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City of Suffolk Shoreline Management Plan

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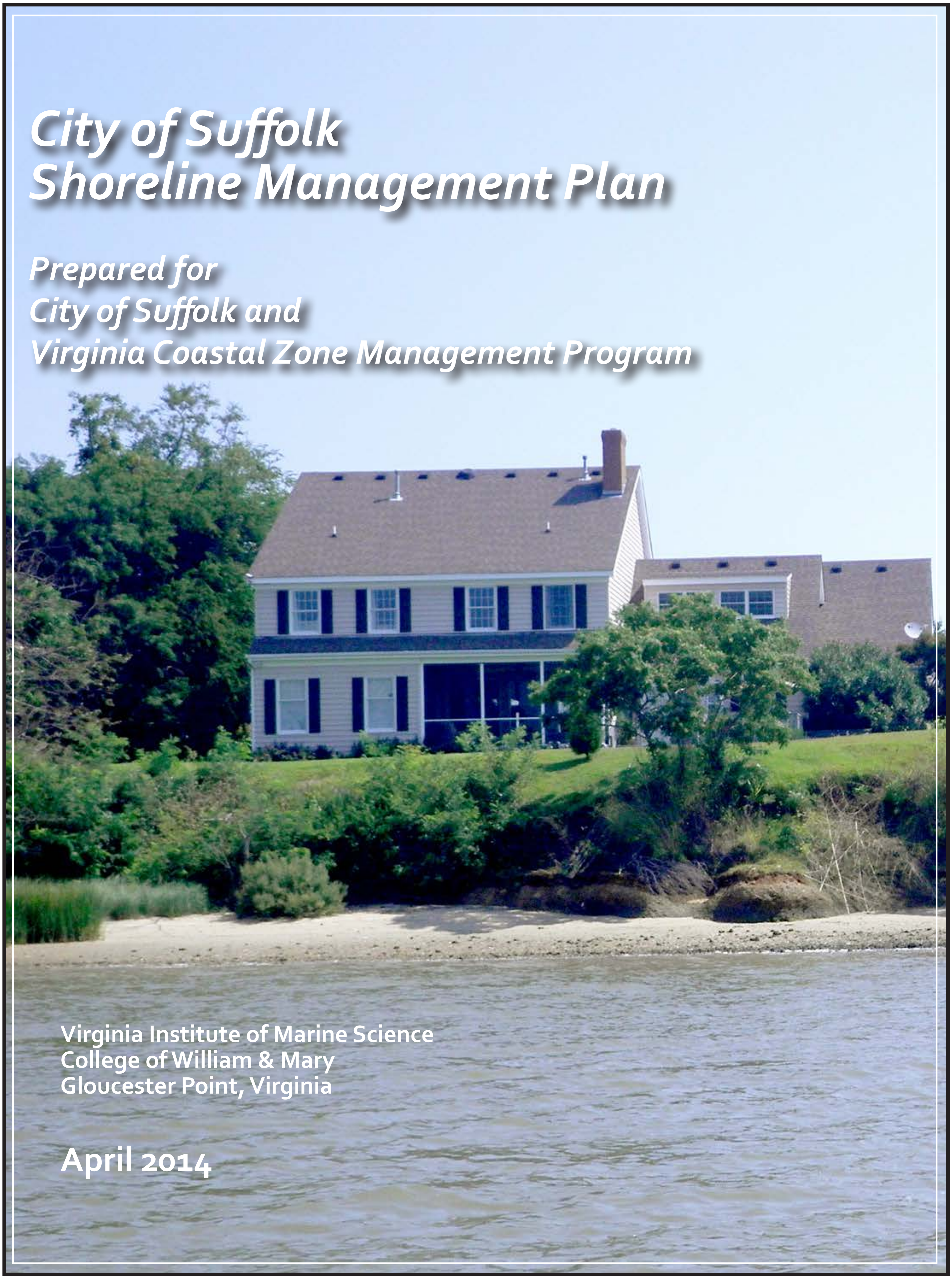

City of Suffolk Shoreline Management Plan

Prepared for
City of Suffolk and
Virginia Coastal Zone Management Program

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

April 2014

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1 Introduction

With approximately 85 percent of the Chesapeake Bay shoreline privately owned, a critical need exists to increase awareness of erosion potential and the choices available for shore stabilization that maintains ecosystem services at the land-water interface. The National Academy of Science published a report that spotlights the need to develop a shoreline management framework (NRC, 2007). It suggests that improving awareness of the choices available for erosion control, considering cumulative consequences of erosion mitigation approaches, and improving shoreline management planning are key elements to minimizing adverse environmental impacts associated with mitigating shore erosion.

Actions taken by waterfront property owners to stabilize the shoreline can affect the health of the Bay as well as adjacent properties for decades. With these long-term implications, managers at the local level should have a more proactive role in how shorelines are managed. City of Suffolk understands that water resources are an integral part of the quality of life for its residents. The City's Comprehensive Plan states that management of development and land disturbing activities directly affect the quality of surface water, drinking water, fisheries and wetland habitat (City of Suffolk Department of Planning, 2006).

The shores of Suffolk range from exposed open river to very sheltered creeks, and the nature of shoreline change varies accordingly (Figure 1-1). While the City's Comprehensive Plan provides general guidance for shore erosion control, a shoreline management plan is useful for evaluating and planning shoreline management strategies appropriate for all the creeks and rivers of Suffolk. It ties the physical and hydrodynamic elements of tidal shorelines to the various shoreline protection strategies.

Much of the City of Suffolk's shoreline is suitable for a "Living Shoreline" approach to shoreline management. The Commonwealth of Virginia has adopted policy stating that Living Shorelines are the preferred alternative for erosion control along tidal waters in Virginia (http://leg1.state.va.us/cgi-bin/legp504.exe?111+ful+CHAP0885+pdf). The

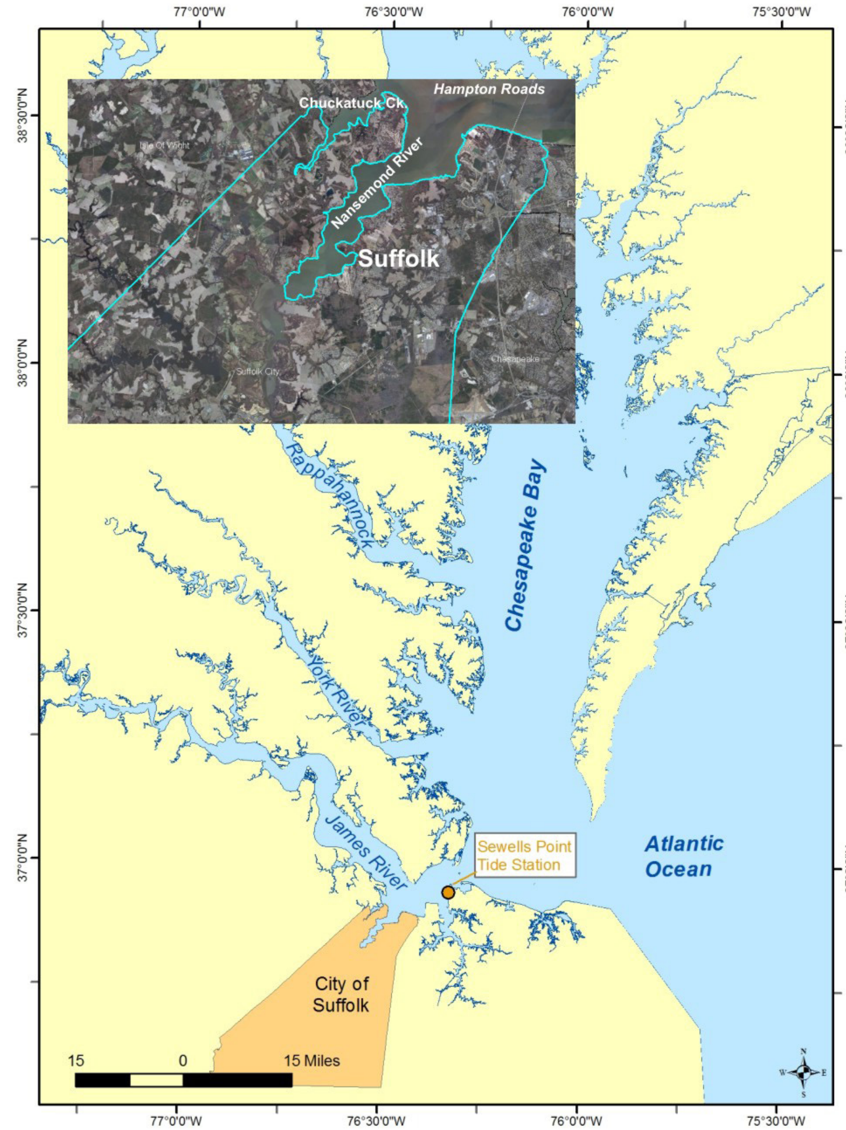

Figure 1-1. *Location of City of Suffolk within the Chesapeake Bay estuarine system. The location of a National Oceanic and Atmospheric Administration tide gauge also is shown.*

policy defines a Living Shoreline as …"a shoreline management practice that provides erosion control and water quality benefits; protects, restores or enhances natural shoreline habitat; and maintains coastal processes through the strategic placement of plants, stone, sand fill, and other structural and organic materials." The key to effective implementation of this policy at the local level is understanding what constitutes a Living Shoreline practice and where those practices are appropriate. This management plan and its use in zoning, planning, and permitting will provide the guidance necessary for landowners and local planners to understand the alternatives for erosion control and to make informed shoreline management decisions.

The recommended shoreline strategies can provide effective shore protection but also have the added distinction of creating, preserving, and enhancing wetland, beach, and dune habitat. These habitats are essential to addressing the protection and restoration of water quality and natural resources within the Chesapeake Bay watershed. The final City of Suffolk Shoreline Management Plan is an educational and management reference for the City and its landholders.

2 Coastal Setting

2.1 Geology/Geomorphology

2.1.1 Geology

City of Suffolk lies in the coastal plain of Virginia. Like many coastal localities, the City boundaries are defined by creeks, rivers and watershed. The City has about 150 miles of main river and creek shoreline with elevations ranging from about 3 feet along the marsh coasts to between 5 feet and 20 feet along fastland shorelines. The shoreline features are defined by the underlying geology which in turn controls the geomorphology of the City. Tidal shorelines include those along the Nansemond and James Rivers and Chuckatuck and Bennett Creeks and their tributaries.

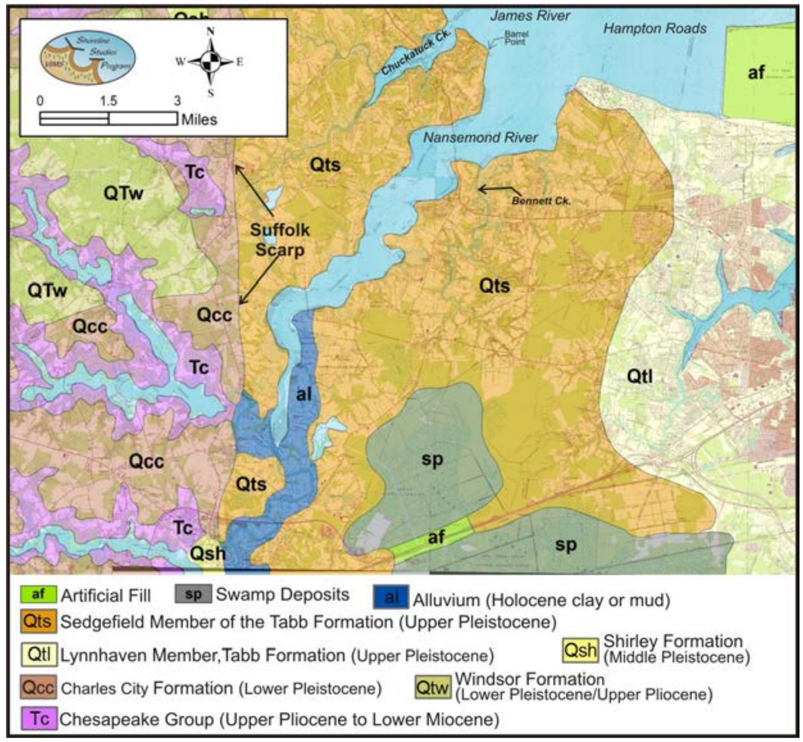

Figure 2-1. *Geology of the City of Suffolk (Mixon* et al.*, 1989) overlain on a USGS topographic map.*

The surficial geology is mapped and shown in Figures 2-1. The geologic units along the City's tidal shorelines range from Upper Pliestocene to recent Holocene sediments of soft muds and marsh (Mixon *et al.*, 1989). The shorelines along the lower (toward the mouth) Nansemond River, lower Chuckatuck and Bennett Creek are the Sedgefield Member of the Tabb Formation (Qts). The Hampton Roads/James River shoreline east of the Nansemond River are Lynnhaven Member of the Tabb Formation (Qtl). Shorelines along the upper Nansemond River, Chuckatuck Creek, Bennett Creek, Knott Creek and Hoffler Creek have extensive marshes, Holocene alluvium (al). These marshes provide medium to high quality habitat for wildlife and fisheries as well as buffering the shore from erosive forces (City of Suffolk Department of Planning, 2006). Several stratigraphic exposures occur along the Nansemond River where the Yorktown Formation is exposed under the surficial deposits.

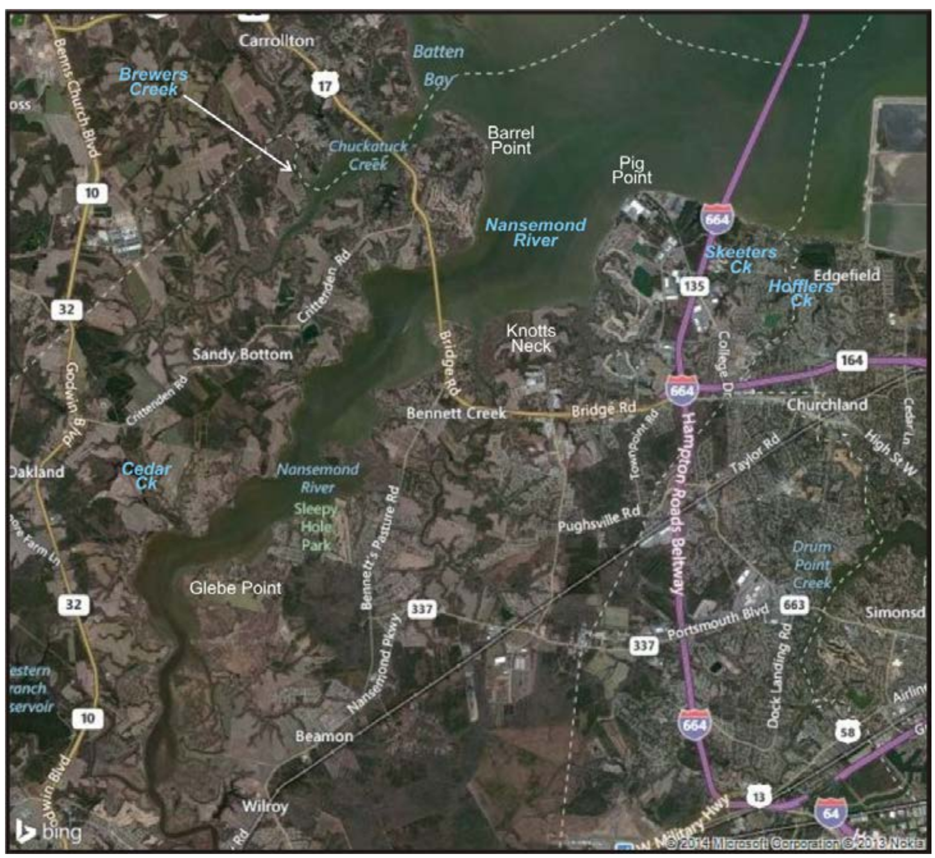

Figure 2-2. *Location of shoreline features in City of Suffolk.*

2.1.2 Shoreline Morphology

The shoreline between Hofflers Creek and Skeeters Creek has been mostly hardened (Figure 2-2). The banks along this reach were once semi-protected from storm waves with marsh headlands and pocket beaches but as these features were lessened by wave attack and houses became threatened by erosion, stone revetments were built along the shore (Figure 2-3). On the east side of the mouth the Nansemond River, today's Tidewater Community College (TCC) occupies a coast that was once a military depot that extended from Pig Point to Skeeters Creek. The shoreline along the James River has been hardened with varying types of material including rock, broken concrete and even bricks over the years (Figure 2-4). This shoreline had intermittent marsh fringe and pocket beaches alongshore, but as the marshes eroded, the upland was exposed to storm waves. As a result, the shoreline was hardened. However, because the shoreline is relatively low, the rock revetments along the coast of TCC have been overtopped by numerous coastal storms (Figure 2-5). Two areas of concern occur along the TCC shoreline both of which will be addressed in Section 5.

Just west of I-664, an experimental shoreline protection project was installed in 1989 to protect the adjacent pond from erosion and possible breaching. This "Seabee" revetment (Figure 2-6) is built with small, concrete, six-sided blocks placed on a stone substrate. The purpose was to see if these units could be substituted for armor stone on revetments. VIMS monitored the project for several years and found it to be very stable (Hardaway *et al.*, 1994). It appears to still be working today.

The shoreline from Pig Point into the Nansemond River alternates between marsh headlands and mostly hardened uplands. Shoreline change rates vary, but a great deal of the shoreline has low to medium erosion rates, meaning the coast is changing between -1 and -5 feet/year (Milligan *et al.*, 2010). As a result of the erosion and the development of the shoreline, revetments are being installed. In some cases, broken

Figure 2-3. *Developed shoreline between Hoflers Creek and Skeeters Creek. The shoreline is protected by rock revetments in front of the houses.*

Figure 2-4. *Broken concrete revetment along the James River shoreline east of the Nansemond River.*

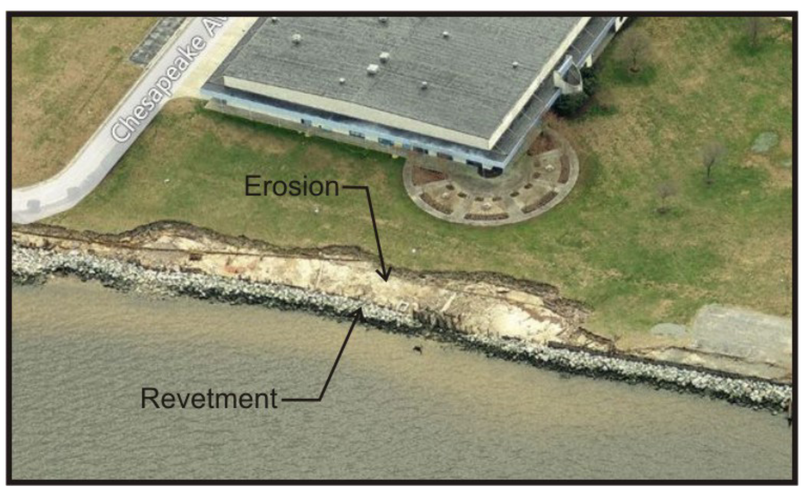

Figure 2-5. *Bing map photo showing the rock revetment at Tidewater Community College and the erosion that has taken place landward due to overtopping during storms.*

concrete also was placed on the shoreline to prevent further erosion. One section of farmland on Knotts Neck has, in addition to broken concrete along the upland bank, two headland breakwaters that were built in the late 1990s and, as a result, a stable beach has been established (Figure 2-7). Because the breakwaters were built far apart, it is an example of headland control where headland breakwaters hold points of land and the shoreline between is allowed to erode to equilibrium.

Figure 2-6. *Experimental Seabee revetment. Photo date, 22 Mar 2009.*

Marsh fringes of varying width occur in the Nansemond River. Some shorelines have only small fringe marshes while broad marshes occur in many areas, particularly along the smaller creeks that flow into the Nansemond. The shoreline along Bennett Creek is mostly broad marsh coast on the "point bars" of the meandering tidal creek with intermittent sediment banks occurring along the outside meanders. The creek is only 300 to 500 feet wide down to Bennett Creek Park at the boat ramp. The Creek narrows even farther upstream. Little development occurs and, as such, there are very few shore protection structures.

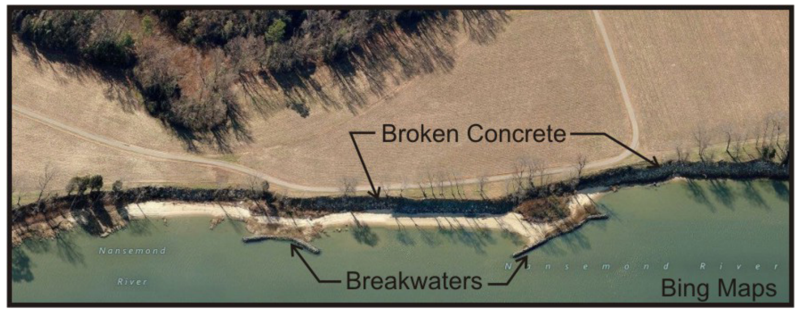

Figure 2-7. *Headland breakwaters on the Nansemond River.*

From the mouth of Bennett Creek westward to the Nansemond River Bridge, a developed high bank reach has been mostly bulkheaded behind a wide marsh fringe (50 to 90 feet wide) which undulates along the shore (Figure 2-8). Upriver from the bridge, pockets of development occur on uplands between extensive marshes. Shore change rates vary significantly along the Nansemond River depending on such factors as shore type, direction of face, and whether or not it has a structure. (Milligan *et al*., 2010). Some areas have very low erosion rates (< 1 ft/year) while others have medium erosion rates (2-5 feet/year). If the upland has a protective marsh in front, it typically has a lower erosion rate.

Figure 2-8. *Houses along a high bank on the Nansemond River are protected by a marsh fringe and bulkheads constructed at the boundary between the upland and marsh.*

The Nansemond River narrows at Glebe Point and becomes more meandering with broad marsh complexes on either side. Little development occurs on either side of the river. The area south of Glebe Point on the eastern side of the River is the Nansemond National Wildlife Refuge. Like the east side of the River, the west side has variable erosion rates but is less developed. Many areas along the shoreline are farmland with only a few houses or subdivisions between.

From Barrel Point to Chuckatuck Creek, a community sits along an upland headland that is eroding, on average, at 3 feet/year. The shoreline faces northeast and has a 7 mile fetch across the James River and Hampton Roads to the north and a 10 mile fetch to the northeast to the Hampton Roads Bridge Tunnel. Waves generated in Chesapeake Bay during northeast storms will impact this shoreline. This shore reach had a very wide and protective marsh fringe in 1937 (Figure 2-9A). By 1954 much of it had eroded away, and the 20-25 ft high upland banks were eroding and providing sand to the shoreline as a beach (Figure 2-9B). With time, development progressed, and by 1994, most of the shoreline had housing and numerous sections were hardened mostly with rock revetments (Figure 2-9C). Today, the entire reach is hardened with rock (Figure 2-9D). Three breakwaters and spur on the east end of the headland has created a beach and fringe marsh that provide coastal habitat as well as protect the adjacent revetment from scour during storm events.

Pike Point on the west end of the headland generally represents the mouth of Chuckatuck Creek. The south shoreline of Chuckatuck Creek resides in the City of Suffolk up to Brewers Creek at which point the Isle of Wight/City of Suffolk boundary turns into and up the center of Brewers Creek. This boundary goes a short way, about a mile, up Brewers Creek before turning southwest. Because of the limited fetch, most of the shoreline has a very low erosion rate (Milligan *et al*., 2010). Two headlands in the Creek have been long hardened with bulkheads for commercial use (Figure 2-10). These water-dependent facilities can be seen in early aerial imagery (1937) (Milligan *et al*., 2010). Along the rest of the Creek, the marsh fringes are still basically intact although in most cases, the peat edge is slowly eroding. Whether or not the bank is stable generally depends on the site location and the width of the marsh fringe. Some intermittent hardening of the upland bank occurs as this Creek is not highly developed along the shoreline.

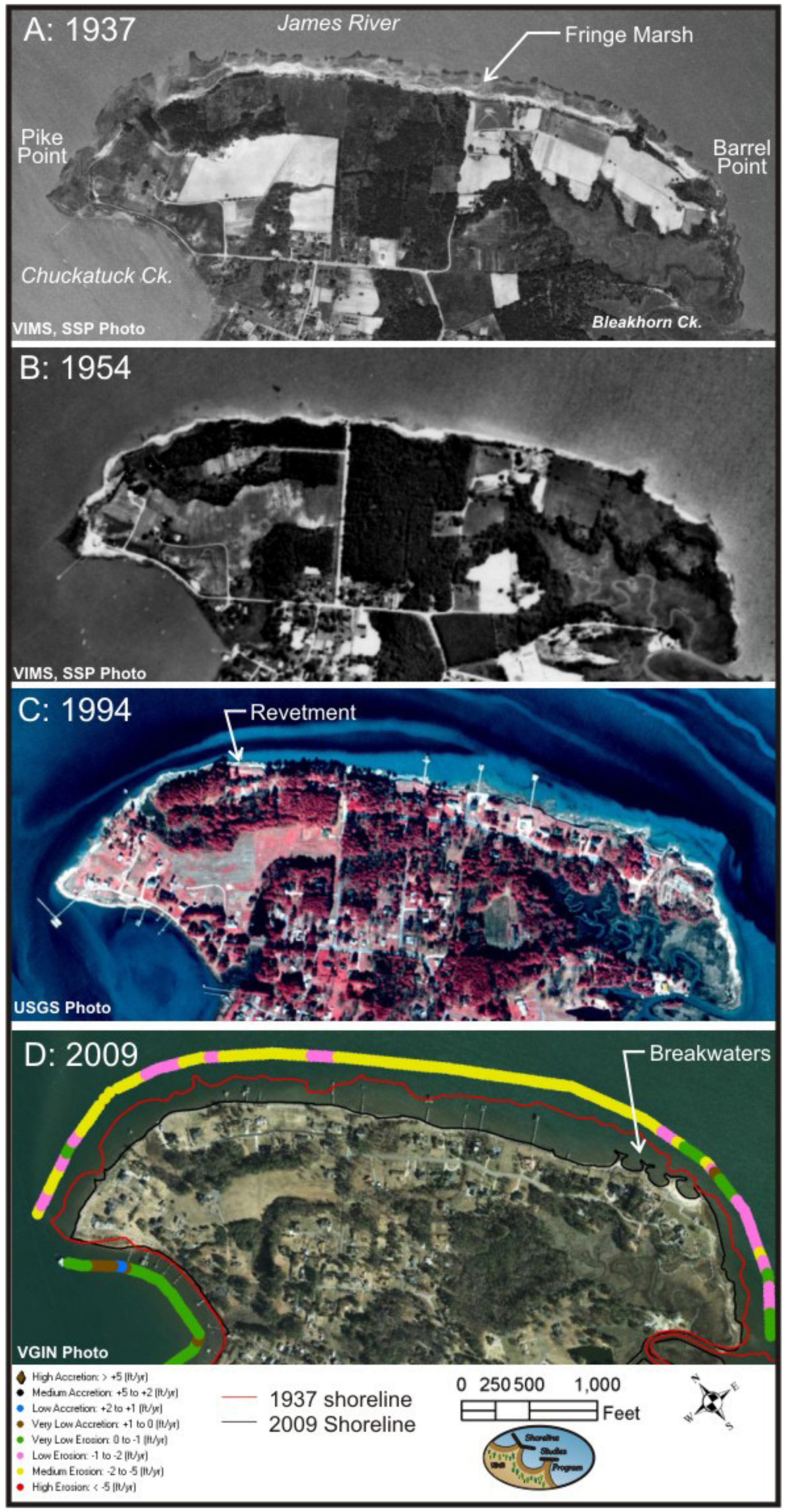

Figure 2-9. *Historical aerial photography between Barrel Point and Pike Point in A) 1937, B) 1954, C) 1994, and D) 2009. The 2009 image also shows 1937 and 2009 digitized shorelines and the calculated end point rate of change from Milligan* et al.*, 2010).*

2.2 Coastal Hydrodynamics

2.2.1 Wave Climate

Shoreline change (erosion and accretion) is a function of upland geology, shore orientation and the impinging wave climate (Hardaway and Byrne, 1999). Wave climate refers to averaged wave conditions as they change throughout the year. It is a function of seasonal winds as well as extreme storms. Seasonal wind patterns vary. From late fall to spring, the dominant winds are from the north and northwest. During the late spring through the fall, the dominant wind shifts to the southwest. Northeast storms typically occur from late fall to early spring (Hardaway and Byrne, 1999).

Figure 2-10. *Commercial land use along Chuckatuck Creek.*

The wave climate of a particular site depends not only on the wind but also the fetch, shore orientation, shore type, and nearshore bathymetry. Fetch can be used as a simple measure of relative wave energy acting on shorelines. Hardaway and Byrne (1999) suggested three general categories based on average fetch exposure:

Low-energy shorelines have average fetch exposures of less than 1 nautical mile and are mostly found along the tidal creeks and small rivers.

Medium-energy shorelines have average fetch exposure of 1 to 5 nautical miles and typically occur along the main tributary estuaries;

High-energy shorelines have average fetch exposures of over 5 nautical miles and occur along the main stem of the bay and mouth of tributary estuaries;

Basco and Shin (1993) described the wave climate in Hampton Roads near the City of Suffolk's coast for use in planning and designing structures. Their analysis utilized moderate winds of 35 miles per hour to generate waves with characteristics that could be expected to impact the coast about once every two years. The storm surge for this event is about 2.5 feet above MHW or about 4.0 feet above MLW. Wave heights and wave periods in Hampton Roads (Figure 2-11) near the shoreline east of the Nansemond River are about 5.0 ft with a 4.5 second period before nearshore shoaling. Farther north along the James River in the vicinity of Barrel Point, wave heights and wave periods are about 4.5 ft with a 4.2 second period.

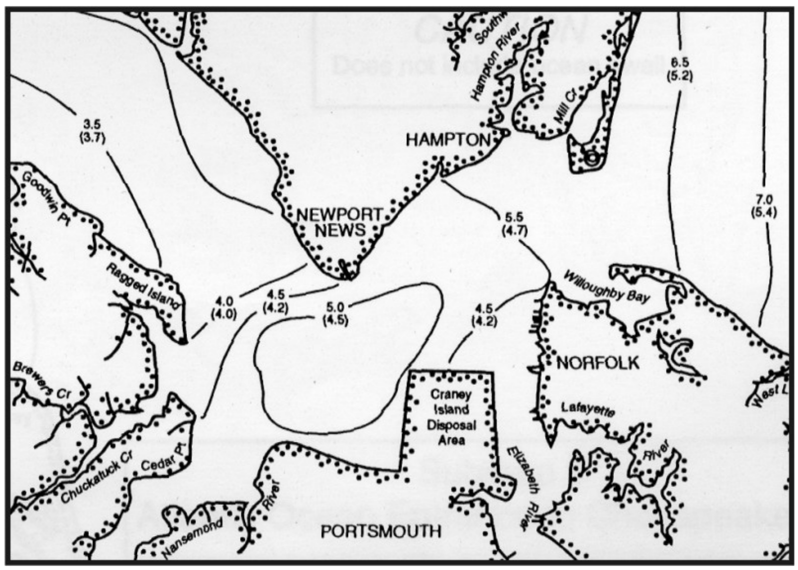

Figure 2-11. *Predicted wave heights that would result from a 35 mph wind during a possible 2-yr event. (From Basco and Shin, 1993). Wave heights and period (in parentheses) are shown.*

Storm surge frequencies described by FEMA (2011) are shown in Table 2-1. These show the 10%, 2% 1% and 0.2% chances of water levels attaining these elevations for any given year along the Hampton Roads and Nansemond River coasts. These percentages correspond to 10 year, 50 year, 100 year, and 500 year events. The mean tide range at Sewells Point is 2.4 feet. For a given storm, maximum wind speeds and direction also are important when developing shoreline management strategies, particularly in regard to determining the level of shore protection needed at the site.

During hurricanes, the coastal regions that would be impacted are shown in Figure 2-12. Most of the areas impacted are found along the Nansemond River, Chuckatuck Creek, and associated tidal creek shorelines. Areas with higher banks, do not flood as readily. However, those high banks that occur along more open shoreline can be exposed to higher wave energies during storms, possibly increasing erosion.

2.2.2 Sea-Level Rise

Location	Annual Chance (feet NAVD)			
	10%	2%	1%	0.2%
Hampton Roads: Entire shoreline within community	5.4	6.8	7.5	8.8
Nansemond River and Tributaries From the mouth to south of the confluence with Cedar Creek	5.4	6.8	7.5	8.8
Remaining shoreline south of the confluence with Cedar Creek	5.1	6.5	7.2	8.5

**Cedar Creek is across from Glebe Point*

Table 2-1. *10 year, 50 year, 100 year, and 500 year storm predicted flood levels relative to NAVD. Source: City of Suffolk Flood Report, FEMA (2011).*

On monthly or annual time scales, waves dominate shore processes and, during storm events, leave the most obvious mark. However, on time scales approaching decades or more, sea level rise is the underlying and persistent force responsible for shoreline change. The recent trend based on wave gauge data at Sewells Point shows the annual rate to be 1.5 feet/100 years (4.44 mm/yr). The historic rate at Sewells Point (1.44 feet/100 years) will result in 0.53 feet rise in water level by 2050. Boon (2012) predicted future sea-level rise by 2050 using tide gauge data from the East Coast of the U.S. Sewells Point has a projected sea-level rise of 2.03 feet (0.62 m +/- 0.22m) by 2050. This increase in sea-level warrants ongoing monitoring of shoreline condition and attention in shoreline management planning.

2.2.3 Shore Erosion

Shoreline erosion results from the combined impacts of waves, sea level rise, tidal currents and, in some cases, boat wakes and shoreline hardening. Table 2-2 shows the average historical shoreline rates of change for various areas throughout the City. As expected, the greatest rates of shoreline change occur along the James River and Hampton Roads shoreline. The more protected Nansemond River and Chuckatuck Creek had lower rates of shoreline change. More detailed shoreline change information can be found in Milligan *et al*. (2010).

The shorelines with the largest historical shoreline rates of change have mostly been hardened. Over the last 50-60 years, shoreline hardening has been the most common management solution to shoreline erosion. Almost 12 miles of shoreline have been hardened over the years. After years of study and review, we now understand the short and long term consequences to those choices, and there is growing concern that the natural character of the shoreline cannot be preserved in perpetuity if shoreline management does not change.

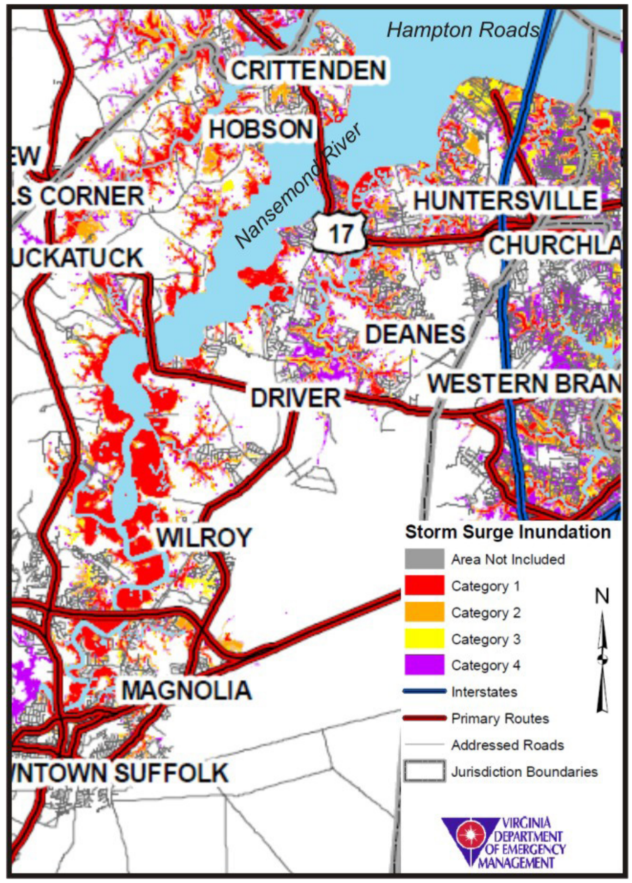

Figure 2-12. *Predicted storm surge levels associated with hurricanes. From the Virginia Department of Emergency Management website 2014.*

Location	Average
Chuckatuck Creek	-0.3
James River, West of Nansemond R.	-2.1
Nansemond River	-1.3
James River, East of Nansemond R.	-3.3

Table 2-2. *End Point rate of change (1937-2009) for City of Suffolk's shoreline. The rates of change are given in feet per year. From Milligan* et al.*, (2010).*

3 Shoreline Best Management Practices

3.1 Implications of Traditional Erosion Control Treatments

Following decades of shoreline management within the constraints of Virginia's evolving regulatory program, we have been afforded the opportunity to observe, assess, monitor and ultimately revise our understanding of how the natural system responds to perturbations associated with traditional erosion control practices. Traditional practices include construction of bulkheads, concrete seawalls, stone revetments, and the use of miscellaneous materials purposefully placed to simulate the function that revetments or bulkheads perform. These structures have been effective at stabilizing eroding shoreline; however, in some places, the cost to the environment has been significant and results in permanent loss of ecosystem function and services.

For example, bulkheads constructed close to the water correlate with sediment loss and high temperatures in the intertidal zone, resulting in impacts to organisms using those areas (Spalding and Jackson, 2001; Rice *et al*. 2004; Rice, 2006). The reduction of natural habitat may result in habitat loss if the bulkhead cannot provide substitute habitat services. The deepening of the shallow water nearshore produced by reflective wave action could reduce habitat available for submerged grass growth.

Less is known about the long-term impacts of riprap revetments. Believed to be a more ecological treatment option than bulkheads, when compared with natural systems, riprap tends to support lower diversity and abundance of organisms (Bischoff, 2002; Burke, 2006; Carroll, 2003; Seitz *et al*., 2006). The removal of riparian vegetation as well as the intertidal footprint of riprap has led to concern over habitat loss to the coastal ecosystem (Angradi *et al*., 2004).

3.2 Shoreline Best Management Practices – The Living Shoreline Alternative

As Virginia begins a new era in shoreline management policy, Living Shorelines move to the forefront as the preferred option for erosion control. In the recent guidance developed by the Center for Coastal Resources Management at the Virginia Institute of Marine Science (CCRM,2013), Shoreline Best Management Practices (Shoreline BMPs) direct managers, planners, and property owners to select an erosion control option that minimizes impacts to ecological services while providing adequate protection to reduce erosion on a particular site. Shoreline BMPs can occur on the upland, the bank, or along the shoreline depending on the type of problem and the specific setting.

Table 3-1 defines the suite of recommended Shoreline BMPs. What defines a Living Shoreline in a practical sense is quite varied. With one exception, all of the BMPs constitute a Living Shoreline alternative. The revetment is the obvious exception. Not all erosion problems can be solved with a Living Shoreline design, and in some cases, a revetment is more practical. Most likely, a combination of these practices will be required at a given site.

Upland Shoreline BMPs	Shoreline BMPs
No Action Needed	No Action Needed
Land Use Management	Enhance/Maintain Marsh Buffer
Forest Management	Widen Marsh
Enhance/Maintain Riparian	Enhance/Maintain Beach
Grade Bank	Plant Marsh with Sill
	Beach Nourishment
	Groin Field with Beach Nourishment
	Offshore Breakwaters with Beach Nourishment
	Revetment

Table 3-1. *Shoreline Best Management Practices.*

3.3 Non-Structural Design Considerations

Elements to consider in planning shoreline protection include: underlying geology, historic erosion rate, wave climate, level of expected protection (which is based on storm surge and fetch), shoreline length, proximity of upland infrastructure (houses, roads, etc.), and the onsite geomorphology which gives an individual piece of property its observable character (e.g. bank height, bank slope). These parameters along with estimated cost help determine the management solution that will provide the best shore protection.

In low energy environments, Shoreline BMPs rarely require the use of hard structures. Frequently the intent of the action is to stabilize the slope, reduce the grade and minimize under cutting of the bank. In cases where an existing forest buffer is present a number of forest management practices can stabilize the bank and prevent further erosion (Figure 3-1). Enhancing the existing forest condition and erosion stabilization services by selectively removing dead, dying and severely leaning trees, pruning branches with weight bearing load over the water, planting and/or allowing for re-generation of mid-story and ground cover vegetation are all considered Living Shoreline treatment options.

Enhancement of both riparian and existing marsh buffers together can be an effective practice to stabilize the coastal slope (Figure 3-2) from the intertidal area to the upland by allowing plants to occupy suitable elevations in dynamic fashion to respond to seasonal fluctuations, shifts in precipitation or gradual storm recovery. At the upland end of the slope, forest buffer restoration and the planting of ornamental grasses, native shrubs and small trees is recommended. Enhancement of the marsh could include marsh plantings, the use of sand fill necessary to plant marsh vegetation, and/or the need for fiber logs to stabilize the bank toe and newly established marsh vegetation.

In cases where the bank is unstable, medium or high in elevation, and very steep, bank grading may be necessary to reduce the steepness of bank slopes for wave run-up and to improve growing conditions for vegetation stabilization (Figure 3-3). The

Figure 3-1. *One example of forest management in a high energy environment.. The edge of the bank is kept free of tree and shrub growth to reduce bank loss from tree fall.*

Figure 3-2. *Maintaining and enhancing the riparian and marsh buffers can maintain a stable coastal slope.*

Figure 3-3. *Bank grading reduces steepness and will improve growing conditions for vegetation stabilization.*

ability to grade a bank may be limited by upland structures, existing defense structures, adjacent property conditions, and/or dense vegetation providing desirable ecosystem services.

Bank grading is quite site specific, dependent on many factors but usually takes place at a point above the level of protection provided by the shore protection method. This basal point may vary vertically and horizontally, but once determined, the bank grade should proceed at a minimum of 2:1 (2Horizontal:1Vertical). Steeper grades are possible but usually require geotechnical assistance of an expert. Newly graded slopes should be re-vegetated with different types of vegetation including trees, shrubs and grasses. In higher energy settings, toe stabilization using stone at the base of the bank also may be required.

Figure 3-4. *This low-energy site had minor bank grading, sand added, and* Spartina alterniflora *planted. This photo shows the site after 24 years.*

Along the shoreline, protection becomes focused on stabilizing the toe of the bank and preventing future loss of existing beach sand or tidal marshes. Simple practices such as: avoiding the use of herbicides, discouraging mowing in the vicinity of the marsh, and removing tidal debris from the marsh surface can help maintain the marsh. Enhancing the existing marsh by adding vegetation may be enough (Figure 3-4).

In medium energy settings, additional shore protection can be achieved by increasing the marsh width which offers additional wave attenuation. This shoreline BMP usually requires sand fill to create suitable elevations for plant growth. Marshes are generally constructed on slopes between 8:1 and 14:1, but average about 10:1 (for every 10 ft in width, the elevation changes by 1 foot) (Hardaway *et al*., 2010). Steeper systems have less encroachment into the nearshore but may not successfully stabilize the bank because the marsh may not attenuate the waves enough before they impact the bank. Shallower, wider systems have more encroachment onto nearshore bottom but also have the advantage of creating more marsh and attenuating wave energy more effectively. Determining the system's level of protection, i.e. height and width, is the encroachment.

If the existing riparian buffer or marsh does not need enhancement or cannot be improved, consider beach nourishment if additional sand placed on the beach will increase the level of protection. Beach nourishment is the placement of good quality sand along a beach shoreline to increase the beach width and raise the elevation of the nearshore area. New sand should be similar in grain size or coarser than the native beach sand. Enhancing and maintaining existing beaches preserves the protection that beaches offer to the upland as sands move naturally under wave forces and wind energy. This encourages beach and dune formation which can further be enhanced and stabilized with beach and dune plants.

Where bank and/or shoreline actions are extremely difficult or limited in effectiveness Land Use Management may be required to reduce risk. Practices and strategies may include: relocate or elevate buildings, driveway relocation, abandon or relocate sanitary drainfields, or hook-up to public sewer. All new construction should be located 100 feet or more from the top of the bank. Re-directing stormwater runoff away from the top of the bank, or re-shaping the top of the bank may also assist in stabilizing the bank.

Creating a more gradual slope can involve encroaching into landward habitats (banks, riparian, upland) through grading and into nearshore habitats by converting existing sandy bottom to marsh or rock. These and other similar actions may require zoning variance requests for setbacks, and/or relief from other land use restrictions that increase erosion risk. Balancing the encroachment is necessary for overall shoreline management.

3.4 Structural Design Considerations

In medium to high energy settings, suitable "structural" Living Shoreline management strategies may be required. For Suffolk, these are marsh sills constructed of stone and offshore breakwaters.

As fetch exposure increases beyond about 1,000 ft, the intertidal marsh width is not sufficient to attenuate wave action, and the addition of sand can increase the intertidal substrate as well as the backshore region. However, as wave exposure increases, the inclusion of some sand retaining structure may be required to prevent sand from being transported away from the site. This is where a marsh sill is appropriate.

3.4.1 Sills

The stone sill has been used extensively in the Chesapeake Bay over the years (Figure 3-5). It is a rock structure placed parallel to the shore so that a marsh can be planted behind it. The cross-section in Figure 3-5 shows the sand for the wetlands substrate on a slope approximating 10:1 from the base of the bank to the back of the sill. The elevation of the intersection of the fill at the bank and tide range will determine, in part, the dimensions of the sill system. If the nearshore depth at the location of a sill is greater than 2 feet, it might be too expensive for a sill relative to a revetment at that location. Nevertheless, the preferred approach would still be the marsh sill.

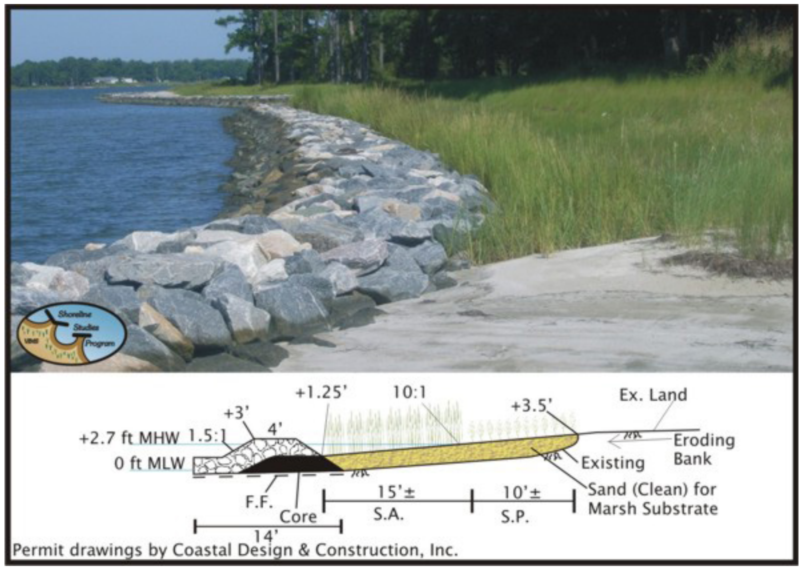

Figure 3-5. Sand fill with stone sills and marsh plantings at Poplar Grove, Mathews County, Virginia after six years and the cross-section used for construction (From Hardaway et al., *2010).*

Hardaway and Byrne (1999) indicate that in lower wave energy environments, a sill should be placed at or near MLW with sand fill extending from about mean tide level on a 10:1 to the base of an eroding bank. The height of the rock sill should be at least equal to mean high water to provide adequate backshore protection. Armor stone should be VA Class I. A recent installation of a sill in a low energy environment in Westmoreland County was on Glebe Creek at Hull Springs Farm (Figure 3-6). The Hull Springs Farm

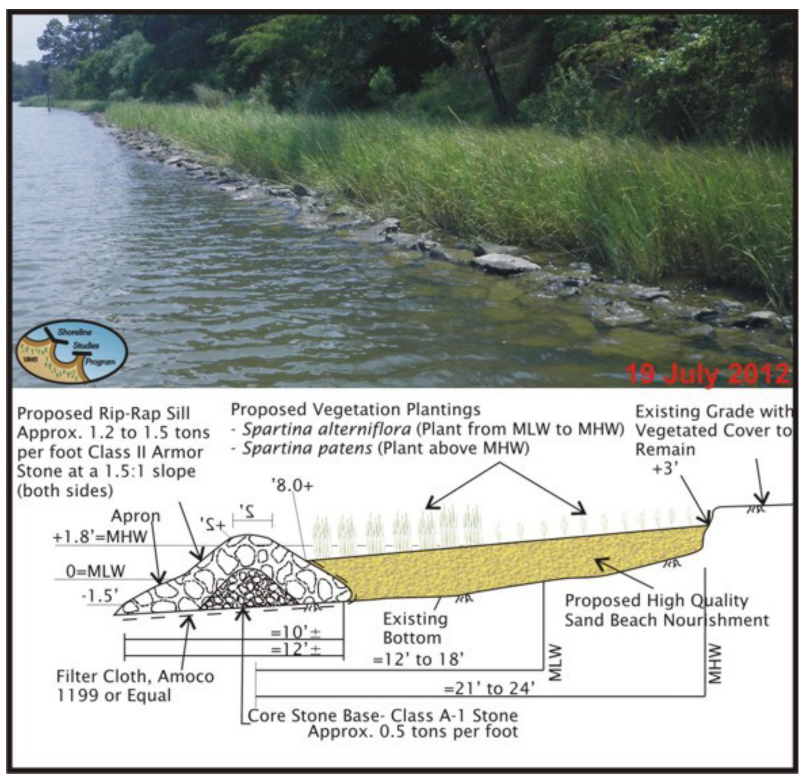

Figure 3-6. Longwood University's Hull Springs Farm four years after construction and the cross-section used for construction (from Hardaway et al., *2010).*

sill was built in 2008 along about 300 feet of shoreline. The sand fill begins at +3 feet on the bank and old bulkhead and extends on a 10:1 slope to about mid-tide (+0.8 ft mean low water) at the back of the sill. This provides planting widths of about 10 feet for *Spartina alterniflora* and 12 feet for *Spartina patens* (Hardaway *et al*., 2010). The sill system was built in August 2008 and went through the Veteran's Day Northeaster (2009) with no impacts to the unprotected base of bank. Marsh fringes were heavily covered with snow and ice during the winter of 2009 but reemerged intact.

For medium energy shorelines, sills should be placed far enough offshore to provide a 40 foot wide (low bank) to 70 foot wide (high bank) marsh fringe (Hardaway and Byrne, 1999). This distance includes the sill structure and is the width needed to attenuate wave action during seasonal storms. During extreme events when water levels exceed 3 feet above mean high water, some wave action (>2 feet) may penetrate the system. For this reason, a sill height of a least 1 foot above mean high water should be installed. Armor stone may be Class II (< 2 miles) to Class III (up to 5 miles).

Sills on high energy sites need to be very robust. Impinging wave heights can exceed 3 feet. Maintaining a vegetative fringe can be difficult. Therefore sill heights should be at least 2 feet above mean high water (MHW). The minimum size for armor stone should be Class III. A sill used along a high energy coast occurs at Westmoreland State Park (Figure 3-7). Placed along a very high eroding bluff, this system will act to capture bank slump and may eventually lead to some bluff stability.

Figure 3-7. *High sills built along Westmoreland State Park's high energy, high bank shoreline. The material that slumps from the bank will be caught behind the sills and stabilize the base of the bank by protecting it from wave attack. A more recent photo shows that the slump material is starting to become vegetated.*

Any addition of sand or rock seaward of mean high water (MHW) requires a permit. A permit may be required landward of MHW if the shore is vegetated. As the energy environment increases, shoreline management strategies must adapt to counter existing erosion problems. While this discussion presents structural designs that typically increase in size as the energy environment increases, designs remain consistent with the Living Shoreline approach wherever possible. In all cases, the option to "do nothing" and let the landscape respond naturally remains a choice. In practice, under this scenario, the risk to private property frequently outweighs the benefit for the property owner. Along medium energy and high energy shorelines, a breakwater system can be a cost-effective alternative for shoreline protection.

3.4.2 Breakwaters

Breakwaters are a series of large rock structures placed strategically offshore to maintain stable pocket beaches between the structures. The wide beaches provide most of the protection, so beach nourishment should be included as part of the strategy and periodic beach re-nourishment may be needed.

Although single breakwaters can be used, two or more are recommended to address several hundred feet of coast. For breakwaters, the level of protection changes with the system dimensions such that larger dimensions generally correspond to bigger fetches and where a beach and dune shoreline is desired. Hardaway and Gunn (2010) and Hardaway and Gunn (2011) provide detailed research on the use of breakwaters in Chesapeake Bay.

Hardaway and Byrne (1999) suggest that breakwater systems in medium energy environments should utilize at least 200 feet of shoreline, preferably more, because individual breakwater units should have crest lengths of 60 to 150 feet with crest heights 2 to 3 feet above mean high water. Minimum mid-bay beach width should be 35-45 feet above mean high water. On high energy coasts, the mid-bay beach widths should be 45 to 65 feet especially along high bank shorelines (Figure 3-8). Crest lengths should be 90 to 200 feet. Armor stone of Class III (500 lbs.) is a minimum, but up to Type I (1500 to 4000 lbs.) may be required especially where a deep near shore exists.

In most cases, breakwater construction includes the addition of sand between the stone breakwater and the shore. In lower energy settings, sand may be vegetated. The backshore region should be planted in appropriate dune vegetation. In higher energy settings, the nourished sand will be re-distributed naturally under wave conditions. In some areas, additional nourishment may be required periodically in response to storms, or on some regular schedule.

Figure 3-8. *The breakwaters at Colonial Beach, Virginia provide a wide recreational beach as well as storm erosion protection for the residential upland. These structures were installed in 1982.*

4 Methods

4.1 Shore Status Assessment

The shore status assessment was made from a small, shallow draft vessel, navigating at slow speeds parallel to the shoreline during field days in August 2012. Existing conditions and suggested strategies were entered in GIS. Once the data were compiled and evaluated, the preferred strategies were subjected to further analysis utilizing other collected data, including the condition of the bank face and toe, marsh width, landscape type, and GPS-referenced photos. The results of this analysis were compared to the results of the model described below.

4.2 Geospatial Shoreline Management Model

The Shoreline Management Model (SMM) is a geo-spatial tool that was developed to assess Shoreline Best Management Practices (Shoreline BMPs) comprehensively along tidal shoreline in Virginia. It is now necessary to provide recommended shoreline strategies that comply with an ecosystem based approach. The SMM has the capacity to assess large geographic regions quickly using available GIS data

The model is constructed using multiple decision-tree pathways that lead the user to a final recommended strategy or strategies in some cases. There are four major pathways levels. The pathways are determined based on responses to questions that determine onsite conditions. Along the upland and the bank, the model queries a site for bank stability, bank height, presence of existing infrastructure, land use, and whether the bank is defended to arrive at an upland management strategy. At the shore the model queries a site for presence and condition of beaches, marshes, the fetch, nearshore water depth, presence of specific types of erosion control structures, and creek setting to drive the shore recommendations. Appendix 1 illustrates the logic model structure.

The responses are generated by searching site specific conditional geospatial data compiled from several sources representing the most current digital data available in shapefile and geodatabase formats (Table 4-1). As indicated in Table 4-1, the majority of these data are

Dataset	Origin	Contribution	Variables
Shoreline Inventory	Comprehensive Coastal Inventory (CCI), Center for Coastal Resources Management (CCRM), Virginia Institute of Marine Science (VIMS)	bank erosion	stable, erosional, defended
		riparian land use	forested
		bank height	0-30 feet, 30-60 feet, >60 feet
		beach	presence or absence
		erosion protection structures	defended; groin field present
Tidal Marsh Inventory	CCRM, VIMS	marsh width	absent, present; <15 feet wide, >15 feet wide
Roads	TIGER /Line, U.S. Census Bureau	permanent structure limiting bank grading	present or absent
Permanent Structures	created inhouse (CCI) for project, unpublished	permanent structure limiting bank grading	present or absent
Fetch	CCI, CCRM, VIMS	fetch (distance to nearest shoreline calculated in 16 directions)	low = 0-0.5 mile; moderate = 0.5 - 2 miles; high = >2 miles.
Non-Jurisdictional Beach Assessment	Shoreline Studies Program VIMS	wide beach (width > 10 feet)	present or absent
Bathymetry	Special Projects Office of the National Ocean Service, NOAA	nearshore water depth	shallow = 1m bathymetric contour > 10m from shoreline; deep = 1m bathymetric contour <10m from shoreline
Tributary Designation	created inhouse (CCI) for project, unpublished	tidal creek	tidal creek, major tributary, bayfront

Table 4-1. *Shoreline Management Model (SMM) Data Sources and Applications.*

collected and maintained for the City of Suffolk Shoreline Inventory. (http://ccrm.vims.edu/gis_data_maps/shoreline_inventories/virginia/suffolk/suffolk_disclaimer.html) developed by CCRM (Angstadt *et al.*, 2013). The model is programmed in ESRI's (Environmental Systems Research Institute) ArcGIS version 9.3.1 and version 10 software.

The shoreline inventory dataset contains several attributes required for the SMM that pertain to riparian land use, bank height, bank erosion, presence of beach, existing shoreline protection structures and marshes. Other data sources provide information on nearshore depth, exposure to wave energy, marsh condition, location of beaches, and proximity of roads and permanent structures to the shoreline.

The model is built using ArcGIS Model Builder and has 13 major processing steps. Through the step-wise process specific conditions, buffers, and offsets may be delineated to accurately assess the impact that a specific condition may have on the model output. For example, a permanent structure built close to the shoreline could prevent a recommendation of bank grading as a best management practice.

To determine if bank grading is appropriate a rough estimate formula that incorporates a 3:1 slope with some padding for variability within a horizontal distance of shoreline and bank top was developed. The shoreline was buffered based on the formula:

((3*mh) + 20) * 0.3048 where:

mh is the maximum height within the inventory height field (0-5 = 5ft; 5-10 = 10ft; 10-30 = 30ft; >30 = 40ft)

20 = is the padding for variability in the horizontal distance between the shoreline and the top of the bank in feet

0.3048 is the conversion from feet to meters.

Shoreline was coded for presence of permanent structures such as roads, houses, out buildings, swimming pools, etc. where observed in recent high resolution imagery to be within the computed buffer.

In the case of determining fetch or exposure to wave energy, the shoreline was divided into 50m segments, and represented by a single point on the line. Fetch distance was measured from the point to the nearest shoreline in 16 directions following the compass rose. The maximum distance over water was selected for each point to populate the model's fetch variable.

Field data from the Shoreline Inventory provided criteria to classify attributes assessed based on height (banks) or width (beaches and marshes) in many cases. Some observations were collected from other datasets and/or measured from high resolution aerial imagery. For example, the Non-Jurisdictional Beach Assessment dataset provided additional beach location data not available in the inventory. To classify beaches for the model as "wide" or "narrow", a visual inspection of imagery from the Virginia Base Mapping Program (VBMP), Bing, and Google Maps was used to determine where all beaches were wider than 10 feet above the high tide line.

Limitations to the model are primarily driven by available data to support the model's capacity to make automated decisions. If an existing structure is in place and the shoreline is stable, the model bases its decision on a stable shoreline. If an existing structure is in place and the shoreline is unstable, the model will return a recommendation based on the most ecological approach and will not consider the presence of the existing structure. In places where sufficient data are not available to support an automated decision, the shoreline is designated as an "Area of Special Concern". This includes shorelines that are characterized by man-made canals, marinas, or commercial or industrial land uses with bulkheads or wharfs. Marsh islands or areas designated as paved public boat ramps receive a "No Action Needed" recommendation.

The model output defines 14 unique treatment options (Table 4-2) but makes 16 different recommendations which combine options to reflect existing conditions on site and choices available based on those conditions. The unique treatment options can be loosely categorized as Upland BMPs or

Shore BMPs based on where the modification or action is expected to occur. Upland BMPs pertain to actions which typically take place on the bank or the riparian upland Shore BMPs pertain to actions which take place on the bank and at the shoreline.

Upland BMPs	Shore BMPs
Enhance Riparian Buffer	Enhance or Maintain Marsh
Forest Management	Widen marsh
Grade Bank	Plant Marsh with Sill
Land Use Management	Enhance or Maintain Beach
	Beach Nourishment
Area of Special Concern	Groin Field with Beach Nourishment
No Action Needed	Offshore Breakwaters with Beach Nourishment
	Revetment
	Area of Special Concern
	No Action Necessary

Table 4-2. *Shoreline Management Model - Preferred Shoreline Best Management Practices.*

5 Shoreline Management for City of Suffolk

5.1 Shoreline Management Model (SMM) Results

In the City of Suffolk, the SMM was run on 340 miles of shoreline. These 340 miles include the main river and creek shorelines as well as the large amount of shoreline along tidal marsh channels. The SMM provides recommendations for preferred shoreline best management practices along all shoreline. At any one location, strategies for both the upland and the shore may be recommended. It is not untypical to find two options for a given site.

The majority of shoreline management in the City of Suffolk can be achieved without the use of traditional erosion control structures, and with few exceptions, very little structural control. Nearly 70% of the shoreline can be managed simply by enhancing the riparian buffer or the marsh if present. Since the majority of the shoreline resides within protected waters with medium to low energy conditions, Living Shoreline approaches are applicable. Along the open James River, Hampton Roads, and mouth of Nansemond River shorelines, the use of breakwaters with beach nourishment is recommended. Sills are recommended a many areas along the Nansemond River. Table 5-1 summarizes the model output for Suffolk based on strategy(s) and shoreline miles. The glossary in Appendix 2 gives meaning to the various Shoreline BMPs listed in Table 5-1.

To view the model output, the Center for Coastal Resources Management has developed a Comprehensive Coastal Resource Management portal (Figure 5-1) which includes a pdf file depicting the SMM output, an interactive map

Shoreline BMPs	Shoreline Length (miles)
Enhance Riparian/Marsh Buffer	2.3
Enhance Riparian/Marsh Buffer OR Beach Nourishment	0.1
Enhance/Maintain Beach	0.1
Enhance/Maintain Marsh	205.9
Enhance/Maintain Riparian Buffer	18.9
Groin Field with Beach Nourishment	0
Maintain Beach OR Offshore Breakwaters with Beach Nourishment	5.1
Plant Marsh with Sill	19.4
Revetment	0.04
Widen Marsh	6.4
Widen Marsh/Enhance Buffer	0.6
Area of Special Concern	1.0
No Action Needed	84.7

Table 5-1. *Occurrence of descriptive Shoreline BMPs in City of Suffolk.*

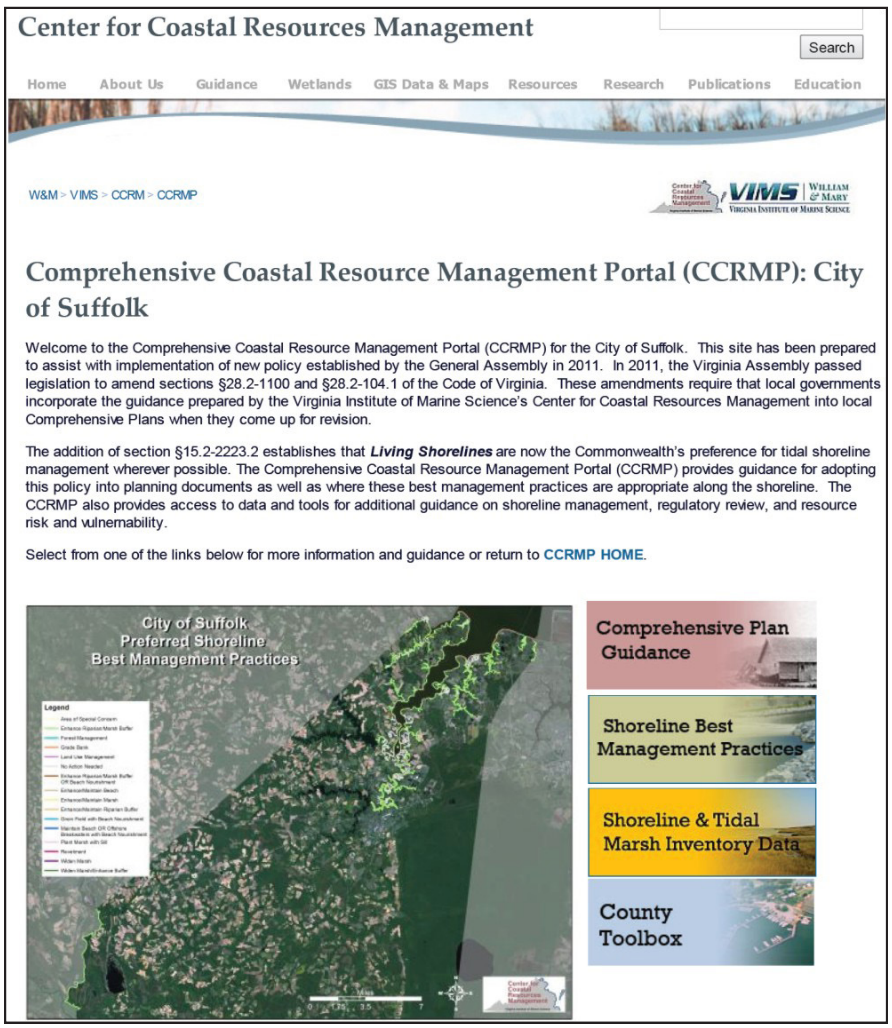

Figure 5-1. *Example of online portal for Comprehensive Coastal Resource Management in City of Suffolk.*

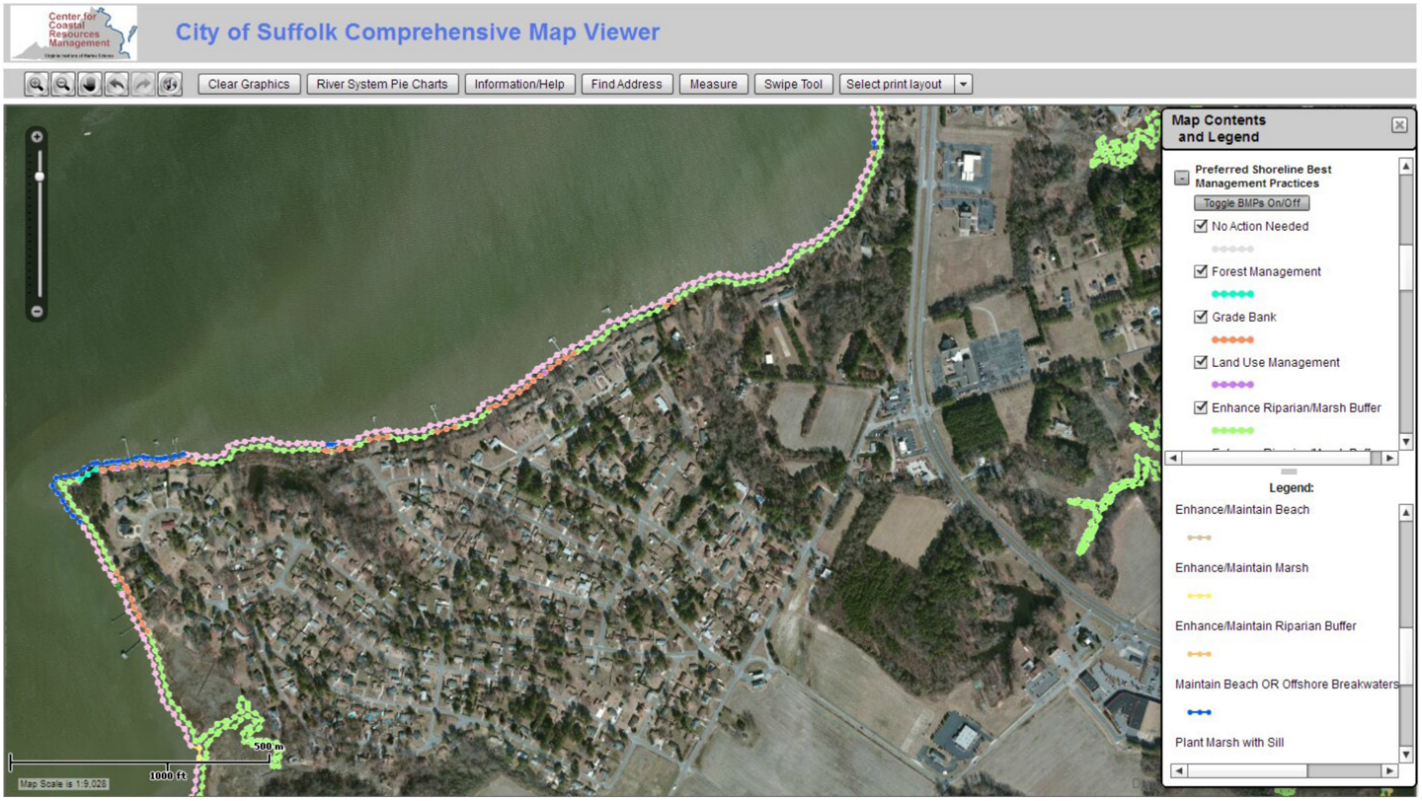

Figure 5-2. *The Map Viewer displays the preferred Shoreline BMPs in the map window. The color-coded legend in the panel on the right identifies the treatment option recommended.*

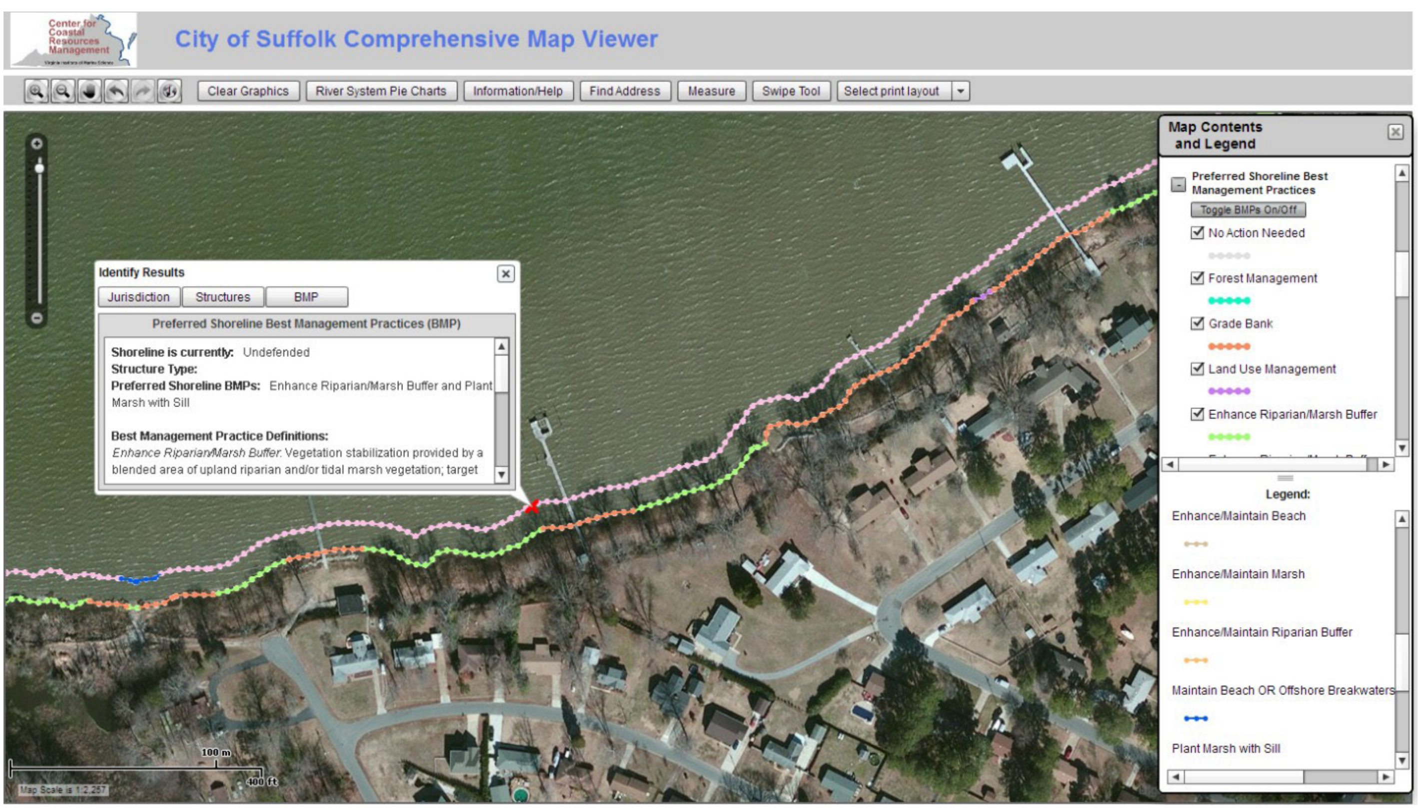

Figure 5-3. *The Map Viewer displays the preferred Shoreline BMPs in the map window. The color-coded legend in the panel on the right identifies the treatment option recommended.*

viewer that illustrates the SMM output as well as the baseline data for the model (http://ccrm.vims.edu/ccrmp/suffolk/index.html).

The pdf file is found under the tab for Shoreline Best Management Practices. The Map Viewer is found in the CountyToolbox and uses a Google type interface developed to enhance the end-users visualization (Figure 5-2). From the map viewer the user can zoom, pan, measure and customize maps for printing. When "Shoreline Management Model BMPs" is selected from the list in the right hand panel and toggled "on" the delineation of shoreline BMPs is illustrated in the map viewing window. The clickable interface conveniently allows the user to click anywhere in the map window to receive specific information that pertains to conditions onsite and the recommended shoreline strategy. Figure 5-3 demonstrates a pop-up window displayed onscreen when a shoreline segment is clicked in the map window.

Recommended Shoreline BMPs resulting from the SMM comply with the Commonwealth of Virginia's preferred approach for erosion control.

5.2 Shore Segments of Concern/Interest

This section describes several areas of concern and/or interest in Suffolk and demonstrates how the preferred alternative from the SMM could be adopted by the waterfront property owners. Areas of Concern occur where shore zones have existing, threatened upland infrastructure such as at Tidewater Community College. Areas of Interest demonstrate how the previously discussed goals of Living Shoreline management could be applied to a particular shoreline.

The conceptual designs presented in this section utilize the typical cross-sections that are shown in Appendix 3. The guidance provided in Appendix 3 describes the environments where each type of structure may be necessary and provides an estimated cost per foot. The designs presented are conceptual only; structural site plans should be created in concert with a professional experienced in the design and construction of shore protection methods in Chesapeake Bay.

5.2.1 Tidewater Community College (Area of Concern)

Tidewater Community College's (TCC) Center for Workforce Solutions is sited on the old military reserve along Hampton Roads east of Pig Point. The shoreline has been hardened with rock and debris over the years. Because the land is low, most of the revetments have been overtopped during storms resulting in intermittent upland bank erosion. One section, about 1,000 feet, along Sandy Drive is an area of concern because of the lack of stone or broken concrete along the shore (Figure 5-4). The eroding vertically exposed banks are undermining the edge of the road. The road has been abandoned at this time.

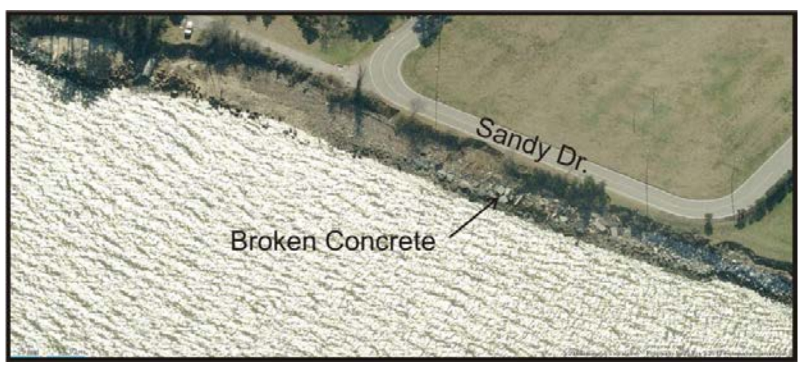

Figure 5-4. *Tidewater Community College shoreline at Sandy Drive.*

One option to manage this reach of shoreline is to install a headland breakwater system offshore (Figure 5-5). This system calls for relatively closely spaced breakwater units with beach nourishment and coastal vegetation plantings. A typical cross-section is shown in Appendix 3. This system would provide shore protection by dissipating wave energy during storms, habitat enhancement for a variety of species, and recreational access for TCC.

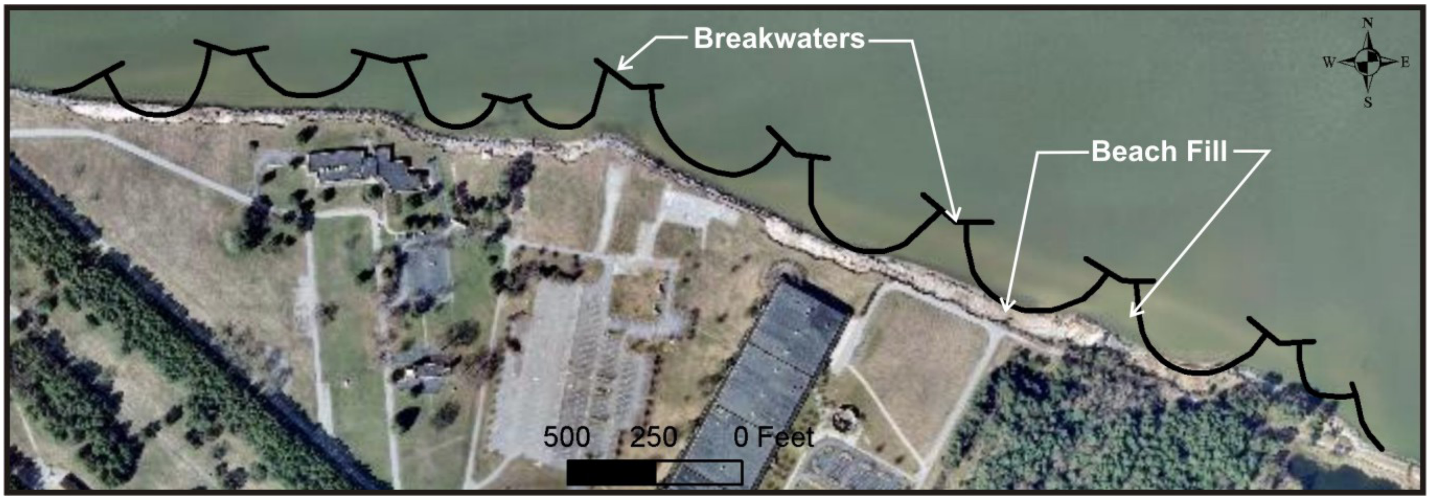

Figure 5-5. *Site-specific application of the Shoreline Management Model recommendation for Tidewater Community College. The breakwater system will stabilize the shoreline, provide shore protection, and create a recreational beach.*

5.2.2 Tidewater Community College (Area of Interest)

TCC shoreline between Interstate 664 and Skeeter Creek is an area of interest (Figure 5-6). This shoreline is mostly unprotected and consists of a marshy drainage. However, the section of the shoreline immediately adjacent to Interstate 664 has a revetment and two offshore breakwaters. In order to protect the woodlands and marshy drainage from continued erosion, a gapped sill system is proposed for the shoreline between the revetment and Skeeters Creek (Figure 5-7).

Figure 5-6. *Tidewater Community College shoreline east of Interstate 664.*

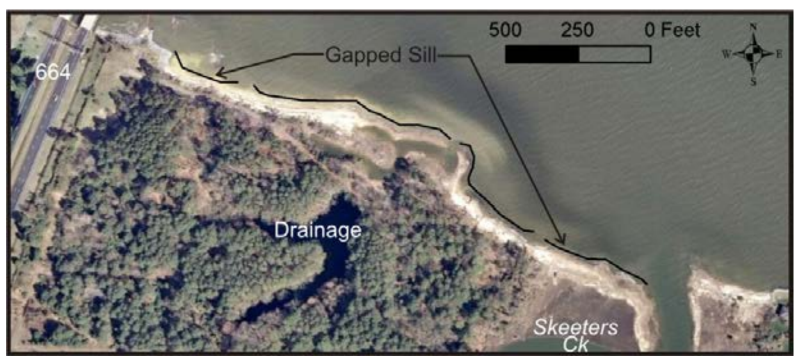

Figure 5-7. *Site-specific application of the Shoreline Management Model recommendation for Tidewater Community College's marsh shoreline. The gapped sill system will stabilize the marsh shoreline and provide shore protection.*

6 Summary and Links to Additional Resources

The Shoreline Management Plan for City of Suffolk is presented as guidance to City planners, wetland board members, marine contractors, and private property owners. The plan has addressed all tidal shoreline in the locality and offered a strategy for management based on the output of a decision support tool known as the Shoreline Management Model. The plan also provides some site specific solutions to several areas of concern that were noted during the field review and data collection in the county. In all cases, the plan seeks to maximize the use of Living Shorelines as a method for shoreline stabilization where appropriate. This approach is intended to offer property owners with alternatives that can reduce erosion on site, minimize cost, in some cases ease the permitting process, and allow coastal systems to evolve naturally.

Additional Resources

VIMS: City of Suffolk Map Viewer

http://ccrm.vims.edu/ccrmp/suffolk/index.html

VIMS: Living Shoreline Design Guidelines

http://www.vims.edu/research/departments/physical/programs/ssp/shoreline_management/living_shorelines/index.php

VIMS: Why a Living Shoreline?

http://ccrm.vims.edu/livingshorelines/index.html

VIMS: Shoreline Evolution for City of Suffolk

http://web.vims.edu/physical/research/shoreline/docs/ Cascade/Shoreline_Evolution/Suffolk_ShoreEvolve-lr.pdf

NOAA: Living Shoreline Implementation Techniques

http://www.habitat.noaa.gov/restoration/techniques/livingshorelines.html

Chesapeake Bay Foundation: Living Shoreline for the Chesapeake Bay Watershed

http://www.cbf.org/document.doc?id=60

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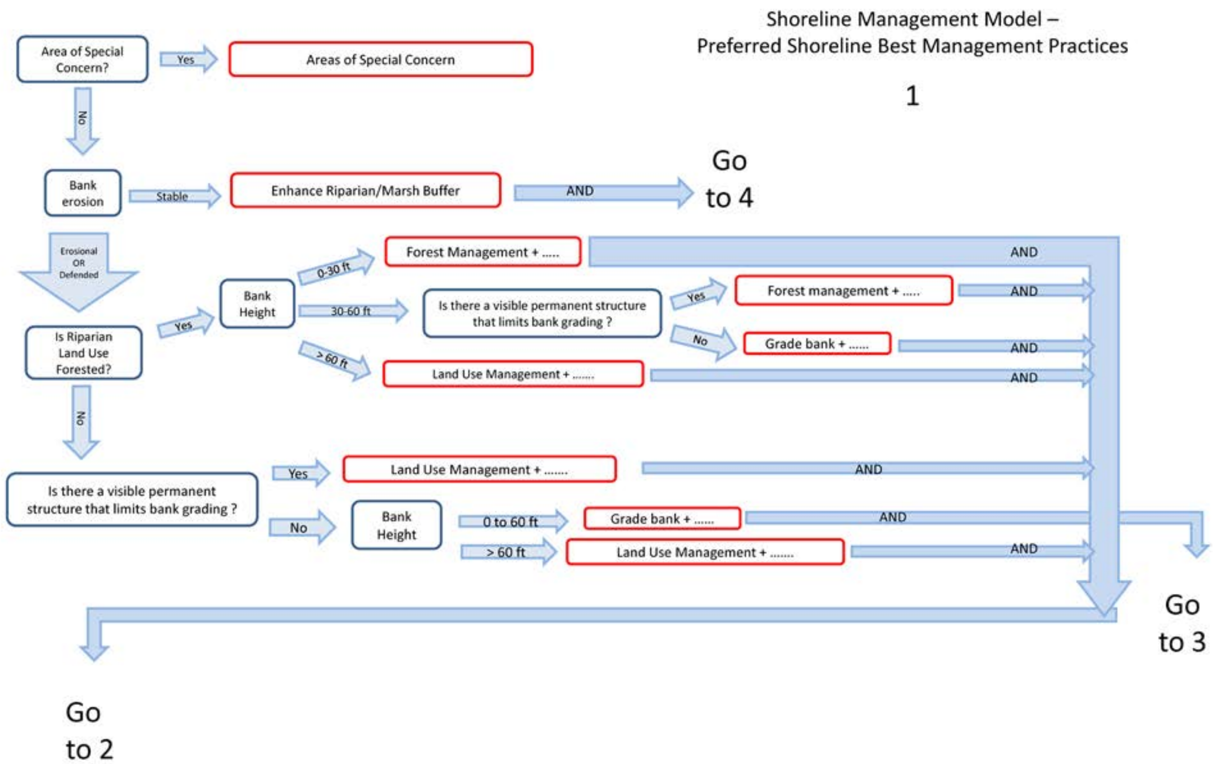
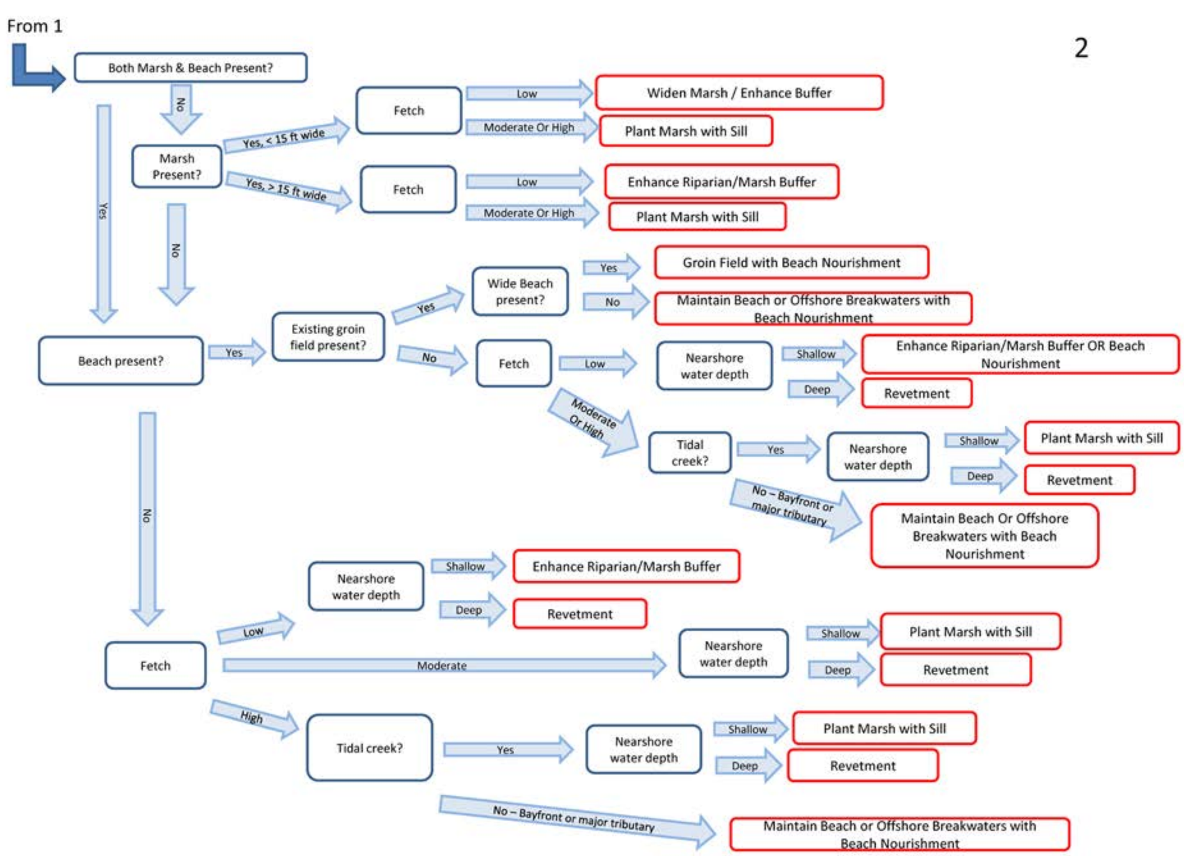
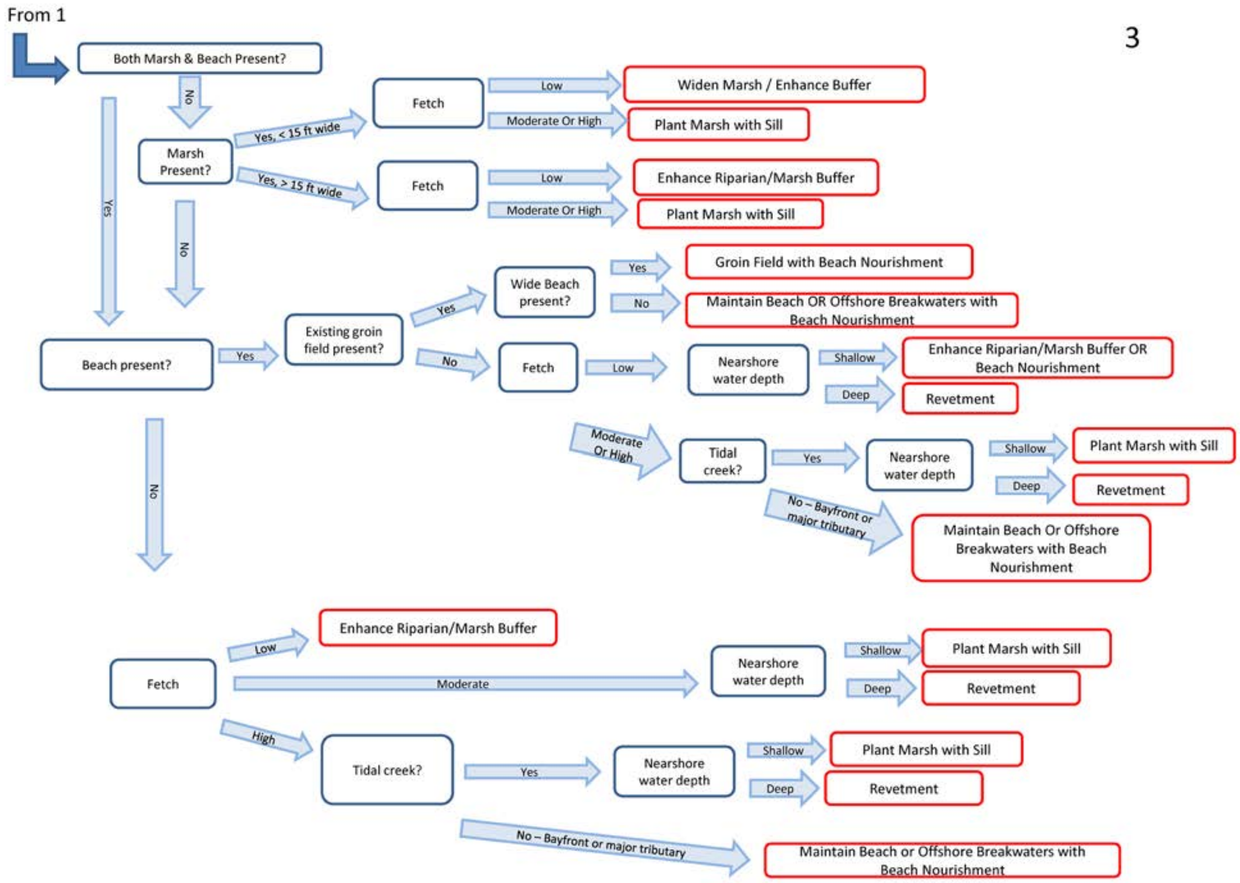
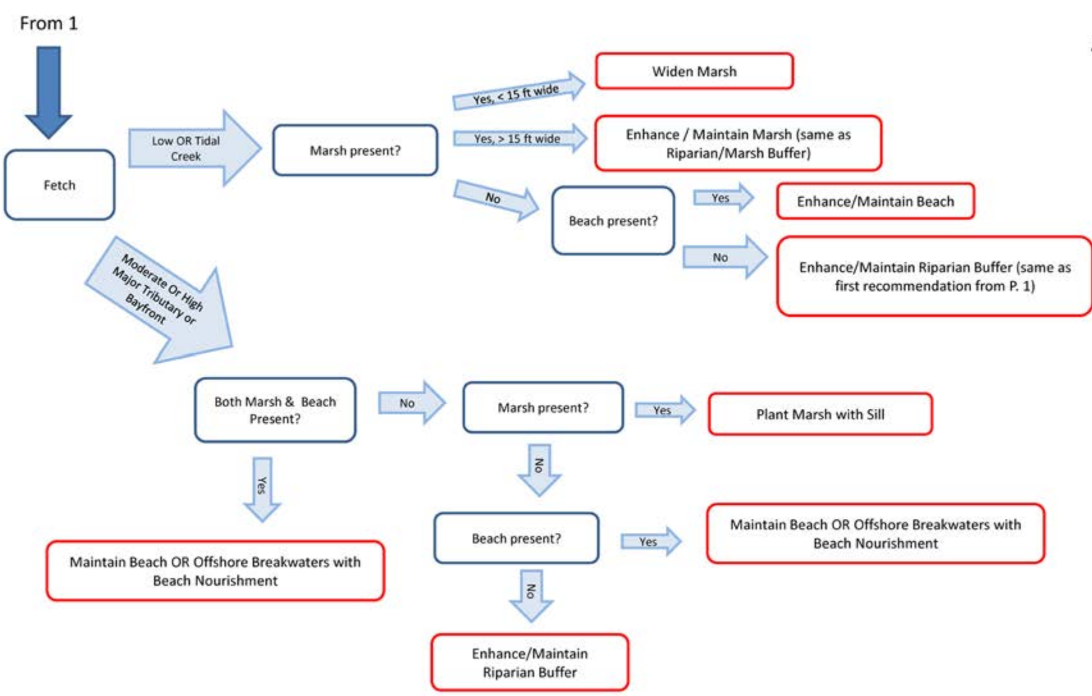
APPENDIX 1

Shoreline Management Model Flow Diagram






From 1
3
Both Marsh & Beach Present?
No
Yes
Marsh Present?
Yes, < 15 ft wide
Yes, > 15 ft wide
Fetch
Low
Widen Marsh / Enhance Buffer
Moderate Or High
Plant Marsh with Sill
Fetch
Low
Enhance Riparian/Marsh Buffer
Moderate Or High
Plant Marsh with Sill
No
Beach present?
Yes
Existing groin field present?
Yes
Wide Beach present?
Yes
Groin Field with Beach Nourishment
No
Maintain Beach OR Offshore Breakwaters with Beach Nourishment
No
Fetch
Low
Nearshore water depth
Shallow
Enhance Riparian/Marsh Buffer OR Beach Nourishment
Deep
Revetment
Moderate Or High
Tidal creek?
Yes
Nearshore water depth
Shallow
Plant Marsh with Sill
Deep
Revetment
No – Bayfront or major tributary
Maintain Beach Or Offshore Breakwaters with Beach Nourishment
No
Fetch
Low
Enhance Riparian/Marsh Buffer
Moderate
Nearshore water depth
Shallow
Plant Marsh with Sill
Deep
Revetment
High
Tidal creek?
Yes
Nearshore water depth
Shallow
Plant Marsh with Sill
Deep
Revetment
No – Bayfront or major tributary
Maintain Beach or Offshore Breakwaters with Beach Nourishment


From 1
4
Fetch
Low OR Tidal Creek
Marsh present?
Yes, < 15 ft wide
Widen Marsh
Yes, > 15 ft wide
Enhance / Maintain Marsh (same as Riparian/Marsh Buffer)
No
Beach present?
Yes
Enhance/Maintain Beach
No
Enhance/Maintain Riparian Buffer (same as first recommendation from P. 1)
Moderate Or High Major Tributary or Bayfront
Both Marsh & Beach Present?
Yes
Maintain Beach OR Offshore Breakwaters with Beach Nourishment
No
Marsh present?
Yes
Plant Marsh with Sill
No
Beach present?
Yes
Maintain Beach OR Offshore Breakwaters with Beach Nourishment
No
Enhance/Maintain Riparian Buffer

APPENDIX 2

Glossary of Shoreline Best Management Practices

Preferred Shoreline Best Management Practices

Areas of Special Concern (Marinas - Canals - Industrial or Commercial with bulkhead or wharf – Other Unique Local Features, e.g. developed marsh & barrier islands) - The preferred shoreline best management practices within Areas of Special Concern will depend on the need for and limitations posed by navigation access or unique developed areas. Vegetation buffers should be included where possible. Revetments are preferred where erosion protection is necessary. Bulkheads should be limited to restricted navigation areas. Bulkhead replacement should be in same alignment or landward from original bulkhead.

No Action Needed – No specific actions are suitable for shoreline protection, e.g. boat ramps, undeveloped marsh & barrier islands.

Upland & Bank Areas

Land Use Management - Reduce risk by modifying upland uses, apply where bank and/or shoreline actions are extremely difficult or limited in effectiveness. May include relocating or elevating buildings, driveway relocation, utility relocation, hook up to public sewer/abandon or relocate sanitary drainfields. All new construction should be located 100 feet or more from the top of the bank. Re-direct stormwater runoff away from top of the bank, re-shape or grade along top of the bank only. May also include zoning variance requests for setbacks, relief from other land use restrictions that increase erosion risk.

Forest Management - Enhance the existing forest condition and erosion stabilization services by selectively removing dead, dying and severely leaning trees, pruning branches with weight bearing load over the water, planting or allow for re-generation of mid-story and ground cover vegetation, control invasive upland species introduced by previous clearing.

Enhance/Maintain Riparian Buffer – Preserve existing vegetation located 100 ft or less from top of bank (minimum); selectively remove and prune dead, dying, and severely leaning trees; allow for natural re-generation of small native trees and shrubs.

Enhance Riparian/Marsh Buffer – Vegetation stabilization provided by a blended area of upland riparian and/or tidal marsh vegetation; target area extends from mid-tide to upland area where plants can occupy suitable elevations in dynamic fashion, e.g. seasonal fluctuations, gradual storm recovery; no action may be necessary in some situations; may include existing marsh management; may include planted marsh, sand fill, and/or fiber logs; restore riparian forest buffer where it does not exist; replace waterfront lawns with ornamental grasses, native shrubs and small trees; may include invasive species removal to promote native vegetation growth

Grade Bank - Reduce the steepness of bank slope for wave run-up and to improve growing conditions for vegetation stabilization. Restore riparian-wetland buffer with deep-rooted grasses, perennials, shrubs and small trees, may also include planted tidal marsh. NOTE - The feasibility to grade bank may be limited by upland structures, existing defense structures, adjacent property conditions, and/or dense vegetation providing desirable ecosystem services.

Tidal Wetland – Beach – Shoreline Areas

Enhance/Maintain Marsh – Preserve existing tidal marsh for wave attenuation. Avoid using herbicides near marsh. Encourage both low and high marsh areas, do not mow within 100 ft from top of bank. Remove tidal debris at least annually. Repair storm damaged marsh areas with new planting.

Widen Marsh – Increase width of existing tidal marsh for additional wave attenuation; landward design preferred for sea level rise adjustments; channelward design usually requires sand fill to create suitable elevations.

Widen Marsh/Enhance Buffer – Blended riparian and/or tidal marsh vegetation that includes planted marsh to expand width of existing marsh or create new marsh; may include bank grading, sand fill, and/or fiber logs; replace waterfront lawns with ornamental grasses, native shrubs and small trees.

Plant Marsh with Sill – Existing or planted tidal marsh supported by a low revetment placed offshore from the marsh. The site-specific suitability for stone sill must be determined, including bottom hardness, navigation conflicts, construction access limitations, orientation and available sunlight for marsh plants. If existing marsh is greater than 15 ft wide, consider placing sill just offshore from marsh edge. If existing marsh is less than 15 ft wide or absent, consider bank grading and/or sand fill to increase marsh width and/or elevation.

Enhance/Maintain Beach - Preserve existing wide sand beach if present, allow for dynamic sand movement for protection; tolerate wind-blown sand deposits and dune formation; encourage and plant dune vegetation.

Beach Nourishment - Placement of good quality sand along a beach shoreline to increase the beach width and raise the elevation of the nearshore area; grain size of new sand should be similar to native beach sand

Enhance Riparian/Marsh Buffer OR Beach Nourishment – Increase vegetation stabilization with a blended area of upland riparian and/or tidal marsh vegetation; restore riparian forest buffer where it does not exist; replace waterfront lawns with ornamental grasses, native shrubs and small trees; may include planted marsh, sand fill, and/or fiber logs.

Consider beach nourishment if existing riparian/marsh buffer does not need enhancement or cannot be improved and if additional sand placed on the beach will increase level of protection. Beach nourishment is the placement of good quality sand along a beach shoreline to increase the beach width and raise the elevation of the nearshore area; grain size of new sand should be similar to native beach sand.

Maintain Beach OR Offshore Breakwaters with Beach Nourishment – Preserve existing wide sand beach if present, allow for dynamic sand movement for protection; nourish the beach by placing good quality sand along the beach shoreline that is similar to the native sand.

Use offshore breakwaters with beach nourishment only where additional protection is necessary. These are a series of large rock structures placed strategically offshore to maintain stable pocket beaches between the structures. The wide beaches provide most of the protection, so beach nourishment should be included; periodic beach re-nourishment may be needed. The site-specific suitability for offshore breakwaters with beach nourishment must be determined, seek expert advice.

Groin Field with Beach Nourishment - A series of several groins built parallel to each other along a beach shoreline; established groin fields with wide beaches can be maintained with periodic beach nourishment; repair and replace individual groins as needed.

Revetment - A sloped structure constructed with stone or other material (riprap) placed against the upland bank for erosion protection. The size of a revetment should be dictated by the wave height expected to strike the shoreline. The site-specific suitability for a revetment must be determined, including bank condition, tidal marsh presence, and construction access limitations.

APPENDIX 3

Guidance for Structural Design and Construction in City of Suffolk

For City of Suffolk, three typical cross-sections for stone structures have been developed. The dimensions given for selected slope breaks have a range of values from medium to high energy exposures becoming greater with fetch and storm wave impact. Storm surge frequencies are shown for guidance. A range of the typical cost/foot also is provided (Appendix 3,Table 1). These are strictly for comparison of the cross-sections and do not consider design work, bank grading, access, permits, and other costs. Additional information on structural design considerations are presented in section 3.4 of this report.

Type of Structure	Estimated Cost per Linear Foot*
Low Sill	$150 -$250
High Sill	$250 - $400
Breakwater	$600 - $1,000

Table 1. Approximate typical structure cost per linear foot.

**Based on typical cross-section. Cost includes only rock, sand, plants. It does not include design, permitting, mobilization or demobilization.*

Stone sills are effective management strategies in all fetch exposures where there is shoreline erosion; however, in low energy environments the non-structural shoreline best management practices described in Chapter 3 of this report may provide adequate protection, be less costly, and more ecological beneficial to the environment. Stone revetments in low energy areas, such as creeks, are usually a single layer of armor. In medium to high wave energy shores, the structure should become a more engineered coastal structure. In the lower fetch areas of Suffolk, a low sill might be appropriate (Appendix 3, Figure 1). Along medium energy shores or where there is nearby upland infrastructure, a high sill would be better (Appendix 3, Figure 2). Using sills on the open river should be carefully considered due to severity of storm wave attack.

Breakwater systems are applicable management strategies along much of the Suffolk's James River and Hampton Roads coast and other areas with a medium to high energy shores. The actual planform design is dependent on numerous factors and should be developed by a professional. However, a typical breakwater tombolo and embayment cross-section is provided to help determine approximate system cost (Appendix 3, Figure 3).

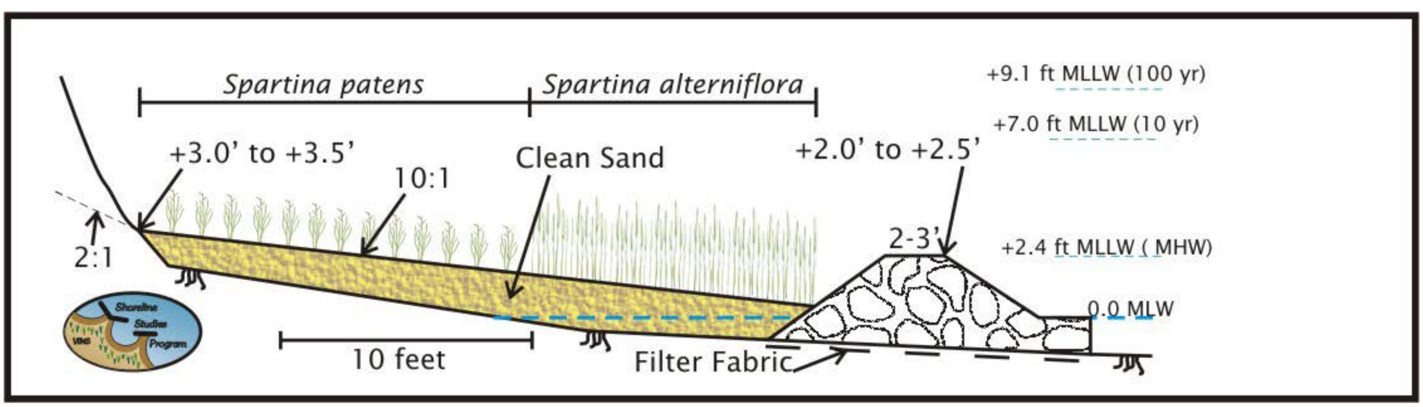


Figure 1. *Typical cross-section for a low sill that is appropriate for low to medium energy shorelines of City of Suffolk. The project utilizes clean sand on an 10:1 (H:V) slope, and the bank can be graded to a (minimum) 2:1slope, if appropriate.*

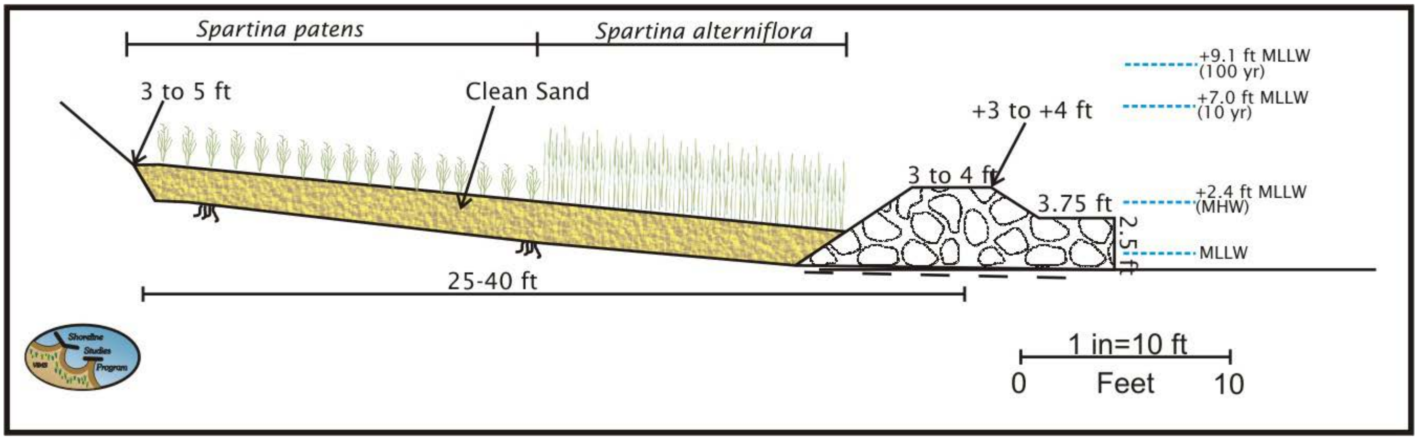


Figure 2. *Typical cross-section for a high sill that is appropriate for the medium to high energy shorelines of City of Suffolk. The project utilizes clean sand on an 10:1 (H:V) slope.*

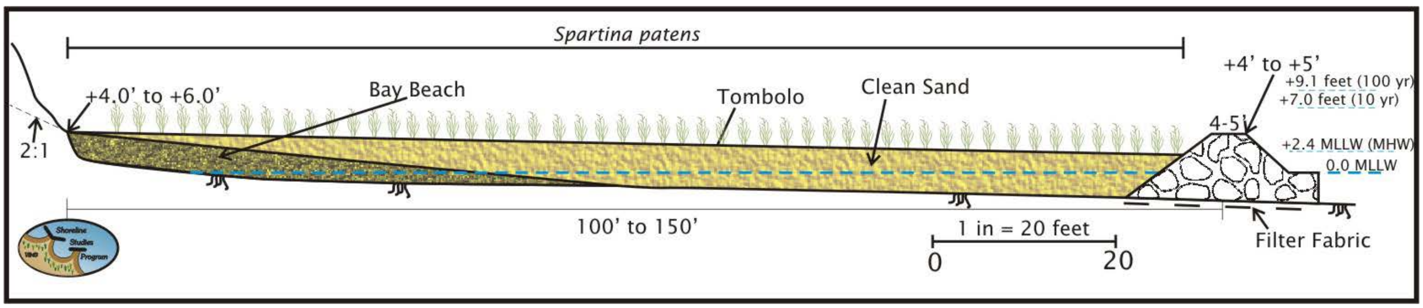


Figure 3. *Typical cross-section for a breakwater system that is appropriate for the medium to high energy shorelines of City of Suffolk. Shown is the cross-section for the tombolo and rock structure. In addition, the typical cross-section for the bay beach between the structures is superimposed in a slightly different color. Note: the beach material is the same for the two cross-sections.*