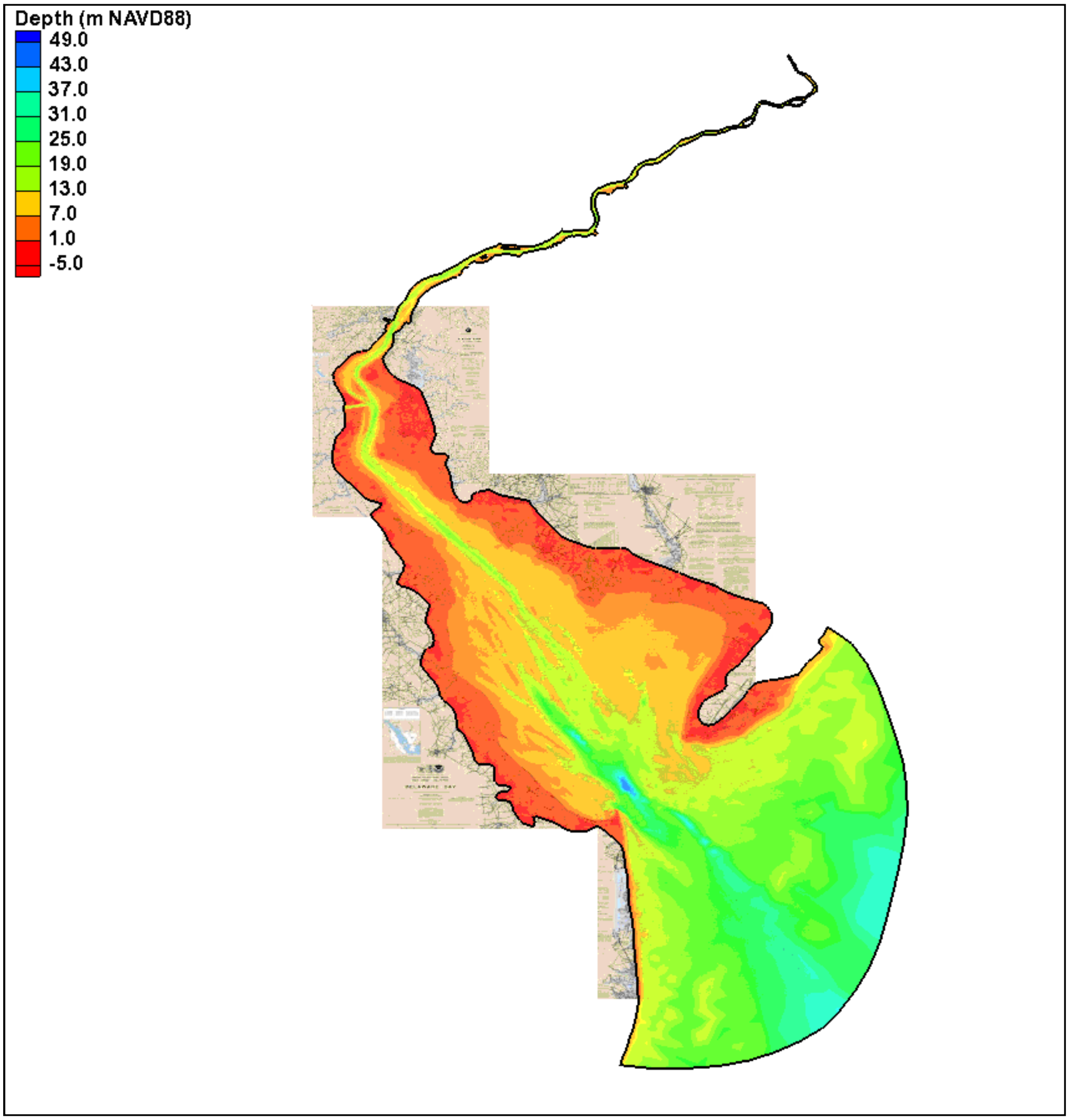

Figure 1.4 Bathymetry and topography of the ADCIRC model.

1.4 Boundary Conditions

To drive the model hydrodynamics, appropriate boundary conditions are selected to provide forcing. An estuary like Delaware Bay is driven by tidal dynamics at the ocean boundary and river inflows upstream, and is modified by surface stresses due to wind. To account for the effects of wind, river inflows, and measured storm surges, the offshore boundary of the model cannot be driven only by the spatially-varying water level time series extracted from the ADCIRC tidal constituent database. The model is first run using only these offshore tidal constituents and the predicted offshore boundary condition for the time period of interest at a single point is extracted and added to the residual water level at the Lewes, DE tide gauge station. The residual water level is the difference between the measured and predicted tide levels. In this manner, the offshore boundary is adjusted as best as possible to reflect the actual conditions during the time period of interest, as no water level gauges are available closer to the offshore boundary. The result is a spatially-constant water level boundary condition with meteorological effects included. While a spatially-constant boundary is not perfectly accurate, this simplification has little adverse effect on the model results along the Delaware shoreline.

There are three rivers in the estuary system that account for the majority of the freshwater inflow to Delaware Bay. These are the Delaware River, the Schuylkill River, and the Christina River. In the ADCIRC model, the influence of these rivers is implemented with a normal flow boundary condition, which can be either constant or varying in time. Table 1.1 outlines the mean daily discharges of these rivers; further detail will be provided about the specific inflow boundary conditions applied to the model.

Table 1.1 Mean daily discharges of Delaware Bay's three major freshwater inflows.

River (Location)	Mean Daily Discharge (m^3/s)
Delaware (Trenton, NJ)	313.5
Schuylkill (Philadelphia, PA)	76.5
Christina (Wilmington, DE)	19.1

Wind stresses can be an important factor influencing the movement of water within Delaware Bay. The Brandywine Shoal Light has a wind gauge with archived data available from 2006 through 2008. Wind from this station was applied uniformly over the entire model when a specific wind time series was applied in a simulation. During model runs of 'average' conditions, a direction of 315° from true north at a speed of 4.9 m/s was applied, corresponding to the prevailing direction and mean speed for the region according to Maurmeyer (1978). Further detail will be provided in subsequent sections about the specific wind boundary conditions applied to the model. Figure 1.5 illustrates the locations of the tidal and riverine boundary conditions applied to the model.

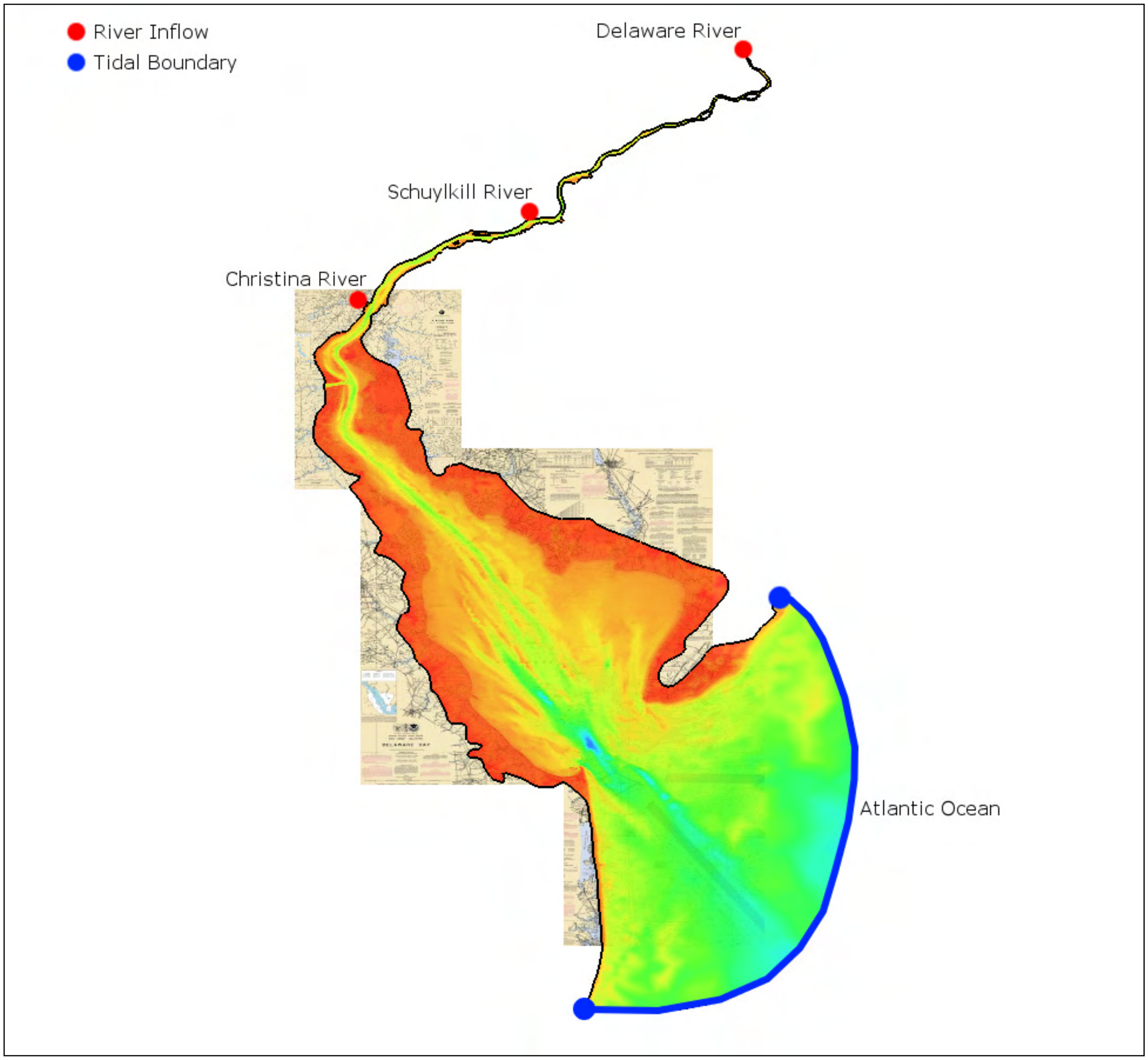

Figure 1.5 Tidal and riverine boundary conditions forcing the ADCIRC model.

1.5 Model Calibration

The ADCIRC model contains several physical parameters that can be varied in order to alter the dynamics of the model and allow for calibration to data collected during a known hydrodynamic scenario. In this exercise, the parameters that were varied were the bottom friction coefficient, the lateral viscosity, and the wave continuity weighting factor. Variability in this last parameter proved to be crucial to the proper simulation of the dynamics of Delaware Bay, where the geometry of the bay induces a tidal amplification effect in the upstream direction.

There are several tide gauges in the Delaware Bay estuary which have records of predicted and measured tide levels. Utilized in this effort were stations at Lewes, DE (NOAA Station 8557380); Cape May, NJ (8536110); Brandywine Shoal Light, NJ (8555889); Ship John Shoal, NJ (8537121); Reedy Point, DE (8551910); and Philadelphia, PA (8545240). The time series of water levels at these locations were used to calibrate the model. Figure 1.6 shows the locations of these stations. A comparison was made between the measured and modeled time series by visual inspection as well as calculation of the root-mean-squared (RMS) error between the actual and simulated time series. An error of 10% or less (as a fraction of the range of the measured tidal elevation) was considered acceptable in the area of interest between Pickering Beach, DE and Lewes, DE.

The time period chosen for the calibration exercise was between October 1, 2007 and October 20, 2007, a span of 20 days. This period was chosen for several reasons. There exists a complete record of verified tidal levels at each calibration station during this period, as well as a complete record of wind data at Brandywine Shoal Light. Also, the measured tidal signal has a minor storm surge residual component that allowed the model to calculate results due to a meteorological event.

The first step in the calibration process was to run a scenario with only the predicted tide signal driving the model. This is the simplest setting, and the variable parameters in the model were adjusted to minimize the error in the tide elevations at the calibration stations. Table 1.2 outlines the values of the calibration parameters that resulted in the best correlation between measured and modeled data under these conditions. Figure 1.6 illustrates the tidal time series comparisons at the calibration stations. Table 1.3 lists the RMS error values at each station.

Table 1.2 ADCIRC model parameters resulting in best model calibration.

Parameter	Value
Wave Continuity Weighting Factor	-0.005
Lateral Viscosity	1.0 m^2/s
Bottom Friction Coefficient (Hybrid Formulation)	0.002

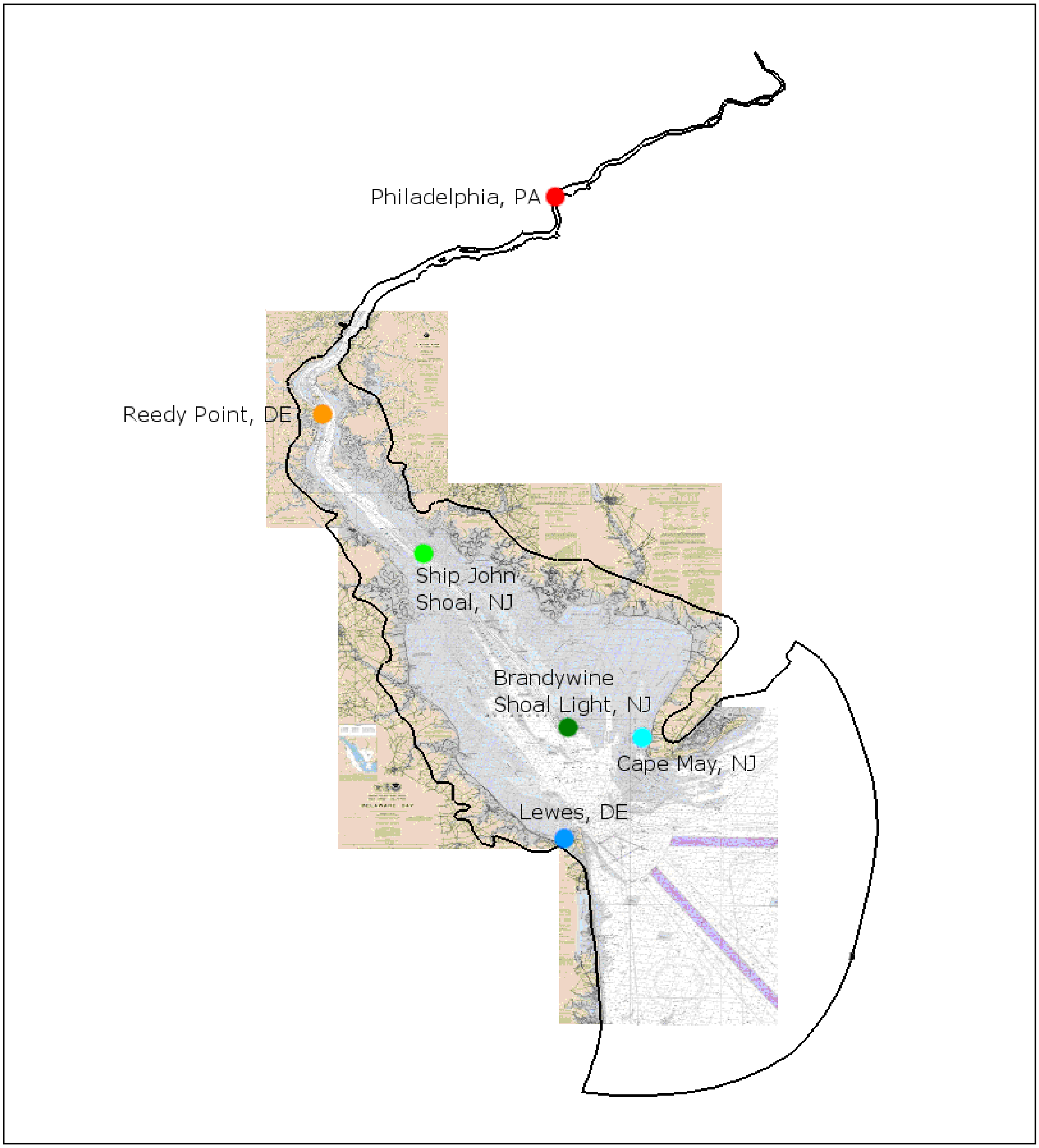

Figure 1.6 Tidal elevation stations used in model calibration.

Figure 1.7 Water level comparisons at calibration stations; model calibration run with predicted conditions.

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Table 1.3 RMS error at each calibration station; calibration run with predicted tide only.

Station	RMS Error (m)	RMS Error (%)
Philadelphia	0.379	18.8
Reedy Point	0.202	11.1
Ship John Shoal	0.226	11.3
Brandywine Shoal	0.112	6.2
Cape May	0.108	5.9
Lewes	0.103	6.4

Visually comparing the modeled and predicted tidal signals in Figure 1.7, the correlation appears to be quite good (10%) for both tidal amplitude and phase in the lower part of the bay (Lewes, Cape May, and Brandywine Shoal). The modeled tide at Ship John Shoal appears to be consistently lower than predicted levels, but is still well in phase. In terms of RMS error, the lower bay gauges are under the 10% threshold. Ship John Shoal and Reedy Point exhibit errors greater than 10%, but only slightly. Philadelphia is the least correlated with an 18.8% error, but this gauge is farthest from the Delaware Bay beaches. Since the area of interest is the lower bay, the model was considered sufficiently calibrated for this phase.

With calibration completed for predicted tides only, the effects of wind, riverine flow, and storm surge were added to the model boundary conditions and water levels at the calibration stations were again compared to assess model accuracy. Figure 1.8 illustrates the inflow rates for the 3 major rivers during the calibration period. All three rivers have a spike in their discharge rates in the middle of the simulation period. Figure 1.9 shows the wind speed and direction at Brandywine Shoal during this time, which was applied to the entire model domain. The wind speed peaked between hours 250 and 300 to just over 15 m/s (34 mph), originating from about 300°, approximately west-northwest. Figure 1.10 displays the composite offshore boundary condition constructed from the residual tide level at Lewes, developed as previously discussed in the *Boundary Conditions* section. The residual water level peaks at about 0.6 m above normal around hour 200, and is sustained at 0.3 m above normal for about 48 hours before subsiding.

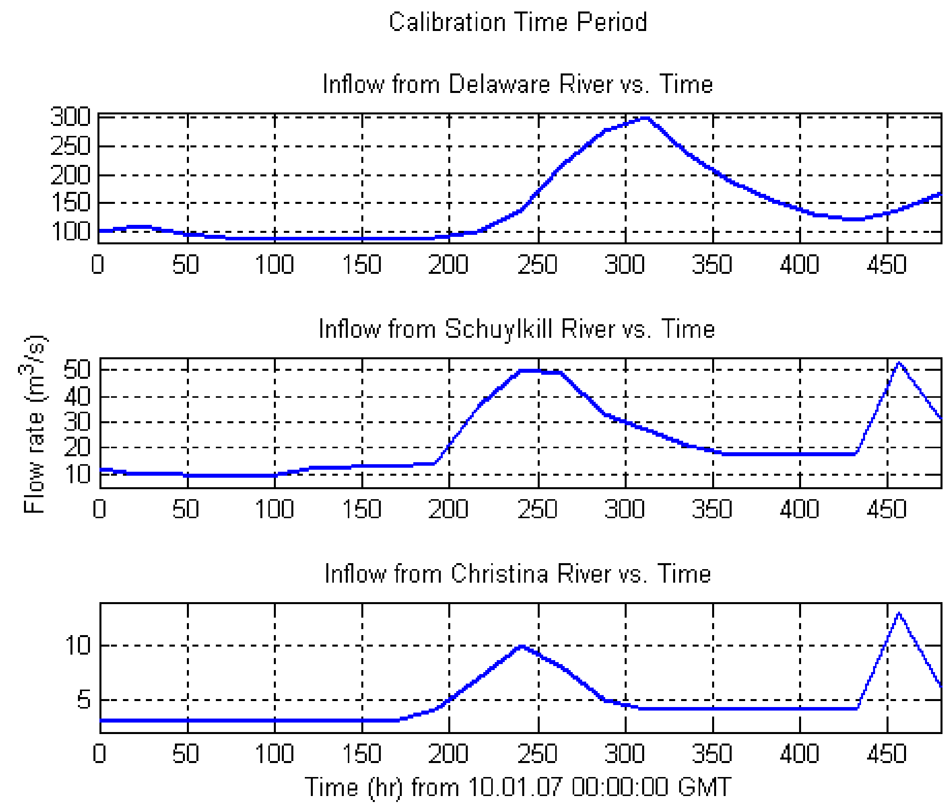

Figure 1.8 River inflows during calibration time period.

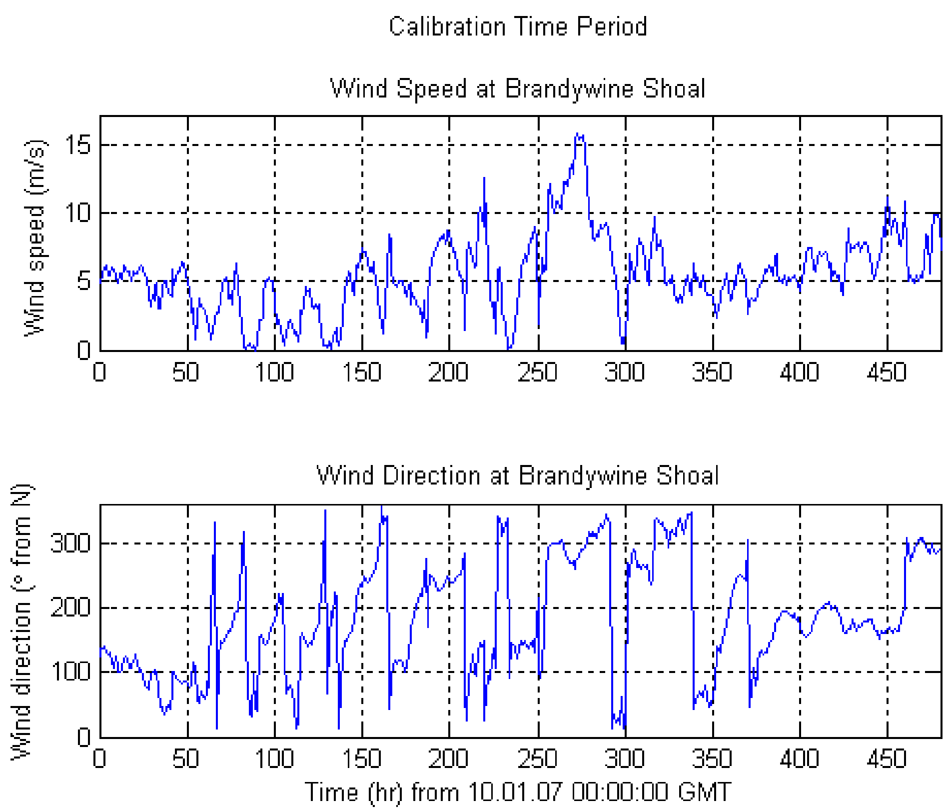

Figure 1.9 Wind speed and direction at Brandywine Shoal during calibration time period.

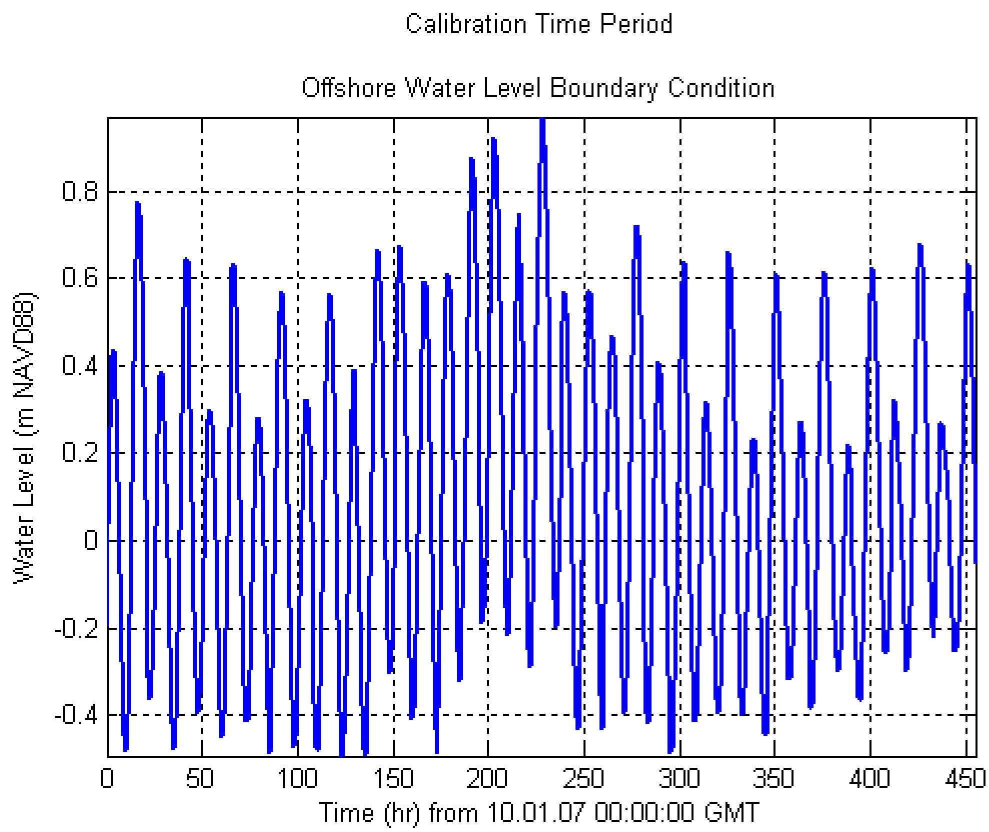

Figure 1.10 Composite offshore boundary condition for calibration time period.

The model was run with the above river flows, wind, and calculated offshore tidal signal; the water level comparisons at the calibration stations are shown in Figure 1.11. Visually, the model results correlate well with measured data in both phase and amplitude. Variations in tidal peaks are replicated, and the small storm surge around hour 250 is reflected well in the model. Numerically, only the Philadelphia gauge is more than a fraction of a percent over the RMS error threshold and the area of interest is well below this threshold. Table 1.4 summarizes the RMS errors at each gauge location.

Table 1.4 RMS errors for calibration time period with wind, flow and surge effects.

Station	RMS Error (m)	RMS Error (%)
Philadelphia	0.371	15.5
Reedy Point	0.209	10.1
Ship John Shoal	0.216	9.5
Brandywine Shoal	0.106	5.6
Cape May	0.102	5.4
Lewes	0.107	6.6

Based on these results, it was determined that the model is accurately representing the hydrodynamics within the lower reaches of Delaware Bay that result from the combined effects of astronomical tide, storm surge, freshwater inflow, and wind stresses.

Figure 1.11 Water level comparisons at calibration stations; model calibration run with environmental forcing applied.

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1.6 Modeling of Average Wind, Tide, and Flow Conditions

In order to use the model to estimate the dominant circulation patterns that exist within Delaware Bay, conditions in the model must recreate as close as possible those that are prevalent over larger time scales. According to Maurmeyer (1978), wind speeds in the region are on average 4.9 m/s and are dominant from the northwest (315° from N). Mean river discharges are outlined above in Table 1.1. The tidal signal used in this model run was the spatially-varying predicted water level extracted from the ADCIRC tidal database and used in the calibration effort. This tidal series highlights a range of the local semidiurnal variability in the high and low peaks, as well as spring/neap cycle variation; as such it is a good representation of ‘average’ tidal conditions in Delaware Bay.

The model was driven with the predicted tidal elevations along with constant river discharges and a constant, uniform wind field. Although not a calibration run, the time series of tidal elevations at each calibration station are presented in Figure 1.12. The applied wind and river discharges appear to have little effect on the tidal elevations in Delaware Bay.

1.7 Modeling of 2008 Mother’s Day Storm

During May 11-13, 2008, the Delaware Bay region was impacted by a serious Nor’easter event, known locally as the Mother’s Day Storm. This event brought high winds, heavy rainfall, and extreme storm surge to the Atlantic Ocean and Delaware Bay coastlines. According to the National Weather Service, a peak wind gust of 30.4 m/s (68 mph) was reported at Lewes, DE. Tide elevations crested at 1.5 m NAVD88, with a peak surge elevation of 1.2 m above the predicted tide at the Lewes tide station. Modeling this event provides several important data sets, including storm surge heights in the entire estuary and flooding patterns along the coastline and its back bays.

The 2008 Mother’s Day Storm was modeled over the time period of May 4-15, 2008. Similar to the calibration run including meteorological effects, the storm model included a time-varying wind field, time-varying river inflows, and the spatially-constant ocean tidal boundary. A ‘ramp-up’ period of 24 hours was required, so model results from the first day of simulation are disregarded. Figure 1.13 illustrates the river discharges during the model run. Discharges in all three rivers peak between hours 100 and 150 and subside afterwards. Figure 1.14 shows the wind speed and direction applied to the model, taken from the Brandywine Shoal Light. Wind speed peaks around hour 200 to a magnitude of 22 m/s (51mph) and originates from the east-northeast, typical for this type of storm. Figure 1.15 displays the composite offshore tidal boundary condition. The peak modeled storm surge reaches a maximum of 1.6 m NAVD88 around hour 200, during the day of May 12. The highest surges are sustained for about 36 hours, and their timing corresponds with the maximum wind speeds at Brandywine Shoal.

Figure 1.16 compares tidal elevations between the model results and measured data at the calibration locations, and Table 1.5 summarizes the RMS errors at each location (from hour 25 onward, after model spinup). As with the calibration runs, the RMS errors are below or just slightly above the 10% acceptability threshold in the lower bay. Tide phase and amplitude are modeled well, but the peak storm surge is consistently overpredicted by about 0.4 m. The overprediction is likely an artifact of the way that the offshore boundary condition was constructed using the residual water level at Lewes, thus overstating the offshore surge and causing a greater surge to be focused into Delaware Bay than existed during the real storm. While the model overpredicts the surge levels for this specific storm, it is still a useful tool to examine the flooding effects along the Delaware Bay shoreline and the coastal back bays during nor'easter events. For this analysis, the purpose was not to perfectly mirror the Mother's Day Storm but to create a detailed physical model of a comparable event for analysis.

Figure 1.12 Water level comparisons at calibration stations; model run of average conditions.

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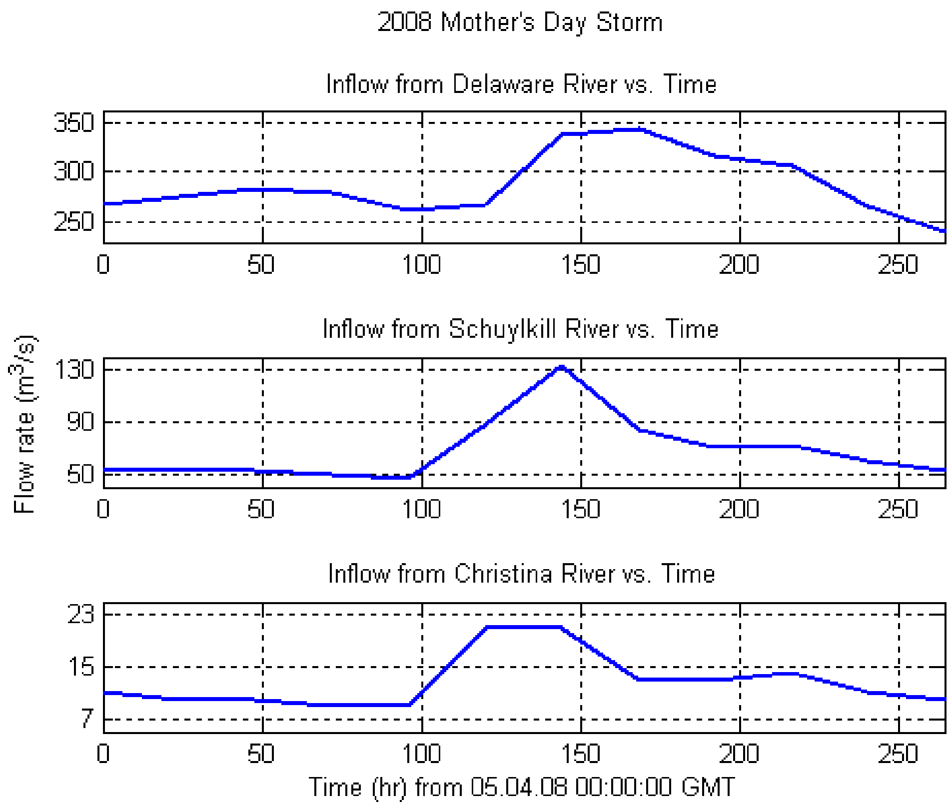

Figure 1.13 River discharges during 2008 Mother's Day Storm simulation.

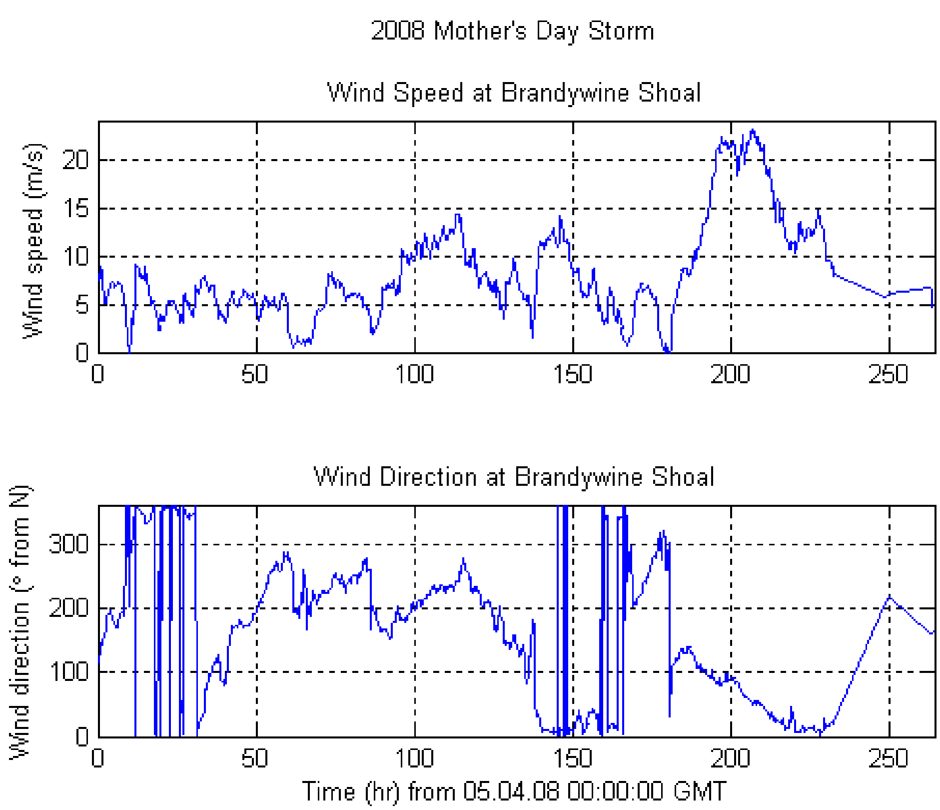

Figure 1.14 Wind parameters at Brandywine Shoal during 2008 Mother's Day Storm simulation.

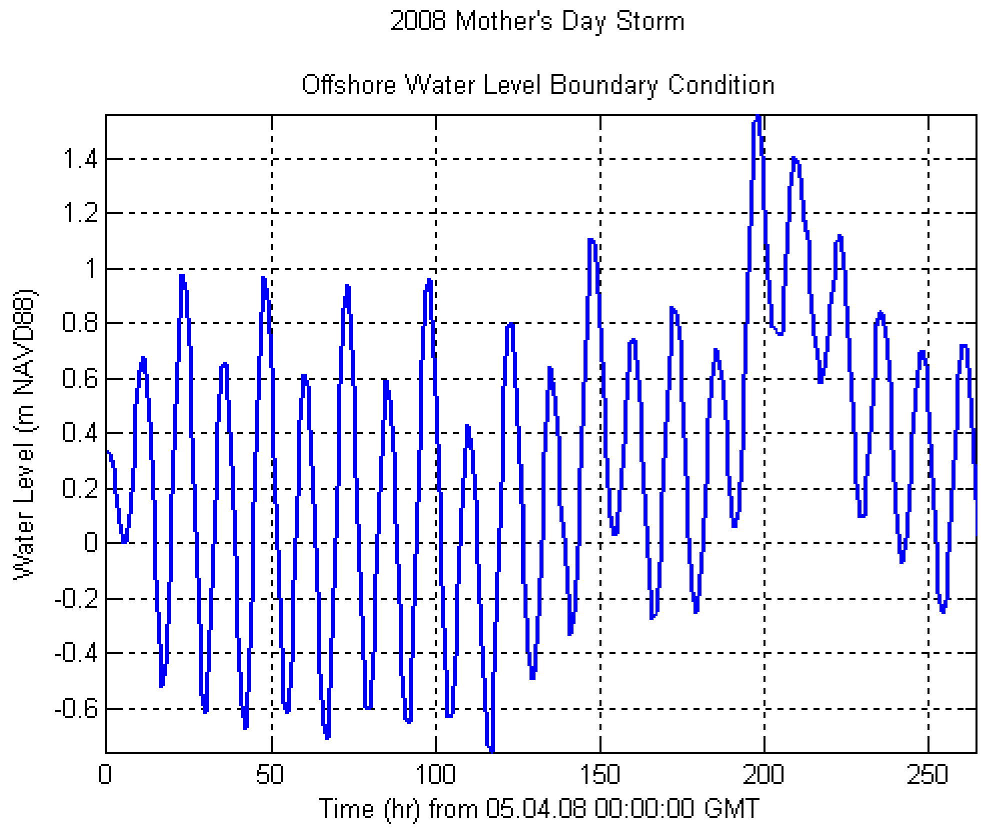

Figure 1.15 Composite offshore boundary condition during 2008 Mother's Day Storm.

Table 1.5 RMS errors for 2008 Mother's Day Storm simulation with wind, flow and surge effects.

Station	RMS Error (m)	RMS Error (%)
Philadelphia	0.457	16.6
Reedy Point	0.265	10.2
Ship John Shoal	0.217	8.2
Brandywine Shoal	0.184	7.1
Cape May	0.202	8.0
Lewes	0.203	8.2

Figure 1.16 Water level comparisons at calibration stations; model run of 2008 Mother's Day Storm.

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1.8 Model Results Overview

The ADCIRC circulation model developed in this phase of work was used to simulate three different physical forcing scenarios for the Delaware Bay region. The first of these was a 20 day ‘snapshot’ of actual, recorded wind, flow, and water level conditions. This set of forcings was used to calibrate the model as well as investigate the circulation patterns that arise during everyday or ‘operational’ physical conditions.

Also simulated was a representative predicted tidal fluctuation combined with mean conditions for river inflow and wind. This setup was used to gain insight on how prevailing physical forcings manifest themselves in the circulation patterns of Delaware Bay; these average conditions can be thought of as the dominant patterns that emerge over larger time scales as transient variations in conditions become of secondary importance.

A simulation was also conducted to model the time period of the 2008 Mother’s Day Storm. This was a significant and destructive nor’easter for the Delaware Bay region. A recreation of this event was utilized to examine circulation patterns during extreme events.

In this investigation, dominant circulation patterns were estimated by examining the time-averaged residual velocity at each location in the model domain. This is simply the average velocity at a location over a set number of tidal cycles, essentially removing cyclical variations and examining only the net circulation of the system. When selecting a period for averaging, the starting point must be after the model is sufficiently ‘spun up’, the time period must encompass the events of interest, and the end point must be at the same point in the tidal cycle as the starting point. One M2 tidal cycle, which dominates the Delaware Bay region, is 12 hours, 25 minutes in duration. The model run of operational conditions was averaged over 24 tidal cycles, or 298 hours. This covers hour 50 to hour 348 in the simulation time, or May 3, 2007 at 02:00:00 GMT to May 15, 2007 at 12:00:00 GMT. The model run using mean conditions was analyzed over the same time period. Model results for the 2008 Mother’s Day Storm were averaged over 9 tidal cycles, from May 10, 2008 at 04:15:00 GMT (hour 148.25) to May 14, 2008 at 20:00:00 GMT (hour 260).

1.9 Operational Conditions

Figures 1.17 to 1.22 present the residual current patterns and magnitudes from Pickering Beach to Cape Henlopen for the calibration/operational conditions model run. Figure 1.23 summarizes the prevailing current patterns on a single map.

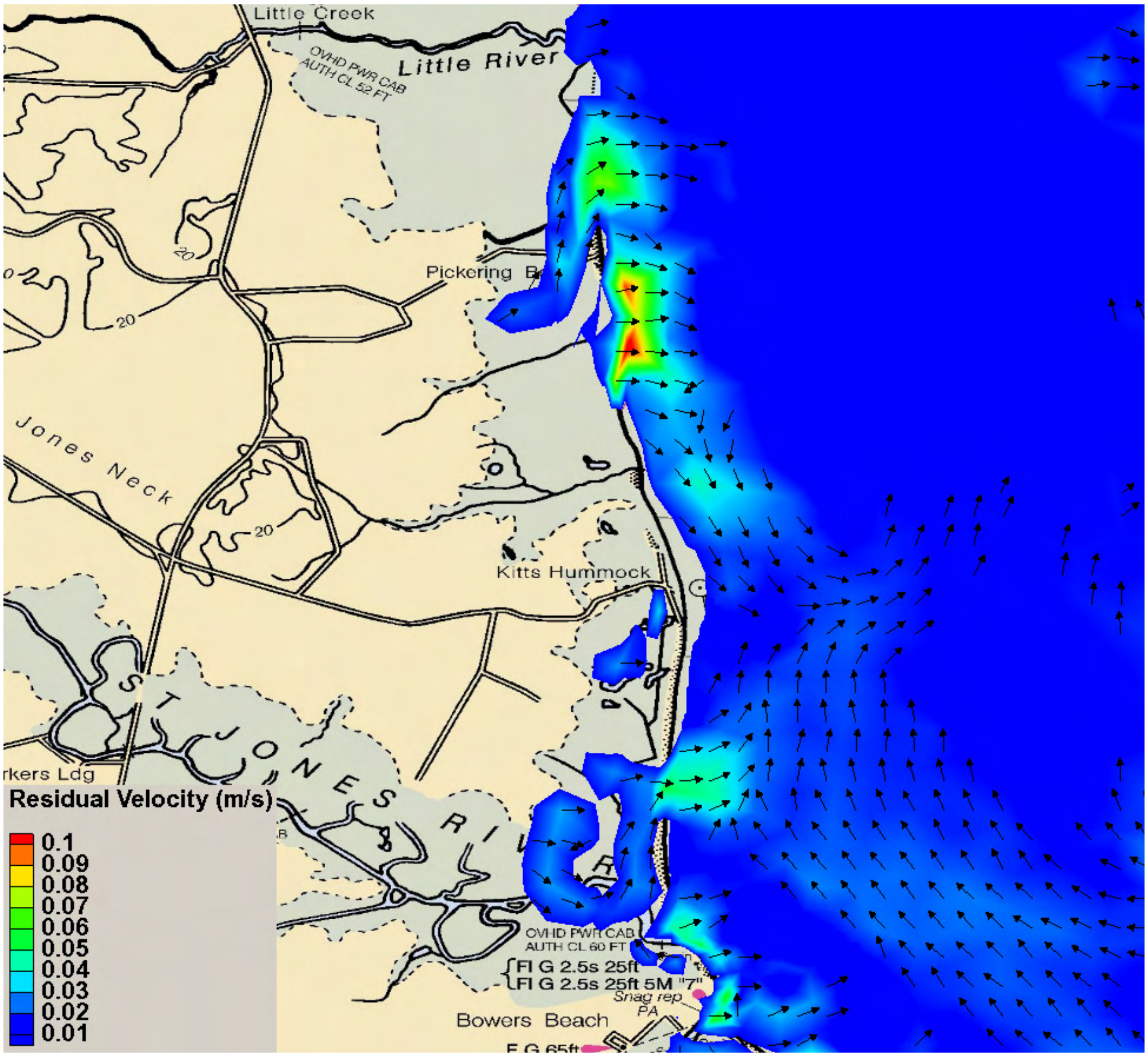


Figure 1.17 Residual currents in the Kitts Hummock area; operational conditions.

Pickering Beach, Bowers Beach, and South Bowers Beach exhibit large offshore-directed flow. At Kitts Hummock, there is a southerly flow that converges with the northeasterly flow offshore of Bowers.

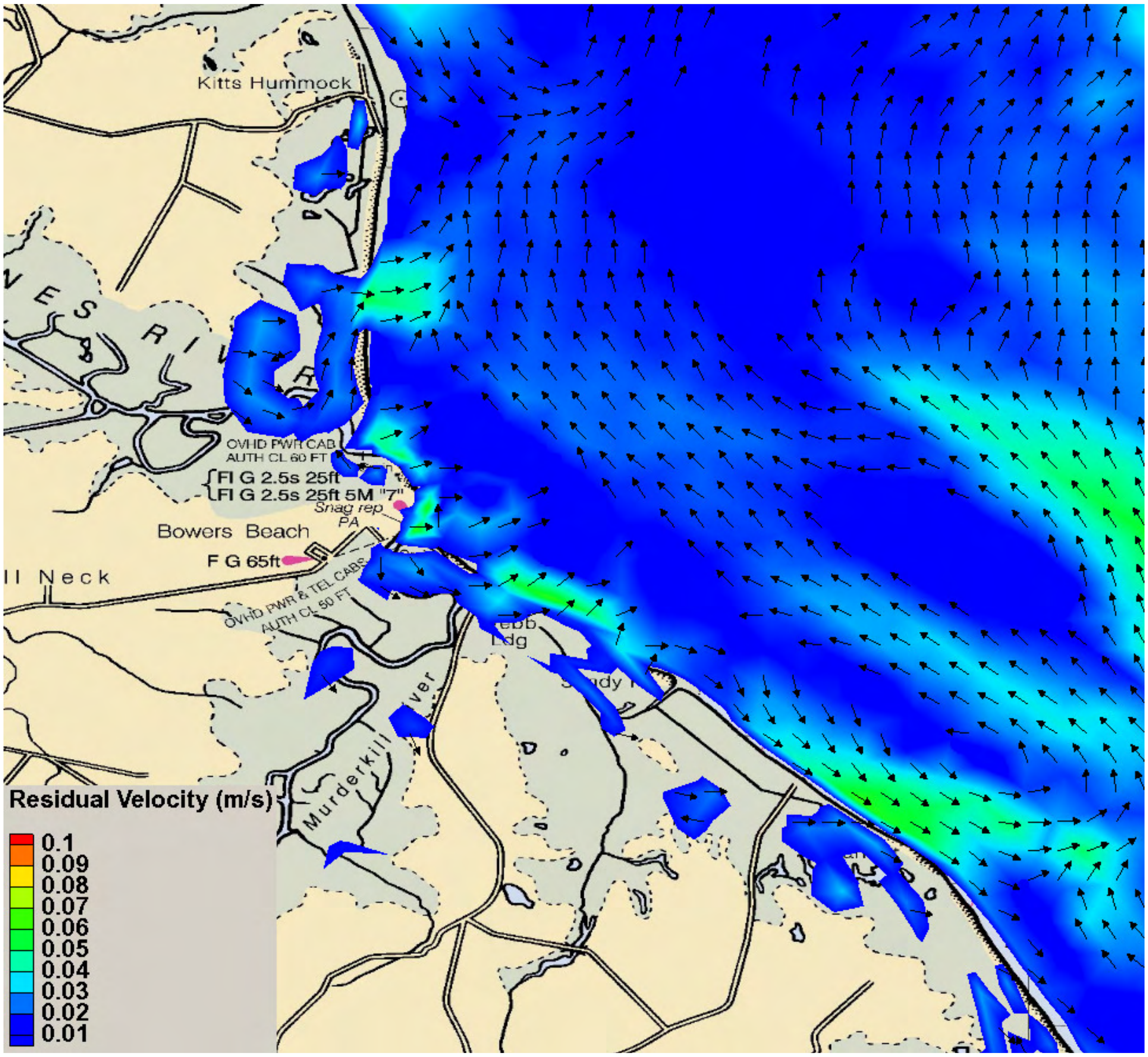


Figure 1.18 Residual currents in the Bowers Beach area; operational conditions.

Offshore of Bowers Beach and South Bowers, there is a distinct residual to the northwest. Nearshore, the net current is moving offshore, perpendicular to the beach.

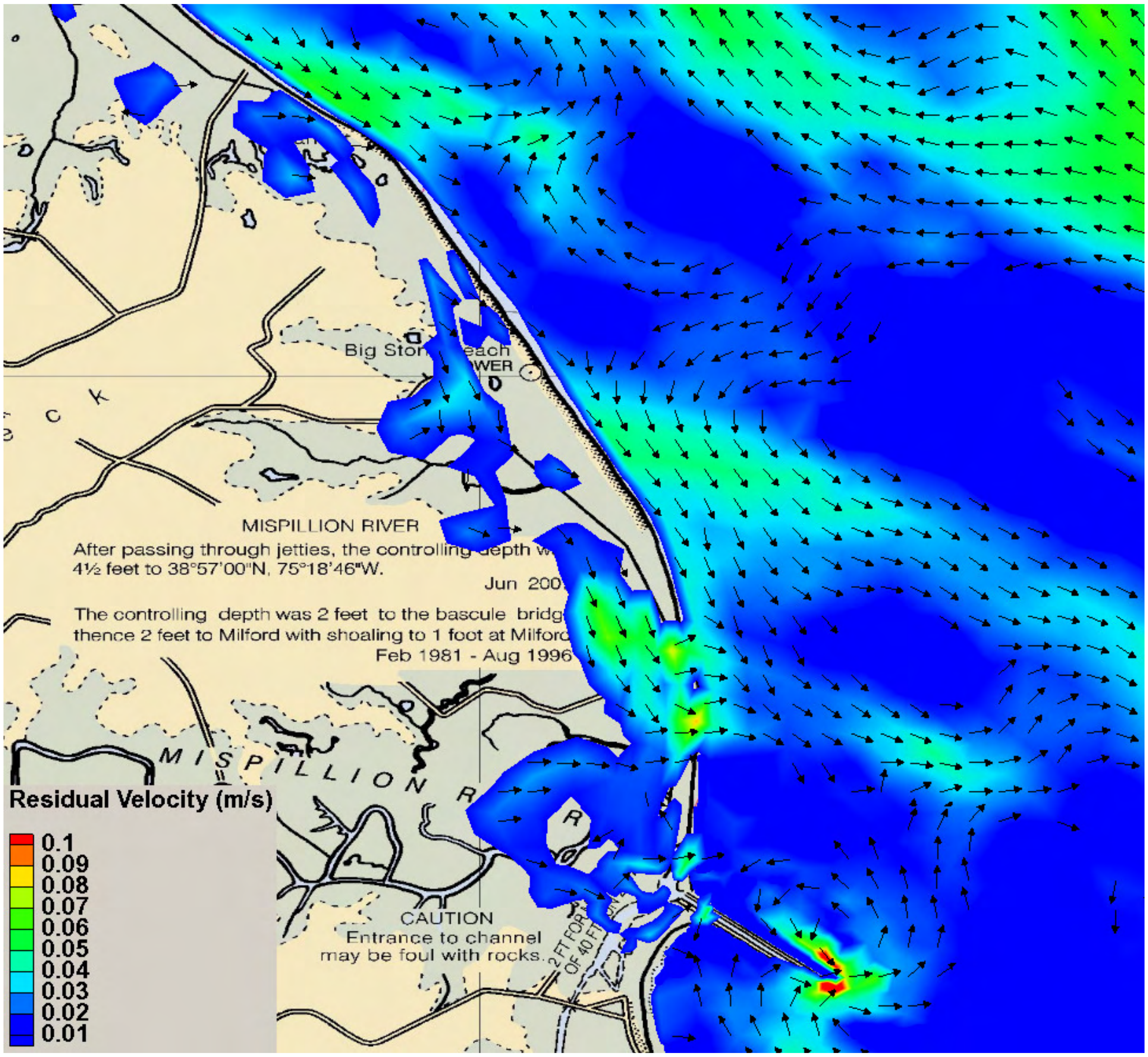


Figure 1.19 Residual currents in the Big Stone Beach area; operational conditions.

In the Big Stone area, residual flows are generally south/southeasterly currents close to shore along with weak residuals offshore.

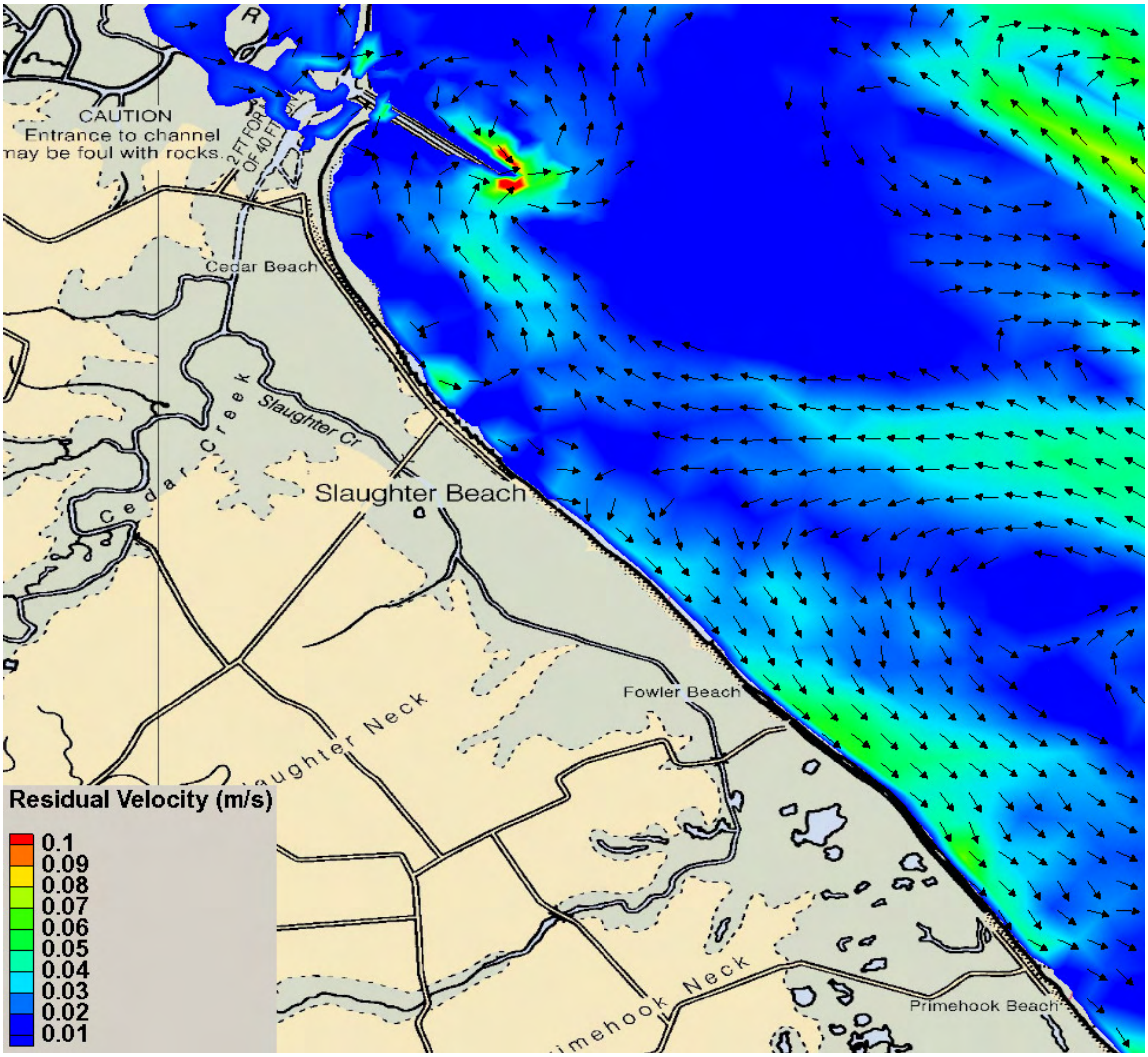


Figure 1.20 Residual currents in the Slaughter Beach area; operational conditions.

At Slaughter Beach, the current close to shore is weak, probably due to the jetties at the channel of the Mispillion Inlet. Along the Fowler Beach shoreline, there is a recurrence of the southeasterly net flow. There is a nodal point in the residual current offshore of Slaughter Beach where the net flow splits to the northwest or southeast.

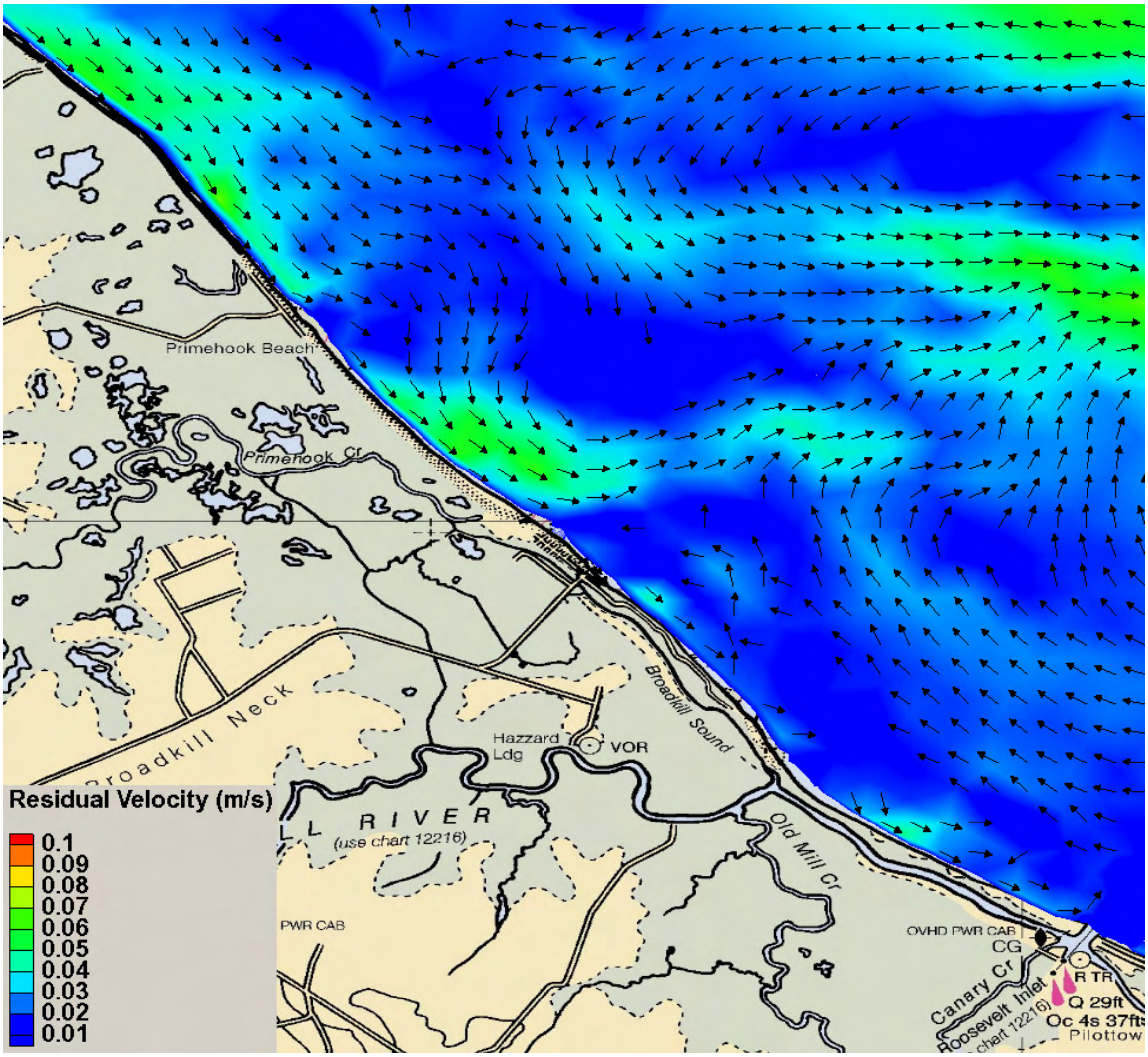


Figure 1.21 Residual currents in the Broadkill Beach area; operational conditions.

In the area from Primehook to just west of Broadkill Beach, there is a generally consistent southeasterly flow along the shore. The alongshore flow from Broadkill Beach south towards Roosevelt Inlet is weakened as a good deal of flow jogs eastward and meets the northwesterly flow further offshore.

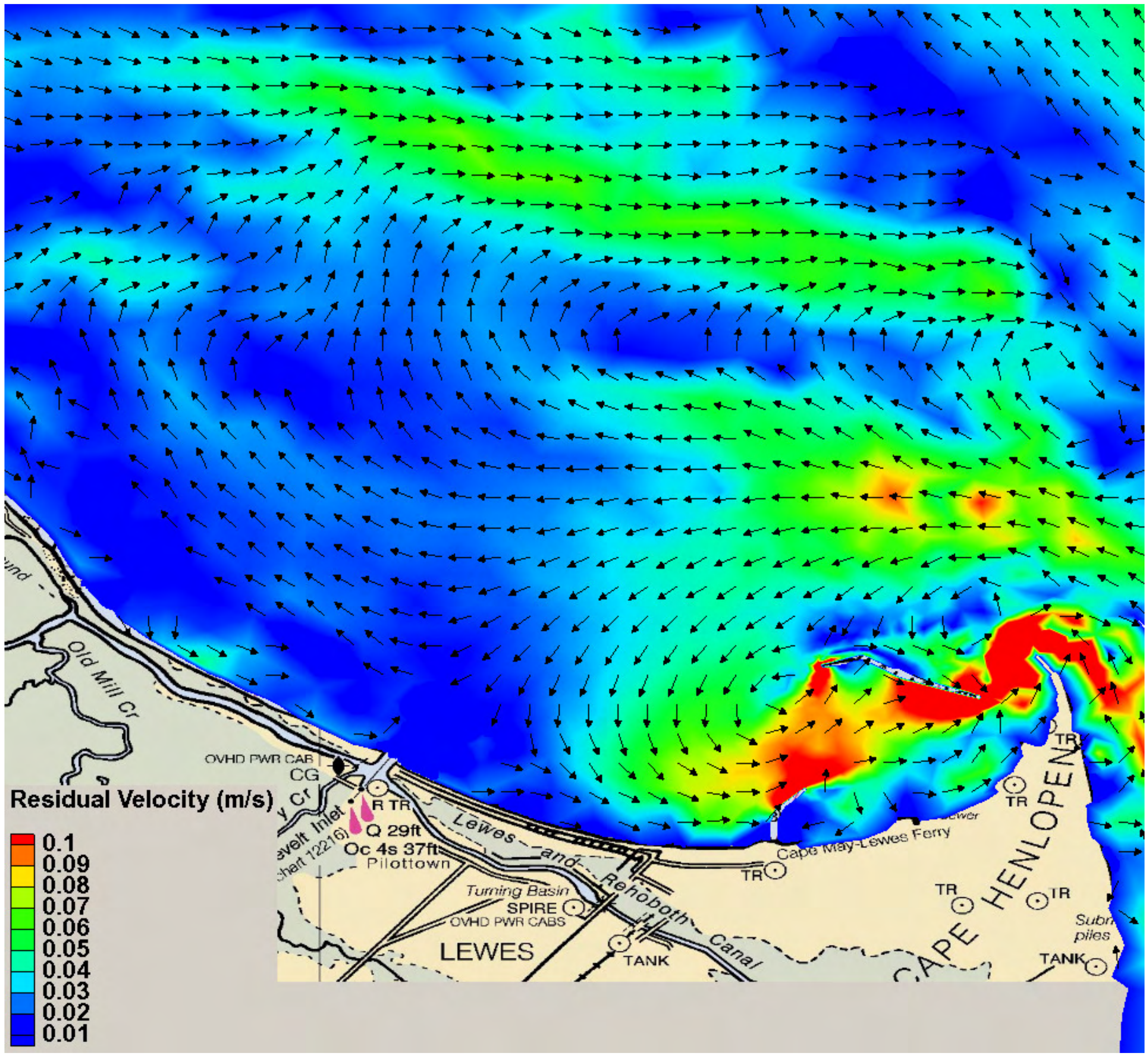


Figure 1.22 Residual currents in the Lewes area; operational conditions.

At the entrance of Delaware Bay, there appears to be a relatively strong net inflow just to the north of Cape Henlopen. As this current curves southward around Lewes Harbor, some of the flow continues up the shoreline towards Broadkill Beach, while a stronger component turns eastward and accelerates into and through Lewes Harbor. Along the bay shoreline, there is a relatively consistent southeasterly flow both north and south of Roosevelt Inlet.

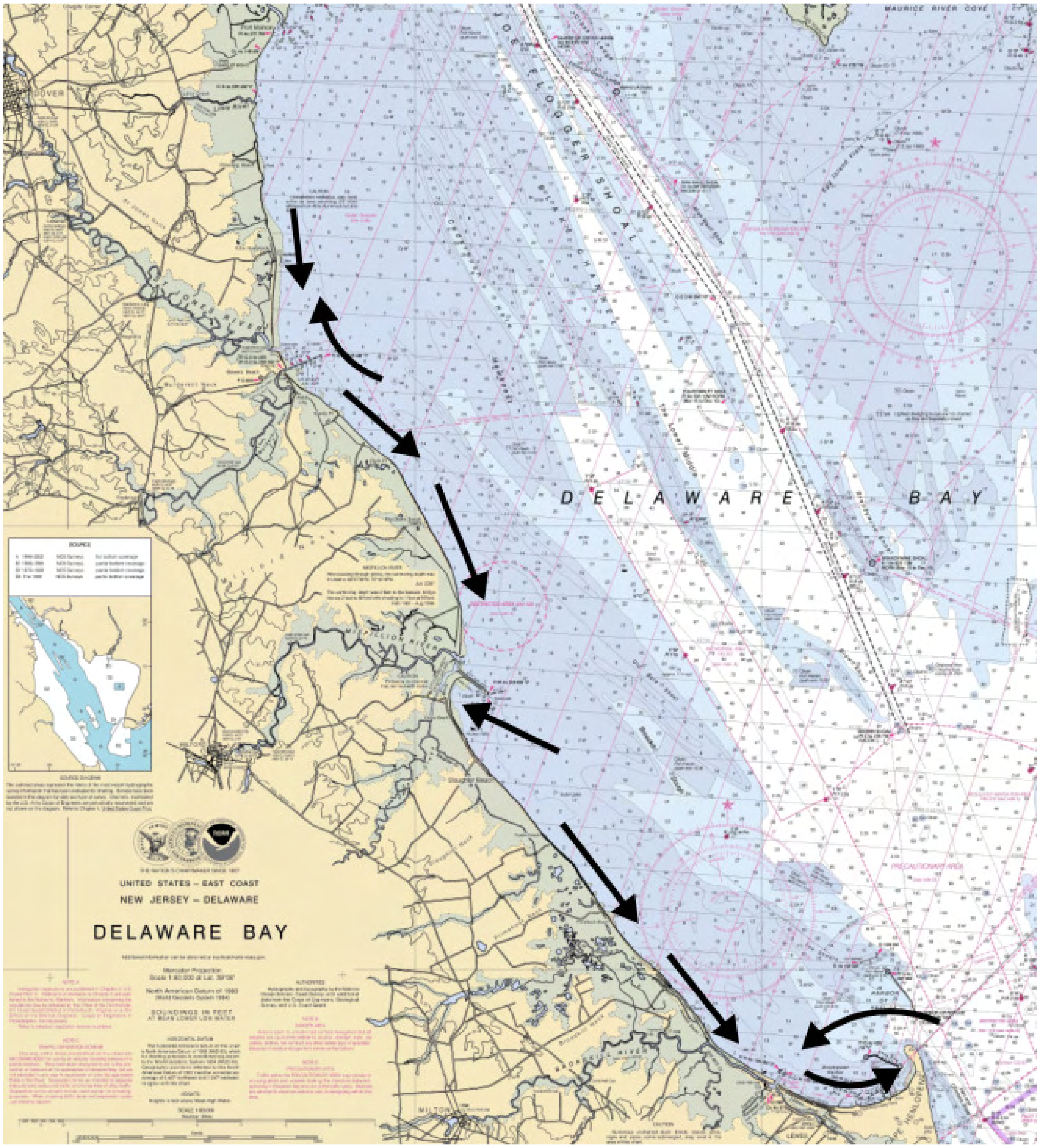


Figure 1.23 Prevailing current patterns along Delaware Bay beaches; operational conditions.

Under the modeled operational conditions, the prevailing nearshore circulation patterns generally show a southerly movement of water along the western shore of Delaware Bay. Exceptions to this trend are a northwesterly flow towards Mispillion Inlet at Slaughter Beach, a northerly flow offshore of Bowers Beach, and westerly flow from the Atlantic Ocean north of Cape Henlopen. The patterns in this model run correlate well with the observed sediment transport patterns from Maurmeyer (1978) except in the area south of Bowers Beach.

1.10 Average Wind, Tide, and Inflow Conditions

Figures 1.24 to 1.29 present the residual current patterns and magnitudes from Pickering Beach to Cape Henlopen for the average conditions model run. Figure 1.30 summarizes the prevailing current patterns on a single map.

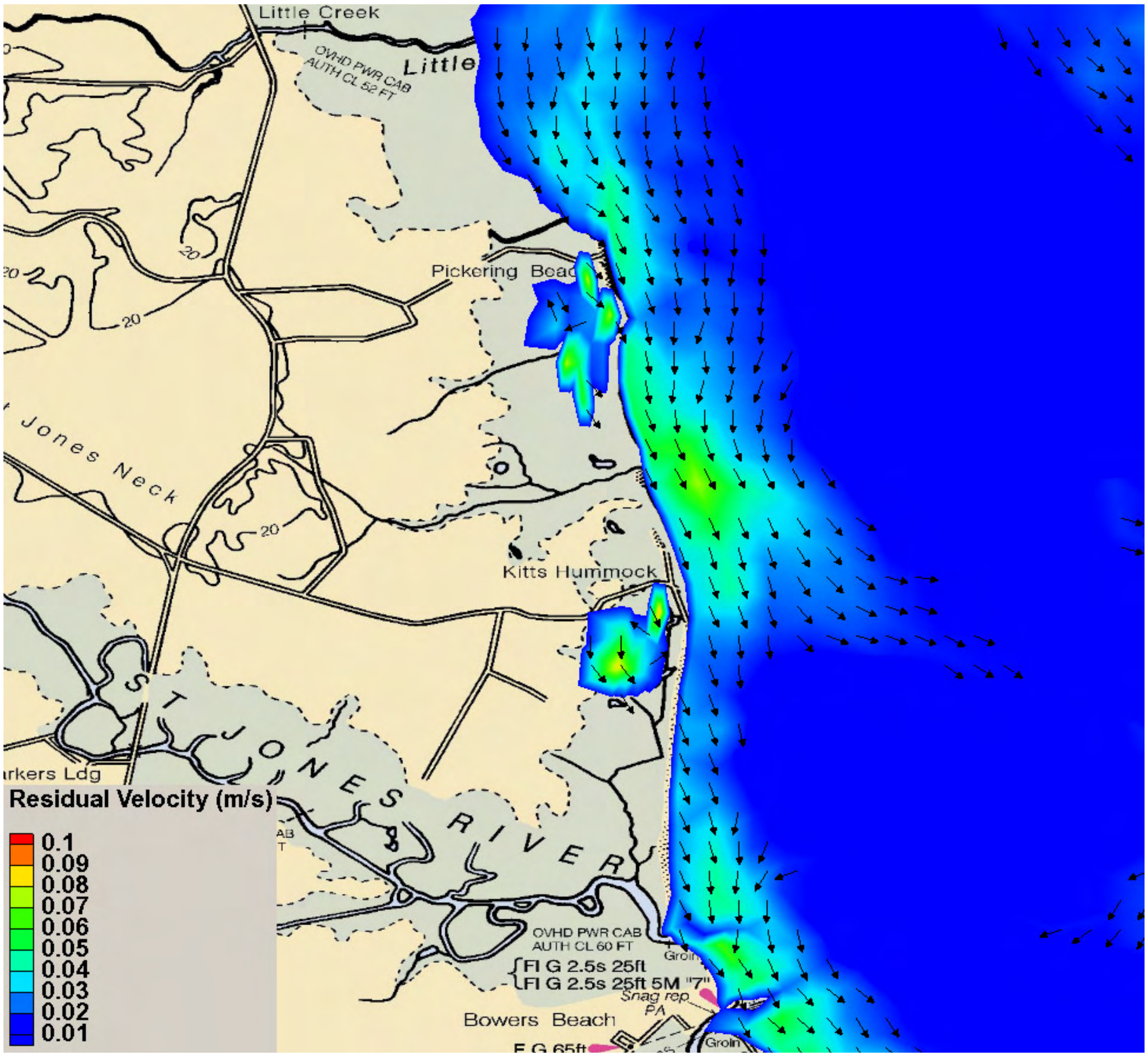


Figure 1.24 Residual currents in the Kitts Hummock area; average conditions.

The Kitts Hummock/Pickering Beach region exhibits a net southerly flow. Little net flow is apparent away from the shoreline.

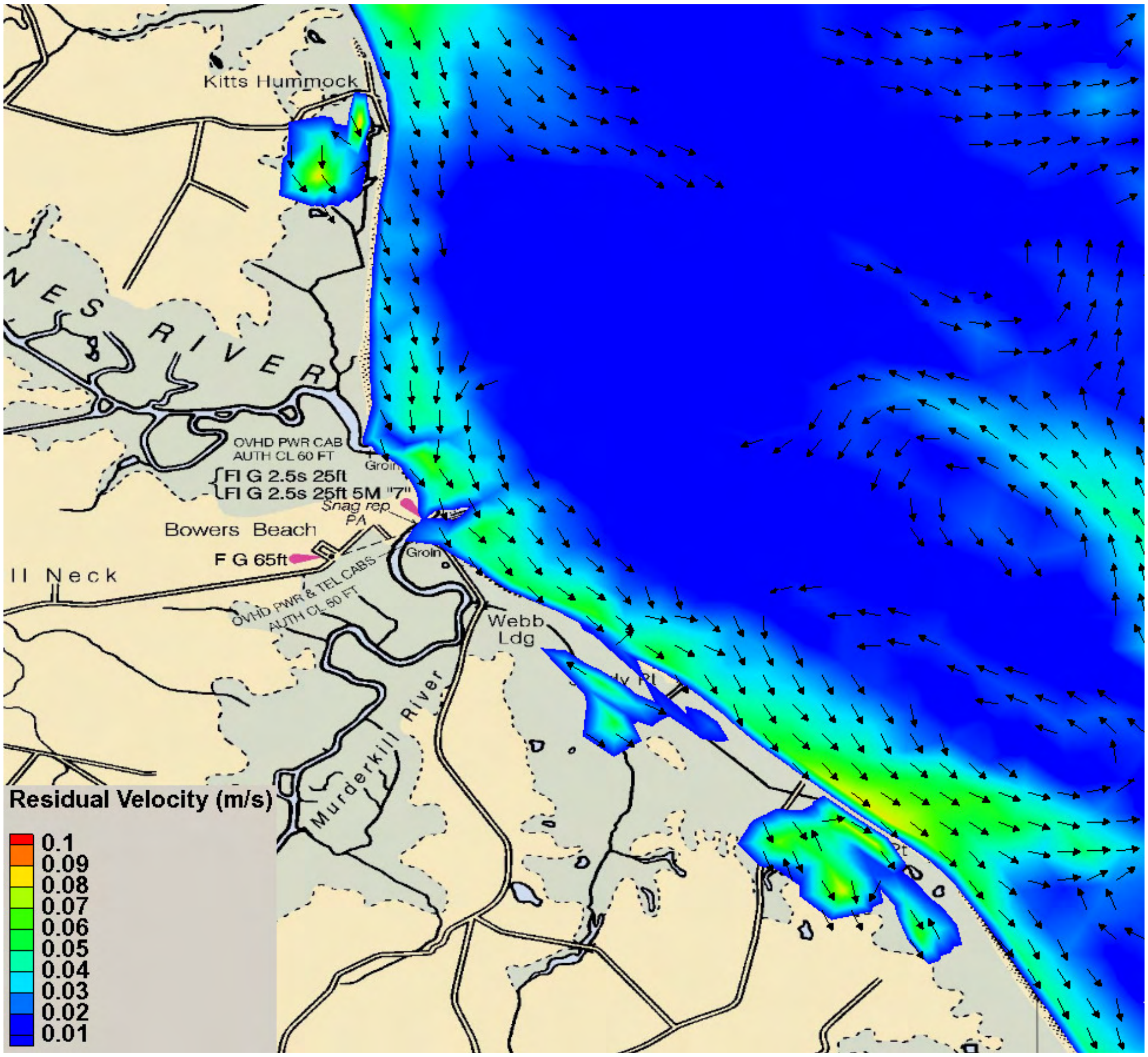


Figure 1.25 Residual currents in the Bowers Beach area; average conditions.

The south/southeasterly net flow trend continues in the Bowers Beach area, with most of the flow concentrated close to shore.

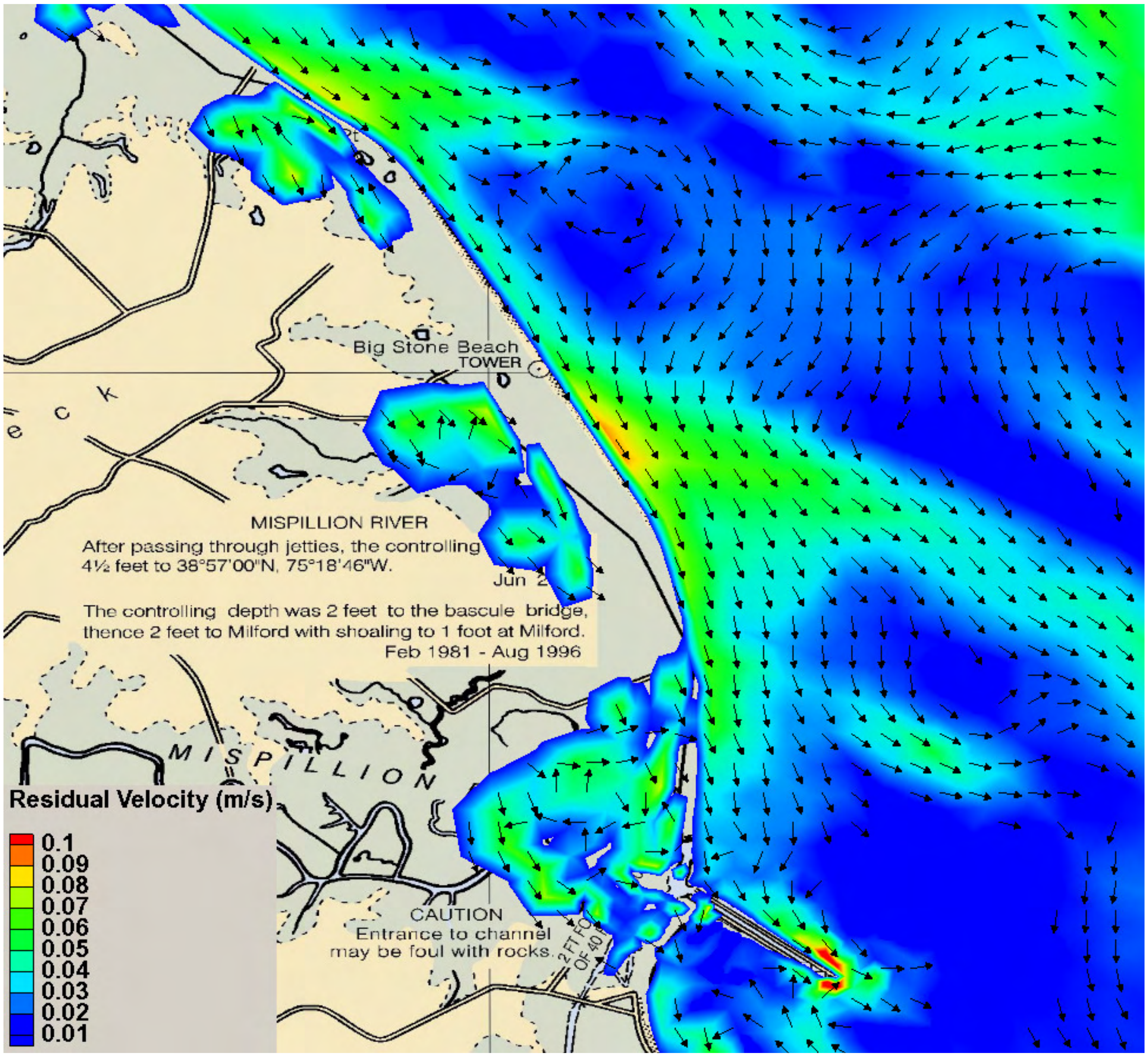


Figure 1.26 Residual currents in the Big Stone Beach area; average conditions.

The Big Stone Beach region exhibits a south/southeasterly net current along the beach. There is a significant increase in net flows just south of the Big Stone Beach tower and on down to the Mispillion delta.

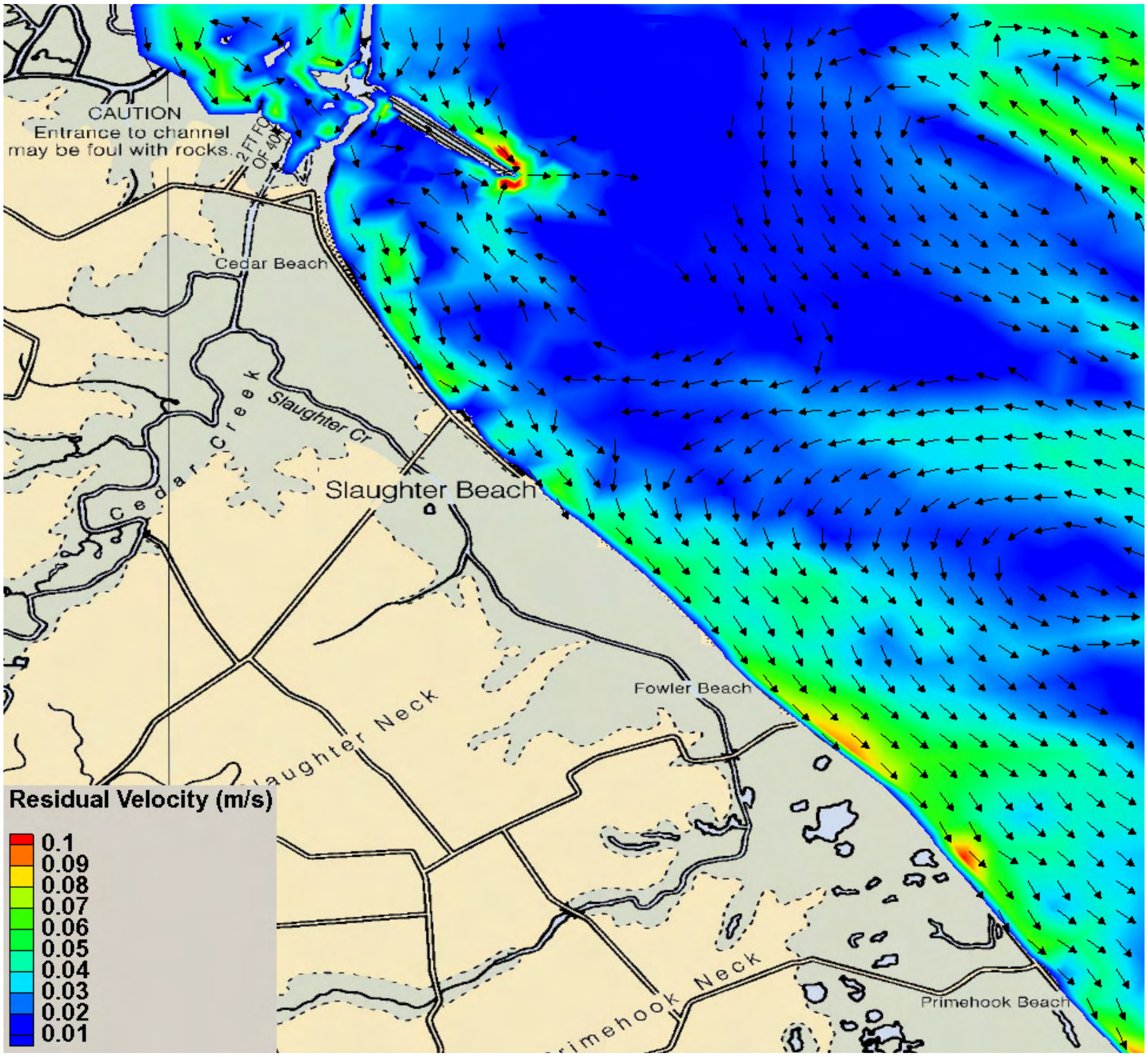


Figure 1.27 Residual currents in the Slaughter Beach area; average conditions.

From Mispillion Inlet southward, the Slaughter Beach area exhibits a southeasterly net flow, with the weak flows near the inlet. Flows converge and strengthen at Fowler Beach southward.

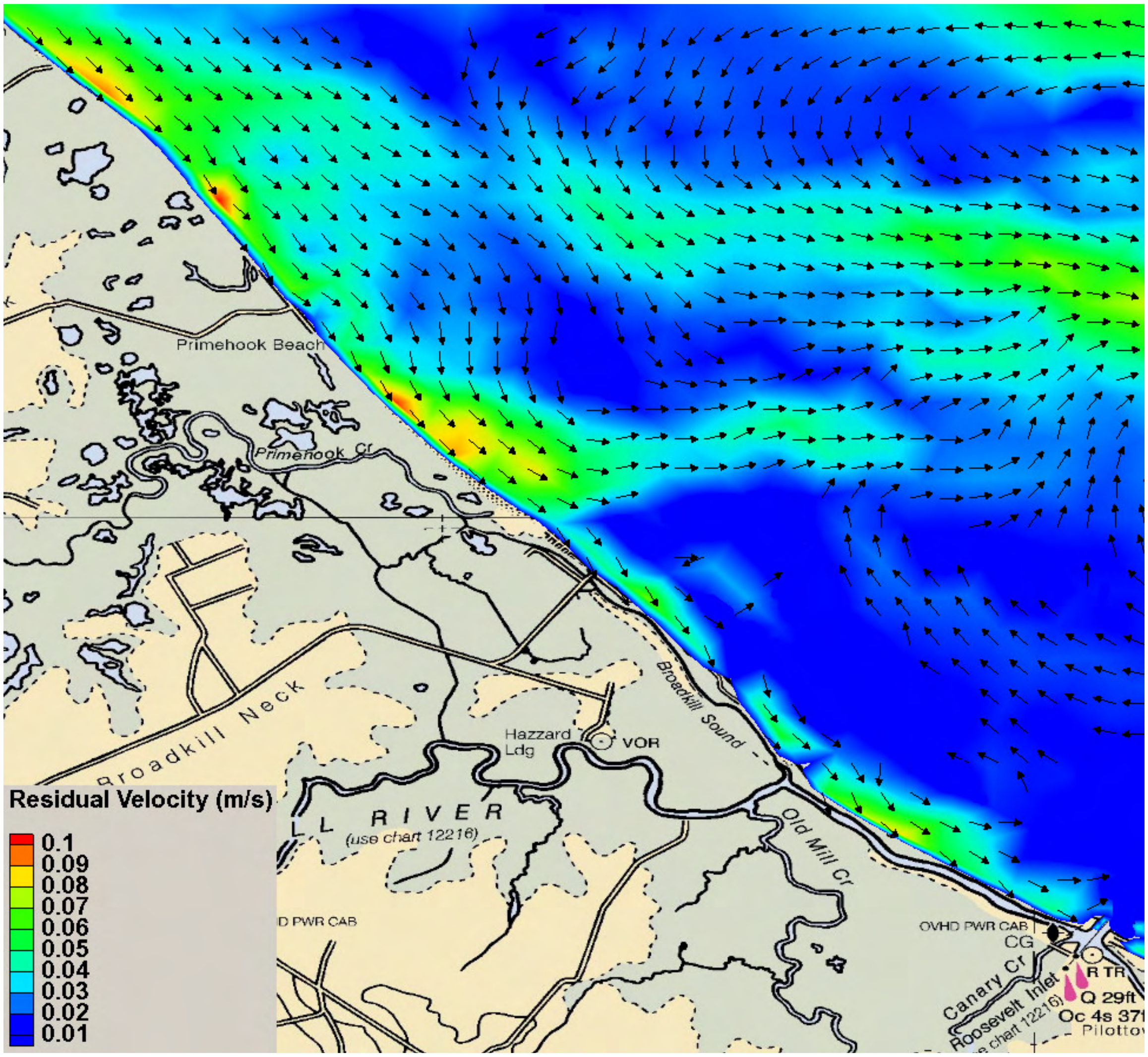


Figure 1.28 Residual currents in the Broadkill Beach area; average conditions.

The region from Fowler Beach to Roosevelt Inlet is characterized by a southeasterly residual flow. The Primehook Beach area has high net flow reaches vastly different from other parts of the shoreline. A flow separation north of Broadkill Beach directs the net flow offshore significantly, reducing the southerly prevailing net currents. This is consistent with the Broadkill area being one of the few historically accretional zones

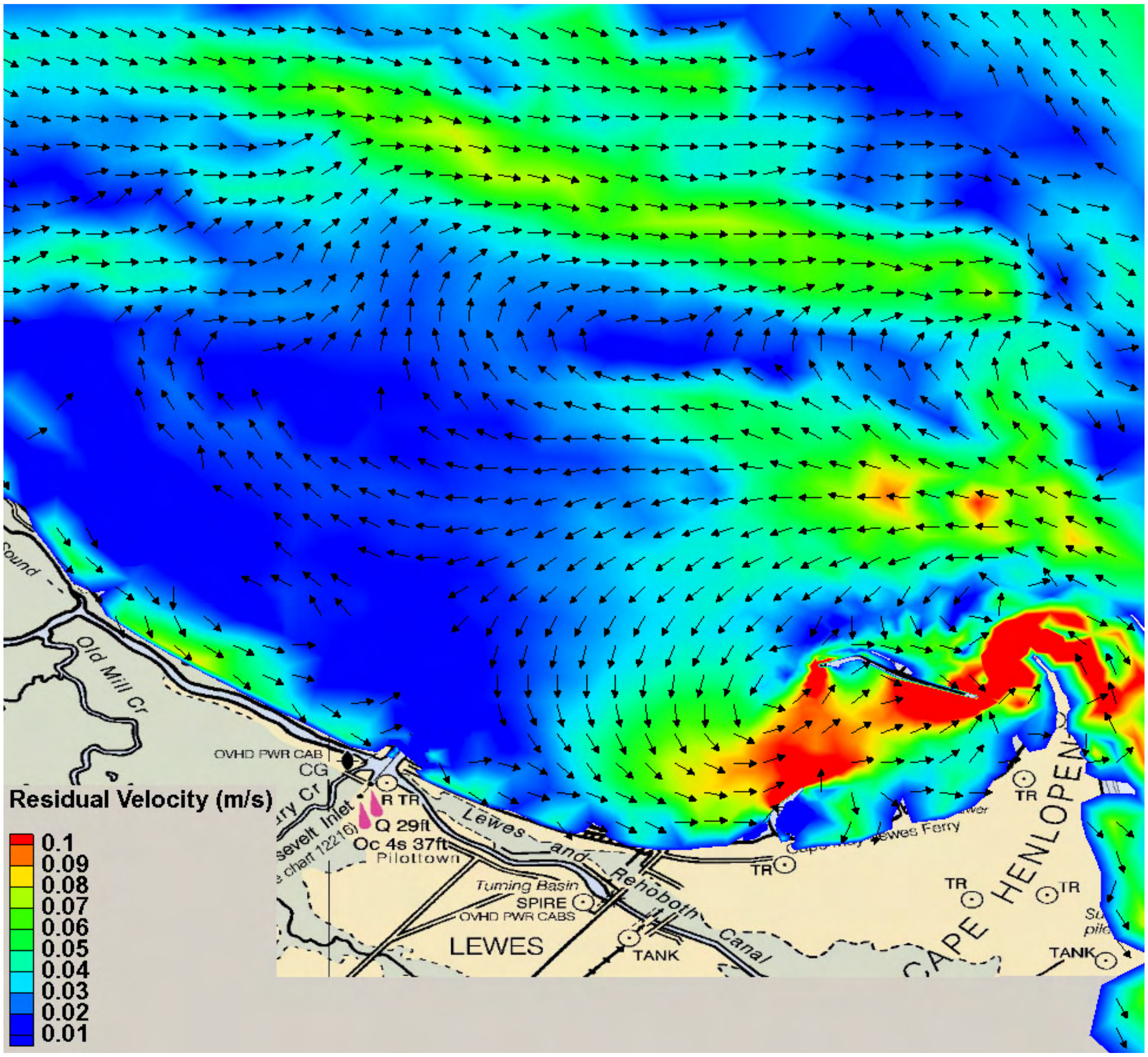


Figure 1.29 Residual currents in the Lewes area; average conditions.

The dominant circulation in the Lewes region is characterized by strong inflow to Delaware Bay just north of Cape Henlopen and a steady southeasterly current in the nearshore from Broadkill Beach to Cape Henlopen. This flow accelerates as it enters Lewes Harbor.

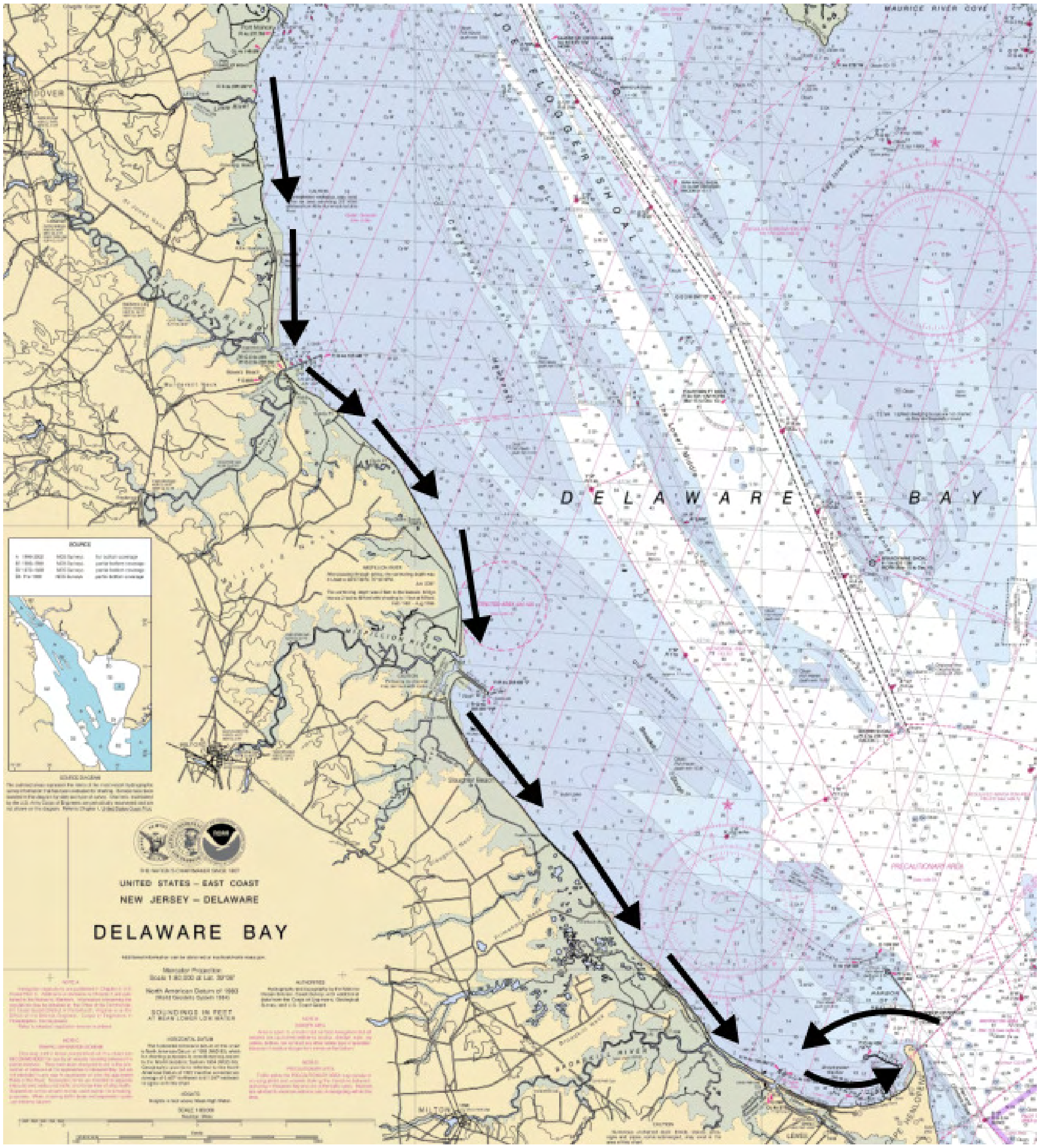


Figure 1.30 Prevailing current patterns along Delaware Bay beaches; average conditions.

Under average conditions with a prevailing NW wind, the net alongshore current is overwhelmingly southward; the only exception being the westerly flow immediately north of Cape Henlopen. This consistent southerly direction supports the longshore sediment transport estimates made in Maurmeyer (1978), wherein each location along the western shore of Delaware Bay experienced a net southerly transport rate.

1.11 2008 Mother's Day Storm

Figure 1.31 illustrates the maximum water surface elevations in Delaware Bay during the 2008 Mother's Day Storm. Figures 1.32 to 1.37 present the residual current patterns and magnitudes from Pickering Beach to Cape Henlopen during the peak of the storm event. Figure 1.38 summarizes the prevailing current patterns on a single map.

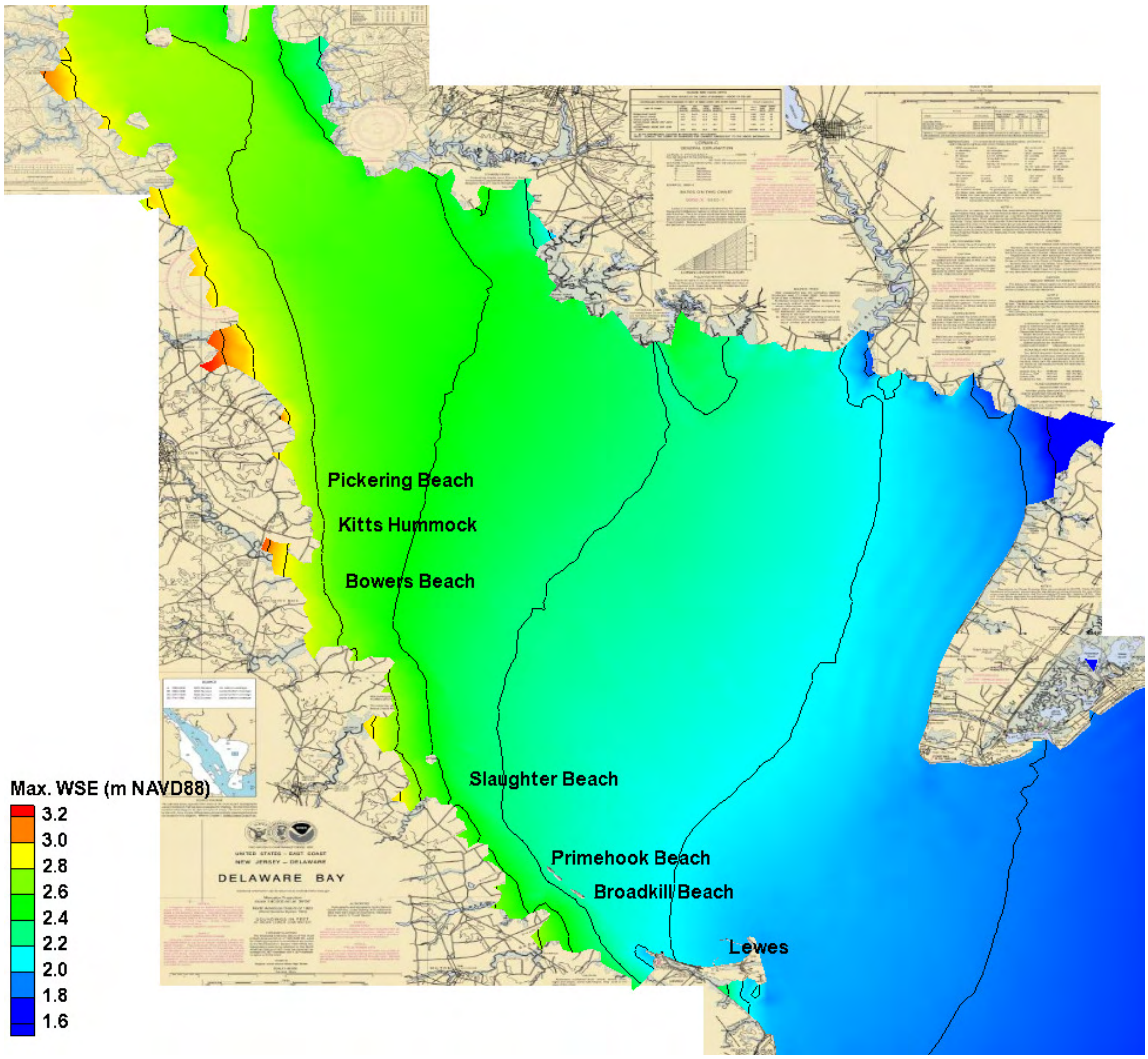


Figure 1.31 Maximum storm surge in Delaware Bay; 2008 Mother's Day Storm.

It is apparent from the map of storm surge that the strong northeast wind during the height of the storm had a dramatic effect on the resulting surge. This wind effectively 'piled up' water on the western shore of the bay, resulting in much higher surge levels for beaches in Delaware than those in New Jersey. The funnel shape of Delaware Bay also caused the surge to be amplified at the northern beaches; the modeled storm surge for Lewes was 1.9 m NAVD88, while Pickering Beach experienced a 2.6 to 2.8 m surge, nearly 50% larger. Some of the river channels and back bays experienced local surge focusing, with elevations reaching 3.2 m NAVD88. Because nor'easters are a common type of extreme event in the region, this result highlights the heightened susceptibility of communities on the western shore of Delaware Bay.

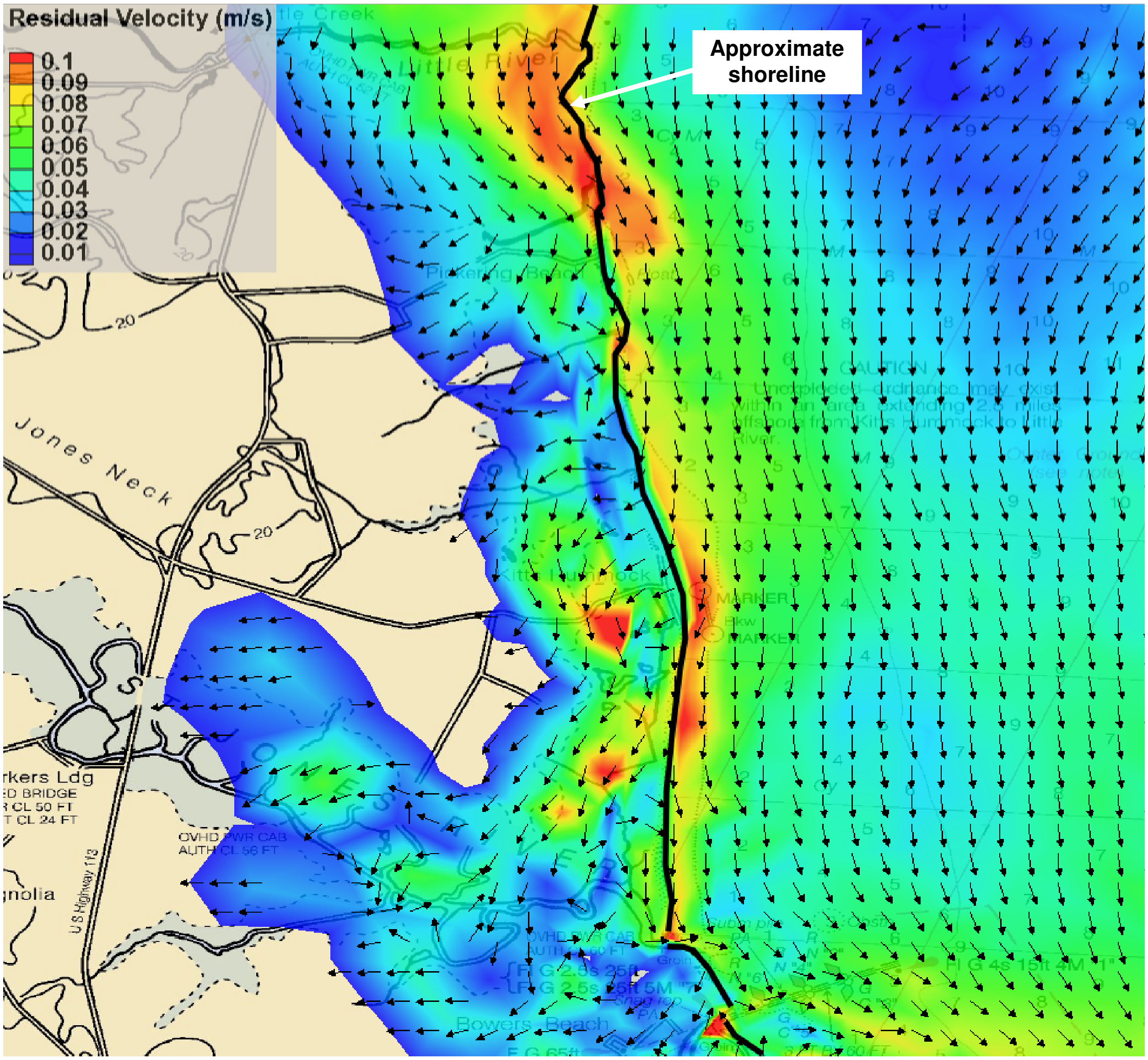


Figure 1.32 Residual currents in the Kitts Hummock area; 2008 Mother's Day Storm.

The model results demonstrate a prediction of flooding of the coastal zone. A southerly alongshore current pattern dominates the Kitts Hummock/Pickering Beach area with residual flows significantly higher than average conditions at the shoreline.

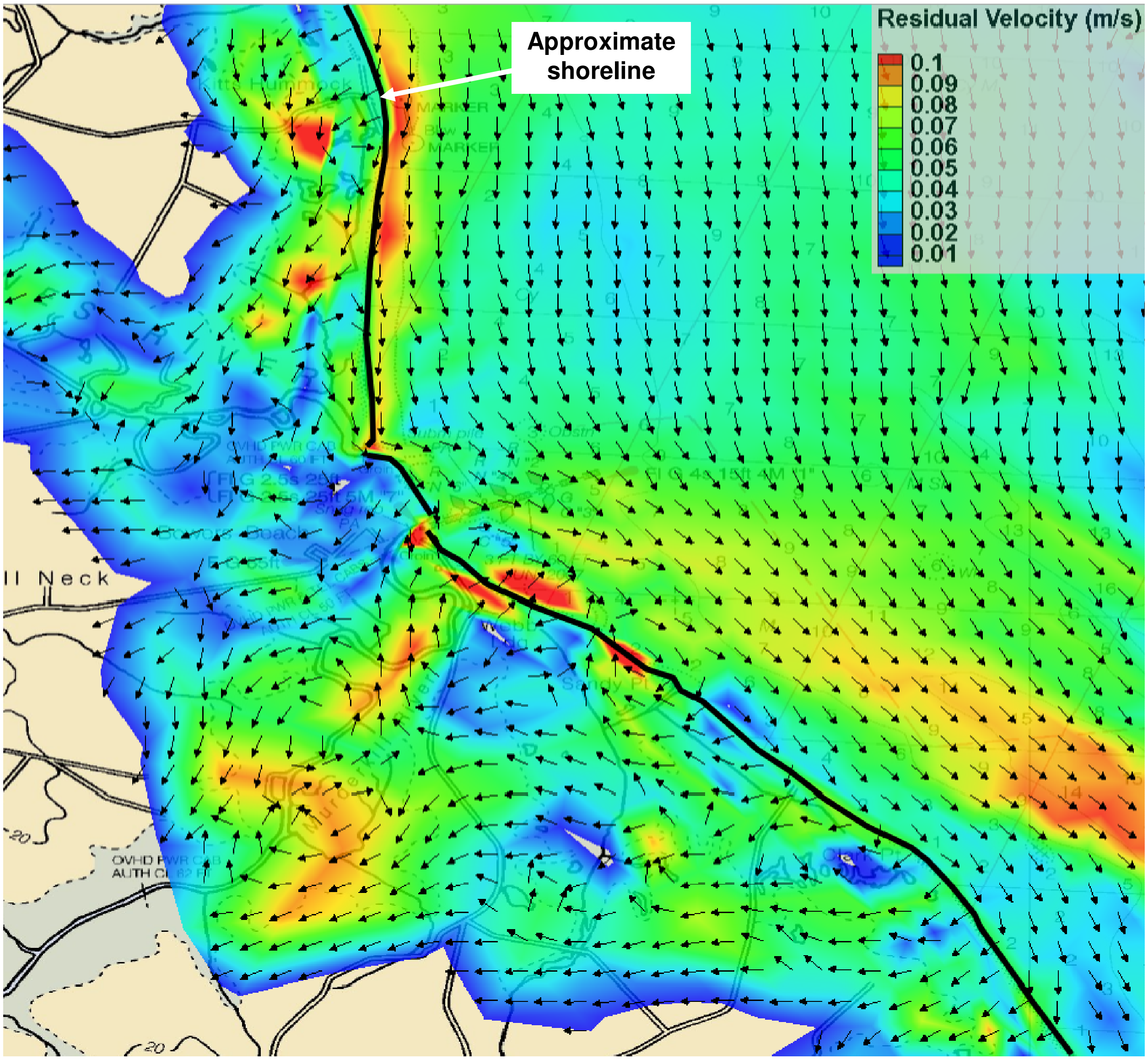


Figure 1.33 Residual currents in the Bowers Beach area; 2008 Mother's Day Storm.

There is a strong landward net flow in the Murderkill River delta southeast of Bowers Beach, while the shoreline of South Bowers exhibits offshore flows. Along the shoreline, currents are consistently south/southeasterly.

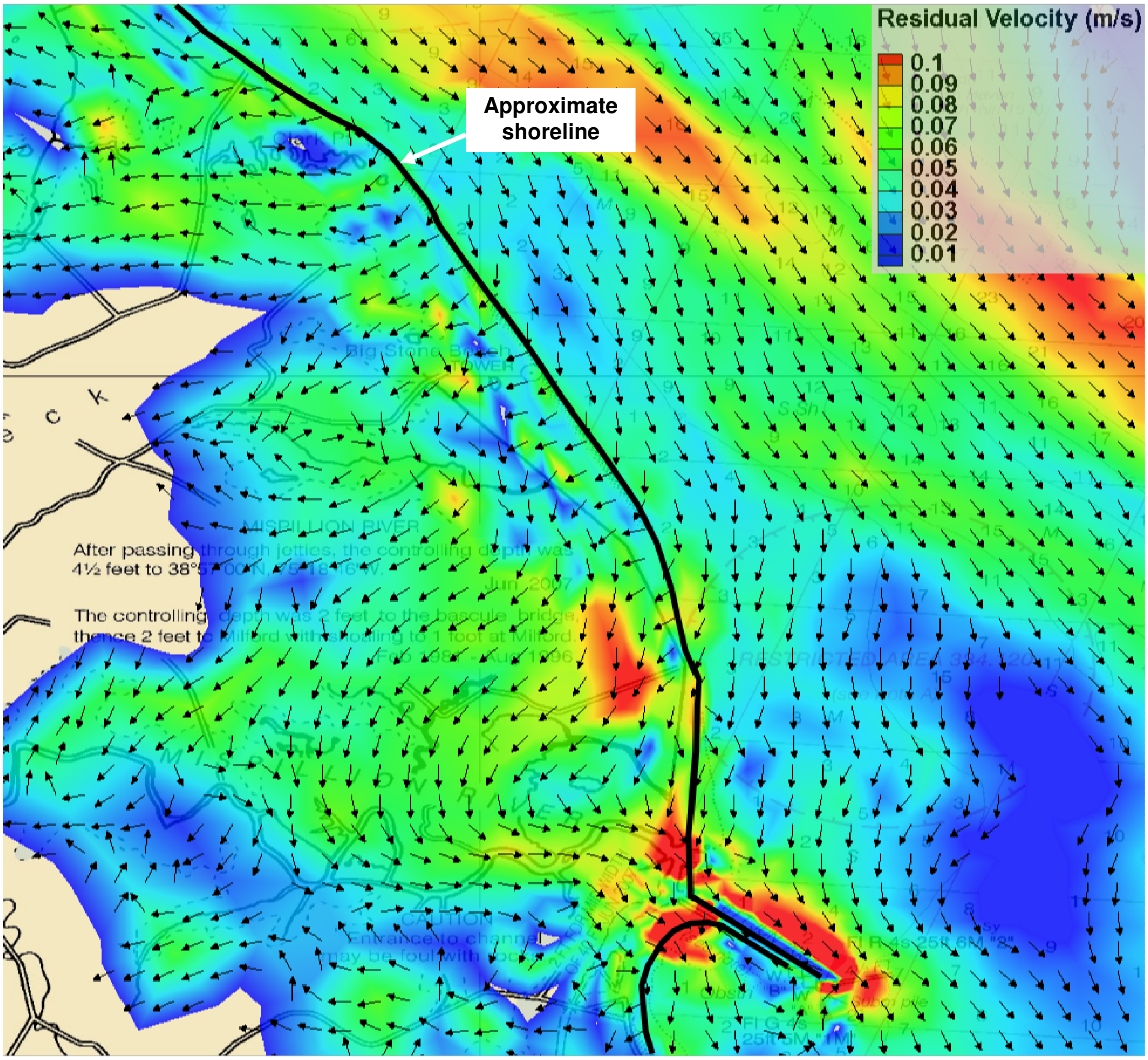


Figure 1.34 Residual currents in the Big Stone Beach area; 2008 Mother's Day Storm.

The marsh behind the Mispillion Inlet is severely flooded. There is a good deal of landward net flow in the flooded regions. Along the shoreline, net currents are directed to the southeast.

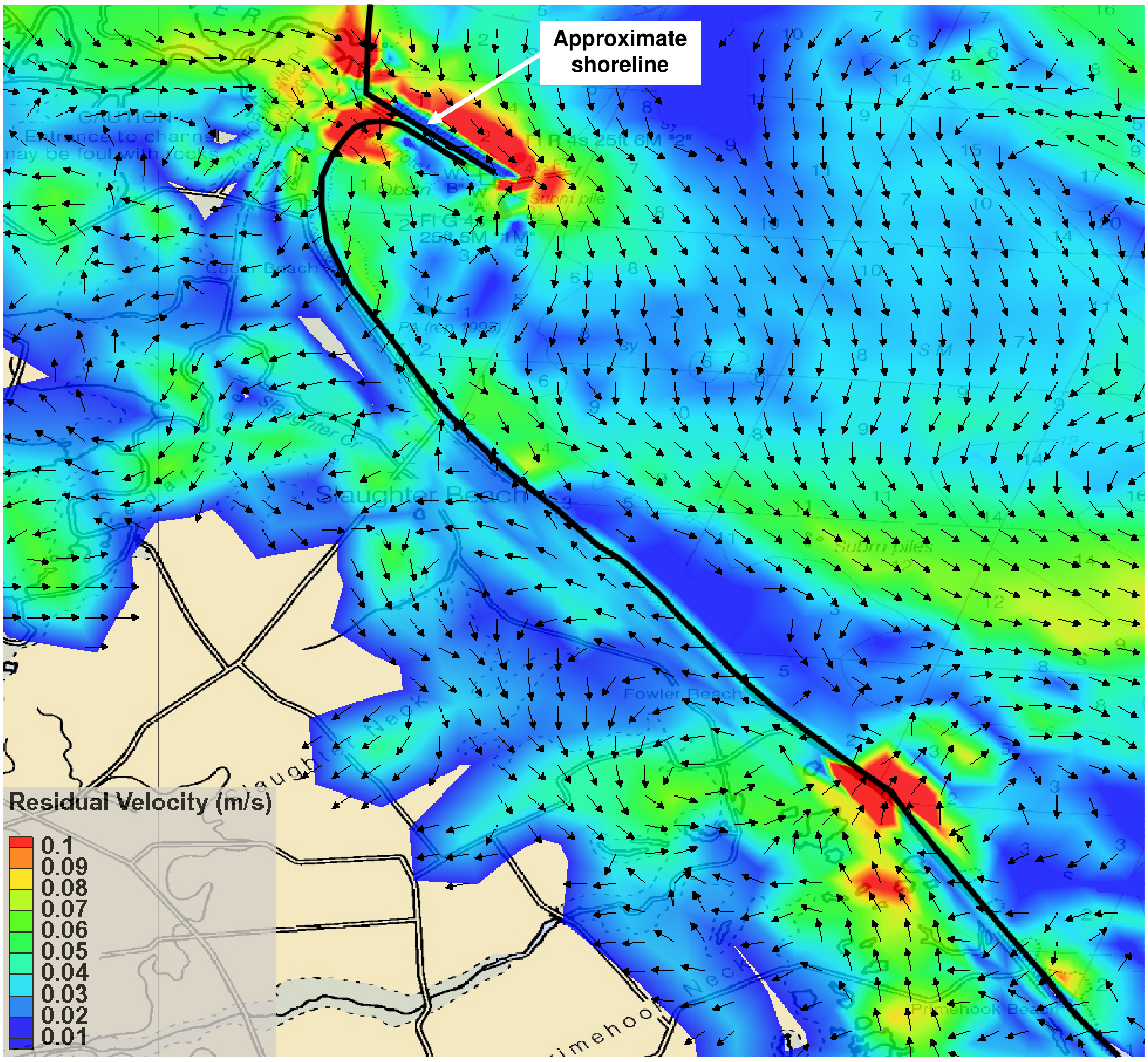


Figure 1.35 Residual currents in the Slaughter Beach area; 2008 Mother's Day Storm.

There is a high amount of net outflow through the Mispillion Inlet, along with southerly alongshore flow adjacent to Slaughter Beach. Flooded areas show net landward flow, and there is a concentrated area of offshore flow between Primehook and Fowler Beach.

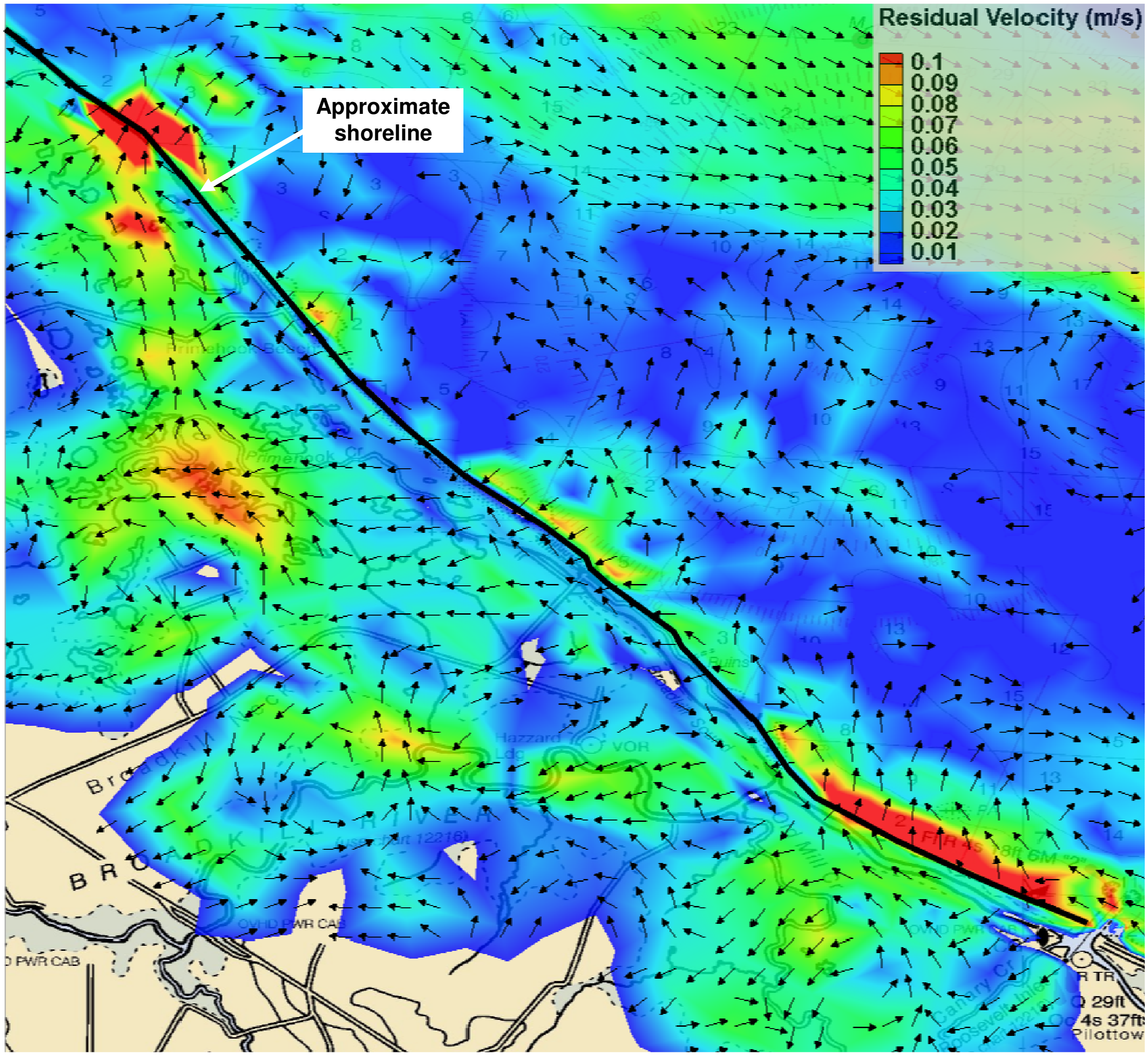


Figure 1.36 Residual currents in the Broadkill Beach area; 2008 Mother's Day Storm.

Similar to the patterns seen around Lewes, residual currents are generally perpendicular to shore rather than parallel. Broadkill Beach itself experiences net overwash, while there are strong outflows north of Roosevelt Inlet and between Primehook and Fowler Beach. Much of the flooded land and back bay areas exhibit net onshore flow.

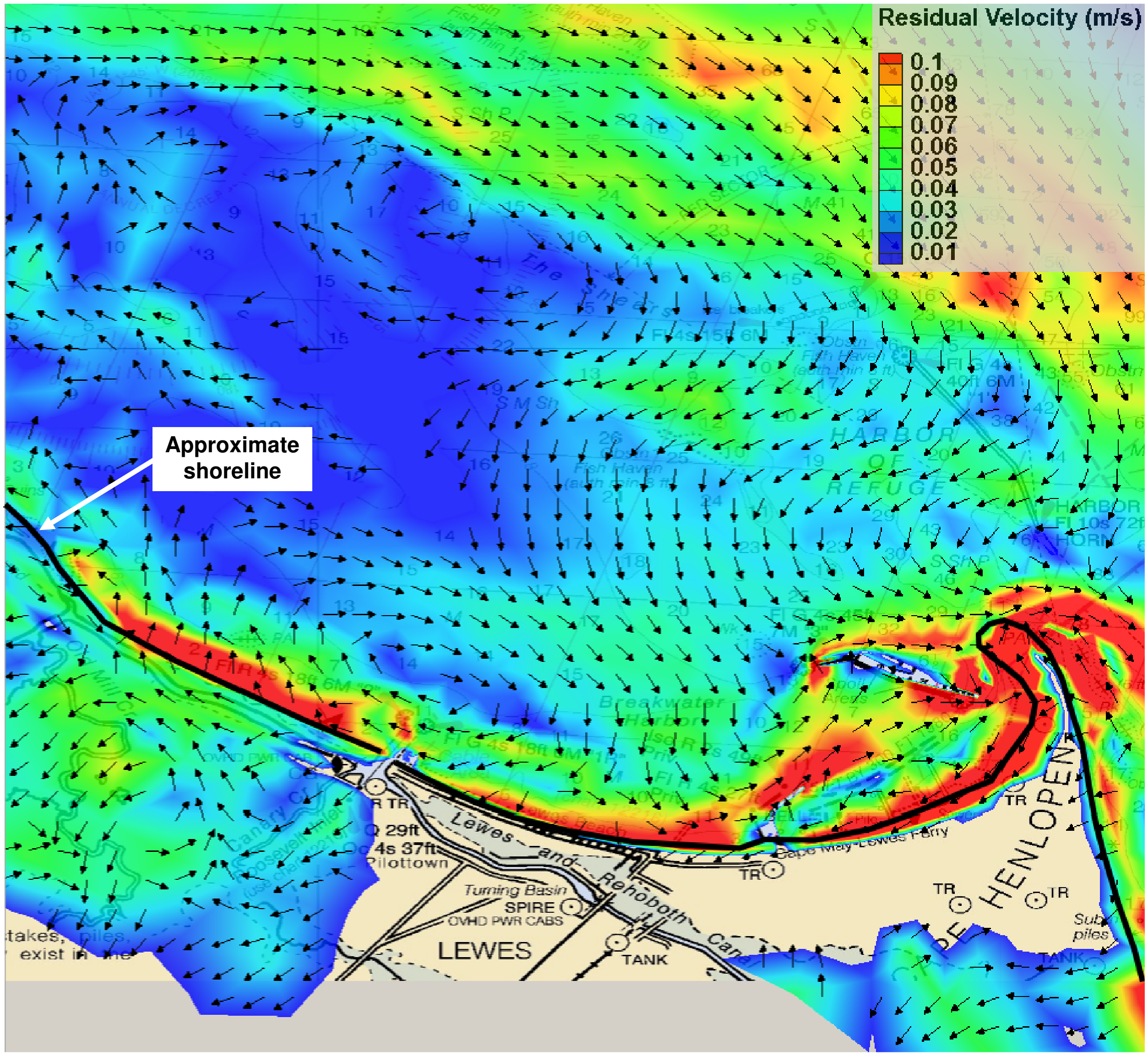


Figure 1.37 Residual currents in the Lewes area; 2008 Mother's Day Storm.

The net flow during the 2008 Mother's Day Storm is markedly different than that observed under less extreme conditions. The most dramatic difference is the extent of flooded upland areas. Strong currents of 0.1 m/s and higher are directed offshore north of Roosevelt Inlet, while a net flow landward exists in the flooded areas. There is also a strong seaward current just north of Cape Henlopen, which did not occur under less extreme conditions.

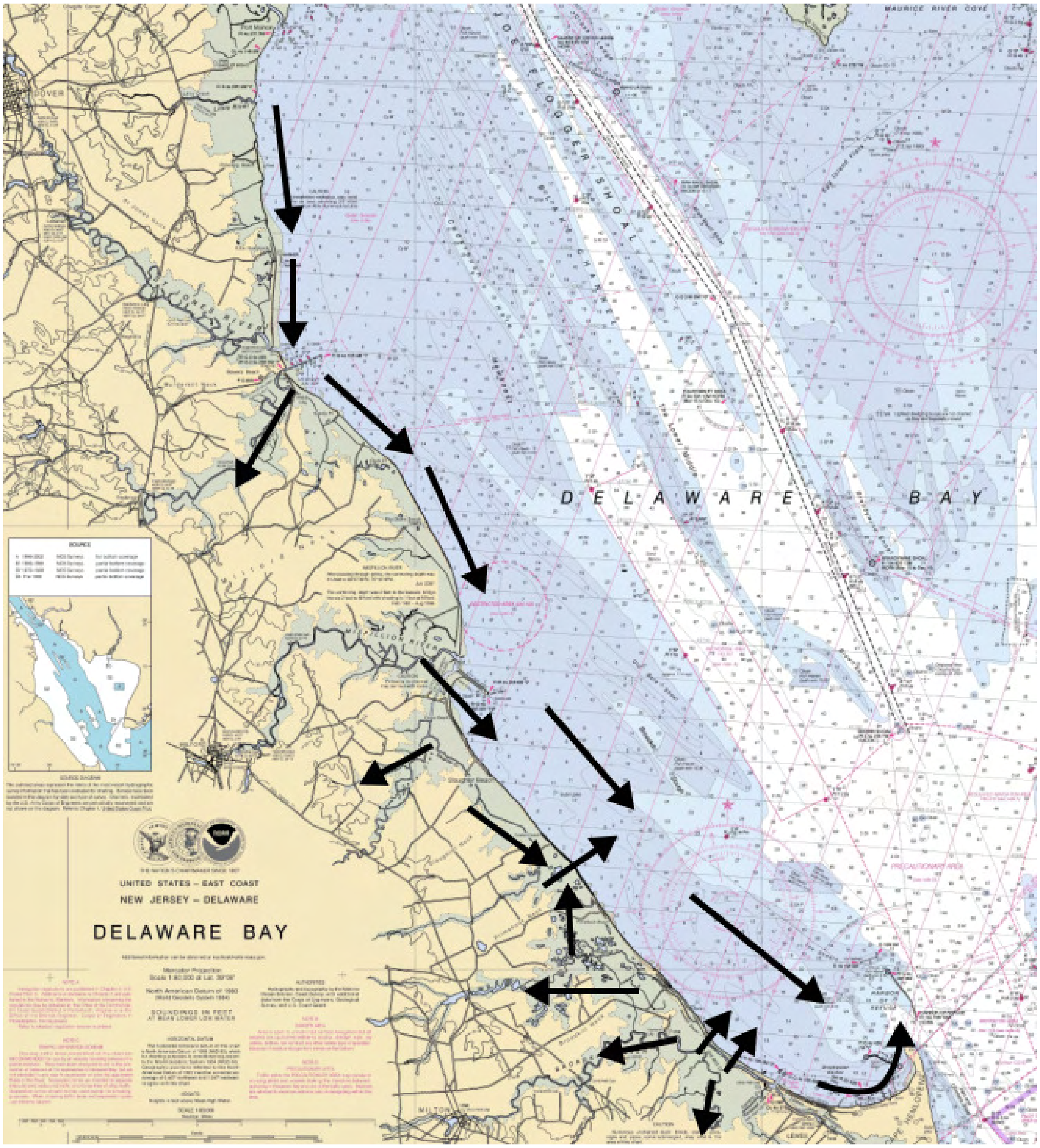


Figure 1.38 Prevailing current patterns along Delaware Bay beaches; 2008 Mother's Day Storm.

The predominant net circulation along the Delaware Bay shoreline during the 2008 Mother's Day Storm is that of south/southeasterly flow. Even at Cape Henlopen, net flow is directed out of the bay. Close to shore, there are many localized areas where the dominant flow is perpendicular to shore; most notable of these areas is between Primehook and Fowler Beach, where net currents in excess of 0.1 m/s define an offshore flow channel in a low-lying marsh area. This is suggestive of a breach location, and while the net flow may be offshore during the storm, the resulting breach could allow normal tides to reach the marsh, leading to saltwater intrusion. In many flooded areas, especially the river basins, the net circulation is directed landward, implying that more water is being pushed upland during the storm than is flowing back to the bay. This suggests that sediment transported onshore through rivers and barrier overwash may remain trapped in the coastal back bays. Essentially, these back bays may become traps, or sinks, of sediment that was once on the beach, and this material is unlikely to return to the beach face quickly enough to offset critical beach erosion caused by the storm.

1.12 Modeling Conclusions

The ADCIRC model was used to simulate the residual circulation patterns of three physical scenarios: operational conditions with measured wind, inflow, and tide conditions; average conditions with mean wind, flow, and predicted tide levels; and the 2008 Mother's Day Storm. Examining the net flow patterns and magnitudes for these circumstances offered insight into the pathways that dominate water movement, and likely sediment transport, along the western shore of Delaware Bay during both normal and extreme events. Examination of net transport directions and areas of localized current acceleration/deceleration in the model results were combined with local observations of past beach fill behavior to develop strategic beach fill placement options; this is discussed in detail in subsequent sections of this report.

Under operational conditions, which were represented by a 'snapshot' in time of measured wind, flow, and tides, the dominant nearshore net flow was in a south/southeasterly direction, towards the mouth of the bay. Exceptions to this trend were a northerly flow offshore of Bowers Beach and a northwesterly current towards Mispillion Inlet. These patterns correlate well with the observed longshore sediment transport directions found in Maurmeyer (1978).

With average forcing conditions applied, the net alongshore circulation was uniformly southeasterly towards the mouth of the bay at all beaches of interest. The exception to this was a westerly flow entering the bay just north of Cape Henlopen. Figure 1.29 illustrates these flow patterns. These patterns agree with the longshore transport directions calculated in Maurmeyer (1978); each location along Delaware's bay coast was calculated to have a net southerly sediment transport.

The 2008 Mother's Day Storm was a significant extreme event for the Delaware Bay beaches. Strong northeast winds amplified the surge on the western shore of the bay, and the bay's funnel shape caused the maximum surge elevation to increase in the upstream direction. The model estimated surges ranging from 1.9 m at Lewes to 2.8 m at Pickering Beach, with some river basins experiencing local water level focusing up to 3.2 m (NAVD88).

Figure 1.38 presents the net circulation patterns during the storm peak. Offshore of the bay beaches, the net circulation direction was southerly; however, patterns were varied in the nearshore. Certain beaches, most notably Fowler Beach and Broadkill Beach, experienced high net offshore flow, possibly indicating barrier breach locations where flood waters that initially overwashed the dune system concentrated and returned to the bay. These localized breaches can have impacts long after the initial storm, with continued saltwater intrusion possible due to normal tidal variation through the newly-created channel.

In many of the flooded river basins and back bays along the shoreline, the net flow direction was in the landward direction, away from Delaware Bay. This may be evidence that sediment from the beaches may be transported into the rivers and back bays during a storm and deposited there, as there is not a strong enough outflow current to remobilize the sediment and return it to the beach. This would result in the coastal back bays behaving as a sink, or trap, of beach material.

2. Wave Modeling

2.1 Introduction

In support of the ADCIRC circulation model described above, a wave development and propagation model was created using the STWAVE model (USACE) and the SMS graphical interface. STWAVE is a steady-state spectral wave propagation model that incorporates wave refraction, wind wave growth, shoaling, and breaking. This wave model will assist in determining the predominant directions and pathways of hydrodynamic and sediment transport along the Delaware Bay coastline under both offshore wave dominated and local wind wave dominated scenarios.

2.2 Data Sources

The bathymetry and topography for the STWAVE model was taken from the same sources as those in the ADCIRC model described in Section 6.2. The model was driven by offshore waves and wind; the offshore wave data was developed using data from NOAA Buoy 44009, and wind data was adapted from Maurmeyer (1978). These data sources are described in detail in Section 5.2 of the Management Plan.

Figures 2.1 and 2.2, respectively, illustrate the seasonal histograms and cumulative distribution functions (CDFs) for the wave data from Buoy 44009. The histograms illustrate the percentage of wave occurrences within a certain range of wave heights. The CDFs show the percentage of wave occurrences falling below a certain wave height limit or threshold.

2.3 Model Grid Development

STWAVE is run on a rectilinear, uniform Cartesian grid. The x-axis of the model was defined roughly parallel to the central axis of Delaware Bay; the offshore boundary is close to NOAA Buoy 44009, and the inshore boundary lies along the northern end of Bombay Hook. Grid spacing was fixed at 400 m; this allows for reasonably quick computation times while providing enough resolution to investigate wave field differences at each location of interest. Figure 2.3 illustrates the model domain and bathymetry.

2.4 Boundary Conditions

The STWAVE model was driven by offshore waves as well as local winds. A total of ten scenarios were modeled; two for each season (annual, winter, spring, summer and fall), both with and without the offshore wave component applied. The offshore wave input spectrum was constructed using the JONSWAP spectrum, assigning direction, significant wave height, and peak period. Direction was the prevailing direction estimated from the wave roses in Figure 5.5. Significant wave height was the average significant wave height during the season of interest. Peak period was the mean period during that season.

Data from Maurmeyer (1978) was used to determine the wind fields for each season. The wind fields were uniform, defined as the mean wind speed during the period from Table 5.2 and the prevailing direction from Figure 5.1. Table 2.1 outlines the wind and wave data for each simulation.

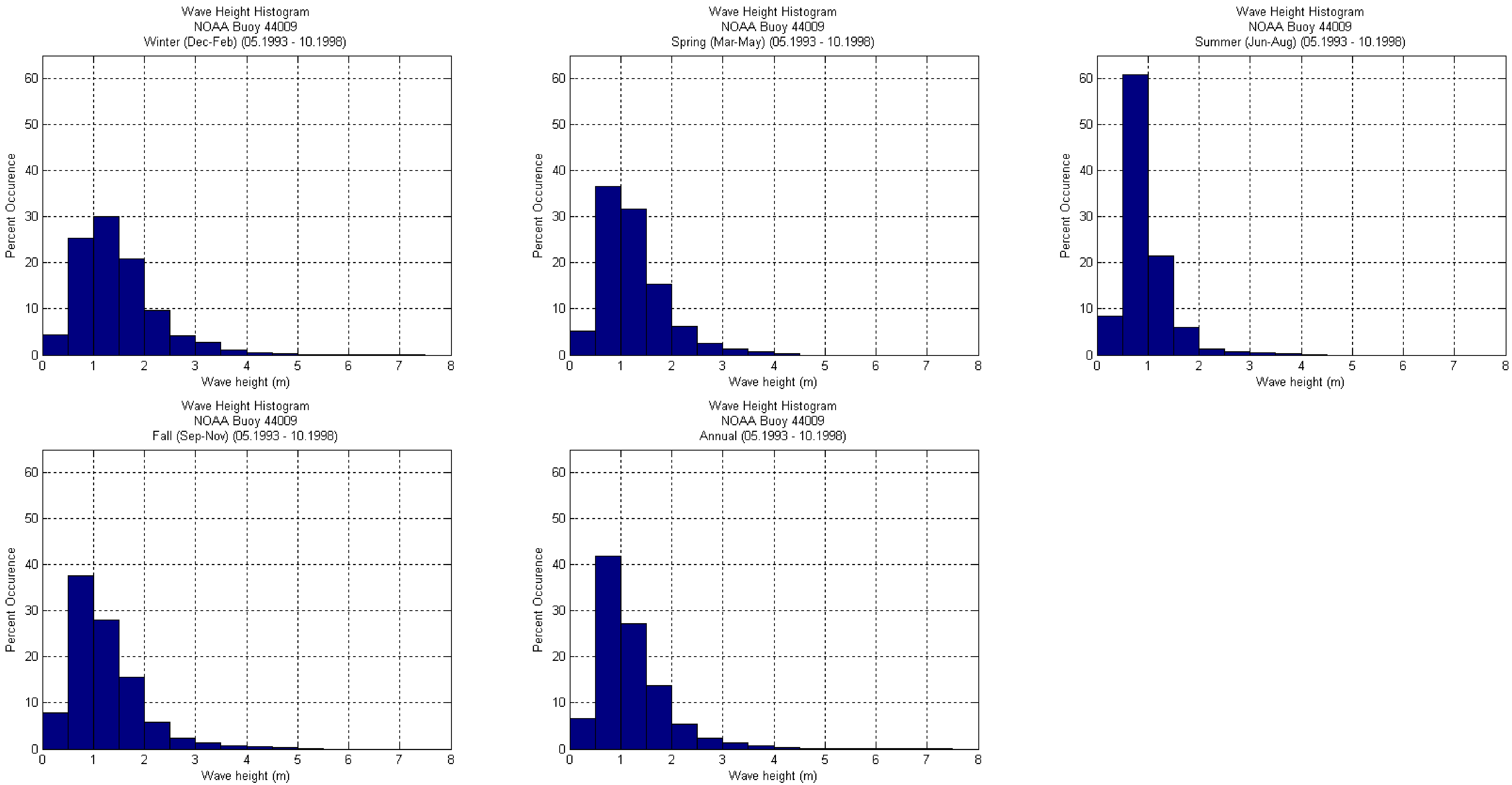


Figure 2.1 Seasonal wave height histograms; NOAA Buoy 44009.

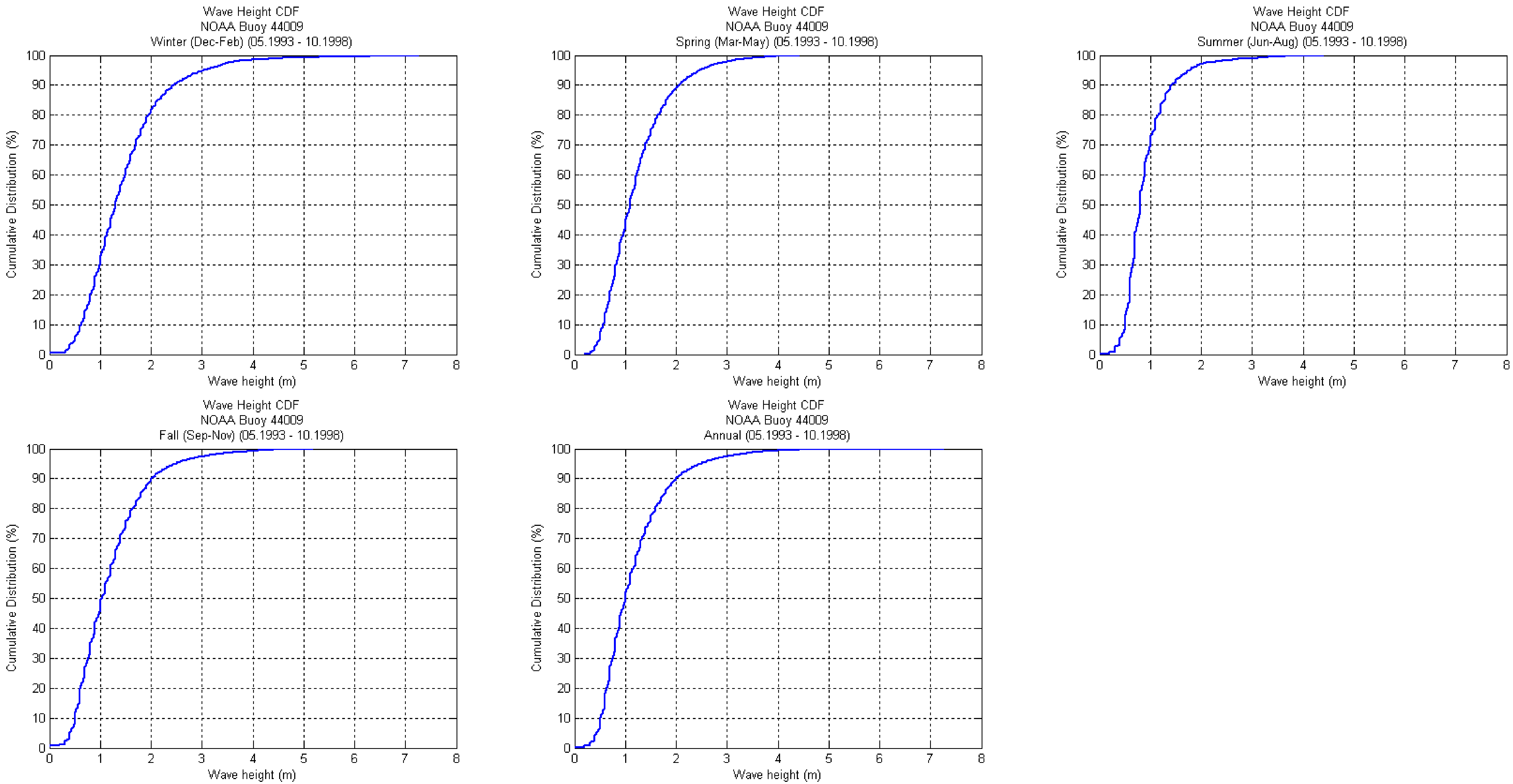


Figure 2.2 Seasonal wave height cumulative distribution functions; NOAA Buoy 44009.

Table 2.1 Wave and wind boundary conditions used in STWAVE modeling.

Scenario	Wave Height (m)	Wave Period (s)	Wave Direction (°N)	Wind Speed (m/s)	Wind Direction (°N)
Annual	1.2	7.6	112.5 (ESE)	4.9	315 (NW)
Winter	1.5	7.7	90 (E)	5.7	315 (NW)
Spring	1.2	7.6	90 (E)	5.3	315 (NW)
Summer	0.9	7.4	135 (SE)	3.6	180 (S)
Fall	1.2	7.7	112.5 (ESE)	4.7	45 (NE)

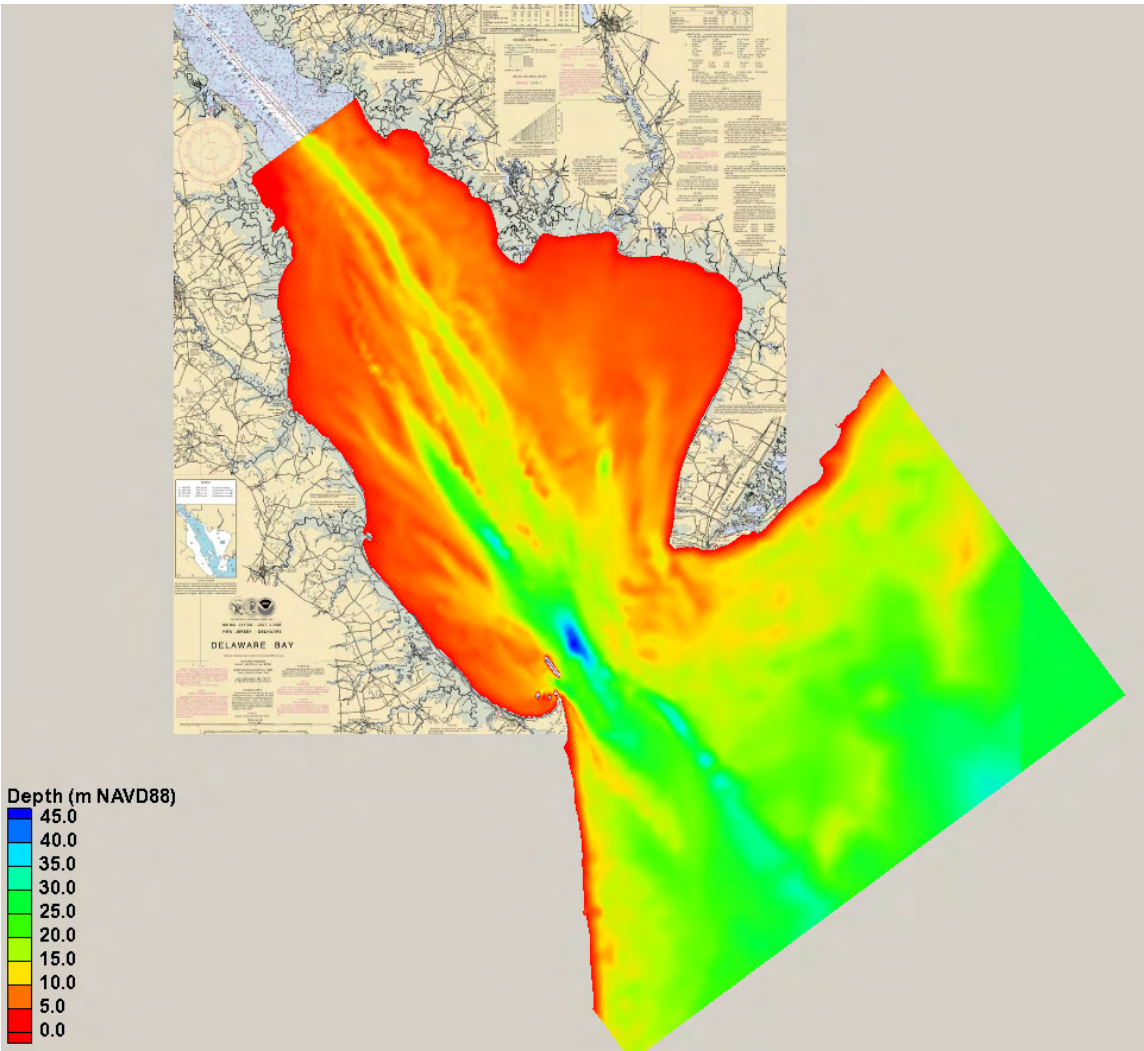


Figure 2.3 STWAVE model domain and bathymetry.

2.5 Model Results Overview

After running the ten scenarios, the wave fields for each case were examined to determine the variations in wave height and direction at each bay beach location. Wave height directly correlates with the energy available to initiate and maintain sediment transport, while the direction dictates where the sediment is transported. These estimates were compared to the results from the circulation model as well as past measurements and estimations of longshore transport.

2.6 Annual Conditions

On an annual basis, according to Figures 2.1 and 2.2, offshore wave heights are less than 1 m about 50% of the time, and less than 0.5 m about 10% of the time. About 42% of wave occurrences are between 0.5 m and 1 m in height.

Figures 2.4 and 2.5, respectively, illustrate the wave height field under average annual conditions with and without the influence of offshore waves.

Table 2.2 outlines the annual wave heights and potential transport directions (based on incident wave angle) at each beach, both with and without the influence of offshore waves. Heights are approximate, based on the variation at each location.

Table 2.2 Wave heights and potential transport directions; annual conditions.

Location	Wave height (w/ off. waves) (m)	Transport direction (w/ off. waves)	Wave height (wind waves only) (m)	Transport direction (wind waves only)
Pickering Beach	0.65	NW	0.10	S
Kitts Hummock	0.50	NW	0.10	S
Bowers Beach	0.45	NW	0.10	S
South Bowers	0.40	NW	0.15	S
Slaughter Beach	0.60	NW/SW	0.15	S
Primehook Beach	0.60	SW	0.20	S
Broadkill Beach	0.70	SW	0.15	S

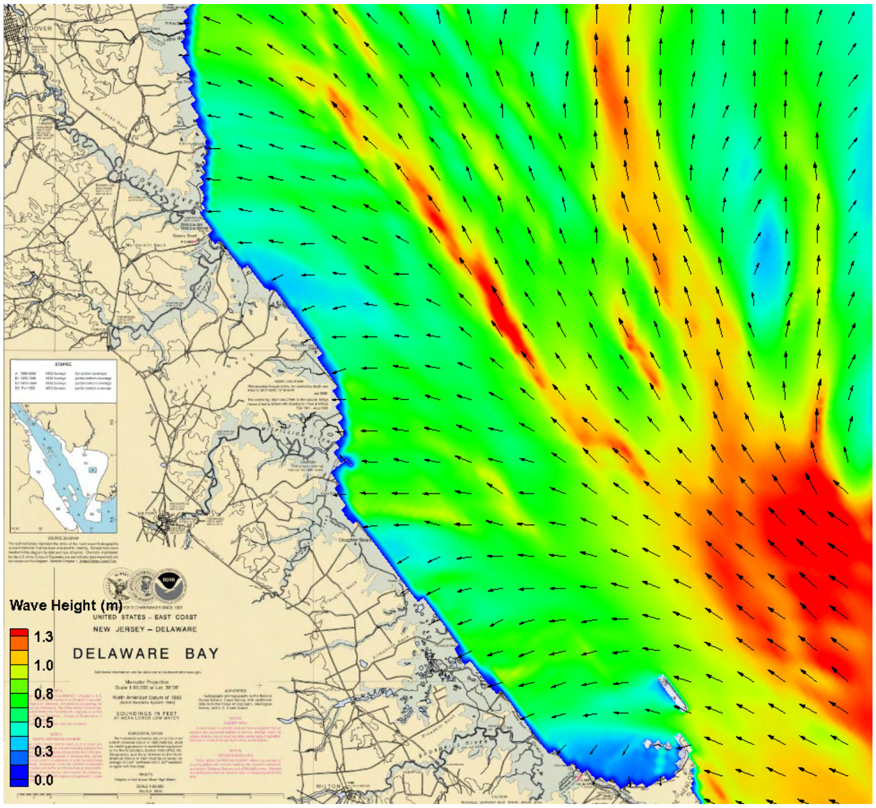


Figure 2.4 Wave heights during average annual conditions; with offshore wave influence.

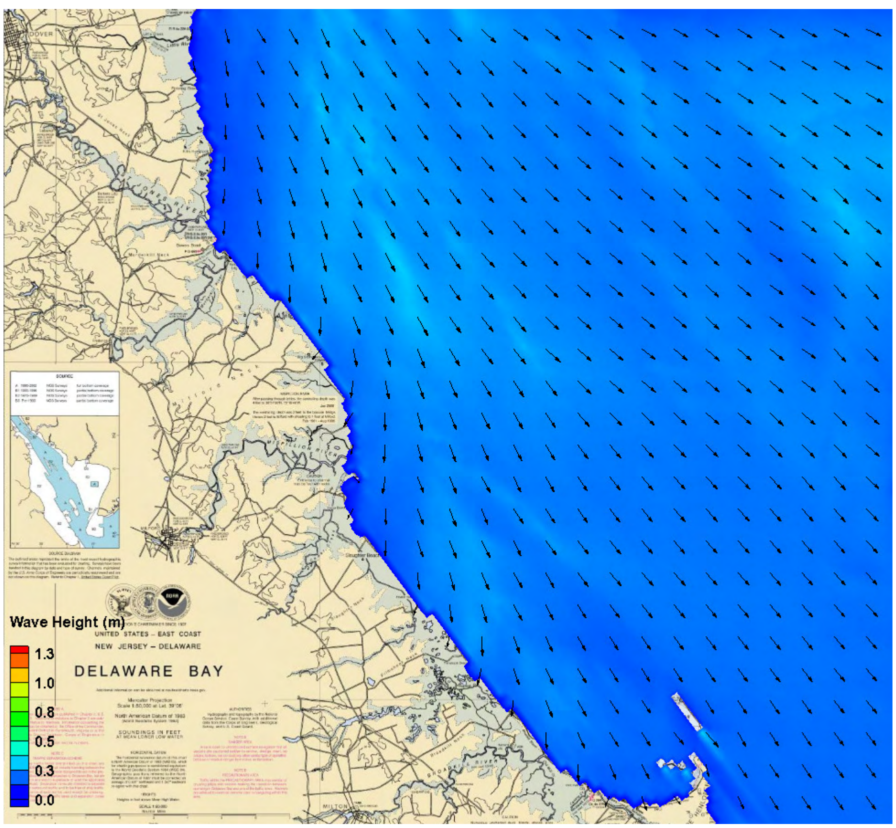


Figure 2.5 Wave heights during average annual conditions; without offshore wave influence.

2.7 Winter Conditions

During the winter season (December to February), according to Figures 2.1 and 2.2, offshore wave heights are less than 1 m about 30% of the time, and less than 0.5 m about 5% of the time. About 30% of wave occurrences are between 1 m and 1.5 m in height.

Figures 2.6 and 2.7, respectively, illustrate the wave height field under average winter conditions with and without the influence of offshore waves.

Table 2.3 outlines the winter wave heights and potential transport directions (based on incident wave angle) at each beach, both with and without the influence of offshore waves. Heights are approximate, based on the variation at each location.

Table 2.3 Wave heights and potential transport directions; winter conditions.

Location	Wave height (w/ off. waves) (m)	Transport direction (w/ off. waves)	Wave height (wind waves only) (m)	Transport direction (wind waves only)
Pickering Beach	0.75	NW	0.10	S
Kitts Hummock	0.60	NW	0.10	S
Bowers Beach	0.45	NW	0.15	S
South Bowers	0.45	NW	0.15	S
Slaughter Beach	0.80	NW/SW	0.20	S
Primehook Beach	0.85	SW	0.25	S
Broadkill Beach	0.95	SW	0.25	S

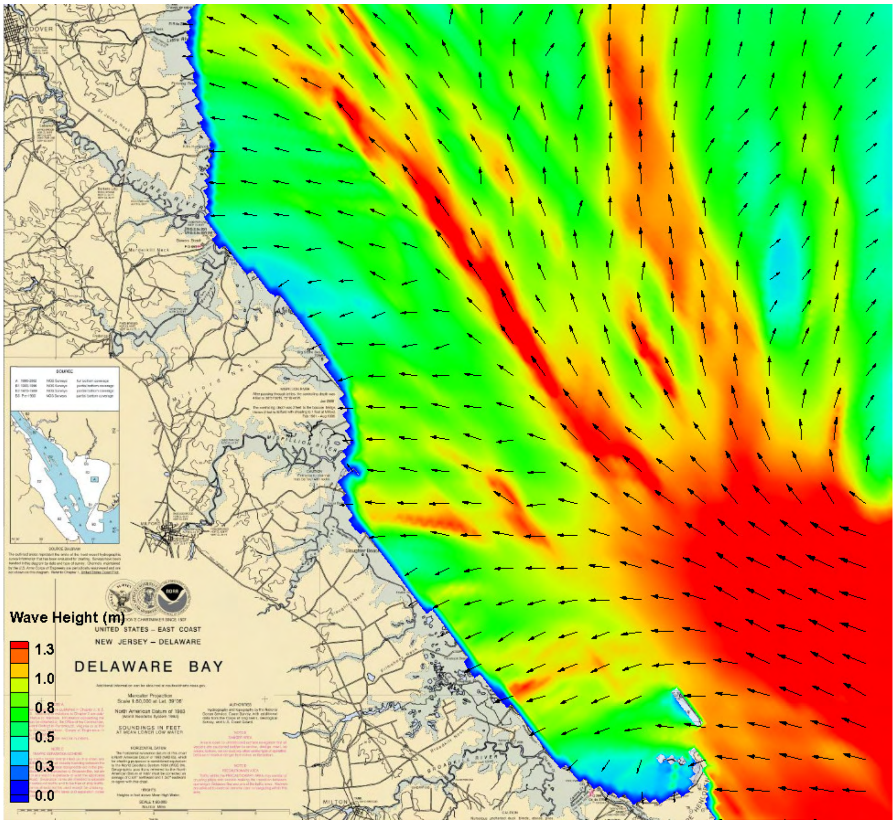


Figure 2.6 Wave heights during average winter conditions; with offshore wave influence.

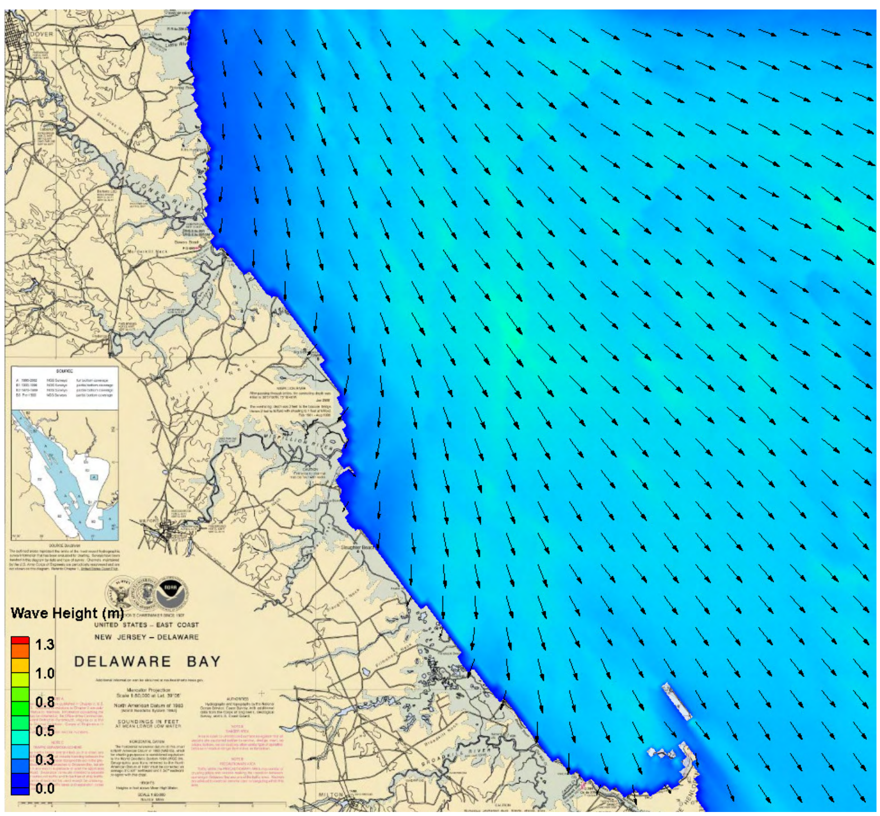


Figure 2.7 Wave heights during average winter conditions; without offshore wave influence.

2.8 Spring Conditions

During the spring season (March to May), according to Figures 2.1 and 2.2, offshore wave heights are less than 1 m about 45% of the time, and less than 0.5 m about 5% of the time. About 36% of wave occurrences are between 0.5 m and 1 m in height.

Figures 2.8 and 2.9, respectively, illustrate the wave height field under average spring conditions with and without the influence of offshore waves.

Table 2.4 outlines the spring wave heights and potential transport directions (based on incident wave angle) at each beach, both with and without the influence of offshore waves. Heights are approximate, based on the variation at each location.

Table 2.4 Wave heights and potential transport directions; spring conditions.

Location	Wave height (w/ off. waves) (m)	Transport direction (w/ off. waves)	Wave height (wind waves only) (m)	Transport direction (wind waves only)
Pickering Beach	0.60	NW	0.10	S
Kitts Hummock	0.45	NW	0.10	S
Bowers Beach	0.40	NW	0.15	S
South Bowers	0.35	NW	0.15	S
Slaughter Beach	0.70	SW	0.15	S
Primehook Beach	0.65	SW	0.25	S
Broadkill Beach	0.80	SW	0.20	S

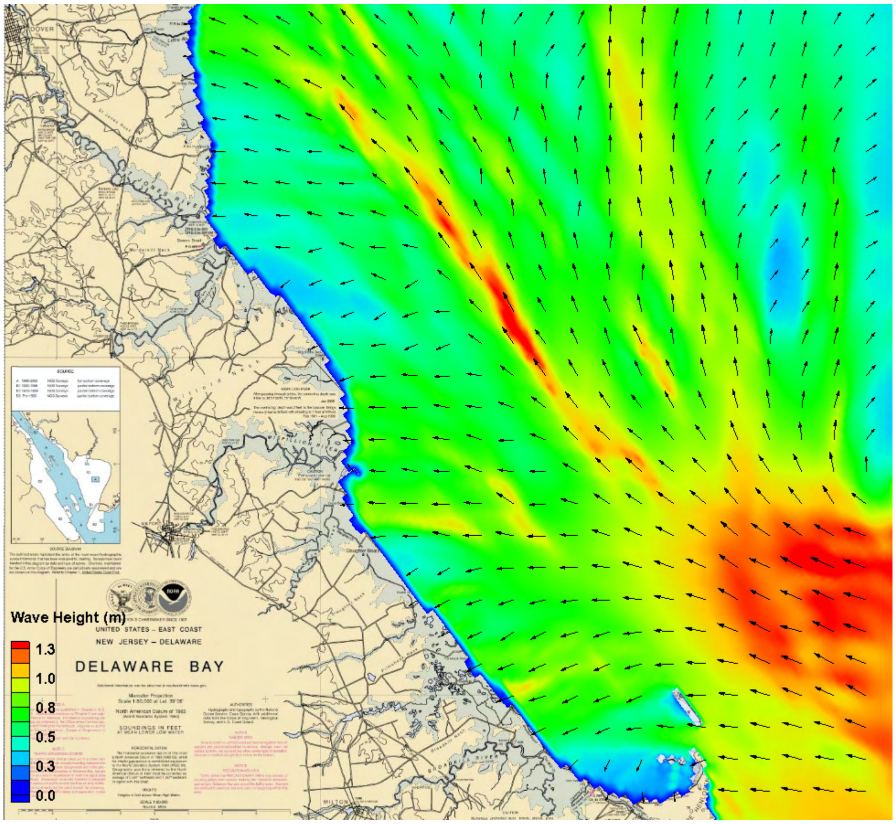


Figure 2.8 Wave heights during average spring conditions; with offshore wave influence.

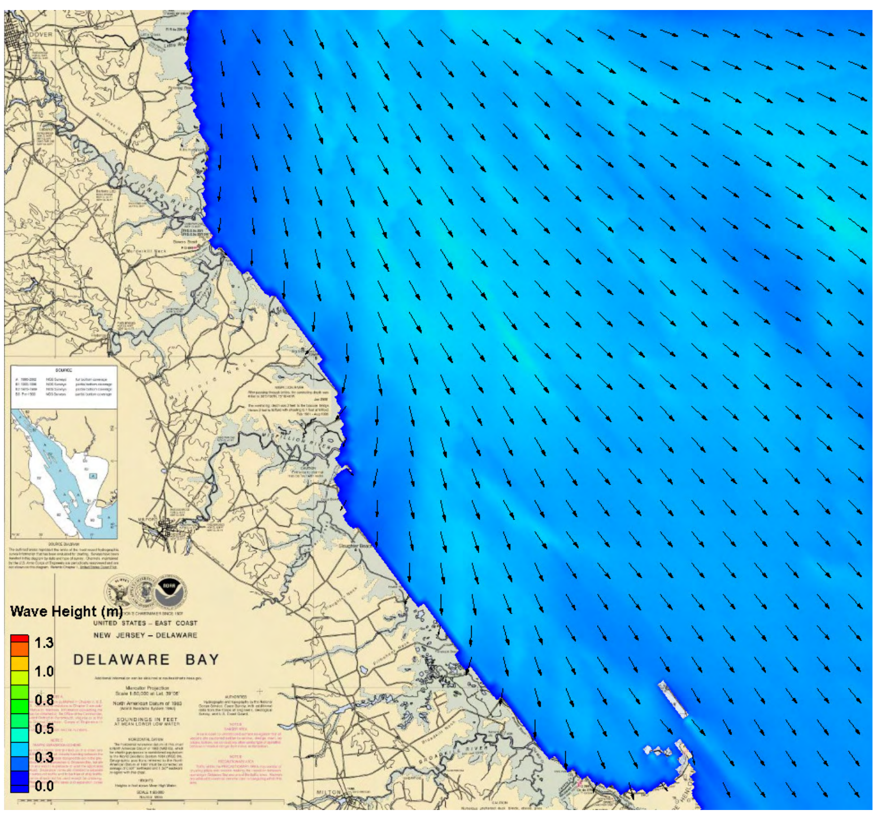


Figure 2.9 Wave heights during average spring conditions; without offshore wave influence.

2.9 Summer Conditions

During the summer season (June to August), according to Figures 2.1 and 2.2, offshore wave heights are less than 1 m about 70% of the time, and less than 0.5 m about 10% of the time. About 61% of wave occurrences are between 0.5 m and 1 m in height.

Figures 2.10 and 2.11, respectively, illustrate the wave height field under average summer conditions with and without the influence of offshore waves.

Table 2.5 outlines the summer wave heights and potential transport directions (based on incident wave angle) at each beach, both with and without the influence of offshore waves. Heights are approximate, based on the variation at each location.

Table 2.5 Wave heights and potential transport directions; summer conditions.

Location	Wave height (w/ off. waves) (m)	Transport direction (w/ off. waves)	Wave height (wind waves only) (m)	Transport direction (wind waves only)
Pickering Beach	0.40	NW	0.05	N
Kitts Hummock	0.35	NW	0.05	N
Bowers Beach	0.30	NW	0.10	N
South Bowers	0.25	NW	0.10	N
Slaughter Beach	0.35	NW	0.10	N
Primehook Beach	0.35	NW	0.10	N
Broadkill Beach	0.40	NW	0.15	N

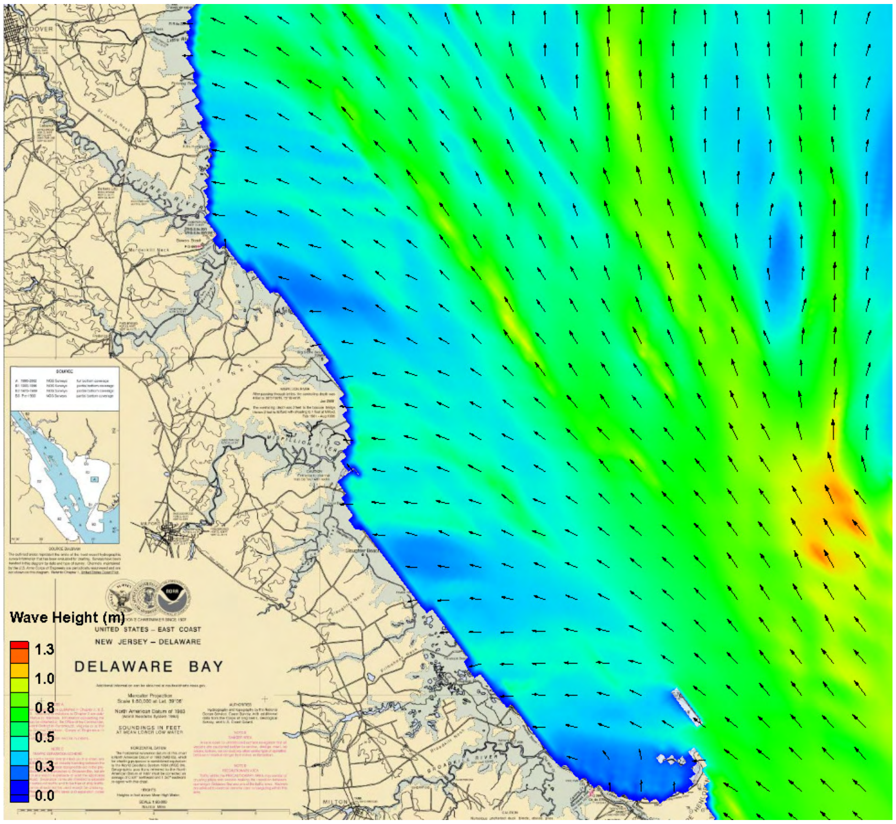


Figure 2.10 Wave heights during average summer conditions; with offshore wave influence.

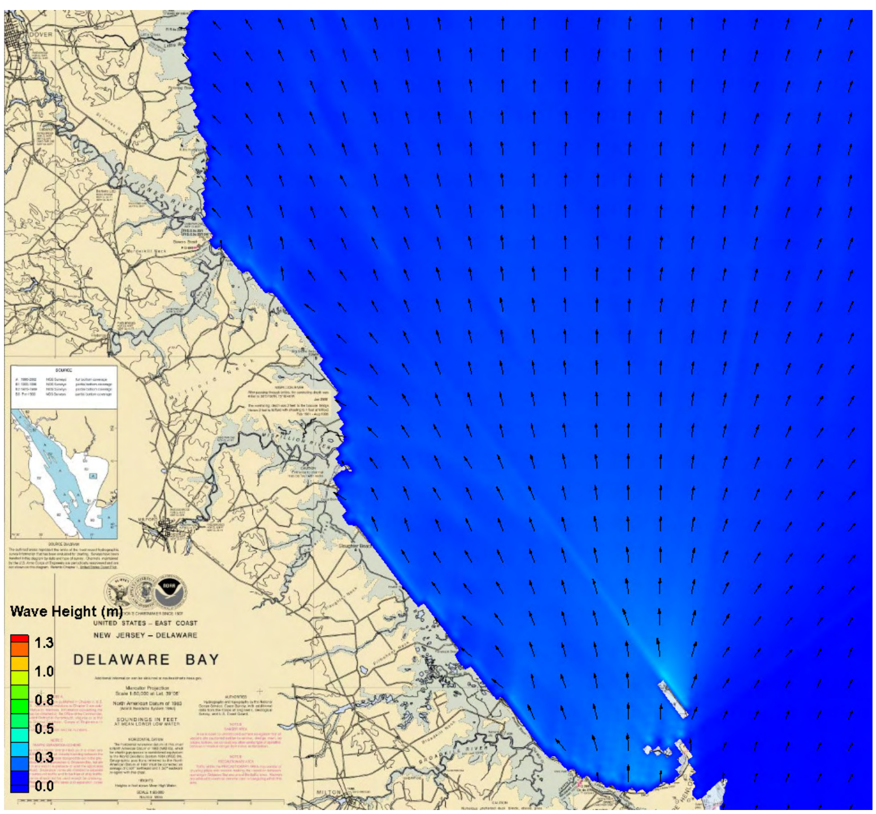


Figure 2.11 Wave heights during average summer conditions; without offshore wave influence.

2.10 Fall Conditions

During the fall season (September to November), according to Figures 2.1 and 2.2, offshore wave heights are less than 1 m about 50% of the time, and less than 0.5 m about 10% of the time. About 38% of wave occurrences are between 0.5 m and 1 m in height.

Figures 2.12 and 2.13, respectively, illustrate the wave height field under average winter conditions with and without the influence of offshore waves.

Table 2.6 outlines the fall wave heights and potential transport directions (based on incident wave angle) at each beach, both with and without the influence of offshore waves. Heights are approximate, based on the variation at each location.

Table 2.6 Wave heights and potential transport directions; fall conditions.

Location	Wave height (w/ off. waves) (m)	Transport direction (w/ off. waves)	Wave height (wind waves only) (m)	Transport direction (wind waves only)
Pickering Beach	0.25	SW	0.20	SW
Kitts Hummock	0.30	SW	0.20	SW
Bowers Beach	0.35	SW	0.20	SW
South Bowers	0.30	SW	0.20	SW
Slaughter Beach	0.70	SW	0.15	SW
Primehook Beach	0.60	SW	0.15	SW
Broadkill Beach	0.75	SW	0.20	SW

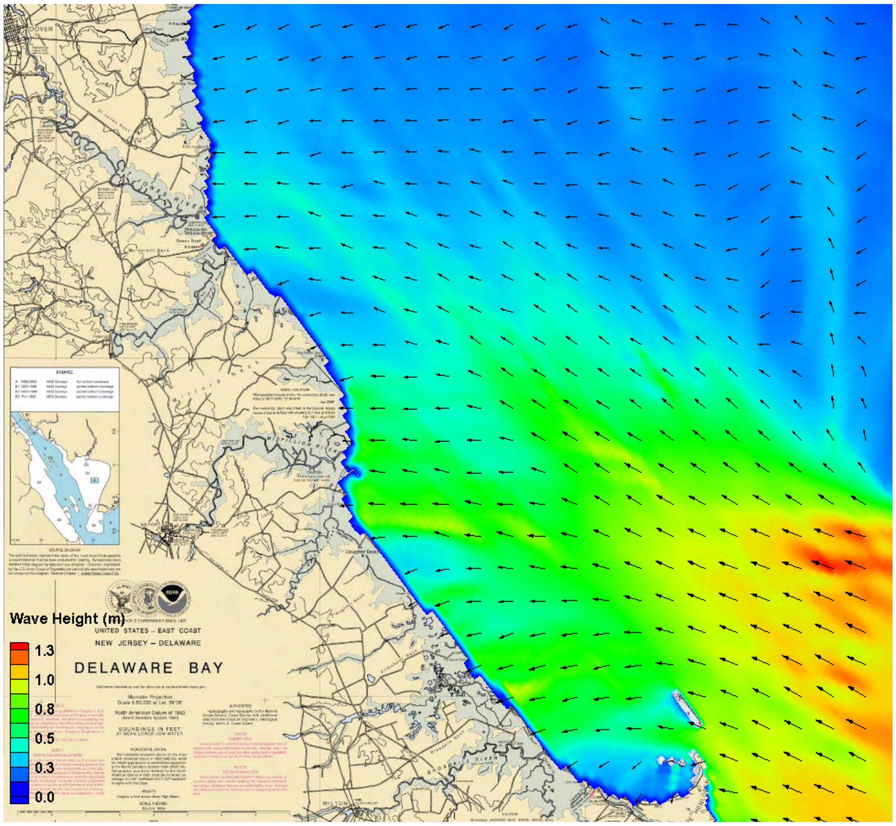


Figure 2.12 Wave heights during average fall conditions; with offshore wave influence.

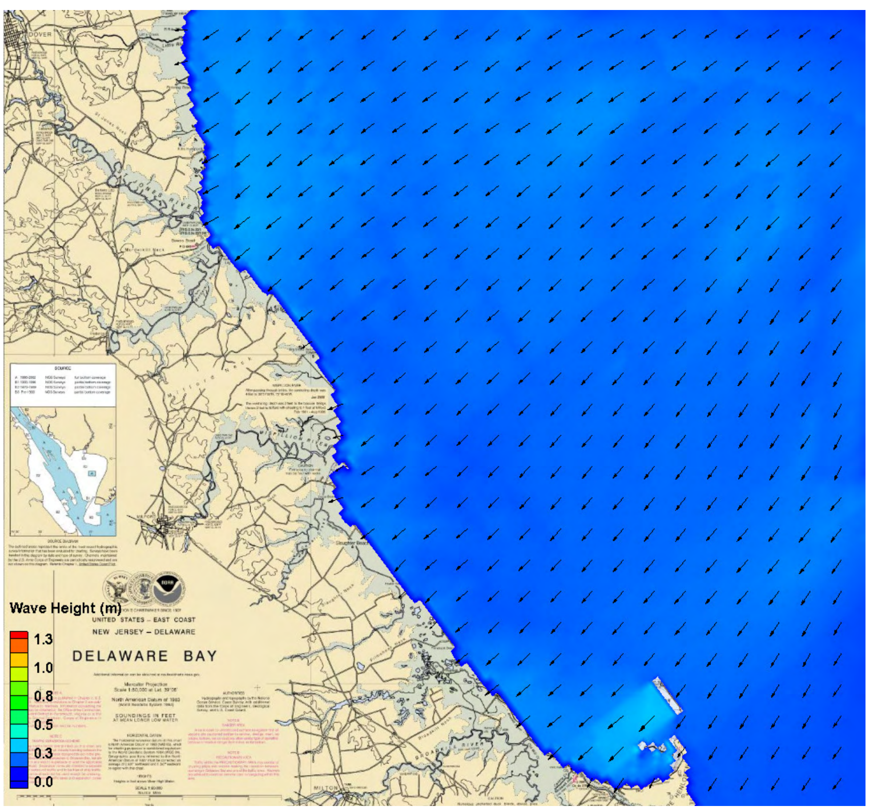


Figure 2.13 Wave heights during average fall conditions; without offshore wave influence.

2.11 Wave Modeling Conclusions

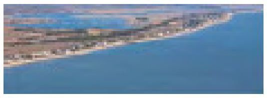
In support of the ADCIRC circulation model, a wave development and propagation model was created using the STWAVE model. This wave model provided some insight to the predominant directions and pathways of hydrodynamic and sediment transport along the Delaware Bay coastline under both offshore wave dominated and local wind wave dominated scenarios.

Ten wave scenarios were examined including conditions with and without the influence of offshore waves for annual, winter, spring, summer and fall conditions. These scenarios were investigated to gain an understanding of the variations in wave height and direction at each bay beach location. These scenarios include conditions with and without the influence of offshore waves for annual, winter, spring, summer and fall conditions. Wave height correlates with the energy available to initiate and maintain sediment transport, while the direction dictates where the sediment is transported.

Results of the wave modeling demonstrate the variability of seasonal conditions affecting the bay beaches. Wave heights are approximate, based on the variation at each location. Several tables and figures were provided for each scenario that showed the wave heights and potential transport directions for the beaches along Delaware's bay coastline with and without the offshore wave influence. With offshore waves included in the simulation, wave heights generally decrease up-bay, with Kitts Hummock and Pickering Beach showing a slight increase during winter, spring and summer likely due to their direct orientation to the mouth of the bay. As would be expected the winter conditions produce the largest wave heights and provide the greatest potential for sediment transport. In contrast the summer conditions provided on average lower wave heights. Localized areas of wave focusing were observed especially during winter conditions at Slaughter Beach and Broadkill Beach. Transport potential varies along the coastline from a southwesterly to a northwesterly direction up-bay during winter and spring conditions. Summer and fall conditions provide a northwesterly and southwesterly potential transport direction, respectively.

Without offshore waves, local wind wave heights are relatively small and show a prevailing southerly transport potential for most conditions other than summer where the winds are out of the south. Comparing the figures demonstrates that offshore waves will generally dominate conditions along the bay beaches. However, during times of inactive offshore conditions the local wind waves will dictate sediment transport potential, although to a lesser rate. A more refined modeling effort in conjunction with a data collection effort to better calibrate the model would better resolve the actual conditions at each community.

Appendix B:
Delaware Bay Beach Aerials
(April 17, 2009)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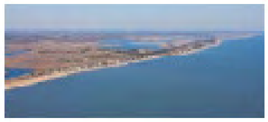
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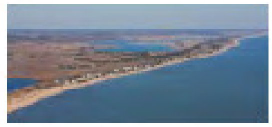
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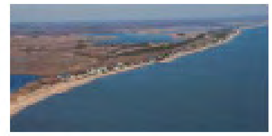
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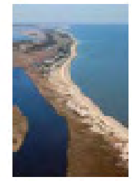
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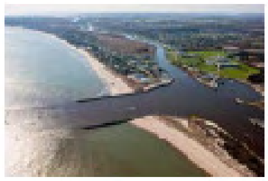
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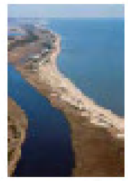
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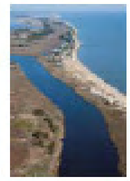
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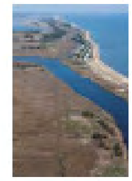
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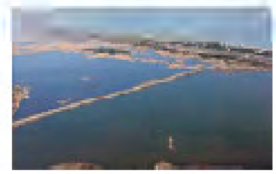
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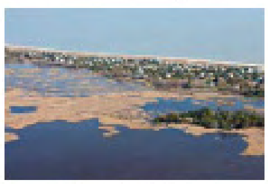
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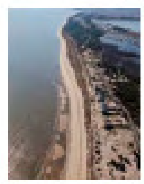
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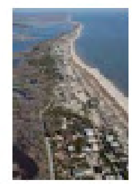
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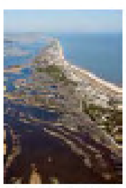
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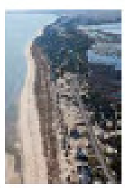
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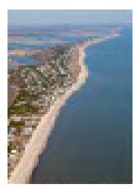
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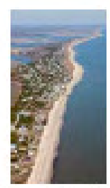
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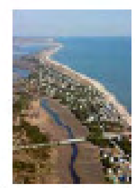
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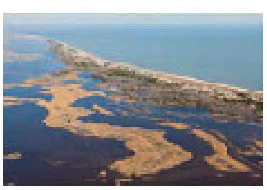
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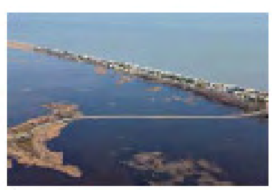
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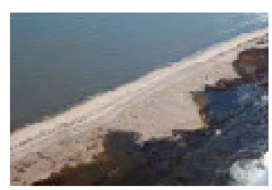
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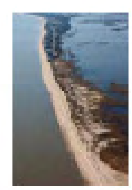
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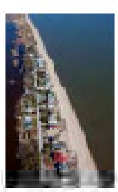
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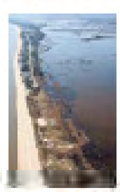
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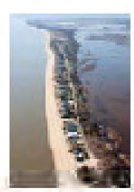
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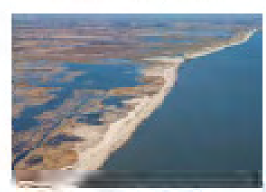
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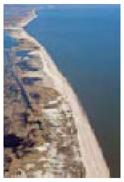
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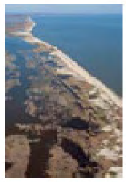
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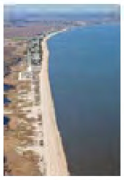
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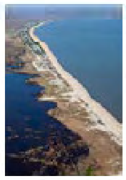
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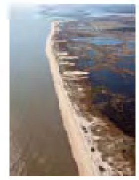
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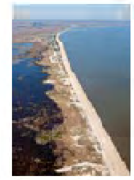
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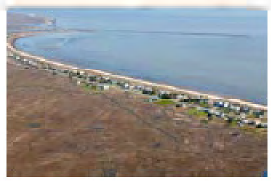
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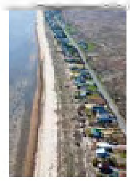
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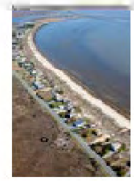
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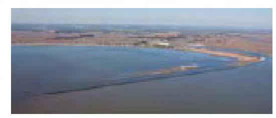
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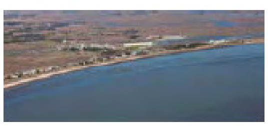
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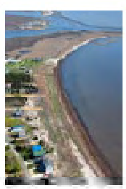
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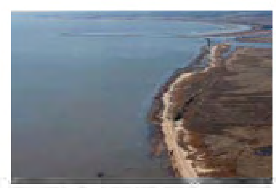
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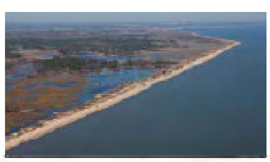
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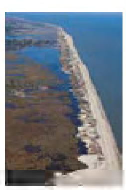
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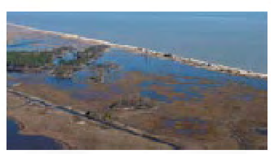
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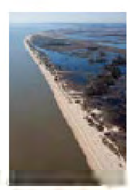
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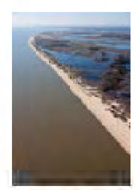
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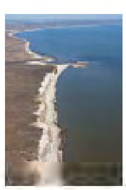
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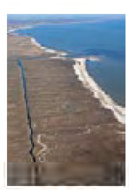
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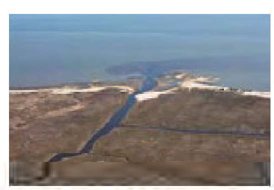
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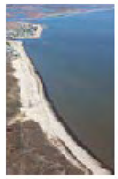
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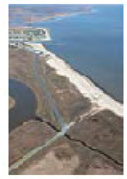
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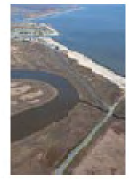
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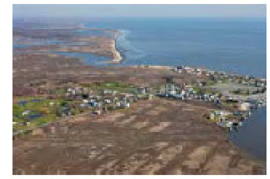
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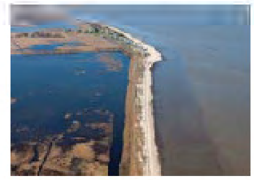
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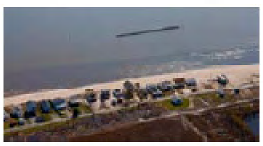
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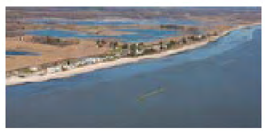
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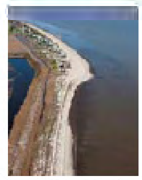
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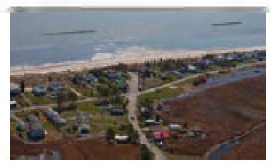
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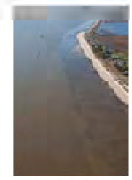
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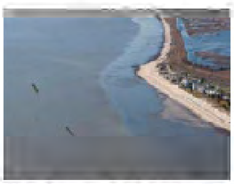
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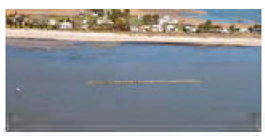
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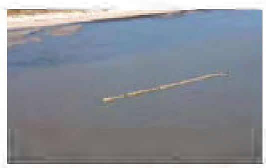
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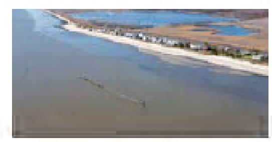
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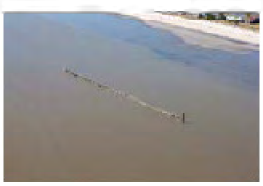
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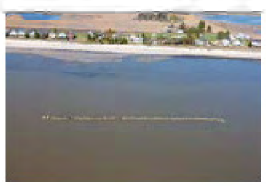
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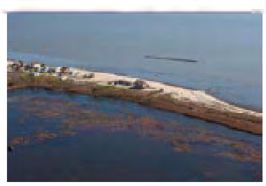
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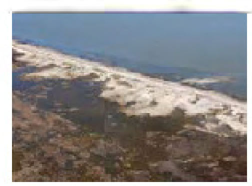
DE Bay 4-17-09 094 Kitts Hummock.jpg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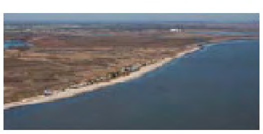
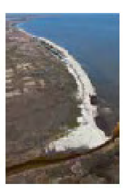

DE Bay 4-17-09 096 Pickering Beach.jpg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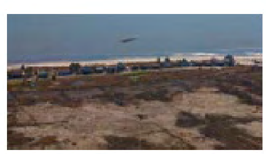
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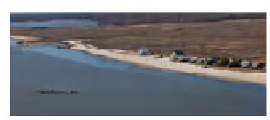
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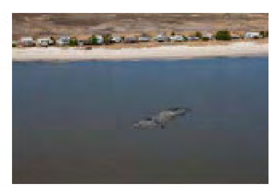
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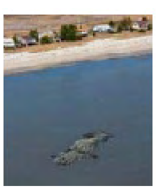
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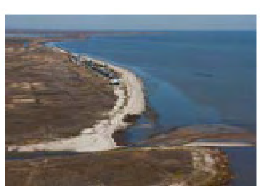
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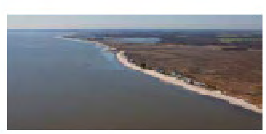
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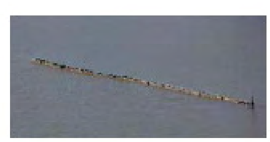
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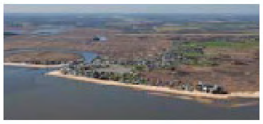
DE Bay 4-17-09 105 Kitts Hummock.jpg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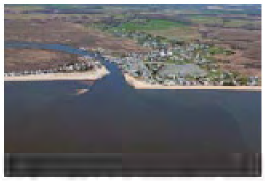
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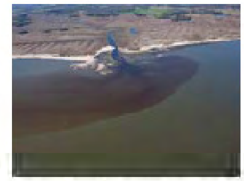
DE Bay 4-17-09 108 Bowers -S. Bowers.jpg


DE Bay 4-17-09 109.jpg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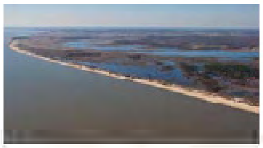
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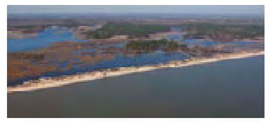
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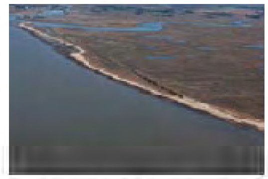
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DE Bay 4-17-09 115 Mispillion.jpg


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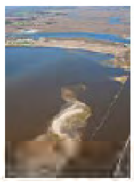
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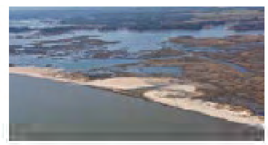
DE Bay 4-17-09 118 Slaughter Beach.jpg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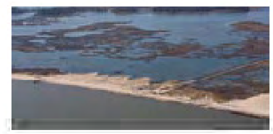
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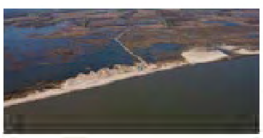
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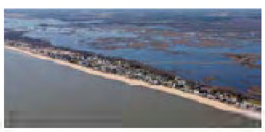
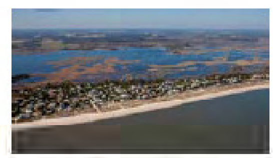

DE Bay 4-17-09 122 Primehook.jpg


DE Bay 4-17-09 123 Primehook.jpg


DE Bay 4-17-09 124 Broadkill Beach.jpg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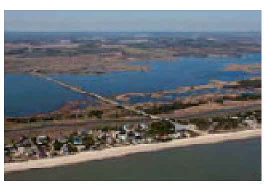
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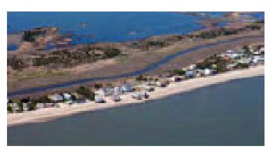
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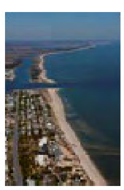
DE Bay 4-17-09 130 Broadkill Beach.jpg


DE Bay 4 17 09 131 Lewes.jpg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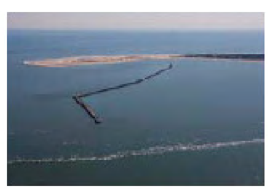
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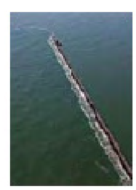
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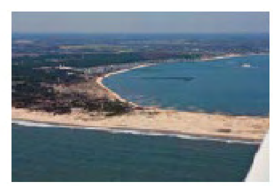
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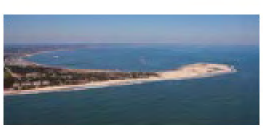
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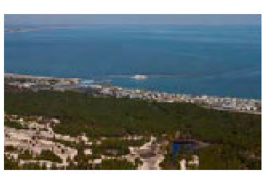
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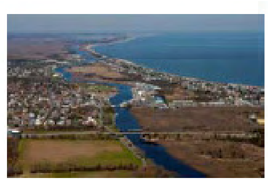
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Digital copies of the aerials are included on the DVD in the back of this binder.

Appendix C:
Digital Copy of Documents Gathered