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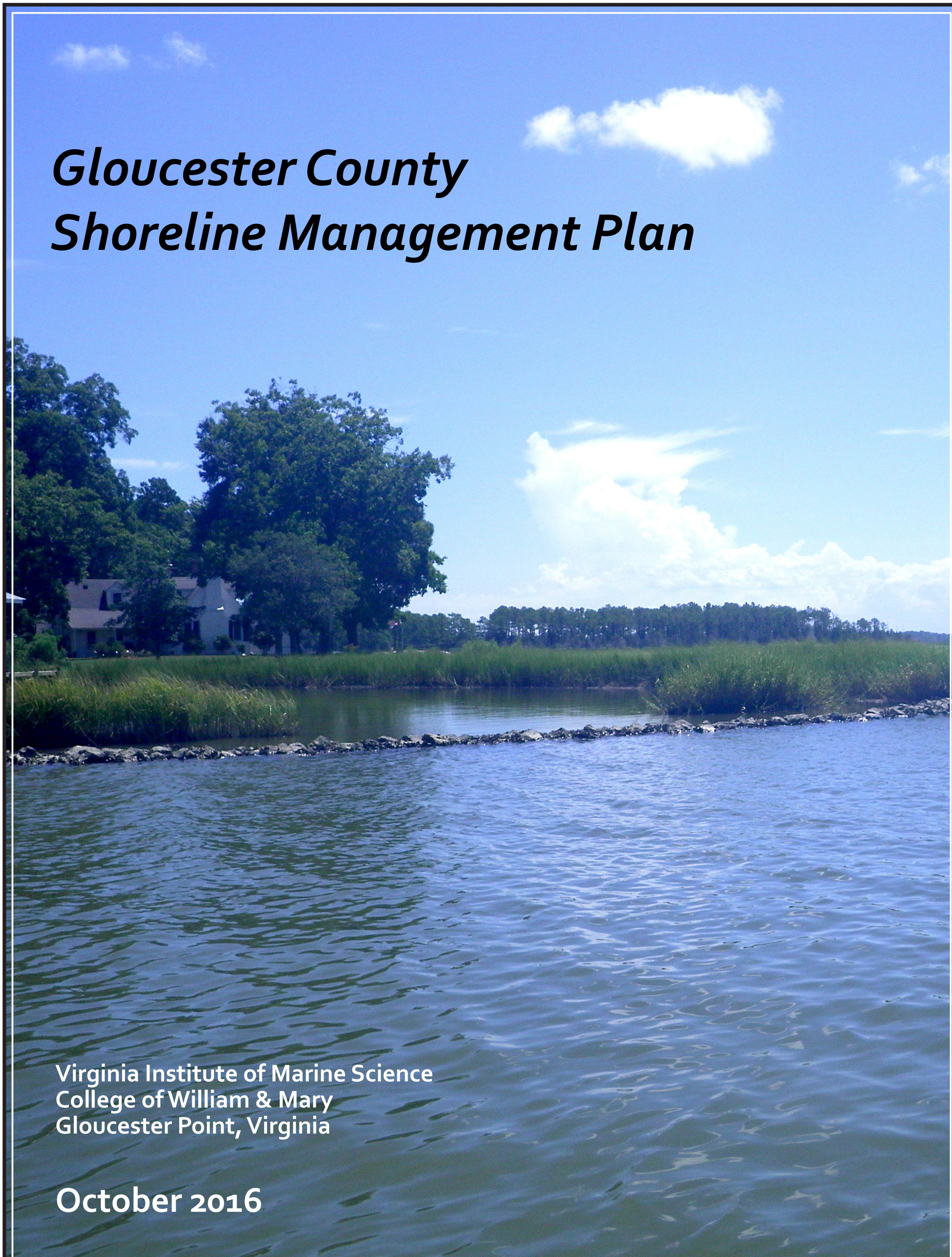

Gloucester County Shoreline Management Plan

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

October 2016

Gloucester County
Shoreline Management Plan

Prepared for
Gloucester County and
Virginia Coastal Zone Management Program

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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. Preserving its natural environment is a local priority particularly in regard to future development considerations (Gloucester County, 2016). The shores of Gloucester range from exposed open-river to very sheltered creeks, and the nature of shoreline change varies accordingly (Figure 1-1). This shoreline management plan is useful for evaluating and planning shoreline management strategies appropriate for all the creeks and rivers of Gloucester. It ties the physical and hydrodynamic elements of tidal shorelines to the various shoreline protection strategies.

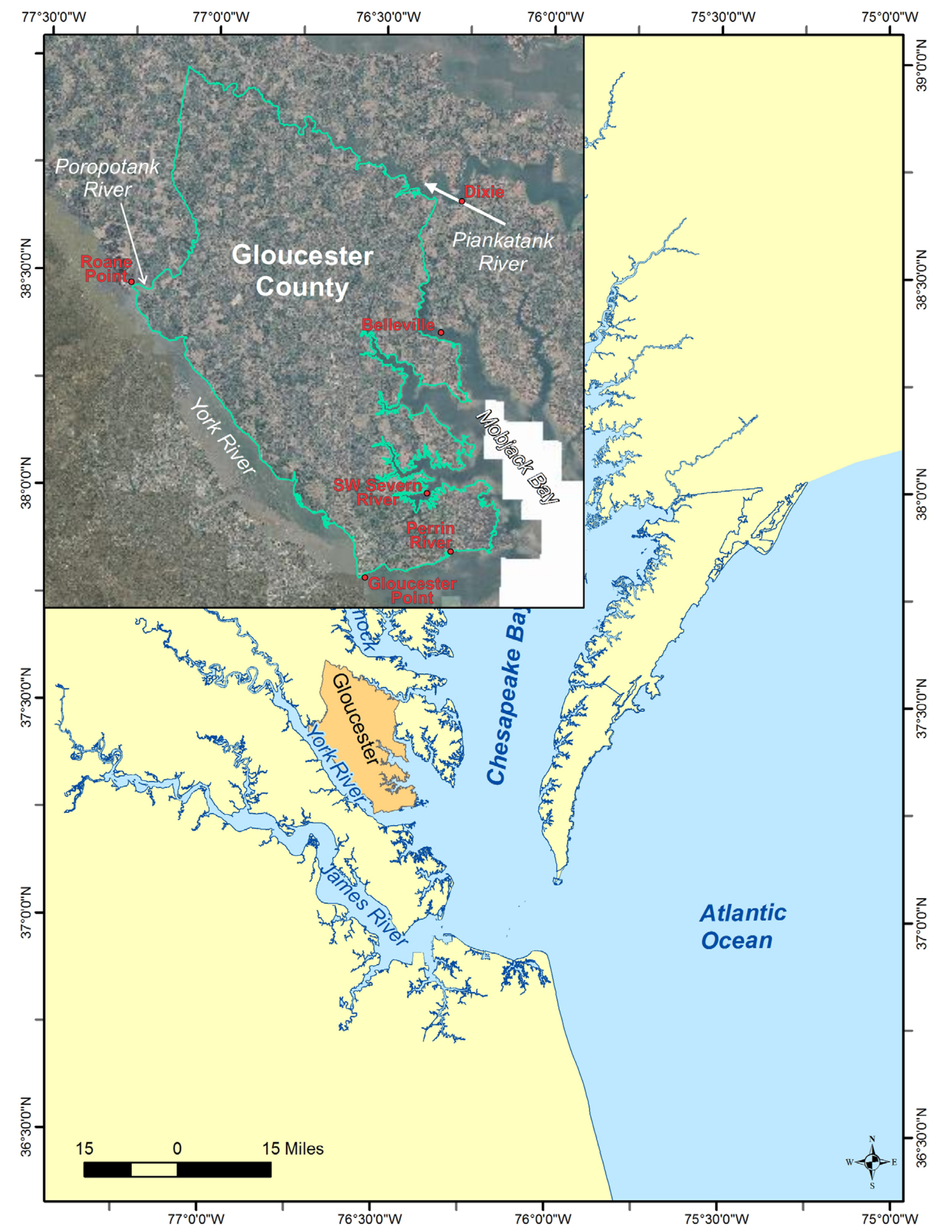


Figure 1-1. Location of Gloucester County within the Chesapeake Bay estuarine system. Tide prediction stations locations depicted in red.

Much of the Gloucester County'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 (leg1.state.va.us/cgi-bin/legp504.exe?111+ful+CHAP0885+pdf). The 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 Gloucester County Shoreline Management Plan is an educational and management reference for the County and its landholders.

2 Coastal Setting

2.1 Geology/Geomorphology

2.1.1 Geology

Gloucester County lies in the coastal plain of Virginia. Like many coastal localities, the County boundaries are defined by creeks, rivers, and watersheds. It is bounded along the Poropotank River on the west, the York River on the south, Mobjack Bay on the east, and Piankatank River on the north (Figure 1-1). Gloucester County has more than 600 miles of shoreline along these three rivers. Gloucester County occupies the southeast portion of what is called the Middle Peninsula .The topography is defined by the underlying geology which in turn controls the geomorphology of the County.

The geologic units along the county's tidal shorelines range from recent Holocene sediments of soft muds and marsh to Upper Pliocene and Lower Miocene strata intermittently exposed on high banks along the York River. The base of the exposed banks on the York River consist of the Yorktown Formation (Tc) which is part of the Chesapeake Group and is overlain by the Shirley Formation (Figure 2-1). The Yorktown Formation of Lower Pliocene age is rich in shallow marine fossils including large shark's teeth, whale vertebrae and numerous mollusks, of which the large scallop, Chesapecten jeffersonius, is the state fossil. These strata were once exposed both up and downriver of Gloucester Point, but subsequent shoreline hardening has covered these. Today, the coastal morphology of Gloucester County is a reflection of these ancient processes, and the varying bank heights along the coast are a result. Erosion of these geologic units contributes to the sedimentary character of material supplied to the littoral system.

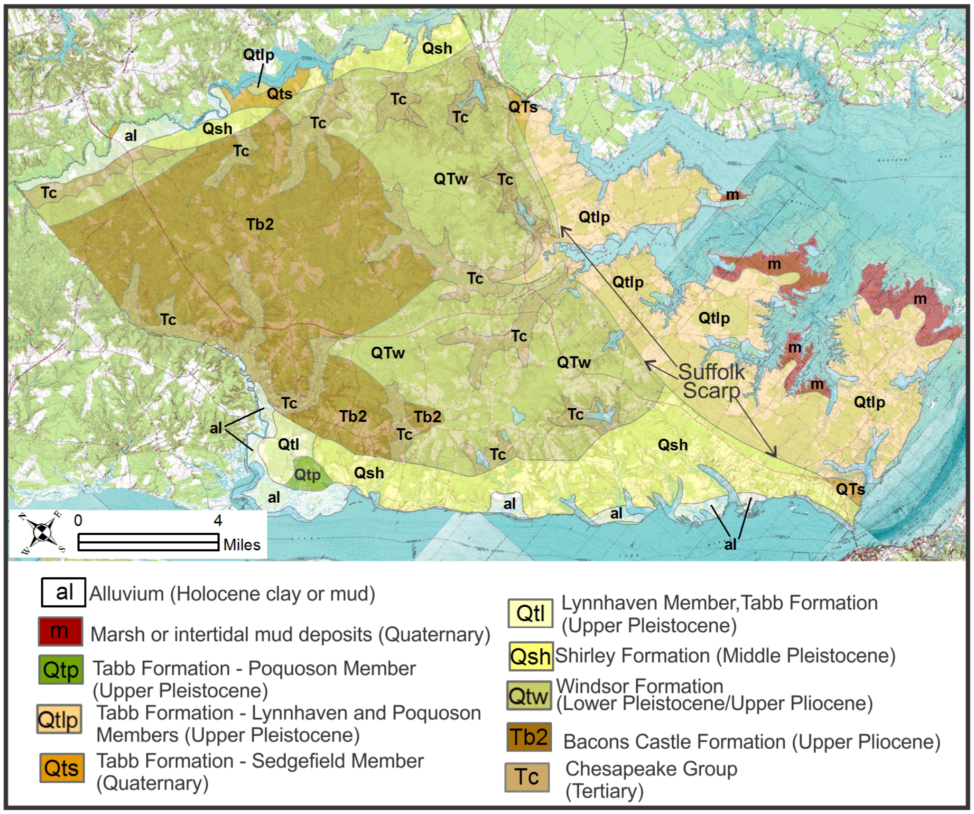


Figure 2-1. *Geology of Gloucester County (Mixon* et al.*, 1989).*

Extensive deposition of shallow marine sediments over three oceanic transgressions formed the Yorktown Formation (Cronin *et al.*, 1984). As sea levels receded, the coastal plain drainages were deeply incised into the Yorktown strata. Subsequent oceanic transgressions extended landward progressively less across the Virginia coastal plain and resulted in deposition of sediments eroded from older strata with unconformities between each formation. In Gloucester County, these include the Windsor Formation (Qtw), the Shirley Formation (Qsh), the Tabb Formation (Lynnhaven (Qtl), Poquoson (Qtp) and Sedgefield (Qts) Members), and the more recent Holocene marsh (m) and alluvium sediments (al) (Figure 2-1).

These riverine and estuarine sediments have been deposited in successive high stands which lie unconformably on each other and which overlie older Pliocene formations. The surficial geology of the shoreline banks include strata from Lower Pleistocene to Upper Pleistocene strata with Holocene marshes occupying secondary tidal creeks. Typically, the older strata are at higher elevations which decrease through time with each successive marine transgression. Therefore, the sediments differ in each strata graphic unit and provide different amounts of gravel, sand, silt, and clay to the littoral system through shoreline erosion.

The coastal morphology, topography, and hydrology of Gloucester County are seen in Figures 2-2, 2-3, and 2-4. Much of the western boundary of Gloucester County is defined by the Poropotank River which narrowly meanders southwestward until it widens in Morris and Poropotank Bays before entering the York River. The York River shoreline of Gloucester County is a relatively straight coast with numerous small lateral tidal creeks. The York River is about 1.7 miles wide at the Poropotank, widening to about 2.3 miles at Carter Creek and then pinching down to about 0.5 miles at Gloucester Point where the Suffolk Scarp intersects and outcrops (Figure 2-2).

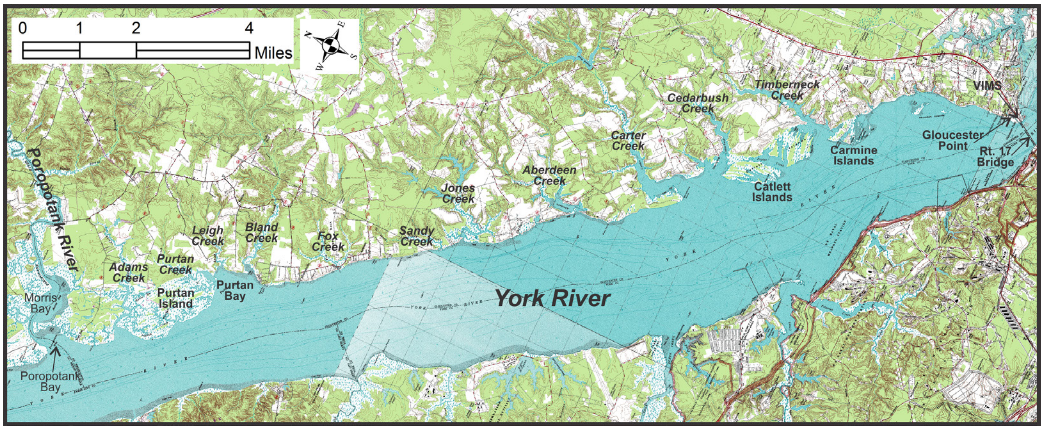


Figure 2-2. *Topographic sheet of the York River section in Gloucester County designated as Reach 1 in this report.*

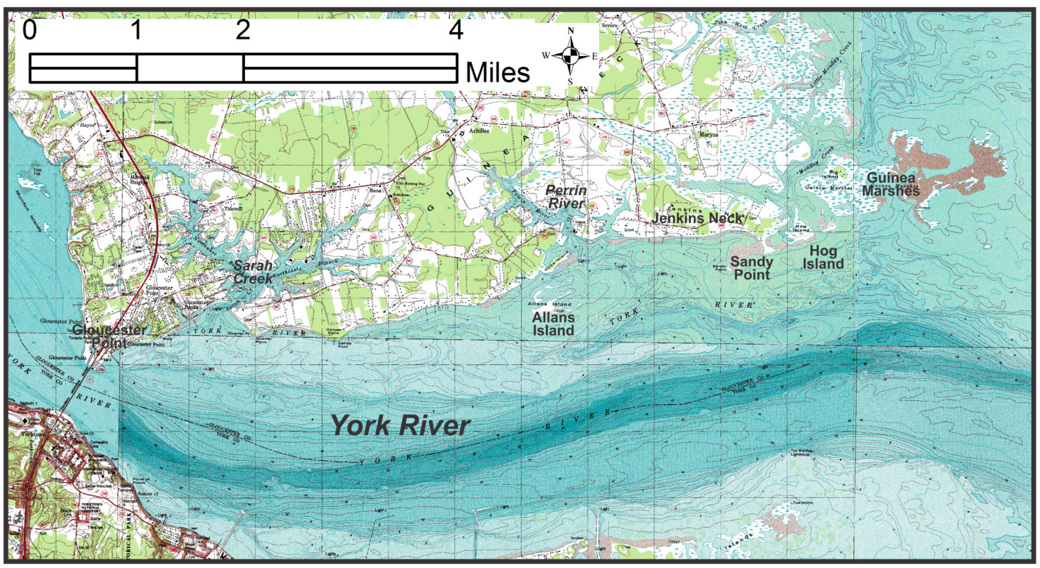


Figure 2-3. *Topographic sheet of the York River section of Gloucester County designated as Reach 2 in this report.*

At Gloucester Point, the York River quickly widens to about 2.5 miles and the Gloucester shoreline have greater fetch exposures to the east of over 25 miles across Chesapeake Bay (Figure 2-3). The Gloucester County shoreline extends easterly to the Guinea Marshes then northward into and along Mobjack Bay (Figure 2-4). Broad marsh shorelines buffer the low upland of Guinea Neck and Robbins Neck. Wide nearshore shoals occur off these marsh complexes, home of thick beds of submerged aquatic vegetation (SAV). The tidal river watersheds of the Severn, Ware, and North Rivers mostly occupy the low upland region east of the Suffolk Scarp.

Gloucester shoreline on the Piankatank River extends from just upriver of Holland Point upriver to past Route 17 (Figure 2-5). The main estuarine trunk stops at about where Carver Creek enters on the Gloucester County side, about 6.5 miles from Holland Point.

2.1.2 Shoreline Morphology

Today's coastal morphology/landscape is a function of the underlying geologic history. All of Gloucester's river shorelines are tidal. The County's shoreline can be divided into four reaches for ease of discussion (Figures 2-2, 2-3, 2-4, and 2-5). These reaches are defined based on shore morphology and drainage patterns. Reach 1 is on the York River from Gloucester Point north to the county line along the Poropotank River. Reach 2 extends from Gloucester Point east to the mouth of Mobjack Bay. The third reach covers Mobjack Bay and its tributaries, while the fourth reach is on the Piankatank River. The Suffolk Scarp is a significant geomorphic feature that represents the ocean coast position during a previous high stand in sea level. It runs generally south to north from Gloucester Point along Route 17 and then along Route 14 to James Store where it continues northward (Figure 2-4). Shorelines east of the Suffolk Scarp are generally very low and easily flooded whereas shorelines west of the scarp are higher.

Reach 1 extends from the Poropotank River, the border between King and Queen and Gloucester Counties, and heads south along the north shore of the York River to Gloucester Point (Figure 2-2). Fetches are generally one to three miles across the York River and less than one mile up the laterally flowing small tidal creeks. The Reach has an average long-term erosion rate of -0.9 ft/yr (Table 2-1) with higher rates recorded at Jones Creek and Catlett Islands. Both have erosion rates from -2 to -5 ft/yr (Milligan *et*

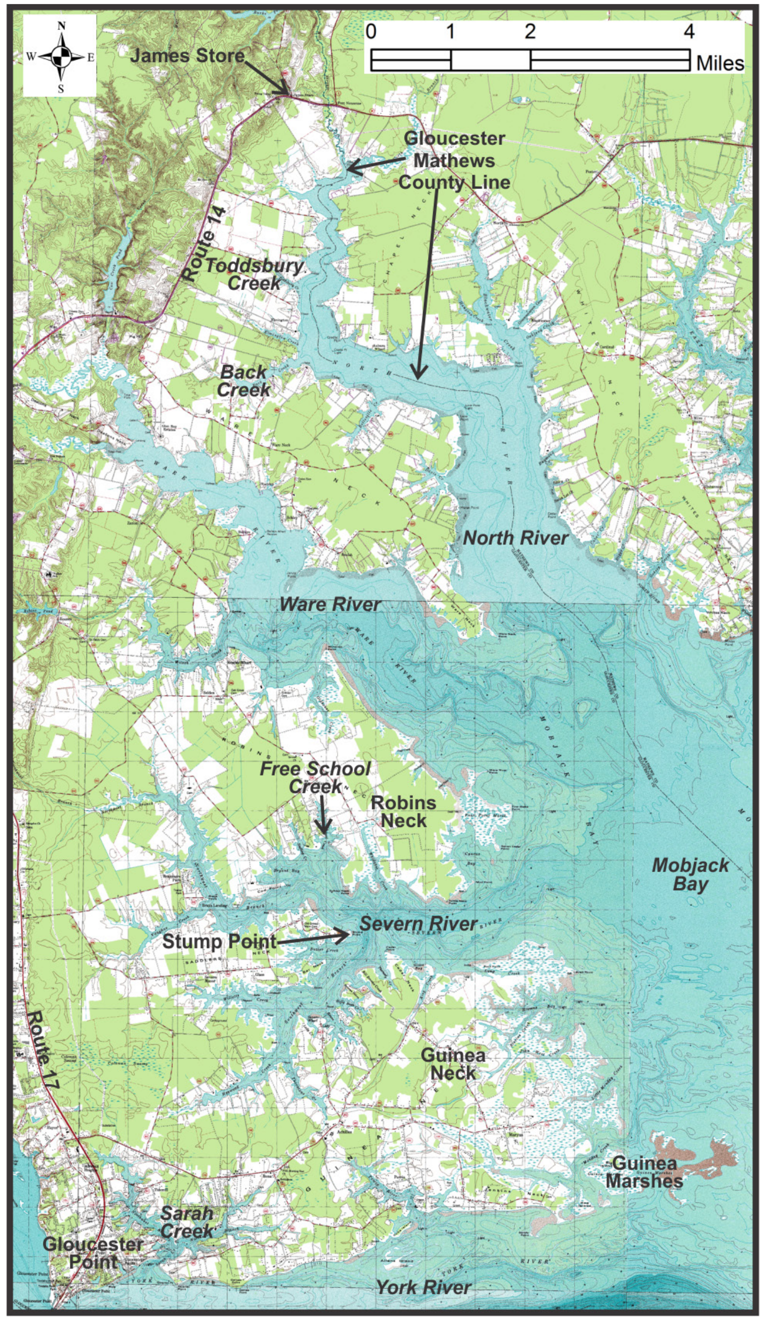


Figure 2-4. *Topographic sheet of the Mobjack Bay of Gloucester County designated as Reach 3 in this report.*

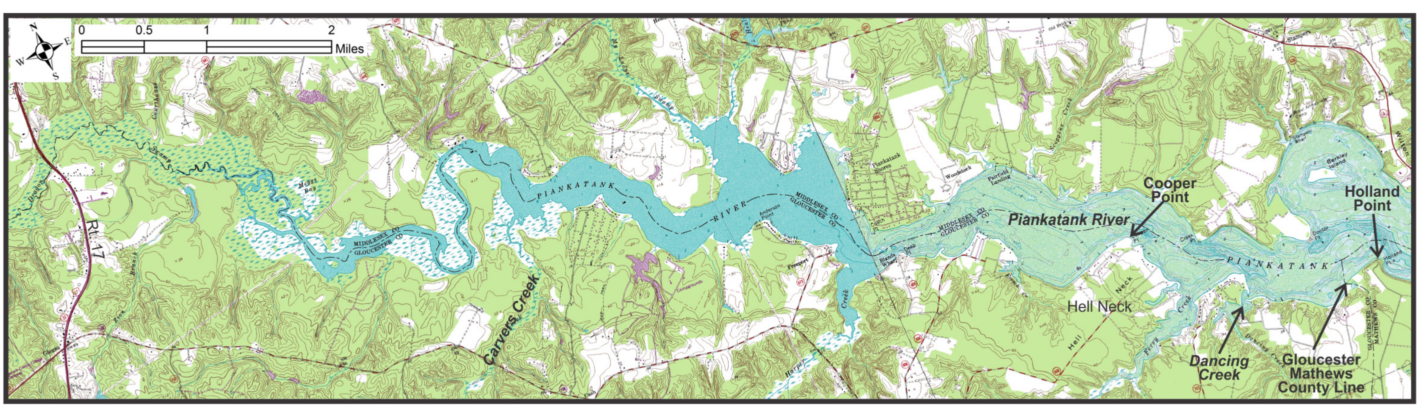


Figure 2-5. *Reach 1 Bing map of the most upriver section of the Chickahominy in James City County.*

Reach Name	Average EPR (ft/yr)	Category
Reach 1: York River North from Gloucester Point	-0.9	Very Low Erosion
Reach 2: York River East from Gloucester To mouth of Mobjack Bay	-0.8	Very Low Erosion
Reach 3: Mobjack Bay and its Tributaries	-0.8	Very Low Erosion
Reach 4: Piankatank River	-0.5	Very Low Erosion

Table 2-1. *Average end point rate of change (1937-2009) for Gloucester County's shoreline. The rates of change are given in feet per year. From Milligan* et al., *(2010).*

al., 2010). Breakwaters were installed at Fox Creek producing a long-term change of +1 to +5 ft/yr (Milligan *et al*., 2010). Along the shore breakwaters and piers result in man-made accretion with the rate of up to +5 ft/yr.

The upper reaches of the Poropatank River occur as a series of meanders with tidal marsh occupying the outside meanders in front of undeveloped, wooded upland banks. The meanders are relatively tight near the headwaters but become more widely spaced toward Morris Bay and the mouth where most of the shoreline is wide marsh. The coastal processes are mostly tidally dominated with very short fetch exposures across to the river. Although erosion rates are very low, landowners have addressed exposed banks by bulkheading the shoreline (Figure 2-6).

At the confluence of the Poropotank and the York River, the marsh shoreline fronting low uplands continues downriver, up Adams Creek, and across Purtan Island (Figure 2-7). With the increased fetch across the York River, shoreline erosion increases dominated by wind driven wave action and the shoreline quickly transitions to actively eroding upland banks (Figure 2-8). For about 2,000 feet downriver of Bland Creek, the mostly 25 foot high upland banks include several residential communities. These shoreline are mostly hardened with bulkheads and revetments. Several breakwater installations also occur along this reach including one at the mouth of Fox Creek (Figure 2-9).

Figure 2-6. *Low bank and bulkheading on the Poropotank River.*

Figure 2-7. *Low, wide marsh shoreline along Gloucester's upper York River.*

Figure 2-8. *Low eroding banks in Purtan Bay.*

Upland banks decrease in elevation from 10 feet to less than 5 feet adjacent to Sandy Creek and Jones Creek along with their marsh shorelines. Again many residential properties have protected their shorelines with breakwaters. The neck of land between Jones Creek and Aberdeen Creek is an old wharf and landing that has low developed upland banks and hardened coast. The uplands rise downriver to over 10 feet and become residential with hardened shorelines toward Aberdeen Creek (Figure 2-10). A small breakwater system resides at the mouth of Aberdeen Creek which has helped maintain a navigation channel. Farther downriver between Aberdeen Creek and Carter Creek developed upland banks are 15 to 20 feet high and are hardened.

Figure 2-9. *Breakwaters at Fox Creek in Gloucester County.*

Figure 2-10. *Eroding upland banks with residential properties on Gloucester's York River that have been hardened with bulkheads and revetments.*

Carter Creek is mostly stable wooded upland banks with marsh fringe of varying widths and very little development. Cedar Bush Creek is more developed with exposed uplands protected mostly by revetments and bulkheads. An oyster bag sill was recently installed with some sand fill as an alternate to shoreline hardening (Figure 2-11). From the mouth of Cedarbush Creek to Timberneck Creek are the Catlett Islands, which are low undeveloped marsh and upland cheniers that are actively eroding on the York River side. These islands are part of the National Estuarine Research Reserve program.

Just inside Timberneck Creek, on the west coast, the upland rises to 25 feet where a large development is under construction. The rest of Timberneck Creek is high upland banks intermittently exposed as overhanging trees shade narrow marsh fringes, but development is limited. From the Timberneck Creek south along the York River to Gloucester Point the upland shoreline increases in elevation from 5 feet to 10 to 20 feet and to over 30 feet.

Figure 2-11. *Eroding upland banks protected with a recently-installed oyster bag sill.*

The shoreline also becomes increasingly developed with consequent shoreline hardening toward Gloucester Point. In addition, six small breakwater installations exist. Closer to Gloucester Point, a series of 15 breakwaters exist and include three large breakwaters at the Virginia Institute of Marine Science (VIMS) (Figure 2-12). Gloucester Point and the Route 17 Bridge mark the end of Reach 1 and the beginning of Reach 2.

Figure 2-12. *Google Earth map showing the breakwaters along the York River at Gloucester Point.*

Reach 2 extends from Gloucester Point to the Guinea Marshes at the mouth of the Mobjack Bay and has an average long-term erosion rate of -0.8 ft/yr (Table 2-1). Most of this reach is eroding to varying degrees except for the shore area east along Gloucester Point where accretion rates are minimal and range from -1 to 0 ft/yr. However a moderate number of sites along the York River are eroding at a much faster rate, anywhere from -2 to -8 ft/yr such as at Sandy Point and Hog Island (Figure 2-3). Accretion occurred along this Reach at sites where man-made structures were installed.

Much of the shoreline along Reach 2 is low with upland elevations decreasing toward the mouth of the York River, eventually becoming only 5 feet above sea level. The shorelines are easily flooded and exposed to long fetch exposures to the east and southeast across and down Chesapeake Bay. In 2010, VIMS installed two breakwater systems, one on its west coast looking up the York River (Reach 1) and one on the east coast looking east down the York River and across Chesapeake Bay (Reach 2) (Figure 2-12). This is an engineered breakwater system designed and constructed for long-term shore protection and beach stability. Wetland plant communities were established across the stable backshore with high marsh species and behind breakwater units with low marsh (intertidal) species.

From VIMS downriver to Sarah Creek, the high upland banks have been developed and hardened with bulkheads and revetments. However, a breakwater system has been installed along this reach, and near the mouth of Sarah Creek, a gabion breakwater system still persists after over 20 years Here the Suffolk Scarp intersects the shoreline (Figure 2-1). Sarah Creek shorelines are upland banks ranging from 5-15 feet on along the Northwest Branch. The shorelines are mostly developed with a few open areas with narrow marsh fringes and exposed banks. Those residential properties are often hardened with bulkheads and revetments (Figure 2-13). Two marinas also reside in Sarah Creek, Yacht Haven and Jordan Marine, and community docks are located along Dockside Condominiums. Tidemill Road crosses the upper reach of the Northwest Branch where concrete filled bags are used to secure the base of the approach

Figure 2-13. *Shoreline hardening in the low fetch environment of Sarah Creek.*

banks to the bridge; these are slowly deteriorating. This bridge prevents sailboats from traveling to those upper reaches of the creek, and residential development is less than the down creek coasts.

Two seafood docks occur along the Northeast Branch of Sarah Creek, and much of the shoreline is residential. Exposed uplands are hardened with bulkheads and revetments. Existing marsh fringes provides some erosion control and reduces the need to harden to shore. As is often the case up sheltered tidal creeks, over-hanging trees will shade out the marsh causing the landowner to harden the bank.

The shoreline east of Sarah Creek to the Perrin River has been protected by a combination of bulkheads, groins, and revetments over the years. Along this shoreline, a narrow beach is protected with short groins in front of a bulkhead. In order to better hold the sand, "T"-heads are used on the groins (Figure 2-14). The shoreline farther east in the lee of Allans Island is relatively stable since the Island offers from storm waves up the York allowing marsh fringe to remain intact.

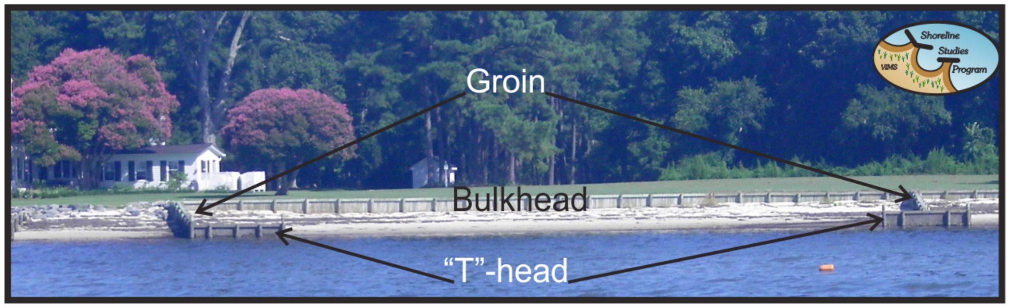


Figure 2-14. *The use of "T"-head groins in Sarah Creek.*

There is one marina, two seafood facilities, and a small boat works up the Perrin River while the rest of the shoreline is mostly residential with little shore hardening except at the mouth. From the mouth of the Perrin, eastward along Jenkins Neck and downriver to the Guinea Marshes, this shoreline was severely impacted by Hurricane Isabel's flooding and wave action in 2003. Since then residential development has increased with existing and new waterfront homes being elevated along with shoreline hardening (Figure 2-15).

Figure 2-15. *Raised houses and shore protection along shorelines that have been significantly impacted by storms.*

Reach 3 extends from the mouth of Mobjack Bay to the North River and includes all the Mobjack shoreline along Guinea Neck, Robbins Neck and Ware Neck as well as the shoreline along the Severn River and Ware River tidal systems. Also included is the western shoreline of the North River. This Reach has an average long-term erosion rate of -0.8 ft/yr. (Table 2-1). However a moderate number of sites along Mobjack Bay were eroding at a much faster rate, anywhere from -2 to -8 ft/yr (Milligan *et al*., 2010). Those sites tend to be marsh points along the open areas of Mobjack Bay including Guinea Neck and Robins Neck. Accretion had occurred along this Reach at sites where man-made structures were installed such as along the south bank of the Ware River.

The drainages for the rivers that feed into Mobjack Bay are limited on their upriver ends by the Suffolk Scarp which generally runs coincident with Routes 17 and 14 in this area (Figure 2-4). The Mobjack Bay shorelines of Guinea Neck and Robbins Neck are broad tidal marsh complexes. These transition up the Severn and Ware Rivers to marsh fringes bordering very low upland banks. The banks get slightly higher toward the upper reaches of the Ware and North Rivers.

The Guinea Marshes mark the confluence of the York River and Mobjack Bay. The marshes extend up the Mobjack Bay coast to the mouth of the Severn River. These wide marsh complexes front the low

Figure 2-16. *Eroding Guinea Marshes at the confluence of the York River and Mobjack Bay.*

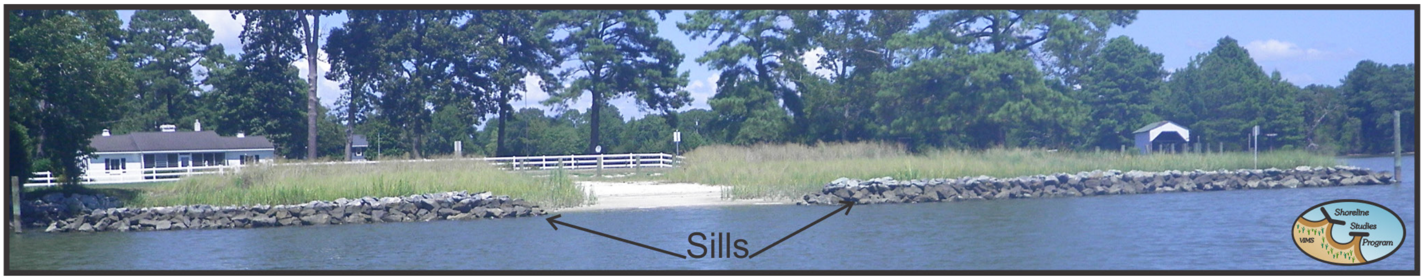


Figure 2-17. *Living Shoreline sills at Jones Wharf on Free School Creek.*

uplands of Guinea (Figure 2-16). There is no residential devolvement along Guinea Neck's shoreline on Mobjack Bay. The Severn River separates at Stump Point into the Southwest Branch and Northwest Branch. Two marinas and some residential development occurs along the Severn River. Shoreline hardening is usually limited to the more exposed low uplands. Just inside Free School Creek is Jones Wharf, a public landing where a shoreline demonstration consisting of rock and oyster bag sills with wetlands plantings and canoe beach was built (Figure 2-17).

The wide marsh along Mobjack Bay shoreline at Robins Neck contains the ubiquitous "ghost forests" which is evidence of rising sea level and the marsh transitioning the low upland (Figure 2-18). Farther north on Robins Neck, the marsh narrows and a low upland section occurs with a small residential section that has been mostly hardened with rock. The Ware River shorelines are mainly residential with some open land. The shorelines are generally protected with bulkheads, revetments, groins,

The county line with Mathews County is down the middle of the North River so only the south and west shorelines are in Gloucester County. At the mouth of the North River, the shoreline has a very low bank with a mix of raised and houses that have not been raised. However, the shoreline is protected with a breakwater system (Figure 2-19). Most of the North River shoreline is similar. Low residential properties protected by revetments, sills, and breakwaters. The North River turns at Back Creek, and the shoreline becomes more exposed to the east down the North River causing marsh fringe erosion and resultant shore protection, mostly with rock (Figure 2-20). North of Toddsbury Creek, the North River becomes a wide meander,

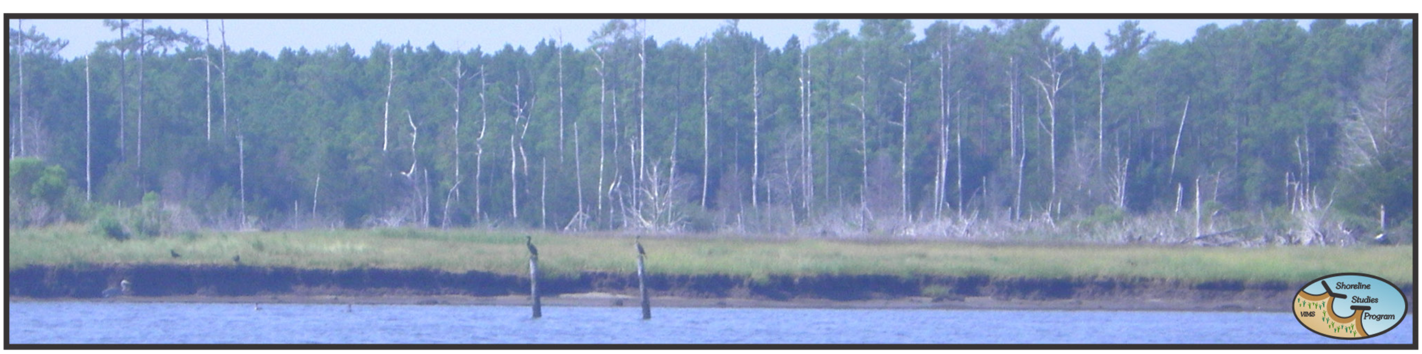


Figure 2-18. *Ghost forest along Jenkins Neck in Mobjack Bay.*

Figure 2-19. *North River residential properties with a low bank and breakwaters for shore protection.*

Figure 2-20. *Low upland residential properties on the North River with eroding marsh fringe and sill for shore protection.*

indicative of the transgressive rise in sea level, flooding the ancestral fluvial like watershed. The points and embayments along the coast are old point bars and meanders created when sea level was much lower. The shoreline continues as low upland banks with eroding marsh fringe and intermittent shore protection.

Reach 4 extends along the south bank of the Piankatank River from west of Holland Point to the River's headwaters (Figure 2-5). It has an average long-term erosion rate of -0.5 ft/yr and is relatively fetch-limited. The shoreline begins as an embayed vegetated stable high bank shoreline with a narrow beach (Figure 2-21). West of Dancing Creek, the upland elevation drops down to about 5-7 feet high. This reach of shoreline is mostly residential properties with various types of shoreline hardening such as revetments and bulkheads (Figure 2-22). The Hell Neck coast and those shorelines farther north have both high and low banks that are intermittently developed and hardened. The wider Piankatank River shoreline eventually becomes marsh dominated with a narrow channel.

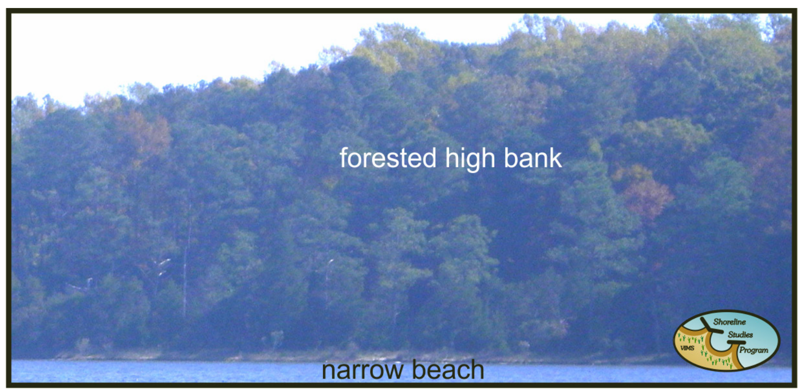


Figure 2-21. *Forested high bank with narrow beach along the Piankatank River.*

Figure 2-22. *Low residential properties along the Piankatank River.*

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 occur from late fall to early spring (Hardaway and Byrne, 1999).

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;

Boat and ship wakes may also contribute to shoreline erosion along this shoreline. Major shipping channel occur in the York River. However, their impact has not been quantified and are likely very site specific.

Basco and Shin (1993) described the wave climate along Gloucester Shoreline 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. Wave heights on the York River are delineated in four sections (Figure 2-23). From the Poropotank River to Cowpen Neck, the wave height is 2.5 feet with 3.0 second period. From Cowpen Neck to Cedarbush Creek, the wave height changes to 3.5 feet with a 3.7 second period. From Cedarbush Creek to Gloucester Point, the wave height is 4.0 feet with 3.9 second period and from Gloucester Point to the mouth of Mobjack Bay, it is 5.0 feet with a 4.5 second period. In Mobjack Bay, waves 5.5 feet high with a 4.7 second period could be expected. The mouth of the Piankatank River has a 5.0 foot wave height with 4.5 second period, but the change in wave conditions was not determined farther up the River along the Gloucester County shoreline.

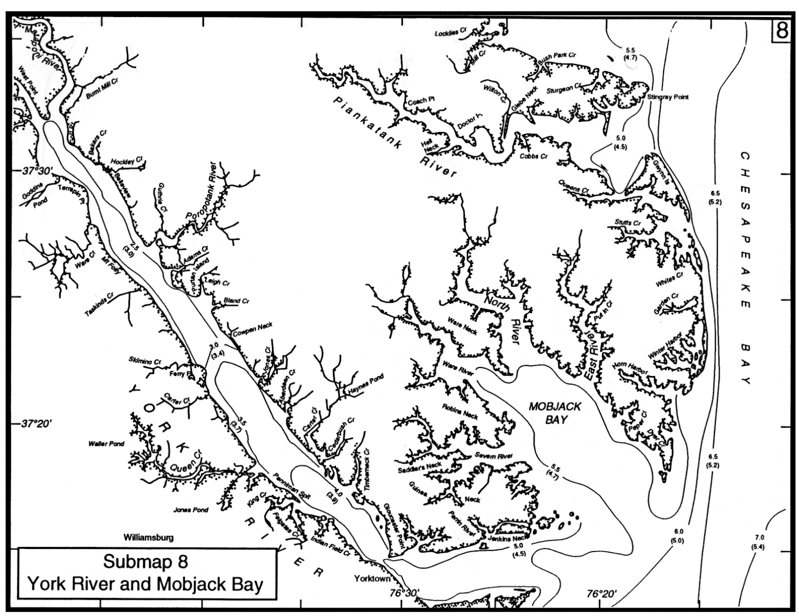


Figure 2-23. Wave climate map for the York River, Mobjack Bay and Piankatank River (from Basco and Shin, 1993).

Storm surge frequencies described by FEMA (2007) are shown in Table 2-2. The table shows the 10%, 2% 1% and 0.2% chances of water levels attaining these elevations for any given year along Gloucester County's shoreline. The storm surges for the entire shoreline are 5.5 MLLW; 7 MLLW; 7.8 MLLW and 9.8 MLLW.

Location	Annual Chance (feet MLLW)			
	10%	2%	1%	0.2%
Chesapeake Bay – Entire Shoreline	5.5	7	7.8	9.8

Table 2-2. *10 year, 50 year, 100 year, and 500 year storm predicted flood levels relative to MLLW (1983-2001). Source: Gloucester County Flood Report, FEMA (2010). Converted from NAVD88 using NOAA's online program VDATUM.*

Tide ranges vary along the Gloucester County shoreline (Table 2-3). The mean tide range is lowest on the Piankatank River at 1.3 feet. The York River and Mobjack Bay have higher tide ranges with the maximum predicted tidal range in Gloucester County at 2.5 feet.

Location	Tide Station	Mean Range (ft)	Spring Range (ft)
Perrin River	Perrin	2.3	2.8
York River	Gloucester Point	2.4	2.9
York River	Roane Point	1.9	2.3
Piankatank River	Dixie	1.3	1.6
Mobjack Bay	Belleville	2.5	3.0
Mobjack Bay	Browns Bay	2.4	2.9
Southwest Branch, Severn	Severn River	2.5	3.0

Table 2-3. *Tide Range in Gloucester County (from NOAA Tides and Currents Website, 2016).*

2.2.2 Sea-Level Rise

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. While trends have not been determined throughout Gloucester County, the recent trend based on wave gauge data at Gloucester Point on the York River shows the annual rate to be 1.25 feet/100 years (3.81 mm/yr). Boon (2012) predicted future sea-level rise by 2050 using tide gauge data from the East Coast of the U.S. Gloucester Point has a projected sea-level rise of 2.29 feet (0.70 m +/- 0.21m) 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, and tidal currents, in some cases, boat wakes and shoreline hardening. Table 2-1 shows the average historical shoreline rates of change for the reaches described in this report throughout the County. Overall, the erosion is very low in most sections of Gloucester County. The York River shoreline is more exposed, and overall has a greater rate of erosion than the shorelines in Mobjack Bay and along the Piankatank River. Individual areas, particularly headlands or points of land have slightly larger rates of change. More detailed shoreline change information can be found in Milligan *et al*., 2010.

Typically, when shorelines exhibit erosion, property owners have tended to harden the shoreline. Over the last 50-60 years, shoreline hardening has been the most common management solution to shoreline erosion. 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. While some areas in Gloucester County have installed living shorelines to address shore erosion control, it is important to manage the unprotected, eroding shorelines in an environmentally-friendly way.

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 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	Enhance Riparian/Marsh Buffer
Area of Special Concern	Enhance Riparian/Marsh Buffer OR Beach Nourishment
Enhance Riparian/Marsh Buffer	Enhance/Maintain Beach
Forest Management	Enhance/Maintain Marsh
Grade Bank	Enhance Riparian/Riparian Buffer
Land Use Management	Maintain Beach OR Offshore Breakwaters with Beach Nourishment
	Plant Marsh with Sill
	Revetment
	Widen Marsh
	Widen Marsh/Enhance Buffer

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.

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

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.

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

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

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).

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.*

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 drain fields, or hook-up to public sewer. All new construction should be located 100 feet or more from the top of the bank. Re-directing storm water 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 Gloucester, 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 two 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.

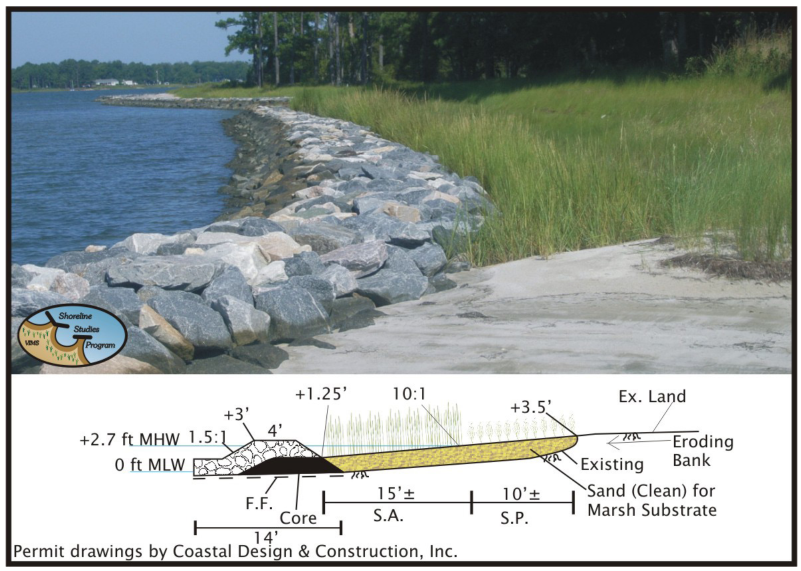


Figure 3-5. *Sand fill with stone sills and marsh plantings shown six years after installation and the cross-section used for construction (From Hardaway* et al., *2010).*

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 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.

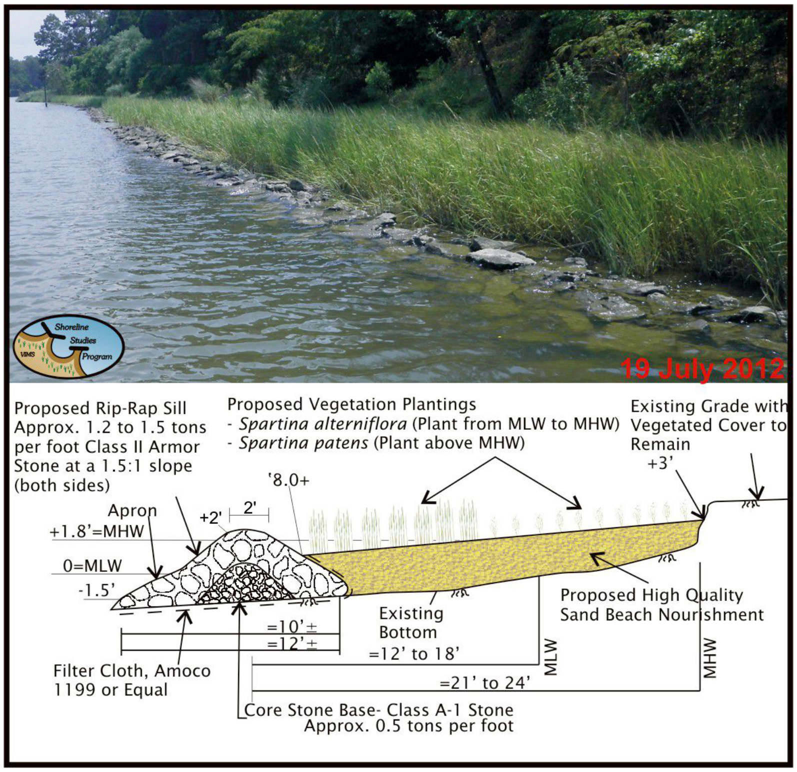


Figure 3-6. *Longwood University's Hull Springs Farm four years after construction and the cross-section used for construction (from Hardaway* et al.*, 2010).*

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 3-7). 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.

3.4.3 Headland Control

Headland Control is a unique shoreline management technique whereby existing geomorphic features (i.e. headlands) are enhanced breakwaters or sills. Headland Control also can include placing stone breakwaters or sills are strategically place along eroding coasts to create headlands (Figure 3-8). These enhanced or created shore headlands are widely-spaced for economy. The adjacent coasts are allowed to continue to erode toward an equilibrium shore position or planform. The final equilibrium planform is a large pocket beach whose dimensions will depend on the amount of sand that will come to reside in the evolving embayment. Sand often is placed directly behind the created headland during construction and then vegetated. Headland control is applied to long reaches of agricultural or unmanaged woodland shores to begin the process of shore stabilization.

Figure 3-7. *Breakwaters at VIMS designed to provide a wide beach for storm erosion protection at the campus.*

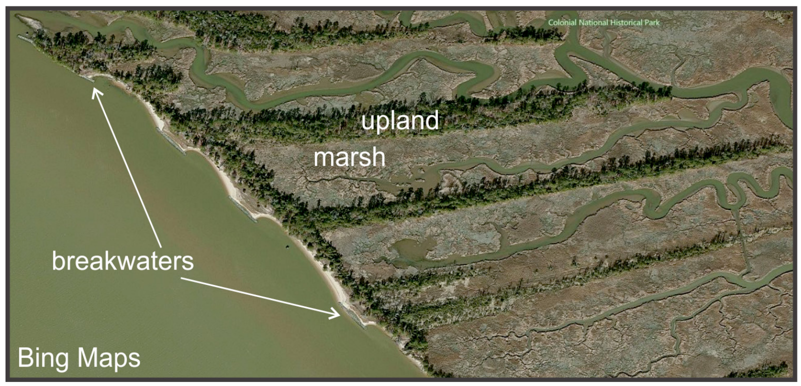


Figure 3-8. *Bing map showing headland breakwaters that were built along Jamestown Island's James River shore.*

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 July and August 2016. 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,

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	Center for Coastal Resources Management (CCRM), Virginia Institute of Marine Science (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	Comprehensive Coastal Inventory (CCI), Center for Coastal Resources Management (CCRM), Virginia Institute of Marine Science (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, Virginia Institute of Marine Science	wide beach (width > 10 ft)	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.*

the majority of these data are collected and maintained for the Gloucester County Shoreline Inventory. (ccrm.vims.edu/gis_data_maps/shoreline_inventories/virginia/gloucester/gloucesterva_disclaimer.html) developed by CCRM (Angstadt *et al*., 2014). 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 Map 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/Marsh Buffer	Enhance/Maintain Marsh
Forest Management	Widen Marsh
Grade Bank	Widen Marsh/Enhance Buffer
Land Use Management	Plant Marsh with Sill
Area of Special Concern	Enhance/Maintain Beach
No Action Needed	Enhance Riparian/Marsh Buffer OR Beach Nourishment
	Maintain Beach OR Offshore Breakwaters with Beach Nourishment
	Revetment

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

5 Shoreline Management for Gloucester County

5.1 Shoreline Management Model (SMM) Results

In the Gloucester County, the SMM was run on 607 miles of shoreline. 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 Gloucester County can be achieved without the use of traditional erosion control structures, and with few exceptions, very little structural control. Almost 80% of the shoreline can be managed simply by enhancing the riparian buffer or the marsh if present. Since the much of the shoreline resides within protected waters with medium to low energy conditions, Living Shoreline approaches are applicable. Table 5-1 summarizes the model output for Gloucester based on strategy(s) and shoreline miles. The glossary in Appendix 2 gives meaning to the various Shoreline BMPs listed in Table 5-1.

ShoreBMP	Length (miles)
Enhance Riparian/Marsh Buffer	11.5
Enhance Riparian/Marsh Buffer OR Beach Nourishment	0.1
Enhance/Maintain Beach	0.3
Enhance/Maintain Marsh	404.5
Enhance/Maintain Riparian Buffer	43.6
Groin Field with Beach Nourishment	0
Maintain Beach OR Offshore Breakwaters with Beach Nourishment	27.1
Plant Marsh with Sill	51.1
Revetment	0.01
Widen Marsh	21.5
Widen Marsh/Enhance Buffer	3.0
Length of shore without Attributes	44.7
UplandBMPS	**Length (miles)**
Area of Special Concern	5.1
Enhance Riparian/Marsh Buffer	516.7
Forest Management	2.4
Grade Bank	40.2
Land Use Management	3.4
No Action Needed	39.6

Table 5-1. *Occurrence of descriptive Shoreline BMPs in the Gloucester County Watershed from the SMM.*

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

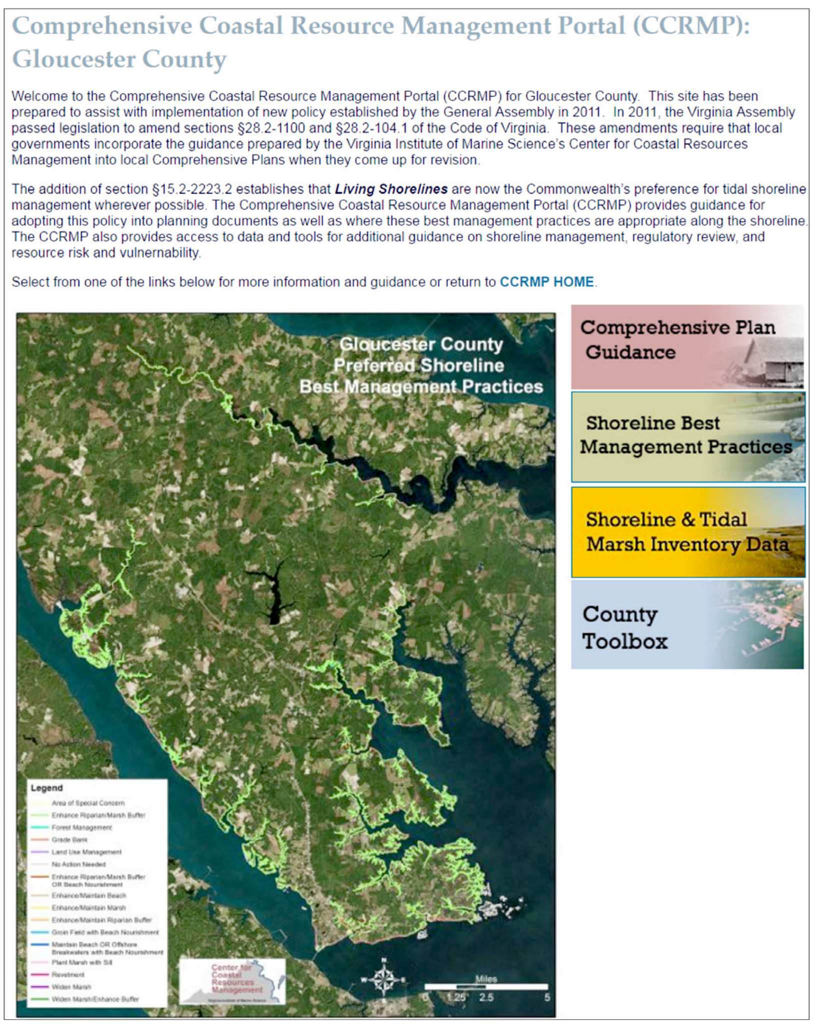


Figure 5-1. *Portal for Comprehensive Coastal Resource Management in Gloucester County.*

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 Interest

This section describes several areas of interest in Gloucester and demonstrates how the preferred alternative from the SMM could be adopted by the waterfront property owners. 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.

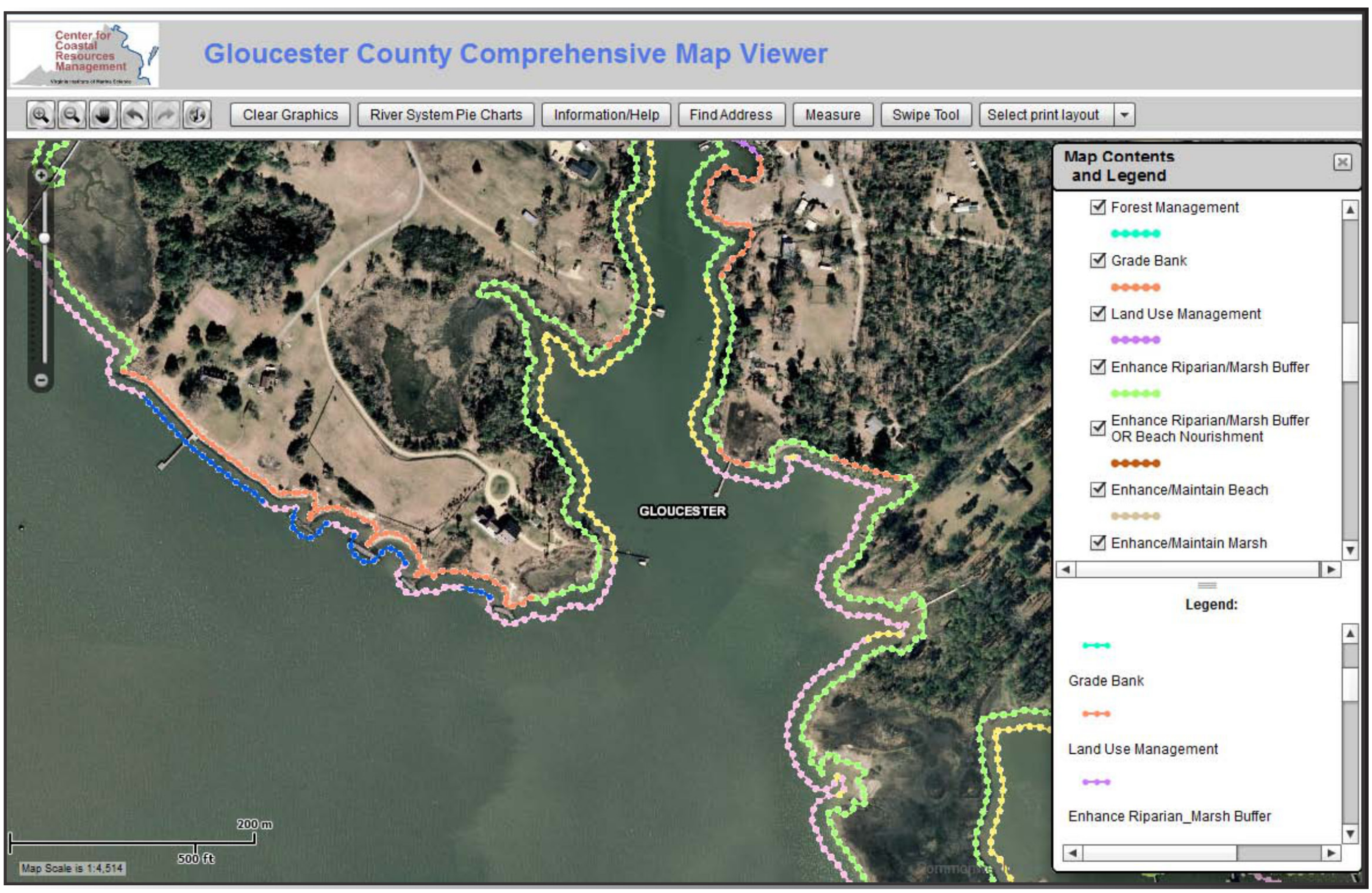


__Figure 5-2.__ The Map Viewer displays the preferred Shoreline BMPs in the map window. The color-coded legend in the panel on the right identifies the treatment option recommended.

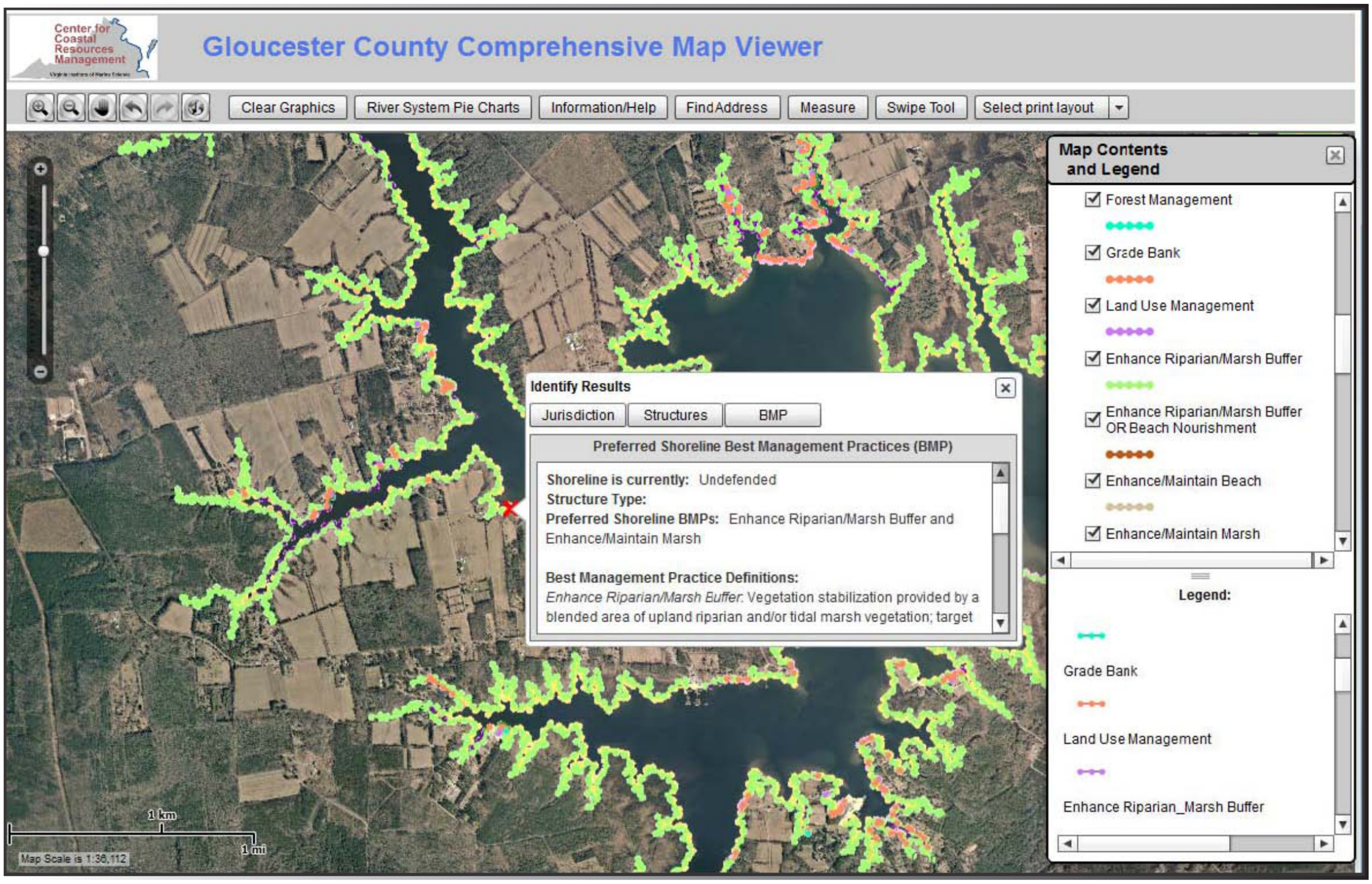


Figure 5-3. *The pop-up window contains information about the recommended Shoreline BMP at the site selected. Additional information about the condition of the shoreline also is given.*

5.2.1. Purtan Bay (Area of Interest)

This area of interest is situated on the York River on a neck of land in Purtan Bay between Purtan Creek and Leigh Creek (Figure 2-2). The approximately 350 feet of actively eroding upland shoreline occurs between adjacent eroding marshes. The marsh shoreline on the west end has about 230 feet on Purtan Bay and turns up Purtan Creek along the west side of the upland. The marsh shoreline on the east side extends about 560 feet along Purtan Bay then turns into the mouth of Leigh Creek. The long-term erosion rate (1937-2009) along this property is very low to low (Milligan *et al*., 2010), but the low bank is scarped and eroding, and the existing marsh is being lost (Figure 5-4).

The site is located in a relatively sheltered embayment but it faces southwest across the York River with about a 3.2 mile long fetch. This is a medium wave energy classification of 1 to 5 miles (Hardaway and

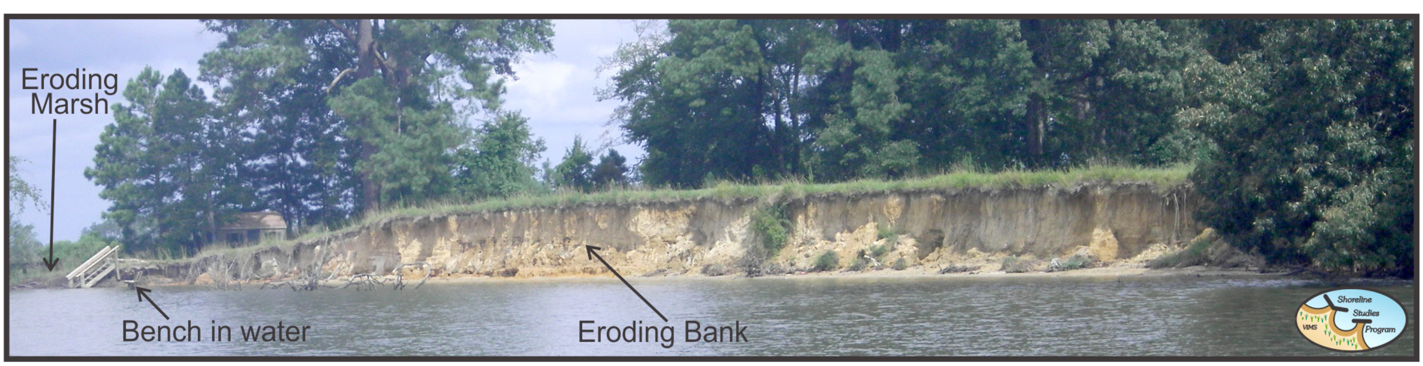


Figure 5-4. *Eroding shoreline at Area of Interest 1 on Purtan Bay.*

Byrne 1999). There was once a large marsh to the west offering shelter from the northwesterly and westerly wind wave climates and the project site had a full marsh fringe across the site that was 60 feet wide (Figure 5-5). That spit eroded away and by 1994 was only a small island (Figure 5-5) and today is just about completely gone.

Historically, the Purtan Creek channel exited near this piece of property and carried with it fine-grained material that likely maintained the nearshore and marshes along this shoreline (Figure 5-5). However, as the mainland marsh to the west and marsh island eroded over time, the Purtan Creek channel shifted farther south and eventually the previous channel was closed off completely by 2011. The material transported by Purtan Creek is now being transported farther south into Purtan Bay.

The SMM recommends a BMP that includes both breakwaters along the higher eroding bank and a sill along the eroding marsh. It is not uncommon for long reaches shoreline have different shore types resulting in different shoreline management strategies. The designer fits them together for a complete shore protection system. A high sill could have been installed along the upland banks or the breakwaters could be closer to shore but the upland would have to be graded in like fashion to accommodate the embayment dimensions.

A conceptual design of a shore protection system which would manage the shoreline includes two breakwaters that transition to five gapped sills along about 800 feet of shoreline (Figure 5-6). The tombolos are low behind the breakwater units to provide low marsh establishment then grading up to the high marsh. Sand fill behind the marsh comes to the top of the existing peat scrap to establish low marsh. The sand fill along the eroding upland bank face was set at +4

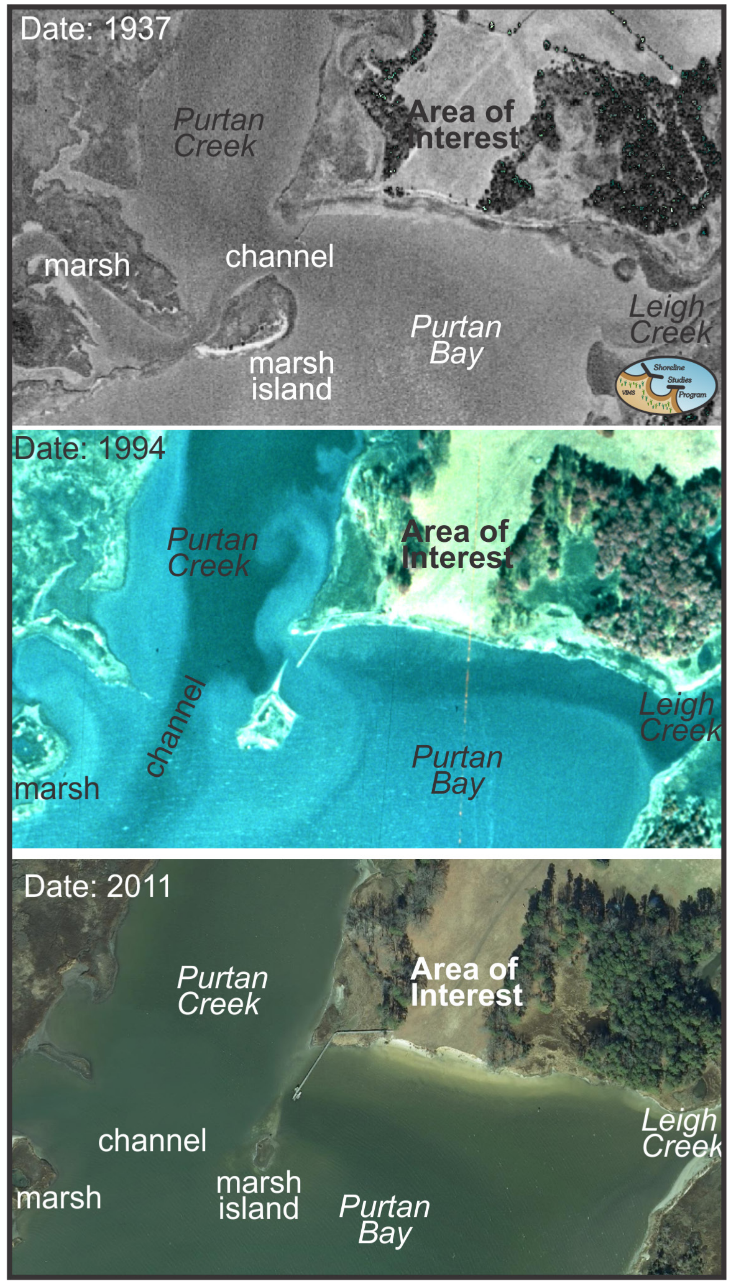


Figure 5-5. *Change in the shoreline and in Purtan Creek channel over time between 1937 and 2011 (Milligan* et al.*, 2010).*

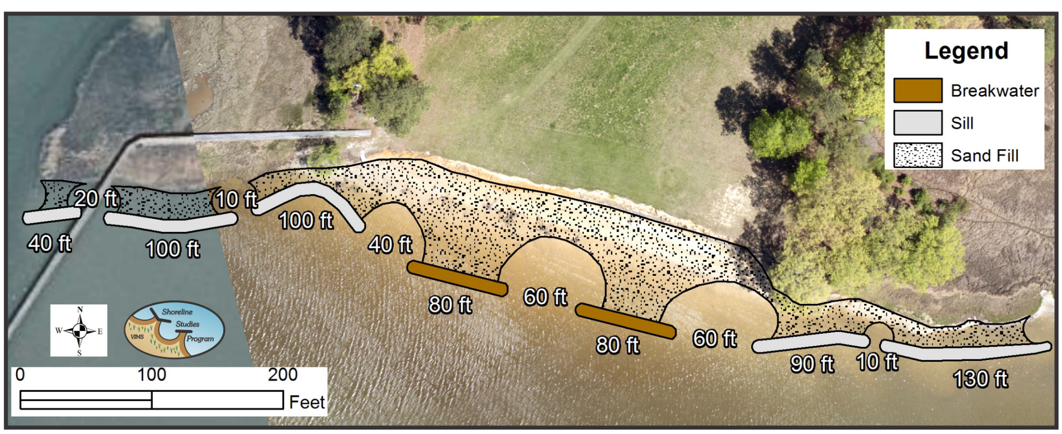


Figure 5-6. *Conceptual design of a shore protection system for the eroding bank and marsh shorelines.*

feet with bank grading to accommodate severe storm wave impacts; the bank should be graded to at least 2:1. A higher level of protection was deemed not necessary at this degree of design and planning due to absence of threatened upland infrastructure. The breakwaters would provide a stable beach for recreational access while the gapped sills would protect the marshes and allow fauna to utilize them. The cross-section for a typical sill for this site is shown in Appendix 3, Figure 1 and the typical breakwater section is shown in Appendix3, Figure 3.

Figure 5-7. *Proposed configuration of Shoreline BMP at Chickahominy Riverfront Park.*

5.2.2 Hell Neck (Area of Interest)

This site is located on the Piankatank River along the north coast of Hell Neck. The project shoreline is about 300 feet long extending upriver from an existing revetment to a marsh fringe. The upland bank is exposed and eroding and transitions north to a stable bank face behind the marsh fringe (Figure 5-7). The project site faces northeast with an average fetch exposure of about 0.8 miles, a low wave energy shoreline. The tide range is 1.2 feet, and the site has an erosion rate of about 1.2 ft/yr (Milligan *et al*., 2010). A series of three medium gapped sills are recommended along the eroding uplands due to a relatively deep nearshore making a breakwater system less cost effective (Figure 5-8). Site access must also be addressed. It is deep enough that the site could be accessed by water; however if the structure is built from land, an access road down a graded bank would need to be included in a final plan. The cross-section for a typical sill for this site is shown in Appendix 3, Figure 2.

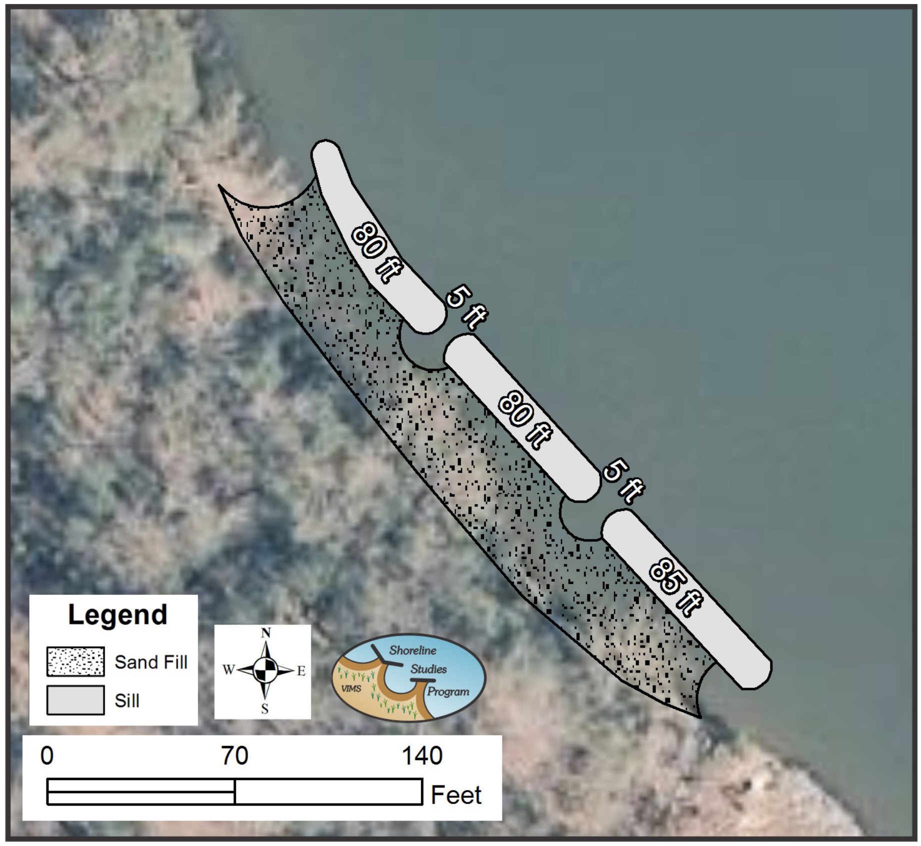


Figure 5-8. *Conceptual design of a shore protection system for the eroding bank and marsh shorelines along the Piankatank River.*

6 Summary and Links to Additional Resources

The Shoreline Management Plan for Gloucester County is presented as guidance to County 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: Gloucester County Map Viewer
cmap2.vims.edu/CCRMP/Gloucester2014/Gloucester_CCRMP_Viewer.html

VIMS: Living Shoreline Design Guidelines
www.vims.edu/research/departments/physical/programs/ssp/_docs/living_shorelines_guidelines.pdf

VIMS: Why a Living Shoreline?
ccrm.vims.edu/livingshorelines/index.html

VIMS: Shoreline Evolution for Gloucester County
web.vims.edu/physical/research/shoreline/docs/Cascade/Shoreline_Evolution/Gloucester_ShoreEvolve-lr.pdf

NOAA: Living Shoreline Implementation Techniques
www.habitat.noaa.gov/restoration/techniques/livingshorelines.html

Chesapeake Bay Foundation: Living Shoreline for the Chesapeake Bay Watershed
www.cbf.org/document.doc?id=60

7 References

Angradi, T.R., Schweiger, E.W., Bolgrien, D.W., Ismert, P., and Selle, T. 2004. Bank stabilization, riparian land use and the distribution of large woody debris in a regulated reach of the upper Missouri river, North Dakota, USA. *River Res. Appl.* 20(7): 829-846.

Angstadt, K., Berman, M.R., Bradshaw, Durhing, K., Killeen, S., Hershner, C., Nunez, K., Procopi, A., Rudnicky, T., and Weiss, D., 2014. Gloucester County – Shoreline Inventory Report. Special Report in Applied Marine Science and Ocean Engineering No. 440, Comprehensive Coastal Inventory Program, Center for Coastal Resources Management Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia, 23062.

Basco, D.R. and C.S. Shin, 1993. Design Wave Information for Chesapeake Bay and Major Tributaries in Virginia. Coastal Engineering Program, Civil and Environmental Engineering Department, Old Dominion University, Norfolk, Virginia. Report No. 93-1.

Bischoff, A., and Humboldt-Universitaet zu Berlin. 2002. Juvenile fish recruitment in the large lowland river oder: Assessing the role of physical factors and habitat availability. Shaker Verlag GmbH, Aachen.

Boon, J.D., 2012. Evidence of Sea Level Acceleration at U.S. and Canadian Tide Stations, Atlantic Coast, North America. *Journal of Coastal Research*, 28: 1437-1445.

Burke, R., Lipcius, R., Luckenbach, M., Ross, P.G., Woodward, J., and Schulte, D. 2006. Eastern oyster settlement and early survival on alternative substrates along intertidal marsh, rip rap, and manmade oyster reef. *J. Shellfish Res*. 25(2): 715.

Carroll R (2003). Nekton utilization of intertidal fringing salt marsh and revetment hardened shorelines. Masters thesis, The College of William and Mary, Virginia Institute of Marine Science, Gloucester Point, VA.

Center for Coastal Resource Management (CCRM), 2013. Comprehensive Coastal Resource Management Guidance. Planning Information and Guidance for the Living Shoreline Preference. Virginia Institute of Marine Science, College of William & Mary. Gloucester Point, Virginia. 27pp.

Cronin, T.M., L.M. Bybell, R.Z. Poore, B.W. Blackwelder, J.C. Diddicoat, and J.E. Hazel, 1984. Age and correlation of emerged Pliocene and Pleistocene deposits, U.S. Atlantic coastal plain. *Palaeogeography, Palaeoclimatology, and Palaeoecology*, 47: 21-51.

Gloucester County, 2016. Comprehensive Plan, Gloucester County, Virginia. Adopted February 2016. http://www.gloucesterva.info/Planning/ComprehensivePlanUpdate/tabid/574/Default.aspx

Federal Emergency Management Agency, 2010. Flood Insurance Study: Gloucester County, Virginia and Incorporated Areas. Flood Insurance Study.

Hardaway, C.S., Jr. and R.J. Byrne, 1999. Shoreline Management in Chesapeake Bay. Special Report in Applied Marine Science and Ocean Engineering No. 356. Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, Virginia.

Hardaway, C.S., Jr., D.A. Milligan, K. Duhring, 2010. Living Shoreline Design Guidelines for Shore Protection in Virginia's Estuarine Environments. Version 1.2. Special Report in Applied Marine Science and Ocean Engineering No. 421. Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, Virginia.

Hardaway, Jr., C.S., D.A. Milligan, C.H. Hobbs, III, C.A. Wilcox, K.P. Obrien and L. Varnell, 2010. Mathews County Shoreline Management Plan Special Report in Applied Marine Science and Ocean Engineering #417. Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia.

Hardaway, C.S., Jr., and J.R. Gunn, 2010. Design and performance of headland bays in Chesapeake Bay, USA. *Coastal Engineering*, 57: 203-212.

Hardaway, C.S., and J.R. Gunn, 2011. A brief history of headland breakwaters for shore protection in Chesapeake Bay, USA. *Shore & Beach*. Vol. 78, No. 4/Vol. 79, No. 1.

Milligan, D.A., C.A. Wilcox, K.P. O'Brien, and C.S. Hardaway, Jr., 2010. Shoreline Evolution: Gloucester County, Virginia James, York, and Chickahominy River Shorelines. Data Summary Report. Shoreline Studies Program, Virginia Institute of Marine Science, Gloucester Point, Virginia.

Mixon, R. B., C. R. Berquist, Jr., W. L. Newell, G. H. Johnson, D. S. Powars, J. S. Schindler, E. K. Rader, 1989. Geological map and generalized cross sections of the coastal plain and adjacent parts of the Piedmont, Virginia. USGS IMAP: 2033. As modified in digital form by United States Geological Survey, 2005.

National Research Council. Mitigating Shore Erosion along Sheltered Coasts . Washington, DC: The National Academies Press, 2007.

Rice, C.A. 2006. Effects of shoreline modification on a northern Puget Sound beach: Microclimate and embryo mortality in surf smelt *(hypomesus pretiosus)*. *Estuaries Coasts.* 29(1): 63-71.

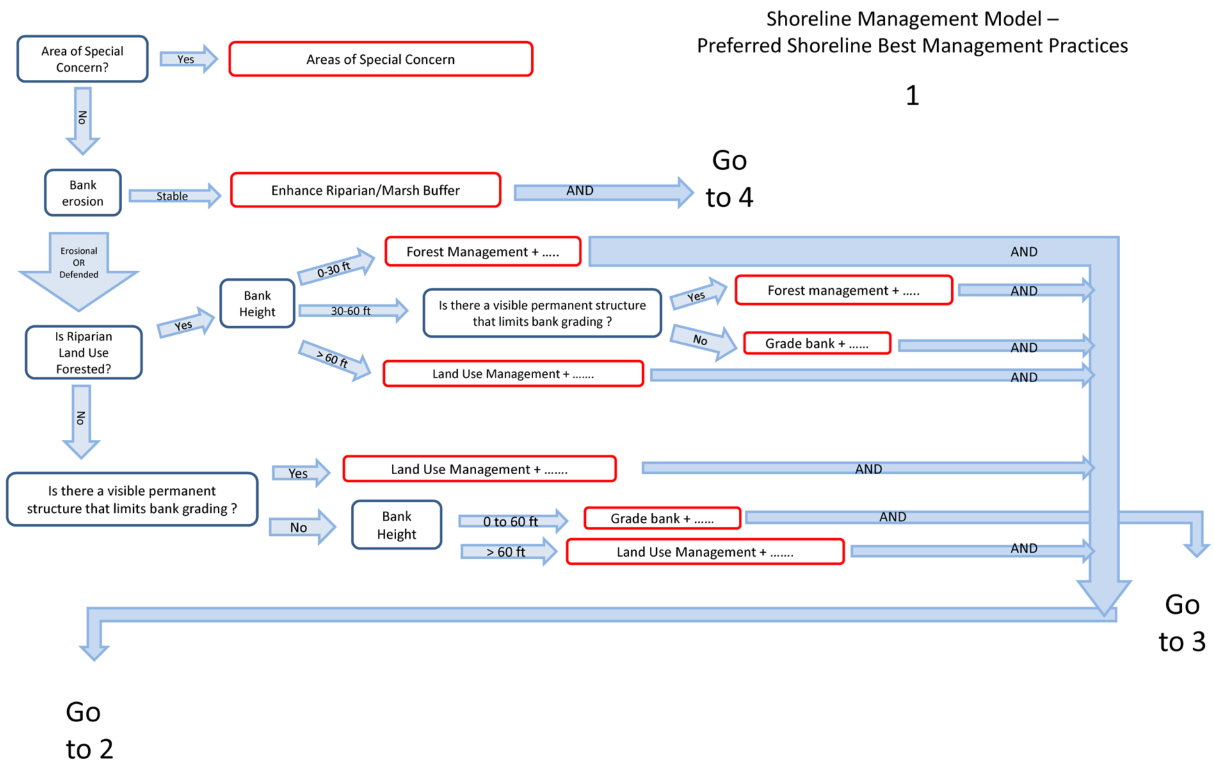
Rice, C., Sobocinski, K., and Puget Sound Action Team, Olympia, WA (USA). 2004. Effects of shoreline modification on spawning habitat of surf smelt *(hypomesus pretiosus)* in Puget sound, Washington. Puget Sound Action Team, PO Box 40900 Olympia WA 98504 USA.

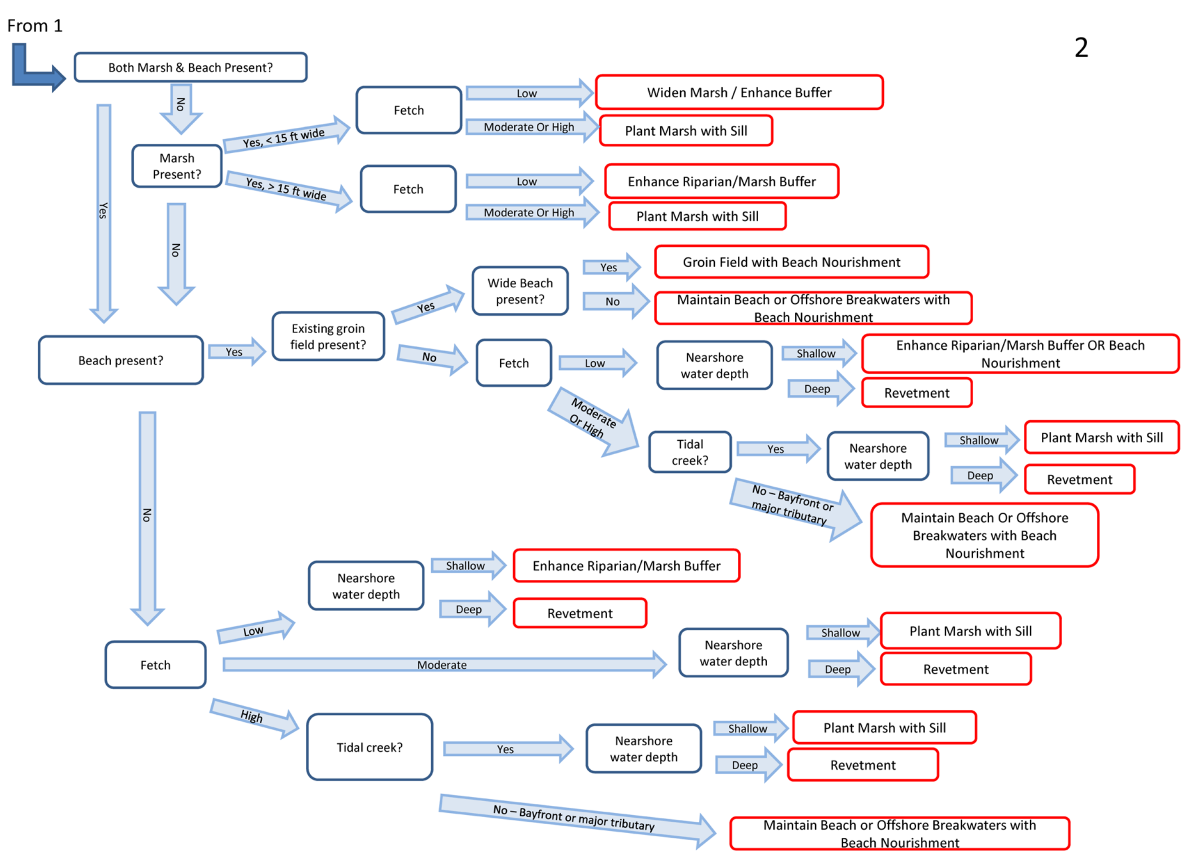
Seitz, R.D., Lipcius, R.N., Olmstead, N.H., Seebo, M.S., and Lambert, D.M. 2006. Influence of shallow-water habitats and shoreline development on abundance, biomass, and diversity of benthic prey and predators in Chesapeake Bay. *Mar. Ecol. Prog. Ser.* 326: 11-27.

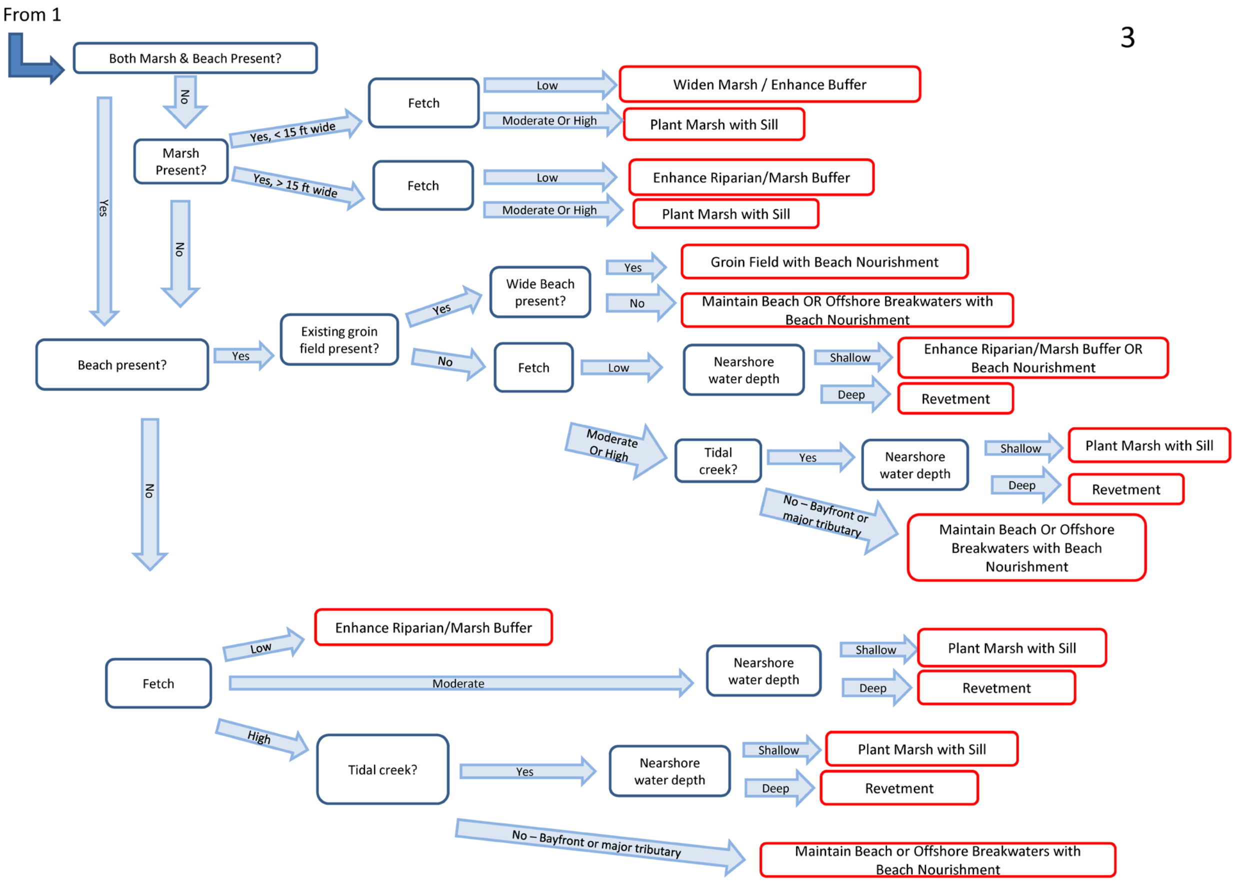
Spalding, V.L. and N.L. Jackson. 2001. Field investigation of the influence of bulkheads on meiofaunal abundance in the foreshore of an estuarine sand beach. *Journal of Coastal Research* 17:363-370.

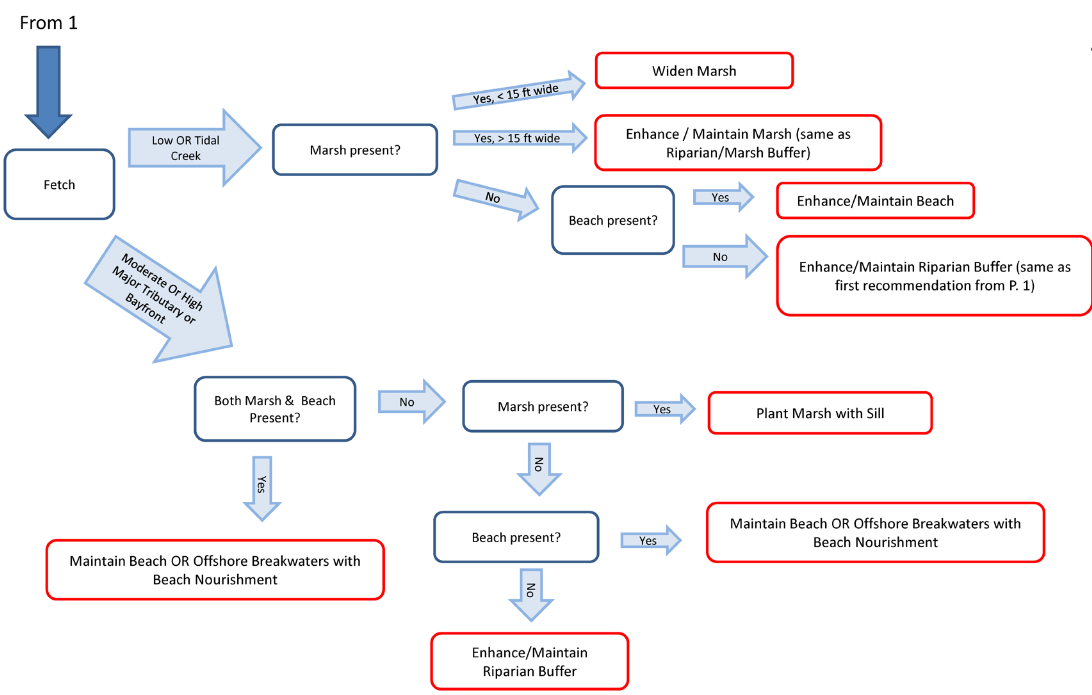
APPENDIX 1

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
Moderate Or High
Widen Marsh / Enhance Buffer
Plant Marsh with Sill
Fetch
Low
Moderate Or High
Enhance Riparian/Marsh Buffer
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 drain fields. All new construction should be located 100 feet or more from the top of the bank. Re-direct storm water 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 Gloucester County

For Gloucester County, three typical cross-sections for stone structures have been developed. The dimensions given for selected slope breaks have a range of values from low 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
Medium 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 very 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 low, medium, and high wave energy shores, the structure should become a more engineered coastal structure. In the lower fetch areas of Gloucester, a low sill might be appropriate (Appendix 3, Figure 1). This cross-section is considered a low sill because its crest elevation is at about mean high water. Very little of the rock is exposed at high tide, and the sand fill is lower so that mostly low marsh will be planted at the site. Along medium energy shorelines or where there is nearby upland infrastructure, a high sill might be better (Appendix 3, Figure 2). This cross-section has a crest elevation that is more than double high water so that it can provide a greater level of protection during storm events. Using sills in higher wave climates requires careful consideration and design due to the severity of storm wave attack.

Breakwater systems are applicable management strategies along the York River and Mobjack Bay with a medium to high energy shores. The actual planform design is dependent on numerous factors and should

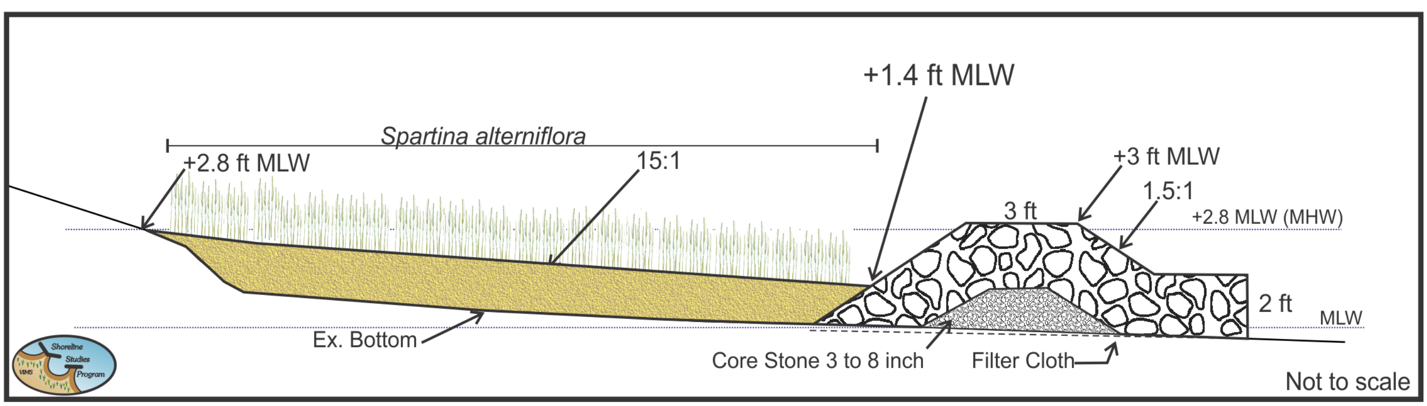


Figure 1. *Typical cross-section for a low sill that is appropriate for low to medium energy shorelines of Gloucester County. The project utilizes clean sand on an 10:1 (H:V) slope, and the bank can be graded to a (minimum) 2:1slope, if appropriate.*

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).

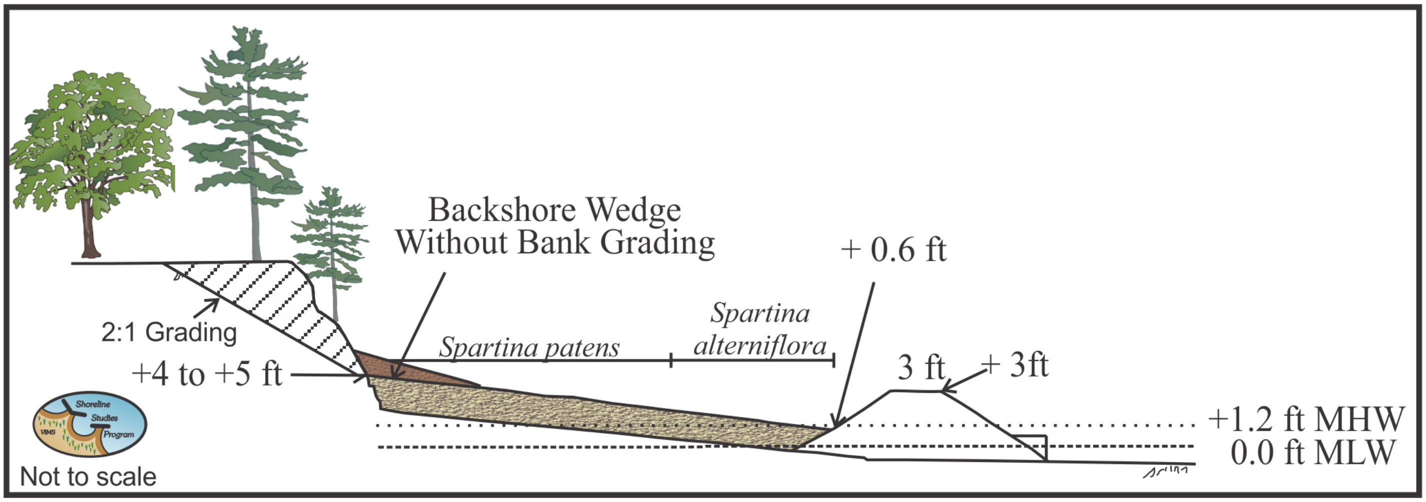


Figure 2. *Typical cross-section for a medium sill that is appropriate for the medium to high energy shorelines of Gloucester County. The project utilizes clean sand, and the bank can be graded to a (minimum) 2:1slope, if appropriate. Modified from Hardaway* et al. *(2010).*

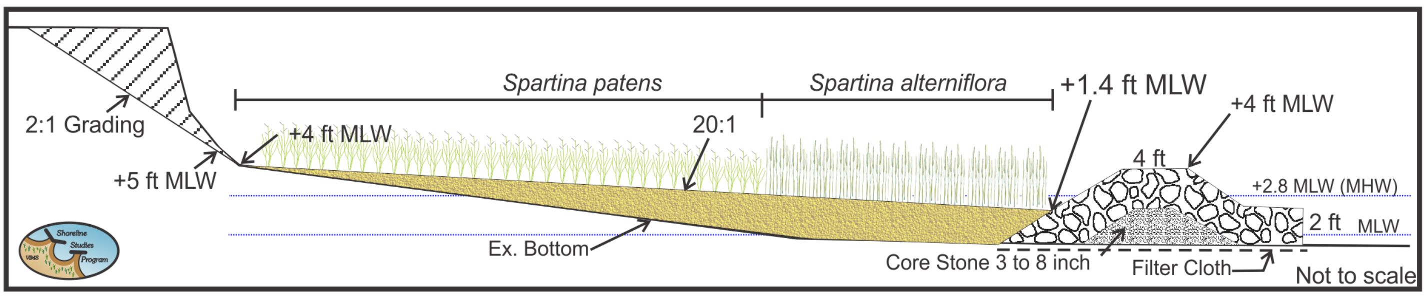


Figure 3. *Typical cross-section for a breakwater that is appropriate for shore protection along the medium to high energy shorelines of Gloucester County. The project utilizes clean sand, and the bank can be graded to a (minimum) 2:1slope, if appropriate.*