

Lynnhaven River Shoreline Management Plan

***Prepared for
City of Virginia Beach and
Virginia Coastal Zone Management Program***

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

April 2013

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Shoreline Studies 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 recently published a report that spotlights the necessity of developing 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. The shores of Lynnhaven River are fairly sheltered coasts (Figure 1-1). In addition, much of the shoreline has existing hardened shore protection. However, much of Lynnhaven River'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+CHAPo885+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 Lynnhaven River Shoreline Management Plan (LRSMP) is an educational and management reference for the watershed and its landholders.



Figure 1-1. Location of Lynnhaven River within the Chesapeake Bay estuarine system.

2 Coastal Setting

2.1 Geology/G geomorphology

The Lynnhaven River lies within the coastal plain of Virginia Beach. It is connected to the Chesapeake Bay via Lynnhaven Inlet where tidal currents run quickly in both ebb and flood directions (Figure 2-1). Lynnhaven Inlet is the only opening to the Lynnhaven River, Broad Creek and Linkhorn Bay watersheds. It lies about 5 miles west of Cape Henry and about 5 miles east of Little Creek. The shorelines, both east and west along the Chesapeake Bay, are sandy beach and dunes with coastal development along much of the coast.

Inside the Inlet, the Lynnhaven River diverges both southwest and southeast into the Western and Eastern Branches (Figure 2-1). Lynnhaven Bay also connects to Broad Bay through Long Creek. The Western Branch and Eastern Branch are separated by Little Neck. The drainage area of the Western Branch is about 8.21 square miles and about 6.53 square miles of drainage area for the Eastern Branch (City of Virginia Beach, 2009). The Eastern Branch narrows southward to about 150 feet at approximately where Route 58 (Virginia Beach Blvd.) crosses the River. The tidal creek continues southward as London Bridge Creek, a narrow channel with minimal branches. The Western Branch of the Lynnhaven River narrows near Route 58 but terminates just beyond as a very narrow, meandering channel bordered by marsh.

The Lynnhaven River watershed is formed by the Tabb Formation (Figure 2-2) of upper Pleistocene age. It was likely deposited during the last major high stand of sea level that extended from approximately 135,000 to 75,000 years ago. The Tabb Formation has been divided from youngest to oldest into the Poquoson, Lynnhaven and Sedgefield Members (Mixon *et al.*, 1989) that are likely the result of small scale variations in sea level with peaks occurring about 80,000, 105,000, and 125,000 years ago (Toscano, 1992). The Poquoson Member forms the east side of Pungo Ridge from sea level to about 11 ft



Figure 2-1. Location of features in the vicinity of Lynnhaven River.

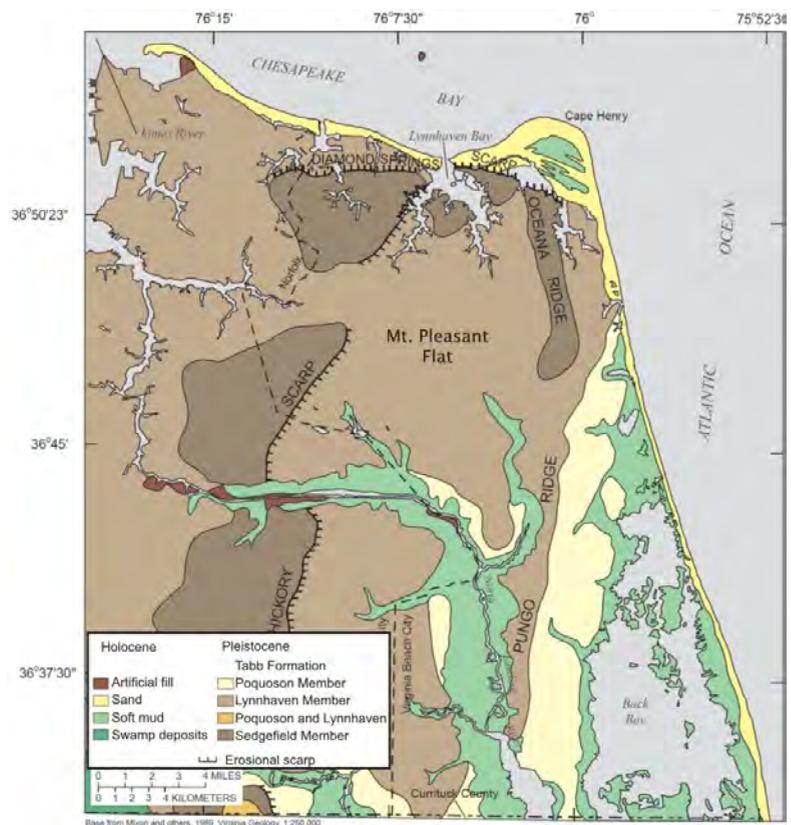


Figure 2-2. Surficial geology and geomorphic features at Virginia Beach, Virginia. (From Smith and Harlow, Jr., 2002)

above sea level. It is a gray, medium to coarse, pebbly sand grading upward into a clayey, fine sand and silt. The Poquoson and Lynnhaven Members are undifferentiated along Virginia Beach's coast.

The Lynnhaven Member underlies most of Virginia Beach (Figure 2-2). The Lynnhaven stretches from the west side of the Pungo Ridge to Hickory Scarp and from Lynnhaven Bay to the southern city limits along the North Carolina border (Smith and Harlow, Jr., 2002). A broad swale (low flat lands and wetlands) less than 20 ft above sea level has formed on the Lynnhaven Member (Mt. Pleasant Flat). The Lynnhaven is composed of gray, pebbly, and cobbled, fine to coarse sand, grading upward into clayey and silty fine sand and sandy silt. These the likely sediments of the shoreline upland banks in the southern portion of both branches of the Lynnhaven River.

The older Sedgefield Member of the Tabb Formation forms Oceana Ridge, which ranges from about 20 to 25 ft above sea level. The Sedgefield also forms much of the higher ground south of the Diamond Springs Scarp around Lynnhaven Bay as well as the higher ground west of Hickory Scarp. The Sedgefield is a pebbly to bouldered, clayey sand and fine to medium shelly sand grading upward to sandy to clayey silt. These sediments likely compose the upland banks on the east and west side of Lynnhaven Bay and the distal end of Little Neck. The Sedgefield appears to be the topographic control for the Lynnhaven River as it developed during the Lynnhaven Member time. The Sedgefield uplands along shore are 5 to 10 ft higher than the adjacent Lynnhaven upland shorelines.

Cape Henry, a major headland at the mouth of Chesapeake Bay, is seen on early charts but was not labeled until the 1612 John Smith Map. Lynnhaven Inlet and Lynnhaven River were labeled on early maps as far back as 1675 (Woodbridge, 2012) although even earlier, the water bodies can be seen on cartographic renditions of Chesapeake Bay. Interior surveying from 1730 to 1750 made it possible to compile a new map of Virginia (1753/1768 Fry-Jefferson map) which clearly labeled Lynnhaven Bay, Lynnhaven River, and Cape Henry (Woodbridge, 2012). Beginning in the early 1800s, the Coast and Geodetic Survey used a system of triangulation to create extremely accurate charts of the coast (Woodbridge, 2012). The early charts of the series refer to Lynnhaven Roads as the slight embayed coast in Chesapeake Bay with Lynnhaven Inlet and Lynnhaven Bay clearly shown (Figure 2-3). A railroad bridge is shown spanning Lynnhaven Inlet. The broad ebb shoal system through which Lynnhaven Inlet is notable.

Today, as in the past, Lynnhaven Inlet and the associated flood and ebb shoals control in part the coastal processes and sediment transport locally. The extensive ebb shoal causes the impinging bay and ocean waves to refract and alter sediment movement. The net littoral drift is generally east to west along the Chesapeake Bay shoreline with minor reversal just west of the Inlet (Hardaway *et al.*, 1993).

Aerial imagery in 1937 shows both a vehicle bridge and railroad bridge spanning the inlet (Figure 2-4). A pear-shaped marsh/sand island (named Pear Island for this report) occurs just inside Lynnhaven Bay. This and other marsh/sand islands occur in Lynnhaven Bay as part of a vegetated supratidal flood shoal system. The Inlet occurs as a sinuous channel with wide sandy beaches

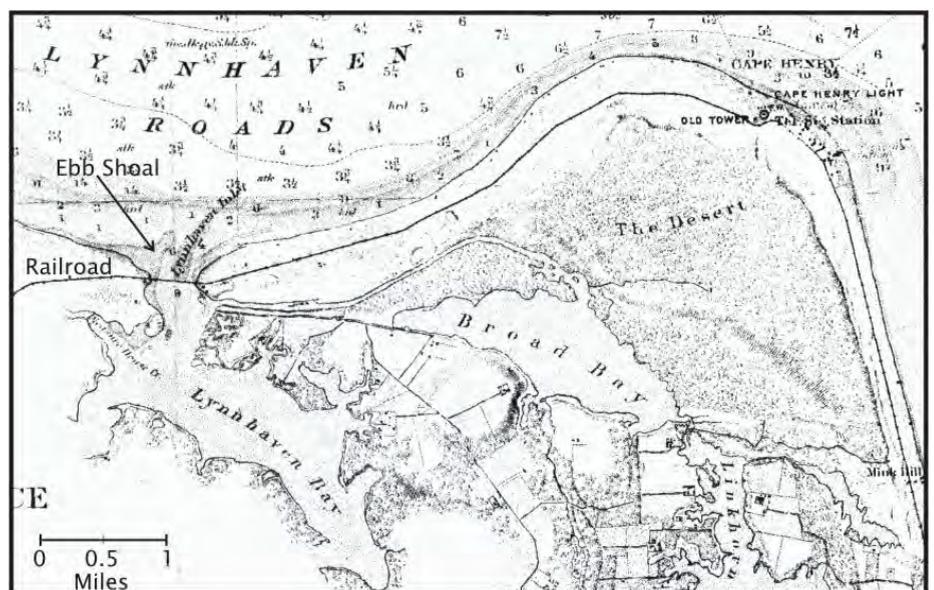


Figure 2-3. Map of Lynnhaven River at the mouth of Chesapeake Bay shown on an 1863 map.

along the Bay shore. In 1954, a sand spit can be seen entering Lynnhaven Inlet from the west along with shore advancement on the Bay shore east of the Inlet (Figure 2-5). Pear Island was smaller. Sand movement in and around the inlet is somewhat complex, and as time went on, dredging became necessary to navigate the Inlet as commerce increased.

The earliest record of inlet dredging was in 1965 with subsequent maintenance dredging in 1968, 1969, 1970 and 1972 (U.S. Army Corps of Engineers, 1980). Dredged material was mostly sand and disposed of along the Ocean Park Bay shoreline just west the inlet and sometimes in Lynnhaven Bay on the west shore just inside the inlet. Aerial imagery in 1970 shows the dredged channel through the ebb shoal (Figure 2-6). It is likely that the dredge material was disposed of along the shoreline as evidenced by the widened beach both east and west of the Inlet as well as inside Lynnhaven Bay. Now a four lane bridge can be seen and "Pear" island has broken into two sections. The 1976 photo indicates that the tidal marsh southwest of the Inlet was a disposal site for some of the dredged material (Figure 2-7).

By 1980, inlet dredging and subsequent disposal continued with more material stacked in Lynnhaven Bay thus "growing" the area in height and planform (Figure 2-8). An infilling of the channel from the west can also be seen as a wide spit feature. Pear Island was smaller. In 1987, aerial imagery by VIMS shows a dredge plant operating just inside the inlet in Lynnhaven Bay with the dredge pipe extending up into the newly constructed disposal basin (Figure 2-9).

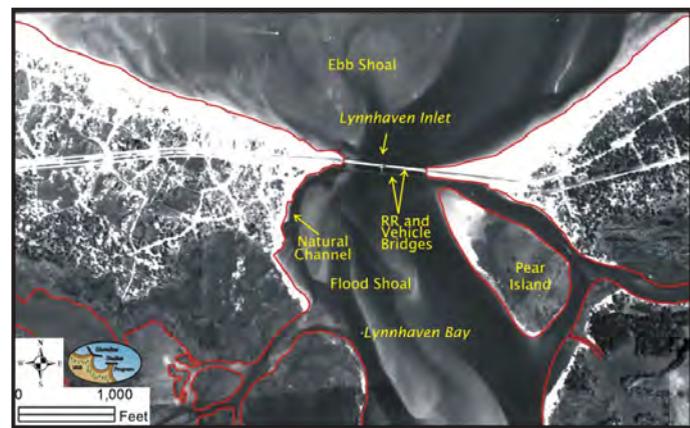


Figure 2-4. Orthorectified image of Lynnhaven Inlet and vicinity in 1937. The 1937 shoreline is shown in red. From Milligan et al. (2012).



Figure 2-5. Orthorectified image of Lynnhaven Inlet and vicinity in 1954. The 1937 shoreline is shown in red. From Milligan et al. (2012).

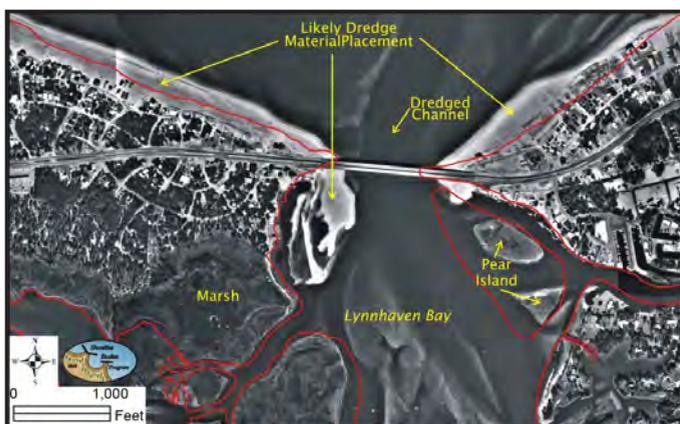


Figure 2-6. Orthorectified image of Lynnhaven Inlet and vicinity in 1970. The 1937 shoreline is shown in red. From Milligan et al. (2012).

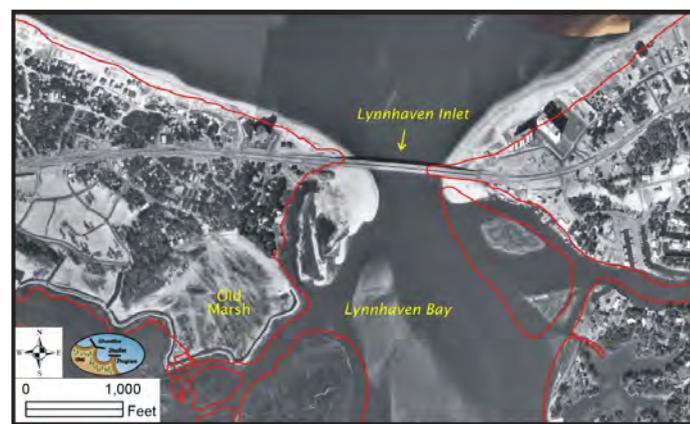


Figure 2-7. Orthorectified image of Lynnhaven Inlet and vicinity in 1976. The 1937 shoreline is shown in red. From Milligan et al. (2012).



Figure 2-8. Orthorectified image of Lynnhaven Inlet and vicinity in 1980. The 1937 shoreline is shown in red. From Milligan et al. (2012).



Figure 2-9. Orthorectified image of Lynnhaven Inlet and vicinity in 1987. The 1937 shoreline is shown in red. From Milligan et al. (2012).

By 2002, the inlet disposal area has a parking lot and boat ramp facility in place, and the southwest disposal area has a small pond that is becoming more vegetated (Figure 2-10). Pear Island is almost non-existent. In fact, most of the shoreline in Lynn Haven Bay is eroding. In 2011, channel dredging can be seen along the Lynn Haven Bay edge of the Inlet disposal area (Figure 2-11). Today this channel continues to be maintained, but the shore is eroding. Hardaway *et al.* (1993) reported that a reversal in littoral drift occurs approximately 2,000 feet west of Lynnhaven Inlet. The report indicated that in order to minimize infilling of the channel with dredged material, future disposal should be placed west of that area.



Figure 2-10. Orthorectified image of Lynnhaven Inlet and vicinity in 2002. The 1937 shoreline is shown in red. From Milligan et al. (2012).

The shorelines along the Lynnhaven River watershed also have gone through some changes as land development has proceeded. This includes channelizing by dredging as well as damming numerous creeks (Figure 2-12). Starting in about 1970, many of the small tidal marsh tributaries to the Lynnhaven River system were dredged to create accessible waterfront. Between 1937 and 2009 approximately 214 acres of tidal marsh were converted to open water. A similar trend is seen in Broad and Linkhorn Bays.



Figure 2-11. Orthorectified image of Lynnhaven Inlet and vicinity in 2011. The 1937 shoreline is shown in red. From Milligan et al. (2012).

Another trend in man-made impacts to the Lynnhaven River watershed is the damming of tidal creeks to create small lake or ponds. Approximately 202 acres of conversion of this type can be seen in Figure 2-12. Further modifications to the landscape include conversion of upland to open water and lakes which is about 16 acres and 43 acres, respectively. Both of these conversions may have been to obtain "borrow" sand.

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;

All of the shorelines in Lynnhaven are low energy shorelines.

Storm surge frequencies described by FEMA (2009) 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 in the Lynnhaven and associated bays. These percentages correspond to a 10 year, 50 year, 100 year, and 500 year event. The mean tide range at Lynnhaven Inlet, Virginia Pilots Dock is 2.22 ft (Figure 2-13). At the Bayville Station on the western side of Lynnhaven Bay, the mean tide is 1.7 ft.

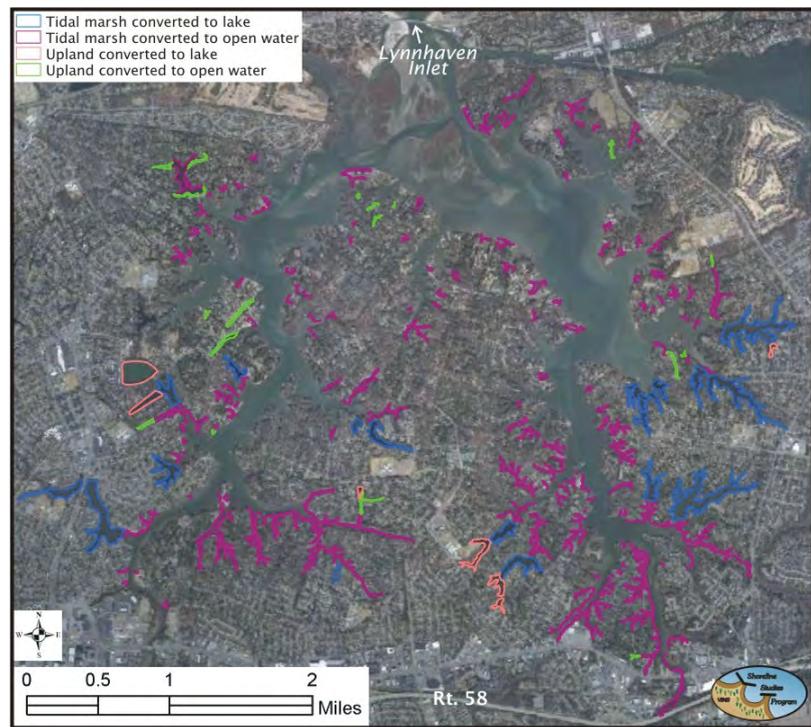


Figure 2-12. Orthorectified image of Lynnhaven River showing the areas where marsh and upland were dredged to create channels and lakes for development.

Flooding Source	Location	Annual Chance (feet NAVD88)			
		10%	2%	1%	0.2%
Lynnhaven Bay	Entire Shoreline	4.9	6.2	6.8	8.2
Lynnhaven River	Entire Shoreline	4.9	6.2	6.8	8.2
Broad Bay	Entire Shoreline	4.3	5.4	5.9	7.1
Linhorn Bay	Entire Shoreline	4.9	5.4	5.9	7.1

Table 2-1. 10 year, 50 year, 100 year, and 500 year storm events. Source: City of Virginia Beach Flood Report, FEMA (2009).

Farther into the Western Branch and Eastern Branch, the mean tide range is 1.9 ft and 1.64 ft, respectively. 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.

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. Recent trends based on wave gauge data at the Chesapeake Bay Bridge Tunnel show the annual rate to be 1.98 feet/100 years (6.05 mm/yr). 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 ft (0.62 m +/- 0.22m) by 2050. The historic rate at Sewells Point (1.44 ft/100 years) will result in 0.53 ft rise in water level by 2050. This potential increase in sea-level rise rates warrant ongoing monitoring and consideration 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, shoreline hardening. Since the shorelines are low energy and an extensive amount of shoreline hardening has occurred (Berman *et al.*, 2012), the average end point rate of shoreline change for Lynnhaven River is only -0.1 ft/yr (1937-2009). The shoreline rates of change for various areas of the River are shown in Figure 2-14.

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.

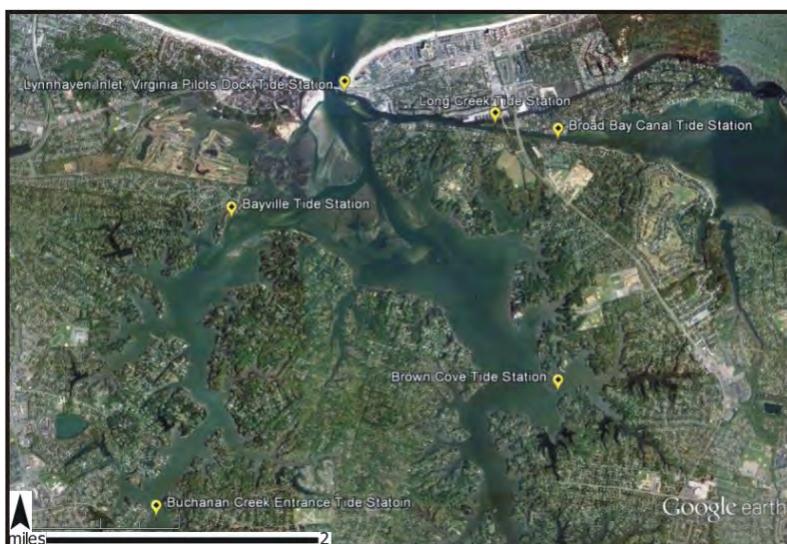


Figure 2-13. Location of tide gauges in Lynnhaven River.



Figure 2-14. End point rates of shoreline change between 1937 and 2009 for segments of the Lynnhaven River (Milligan *et al.*, 2012).

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.

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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 Buffer	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 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



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.



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

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.

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.*, 2010a). 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 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)



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



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.

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

Suitable “structural” Living Shoreline management strategies may be required in some areas of Lynnhaven River. As fetch exposure increases beyond about 1,000 ft and the intertidal marsh width is not sufficient to attenuate wave action, 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 low marsh sill is appropriate.

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.

Hardaway and Byrne (1999) indicate that in low 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. Much of the shoreline in Lynnhaven River has already been hardened. However, in cases where a structure is failing or the landowner wants a more environmental edge, a sill can be placed in front of an existing structure (Figure 3-6).

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.

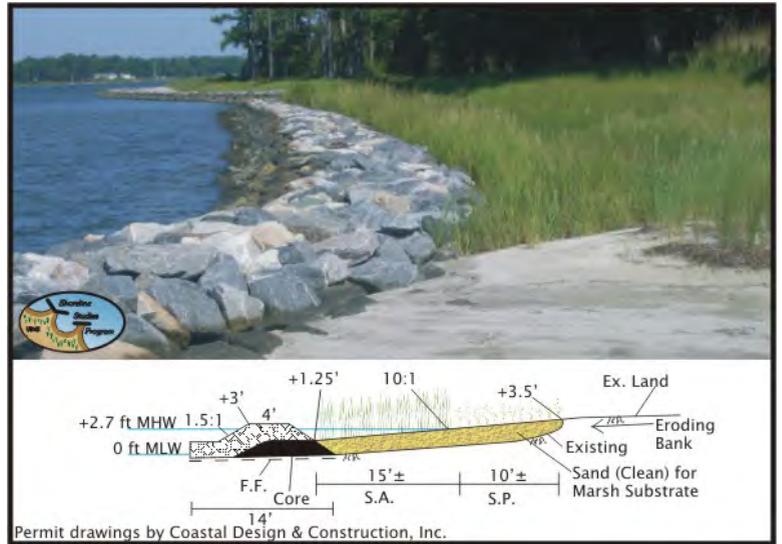


Figure 3-5. Sand fill with stone sills and marsh plantings at Poplar Grove, Mathews County, Virginia after six years and the cross-section used for construction (From Hardaway et al., 2010b).



Figure 3-6. Low marsh sill built in front of a rock revetment in Lynnhaven Bay.

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 several field days in September 2012. Existing conditions and suggested strategies were noted on maps which were transcribed in the office to display 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 collected and maintained for the City of Virginia Beach Shoreline Inventory (http://ccrm.vims.edu/gis_data_maps/shoreline_inventories/virginia/virginia_beach/va_bch_disclaimer.html) developed by CCRM (Berman *et al.*, 2012). 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:

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.

$((3 * mh) + 20) * 0.3048$ 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 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 Lynnhaven River Watershed

5.1 Shoreline Management Model (SMM) Results

In Lynnhaven River Watershed, the SMM was run on 174 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 uncommon to find two options for a given site.

By and large, the majority of shoreline management in the watershed can be achieved without the use of traditional erosion control structures, and with few exceptions, very little structural control. Nearly 71% 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. Table 5-1 summarizes the model output for the Lynnhaven Watershed 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 as well as an interactive map viewer that illustrates the SMM output as well as the baseline data for the model (http://ccrm.vims.edu/ccrmp/va_beach/index.html).

The pdf file is found under the tab for Shoreline Best Management Practices. The Map Viewer is found

Shoreline BMPs	Shoreline Length (miles)
Enhance Riparian/Marsh Buffer	123.4
Enhance/Maintain Riparian Buffer	30.7
Forest Management	1.4
Grade Bank	30.6
Land Use Management	3.7
Enhance/Maintain Marsh	45.5
Widen Marsh	27.0
Widen Marsh/Enhance Buffer	7.6
Plant Marsh with Sill	7.4
Enhance Riparian/Marsh Buffer OR Beach Nourishment	0.2
Enhance/Maintain Beach	0.1
Groin Field with Beach Nourishment	0
Maintain Beach OR Offshore Breakwaters with Beach Nourishment	0.1
Revetment	0.3
Area of Special Concern	9.1
No Action Needed	25.5

Table 5-1. Occurrence of descriptive Shoreline BMPs in the Lynnhaven River Watershed.

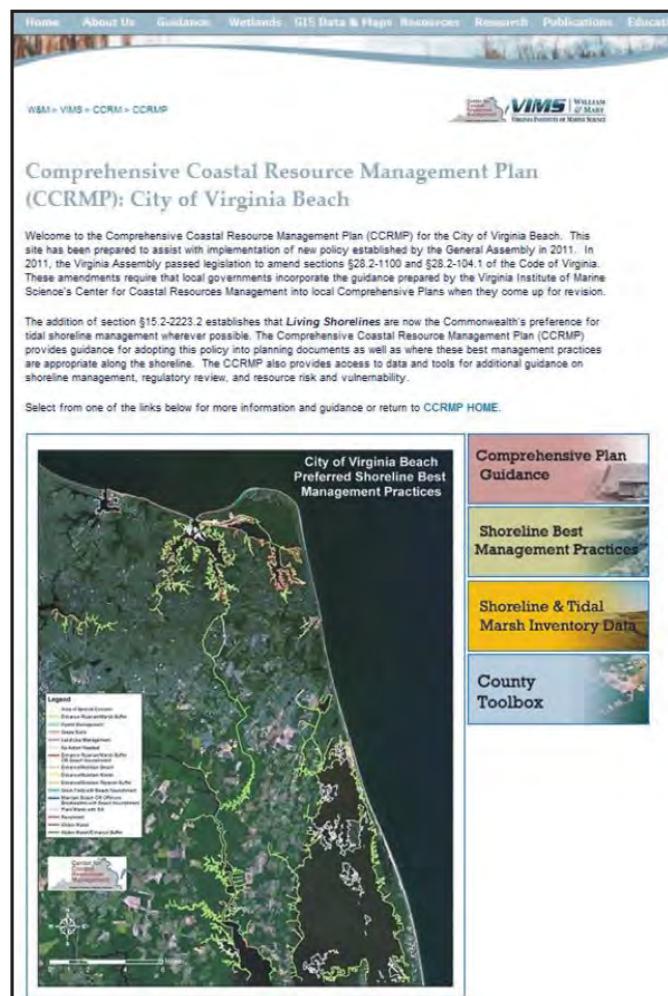


Figure 5-1. Portal for Comprehensive Coastal Resource Management in the City of Virginia Beach.

in the County Toolbox 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 two areas of interest in Lynnhaven River 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 are located in Figure 5-4 and 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

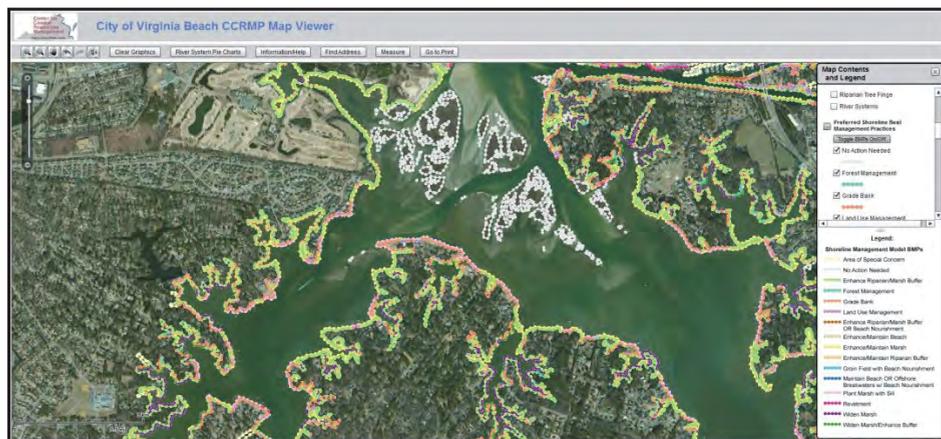


Figure 5-2. The Map Viewer displays the preferred Shoreline BMPs in the map window. The color-coded legend in the panel on the right identifies the treatment option recommended.

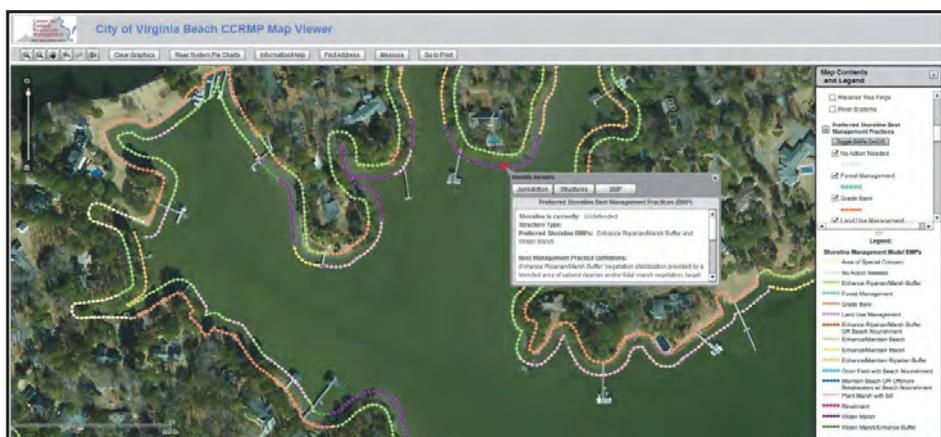


Figure 5-3. The pop-up window contains information about the recommended Shoreline BMP at the site selected. Additional information about the condition of the shoreline is also given.

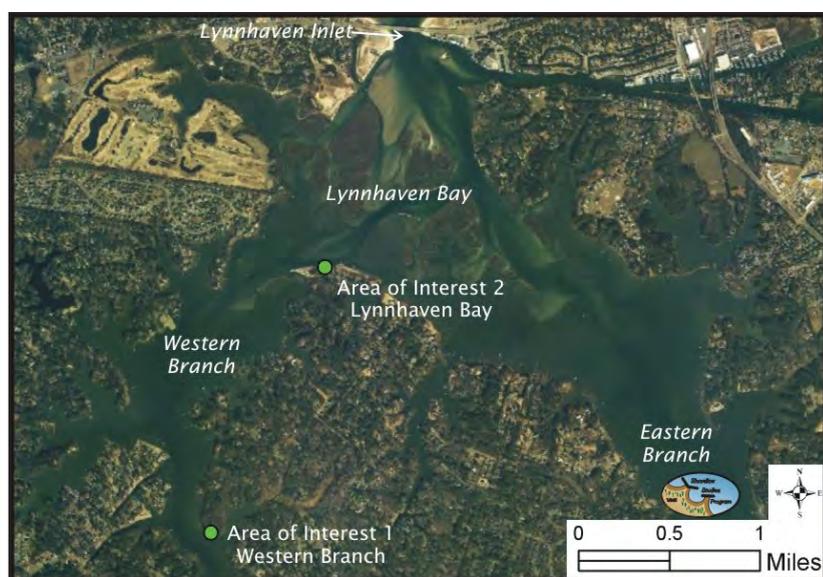


Figure 5-4. Location of Area of Interest sites on the 2011 VBMP image.

estimated cost per foot. The designs presented are conceptual only; structural site plans should be created in concert with a professional.

5.2.1 Little Neck: Western Branch of Lynnhaven River

At this unprotected site, the upland is wooded with a few trees occurring along the bank face and base of bank (Figure 5-5). A very narrow marsh fringe occurs in places along the length of the shoreline. The project site extends along shore for about 780 feet with either end transitioning into vegetated marsh spits. Material for these spits may have come from the slowly eroding adjacent upland banks.

This site faces south-southwest with fetch exposures to the west, southwest, south, and southeast 0.17, 0.14, 0.3, and 0.12 miles, respectively. Historically, the site has eroded between 0.2 and 0.5 ft/yr along the shoreline (Milligan *et al.*, 2012). Storm surge frequencies are 6.3 ft MLLW, 7.6 ft MLLW, and 8.2 ft MLLW for the 10, 50, and 100 year events, respectively.

The proposed alternative is for a small sill system along the length of the upland section of the project coast as illustrated in Appendix 3, Figure 1. In this case, bank grading should not be considered due to the already wooded nature of the riparian buffer. Continued bank erosion will provide some sediment to the proposed sill system, and, with time, the bank face will slowly stabilize. Similar sites occur within the Lynnhaven River watershed where upland bank instability is evidenced by a vertically-exposed bank face.



Figure 5-5. Ground photo showing existing conditions of Area of Interest 1 and its approximate location on the Western Branch of Lynnhaven River on the 2011 VBMP image.

5.2.2 Little Neck: Lynnhaven Bay

This project shoreline occurs on the northern boundary of Little Neck and faces almost due north with fetch exposures to the northwest, north and northeast of 0.34, 0.35 and 0.5 miles, respectively. The northwest fetch is bounded by upland while the north and northeast fetches measure to vegetated marsh islands, part of the flood shoal complex. During storms these flats are submerged and while providing significant wave attenuation capacity, some wave activity can be generated toward the project shore under high northerly wind conditions.

The shoreline currently has a wood bulkhead that is in poor condition and an even earlier bulkhead may have existed at the site (Figure 5-6). Some backfill appears



Figure 5-6. Ground photo showing existing conditions of Area of Interest 2 and its approximate location on Lynnhaven Bay on the 2011 VBMP image.

to be lost through gaps in the structure. Ample beach existed along this shore segment in 1970, and a bulkhead appears in 1980 imagery (Milligan *et al.*, 2012). The beach diminished in width over time and was gone by 1994. Today no beach exists, and a small channel runs along the nearshore. Further offshore sand shoals rise up and are part of the flood shoal complex that becomes vegetated wetland islands about 1,500 feet out.

This site is an opportunity to install a Living Shoreline, a stone sill, along the old bulkhead. A conceptual plan is presented in Appendix 3, Figure 2. The question at hand is whether to remove the bulkhead or leave it. The bank face is heavily vegetated and generally appears stable. It may have been graded in the past. A terrace occurs behind the bulkhead before the land rises to grade. This is vegetated as well. The advantage to leaving the bulkhead is twofold. Cost would be the main advantage, but by not disturbing the upland terrace through the removal process, a graded, vegetated barrier will be left between the proposed marsh and the upland. This can only enhance the shore protection capability of the sill. On the other hand, removal of the bulkhead would provide a better connection for local fauna between the upland and the new marsh.

6 Summary and Links to Additional Resources

The Shoreline Management Plan for Lynnhaven River 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 Lynnhaven River 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 site specific solutions to several areas of interest within the watershed that were noted during the field review and data collection process. 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 alternatives that can reduce erosion on site, minimize cost, in some cases ease the permitting process, and allow coastal systems to evolve more naturally.

Additional Resources

VIMS: City of Virginia Beach Map Viewer

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

VIMS: Living Shoreline Design Guidelines

<http://web.vims.edu/physical/research/shoreline/LivingShorelineDesign.html>

VIMS: Why a Living Shoreline?

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

VIMS: Shoreline Evolution for City of Virginia Beach

<http://web.vims.edu/physical/research/shoreline/Publications-Evolution.htm>

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>

Lynnhaven River Now

<http://www.lynnhavenrivernow.org/>

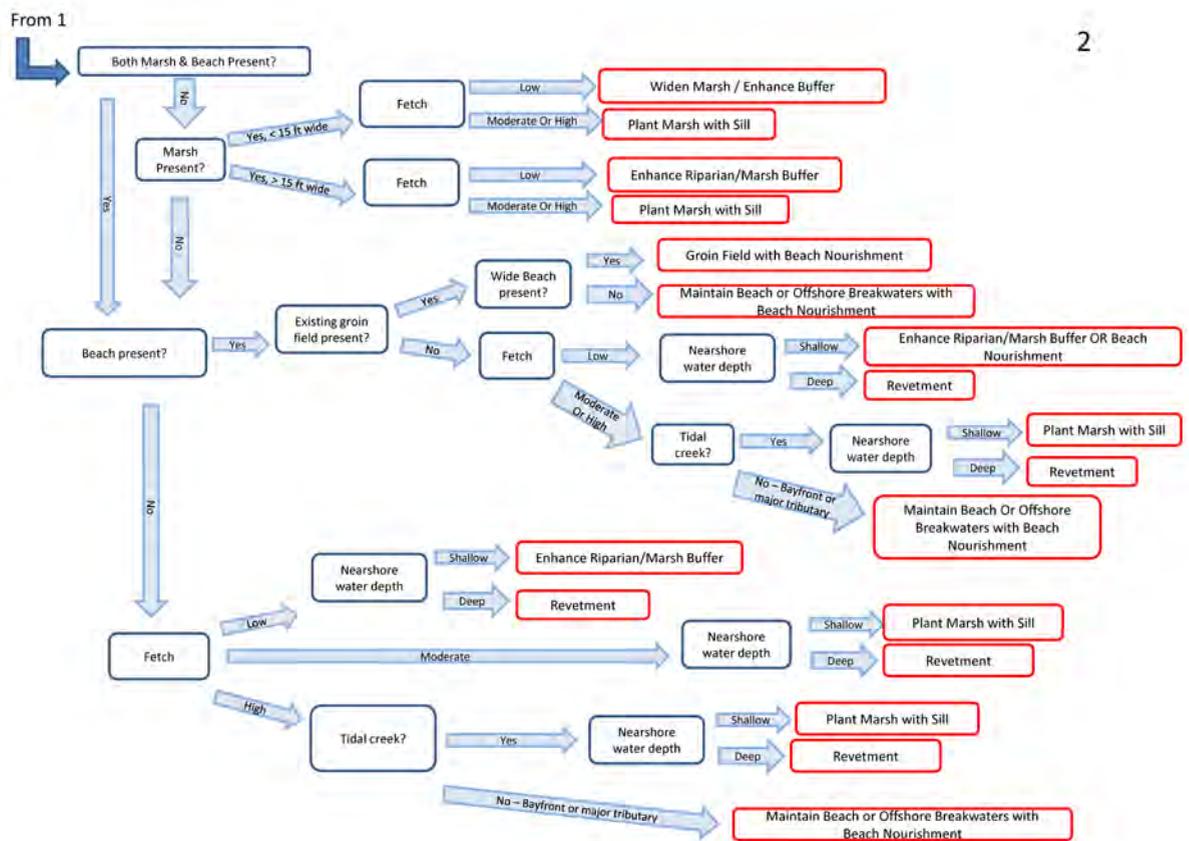
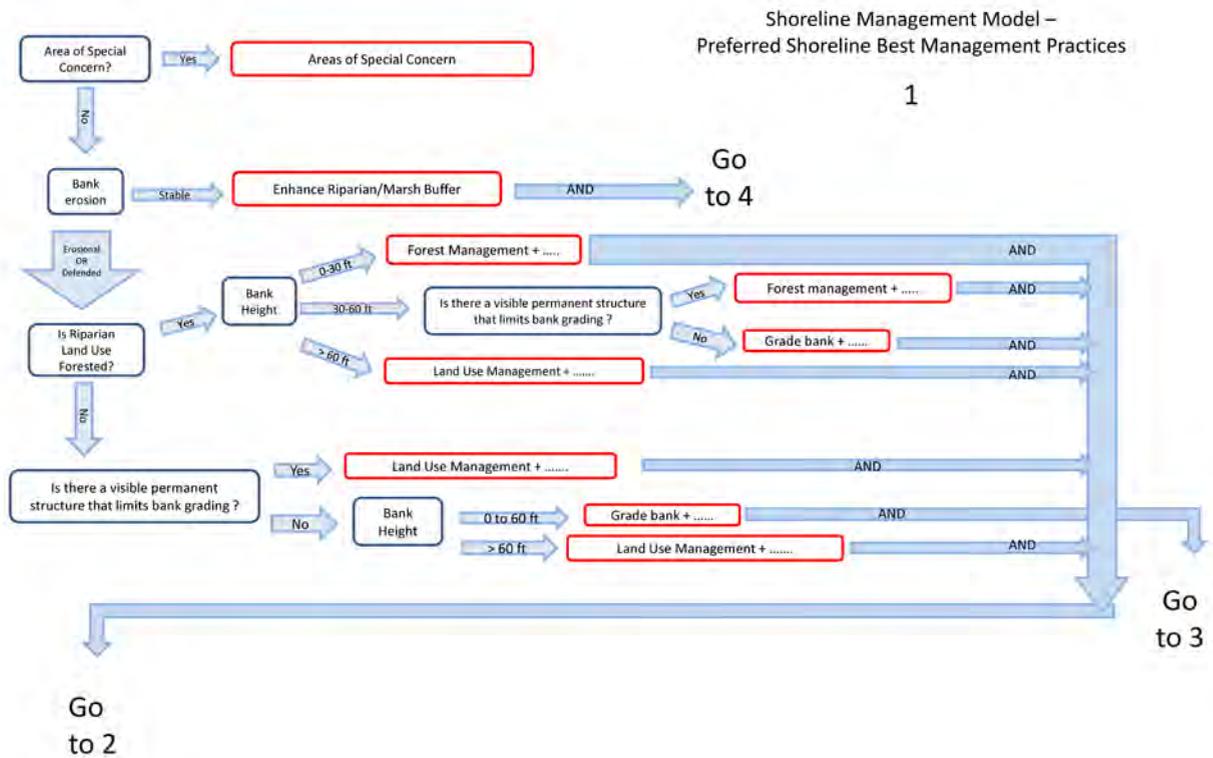
7 References

- Angradi, T.R., E.W. Schweiger, D.W. Bolgrien, P. Ismert, and T. Selle, 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.
- Berman, M.R., H. Berquist, S. Killeen, C. Hershner, K. Nunez, K. Reay, T.H. Rudnicky, and D. Schatt, 2012. *City of Virginia Beach - Shoreline Inventory Report, Comprehensive Coastal Inventory Program*, Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, Virginia.
- 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. *J. Coast. Res* 28: 1437-1445.
- Burke, R., R. Lipcius, M. Luckenbach, P.G. Ross, J. Woodward, and D. Schulte, 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, Virginia Institute of Marine Science, College of William & Mary. Gloucester Point, Virginia.
- Center for Coastal Resources 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.
- City of Virginia Beach, 2009, *Virginia Beach Comprehensive Plan Technical Report and Reference Handbook*. City of Virginia Beach, Virginia.
- Federal Emergency Management Agency, 2009. *Flood Insurance Study: City of Virginia Beach, Virginia and Incorporated Areas*.
- Hardaway, Jr., C.S, D.A. Milligan, and G.R. Thomas, 1993. *Ocean Park, City of Virginia Beach, Public Beach Assessment Report*. Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, Virginia.
- 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, 2010a. *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, C.S., Jr., D.A. Milligan, C.H. Hobbs, III, C.A. Wilcox, K.P. O'Brien, L. Varnell, 2010b. *Mathews County Shoreline Management Plan*. Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, Virginia.

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- Milligan, D.A., C.A. Wilcox, C.S. Hardaway, Jr., M.C. Cox, 2012. Shoreline Evolution: City of Virginia Beach, Virginia, Chesapeake Bay, Lynnhaven River, Broad Bay, and Atlantic Ocean Shorelines. Data Summary Report. Virginia Institute of Marine Science, College of William & Mary, 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, 2007. Mitigating Shore Erosion along Sheltered Coasts. The National Academies Press, Washington, D.C.
- 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., K. Sobocinski, 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, Olympia, Washington.
- Seitz, R.D., R.N. Lipcius, N.H. Olmstead, M.S. Seebo, and D.M. Lambert, 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.
- Smith, B.S. and G.E. Harlow, Jr., 2002. Conceptual Hydrogeologic Framework of the Shallow Aquifer System at Virginia Beach, Virginia. Water-Resources Investigations Report 01-4262. U.S. Department of the Interior, U.S. Geological Survey.
- 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. *J. Coast. Res.* 17:363-370.
- Toscano, M.A., 1992. Record of oxygen-isotope stage 5 on the Maryland inner shelf and Atlantic Coastal Plain – Post transgressive-highstand regime. In Fletcher, C.H., III, and J.F. Wehmiller (eds.), *Quaternary Coasts of the United States: Marine and Lacustrine Systems*, SEPM Special Publication 48: 89-99.
- U.S. Army Corps of Engineers, 1980. Dredging Quantities and Disposal Areas. Norfolk District, Corps of Engineers, Norfolk, Virginia.
- Woodbridge, W.C., 2012. Mapping Virginia. University of Virginia Press, Charlottesville, Virginia.

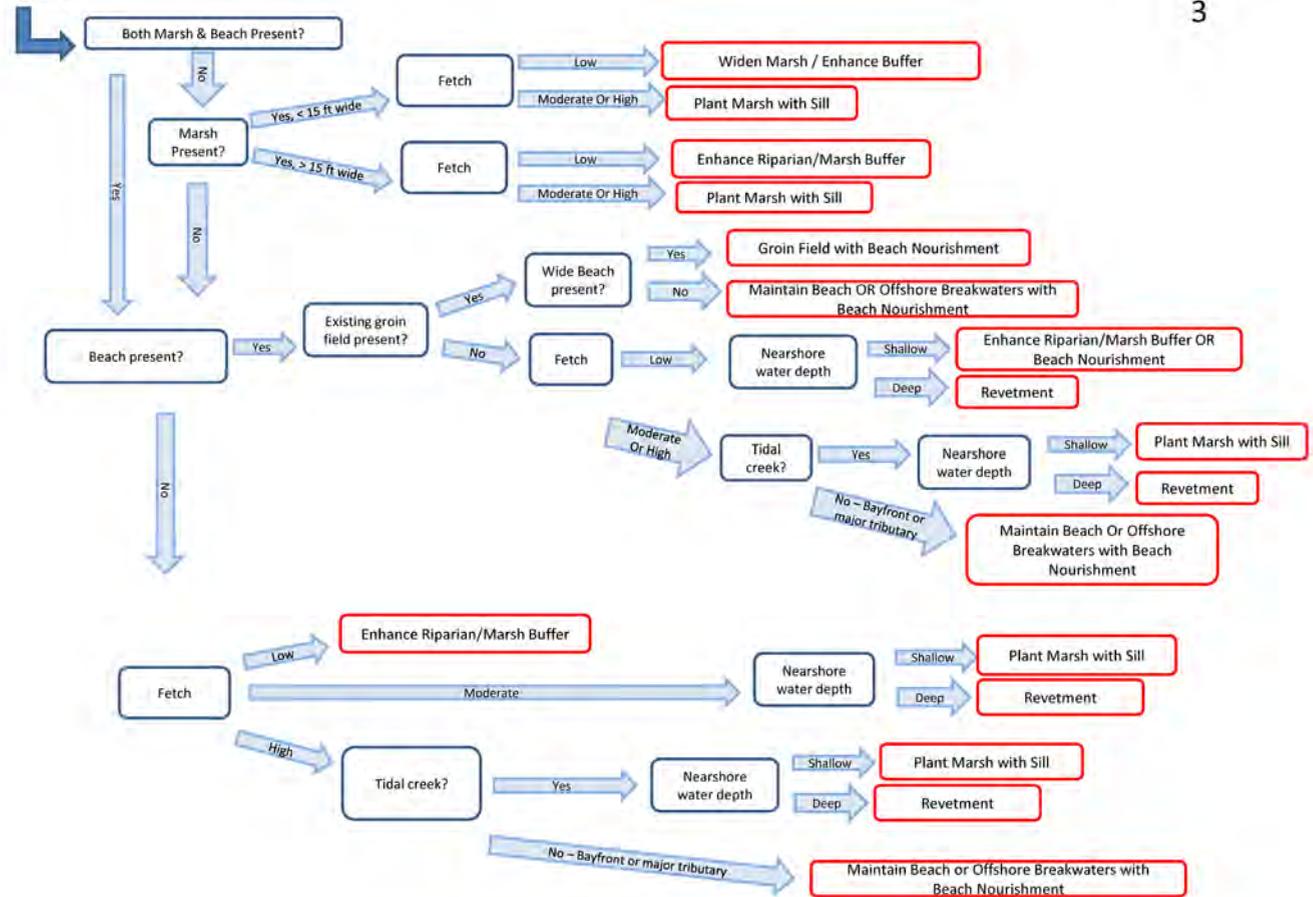
APPENDIX 1

Shoreline Management Model Flow Diagram



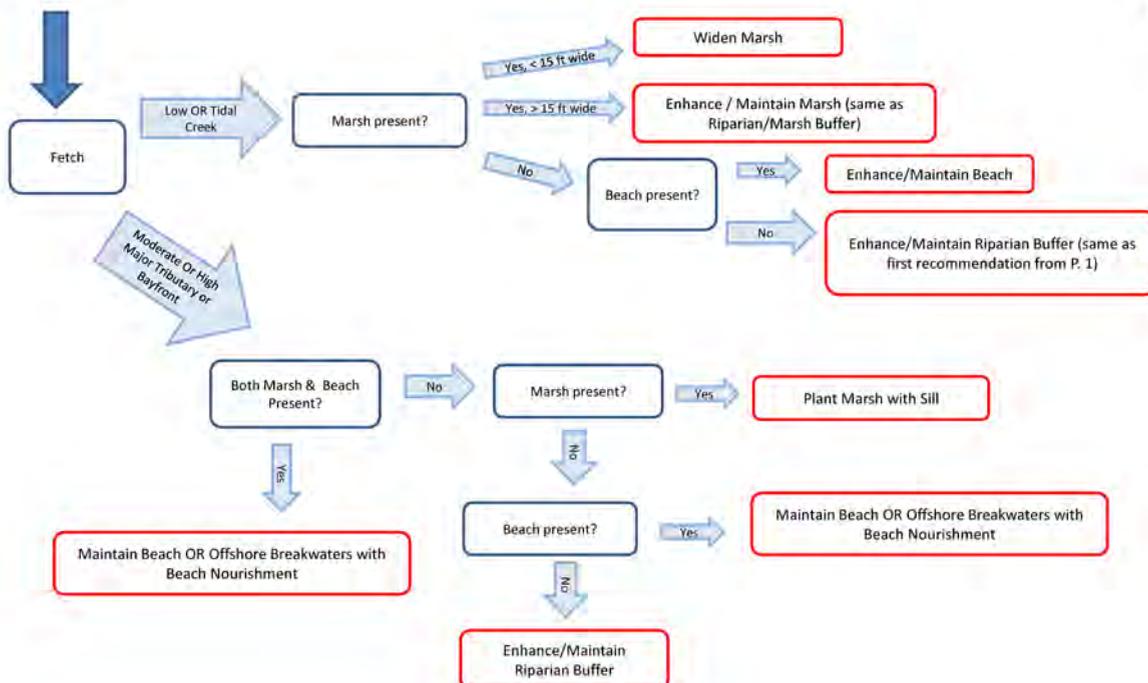
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APPENDIX 2

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. Land use management also may 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 the 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 Lynnhaven River

For Lynnhaven River, two typical cross-sections for stone structures have been developed. The dimensions given for selected slope breaks have a range of values from low to medium energy exposures. Storm surge frequencies are shown for guidance. A range of the typical cost/foot also is provided (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.

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. Along the shores of Lynnhaven River, a low sill might be appropriate (Appendix 3, Figure 1). Along Lynnhaven Bay or areas with an existing bulkhead, a sill as shown in Appendix 3, Figure 2 might be more appropriate.

Type of Structure	Estimated Cost per Linear Foot*
Low Sill, Lynnhaven River	\$150 - \$250
Low Sill, Lynnhaven Bay	\$400 - \$500

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

Table 1. Approximate typical structure cost per linear foot.

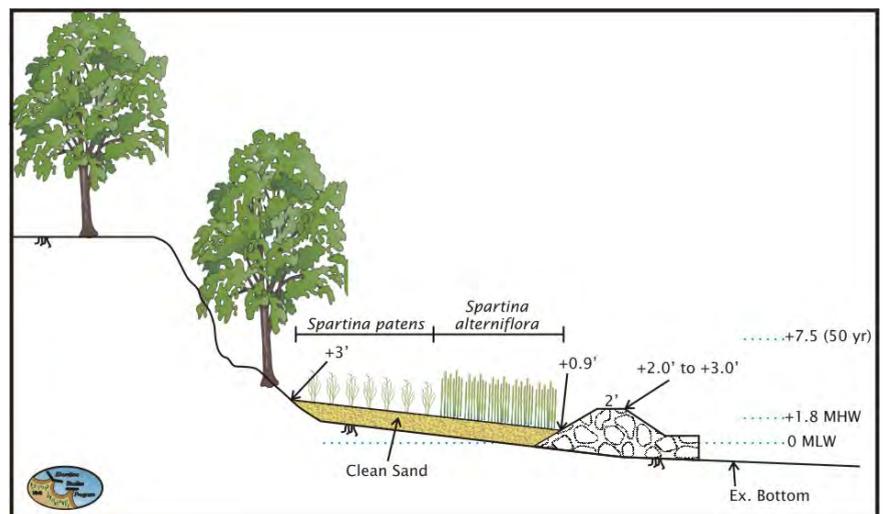


Figure 1. Typical cross-section for a low sill that is appropriate for low energy shorelines of Lynnhaven River. The project utilizes clean sand on a 10:1 (H:V) slope, and the bank can be graded to a (minimum) 2:1 slope, if appropriate.

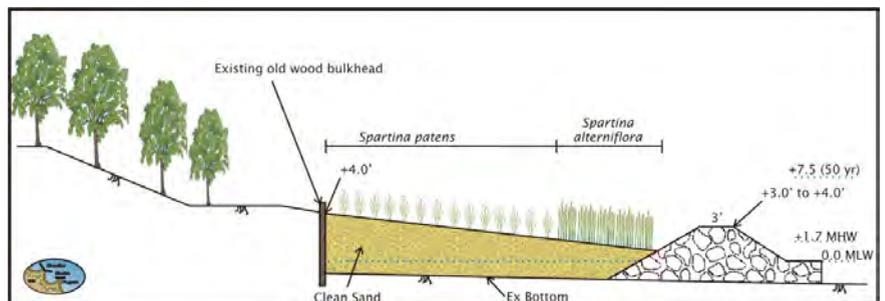


Figure 2. Typical cross-section for a slightly higher sill that is appropriate for the shorelines of Lynnhaven Bay in an effort to replace or protect a failing bulkhead. The project utilizes clean sand on a 10:1 (H:V) slope, and the bank can be graded to a (minimum) 2:1 slope, if appropriate.