Shoreline Management Plan with Habitat Enhancement for Town of Saxis, Virginia

C. Scott Hardaway Jr.
Virginia Institute of Marine Science

Donna Milligan
Virginia Institute of Marine Science

George R. Thomas
Virginia Institute of Marine Science

Rebecca C.H. Brindley

Lyle M. Varnell
Virginia Institute of Marine Science

See next page for additional authors

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Authors
C. Scott Hardaway Jr., Donna Milligan, George R. Thomas, Rebecca C.H. Brindley, Lyle M. Varnell, Walter L. Priest, and Sharon Dewing

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C. Scott Hardaway, Jr.
Donna A. Milligan
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Lyle M. Varnell
Walter L. Priest

Department of Physical Sciences

Department of Resource Management & Policy

Virginia Institute of Marine Science
College of William & Mary
Gloucester Point, Virginia 23062

February 1999
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Chesapeake Bay Local Assistance Department

Virginia Institute of Marine Science
College of William & Mary
Gloucester Point, Virginia 23062

February 1999
EXECUTIVE SUMMARY

The Town of Saxis, Virginia is located on the Chesapeake Bay side of upper Accomack County on the tip of the Freeschool Marsh peninsula and is often referred to as Saxis Island. The Town’s western boundary, which fronts Pocomoke Sound, is experiencing severe erosion. Historically, the shore eroded at a rate of almost 5 feet/year (Hobbs et al., 1975).

To address regional environmental planning and restoration initiatives, the present Shoreline Management Plan with Habitat Enhancement for the Town of Saxis incorporates habitat considerations into shoreline stabilization design. The primary goal of this project is effective erosion control, and the options presented were designed to achieve a high level of protection. Through our evaluation process, we compared various structural configurations and their relative impacts on, and potential benefits to, target species. It was anticipated early on that headland breakwaters, beach nourishment, and wetlands plantings would be utilized to realize project goals.

In order to develop the Saxis Shoreline Management Plan with Habitat Enhancement, the following techniques were used to assess Saxis’s Pocomoke Sound shoreline from Starling Creek northward to North End Point, including the 9,000 ft of shore within the town limits.

• The physical setting of Saxis’s shore zone was described by a topographic/hydrographic survey, and a geotechnical analysis, consisting of hand auger and surface samples, was performed along the existing shore and nearshore areas to assess bottom and foundation conditions for potential breakwaters.
• Vertical aerial imagery was used to determine present shoreline position and vegetative communities. These data were compared to historical shoreline positions, and rates of shoreline change were calculated between shoreline positions.
• Oblique, low-level, aerial video was obtained along Saxis’s shoreline, and it was compared to oblique aerial video made by VIMS in 1990 and 1985. This semi-quantitative assessment showed changes in land use, shore structures, and morphologic features through the period of record.
• In order to quantify the general wave climate acting upon the Saxis shoreline, the local wind climate was evaluated utilizing the long-term wind data set for Patuxent Naval Air Station. The wind field evaluation and effective fetch as well as bathymetric contours and storm surge were input to the SMB computer modeling program which generates simulated wave height, period, and length for a suite of wind speeds.
• RCPWAVE, a linear wave model, takes an incident wave condition at the seaward boundary of the grid, propagates it shoreward across the nearshore bathymetry, and allows the wave to diffract, shoal, refract, and dissipate due to friction. Wave height and angle at the approximate depth where shore structures would be located were used to characterize the average annual wave conditions.
• The output wave data was mean-weighed with the wind data in order to describe the relative amounts of energy impacting the shore.
• The Static Equilibrium Bay model was used to determine beach planforms for the design of the breakwater system.
• Data on avian presence were collected by roving survey using binoculars and a spotting scope. Birds were enumerated by species and to the subhabitat they were occupying at the time the encounter was logged.
Fish and blue crabs were collected by beach seine. Oyster and clam surveys were conducted with a hand dredge at random sites.

Aerial photographs were used in concert with a ground-truthing survey to assess vegetative community structure.

Saxis’s shoreline is characterized as low marsh with narrow beach. The upland generally is densely vegetated except for a few lawn areas. Much of the vegetation is the invasive species common reed grass (*Phragmites australius*). Submerged aquatic vegetation existed in the nearshore region in the early part of this century but had disappeared by 1965.

The shore has had an historical erosion rate of 4.9 ft/yr (1851-1942). However, in recent history, anthropogenic changes along the shoreline altered this rate. Infilling and bulkheading of the industrial peninsula north of Starling Creek began in 1938. Aerial photos indicate a dredged approach channel in 1955, but the earliest record of dredging is 1961. Since that time, sandy dredge material has been placed along Saxis’s shoreline in 1965 and 1974. Dredged material was placed in a dredge spoil containment area in 1966 and 1970. The sandy dredge material placed on the shoreline reduced the overall rates of erosion along the shoreline by supplying material to the littoral transport system. Between 1942 and 1968, the average erosion rate decreased to about 1.2 ft/yr, and the distal end of North End Point spit prograded about 400 ft/yr at a rate of over 15 ft/yr. Between 1968 and 1986, the average overall erosion rate had increased to 1.7 ft/yr.

From 1986 to 1998, Saxis’s shoreline regained a high, overall average rate of erosion – about 3.8 ft/yr which is near historical rates (1851-1942). A barge grounded several years ago approximately in the middle of the Town’s shoreline. This barge has segmented the coast by acting as a detached breakwater and allowing the deposition of sand salient in the lee of the structure that has interrupted the littoral transport system. During this same period, a subaqueous sand bar has grown over 600 ft off the distal end of North End Point spit almost closing off the embayment in the lee of the spit.

With the longest effective fetch to the southwest as well as the high frequency of winds from that direction, waves are generated that significantly impact the alongshore transport system tending to drive sediment to the north. The southwest and west conditions combined are more frequent than the northwest which supports our other analyses since the morphologic evidence points to a northward trending littoral transport system (*i.e.* shoreline offsets and North End Point spit). As southwest waves approach the Saxis shoreline, they shoal nearly 35° before they impact the shore because of the nearshore bathymetry. Westerly waves are impacted by the nearshore bathymetry, shoaling about 8°. The northwest component is altered little by the nearshore; the angle of wave approach only changes by about 2°, and the wave height does not diminish as rapidly as other directions. During northwest storm conditions, waves are onshore-offshore along the Town’s shoreline, but waves directly impact the spit at North End Point tending to elongate it. During southwest and west conditions, the North End Point spit is sheltered from wave energy. Under modal conditions, a very few, small regions of increased wave energy are shown along the shore. However, under storm conditions, energy tends to be concentrated (convergence) just south of the cape stabilized with well casings near the northern limit of the Town. North and south of this cape, some divergence (spreading laterally) of wave energy occurs. The northwest modal and storm conditions show very little convergence or divergence whereas the storm trajectory for southwest condition shows convergence in the region of the dredge spoil containment area.
A diverse assemblage of birds was observed during the survey. A mixture of year-round residents, wintering birds, migrants, and summer nesting birds were all well represented. Fish and blue crab sampling data were consistent with other local studies which assessed fish population structure for the Bay side of Virginia’s Eastern Shore. No live oysters or clams were collected. Other faunal observations included raccoon tracks and scat, deer tracks, fox tracks, horseshoe crab corpses, and direct observations of toads, muskrats, and tiger beetles.

The proposed Saxis Shoreline Management Plan with Habitat Enhancement has seven breakwaters (300 ft crest length) placed about 200 ft from existing MLW and spaced 450 ft apart. Relatively large tombolos will be created in the lee of these long breakwaters enabling the establishment of shrub mix and high marsh grass habitats favorable to birds. Alteration of the wave climate behind the breakwaters will provide a protective barrier for the establishment of SAV. In order to insure long-term protection and enhance habitat substrate, seven, 100 ft long inter-bay breakwaters also are proposed. Dunes are sparse along the present shoreline. The proposed dunes would provide habitat for colonial wading birds and mammals which utilize the shore. The dunes also would provide aesthetics and complement the offshore breakwaters by providing increased upland erosion control.

Historical aerial photographs provide evidence that vegetated, tidal marshes once were a more prominent feature along this shoreline, but this habitat is rapidly being lost from the existing shoreline. Vegetated, intertidal areas will be restored along the proposed shoreline with a mixture of saltmarsh cordgrass (*Spartina alterniflora*) and saltmeadow hay (*Spartina patens*). Generally, saltmarsh cordgrass grows in the Mid-Atlantic region between MTL and MHW, whereas saltmeadow hay generally is found at slightly higher elevations immediately landward of the saltmarsh cordgrass community. Extensive scrub shrub plantings are proposed to provide much needed habitat for colonial wading birds and neotropical migrant birds.

From an ecological perspective, the proposed design provides the fundamental constituents of a structurally diverse estuarine ecosystem. The proposed habitat enhancement plan will produce approximately 17.8 acres of newly-constructed habitats. The stabilization structures and beach fill will displace some existing beach and shallow, sub-tidal bottom. There will be some conversion of aquatic habitats to upland habitat, but there will be no net loss of habitat. The high berm feature at +6 ft MLW will address a 25-yr storm event, but the overall system will withstand a 50-yr event with the exception of some sand and vegetation repair. The breakwaters, themselves, will remain intact in the 100-yr event while there may be a need for replacing sand and vegetation within the system.
ACKNOWLEDGMENTS

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I. INTRODUCTION

The Town of Saxis, Virginia is located on the Bay side of upper Accomack County on the tip of the Freeschool Marsh peninsula and is often referred to as Saxis Island (Figure 1). The Town’s western boundary, which fronts Pocomoke Sound, is experiencing severe erosion. The Shoreline Situation Report for Accomack County (Hobbs et al., 1975), prepared by the Virginia Institute of Marine Science (VIMS) indicated that the historic erosion rate was almost 5 feet/year (ft/yr). Hobbs et al. (1975) further suggested that, since erosion rates greater than 3 ft/yr are considered severe, a detailed study was needed to determine the best course of action. The Saxis Town Plan (Saxis Planning Commission, 1997) also reported that severe shoreline erosion exists in Saxis and that its effect on the Town could be devastating if nothing were done and recommends a detailed study to determine the type of erosion control measures best suited to Saxis’s shoreline conditions as part of the Natural Resources Goals and Objectives. The Norfolk District U.S. Army Corps of Engineers (USACE) is presently in the feasibility phase of a study being conducted under Section 206 authority of the Water Resources Development Act (WRDA) of 1996 to determine the Federal interest in improving aquatic habitat along Saxis Island shoreline.

Tidewater localities which depend on commercial and recreational fishing interests or nature-based tourism often face conflicting issues when dealing with erosion control and shoreline stabilization. The stabilization strategies which are available to address the broad spectrum of shoreline situations often impact critical habitats of the same marine and estuarine fauna which support fishing interests and tourism. However, if habitat is considered in the planning process, a shoreline management plan can provide effective shoreline stabilization and an opportunity for local habitat preservation and/or enhancement. Shoreline stabilization projects which are implemented over large areas of shoreline can achieve regional or statewide habitat enhancement/restoration goals. Shoreline erosion can have a significant negative impact on water quality in Chesapeake Bay, causing sedimentation and contributing to increased pollutant load (Ibson et al., 1990).

The management plan for the Town of Saxis provides a unique vehicle for addressing regional environmental planning and restoration initiatives by incorporating habitat considerations into shoreline stabilization design. The primary goal of this project is effective erosion control, and the options presented are designed to achieve a high level of protection. However, through evaluation, various structural configurations and their relative impacts on and potential benefits to target species can be determined. Target species are listed in Habitat Requirements for Chesapeake Bay Living Resources (Chesapeake Bay Program, 1991). Additional guidance and references on target species and critical habitats are in Fish and Wildlife Habitat Restoration Opportunities for the Eastern Shore of Virginia: Planning Aid Report and Baseline Biological Conditions Assessment (Mitchell and Sherfy, 1996).

The goal of the present study is to identify the best course of action to manage shoreline erosion in Saxis and to provide a detailed Shoreline Management Plan with Habitat Enhancement which can be presented to potential State and Federal funding agencies. While the Plan itself will not resolve the erosion conditions in Saxis, it will allow the Town to market its
need and the method of resolution of this need, to agencies and leaders with the resources to implement the Plan’s suggested actions. The shoreline management plan will provide the necessary level of shoreline stabilization while minimizing adverse impacts to estuarine habitat and providing maximum habitat enhancement opportunities. The habitats needed to fulfill the life history requirements of target species desirable for Saxis Island were emphasized in the Plan. The Plan also will present opportunities to enhance local fisheries and provide increased opportunities in eco-tourism.
Figure 1. Town of Saxis and study site location.
II. METHODS

In order to develop the Saxis Shoreline Management Plan with Habitat Enhancement, the following techniques were used to assess Saxis’s Pocomoke Sound shoreline from Starling Creek northward to North End Point, including the 9,000 ft of shore within the town limits.

A. Topographic and Hydrographic Survey with Geotechnical Sampling

The physical setting of Saxis’s shore zone was described by a topographic/hydrographic survey. The survey extended from the north end of the commercial wharf and bulkhead northward about 6,000 ft to the north end of the town limits. The survey included the following elements.

1. Top, bottom, and contours of the existing bank.
2. Mean High Water (MHW) and Mean Low Water (MLW),
3. Existing dunes and vegetated wetlands;
4. Existing upland features such as shore protection structures and outfalls.

A baseline with control points was established along the Saxis Bay shoreline (Figure 2) using total station in conjunction with Global Positioning System (GPS) control. All survey data were converted into the Virginia State Plane North coordinates (NAD1983) for plotting (Table 1). Beach profile cross-sections were plotted using the U. S. Army Corps of Engineers’ (1994) Interactive Survey Reduction Program (ISRP). The mean tide range at Saxis is 2.3 ft with a spring range of 2.7 ft (NOAA, 1989).

Figure 3 gives a pictorial definition of the beach terminology, and Appendix 1 contains a glossary of additional terminology. The berm is a relatively flat feature on the beach’s backshore caused by seasonal wave action. Midbeach refers to a point on the foreshore or beach face approximately halfway between mean high water (MHW) and mean low water (MLW). The toe of the beach is located at the break in slope between the beach face and the nearshore region.

A geotechnical analysis, consisting of hand auger and surface samples, was performed along the existing shore and nearshore areas to assess bottom and foundation conditions for potential breakwaters. Nearshore sediment samples and beach samples were taken to determine grain-size characteristics of the shore zone. Surface samples were taken on the beach’s upper berm, midbeach, toe, and nearshore on profiles 8+06, 23+63, and 40+96 (Figure 2). The hand auger borings were taken at stations 1+37, 11+24, 21+77, 36+74, and between 44+94 and 49+29 at the toe of beach, 50 ft, 100 ft and 150 ft offshore. The samples were analyzed for percent gravel, sand, silt, and clay. The VIMS’s Rapid Sand Analyzer (RSA) was used to determine the grain size distribution of the sand fraction.
Figure 2. Control points established along the Saxis shoreline and used for beach profiling.
Table 1. Information on data used in the report.

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Figure 3. Beach terminology used in this report.

UPLAND BEACH
BACKSHORE
BERM
NEARSHORE ZONE
FORESHORE
TOE BAR
BASE OF DUNE (BOD)

MHW = MEAN HIGH WATER
MLW = MEAN LOW WATER
B. Determine Long-Term Shoreline Change Patterns

Understanding long-term shoreline change is critical to assessing shoreline reaches. Vertical aerial imagery was taken on 20 January 1998 and 4 August 1998 and printed at a scale of one inch to 200 ft (1"=200'). This aerial imagery was used to determine shoreline position and vegetative communities. Historical shoreline positions were obtained from VIMS's archives and compared to the present shoreline position (Table 1). Shorelines from different sources were overlain for comparison and three shore grids were established on the shore change maps (Figure 4 and Figure 5). The historic and recent shorelines were digitized, and the change in shore position was determined in the alongshore direction for each grid at 100 ft increments. Rates of shoreline change were calculated between shoreline positions, and the rates were averaged across each shore grid to give an overall average rate of change. The End Point Rate (EPR) method (Fenster et al., 1993), which is the rate of change calculated from the first and last shoreline positions available, is useful to determine the overall rate of change along a shore reach where an average rate may be influenced by shorter-term changes due to anthropogenic actions or other factors.

C. Establish Existing and Previous Shoreline Conditions

Oblique, low-level, aerial video was obtained along Saxis’s shoreline at about 500 ft altitude and about 500 ft offshore using an AG-180 Panasonic VHS video camera with ½ inch tape. To evaluate changes in the shore zone, the video imagery was compared to similarly-obtained oblique aerial video made by VIMS in 1990 and 1985. This semi-quantitative assessment shows changes in land use, shore structures, and morphologic features through the period of record.

Shoreline and land use categories were coded onto mylar prints of 7.5 minute topographic maps and then digitized. The digitized information was converted to Geographic Information System (GIS) format for ease of comparison and display. The longshore error may be +/- 100 ft over a mile of shoreline. Shoreline conditions include marsh or bank, eroding or stable, hardened with structures or otherwise altered.

D. Wave Climatology

In order to quantify the general wave climate acting upon the Saxis shoreline, it was necessary to evaluate the local wind climate. The long-term wind data for Patuxent Naval Air Station are the only available data applicable at Saxis. Hourly wind measurements taken between 1945 and 1989 are summarized in Table 2. These data are used to generate a corresponding wave field using procedures developed by Sverdrup and Monk (1947) and Bretschneider (1958) as modified by Kiley (1982). The model, known as SMB, generates waves which cross Chesapeake Bay and Pocomoke Sound and are directed toward Saxis. Effective fetch, a parameter in wind wave growth, was determined for the three directions, northwest (NW), west (W), and southwest (SW), which are assumed to impact Saxis. To accomplish this, procedures outlined in the U.S. Army Corps of Engineers (USACE) Shore Protection Manual (1977 and 1984) were used.
Figure 4. Saxis historic shoreline positions and location of Shore Grid 1.
Figure 5. Saxis historic shoreline positions and location of Shore Grids 2 and 3.
Table 2. Summary wind conditions at Patuxent River NAS, Maryland from 1945-1989.

<table>
<thead>
<tr>
<th>Wind Speed Range (mph)</th>
<th>Mid Range (mph)</th>
<th>South SSE</th>
<th>Southwest SSW</th>
<th>West WSW</th>
<th>Northwest WNW</th>
<th>North NNW</th>
<th>Northeast NNE</th>
<th>East ENE</th>
<th>Southeast ESE</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;5</td>
<td>2</td>
<td>7323*</td>
<td>5396</td>
<td>1.4</td>
<td>123</td>
<td>1.5</td>
<td>131</td>
<td>1.5</td>
<td>175</td>
<td>2.0</td>
</tr>
<tr>
<td>5-7</td>
<td>6</td>
<td>17730</td>
<td>14261</td>
<td>3.7</td>
<td>324</td>
<td>3.3</td>
<td>289</td>
<td>3.9</td>
<td>342</td>
<td>4.0</td>
</tr>
<tr>
<td>8-12</td>
<td>10</td>
<td>16959</td>
<td>18887</td>
<td>4.4</td>
<td>429</td>
<td>3.2</td>
<td>280</td>
<td>3.8</td>
<td>333</td>
<td>4.2</td>
</tr>
<tr>
<td>13-18</td>
<td>16</td>
<td>7323</td>
<td>11563</td>
<td>3.0</td>
<td>263</td>
<td>3.2</td>
<td>140</td>
<td>3.2</td>
<td>278</td>
<td>3.2</td>
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<td>19-24</td>
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<td>771</td>
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<td>0.2</td>
<td>18</td>
<td>0.2</td>
<td>18</td>
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<td>105</td>
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</tr>
<tr>
<td>25-31</td>
<td>28</td>
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<td>385</td>
<td>0.1</td>
<td>9</td>
<td>0.1</td>
<td>9</td>
<td>0.1</td>
<td>61</td>
<td>0.1</td>
</tr>
<tr>
<td>32-38</td>
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<td>193</td>
<td>385</td>
<td>0.05</td>
<td>9</td>
<td>0.05</td>
<td>9</td>
<td>0.05</td>
<td>13</td>
<td>0.05</td>
</tr>
<tr>
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<td>193</td>
<td>0.05</td>
<td>9</td>
<td>0.05</td>
<td>9</td>
<td>0.05</td>
<td>193</td>
<td>0.05</td>
</tr>
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<td>193</td>
<td>0</td>
<td>0.05</td>
<td>4</td>
<td>0.05</td>
<td>4</td>
<td>0.05</td>
<td>0</td>
<td>0.05</td>
</tr>
<tr>
<td>55-63</td>
<td>59</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0*</td>
</tr>
<tr>
<td>&lt;64</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0*</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>50877*</td>
<td>52420*</td>
<td>38737*</td>
<td>58201*</td>
<td>52034*</td>
<td>38350*</td>
<td>26594*</td>
<td>37002*</td>
<td>385440*</td>
</tr>
</tbody>
</table>

*Total Number of hours  ^Percent of Data Set  ^Calculated Hours per Year
The wind field evaluation and effective fetch as well as bathymetric contours and storm surge are input to the SMB program which provides wave height, period, and length for a suite of wind speeds. In this case, wind speeds of 10 to 50 mph at 5 mph increments and 50 to 100 mph at 10 mph increments were used. Specified storm surges ranged from 2 to 9 feet. Offshore, the wind and wave direction were assumed the same. However, at about -15 ft MLW, the waves enter the nearshore shoaling region and must be evaluated using a hydrodynamic wave refraction model. The predicted wave heights and periods for the three subject directions (SW, W and NW) are used as input to the hydrodynamic model, RCPWAVE.

RCPWAVE is a linear wave propagation model designed by the USACE (Ebersole et al., 1986) for engineering purposes. It computes changes in wave characteristics that result naturally from refraction, shoaling, and diffraction over complex topography. To this fundamental, linear theory-based model, we have added routines to estimate wave energy dissipation due to bottom friction (Wright et al., 1987). The use of RCPWAVE to model the hydrodynamics at Saxis assumes that only the offshore bathymetry affects wave transformation; the application does not include the effects of tidal currents.

RCPWAVE takes a simulated incident wave condition at the seaward boundary of the grid and allows it to propagate shoreward across the nearshore bathymetry. Frictional dissipation due to bottom roughness is accounted for in this analysis and is relative in part to the mean grain size of the bottom sediment. Waves also tend to become smaller over shallower bathymetry and remain larger over deeper bathymetry. Upon entering shallow water, waves are subject to refraction, in which the direction of wave travel changes with decreasing depth in such a way that wave crests tend to become parallel to the depth contours. Irregular bottom topography can cause waves to be refracted in a complex way and produce variations in the wave height and energy along the coast. In general, waves break when the ratio of wave height to water depth equals 0.78 (Komar, 1976).

Two grids (Figure 6) of the study region were digitized from a National Oceanic and Atmospheric Administration chart no. 12228, updated to 19 September 1992 by BBA Chart Kits. Bathymetric Grid 1 was used for the west and northwest winds while bathymetric Grid 2 accommodates the southwest wind. The process, which calculates the impinging wave climate at a site, was developed and used during previous projects (Hardaway et al., 1991; Hardaway et al., 1993; Milligan et al., 1995; Milligan et al., 1996). The conditions input into RCPWAVE are listed in Table 3.

The output of RCPWAVE is wave heights and angles along the entire modeled shore. Wave height and angle at the approximate depth where shore structures would be located were used to characterize the modal, or average, annual conditions at Saxis. The RCPWAVE output wave data at the proposed structures was exported from the overall data file along three parallel lines in the nearshore region. Line 1 ranges from the bulkhead to the end of the dredge spoil area. Line 2 extends from just northwest of the dredge spoil area to just past the barge along the shoreline. Line 3 runs from just past the barge to the offset area near the Town limit. The data were averaged along each line. The average output wave heights and angles relative to the shoreline along the three lines also are shown in Table 3 for each case. Wave angles are shown as
Figure 6. Location of Bathymetric Grid 1 and 2 used in RCPWAVE.
Table 3. Incident wave conditions input to RCPWAVE and wave height and wave angle output averaged along the shoreline.

<table>
<thead>
<tr>
<th>Direction</th>
<th>Wind Speed</th>
<th>Surge Height In (feet)</th>
<th>Period Height In (seconds)</th>
<th>Height Out (feet)</th>
<th>Shore Relative Angle*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwest</td>
<td>10</td>
<td>2.0</td>
<td>0.53</td>
<td>1.53</td>
<td>0.4</td>
</tr>
<tr>
<td>Input Angle = -15</td>
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<td>0.82</td>
<td>1.87</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>2.0</td>
<td>1.10</td>
<td>2.14</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>3.0</td>
<td>1.39</td>
<td>2.40</td>
<td>1.1</td>
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<tr>
<td></td>
<td>30</td>
<td>3.0</td>
<td>1.65</td>
<td>2.60</td>
<td>1.1</td>
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<tr>
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<td>4.0</td>
<td>1.95</td>
<td>2.82</td>
<td>1.5</td>
</tr>
<tr>
<td>10-yr</td>
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<td>4.0</td>
<td>2.20</td>
<td>2.99</td>
<td>1.5</td>
</tr>
<tr>
<td>25-yr</td>
<td>45</td>
<td>5.5</td>
<td>2.51</td>
<td>3.18</td>
<td>2.2</td>
</tr>
<tr>
<td>50-yr</td>
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<td>6.2</td>
<td>2.83</td>
<td>3.36</td>
<td>2.1</td>
</tr>
<tr>
<td>50-yr</td>
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<td>3.39</td>
<td>3.67</td>
<td>2.5</td>
</tr>
<tr>
<td>50-yr</td>
<td>70</td>
<td>6.9</td>
<td>3.84</td>
<td>3.92</td>
<td>2.7</td>
</tr>
<tr>
<td>100-yr</td>
<td>80</td>
<td>7.6</td>
<td>4.39</td>
<td>4.18</td>
<td>3.0</td>
</tr>
<tr>
<td>West</td>
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<td>2.0</td>
<td>0.79</td>
<td>1.88</td>
<td>0.5</td>
</tr>
<tr>
<td>Input Angle = 30</td>
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<td>1.15</td>
<td>2.29</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>2.0</td>
<td>1.47</td>
<td>2.61</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>3.0</td>
<td>1.83</td>
<td>2.92</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>3.0</td>
<td>2.10</td>
<td>3.16</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
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<td>2.46</td>
<td>3.41</td>
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<td>10-yr</td>
<td>40</td>
<td>4.0</td>
<td>2.70</td>
<td>3.61</td>
<td>1.5</td>
</tr>
<tr>
<td>25-yr</td>
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<td>5.5</td>
<td>3.06</td>
<td>3.83</td>
<td>1.9</td>
</tr>
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<td>50-yr</td>
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<td>6.2</td>
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<td>4.07</td>
<td>2.2</td>
</tr>
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<td>50-yr</td>
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<td>4.04</td>
<td>4.43</td>
<td>2.4</td>
</tr>
<tr>
<td>50-yr</td>
<td>70</td>
<td>6.9</td>
<td>4.44</td>
<td>4.70</td>
<td>2.5</td>
</tr>
<tr>
<td>100-yr</td>
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<td>7.6</td>
<td>5.02</td>
<td>5.01</td>
<td>2.8</td>
</tr>
<tr>
<td>Southwest</td>
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<td>2.19</td>
<td>0.3</td>
</tr>
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<td>2.73</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
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<td>2.0</td>
<td>2.10</td>
<td>3.17</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>3.0</td>
<td>2.62</td>
<td>3.58</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>3.0</td>
<td>3.02</td>
<td>3.99</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>4.0</td>
<td>3.51</td>
<td>4.35</td>
<td>0.8</td>
</tr>
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</tr>
<tr>
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<td>5.5</td>
<td>4.29</td>
<td>5.06</td>
<td>1.2</td>
</tr>
<tr>
<td>50-yr</td>
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<td>6.2</td>
<td>4.66</td>
<td>5.28</td>
<td>1.4</td>
</tr>
<tr>
<td>50-yr</td>
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<td>6.9</td>
<td>5.33</td>
<td>5.64</td>
<td>1.5</td>
</tr>
<tr>
<td>50-yr</td>
<td>70</td>
<td>6.9</td>
<td>5.76</td>
<td>5.86</td>
<td>1.8</td>
</tr>
<tr>
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<td>7.6</td>
<td>6.41</td>
<td>6.17</td>
<td>1.8</td>
</tr>
</tbody>
</table>
grid relative, meaning that an angle of zero is perpendicular to the shoreline. Negative numbers are impacting the shore from the northwest and tending to drive littoral sediments to the south. Positive numbers are generally from the southwest and west and tend to drive sediment to the north.

The wind analysis was used to determine the relative amounts of energy impacting the shore. The output wave data was mean-weighed with the wind data in order to describe the annual, modal condition along each section of the shoreline. These modal conditions determine the long-term angle of wave approach which significantly influences morphologic shape of the shore and will dictate the beach planform shape between headland breakwaters.

Storm surge may pose a threat to certain resources regardless of potential wave impacts. The wave climate assessment included a determination of the frequency of storm surges and flooding based on research by Boon et al. (1978) (Table 4). This assessment is critical when determining the potential impacts of the local wave climate and related storm surge on shoreline management strategies. Since much of Saxis Island lies within the 100 yr flood plain, the wave climate and storm surge level will determine the dimensions of any structural option that might be considered.

<table>
<thead>
<tr>
<th>Storm Event Frequency</th>
<th>Storm Surge Height (ft MLW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 year</td>
<td>5.5</td>
</tr>
<tr>
<td>25 year</td>
<td>6.2</td>
</tr>
<tr>
<td>50 year</td>
<td>6.9</td>
</tr>
<tr>
<td>100 year</td>
<td>7.6</td>
</tr>
</tbody>
</table>
E. Equilibrium Bay Determination

Headland breakwaters with beach nourishment are a structural option in the design of a shore protection system for Saxis. Headland control is accomplished with breakwaters that accentuate existing features or create permanent headlands that allow adjacent, relatively wide embayments to become stable. The description of the bay shape is a necessary part of any breakwater design. Beach planform calculations can be performed using the net impinging wave approach and procedures developed by Silvester and Hsu (1993). A minimum beach width between headland breakwaters was determined utilizing minimum beach width parameters developed by Hardaway et al. (1997).

The final shape of the shore can be determined by the Static Equilibrium Bay model (SEB) which is illustrated in Figure 7A. Hsu et al. (1989a) defined bay curvature utilizing a parabolic bay shape. Incoming wave crests impinge at an angle ($\beta$) to a straight beach (i.e. the tangential beach). The point of diffraction can be a naturally occurring headland or it can be the tip of a breakwater. The line joining the point of diffraction to the downcoast limit of the bay ($R_o$) is termed the “control line”, and its angle to the incident wave crest is the obliquity of the waves ($\beta$). When the bay is in static equilibrium, $\beta$ is equal to the angle between $R_o$ and the downcoast tangential beach. From the definition sketch in Figure 7A, it is seen that the variables which determine bay shape are an arc of length $R$ angled $\varphi$ to the wave crest line, which is assumed parallel to the tangential beach at the downcoast limit of the bay (Hsu et al., 1989b).

Figure 7B illustrates the connection between the wave climate analysis and SEB model. The wave climate analysis is necessary to determine the variable needed as input to SEB model. As described in the previous section, the waves generated in the SMB analysis are used as input to RCPWAVE. RCPWAVE output is average wave height and angle at the location of the proposed breakwaters. These are the variables needed for the SEB model.

F. Biological Surveys

1. Avian Fauna

Data on avian presence were collected by roving survey using binoculars and a spotting scope. Birds were identified to species and to the subhabitat they were occupying at the time the encounter was logged. For the purposes of this study, subhabitat categories were Sound (Pocomoke), beach, paved areas, marsh, dredge spoil pond, washover ponds/isolated back-beach wetlands, shrub/scrub, lawn, and shoreline structures. If a species was observed within more than three subhabitats during the study, they were assigned to the “cosmopolitan” subhabitat category.

The entire length of the Saxis shoreline adjacent to Pocomoke Sound, the upland portions of the island including the causeway, and the marshes surrounding Saxis Island were surveyed four times. Chosen sample dates corresponded with critical seasonal migratory patterns and included one winter (23 March 1998), two spring (early/mid spring (6 May 1998) and late spring (27 May 1998)) and one summer (25 June 1998) survey.
Figure 7A. Parameters of the Static Equilibrium Bay (after Hsu et al., 1989).

Figure 7B. Parameters related to wind/wave generation (SMB), nearshore wave refraction (RCPWAVE) and beach planform prediction (SEB).
2. Fish and Blue Crabs

Fish and blue crabs were collected by beach seine. Six randomly selected sample sites were seined during the spring (27 May 1998) and summer (25 June 1998). Sample sites (Figure 8) included areas within the direct footprint of the proposed shoreline stabilization effort and areas adjacent to the proposed breakwater/beach nourishment area. Collected fauna were enumerated by species. Due to the presence of large debris, exposed roots and stumps, and marsh peat outcrops within the intertidal zone and immediately channelward of MLW, a 50 ft long seine, rather than a 100 ft long seine, with a mesh size of 5 millimeters was used. Sample site positions were determined with a hand-held Global Positioning System (GPS) unit.

Random sample sites were established by randomly selecting a number between 0 and 2,000. The random number generated (using a random number function on a calculator) was used to determine the distances between sample sites, and the distance from the base sampling station located on the south shore of the island immediately north of the terminus of the broken concrete revetment.

3. Oysters and Clams

Sample sites for oyster and clam surveys also were chosen by random distance measurements. An additional random component (offshore distance) was included which ran from mean high water to approximately 250 feet offshore and which encompassed the footprint of the proposed breakwater/beach nourishment effort. Three random distances were chosen along the offshore distance component at each of six sample sites. This resulted in a total of 18 separate sample sites for oysters and clams. At each sample site, an area of approximately one square meter was dredged with a hand dredge. The dredge sampled approximately the top 10 cm of the substrate which is a sufficient collection depth for nearshore beach environments. Sampling occurred on 18 August 1998 (Figure 8).

4. Vegetation

Aerial photographs of the Saxis shoreline taken 4 August 1998 were used in concert with a ground-truthing survey to assess the vegetative community structure along the affected shoreline. The photographs were digitized to determine the relative percent area of each identified community. For the purposes of this study, vegetation communities were classified into the following categories: beach, dune scarp, marsh, phragmites dominated, scrub shrub, and old field.
Sampling Locations
Saxis, Virginia

Figure 8. Fish and shellfish random sampling locations along the Saxis shoreline.
III. RESULTS

A. Geomorphic Setting

The Town of Saxis is a low, upland feature on the open Pocomoke Sound side of Freeschool Marsh. The shoreline within the town limits on Pocomoke Sound has an historical erosion rate of about 4.9 ft/yr while North End Point eroded at a rate 1.2 ft/yr (Byrne and Anderson, 1978). The erosion at North End Point reflects recession of the shoreline and not the lengthing of the spit. The shore faces approximately NW with average fetch to the NW, W and SW of 2.3 nautical miles (nm), 8.4 nm and 18.7 nm, respectively. The shoreline is characterized as low marsh with a narrow beach. The beach overlies a marsh substrate along most of the shoreline. Rosen (1976) defined Saxis’s shoreline as consisting of two types: a predominantly marsh shore along the southern half, and an impermeable beach along the north half with marsh shore occurring again across North End Point. Impermeable beaches are underlain with an erosion-resistant clay or marsh substrate.

The upland generally is densely vegetated except for a few lawns. Much of the vegetation is the common reed grass (*Phragmites australius*), a dominant species that out competes other more valuable wetlands species. There also several ponds that retain upland runoff and drainages that are piped through the beach to the Sound.

The nearshore zone is relatively shallow with no bars, indicating a general lack of sand in the littoral system. Some submerged aquatic vegetation (SAV) and sands were shown in the 1955 and 1960 aerial photos but both had disappeared by 1965 (Orth and Moore, 1984).

1. Shore Change Analysis

In recent history, Saxis’s shoreline has been characterized by recession or erosion. In 1851, the shoreline may have been largely marsh judging from the undulating appearance of the shoreline itself as depicted on the early charts (Figure 9). From 1851 to 1942, the shoreline eroded at an average rate of about 4 ft/yr. This is an average of Shore Grids #1, 2, and 3 (Figures 9, 10, and 11). Aerial imagery from 1938 shows several small marsh headlands along the coast near Starling Creek. The shoreline was mostly marsh with little or no beach except for the North End Point spit which grew almost 800 ft in length from 1851 to 1942, an accretion rate of 8.8 ft/yr (No shore grid was created for the spit proper, but the spit is shown in Figure 5). Between 1938 and 1942, the “industrial peninsula” or bulkhead on the north side of Starling Creek was beginning to form by anthropogenic filling of the creek mouth. A dredged approach channel is evident on the 1955 aerial imagery, as can an offshore sand bar system with what appears to be patches of SAV in the bar troughs. We believe these bars existed in the 1938 imagery but could not be seen due to sun glint.
Figure 9. Saxis shoreline change and historical shore positions along Shore Grid 1 between the industrial wharf and the grounded barge.
Figure 10. Saxis shoreline change and historical shore positions along Shore Grid 2 between the grounded barge and North End Point.
Figure 11. Saxis shoreline change and historical shore positions along Shore Grid 3 at North End Point.
The earliest records of dredging at Starling Creek is from the USACE who sponsored the approach channel dredging in 1961 when 49,300 cubic yards (cy) were removed. The material was placed in the marsh area southeast of the harbor (Figure 12). In 1965, 93,400 cy of material was dredged from the harbor and channel and placed upland, on the shoreline, and in the nearshore. The material placed along the shoreline extended about 700 ft alongshore from the area of the industrial peninsula and over 500 ft offshore. The impinging wave climate subsequently moved the material alongshore, mostly northward.

Between 1942 and 1968, Saxis’s shoreline receded at an average rate of about 1.2 ft/yr (Figures 9, 10, and 11). The distal end of the North End Point spit continued to prograde a distance of about 400 ft (Figure 5) at a rate of over 15 ft/yr; this most likely reflects the increase in sandy dredge material available to northerly-drifting littoral transport. The bulges (Shore Grid #1 between 1,000 ft and 2,000 ft alongshore) (Figure 9) in the 1968 shoreline just north of the present bulkhead are most likely the remains of the dredge material placed there in 1961. This material and its dispersal northward caused an accretion, or added beach width, and probably is responsible for the lesser overall average rates of erosion. Other notable features of the 1968 shoreline are the protuberances on Shore Grid #2 at 1,100 ft, 2,700 ft and 3,900 ft alongshore (Figure 10). The bulges at 1,100 ft and 2,700 ft appear due to drainages exiting the shoreline creating mini-deltas (i.e. a littoral block). The drainage at 1,100 is shown in the 1938 aerial imagery while the drainage at 2,700 ft first appears in the 1955 aerial imagery; both can be seen in 1960 aerial imagery. The bulge at 3,900 ft appears to be due to some type of shoreline structure shown in 1960 aerial imagery. The large dredge cut that is shown on Shore Grid # 3's 1968 shoreline (Figure 11) apparently was created after 1960 as it does not appear in 1960 aerial imagery. By 1986, this feature had completely filled in.

Starling Creek and its approach channel were dredged again in 1966 with about 57,600 cy of spoil placed in an upland dredge containment area; this dredge spoil area is shown on Figure 4. The 72,300 cy of material dredged in 1970 also was placed in the containment area. Erosion of the containment dike supplied sediments to the littoral system in subsequent years. In 1986, the erosion rate along Shore Grid #1 (Figure 9) was still less than 1 ft/yr but the rates along Shore Grids #2 and #3 (Figures 10 and 11) had increased to 3.9 ft/yr and 1.8 ft/yr, respectively. In 1974, dredged material was placed both upland and on the shore. The material placed along the shoreline and just offshore was located on Shore Grid # 2 between about 800 and 1,300 ft alongshore. This placement is not shown on the shore plot (Figure 10) because it eroded before 1986.

The drainage ditch, apparently responsible for the shore protuberance at 2,700 ft in 1968, was rerouted to a more westerly position. Decreased outflow of sediment and a change in outflow location between 1968 and 1986 eroded the original mini-delta away to a point at about 2,300 ft alongshore on Shore Grid #2 (Figure 10). This new, more southerly point or cape was reinforced in 1986 by a series of concrete well casings placed side-by-side alongshore for about 450 ft following the approximate MLW contour and has resulted in a shoreline offset to the north.
Figure 12. Amount of material dredged from Starling Creek and location of dredge deposition along the shoreline (after USACE, Unknown).
The dredged material placed along shore in 1974 had been eroded away by 1986. North End Point spit, which had been lengthening at a rate of 15 ft/yr between 1942 and 1968, was reduced in subaerial extent between 1968 and 1986 by about 400 ft. The spit had not only eroded back to its 1942 length but also was a much narrower spit feature (Figure 5). The distal end of the spit was hardened with bulkheads and groins by 1986.

From 1986 to 1998, Saxis’s shoreline regained a higher, overall average rate of erosion -- about 3.8 ft/yr which is near historical rates (1851-1942) (Figures 9, 10, and 11). This probably is because no appreciable amount of dredge material was deposited during that time span, but erosion of the dredge spoil containment area dike occurred. An old barge grounded several years ago and acts like a detached breakwater. The main impact of the barge has been to segment the Saxis coast by sheltering the shoreline from wave action allowing sand to accumulate in the lee creating a salient, as shown by the 1998 shoreline (Figure 10). The sand salient disrupts the longshore transport system which has widened the beach to the south. There is an opposite impact to the north shore where the beach becomes narrower, and the underlying marsh peat substrate is intermittently exposed. The beach widens further north since the cape hardened with concrete well casings creates another littoral barrier. During storms, the entire shoreline may lose its beach thereby exposing the underlying peat, but post-storm recovery generally returns some sand to the shore zone.

By 1998, a subaqueous sand bar had grown over 600 ft beyond the 1986 limits of North End Point almost closing off the embayment in the lee of the spit (Figure 5). At the southern end of Saxis, hardening of the shore just north of the commercial wharf bulkhead extends north about 900 ft and consists mostly of broken concrete. This structure has been created over time to prevent flanking of the wharf’s bulkhead as well as to prevent erosion of the upland area.

2. Shore Condition Description

Shoreline conditions for 1985, 1990, and 1998 show little change in land use or shoreline attributes (Figure 13). The date of the shore position depicted in Figure 13 is 1979, but aerial video coverage starts in 1985. The dredge cut shown on the 1979 shoreline had filled in by 1986 (Figure 11) and become an eroding marsh shoreline.

The major change along the shoreline over 13 years of aerial video coverage has been the grounding of the barge. The broken concrete revetment, gabion sill, and concrete well casings along the Town’s shoreline were installed prior to 1985. There were no changes in land use attributes over the 13 years of aerial video coverage.
Shorezone Characteristics
Saxis, Virginia

Figure 13. Shorezone characteristics along the Saxis shoreline.
3. **Sediment Analysis**

Median grain size and sorting of the sand portion of the sample were calculated. The median is defined as the size for which one-half of the particles are coarser and one-half are finer. The sorting of sediments can be described by the Inclusive Graphic Standard Deviation (Folk, 1980). The spread of the grain size distribution about the mean defines the concept of sorting. Well-sorted sands will have a frequency distribution curve that is sharp peaked and narrow; this means only a few size classes are present (Friedman and Sanders, 1978). Poorly sorted sediments have substantial proportions of the sediment in each of several size classes.

The sediment statistics for samples taken along Saxis’s shoreline are shown in Table 5. The grain-size distribution of beach sand generally varies across the shore and to a lesser degree, alongshore as a function of the mode of deposition. The coarsest sands usually are found where the backwash meets the incoming swash in a zone of maximum turbulence at the base of the subaerial beach; here the sand is deposited abruptly creating a step or toe. Just offshore the sand becomes finer. Another area of coarse particle accumulation is the berm crest where runup deposits all grain sizes as the swash momentarily stops before the backwash starts (Bascom, 1959; Stauble *et al.*, 1993). This is a typical model of estuarine beach sediments in the Chesapeake Bay (Hardaway *et al.*, 1991).

In the onshore/offshore direction, midbeach and toe contain the most gravel. Profile 23+63 has the coarsest material as indicated by the percentage of gravel in the sample as well as the mean grain size of the sand. The sediment becomes finer offshore of the beach. The samples taken 100 ft from the toe were taken with a hand auger and indicate the type of material in the top foot of the offshore. This material is much finer than the beach sediments and consists of significant portions of silt and clay particles particularly at 36+74. This sample contains the largest percentage of silt and clay and is located just offshore of the eroding dredge spoil containment area. The amount of silt and clay in the nearshore auger samples decreases away from this profile particularly to the south possibly indicating offshore and some northerly transport of eroded fine material. The median size of sand in the auger samples is similar, all medium-sized sand, however, the sorting varies alongshore. The samples taken on the beach at berm and midbeach along the entire shore have no silt and clay in them.
Table 5. Sediment statistics for surface and hand auger samples.

<table>
<thead>
<tr>
<th>Profile</th>
<th>Type</th>
<th>Location</th>
<th>%Gravel</th>
<th>%Sand</th>
<th>%Silt + %Clay</th>
<th>%Silt</th>
<th>%Clay</th>
<th>Median</th>
<th>Class</th>
<th>Sorting</th>
<th>Class</th>
</tr>
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<td>1+37</td>
<td>Auger</td>
<td>100' from Toe</td>
<td>6.4</td>
<td>67.7</td>
<td>25.9</td>
<td>14.6</td>
<td>11.3</td>
<td>1.3945</td>
<td>Med</td>
<td>0.7116</td>
<td>Mod</td>
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<td>8+06</td>
<td>Surface</td>
<td>Berm</td>
<td>3.2</td>
<td>96.8</td>
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<td>0.0</td>
<td>0.0</td>
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<td>0.0</td>
<td>0.8367</td>
<td>Coarse</td>
<td>1.3008</td>
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<td></td>
<td>Toe</td>
<td>31.3</td>
<td>66.1</td>
<td>2.7</td>
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<td>2.3</td>
<td>1.0494</td>
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<td>Mod Well</td>
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<td></td>
<td></td>
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<td>8.4</td>
<td>87.1</td>
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<td>0.6</td>
<td>3.9</td>
<td>1.6521</td>
<td>Med</td>
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<td>67.1</td>
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<td>12.9</td>
<td>15.8</td>
<td>1.5841</td>
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<td>0.3993</td>
<td>Poor</td>
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<td>21+77</td>
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<td>59.2</td>
<td>38.9</td>
<td>25.4</td>
<td>13.5</td>
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<td>0.0</td>
<td>0.5300 V. Coarse</td>
<td>0.7792</td>
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<td>0.1</td>
<td>0.0</td>
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<td>Mod Well</td>
</tr>
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<td>47.8</td>
<td>31.0</td>
<td>16.8</td>
<td>1.3250</td>
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<td>0.6245</td>
<td>Mod Well</td>
</tr>
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<td>Surface</td>
<td>Berm</td>
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<td>100.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>1.5189</td>
<td>Med</td>
<td>0.4606</td>
<td>Well</td>
</tr>
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<td></td>
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<td>Mod</td>
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<td>Toe</td>
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<td></td>
<td>Offshore</td>
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<td>93.9</td>
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<td>0.8</td>
<td>3.5</td>
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<td>Mod</td>
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<td>Auger</td>
<td>100' from Toe</td>
<td>1.2</td>
<td>88.3</td>
<td>10.5</td>
<td>4.1</td>
<td>6.4</td>
<td>1.1575</td>
<td>Med</td>
<td>1.0735</td>
<td>Poor</td>
</tr>
</tbody>
</table>

Grain Size (phi) | Sorting (phi)  
--- | ---  
<-1 | Gravel | 0.35 | Very Well Sorted  
(1)-0 | Very Coarse Sand | 0.35-0.5 | Well Sorted  
0-1 | Coarse Sand | 0.5-0.71 | Mod. Well Sorted  
1-2 | Medium Sand | 0.71-1.0 | Moderately Sorted  
2-3 | Fine Sand | 1.0-2.0 | Poorly Sorted  
3-4 | Very Fine Sand | 2.0-4.0 | Very Poorly Sorted  
4-8 | Silt | 4.00 | Very Poorly Sorted  
>8 | Clay |  |
B. Hydrodynamic Setting

The assessment of hydrodynamic conditions at Saxis’s shoreline results in the determination of the annual, modal conditions as well as the storm conditions impacting the site. The assessment is based on the wind field analysis as well as the hydrodynamic modeling. Winds less than 7 mph were not used in the analysis because they typically generate wind chop which is not sufficiently large or organized to move sediment. Winds from 10-36 mph generate local wind waves when propagated over a Bay fetch (Ludwick, 1987). Long-term wind frequencies in the area indicate the southwest wind is dominant in the 8-12 mph range followed by the northwest, then west. However, as wind speeds increase, the northwest component becomes dominant while the southwest and west have similar frequencies. Overall, the northwest component is slightly more frequent than the southwest, and both are more frequent than the west condition.

Two types of storms can impact the area. A storm that will impact Saxis from the southwest is a hurricane or other low-pressure system off the Atlantic coast of the Eastern Shore. A storm of this type could generate large waves over the southwest fetch as well as produce a large storm surge. However, this is a rare event, and the wind data indicate that storm conditions experienced at Saxis are generally from the northwest. These second, more frequent types of storms are the extratropical storms or northeasters. While Saxis is protected from northeast winds, except along the spit that has formed off North End Point into Robin Hood Bay, these storms tend to generate winds from the northwest as the system moves northward. Northeasters have a smaller storm surge than a hurricane but can last several tidal cycles longer.

RCPWAVE allows us to determine the wave climate along a shore reach. Individual cases indicate specific conditions. In general, southwest and west waves bend in the nearshore but still impact the shore at an angle. When waves approach at an angle to the shoreline, alongshore sediment transport is initiated. With the longest effective fetch to the southwest as well as the high frequency of wind from that direction, waves are generated that significantly impact the alongshore transport system tending to drive sediment to the north. These southwest and west conditions combined are more frequent than the northwest which supports our other analyses since the morphologic evidence points to a northward trending littoral transport system (i.e. shoreline offsets and North End Point spit). Generally, the southwest waves are significantly altered by the nearshore since wave heights 200-300 ft offshore are smaller than northwest and west waves even though the southwest wave starts out larger. In addition, the southwest wave shoals nearly 35° before it impacts the shore. Westerly waves are impacted by the nearshore bathymetry, shoaling about 8°. The northwest component is altered little by the nearshore; the angle of wave approach only changes by about 2°, and the wave height does not diminish as rapidly as other directions. Because of the shoreline orientation, the northwest waves have an angle of about 13° to the south, but are shore normal further inshore, indicating a possible onshore-offshore net movement of sand during storms.
Figure 14 shows wave vector plots for two modal conditions. Figure 14A depicts waves from the west at a water level just slightly less than MHW. Under these minimal conditions, waves diminish in height over the flat nearshore rather than break at the shore. The 8 ft (2.4 m) contour is about 800 yards (0.7 km) from MLW which is ample width to reduce these waves. Waves have a definite angle to the coast, orientated at a positive 20° angle (100° TN). The average wave heights and angles parallel to the shore approximately 200-300 ft offshore for each wave condition are shown in Table 3. A typical condition using a wave from the northwest is shown in Figure 14B. This wave is more onshore (i.e. wave crests shore parallel), the average wave height is 1.1 ft, and makes an angle of -12° (132° TN) with the shoreline. Further analysis reveals that as the wave moves closer to shore, the wave crests become even more shore parallel before they break.

Figure 15A represents a 10-yr event from the northwest (surge is 5.5 ft MLW). As upland contours are not digitized past the +5 ft MLW, higher surges are shown impacting the inland area. In general, waves are onshore-offshore, but waves definitely impact the spit at North End Point tending to elongate it. During southwest and west conditions, the North End Point spit is sheltered from wave energy as shown in Figure 15B. This 50-yr event (surge 6.9 ft MLW) from the southwest tends to drive the sediment northward. Note: Figure 15B shows a different grid (#2) with a different y-axis orientation than the previous three examples.

Wave trajectories indicate the direction of travel of a wave crest and can describe areas of convergence and divergence of wave energy along the shore due to offshore bathymetric contours. Figure 16 shows the wave trajectories of two different wave modeling conditions that would impact the shore from the west. Figure 16A depicts a modal condition, and Figure 16B shows a 25-yr storm condition. Under modal conditions, a very few, small regions of increased wave energy are shown along the shore. However, under storm conditions, energy tends to be concentrated (convergence) just south of the cape stabilized with well casings near the northern limit of the Town. North and south of this cape, some divergence (spreading laterally) of wave energy occurs. Wave trajectories for the other two directions were not shown, but northwest modal condition and storm condition show very little convergence or divergence while the storm trajectory for southwest condition shows convergence in the region of the dredge spoil containment area.

Individual wave modeling cases must be mean-weighed with wind frequencies in order to determine the average annual energy acting on the shoreline. Utilizing the wind analysis and output from RCPWAVE, the average modal wave angle impacting the shore is 107° TN, making a +13° angle with the Saxis shoreline indicating that over time, net littoral transport is to the north. The wave modeling results were used to develop equilibrium bay planforms for the shore protection system at Saxis.
Figure 14. Wave vector plots for modal conditions on Grid 1 from the A.) West, and B.) Northwest.
Figure 15. Wave vector plots for A.) Grid 1, 10-yr event from the northwest, and B.) Grid 2, 50-yr event from the southwest.
Figure 16. Wave trajectory plots for Grid 1 from the west under A.) modal conditions, and B.) 25-yr event.
C. Biological Setting

1. Avian Fauna

The birds observed during the winter, spring and summer surveys, as well as the habitat the birds were observed in or over, are listed in Table 6. These observations represent a diverse assemblage of birds that include a mixture of year-round residents, wintering birds, migrants, and summer nesting birds. A comparison with the Christmas Bird Counts (CBC) compiled by the Audubon Society (Teta Cain, personal communication) and the Breeding Bird Survey compiled by the U.S. Fish and Wildlife Service (Sauer et al., 1997) indicated our data are representative of species that would normally be expected to utilize the habitats sampled.

There was no one group of birds that dominated the avifauna; pelagic birds, wading birds, waterfowl, raptors, shorebirds, gulls and terns, and passerines were all well represented in the results of the survey.

2. Fish and Blue Crabs

Anchovies dominated spring samples, whereas anchovies and Atlantic silversides were co-dominant during the summer sampling period (Figure 17). Relative abundances of summer flounder and Atlantic Croaker were greater during the spring sampling period. Blue crabs and Atlantic menhaden were more abundant during the summer sampling period. These data are consistent with other local studies which assessed fish population structure for the Bay side of Virginia’s upper Eastern Shore using beach haul seines (Seaver and Austin, 1995).

3. Oysters and Clams

No live oysters or clams were collected. Only sparse cultch was observed at a few sample locations.

4. Vegetation

The vegetation communities along Saxis’s shoreline are depicted in Figure 18. The vegetation along the shoreline is dominated by common reed (Phragmites australis). Significant stands of emergent marsh, scrub shrub, and old field communities also are found. The characteristic vegetation of these communities is listed in Table 7. The areal extent of the existing communities is given in Table 8. The lawn and developed communities are not included because their landward limits could not be established.
Table 6. Birds observed on Saxis Island during this study.

<table>
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<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Winter</th>
<th>Spring1</th>
<th>Spring2</th>
<th>Summer</th>
<th>Location Code</th>
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</thead>
<tbody>
<tr>
<td>Common Loon</td>
<td>Gavia immer</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>s</td>
</tr>
<tr>
<td>Brown Pelican</td>
<td>Pelecanus occidentalis</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>s</td>
</tr>
<tr>
<td>Double-crested Cormorant</td>
<td>Phalacrocorax auritus</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>s,m</td>
</tr>
<tr>
<td>Great Blue Heron</td>
<td>Ardea herodias</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>m</td>
</tr>
<tr>
<td>Great Egret</td>
<td>Casmerodius albus</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>m</td>
</tr>
<tr>
<td>Snowy Egret</td>
<td>Egretta thula</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>m</td>
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<tr>
<td>Green Heron</td>
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<td></td>
<td></td>
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<td>x</td>
<td>x</td>
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<td>x</td>
<td></td>
<td></td>
<td></td>
<td>c</td>
</tr>
<tr>
<td>Northern Harrier</td>
<td>Circus cyaneus</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>m</td>
</tr>
<tr>
<td>Sharp-shinned Hawk</td>
<td>Accipiter striatus</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>m</td>
</tr>
<tr>
<td>Clapper Hawk</td>
<td>Rallus longirostris</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>m</td>
</tr>
<tr>
<td>Killdeer</td>
<td>Charadrius vociferus</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>b,p,d</td>
<td></td>
</tr>
<tr>
<td>Lesser Yellowlegs</td>
<td>Tringa flavipes</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>d</td>
</tr>
<tr>
<td>Willet</td>
<td>Catoptrophorus semipalmatus</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>d,b</td>
<td></td>
</tr>
<tr>
<td>Ruddy Turnstone</td>
<td>Arenaria interpres</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>b</td>
</tr>
<tr>
<td>Least Sandpiper</td>
<td>Caldris minuilla</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>b,a,d</td>
<td></td>
</tr>
<tr>
<td>Dunlin</td>
<td>Caldris alpina</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>b</td>
</tr>
<tr>
<td>Laughing Gull</td>
<td>Larus atricilla</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>d,m,s</td>
<td></td>
</tr>
<tr>
<td>Bonaparte’s Gull</td>
<td>Larus philadelphia</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>m</td>
</tr>
<tr>
<td>Ring-billed Gull</td>
<td>Larus delawarensis</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>s</td>
</tr>
<tr>
<td>Herring Gull</td>
<td>Larus argentatus</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>b,s</td>
<td></td>
</tr>
<tr>
<td>Gr. Black-backed Gull</td>
<td>Larus marinus</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>s</td>
</tr>
<tr>
<td>Royal Tern</td>
<td>Sterna maxima</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>s</td>
</tr>
<tr>
<td>Common Tern</td>
<td>Sterna hirundo</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>w</td>
</tr>
<tr>
<td>Least Tern</td>
<td>Sterna albifrons</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>b</td>
</tr>
<tr>
<td>Mourning Dove</td>
<td>Zenaida macroura</td>
<td>x</td>
<td>x</td>
<td></td>
<td>b,t</td>
<td></td>
</tr>
<tr>
<td>Belted Kingfisher</td>
<td>Megaceryle Alecyn</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>w,m</td>
</tr>
<tr>
<td>Barn Swallow</td>
<td>Hirundo rustica</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>t,d</td>
<td></td>
</tr>
<tr>
<td>Tree Swallow</td>
<td>Iridoprocne bicolor</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>d</td>
</tr>
<tr>
<td>Purple Martin</td>
<td>Progne subis</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>t,d</td>
<td></td>
</tr>
<tr>
<td>Fish Crow</td>
<td>Corvus ossifragus</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>m</td>
</tr>
<tr>
<td>Robin</td>
<td>Turdus migratorius</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>l</td>
</tr>
<tr>
<td>European Starling</td>
<td>Sturnus vulgaris</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>c</td>
</tr>
<tr>
<td>Yellow-rumped Warbler</td>
<td>Dendroica coronata</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>t</td>
</tr>
<tr>
<td>Common Yellowthroat</td>
<td>Geothlypis trichas</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>t</td>
</tr>
<tr>
<td>Savannah Sparrow</td>
<td>Passerculus sandwichensis</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>m</td>
</tr>
<tr>
<td>Song Sparrow</td>
<td>Melospiza melodia</td>
<td>x</td>
<td>x</td>
<td></td>
<td>t,w</td>
<td></td>
</tr>
<tr>
<td>Northern Junco</td>
<td>Junco hyemalis</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>t</td>
</tr>
<tr>
<td>Red-winged Blackbird</td>
<td>Agelaius phoeniceus</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>l,m</td>
<td></td>
</tr>
<tr>
<td>Boat-tailed Grackle</td>
<td>Quiscalus major</td>
<td>x</td>
<td></td>
<td></td>
<td>d,m</td>
<td></td>
</tr>
<tr>
<td>Common Grackle</td>
<td>Quiscalus quiscula</td>
<td>x</td>
<td></td>
<td></td>
<td>t</td>
<td></td>
</tr>
<tr>
<td>House Sparrow</td>
<td>Passer domesticus</td>
<td>x</td>
<td>x</td>
<td></td>
<td>p</td>
<td></td>
</tr>
</tbody>
</table>

Location Code Legend

- s = sound
- m = marsh
- t = scrub shrub
- w = washover ponds/isolated back-beach wetlands
- b = beach
- d = disposal area
- l = lawn
- p = paved areas
- c = cosmopolitan
- a = shoreline structures
Figure 17. Results of beach seine sampling along the Saxis Island shoreline, 1998.
Vegetative Community Structure
Saxis, Virginia

Figure 18. Vegetative community structure along the Saxis shoreline.
Table 7. Principal plant species characteristic of the major vegetated community types along the Saxis shoreline.

<table>
<thead>
<tr>
<th>Community Type</th>
<th>Plant Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phragmites Dominated</td>
<td>Common reed - <em>Phragmites australis</em></td>
</tr>
<tr>
<td></td>
<td>Groundsel tree - <em>Baccharis halimifolia</em></td>
</tr>
<tr>
<td>Marsh</td>
<td>Smooth cordgrass - <em>Spartina alterniflora</em></td>
</tr>
<tr>
<td></td>
<td>Saltmeadow hay - <em>Spartina patens</em></td>
</tr>
<tr>
<td></td>
<td>Marsh elder - <em>Iva frutescens</em></td>
</tr>
<tr>
<td>Scrub shrub</td>
<td>White mulberry - <em>Morus alba</em></td>
</tr>
<tr>
<td></td>
<td>Black locust - <em>Robinia pseudoacacia</em></td>
</tr>
<tr>
<td></td>
<td>Black Cherry - <em>Prunus serotina</em></td>
</tr>
<tr>
<td></td>
<td>Hackberry - <em>Celtis occidentalis</em></td>
</tr>
<tr>
<td></td>
<td>Wax myrtle - <em>Myrica cerifera</em></td>
</tr>
<tr>
<td></td>
<td>Groundsel tree - <em>Baccharis halimifolia</em></td>
</tr>
<tr>
<td>Old field</td>
<td>Pokeweed - <em>Phytolacca americana</em></td>
</tr>
<tr>
<td></td>
<td>Horseweed - <em>Erigeron canadensis</em></td>
</tr>
<tr>
<td></td>
<td>Dog-fennel - <em>Eupatorium capillifolium</em></td>
</tr>
<tr>
<td></td>
<td>Blackberry - <em>Rubus argutus</em></td>
</tr>
<tr>
<td>Beach</td>
<td>American beachgrass - <em>Ammophila breviligulata</em></td>
</tr>
<tr>
<td></td>
<td>Bitter panicum - <em>Panicum amarum</em></td>
</tr>
<tr>
<td></td>
<td>Seaside goldenrod - <em>Solidago sempervirens</em></td>
</tr>
</tbody>
</table>

Table 8. Areal coverage of the various vegetation communities along the Saxis shoreline, exclusive of lawns.

<table>
<thead>
<tr>
<th>Community Type</th>
<th>Area (sq. ft.)</th>
<th>Area (acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phragmites Dominated</td>
<td>867,000</td>
<td>19.9</td>
</tr>
<tr>
<td>Marsh</td>
<td>401,000</td>
<td>9.2</td>
</tr>
<tr>
<td>Beach</td>
<td>234,000</td>
<td>5.4</td>
</tr>
<tr>
<td>Scrub shrub</td>
<td>154,000</td>
<td>3.5</td>
</tr>
<tr>
<td>Old field</td>
<td>43,500</td>
<td>1.0</td>
</tr>
<tr>
<td>Rubble</td>
<td>16,000</td>
<td>0.4</td>
</tr>
<tr>
<td>Dune</td>
<td>5,000</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,720,500</strong></td>
<td><strong>39.5</strong></td>
</tr>
</tbody>
</table>
5. Subsidiary Observations

Auxiliary evidence of faunal utilization of the nearshore and beach also was catalogued and included raccoon tracks and scat, deer tracks, fox tracks, horseshoe crab corpses, and direct observations of toads, muskrats, and tiger beetles. Two subspecies of the tiger beetle have been documented in Virginia—*Cincindela dorsalis dorsalis* and *Cincindela dorsalis media*. *C. dorsalis dorsalis* is a federally-listed, endangered species. The two are easily confused. *C. dorsalis media* is smaller and slightly darker in coloration but has only been documented on Atlantic Coast beaches. We were unable to collect a tiger beetle individual to identify to subspecies; however, it is probable that since the observed tiger beetles were on a bay beach rather than an ocean beach, they are the federally-endangered Northeastern Beach tiger beetle (*C. dorsalis dorsalis*).
IV. DISCUSSION

A. Physical Environment

The geomorphic evolution of Saxis’s shoreline indicates a net movement of littoral materials to the north. This is supported by the wave climate analysis which indicates a slight, but dominant, net northerly longshore transport. The southerly wind/wave field dominates in duration and fetch and drives the northerly transport, but the overall wave climate is significantly modified by the northwesterly wind/wave field which is almost shore normal.

An added volume of sandy dredge material can, for a short time, provide a wave buffer and reduce shoreline recession. In addition, even small offshore features (i.e. the barge) can significantly impact littoral processes. The barge is an empirical element that strongly supports the identified trends in shoreline evolution and wave climatology. Adding sand to the coast would increase beach width and provide a protective beach zone; offshore breakwaters would keep the sand contained in a series of equilibrated pocket beaches. Downdrift impacts to North End Point would be apparent and should be addressed in the final design scenario, possibly with strategically-placed, headland breakwaters.

B. Biological Environment

The flora and fauna associated with this area is typical of non-vegetated Bay beach ecosystems which have been developed and have a history of manipulation from the placement of dredge spoil. The major fish species observed during the study included filter feeders (menhaden and anchovies), omnivores (Atlantic silversides) and forage fishes (summer flounder and croaker). No species collected was considered unusual or unique to this ecosystem. However, no killifishes were collected and the absence of species such as the sheepshead minnow, banded killifish, striped killifish, and the mummichog was unexpected. Killifishes spawn within areas containing aquatic vegetation (SAV beds or intertidal marshes). Eggs are either attached to aquatic plants or buried in quiescent waters. This shoreline provides little of the critical habitat for killifishes; only a few areas of low marsh outcrops are present along this shoreline. Due to this, large numbers were not expected, but neither was a complete absence. Good killifish habitat is available within the Greater Saxis Ecosystem, and these areas peripheral to Saxis’s shoreline are probably preferred. Killifishes are excellent prey for forage fishes and colonial wading birds, and their absence may influence the behavior of colonial waders along this reach of shoreline. Historical aerial photographs of Saxis provide evidence that the Town’s shoreline once was fronted by vegetated, intertidal marsh and SAV beds. Therefore, killifishes and other absent species endemic to vegetated marshes such as the mosquitofish (Gambusia holbrooki) may have had an historical presence in this area. The shoreline design resulting from this study restores habitats critical to killifishes and other important estuarine species which were not observed during this study.

The absence of oysters or clams observed within the study boundaries also was unexpected. Catch data provided by the Virginia Marine Resources Commission shows clams are harvested within the Greater Saxis Ecosystem. The design incorporates areas which may
support oyster and clam resources. Intertidal and subaqueous areas in the lee of the breakwaters (the same areas where SAV is recommended for planting) may provide habitats favorable for the establishment of mollusk resources.

With the exception of the narrow beach and non-vegetated intertidal sand community, Saxis’s shoreline contains little favorable bird habitat. The shoreline is dominated by reed grass, and this community provides little functional habitat to the vast majority of locally-common birds and those using the Atlantic flyway. Only sparse scrub shrub communities are found along this shoreline reach. Colonial wading birds such as the great blue heron, great egret, snowy egret and the little blue heron prefer to nest in isolated areas of shrubby vegetation in mixed bird colonies. The shoreline design resulting from this study incorporates scrub shrub communities which are isolated from upland areas by the proposed dune/beach system. The species chosen for planting (wax myrtle, yaupon, highbush blueberry, and beach plum) are of high relative value as food sources and nesting sites for a wide range of bird species.

C. Shore Protection Options

There are four basic approaches to shoreline management: 1) No action; 2) Defend an erosional area with a defensive structures such as bulkheads, seawalls or revetments; 3) Maintain and/or enhance existing shore zone features such as beach and dunes that presently offer limited protection; or 4) Create a shore zone system of beaches and dunes, generally using headland control with stone breakwaters.

A management strategy based on the first approach listed above may be appropriate in areas where no property improvements are threatened by erosion and/or the shoreline is stable or accretional; although accretion in the form of a spit or a widening beach may pose problems to navigation or access to the waterfront. Defending an erosional area generally means protecting upland structures threatened by erosion and not the beach in front of the structure. Defensive structures such as seawalls and revetments can, in some cases, increase erosion rates in front of it and, in many cases, alter the natural beach profile. Approaches 3 and 4 are similar in that a shore zone system is either maintained or created along an entire shoreline reach. Generally, this is accomplished with breakwaters and/or headland control. Beach nourishment or maintaining beach features are part of this approach.

Headland control is a concept that can allow long stretches of shoreline to be addressed in a more cost/effective way. It is accomplished by accentuating existing features or creating permanent headlands that allow adjacent, relatively wide embayments to become stable. This can greatly reduce the cost of managing the shoreline reach by reducing the linear feet of structure necessary.

Headlands generally are created with a breakwater. Offshore breakwaters are considered an “offensive” strategy to shoreline erosion control since they address the impinging waves before they reach the shore. However, breakwaters, groins, seawalls and beach nourishment all may play a part in developing a shoreline protection system. The dimensions and position of any shore protection system are dependent on wave climate, costs, what is being protected and what
level of protection is desired (e.g. for a design storm surge and wave height).

Headland breakwaters have been used extensively around the Chesapeake Bay over the last 15 years for erosion control and habitat enhancement (Hardaway and Gunn, 1991; Hardaway and Gunn, 1998). Hardaway et al. (1991) evaluated 15 breakwater systems in terms of numerous parameters including breakwater length, gap, distance offshore and the indentation of the adjacent embayments. These breakwater installations have also shown that a stable beach planform can exist with subtidal attachments. The advantage to a subtidal attachment is that wetland habitat is increased in the breakwater’s lee, but beach stability is not compromised.

Shore erosion abatement and habitat enhancement along the Saxis shoreline are the main goals of this shore protection system. Results of our analyses show that a system should be designed for a unidirectional wave field from the SSW; these waves will approach Saxis at a sub-shore parallel angle. This will allow wider gaps between the headland features. A relatively long crest length of the headland breakwater allow for the creation of a large tombolo. With additional subaerial habitat, many opportunities for enhancement are available. The wave protection provided by the structures will allow the establishment of SAV in the lee of the breakwater.
V. SHORE PROTECTION SYSTEM COMPONENTS

The Saxis Shoreline Management Plan with Habitat Enhancement consists of a series of headland breakwaters, beach nourishment, and vegetative plantings and was developed utilizing the historic shoreline geomorphology, wave climate analysis and storm surge frequency as well as strong consideration for habitat resources (Figure 19).

A. Structures

1. Rock Breakwaters

The proposed system has seven headland breakwaters (300 ft crest length) placed about 200 ft from the existing MLW shoreline and spaced 450 ft apart. Relatively large tombolos will form in the lee of these long breakwaters enabling the establishment of shrub mix and high marsh grass habitats favorable to birds. Alteration of the wave climate behind the breakwaters will provide a protective barrier for the establishment of SAV. In order to insure long-term protection and enhance habitat substrate, seven, 100 ft inner-bay breakwaters should be inset. These increase both shoreline length and the available area for shrub mix and intertidal grass habitats.

2. Beach Fill

Approximately 110,000 cy of beach fill will be added to the system. A +6 ft MLW berm feature will address a 25-yr storm event, but the overall system will withstand a 50-yr event with the exception of some sand and vegetation repair. The breakwaters, themselves, will remain intact in the 100-yr event while there may be a need for replacing sand and vegetation within the system.

B. Habitats

The proposed shoreline habitat enhancement plan provides a vehicle with which to address habitat deficiencies (primarily due to historical losses from erosion and invasion by reed grass) for this reach of shoreline. From an ecological perspective, the proposed design provides the fundamental constituents of a structurally diverse estuarine ecosystem. Various select habitats and vegetative continua have been planned which build upon the existing ecosystem character and provide opportunities for the development of a self-sustaining estuarine system.

The value of any designed habitat ultimately depends upon the success of the constituent species. Invasive plant species, particularly Phragmites australis, can significantly alter community structures and desired habitat functions and values. An invasive species eradication and control plan, not discussed in this plan, should be incorporated into the final implementation plan.
Saxis, Virginia

SCALE 1" = 400'

Figure 19. Proposed beach management plan for the Saxis shoreline.
1. **Submerged Aquatic Vegetation (SAV)**

SAV has been shown to be a resource of high habitat value to estuarine fish and blue crabs. It also is an important food source for certain waterfowl species. No SAV resources are located near the study site; however, historical aerial surveys provided evidence that SAV once may have been abundant in the littoral marine system around Saxis. SAV typically does not survive well in shallow waters along eroding shorelines. Therefore, we hypothesize that the present absence of SAV is related to the erosion and retreat of Saxis’s shoreline.

We propose to restore SAV habitat to this area by planting in the lee of the proposed, large, offshore breakwaters (Figures 20 and 21). We anticipate that this area will stabilize in a relative short time after construction. The lee of the breakwaters are candidates for the introduction of SAV due to their ability to absorb energy and thus create a relatively low energy environment landward of the structures. Shallow and low energy nearshore areas can support successful SAV communities (Orth *et al.*, 1997). To the best of our knowledge, planting SAV in the lee of offshore breakwaters has not been attempted elsewhere. Therefore, the success of this effort cannot be predicted reliably without proper experimentation. However, if successful, we estimate approximately one acre of SAV could be supported by the proposed shore protection system.

2. **Intertidal Marsh**

Intertidal marshes support a myriad of estuarine fauna. They are critical spawning and nursery grounds for estuarine fishes and shellfishes, are habitat for resident species which support the base-level estuarine food chain, and are a major source of primary production for the littoral marine system. Intertidal marshes also have important water-quality and erosion-control functions. Sparse, low-marsh areas exist along the current shoreline. These generally are small and non-contiguous vegetated outcrops which are experiencing relatively rapid erosion. Historical aerial photographs provide evidence that vegetated intertidal marshes once were a more prominent feature along this shoreline. Restoration of this type of community is very important since these habitats are rapidly being lost from the existing shoreline and since sampling failed to collect any killifishes. Killifishes are resident species of intertidal marshes and have important food-chain functions. They are detritivores and primary consumers that are an important food source for a variety of marine and avian fauna.

Vegetated, intertidal areas will be restored along the proposed shoreline from approximately mean tide level (MTL) to approximately 1.5 times MTL (Figures 20 and 21). A mixture of saltmarsh cordgrass (*Spartina alterniflora*) and saltmeadow hay (*Spartina patens*) is proposed for planting. Generally, saltmarsh cordgrass grows in the Mid-Atlantic region between MTL and MHW, whereas saltmeadow hay generally is found at slightly higher elevations immediately landward of the saltmarsh cordgrass community.
Figure 20. Preliminary Saxis Shoreline Management Plan with Habitat Enhancement utilizing a full tombolo profile.

Mean High Water = 2.3'
Upper Limit Wetlands = 3.5'

- Beach
- Marsh Mix: Saltmeadow Hay - Spartina patens, Smooth Cordgrass - Spartina alterniflora
- Beach Mix: Saltmeadow Hay - Spartina patens, American Beachgrass - Ammophila breviligulata, Bitter Panicgrass - Panicum amarum
- Shrub Mix 1: Beach Plum - Prunus maritima, Black Cherry - Prunus serotina, Wax Myrtle - Myrica cerifera, Yaupon - Ilex vomitoria, Inkberry - Ilex glabra
- Shrub Mix 2: Red Cedar - Juniperus virginiana, Choke Cherry - Aronia melanocarpa, Blueberry - Vaccinium corymbosum, Groundsel Tree - Baccharis halimifolia, Switchgrass - Panicum virgatum, Persimmon - Diospyros virginiana
Figure 21. Preliminary Saxis Shoreline Management Plan with Habitat Enhancement utilizing a reduced tombolo profile.
The small, inter-bay breakwaters were incorporated into the shoreline stabilization design, in part, to maximize the amount of restored habitat. Typically, the mid-bay areas are higher energy shorelines which may not support intertidal vegetation as well as areas closer to the large breakwaters. The small, inter-bay breakwaters increase the area of anticipated success by reducing the characteristic increased energy environments between the large breakwaters.

3. **Scrub Shrub**

Extensive scrub shrub plantings are proposed to provide much needed habitat for colonial wading birds and neotropical migrants. The present shoreline generally is characterized by vegetated communities of low habitat and food value for a majority of avian species found in the Chesapeake Bay region (Figure 18). The selected vegetation community mix would provide nesting habitat and serve as a favored food source for neotropical migrants. Selected plant species also will provide aesthetic value and are the upland extent of the proposed shoreline habitat continuum.

4. **Dune and Beach**

The beach habitat along the current shoreline is narrow. Generally, the value of beach as a habitat increases with increasing width and length. The proposed shoreline modification would increase both the width and length of the beach habitat. The shoreline plan was designed with flexibility in mind. The desired amount of beach habitat can be balanced with the desired amount of vegetated wetlands. The amount of beach habitat necessary for this shoreline reach ultimately may depend upon the conclusions of a survey for the Northeast Beach tiger beetle. In absence of such a survey, we recommend an equitable mix of habitats to maximize the probability of increased biodiversity opportunities.

Dunes are sparse along the present shoreline. Generally, a healthy beach community is enhanced by the presence of dunes by interacting with the adjacent beach geologically and as habitat. Dunes also provide enhanced protection of uplands. The dunes designed for the entire reach of the proposed shoreline would provide habitat for colonial wading birds and mammals which utilize the shore. This feature also would provide aesthetics and complement the offshore breakwaters by providing increased upland erosion control.

5. **Rock Breakwaters as Habitat**

Although of lesser habitat value than natural marine habitats generally characteristic of the coastal plain, rock structures provide hard settling substrate and crevices. Over time, these structures become substrate to a variety of organisms which are important for supporting base-level food chains. Crevices provide protected areas of varying size for prey. Also, rock structures generally attract mobile aquatic fauna which make them attractive forage areas for wading birds.

The proposed breakwaters would provide approximately 26,600 ft² of intertidal and subaqueous structure for use by littoral marine fauna and wading birds. It is our opinion, once mature and fully functional, the habitat provided by the proposed rock structures will
compliment and interact well with the natural-based restoration components.
VI. SUMMARY OF THE MANAGEMENT PLAN

The proposed Saxis Shoreline Management Plan has seven breakwaters (300 ft crest length) placed about 200 ft from existing MLW and spaced 450 ft apart. In order to insure long-term protection and enhance habitat substrate, seven, 100 ft long inter-bay breakwaters also are proposed. The breakwater system can be phased, if necessary.

The proposed habitat enhancement plan will produce approximately 17.8 acres of newly constructed habitats (Table 9). The stabilization structures and beach fill will displace a commensurate amount of the existing beach and shallow sub-tidal bottom. There will be some conversion of aquatic habitats to upland habitat, but there will be no net loss of habitat.

Table 9. The approximate areas of the habitats that will be produced by the shoreline protection plan (based on the reduced tombolo profile plan).

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Square Feet</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beach</td>
<td>159,000</td>
<td>3.7</td>
</tr>
<tr>
<td>Tidal Marsh</td>
<td>79,500</td>
<td>1.8</td>
</tr>
<tr>
<td>Dune</td>
<td>257,000</td>
<td>5.9</td>
</tr>
<tr>
<td>Scrub shrub</td>
<td>216,000</td>
<td>5.0</td>
</tr>
<tr>
<td>SAV</td>
<td>35,000</td>
<td>0.8</td>
</tr>
<tr>
<td>Breakwaters</td>
<td>26,600</td>
<td>0.6</td>
</tr>
<tr>
<td>Total</td>
<td>773,100</td>
<td>17.8</td>
</tr>
</tbody>
</table>
VII. LITERATURE CITED


Chesapeake Bay Program, 1991. *Habitat Requirements for Chesapeake Bay Living Resources*.


U.S. Army Corps of Engineers, Unknown. *Dredging Quantities and Disposal Areas*. Norfolk District, Norfolk, VA.


Appendix 1
Glossary
ACCRETION. May be either natural or artificial. Natural accretion is the buildup of land, solely by the action of the forces of nature, on a BEACH by deposition of water- or airborne material. Artificial accretion is a similar buildup of land by reason of an act of man, such as the accretion formed by a groin, breakwater, or beach fill deposited by mechanical means.

ALONGSHORE. Parallel to and near the shoreline; LONGSHORE.

ANTHROPOGENIC. Relating to, or involving, the impact of man on nature.

ARTIFICIAL NOURISHMENT. The process of replenishing a beach with material (usually sand) obtained from another location.

BACKSHORE. That zone of the shore or beach lying between the foreshore and the coastline comprising the berm or berms and acted upon by waves only during severe storms, especially when combined with exceptionally high water.

BAR. A submerged or emerged embankment of sand, gravel, or other unconsolidated material built on the sea floor in shallow water by waves and currents.

BATHYMETRY. The measurement of depths of water in oceans, seas, and lakes; also information derived from such measurements.

BEACH. The zone of unconsolidated material that extends landward from the low water line to the place where there is marked change in material or physiographic form, or to the line of permanent vegetation (usually the effective limit of storm waves). The seaward limit of a beach--unless otherwise specified--is the mean low water line. A beach includes FORESHORE and BACKSHORE. See also SHORE.

BEACH BERM. A nearly horizontal part of the beach or backshore formed by the deposit of material by wave action. Some beaches have no berms, others have one or several.

BEACH EROSION. The carrying away of beach materials by wave action, tidal currents, littoral currents, or wind.

BEACH FACE. The section of the beach normally exposed to the action of the wave uprush. The FORESHORE of a BEACH. (Not synonymous with SHOREFACE.)

BEACH FILL. Material placed on a beach to renourish eroding shores.

BEACH WIDTH. The horizontal dimension of the beach measured normal to the shoreline.

BOTTOM. The ground or bed under any body of water; the bottom of the sea.

BREAKWATER. A structure protecting a shore area, harbor, anchorage, or basin from waves.
BULKHEAD. A structure or partition to retain or prevent sliding of the land. A secondary purpose is to protect the upland against damage from wave action.

CAPE. A relatively extensive land area jutting seaward from a continent or large island which prominently marks a change in, or interrupts notably, the coastal trend; a prominent feature.

CONTOUR. A line on a map or chart representing points of equal elevation with relation to a DATUM. It is called an isobath when connecting points of equal depth below a datum.

CONVERGENCE. (1) In refraction phenomena, the decreasing of the distance between orthogonals in the direction of wave travel. Denotes an area of increasing wave height and energy concentration. (2) In wind-setup phenomena, the increase in setup observed over that which would occur in an equivalent rectangular basin of uniform depth, caused by changes in planform or depth; also the decrease in basin width or depth causing such increase in setup.

CULTCH. Material (such as oyster shells) laid down on oyster grounds to furnish points of attachment for the spat.

DATUM, PLANE. The horizontal plane to which soundings, ground elevations, or water surface elevations are referred. The plane is called a tidal datum when defined by a certain phase of the tide. A common datum used on topographic maps is based on MEAN SEA LEVEL.

DIFFRACTION (of water waves). The phenomenon by which energy is transmitted laterally along a wave crest. When a part of a train of waves is interrupted by a barrier, such as a breakwater, the effect of diffraction is manifested by propagation of waves into the sheltered region within the barrier's geometric shadow.

DIVERGENCE. (1) In refraction phenomena, the increasing of distance between orthogonals in the direction of wave travel. Denotes an area of decreasing wave height and energy concentration. (2) In wind-setup phenomena, the decrease in setup observed under that which would occur in an equivalent rectangular basin of uniform depth, caused by changes in planform or depth. Also the increase in basin width or depth causing such decrease in setup.

DOWNDRIFT. The direction of predominant movement of littoral materials.

DUNES. (1) Ridges or mounds of loose, wind-blown material, usually sand. (2) Bed forms smaller than bars but larger than ripples that are out of phase with any water-surface gravity waves associated with them.

DURATION. In wave forecasting, the length of time the wind blows in nearly the same direction over the FETCH (generating area).

EMBAYMENT. An indentation in the shoreline forming an open bay.
EROSION. The wearing away of land by the action of natural forces. On a beach, the carrying away of beach material by wave action, tidal currents, littoral currents, or by deflation.

FETCH. The area in which seas are generated by a wind having a fairly constant direction and speed.

FORESHORE. The part of the shore, lying between the crest of the seaward berm (or upper limit of wave wash at high tide) and the ordinary low-water mark, that is ordinarily traversed by the uprush and backrush of the waves as the tides rise and fall. See BEACH FACE.

GENERATION OF WAVES. (1) The creation of waves by natural or mechanical means. (2) The creation and growth of waves caused by a wind blowing over a water surface for a certain period of time. The area involved is called the generating area or FETCH.

GEOMORPHOLOGY. That branch of both physiography and geology which deals with the form of the Earth, the general configuration of its surface, and the changes that take place in the evolution of landform.

GROIN (British, GROYNE). A shore protection structure built (usually perpendicular to the shoreline) to trap littoral drift or retard erosion of the shore.

GROIN SYSTEM. A series of groins acting together to protect a section of beach. Commonly called a groin field.

HEADLAND (HEAD). A high, steep-faced promontory extending into the sea.

HINDCASTING, WAVE. The use of historic synoptic wind charts to calculate characteristics of waves that probably occurred at some past time.

HURRICANE. An intense tropical cyclone in which winds tend to spiral inward toward a core of low pressure, with maximum surface wind velocities that equal or exceed 33.5 meters per second (75 mph or 65 knots) for several minutes or longer at some points. Tropical storm is the term applied if maximum winds are less than 33.5 meters per second.

IMPERMEABLE BEACH. This type of beach is composed of a veneer of sand overlying, impermeable, pre-Holocene sediments having a high clay content.

INSHORE (ZONE). In beach terminology, the zone of variable width extending from the low water line through the breaker zone. Also SHOREFACE.

LEE. (1) Shelter, or the part or side sheltered or turned away from the wind or waves. (2) (Chiefly nautical) The quarter or region toward which the wind blows.

LITTORAL DRIFT. The sedimentary material moved in the littoral zone under the influence of waves and currents.
LITTORAL TRANSPORT. The movement of littoral drift in the littoral zone by waves and currents. Includes movement parallel (longshore transport) and perpendicular (on-offshore transport) to the shore.

LITTORAL TRANSPORT RATE. Rate of transport of sedimentary material parallel or perpendicular to the shore in the littoral zone. Usually expressed in cubic meters (cubic yards) per year. Commonly synonymous with LONGSHORE TRANSPORT RATE.

LITTORAL ZONE. In beach terminology, an indefinite zone extending seaward from the shoreline to just beyond the breaker zone.

LONGSHORE. Parallel to and near the shoreline; ALONGSHORE.

LONGSHORE TRANSPORT RATE. Rate of transport of sedimentary material parallel to the shore. Usually expressed in cubic meters (cubic yards) per year. Commonly synonymous with LITTORAL TRANSPORT RATE.

MARSH. An area of soft, wet, or periodically inundated land, generally treeless and usually characterized by grasses and other low growth.

MARSH, SALT. A marsh periodically flooded by salt water.

MEAN HIGH WATER (MHW). The average height of the high waters over a 19-year period. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value. All high water heights are included in the average where the type of tide is either semidiurnal or mixed. Only the higher high water heights are included in the average where the type of tide is diurnal. So determined, mean high water in the latter case is the same as mean higher high water.

MEAN LOW WATER (MLW). The average height of the low waters over a 19-year period. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value. All low water heights are included in the average where the type of tide is either semidiurnal or mixed. Only lower low water heights are included in the average where the type of tide is diurnal. So determined, mean low water in the latter case is the same as mean lower low water.

MEAN SEA LEVEL. The average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings. Not necessarily equal to MEAN TIDE LEVEL.

MEAN TIDE LEVEL. A plane midway between MEAN HIGH WATER and MEAN LOW WATER. Not necessarily equal to MEAN SEA LEVEL.

NEARSHORE (zone). In beach terminology an indefinite zone extending seaward from the shoreline well beyond the breaker zone.
NOURISHMENT. The process of replenishing a beach. It may be brought about naturally by longshore transport, or artificially by the deposition of dredged materials.

OFFSHORE. (1) In beach terminology, the comparatively flat zone of variable width, extending from the breaker zone to the seaward edge of the Continental Shelf. (2) A direction seaward from the shore.

OLD FIELD. Refers to the natural plant succession that occurs when a cultivated field or lawn is no longer maintained in an artificial state.

ONSHORE. A direction landward from the sea.

PERCHED BEACH. A beach or fillet of sand retained above the otherwise normal profile level by a submerged dike.

PHI. Denoted $\phi$. The phi scale is $\phi = -\log_2 d$, where $d$ is the particle diameter in millimeters. Smaller phi sizes are coarser than larger phi sizes.

POCKET BEACH. A beach, usually small, in a coastal reentrant or between two littoral barriers.

PROFILE, BEACH. The intersection of the ground surface with a vertical plane; may extend from the top of the dune line to the seaward limit of sand movement.

RECESSION (of a beach). (1) A continuing landward movement of the shoreline. (2) A net landward movement of the shoreline over a specified time.

REFRACTION (of water waves). (1) The process by which the direction of a wave moving in shallow water at an angle to the contours is changed: the part of the wave advancing in shallower water moves more slowly than that part still advancing in deeper water, causing the wave crest to bend toward alinement with the underwater contours. (2) The bending of wave crests by currents.

REVETMENT. A facing of stone, concrete, etc., built to protect a scarp, embankment, or shore structure against erosion by wave action or currents.

SCRUB SHRUB. Refers to a more advanced state of OLD FIELD vegetation succession that is characterized by the presence of shrubs and small trees.

SHOAL (verb). (1) To become shallow gradually. (2) To cause to become shallow. (3) To proceed from a greater to a lesser depth of water.

SHORE. The narrow strip of land in immediate contact with the sea, including the zone between high and low water lines. A shore of unconsolidated material is usually called a BEACH.
SHOREFACE. The narrow zone seaward from the low tide SHORELINE, covered by water, over which the beach sands and gravels actively oscillate with changing wave conditions. See INSHORE (ZONE).

SHORELINE. The intersection of a specified plane of water with the shore or beach (e.g., the high water shoreline would be the intersection of the plane of mean high water with the shore or beach). The line delineating the shoreline on National Ocean Service nautical charts and surveys approximates the mean high water line.

SPIT. A small point of land or a narrow shoal projecting into a body of water from the shore.

STORM SURGE. A rise above normal water level on the open coast due to the action of wind stress on the water surface. Storm surge resulting from a hurricane also includes that rise in level due to atmospheric pressure reduction as well as that due to wind stress.

SURF. The wave activity in the area between the shoreline and the outermost limit of breakers.

SURF ZONE. The area between the outermost breaker and the limit of wave uprush.

TIDAL RANGE. The difference in height between consecutive high and low (or higher high and lower low) waters.

TOMBOLO. 1.) A bar or spit that connects or "ties" an island to the mainland or to another island. 2.) A subaerial attachment of sand to a headland breakwater.

TOPOGRAPHY. The configuration of a surface, including it relief and the positions of its streams, roads, building, etc.

UPDRIFT. The direction opposite that of the predominant movement of littoral materials.

WAVE DIRECTION. The direction from which a wave approaches.

WAVE HEIGHT. The vertical distance between a crest and the preceding trough.

WAVE PERIOD. The time for a wave crest to traverse a distance equal to one wavelength. The time for two successive wave crests to pass a fixed point.

WIND WAVES. (1) Waves being formed and built up by the wind. (2) Loosely, any wave generated by wind.