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An integrated habitat enhancement approach to shoreline stabilization for a Chesapeake Bay island community

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Abstract

Shore protection and habitat enhancement along a residential island were the main goals of this shoreline study. The physical and geological factors necessary to design shoreline stabilization structures capable of confidently supporting suitable and stable habitat enhancement/restoration substrate are emphasized since this area of study generally may be unfamiliar to wetland resource managers. Erosion along the targeted shoreline is influenced by a unidirectional wave field from the south-southwest. Results of our analyses show that a headland control system comprised of headland breakwaters could be used successfully to stabilize the existing shoreline and provide resource managers flexibility in habitat restoration decisions. Headland breakwaters are designed to diffract wave energy so that shore planform equilibrium is attained and can be sized and positioned to maximize the length of stabilized shoreline. Maximization of the new shoreline length provides increased subaerial, intertidal, and subaqueous environments for flexible habitat restoration alternatives. The final restoration design developed through this study will create approximately 69,000 m^2 of new habitat including stable beach, dune, tidal marsh, scrub shrub, and submersed aquatic vegetation. An additional 2,000 m^2 of rock substrate habitat is provided directly by the headland control structures.

Introduction

Coastal localities which depend on commercial and recreational fishing interests and/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 resources 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 habitat preservation/enhancement.

Tidal wetlands, beaches, and dunes in the Virginia portion of the Chesapeake Bay have experienced natural and anthropogenic losses which have greatly outpaced compensatory mitigation of these resources. From 1988–1998, permitted tidal wetland losses from shoreline alterations associated with development and erosion control have averaged 13.76 hectares per year, while required compensatory mitigation has averaged only 0.70 hectares (Virginia Institute of Marine Science Wetlands Program 2001). Associated losses of beach and dune habitats also have occurred; however, these losses are not generally summarized.

Through this project, a comprehensive shoreline management plan for an island community experiencing severe erosion was developed; the plan incorporated a large-scale habitat restoration component without compromising shoreline stabilization. Shoreline stabilization projects which are implemented over large areas of shoreline can be an effective vehicle to offset habitat losses and achieve regional or statewide habitat enhancement/restoration goals.

There are four basic approaches to shoreline management: 1) No action; 2) Defend an erosional area with 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 habitat; or 4) Create a shore zone system of beaches, dunes, and fringe marshes generally using headland control with stone breakwaters (Hardaway and Gunn 1999; Hardaway and Byrne 1999). All of these approaches were considered during this study. When no action is taken to protect a shore, consequences are evident with continued erosion, particularly the loss of land and habitat as well as the threat to upland structures. Shoreline protection structures, such as bulkheads or stone revetments, placed upon or against an existing shoreline, at best, maintain the present habitat situation but generally remove, isolate, or impact existing habitat. Non-structural shoreline erosion control methods such as beach nourishment and marsh fringe creation can effectively mitigate erosion but generally require frequent maintenance and associated ongoing costs. Creation of a protected shore zone system using headland breakwaters and beach nourishment can reduce future costs and maintain a predictable shore planform, but requires a detailed characterization of local physical, geological, and biological parameters and an analysis of historical and anthropogenic shoreline changes. These data are necessary to understand the erosional forcing factors which must be compensated for in the design of headland breakwaters for shore protection. With proper background data, headland control structures can be designed and positioned in a manner that allows for a confident prediction of the equilibrium shore planform. Such planforms are necessary for habitat restoration planning.

Characterization of the local flora and fauna, both from an historical perspective and at the time of concern, also are required for habitat restoration planning. Existing natural resources must be analyzed to determine use characteristics of the littoral marine system and the extent of potential direct losses of existing habitats from shoreline stabilization. The amount of direct habitat losses generally are factored into restoration initiatives. Analyses of the extent and character of historical shoreline habitats can guide restoration goals and can be used as a baseline for restoration planning.

Methods

Study Site

Saxis Island is located on the Bay side of upper Accomack County, Virginia (Figure 1). The Town's northwestern boundary, which fronts Pocomoke Sound, has eroded at a rate of approximately 1.52 m/year (Hobbs et al. 1975). The mean tide range at Saxis is 0.7 m with a spring range of 0.82 m(NOAA 1989). The shore faces approximately northwest with average fetches to the northwest, west, and southwest of 4.3 kilometers (km), 15.6 km and 34.7 km, respectively. The shoreline is characterized as predominantly marsh along the southern half, and an impermeable beach (underlain with marsh peat substrate) along the north half with marsh shore re-occurring northward.

Shore Change

Shoreline positions were determined from aerial image archives (1938, 1942, 1955, 1985, and 1990) and an 1851 topographic map and were compared to the 1998 shoreline. Shoreline positions and rates of change were digitally analyzed using the End Point Rate (EPR) method (Fenster et al. 1993), to determine the overall rate of shore change.

Hydrodynamic Analysis

Wave energy impacting the shore zone defines erosional and depositional patterns and guides shore protection strategies. Wave climate characterization requires knowledge of fetch exposure, dominant wind direction(s), and storm surge frequency. Wind data from Patuxent Naval Air Station were used to model local wind driven wave fields using procedures developed by Sverdrup and Munk (1947), Bretschneider (1958) as modified by Kiley (1982), known as SMB. Effective fetch, a parameter in wind wave growth required for wave field analysis, was determined for the predominant exposed directions (NW, W and SW) for Saxis Island (U.S. Army Corps of Engineers 1984). Specified storm surges were determined after

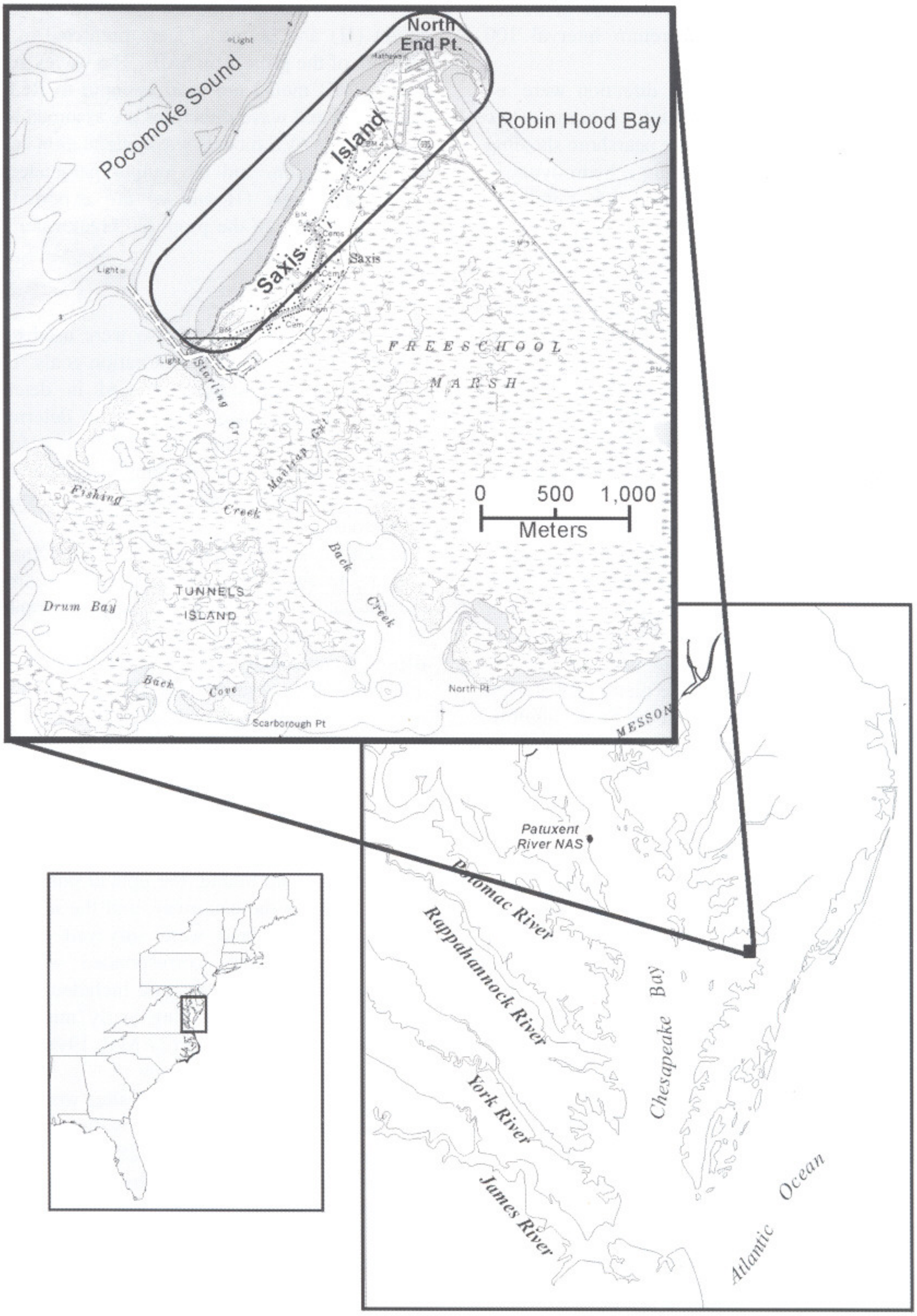

Figure 1. Town of Saxis and study site location.

Boon et al. (1978) and range from 0.30 m (return interval one year) to 2.74 m (return interval 100 years).

Offshore, the wind and wave direction were assumed the same. However, at about −4 m mean low water (MLW), the waves enter the nearshore shoaling region and must be evaluated using a hydrodynamic wave refraction model. The predicted significant wave heights and periods for the three subject directions are used as input to the linear wave propagation model RCPWAVE (Ebersole et al. 1986). It computes changes in wave characteristics that result naturally from refraction, shoaling, and diffraction over complex topography. Routines to estimate wave energy dissipation due to bottom friction were added after 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 calculates wave heights and directions of propagation (wave orthogonals) along the entire modeled shore. Wave height and direction of wave approach toward shore at the approximate depth where potential offshore structures would be located were used to characterize mean annual conditions at Saxis. The final shape of the shore planform between headlands can be determined with the Static Equilibrium Bay (SEB) model.

The SEB model is an empirical model that utilizes the net wave conditions impacting the shore to determine the beach planform between headland breakwaters. Hsu et al. (1989a) defined bay curvature utilizing a parabolic bay shape (Figure 2A). Incoming wave crests impinge at an angle (β) 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 (β). When the bay is in static equilibrium, β is equal to the angle between R_o and the downcoast tangential beach. Therefore, the variables which determine bay shape are an arc of length R angled θ 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 2B illustrates the connection between the wave climate analysis and SEB model. The wave climate analysis is necessary to determine the variables needed as input to the SEB model. The wind field for a bay site is used to determine the annual significant wind and the design storm wind. Wave height (H) and period (T) are predicted at a point offshore of the project by SMB. The waves generated in the SMB model are used as input to RCPWAVE since wind and wave directions are assumed to be the same. RCPWAVE models wave attenuation across the nearshore region, and the output parameters wave height and angle (H and α) are exported at the approximate site of the proposed breakwater project.

Biological Surveys

Present and historical data also were used to assess habitat losses and develop restoration goals. The time series of aerial photographs used in determining shoreline changes also were used to determine the historical character and extent of habitat for Saxis Island. Assessment of the existing habitats and associated fauna and flora included surveys of vegetation communities, birds, nekton and benthic macrofauna.

Recent aerial photographs were used in concert with a site survey to assess vegetative community structure along the 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 australis*-dominated, scrub shrub, and old field.

Data on birds were collected by roving survey. Birds were identified to species and the subhabitat they were occupying at the time the encounter was logged. 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.

Six randomly-selected sample sites were seined (5 mm mesh) for fish and blue crabs during the spring (27 May 1998) and summer (25 June 1998). Collected fauna were enumerated by species.

Sample sites for oyster and clam surveys also were chosen by random distance measurements. An additional random component (offshore distance) extended from mean high water (MHW) to approximately 75 m offshore. Three random distances were chosen along the offshore component at each of six oyster and clam sample sites. A total of 18 separate sites

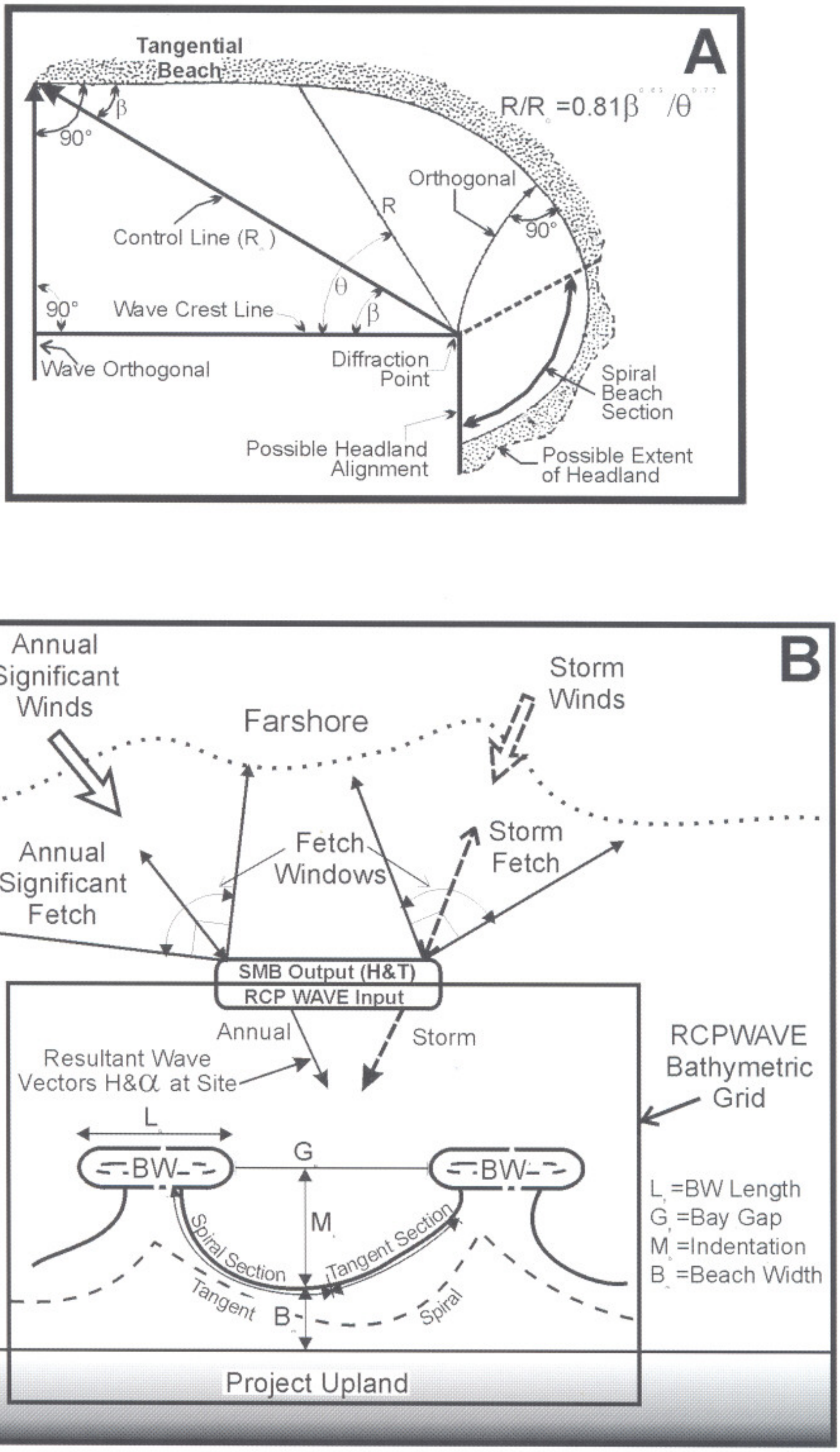

Figure 2. Parameters related to A) the Static Equilibrium Bay model (after Hsu et al. (1989a)), and B) wind/wave generation (SMB), nearshore wave refraction (RCPWAVE), and beach planform prediction (SEB).

were sampled for oysters and clams on 18 August 1998. 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.

Plan Development

The shoreline management plan will be a result of the convergence of erosion control design based on shore zone energy models and restoration goals based on current and historical natural resources. Inherent in both erosion control options and restoration goals are variables such as community desires and expectations, and costs. Therefore, shoreline management plans, by nature, must use science-based information as the basis for conceptual design end points integrating all pertinent variables (Figure 3).

The decision to provide long-term erosion control and habit restoration on Saxis Island required the development of a shore zone system, which consists of breakwaters, beach nourishment, and vegetative plantings as a series of headlands and pocket beaches. This methodology of utilizing stable beach planforms as a foundation for coastal habitats has been shown to be effective (references). The configuration of breakwater dimension and placement is based, in part, on the hydrodynamic setting and the known empirical relationships between placement and planform. Counteracting the erosional forces of storm waves can be addressed in various structural configurations without compromising erosion control, which provides for flexible restoration alternatives. The level of protection is discerned by the designed storm (based on storm surge frequency). The minimum design planform for shore protection can be enhanced to increase the aereal extent of vegetative communities. Inherent in pocket beach morphology are elevation gradients, which are also coincident to intertidal and supra-tidal

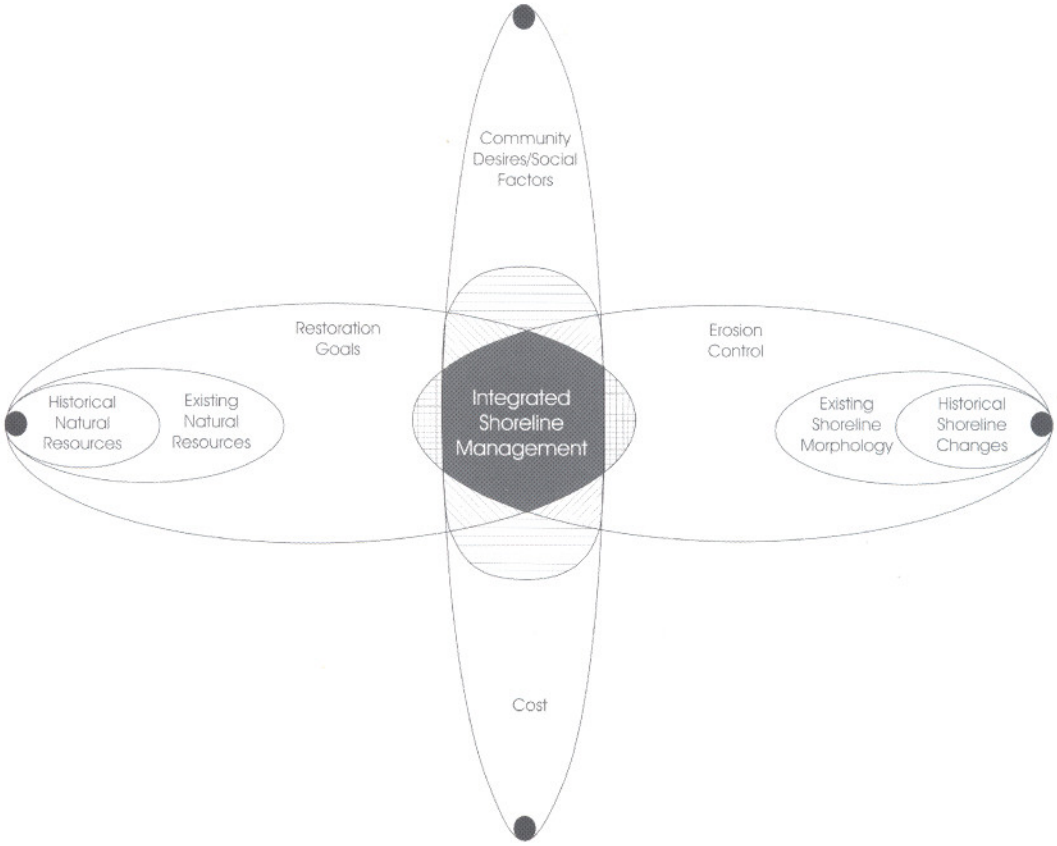

Figure 3. Diagram of conceptual integrated shoreline management plan development. Final plan specifications are a convergence of many factors that build upon science-based information.

estuarine habitats. Integration of erosion control and habitat restoration therefore entails full vegetative application at the appropriate elevations within the substrate stabilized by breakwaters. To the extent possible, the offshore limits of the system must not encroach beyond the what is required for shore protection.

Results

Shore Change

Saxis Island shoreline change is a result of both natural variations in erosional patterns and anthropogenic impacts. In 1851, the shoreline may have been primarily marsh judging from the characteristic undulations (Figure 4). Aerial imagery from 1936 shows that the shoreline was primarily marsh, including several small marsh headlands with little beach. Overall, the shoreline eroded at an average rate of about −1.2 m/yr between 1851 to 1942.

Between 1942 and 1968, Saxis's shoreline receded at an average rate of about −0.4 m/yr which is considerably less than the previous time period. During the 1960s and early 1970s dredge material deposition upon the southern shoreline and subsequent longshore dispersal northward increased beach width, and probably is responsible for the lesser overall average erosion rate. From 1986 to 1998 the Saxis shoreline regained a higher average erosion rate of about 1.16 m/yr (comparable to the rate calculated for 1851–1942). Some submersed aquatic vegetation (SAV) and sand bars existed at the site during the late 1950s, but both had disappeared by 1965 (Orth and Moore, 1984).

Shoreline conditions for 1985, 1990, and 1998 show little change in land use or shoreline attributes.

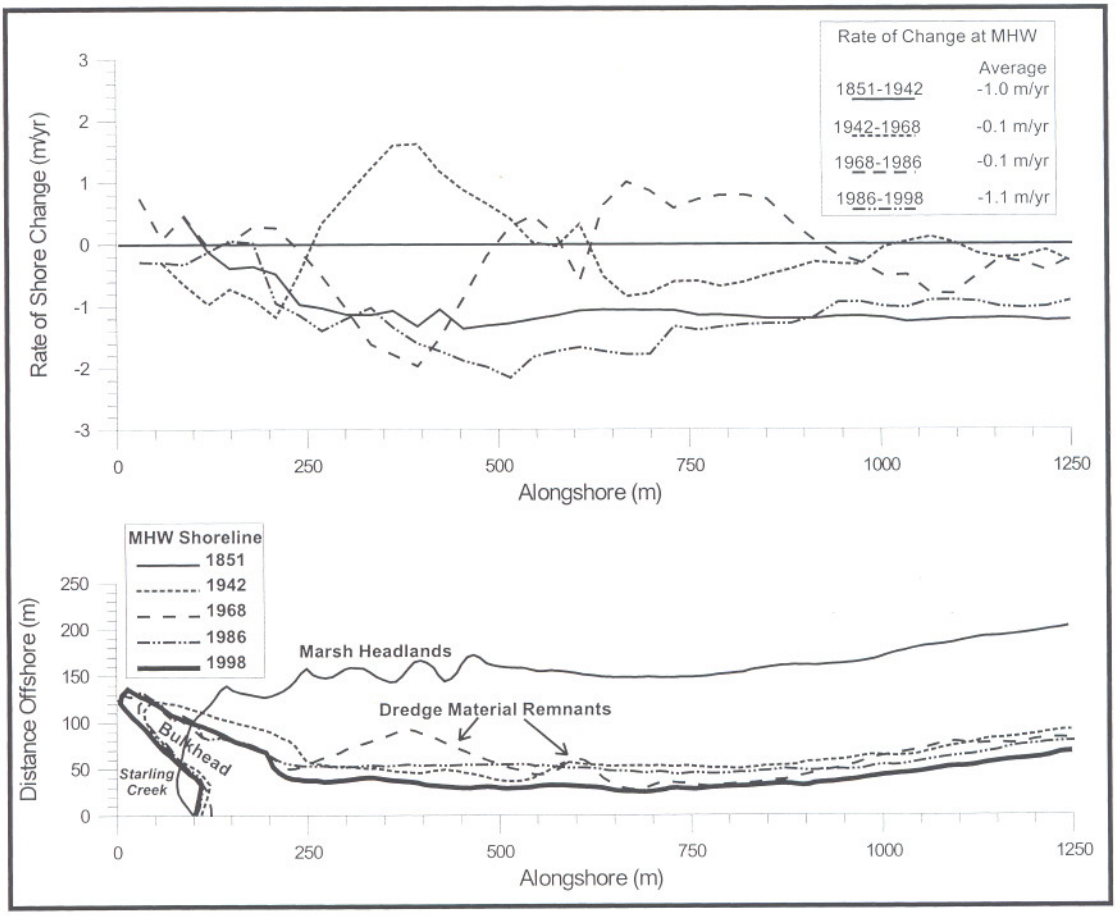

Figure 4. Saxis shoreline change and historical shore positions along the southwestern-most section of Saxis Island project site.

The present nearshore zone is relatively shallow with no bars, indicating a general lack of sand in the littoral system.

Hydrodynamic Analysis

Long-term wind frequencies indicate that winds blowing from the southwest are dominant in the 4-5 m/s range followed by the northwest, then west. However, as wind speed increases, 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. The influence of nearshore bathymetry results in a refraction of southwesterly waves of approximately 35° from the original direction of propagation before impacting the shore, with a westerly wave refraction of approximately 8° from the original direction of propagation. The waves coming from the northwest are altered little by the nearshore; the angle of wave approach only changes by an average of about 2° and the wave height does not diminish as rapidly as with other directions. Because of the shoreline orientation, the larger northwesterly waves have angles of about 13° off normal (0°) to the shore, but are shore normal further inshore, indicating a possible mechanism for onshore-offshore movement of sand during storms. With the longest effective fetch to the southwest as well as a high frequency of wind from that direction, waves are generated that significantly impact the alongshore transport system tending to drive sediment to the north. Current shoreline morphology points to a northward trending littoral transport system supporting the wind-wave analysis.

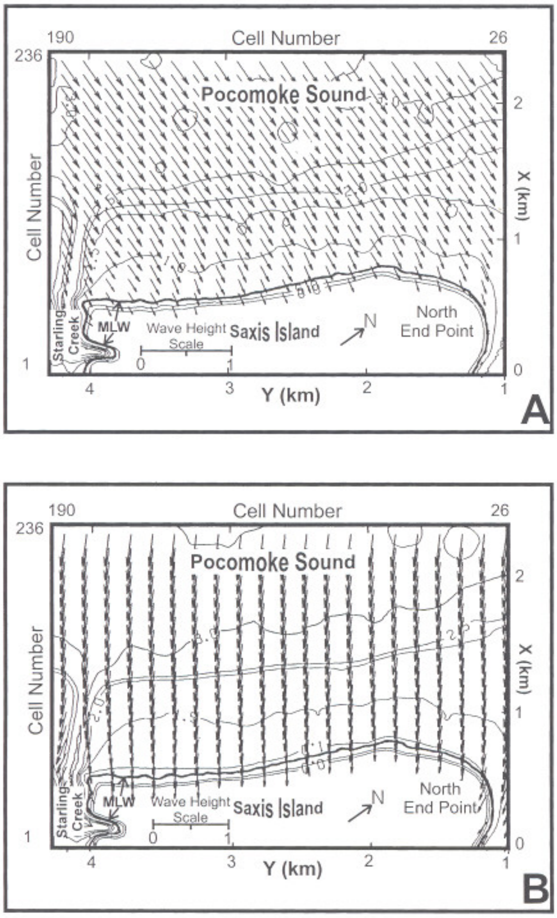

Figure 5. Wave vector (orthogonal) plots for annual conditions from the A) West and B) Northwest.

Figure 5 shows typical wave vectors for two example conditions modeled using RCPWAVE. Figure 5A 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 waves have a definite angle to the coast, orientated at a positive 20° angle off normal (0°) to the shore (bearing 100° TN). A typical condition using a wave from the northwest is shown in Figure 5B. These waves have an average significant wave height of 0.33 m and make an angle of −12° off normal (bearing 132° TN) with the shoreline. As the wave moves closer to shore they continue to bend further toward shore normal before impacting the shoreline.

Individual wave modeling cases must be mean-weighted 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 wave angle impacting the shore bears 107° TN, making a +13° angle off normal with the Saxis shoreline. This indicates a northward net littoral transport of sediment. Wave modeling results were used to develop equilibrium bay planforms for the shore protection system.

Biological Surveys

Historical habitat analyses showed a greater abundance of dunes, saltmarsh, scrub-shrub and SAV communities relative to the current shoreline. The location and extent of these and other communities were used to develop restoration goals.

The Saxis shoreline is dominated by common reed

(*Phragmites australis*), with significant stands of emergent marsh, scrub shrub, and old field communities (Figure 6). The areal extent of the existing communities and its characteristic vegetation are listed in Table 1. Landscape features such as lawn and developed are present adjacent to the Saxis shoreline, but were not included in the study.

Filter feeders (menhaden and anchovies), omnivores (Atlantic silversides) and forage fishes (summer flounder and croaker) dominate the local nekton. No species was considered unusual or unique to this ecosystem. However, no killifishes were collected, and the absence of species such as the sheepshead minnow, 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 currently provides little of the critical habitat for killifishes.

Anchovies dominated spring samples, whereas anchovies and Atlantic silversides were co-dominant during the summer sampling period. 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 fish population studies (Seaver and Austin 1995).

No live oysters or clams were collected; only sparse cultch was observed at a few sample locations. The absence of oysters or clams observed within the study boundaries also was unexpected.

Birds were represented by a diverse assemblage that included a mixture of year-round residents, wintering birds, migrants, and summer nesting birds. 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. These data are generally consistent with the results of other local bird population studies (Audubon Society Christmas Bird Counts and the U.S. Fish and Wildlife Service Breeding Bird Survey (Sauer et al. 1997)).

With the exception of the narrow beach and non-vegetated intertidal sand community, the Saxis shoreline contains little favorable bird habitat. The shoreline is dominated by reed grass, and this community provides little functional habitat to the vast

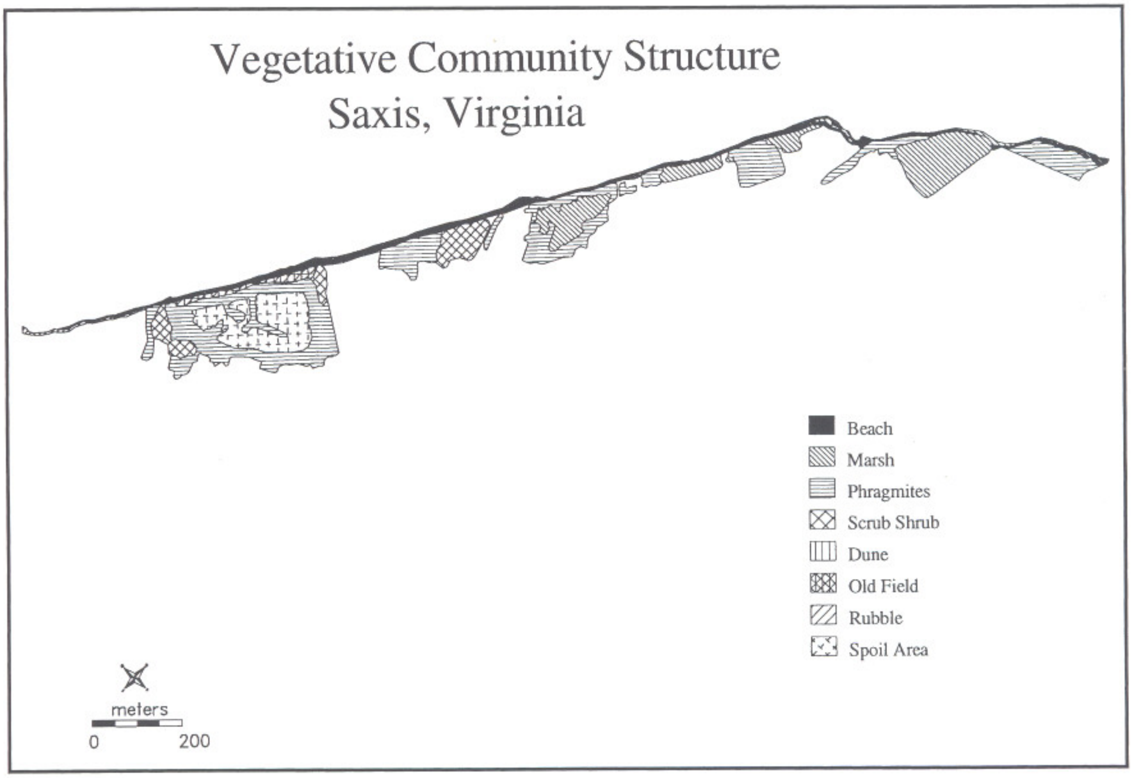

Figure 6. Vegetative community structure along the Saxis shoreline.

Table 1. Areal coverage and principal plant species characteristic of the major vegetated community types along the Saxis shoreline.

Vegetated Community Type	Area (m^2)	Principal Plant Species
Phragmites- Dominated	80,547	Common reed – *Phragmites australis*
Marsh	37,254	Groundsel tree – *Baccharis halimifolia* Smooth cordgrass – *Spartina alterniflora*
		Saltmeadow hay – *Spartina patens*
Scrub shrub	14,307	Marsh elder – *Iva frutescens* White mulberry – *Morus alba*
		Black locust – *Robinia pseudoacacia*
		Black Cherry – *Prunus serotina*
		Hackberry – *Celtis occidentalis*
		Wax myrtle – *Myrica cerifera*
Old field	4,041	Groundsel tree – *Baccharis halimifolia* Pokeweed – *Phytolacca americana*
		Horseweed – *Erigeron canadensis*
		Dog-fennel – *Eupatorium capillifolium*
Beach	21,739	Blackberry – *Rubus argutus* American beachgrass – *Ammophila breviligulata*
		Bitter panicum – *Panicum amarum*
		Seaside goldenrod – *Solidago sempervirens*
Rubble	1,486	
Dune	465	
Total	**159,840**	

majority of locally-common birds or those using the Atlantic flyway. Only sparse-scrub shrub communities are found along this shoreline.

Plan Development

The initial breakwater system required a minimum design beach/dune width for the pocket beach to be approximately 27m from MLW to the crest of the dune. The dune crest needed to be approximately +6 ft above MLW to address the 25-yr storm (the desired level of protection identified by stakeholders). This sets the minimum distance for MHW from the upland property. The breakwaters are then positioned around the relationship of the beach planform configuration using the SEB analysis. The resultant stable embayment offered increased intertidal, beach and dune habitat from the current situation. However, by keeping the same offshore position, opening the breakwater gap and adding a small inner bay structure, a significant increase in shoreline length, and consequently habitat, is attained. The shoreline management plan for Saxis Island was designed by building upon the minimum beach planform and consists of a series of headland breakwaters, beach nourishment and vegetative plantings influenced by the historic shoreline geomorphology, wave climate analysis, and storm surge frequency (Figure 7).

A diverse coastal habitat supporting aquatic, terrestrial, and avian fauna was the desired restoration goal developed from current and historical natural resources data. Optimization of shoreline lengths and elevations needed to both achieve the maximum level of restored estuarine edge and support the communities identified in the restoration goal was achieved by varying the lengths and heights of the offshore and inner bay breakwaters, which controls the amount and configuration of substrate available for community restoration. Bird habitat restoration requires substrate at the proper elevation and distance from the shoreline to support scrub-shrub and herbaceous communities. In response, dune and terrace elements were added to the plan that would support these communities. Marsh vegetation requires substrate at broad, protected intertidal elevations to increase the probability of success and sustainability. In response, offshore and inner bay breakwater length, substrate placement, and tombolo configuration was

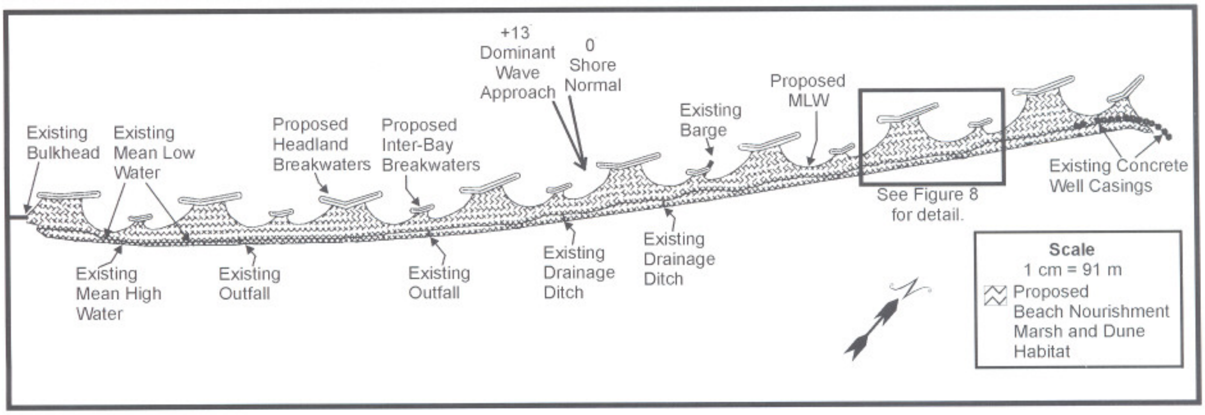

Figure 7. Proposed Shoreline Management Plan for the Saxis shoreline.

designed to provide optimum conditions in the lee of the breakwaters. Nonvegetated beach communities require substrate placement that maximize intertidal and supra-tidal widths, and beach length. In response, offshore and inner bay breakwater heights and lengths were designed to provide the necessary stable substrate configurations without compromising the amount of area necessary for intertidal marsh restoration. SAV communities require sandy substrate in a protected subtidal setting. In response, offshore breakwater length, height and tombolo configuration was designed to maximize stable subtidal areas in the lee of the breakwater without compromising the amount of area necessary for either intertidal marsh or beach restoration.

The final integrated system has seven headland breakwaters (91 m crest length) placed about 61 m from the existing MLW shoreline and spaced 138 m apart. Relatively large tombolos will be created in the lee of these long breakwaters with beach fill placed as designed for community restoration. In order to insure long-term protection and increase habitat substrate availability, seven 30.5 m inter-bay breakwaters will be inset. 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 linear area of stable shoreline by reducing the characteristic increased energy environments between the large breakwaters.

Approximately 84,100 cubic meters of beach fill is required to meet erosion control and habitat restoration goals. A + 1.8 m MLW berm feature will address a 25-yr storm event, but the overall system will withstand a 50-yr event with the possible exception of some sand and vegetation repair. The breakwaters will remain intact in a 100-yr event while there may be a need for replacing some sand and vegetation within the system. Intertidal marsh will be restored along the proposed shoreline from approximately mean tide level (MTL) to approximately 1.1 m above MLW elevation (Figure 8). 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. Herb communities (beach mix) will be planted in areas above 3.5 m above MLW. Scrub-shrub (shrub mix) will be planted at the higher (+ 6 MLW) elevations and in lower (+4 MLW) areas protected by dunes.

Discussion

Based on the local needs, desires, and physical setting of the Saxis Island littoral system headland breakwaters with beach nourishment are the preferred structural option for shore stabilization. A detailed understanding of local physical and geological factors is necessary to properly design a headland breakwater 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

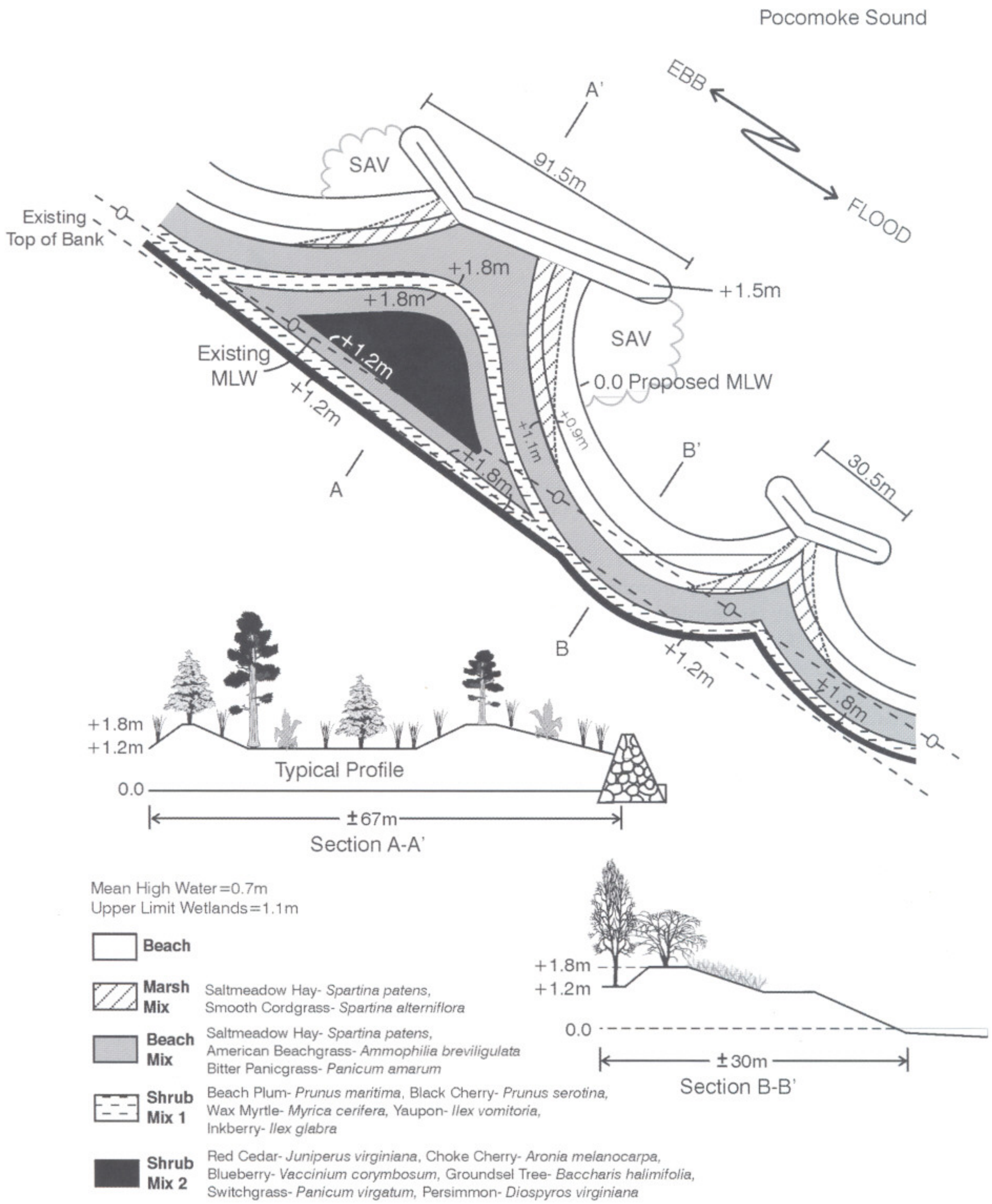

Figure 8. Detail of the Shoreline Management Plan with Habitat Enhancement for the Town of Saxis.

erosion control and habitat enhancement (Hardaway and Gunn 1991; Hardaway et al. 1993; 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 and demonstrated that a stable beach planform can exist with intertidal attachments. The advantage to an intertidal attachment is that wetland habitat is increased in the breakwater's lee, but beach stability is not compromised.

The optimized shoreline design provides approximately 72,000 m^2 of intertidal, beach and subaqueous habitats for use by marine, terrestrial, and avian fauna. The accuracy of the amount of restoration area is reasonably assured due to the level of study supporting the shoreline design. The probability of restoration success also is increased due to the level of substrate stability provided by the breakwaters. The benefits of flexible habitat restoration alternatives afforded by sound shoreline stabilization have been demonstrated through this study.

From an ecological perspective, the proposed design provides the fundamental constituents of a structurally diverse estuarine ecosystem. Select habitats and vegetative continua have been designed which build upon the existing ecosystem character and provide opportunities for the development of a self-sustaining estuarine system (Table 2). The design incorporates intertidal and protected subaqueous areas that may provide habitats favorable for the establishment of SAV, oyster, and clam resources. Planned scrub-shrub (wax myrtle, yaupon, highbush blueberry, and beach plum), herbaceous (Saltmeadow hay, American Beachgrass, and bitter panicgrass), and intertidal beach communities are of high relative value as food sources, forage areas, and nesting sites for a wide range of bird species.

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. 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 and add to the overall diversity of the system.

Table 2. The approximate areas of the habitats that will be produced by the shoreline protection plan.

Habitat	Area (m^2)
Beach	14,777
Tidal Marsh	7,388
Dune	23,885
Scrub shrub	20,074
SAV	3,253
Breakwaters	2,472
Total	**71,849**

Although this shoreline management plan was developed to meet specific erosion control needs and habitat restoration goals, design changes generally can be incorporated with relative ease to respond to changes in stakeholder desires and/or community needs. Any changes will necessarily require modifications of the original project goals, and unless proposed changes are significant with respect to erosion control needs and/or cost an increase in one substrate use will require the sacrifice of all or part of another substrate use. For example, if tourism and recreation needs increase stable public- use beach(es) can be created by removal of one or more inner bay breakwaters and vegetation planting either prior to project completion or after build out. Also, slight changes to the offshore breakwater configuration can be made to alter the amount and configuration of stable substrate, which can be done to respond to desired changes in the overall vegetation restoration plan.

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