Living Shoreline Design Guidelines for Shore Protection in Virginia's Estuarine Environment

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

September 2021

Living Shoreline Design Guidelines for Shore Protection in Virginia's Estuarine Environments

Version 3.0

Special Report in Applied Marine Science and Ocean Engineering #473

C. Scott Hardaway, Jr.
Donna A. Milligan
Shoreline Studies Program

Karen Duhring
Center for Coastal Resources Management

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

This project was funded by the Virginia Coastal Zone Management Program at the Department of Environmental Quality through Grant #NA19NOS4190163 Task 92.02 of the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, under the Coastal Zone Management Act of 1972, as amended. The views expressed herein are those of the authors and do not necessarily reflect the views of the U.S. Department of Commerce, NOAA, or any of its subagencies.

Suggested Reference: Hardaway, Jr., C.S., Milligan, D.A., & Duhring, K. (2021). Living shoreline design guidelines for shore protection in Virginia's estuarine environment (SCRAMSOE #473). Gloucester Point, VA: Virginia Institute of Marine Science.

September 2021

Executive Summary

In December 2006, the Virginia Department of Environmental Quality's Coastal Zone Management Program held a Living Shoreline Summit to promote the use of this shore management strategy. The Summit showed that there is great potential for living shorelines, but that more work is needed to ensure waterfront property owners are aware of this technique as early as possible in the decision process. Providing educational programs for consultants and contractors who work in this field to ensure that they are familiar and comfortable with living shoreline strategies is one way to achieve this. As a result, funding was provided to develop living shoreline design guidance for shore protection. These guidelines were developed in 2010 and revised in 2017 and most recently in 2021. They are meant to address the need to educate consultants, contractors, and other professionals in the use of living shoreline strategies. They provide the necessary information to determine where they are appropriate and what is involved in their design and construction. The guidelines focus on the use of created marsh fringes but also touch on the use of beaches for shore protection as well as more recent use of intertidal oyster reefs.

The 2021 guidelines include the most recent understandings of Chesapeake Bay shorelines in terms of their evolution and sea-level rise, hydrodynamic setting, and the significant storms that have impacted the coast. It also provides specific map and site visit parameters that should be addressed when a shoreline is being assessed. Tools are provided for determining some of these parameters.

The design considerations that go into individual shore management strategies are given. These strategies include the entire coastal profiled from riparian zone to the nearshore. Level of protection, encroachment onto state bottom, and coastal resiliency are described to demonstrate their impact on shore protection design. Finally, living shoreline performance case studies and design examples are provided to demonstrate best management strategies as well as showing where issues occur.

Table of Contents

Introduction

1.1 Statement of the Problem and Purpose

The Chesapeake Bay has about 6.5 million people living in its coastal counties (Cohen, 2018) and much of the shoreline is privately-owned. For communities along the shore, the continual shore retreat may be a problem. When land along the shore shows signs of **erosion**, property owners tend to address it.

In the past, shore stabilization strategies generally were stone revetments or wood bulkheads. Though these strategies are effective at shore stabilization, they can create a disconnect between the upland and the water and typically provide few natural habitats along the shoreline. In fact, over the last 11 years, almost 1,500 new bulkheads or revetments were permitted in Virginia (VMRC, 2021). Estimates suggest that about 18% of the shorelines are hardened with bulkheads and revetments in Maryland and Virginia, which is about 2,000 miles of shoreline (Horan et al., 2014). In the past 30 years, a more natural approach to shore stabilization, termed “living shorelines,” has used marshes, beaches, and dunes effectively to protect the shoreline along Virginia’s creeks, rivers, and bays. Numerous benefits result from this approach to shoreline management including creating critical habitat for marine plants and animals, improved water quality, and reduced sedimentation. In addition, most waterfront property owners enjoy a continuous connection to the water that allows for enhanced recreational opportunities.

Today, living shorelines are recognized as not only a viable option for shore protection, but they are actually a preferred method. Studies of these types of systems have shown that well designed and constructed projects provide habitat and create a natural resilience for communities. To increase the installation of these systems, educating the designers, consultants and contractors who work in the coastal zone is one way to achieve this goal. They are often the people who recommend a shore protection system to property owners, and therefore are the key to involving homeowners in the living shoreline design process. As a result, funding was provided to develop living shoreline design guidance for shore protection and the first contractor’s training course was held in 2010. In an effort to grow the number of contractors, local staff, and non-profit organizations who are familiar with correct living shoreline project design, the guidance and course was again offered in 2017. This latest update offered courses online with both asynchronous and synchronous content due to public health concerns for in-person training. The course materials and class recordings are available online (www.vims.edu/research/departments/physical/programs/ssp/shoreline_management/living_shorelines/class_info).

These guidelines are meant to address the need to educate consultants, contractors, and other professionals in the use of living shoreline strategies for shoreline protection. It provides the necessary information to determine where they are appropriate and what is involved in their design and construction. The guidelines focus on the use of created tidal marsh fringes, but also touch on the use of oyster reefs and beaches for shore protection. The guidelines were created for the Virginia portion of the Chesapeake Bay estuarine system (Figure 1-1) but may be applicable to other similar estuarine environments. These references and tools are for guidance only and should not replace professional judgments made at specific sites by qualified individuals.

Figure 1-1. Virginia Portion of the Chesapeake Bay estuary and location of tide gauges.

1.2 Chesapeake Bay Shorelines

1.2.1 Shoreline Evolution and Sea-Level Rise

Understanding how a shore reach has evolved is important to assessing how to manage it. The **geomorphology** of Chesapeake Bay is a function of the ancestral channels, rising **sea level**, and the **hydrodynamic** impacts of tides and waves. The underlying geology of Chesapeake Bay is the foundation upon which coastal habitats are formed and are constantly moving. The location of uplands, marshes, shoals, and channels are a function of geology. From a historical perspective, the geomorphology can determine where development will occur. Cities and towns were settled along river and Bay reaches with access to deep water, or they were havens from storms and open water.

The Atlantic Ocean has come and gone numerous times over the Virginia coastal plain in the past million years due to warming and cooling of the planet. The westernmost advance of the sea during each melting of the glaciers is marked by a sand ridge called a **scarp**. The land to the east of each scarp is called a **terrace**. The scarps and terraces occur at lower elevations and are younger from west to east. Ancient riverine and coastal scarps, generally formed during sea-level high stands, dictate where high and low upland banks occur. The Suffolk Scarp, for example, runs from Suffolk northward, passes through Gloucester, and continues into Lancaster and Northumberland Counties (Figure 1-2). Lands east of the scarp are low, generally less than 15 ft above sea level, with many thousands of acres of frequently flooded tidal marsh. Lands to the west rise up as high as 30 to 50 ft and flooding usually only occurs along intermittent low drainages.

During the last low stand, the ocean coast was about 60 miles to the east because sea level was about 400 ft lower than today and the coastal plain was broad and low (Toscano, 1992). This low-stand occurred about 18,000 years ago during the last glacial maximum. The present estuarine system was a meandering series of rivers working their way to the coast. As sea level began to rise and the coastal plain watersheds began to flood, shorelines began to recede. The slow rise in sea level is one of two primary long-term processes which cause the shoreline to recede; the other is wave action, particularly during storms. As shores recede or erode, the bank material provides the sands for the offshore bars, tidal marshes, beaches, and dunes.

Global mean sea level has risen about 8–9 inches since 1880, with about a third of that coming in just the last two and a half decades (Lindsey, 2021). The worldwide change mainly results from two factors: the addition or removal of water resulting from the shrinkage or growth of glaciers and land-based ice caps and the expansion or contraction of ocean waters resulting from a change in temperature. In 2019, global mean sea level was 3.4 inches above the 1993 average—the highest annual average in the satellite record (1993-present). From 2018 to 2019, global sea level rose 0.24 inches (Lindsey, 2021).

Relative sea level change at any given location is due to a combination of worldwide change in sea level and any local rise or fall of the land surface. The lower Chesapeake Bay has an anomalously high rate of relative sea-level rise relative to global changes (Table 1-1) because of high rates of land subsidence due to **glacial rebound** and groundwater withdrawal. Estimates of local subsidence due to compaction of the aquifer system from groundwater withdrawal range from 1.5-3.7 mm/yr (Eggleston & Pope, 2013), but Buzzanga et al. (2020) found that Hampton Roads, Virginia has an overall subsidence rate of -3.6 +/- 2.3 mm/year making it very much on the high end of the estimate. Engelhart and Horton (2012) estimate glacial rebound may be causing about 1 mm/yr of land subsidence in the southern Chesapeake Bay. Boon, Brubaker, and Forrest (2010) estimated that, on average, about 53% of the relative sea-level rise in Virginia is due to local subsidence. Recent analysis confirms that mean sea levels have risen more than 1 foot over the last century. The projections of future sea levels are variable, but all forecast scenarios indicate future sea levels will be higher than they are today. Living shoreline projects with nature-based features are sensitive to sea-level rise so it is important to account for this parameter.

1.2.2 Hydrodynamic Setting

The elevation and power of the water at the shoreline are important factors in shore stabilization. The power of the wave is reflected in the **wave climate** that impacts a site. The wave climate varies throughout the Chesapeake Bay estuarine environment due to variation in proximity to the ocean, predominant tidal energy, **fetch** distances, **mean tide range**, currents, and boat wakes. Near the mouth of the Bay, the waves tend to have both bay-internal and bay-external (oceanic) origins. Boon et al. (1990) found that the largest waves (greater than 2ft) in this area were southerly-directed, bay-internal waves with short periods that were created during winter storms. They comprised 2-10% of all the wave measurements taken during the fall and winter months. However, the more prevalent,

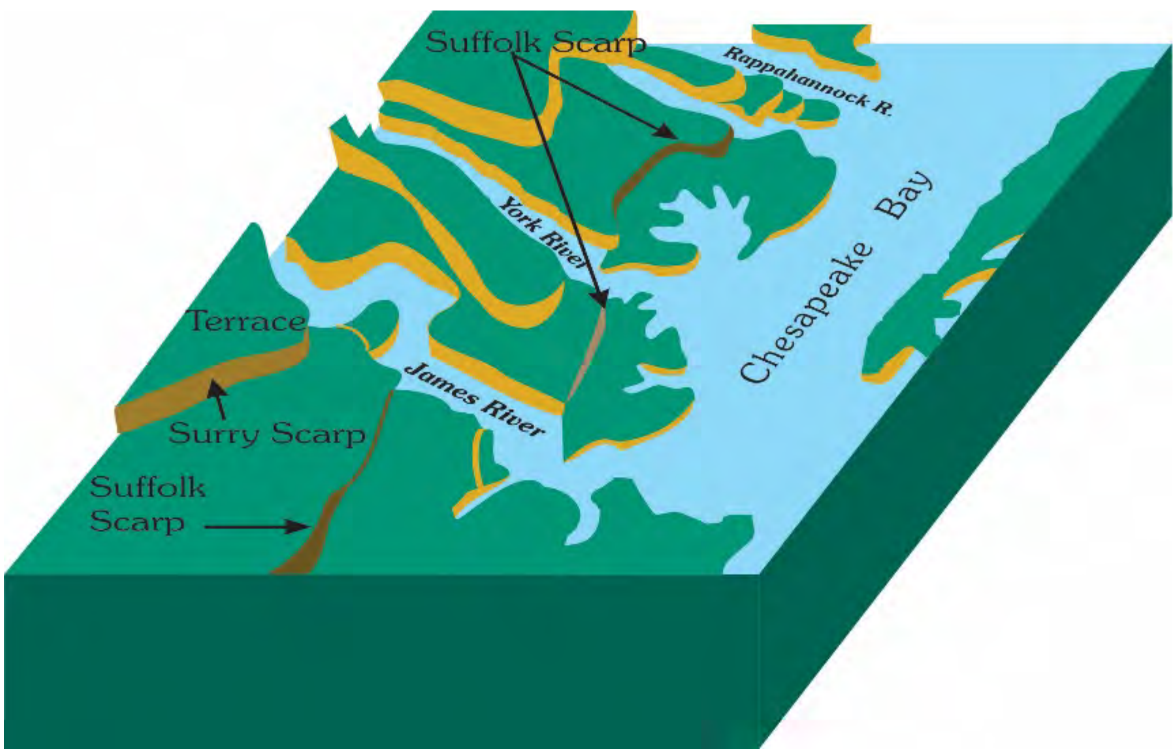

Figure 1-2. Ancient scarp features of the Virginia Coastal Plain (after Peebles, 1984 from Hardaway and Byrne 1999).

Table 1-1. Rate of sea-level rise at selected tide gauge sites in Chesapeake Bay. Data retrieved from NOAA (2021).

Location	Time Frame	Mean SL Trend (mm/yr)	Mean SL Trend (ft/100 yrs)
Baltimore, MD	1902-2020	3.22 ± 0.13	1.06
Annapolis, MD	1928-2020	3.71 ± 0.20	1.22
Cambridge, MD	1943-2020	3.87 ± 0.30	1.27
Solomons Island, MD	1937-2020	3.93 ± 0.23	1.29
Washington, DC	1924-2020	3.43 ± 0.28	1.13
Dahlgren, VA	1972-2020	5.54 ± 0.69	1.82
Lewisetta, VA	1970-2020	5.70 ± 0.59	1.87
Yorktown, VA	1950-2020	4.90 ± 0.34	1.61
Kiptopeke, VA	1951-2020	3.81 ± 0.30	1.25
Chesapeake Bay Bridge Tunnel, VA	1975-2017	5.92 ± 0.72	1.94
Sewells Point, VA	1927-2020	4.73 ± 0.22	1.55

medium-sized waves (0.7 ft to 2 ft) are about equally divided between bay-internal and oceanic waves. During the calmer summer months, locally-generated waves only achieve minimal height, while oceanic waves account for 80% of the medium-sized waves. So, the lower bay shorelines and **benthic** regions are affected by oceanic waves year-round (Boon et al., 1990). Farther away from the Bay mouth, the influence of oceanic waves decreases. Boon et al. (1992) found that the longer-period oceanic waves may contribute some fair-weather waves as far north as Mathews, Virginia, but generally, this area and farther north are outside the Chesapeake Bay mouth region where long-period, non- local waves are present in appreciable numbers.

Varnell (2014) showed a mean increase in shoreward energy along tidal shorelines in lower Chesapeake Bay from 1948 to 2010 due to the longer and more frequent duration of high tide inundation. Energy delivery in lower Chesapeake Bay was primarily from the northeast, and the shoreward energy trend is applicable for shorelines along the Bay's main stem below the mouth of the Mobjack Bay and in adjacent tributaries with fetches of at least three miles. Of those waves generated within the Bay, fetch is the factor that determines what size waves can impact a site. Generally, the larger the fetch (open water distance) along a shore reach, the larger the potential wave energy or wave climate acting on the shoreline and the greater potential for shore change. The greater the fetch exposure, the higher the waves for any given wind speed.

Hardaway and Byrne (1999) categorized wave energy acting on a shoreline into general categories based on a fetch. Fetch exposures are classed as very low, low, medium and high as < 0.5 mile, 0.5 to 1 mile, 1-5 miles and 5-15 miles, respectfully. These categories are typical for creeks and rivers so an additional class is very high (>15 miles) for sites at the mouths of rivers and along the main stem of the Bay. Generally, seasonal winds come from the southwest during the spring and summer and from the northwest in late fall and winter. Wind data from Norfolk International Airport shows the frequency of winds from different directions (Table 1-2). Most winds come from the north and southwest. However, winds from the north and northeast have more occurrences of winds that are larger than 30 mph.

Tide range is another important hydrodynamic factor in effective shore stabilization strategies since projects must be sized correctly for the hydrodynamic regime at the site. The mean tide range is the difference between mean high and **mean low water** levels. The **great diurnal tide range** (spring tide range) is the difference between high and low tidal levels during the periods of increased range around the full and new moons. These ranges vary greatly throughout the lower Chesapeake Bay (Figure 1-3 and Figure 1-4). The tidal datums are based on the 19-year time period established by the National Ocean Service (NOS). The National Tidal Datum Epoch (NTDE) currently used to establish the tidal datum values was 1983-2001. The NTDE needs to be regularly revised to account for long-term effects of land movement, sea-level rise, and changes in **tidal constituents** (NOAA, 2021). This epoch is now undergoing revision and will be replaced using water level data collected between 2002-2020. This new NTDE has a proposed release date of 2025. This information is provided for consideration because due to relative sea-level rise locally, the distinct regions in which tidal marsh plants grow (**biologic benchmarks**) may vary slightly from mapped tidal datums. The difference in these zones should be considered particularly when issues arise with plant growth at a site.

In addition to wind-waves, boat-generated waves can impact Chesapeake Bay shorelines by increasing erosion, sediment resuspension, and nearshore turbidity, particularly in shallow and narrow waterways (Bilkovic et al., 2017). The additional contribution to wind-wave energy from boat wakes tends to be relatively minor except when the height of the largest boat generated waves substantially exceed that of the largest wind-waves. Some tidal creeks are not expected to have erosion problems based solely on narrow fetch distances, yet they are experiencing erosion trends. This phenomenon is commonly attributed to observed boating activity although the available scientific data to validate this observation is limited. The reflection of boat wakes off armored shorelines is another factor that may contribute to the overall wave energy at a given site.

While wind-waves are generally the primary energy force impacting shorelines, tidal currents and freshwater inflows can affect vegetation, cause bank scour, and transport debris during storms (Miller et al., 2016). Project locations with meandering river banks, tidal inlets, stormwater outfalls and other freshwater inputs should factor in the effects of currents on the local hydrodynamic setting.

Table 1-2. Wind occurrences between 1945 and 2010 at Norfolk International Airport.

Number of Occurrences (mph)	S	SW	W	NW	N	NE	E	SE	Total
0-5	6,072	5,452	7,272	7,364	36,097	2,879	3,833	3,618	72,587
5-10	40,130	32,463	28,302	26,169	27,514	26,834	22,295	20,215	223,922
10-20	25,990	33,523	18,711	17,884	34,078	31,018	13,132	9,523	183,859
20-30	1,924	3,740	2,161	2,496	4,569	3,969	811	351	20,021
30-40	46	112	79	49	168	287	51	18	810
40-90	0	1	2	2	14	20	9	1	49
Total	74,162	75,292	56,527	53,965	102,440	65,007	40,131	33,726	501,250

Percent of Occurrences (mph)	S	SW	W	NW	N	NE	E	SE	Total
0-5	1.2	1.1	1.5	1.5	7.2	0.6	0.8	0.7	14.5
5-10	8.0	6.5	5.6	5.2	5.5	5.4	4.4	4.0	44.7
10-20	5.2	6.7	3.7	3.6	6.8	6.2	2.6	1.9	36.7
20-30	0.4	0.7	0.4	0.5	0.9	0.8	0.2	0.1	4.0
30-40	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.2
40-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	14.8	15.0	11.3	10.8	20.4	13.0	8.0	6.7	100.0

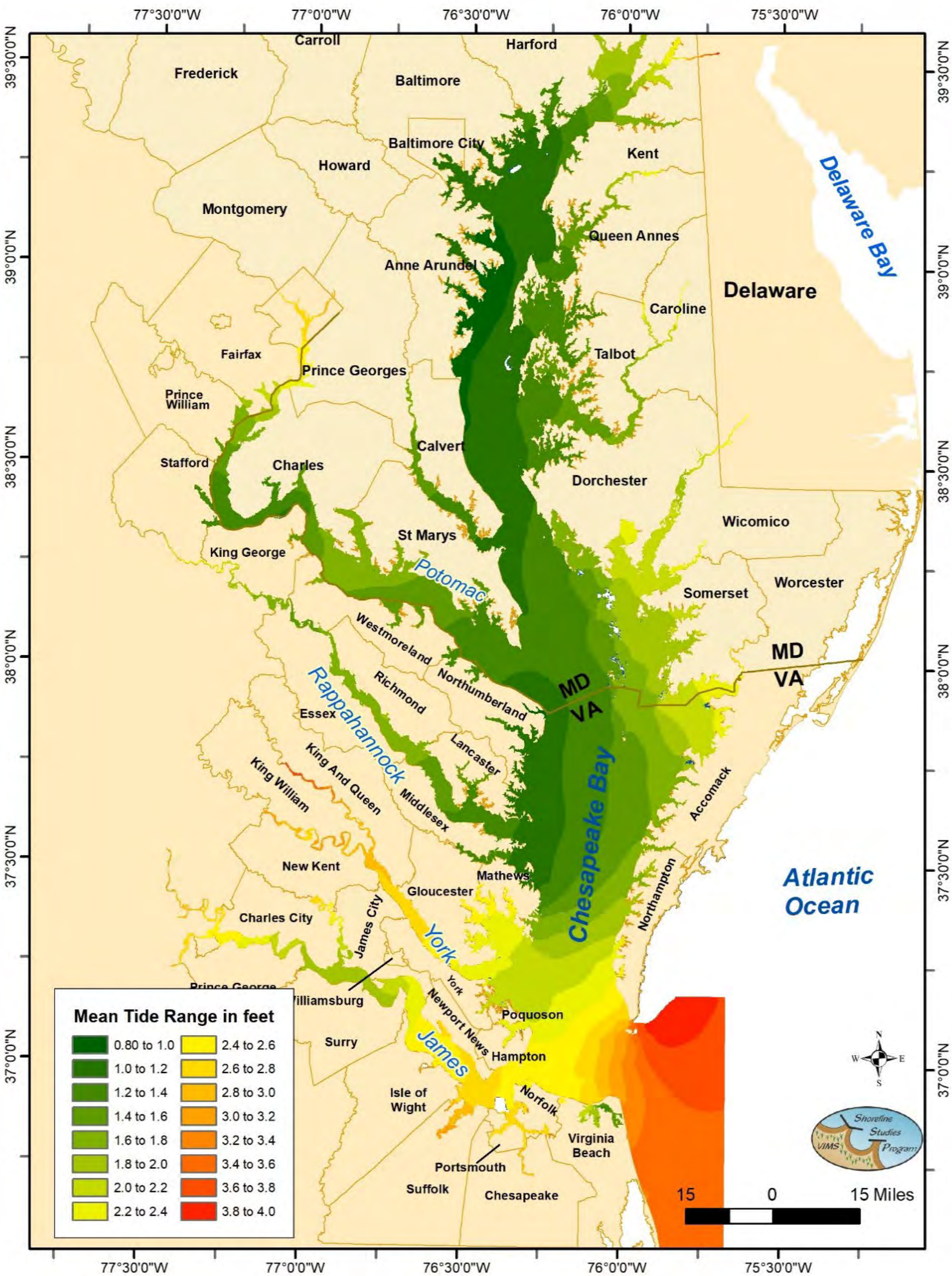

Figure 1-3. Mean tide ranges in Chesapeake Bay. Tide range polygons interpolated in ArcGIS from data points obtained from NOAA Tides & Currents online. Area Google Earth Map is available at
https://www.vims.edu/research/departments/physical/programs/ssp/shoreline_management/living_shorelines/class_info/tideranges_and_conversions/index.php

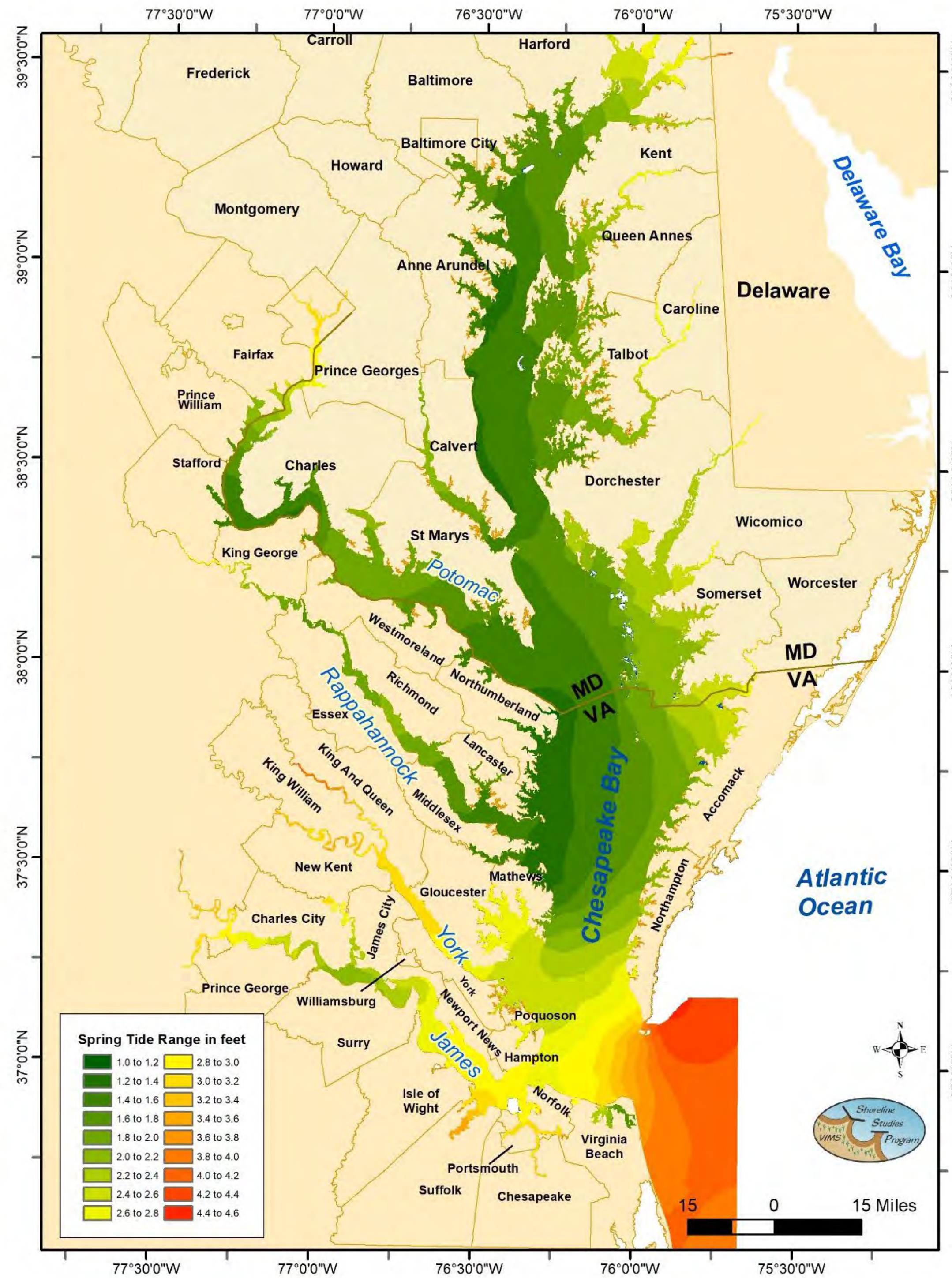

Figure 1-4. Great diurnal (spring) tide ranges in Chesapeake Bay. Tide range polygons interpolated in ArcGIS from data points obtained from NOAA Tides & Currents online. Area Google Earth Map is available at https://www.vims.edu/research/departments/physical/programs/ssp/shoreline_management/living_shorelines/class_info/tideranges_and_conversions/index.php

1.2.3 Significant Storms

High water levels during a storm often result in shoreline erosion and can affect the performance of erosion control efforts at a managed site. Determining the maximum elevation of a surge during a storm is important for design since higher water levels allow waves to travel farther inland or impact higher on a bank. Heavy precipitation during storms may cause erosion and landslides due to stormwater runoff flowing downhill at a shoreline.

Several large storms have impacted various sections of Virginia's coast in the last two decades and can provide information on how storms affect the Chesapeake Bay estuarine system. On September 18, 2003, Hurricane Isabel passed through the Virginia coastal plain. Hurricane Isabel is considered to be one of the most significant tropical cyclones to affect portions of northeastern North Carolina and east-central Virginia since Hurricane Hazel in 1954 and the Chesapeake-Potomac Hurricane of 1933. The main damaging winds, with gusts up to 69 mph at Gloucester Point, began from the north and shifted to the east, then south. Storm surges of 3 to 5 feet above normal tide levels were observed over the central portions of the Chesapeake Bay and 5 to 6.5 feet above normal tide over the southern portion of the Bay in the vicinity of Hampton Roads, Virginia. High surges were also observed at the headwaters of the tributaries, reaching 8.2 feet above normal levels in Richmond City and nearly 5.5 feet above normal in Washington, D.C. (Beven & Cobb, 2003). The highest water level recorded at the Gloucester Point tide gauge was 8.2 feet above MLLW, and data from the gauge indicated the water level was still rising when the station was destroyed (NOAA, 2021).

Tropical Storm Ernesto (September 1, 2006) brought wind speeds of 60 mph and a peak gust of 75 mph with water levels rising above 6.0 feet above MLLW at the Yorktown USCG Training Center tide station (NOAA, 2009). The sustained wind measured at Chesapeake Bay Bridge Tunnel (CBBT) was about 56 miles per hour as the storm approached the lower Bay area. The storm generated a surge of about 3.2 feet at the Chesapeake Bay Bridge Tunnel and more than 2 feet in the middle to upper Bay regions (Knabb & Mainelli, 2006).

The Veterans Day Northeaster, which began impacting the Chesapeake Bay estuarine system on November 11, 2009, was a significant storm that impacted a wide area. No longer a hurricane, Tropical Storm Ida made landfall on the Gulf of Mexico Coast on November 10. It redeveloped as a coastal low-pressure system south of Cape Hatteras, intensified, and became a northeast storm. A high-pressure system blocked northward movement of the low resulting in several days of higher than normal tides. At Sewells Point, the gauge peaked just before midnight on November 12, 2009 at 7.74 feet above MLLW, which was 5 feet higher than the predicted tide. This ranks it as the 5th highest water elevation on record since 1930 and was just 0.2 feet below Hurricane Isabel's storm surge (Ziegenfelder, 2009). The peak wind gust in Norfolk was 74 mph while actual precipitation observations over a 72-hour period at Norfolk International Airport were 7.4 inches, which is almost triple the normal amount of precipitation for the month (Ziegenfelder, 2009). Water levels of 6.9 feet above MLLW with wind speeds at 48 mph and gusts at 58 mph (NOAA, 2009) at Yorktown, Virginia occurred just before midnight on November 12, 2009.

Hurricane Irene made landfall near Cape Lookout, North Carolina on August 27, 2011 as a strong Category 1 storm (Avila & Cangialosi, 2012). In lower Chesapeake Bay, top sustained winds were recorded at 67 miles per hour on the Chesapeake Bay Bridge Tunnel and the maximum wind gusts were recorded at 76 miles per hour in Williamsburg (Avila & Cangialosi, 2012). Money Point in Chesapeake, Virginia had the largest storm surge in Chesapeake Bay of 4.82 feet, and the total storm tide was 8.48 feet (Avila & Cangialosi, 2012). Storm surge decreased up the Bay. Hurricane Irene may have even increased the rate of aftershocks following an earthquake on 23 August 2011 in Virginia (Lovett, 2013).

Hurricane Sandy was a unique storm that made landfall in New Jersey on October 29, 2012 with 80 mph sustained winds (Blake et al., 2013). With 72 deaths in the United States, Sandy was the deadliest hurricane since Agnes in 1972. With its high storm surge, NOAA tide gauges recorded storm tide values of between 9 and 10 feet above **mean higher high water (MHHW)** in New Jersey and New York, damage was significant and power outages were widespread. In Chesapeake Bay, tide gauges recorded heights of 5 to 6 feet above MHHW, and heavy rains in eastern Maryland and Virginia occurred during the storm. Overall, U.S. damage estimates were near $50 billion making Sandy the second-costliest hurricane since 1990 (Blake et al., 2013).

Hurricane Matthew impacted South Carolina as a Category 1 hurricane on 8 October 2016. It was the first tropical storm to make landfall in the US in October since Hurricane Hazel in 1954 (Stewart, 2017). The eye wall of the storm moved back offshore and remained offshore while moving north causing heavy rains onshore. Severe coastal flooding occurred in southeastern Virginia with the highest inundations of 3-4 feet in Hampton Roads (Stewart, 2017). Catastrophic bank collapse and shoreline erosion also was reported after this storm due to the large volume of stormwater runoff.

Between 2000 and 2020, the Mid-Atlantic saw nearly twice as many hurricanes as the preceding two decades, 1980–2000 (Marisa, 2021). Since the 1980s, North Atlantic hurricanes, which includes the Atlantic north of the equator, the Gulf of Mexico, and the Caribbean, have increased in intensity, frequency, and duration with more storms occurring earlier in the year. Tropical Storm Bertha in late May 2020 was the sixth consecutive year for a tropical storm before June 1. The strongest hurricanes threatening the Virginia coast, categories 4 and 5, have also increased in frequency including Hurricane Florence (Category 4) in 2018 and Hurricane Dorian (Category 5) in 2019. This increase in wind speed of storms has consequences for the shorelines they impact. Modeling of storm winds showed that a 10% potential increase in wind speed can lead to a 20% increase in the significant wave heights generated by these winds (Takagi et al., 2011). Rapid intensification of tropical systems has also been increasing, with storms reaching wind speeds and precipitation amounts not experienced before.

Effective shoreline management strategies take all of these shoreline parameters into consideration, including historic shoreline evolution and sea-level rise trends, the physical location of the project site in relation to predominant wind direction and fetch distances, stormwater runoff patterns and the storm surge history of the site. It is important to assess historic shoreline trends to understand what physical parameters are having the most effect on shore transgression. It is also important to forecast future conditions such as sea-level rise and habitat changes based on available information to achieve sustainable shoreline protection over time. It is becoming more challenging to determine how living shoreline designs should incorporate both current and expected future water level conditions.

2 Site Evaluation

2.1 Shoreline Variables

To determine the appropriate course of action, if any, along tidal shorelines, it is important to understand the nature of the problem and the coastal setting. Many parameters affect the estuarine shorelines of Virginia, but the importance of any given parameter is site- specific. For the purpose of site evaluation, the parameters can be categorized as map parameters that are not easily observed and site visit parameters that are not easily captured remotely in maps or aerial photographs. Site visit parameters also include ground-truthing data collected from remote sources while maps can be used to verify seasonal on-site observations. Consideration for many parameters is imperative regardless of shoreline project type. Some of the parameters are especially important for nature-based living shoreline type projects. A presentation created for the training class on this topic can be found here https://www.vims.edu/research/departments/physical/programs/ssp/_docs/2-site-parameter-tools-presentation-2021.pdf.

Map Parameters: fetch, depth offshore, shoreline morphology, shoreline orientation, nearshore morphology, submerged aquatic vegetation (SAV), tide range, storm surge frequency, erosion rate, design wave determination, sea level rise, artificial shellfish reefs

Site Visit Parameters: fastland bank condition, bank height, bank composition, nearshore stability, confirm nearshore water depth, Resource Protection Area buffer, upland land use/proximity to infrastructure/cover, width and elevation of sand beach or low marsh, width and elevation of backshore region, boat wakes, existing shoreline defense structures, natural and created shellfish reefs

Map parameters can be determined from a variety of available, online resources. This online data can be used to pre-evaluate a site, but visiting the site is still necessary to confirm parameters needed for project design. Specific characteristics of the site visit parameters are discussed in the next section, and a Site Evaluation Sheet has been developed to help standardize data collection for each site (Appendix A).

The VIMS Center for Coastal Resources Management (CCRM) has online tools to assist with evaluating existing shoreline conditions, such as bank conditions, existing natural erosion buffers, marine resources, and bathymetric contours. These tools include comprehensive shoreline and tidal marsh inventories, decision tools, and a shoreline management model with best practice recommendations. This information is served online on a locality basis through Comprehensive Coastal Resource Management portals that include comprehensive map viewers that display various shoreline data layers (http://www.vims.edu/ccrm/ccrmp/index.php).

The Shoreline Studies Program at VIMS has digitized historic and recent shorelines along the Virginia portion of Chesapeake Bay. These 1937, 2009, and 2017 shorelines were used to calculate the long-term rate of change at points along the shoreline. These shorelines and change rates are depicted on a shoreline evolution GIS map viewer (www.vims.edu/research/departments/physical/programs/ssp). Google Earth, in particular, is an excellent tool that is free to the public (http://earth.google.com/). Google Earth can be used to determine fetch, shoreline geometry, shoreline orientation, and, in some cases, erosion trends by viewing imagery from the past. In addition, custom Google Earth applications for some parameters such as tide range and bathymetry were developed by the VIMS Shoreline Studies Program and made available on their website (https://www.vims.edu/research/departments/physical/programs/ssp/shoreline_management/living_shorelines/class_info/tideranges_and_conversions/index.php).

Navigational charts are available from the National Oceanic and Atmospheric Administration's (NOAA) Office of Coast Survey. Their interactive Chart Catalog provides a map to locate nautical charts that can be downloaded in Adobe Acrobat format (http://www.charts.noaa.gov/InteractiveCatalog/nrnc.shtml). These are convenient tools for determining depth offshore and nearshore morphology.

NOAA's Digital Coast web site provides easy access to authoritative data and tools to help conduct shoreline evaluations, including imagery, land cover, and coastal Lidar elevation data. This site also has information that might be helpful for property owner education to explain the benefits of integrated green infrastructure practices (https://coast.noaa.gov/digitalcoast/).

2.1.1 Map Parameter Measurement

A. Shoreline Orientation

The shoreline orientation is the direction the shoreline faces and is measured perpendicular to the shore (Figure 2-1). If **shore orientations** vary significantly along the length of the subject shoreline, they should be measured separately. For example, shore orientation A, shown in Figure 2-1, is approximately southeast while shore orientation B is east. It has been shown that shorelines that face northward along the main tributary estuaries of the Chesapeake Bay erode two to three times faster than southern-facing shores (Hardaway and Anderson, 1980). Therefore, this becomes an important parameter when fetch exposures increase above about 1/3 mile. North-facing shorelines in tidal creeks may be shaded if the bank is high and/or trees are present. This might restrict the ability to create a marsh fringe or to improve upland **riparian** buffer vegetation.

B. Fetch

Fetch is one of the most important overall parameters. Two assessments of fetch, average and longest, will provide the information needed for project design (Figure 2-1). Average fetch is calculated by determining the distance to the far shore along five transects. The main transect is perpendicular to the shore orientation and two transects 22.5 degrees apart are located on either side. These five measurements are then averaged [(F1+F2+F3+F4+F5)/5]. The second measurement, longest fetch, is the distance from the site across open water to the farthest shore. This measurement can be important to determine possible conditions during storms when water levels and wave energy are higher.

Hardaway and Byrne (1999) stated that average fetch exposures can be classed as very low, low, medium and high as < 0.5 mile, 0.5 to 1 mile, 1-5 mile and 5-15 miles. These categories are typical for creeks and rivers so an additional class might be very high (> 15 miles) for sites at the mouths of rivers and along the Bay. Higher shoreline erosion rates generally occur along more open shore reaches (i.e., those with greater fetch exposures). If two or more fetch exposures occur due to a significant change in shoreline orientation, then a separate fetch measurement is required for each fetch exposure.

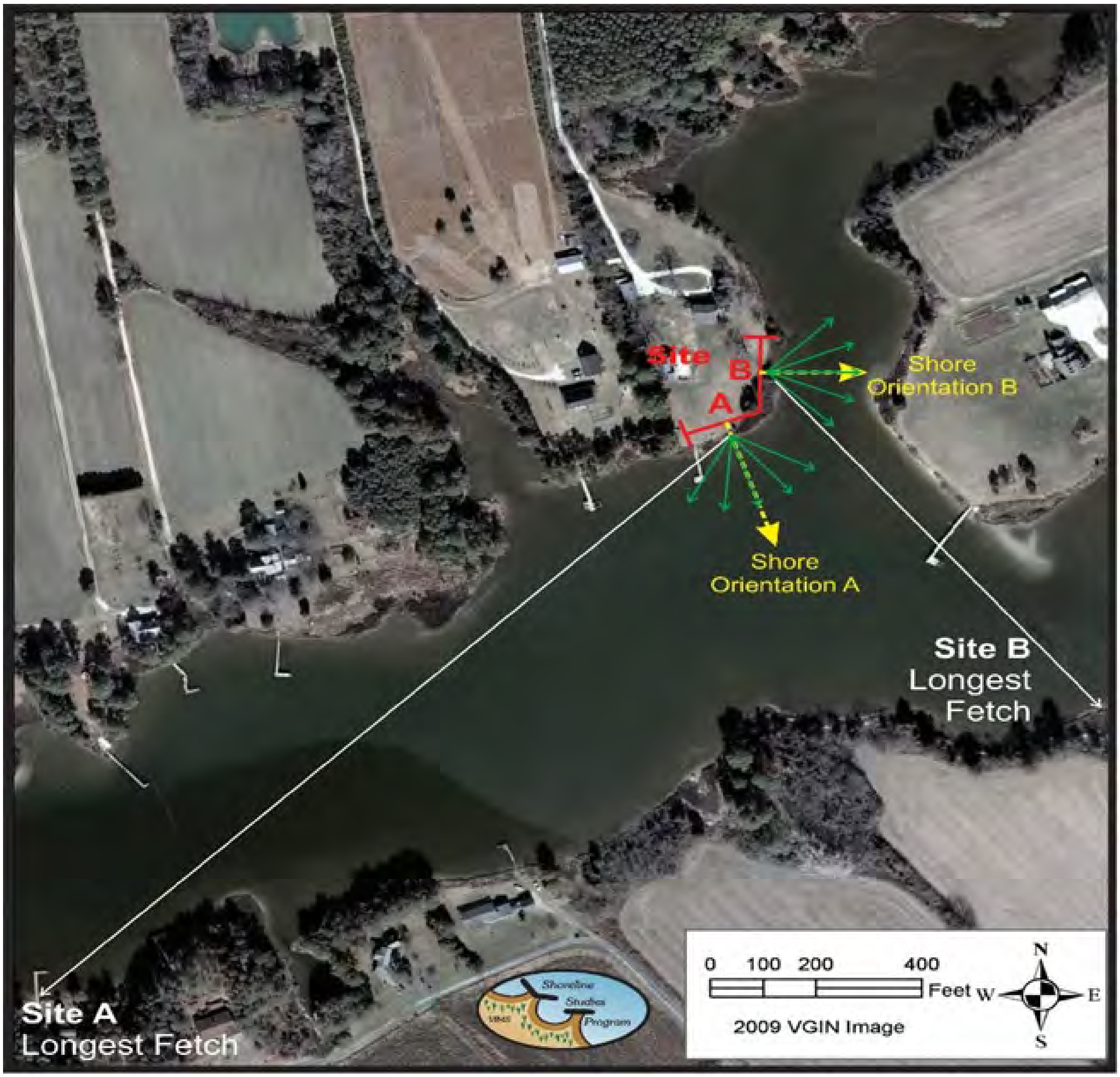

Figure 2-1. Photo depicting the longest fetch for two sections of a site. Section A's shore orientation (direction of face) is southeast while Section B's orientation is east. The green arrows show the vectors measured to determine average fetch while the white arrows show the vector of the longest fetch. Average fetches are measured from the shoreline to the opposite shoreline along the vector line.

C. Shore Morphology

Shore morphology, or structure, can be a difficult parameter to assess because of the variation in types of shoreline throughout Chesapeake Bay. The essence of this parameter is to determine the level of protection from wave action provided by the morphology. A pocket or embayed shoreline (Figure 2-2) tends to cause waves to diverge, spread wave energy out, and thus reduce erosion impacts (Figure 2-3). Open, linear shorelines and headlands tend to receive the full impact of the wave climate. The irregular shoreline, sometimes caused by scattered marsh patches or groins, tends to breakup **wave crests** along its length, reducing impacts.

Figure 2-2. Photo illustrating four different kinds of shoreline morphology in Chesapeake Bay. Photos: VGIN 2009.

According to Hardaway and Byrne (1999), before any shoreline strategy is planned, the site should be evaluated within the context of the "reach." A "reach" is defined as a segment of shoreline where the erosion processes and responses are mutually interacting. For example, very little sand is transported by wave action beyond a major headland, creek mouth, tidal inlet, or major change in orientation which is an important factor in planning shore protection structures. Also, several properties with different owners and land uses may occur along a reach.

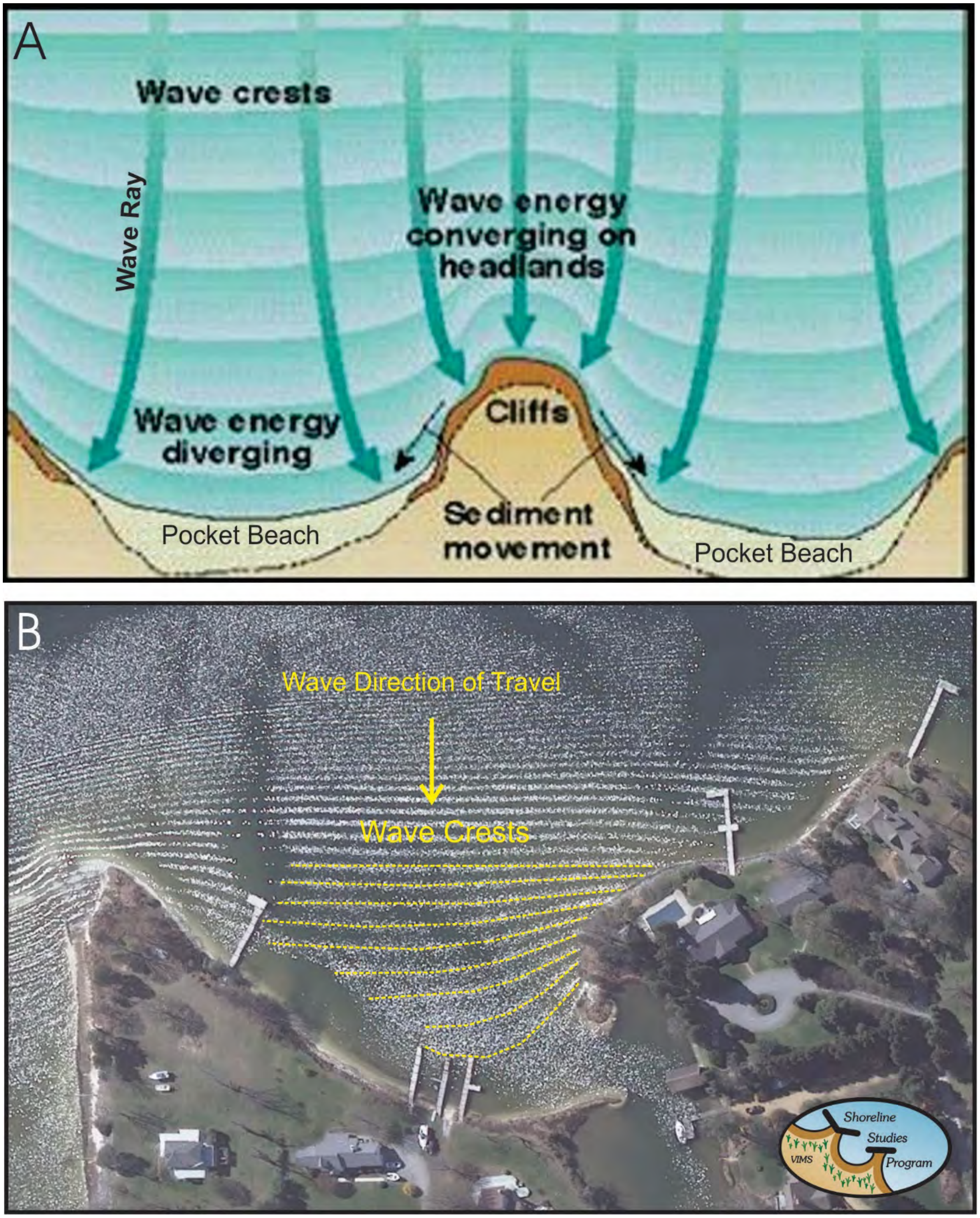

Figure 2-3. ***Refraction*** *of incoming waves occurs due to changes in depth contours. A) waves are refracted with a pocket beach such that they diverge or spread but converge or concentrate on the outside edges and at headlands. B) Waves are refracted at a pocket shoreline at Tabbs Creek, Lancaster, VA.*

D. Depth Offshore

The nearshore gradient will influence incoming waves and the amount of scour or sediment transport that can be expected. The distance from the shoreline to the 6-ft contour reflects the slope and extent of the nearshore estuarine shelf. A broad shallow nearshore tends to attenuate waves relative to an area with the same fetch but with deeper water offshore. This parameter is measured on a chart from the middle of the subject shore and normal (perpendicular) to the shore in the offshore direction. Some maps may have the bathymetry in meters, in which case the measurement is to the 2-meter contour. The Shoreline Studies program has a Google Earth application that displays the 3- and 6-foot contours in Chesapeake Bay derived from NOAA bathymetry data.

The very nearshore depth where possible sills or breakwaters may be sited may dictate the cost feasibility of these structures. If a site has a deep nearshore (greater than about 3 ft deep, 30 ft seaward of MLW), a revetment located against the upland bank might be the preferred alternative from a cost-benefit perspective. Field verify the nearshore depth on site by walking at least 30 feet seaward from the approximate mean low water and measuring the water depth at low water with a measuring rod.

E. Nearshore Morphology

This parameter evaluates the occurrence or lack of offshore tidal flats and sand bars. These features are often associated with a shallow nearshore region as indicated in Depth Offshore parameter. Extensive tidal flats and/or sand bars will act to reduce wave action against the shoreline. Sand flats indicate that sand is available in the overall system and can indicate a hard bottom that will hold a structure with minimal settling. Measuring these features is somewhat qualitative, and the situation is best analyzed using recent vertical aerial photography, such as on Google Earth, or at the site at low tide (Figure 2-4). Navigational charts will also show the existence of tidal flats along tidal shorelines and could be used to support field observations.

F. Nearshore Submerged Aquatic Vegetation (SAV) & Shellfish Reefs

Nearshore SAV, where present, can have a significant effect on wave attenuation (Figure 2-5). Seagrass beds efficiently attenuate waves before reaching the shoreline (Fonseca and Cahalan, 1992; Koch, 1996; Nowacki, Beudin, & Ganju, 2017). The distribution of SAV within Chesapeake Bay is mapped annually and these maps are made available at a VIMS web site (http://web.vims.edu/bio/sav/). In addition, a site visit in the summer will help determine if SAV exists adjacent to the site. If SAV habitat is located offshore of a project site, it can affect the acceptability of certain structures. In general, avoiding construction in these areas is the preferred course of action by the regulatory agencies.

Naturally occurring oyster reefs are no longer common in Chesapeake Bay, but the number of created artificial reefs, backyard oyster gardening and the shellfish aquaculture industry have all been increasing in Virginia. There is a growing popularity to incorporate shellfish reef elements in living shoreline designs as submerged or intertidal features. A living shoreline reef is designed to evolve to provide wave attenuation and habitat benefits where the natural recruitment and growth of shellfish is already productive and where water quality conditions are suitable.

Figure 2-4. A VGIN 2009 photo shows the channel into Cranes Creek in Northumberland County, VA. Sand bars north of the channel will attenuate waves while the shoreline adjacent to the channel has no bars and will feel the full effect of the waves impacting the shoreline.

The presence of live adult oysters and spat set on structures or natural reefs in the project vicinity suggests the potential for a successful living shoreline reef. Mapped information can be used to help predict if a project site is suitable for new shellfish reef projects. The Chesapeake Bay Foundation has information and maps on utilizing oysters as part of living shoreline designs (https://www.cbf.org/about-cbf/locations/virginia/issues/living-shorelines/are-oysters-an-option-for-your-living-shoreline.html). The Virginia Marine Resources Commission (VMRC) maintains a Chesapeake Bay map with locations of large oyster sanctuary reefs and private oyster ground leases that might (but not always) indicate productive shellfish harvesting (https://www.mrc.virginia.gov/links.shtm). A VIMS Virginia Oyster Productivity Information Tool identifies areas where current conditions could support a shellfish aquaculture growing operation and possibly also a productive living shoreline shellfish reef based on a model of surrounding ecosystem conditions (https://cmap2.vims.edu/OysterInfoToolVa/).

Figure 2-5. A VIMS aerial photo of Pond Point on the East River in Mathews County, VA (dated 21 April 2009) showing extensive SAV in the nearshore, as well as sandbars.

G. Tide Range and Sea Level Rise

The pattern of tide ranges throughout the Bay are a function of the Coriolis Effect (Boon, 2004). This parameter is important for determining the size and crest height of project structures for energy dissipation as well as the width and slope of the created marsh fringe, particularly for intertidal species like *Spartina alterniflora*. The tide range is also important for the growth of living reef elements such as oysters and ribbed mussels. The local tide range at the nearest tide station can be found at the NOAA Tides and Currents website (http://tidesandcurrents.noaa.gov) or in Figures 1-3 and 1-4 which were generated using NOAA data. The VIMS Tidewatch Network web site provides tide observations and forecasts for eight individual stations in Virginia plus peak water levels and analyses of recent storms (http://www.vims.edu/bayinfo/tidewatch/index.php). The related VIMS Tidewatch Map provides 36-hour water level forecasts based on real-time tide and weather data (https://cmap2.vims.edu/SCHISM/TidewatchViewer.html).

Important sea-level rise considerations for living shoreline project designs include accurate, short-term tide range estimates and the potential for long-term marsh migration up slope. The reported local tide range based on the previous tidal epoch that ended in 2001 may not be accurate or consistent with observed water levels at a project site. Sea-level rise may also be important when deciding if landward or channelward slope changes are the best approach. More than one sea-level rise scenario should be evaluated ranging from a continuation of the historic trend at a minimum to a high rate of sea-level rise in future scenarios. U.S. Sea-Level Report Cards project recent sea-level trends to the year 2050 and are available for localities in Chesapeake Bay and around the US (https://www.vims.edu/bayinfo/bay_slrc/index.php). Another source for visualizations of current and future seal-level rise scenarios can be viewed using AdaptVA sea-level rise tools (http://adaptva.org/info/forecasts.html).

H. Storm Surge

Storm surge return frequencies can be found in FEMA's Flood Insurance Studies (FIS) for all localities in Virginia. Knowing the predicted water level during certain storms will help determine the level of protection that a living shoreline project can provide. A 100-yr storm surge means that there is a 1-percent chance that the stated water level will occur in any given year. The 50-yr and 25-yr storm surge levels have a 2 percent and 4 percent chance of occurring in any given year. Storm waves on top of the storm surge increase the height of the water that impacts the coast.

The FIS are available through FEMA's portal (http://msc.fema.gov/portal). This site allows you to input an address, then click on "show all products for this area" to get a list of Effective Products. The FIS should be part of this list and available for download. Virginia's Flood Risk Information System is another tool that serves FEMA Flood Insurance Rate Maps (FIRM) and Flood Insurance Studies (FIS) data in an easy to use map viewer (https://consapps.dcr.virginia.gov/VFRIS/).

Generally, FEMA provides storm surge levels relative to the North America Vertical Datum 1988 (NAVD88). In order to determine the water level relative to a tidal datum, usually MLLW, it must be converted. To simplify conversion, Figure 2-6 shows the elevation difference between NAVD88 and MLLW in Chesapeake Bay. Add this elevation difference to the FEMA surge to get the water level relative to MLLW. A VIMS Shoreline Studies Program custom Google Earth application shows the elevation difference between NAVD88 and MLLW around the Bay (https://www.vims.edu/research/departments/physical/programs/ssp/shoreline_management/living_shorelines/class_info/tideranges_and_conversions/index.php).

I. Erosion Rate

Long-term erosion rates indicate how critical or necessary shore stability is at a site. Some sites may have undercut banks or precipitation-caused erosion but show almost immeasurable rates of change over the long-term. This may indicate a landscaping issue rather than a wave or tide-induced shore erosion issue. The easiest way to determine long-term shoreline change rates is to use the Shoreline Studies Program's (SSP) shoreline evolution database and interactive map viewer that displays rates of change between 1939, 2009, and 2017 (http://www.vims.edu/research/departments/physical/programs/ssp/shoreline_evolution/gis_maps/index.php). This tool has interactive layers that can be turned on and off for viewing. The 1937, 2009, and 2017 photos can be displayed as well as the calculated rates of change along the shoreline. Not all Virginia shorelines have been completed in each locality. However, SSP is adding localities and updating others.

Generally, the long-term end point shore rate of change shown on the map viewer is the long-term rate of change, usually determined between 1937/38 and 2009 and between 1937/38 and 2017. Shoreline evolution reports are available at the VIMS Shoreline Studies Program web site for most localities as well although many are outdated. If a specific project site does not exist in the VIMS shoreline evolution database or to see shoreline changes since 2009, the time slider in Google Earth is an alternative tool. The time slider shows historical aerial imagery, where available. By measuring from fixed onshore features to the shoreline in each year of available photos, determining the difference and dividing by the number of years will provide an estimated shore erosion rate. For instance, if photos dated 1994 and 2009 are available (Figure 2-7A and B), the measured distance from the tennis court to the shoreline is 218 ft and 204 ft, respectively. By subtracting these numbers (14 ft) and dividing by the number of years between photos (15 years), the rate of change is -0.9 ft/yr, which is very low erosion (Milligan et al., 2009).

J. Design Wave

The frequency and size of impinging waves upon the base of the bank are the primary cause for shoreline erosion. Many methods are available for determining a maximum design wave. A great deal of time and money can be used modeling detailed site conditions. However, a roughly-estimated wave will provide the necessary information for design of small living shoreline systems, particularly rock size. The Virginia Department of Transportation (2017) used the Corps' deep-water forecasting relationship which is based on successive approximations in which wave energy is added due to wind stress and subtracted due to bottom friction and percolation. A wave height and period can be estimated based on wind speed, duration, and fetch length (Figure 2-8).

Using the curves includes deciding on a sustained wind speed and knowing the average fetch. Table 1-2 may be of use in determining an average wind speed. At a site with a 2-mile fetch with a storm that has a 40-mph onshore wind, the design wave is roughly-estimated at about 1.75 ft, 2.5 second. These are **significant wave heights** which are defined as the average of the highest 33% of the wind/wave field and are often used in rock size determination.

This method does not account for wave attenuation across the fetch. The predicted wave may be more or less than an actual storm wave, but it is a quick, easy method that provides a basis for design. Many more sophisticated, computerized wave models exist and can be used for this purpose as well.

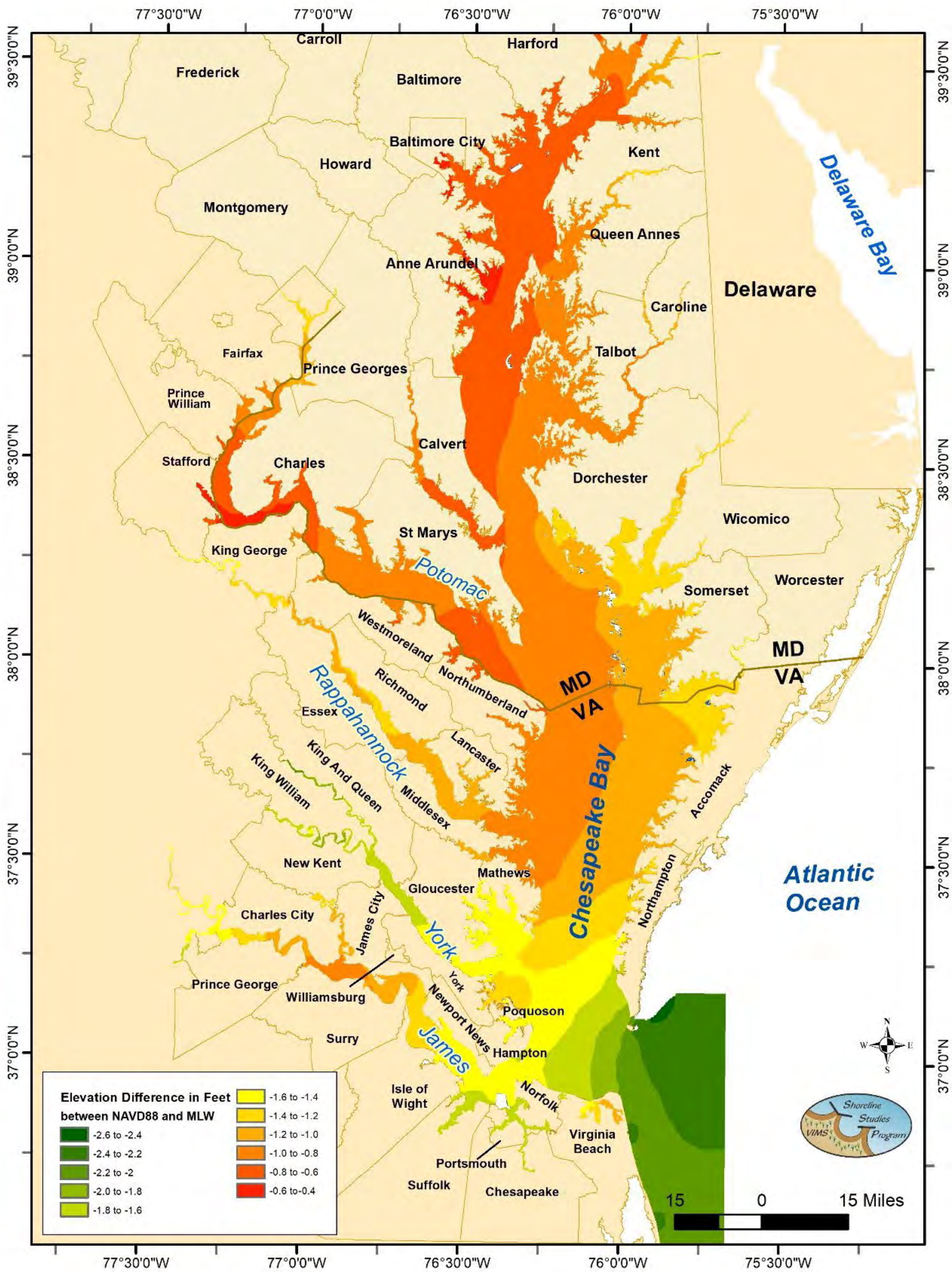

Figure 2-6. Map depicting the elevation difference between NAVD88 and MLW in Chesapeake Bay. Data calculated using NOAA's VDATUM grids. Datum transformation grid TSS was subtracted from the MLLW datum transformation grid to obtain the elevation differences. A Google Earth application is available at www.vims.edu/research/departments/physical/programs/ssp/shoreline_management/living_shorelines/class_info

2.1.2 Site Visit Parameters

A. Site Boundaries

Knowing the legal parcel boundaries of a project site is an important aspect in determining what strategies are necessary. Transitioning into adjacent parcels might need to be considered. End effects as well as downdrift impacts of structures must be considered. Understanding the project sites' setting within the coastal reach also is important, for example: is the shoreline easily accessible for project construction, what significant or sensitive natural and cultural resources are located in the parcel vicinity, and what are the predominant land and water uses. Virginia parcel boundaries can be viewed using the AdaptVA interactive map viewer in the Infrastructure category under General Infrastructure (http://cmap2.vims.edu/AdaptVA/adaptVA_viewer.html). Zoom in to see the available tax map parcels from the Virginia GIS Clearinghouse portal.

B. Site Characteristics

In order to determine if living shoreline projects are feasible, knowing the upland land and shoreline recreation uses, the proximity of the shoreline to infrastructure, as well as the amount and type of vegetation cover is important. Keep in mind that not all upland improvements are readily visible. Underground utilities, drinking water wells and septic systems also should be located. These improvements and characteristics may affect the level of protection needed, the location of design features and/or construction access and staging.

C. Stormwater Runoff

The existing stormwater runoff patterns and management strategies should be evaluated. Recognizing where erosion is primarily caused by stormwater runoff versus tidal waters will be important for selecting shore management strategies. Not accounting for stormwater runoff patterns at living shoreline project sites can lead to challenges with project construction and establishment, especially with the heavy rainfall events recently experienced in coastal Virginia. Stormwater runoff velocity and volume increases with the amount of hard impervious surfaces located near the shoreline that prevent water from soaking into the ground. Runoff also can flow easily over bare ground with compacted soils such as that found under the heavy shade of trees where recreation activities occur.

Erosion caused by upland runoff commonly occurs at docks, piers and boat ramps because of the direct access pathways down slope that channel flowing water. Look for existing stormwater conveyances at large impervious surfaces close to the shoreline, like parking lots, buildings, and recreation areas. Existing residential practices may include roof gutters, rain barrels, dry wells that may not be plainly visible, mulched landscape areas, pathway steps, and other small-scale attempts to control runoff. Collect local knowledge of site conditions during rainfall events from the property owner or visit the site during a heavy rainfall to monitor runoff patterns.

Stormwater best management practices along shorelines are designed to slow and capture stormwater runoff before it leaves the upland area. New ponding of water may result and could affect property uses and adjacent properties. Seeking expert advice may be necessary to ensure the best technique is chosen and correctly designed. The Chesapeake Stormwater Network provides a variety of information about stormwater management, including how to recognize and evaluate different small and large-scale Best Management Practices (http://chesapeakestormwater.net/). The Virginia Conservation Assistance Program (VCAP) provides stormwater management tools, technical assistance, and funding support for some practices, including living shorelines (http://vaswcd.org/vcap). The Chesapeake Bay Landscape Professional certification program has a directory of professionals with stormwater management practice training and experience (https://cblpro.org/). Local government staff responsible for enforcing the Chesapeake Bay Preservation Act and stormwater engineers might also be able to assist with evaluations of stormwater runoff problems and possible solutions at a particular site.

D. Bank Condition

The condition of the fastland bank is the best indication of how frequently wave action reaches the base of bank. Other factors can make significant contributions to erosion, such as upland runoff, freeze/thaw and groundwater seepage, but storm waves are the main cause of most shore erosion in Chesapeake Bay. Stable banks are indicated by a relatively gentle bank face slope with abundant vegetative cover and no undercutting along the base of bank (Figure 2-9A). The other extreme is the vertically exposed bank that may be slumping and generally lacks stabilizing vegetation (Figure 2-9B). The intermediate case is a bank that is partially stable along much of its slope but has evidence of undercutting along the base of bank by wave and water action (Figure 2-9C) or stormwater runoff over the top of the bank. In fetches larger than 0.5 miles, undercutting and an exposed base of bank reveals potential long-term instability of the bank slope. Seeping or free-flowing groundwater visible on the bank may be an important factor to consider for bank grading feasibility and restoring vegetation on the graded slope.

E. Bank Height

Bank height may be uniform across the entire project parcel or it might be variable. Bank height can be measured from a chart or obtained from the VIMS shoreline inventory that used lidar data, but a site assessment is recommended. The fastland bank height is measured from **mean high water (MHW)** to the top of the bank. High banks erode slower than low banks exposed to a similar wave climate (Hardaway and Anderson, 1980). The main effect is that high banks tend to slump material from the upper bank to the base of the bank. This slump material offers a wave buffer for a period of time before the in-situ bank is once again eroded. Usually a severe storm will carry the slump material off leaving the base of bank exposed and the process begins again. When low banks erode the sediments are quickly removed, and the process continues. If the base of bank is eroding, the entire bank face slope is potentially unstable.

For very low sandy shorelines, the base and top of the bank may not easily be determined because the slope is very gradual. The bank face is essentially indiscernible. This condition usually is associated with shore features such as a marsh fringe or a wide beach and backshore. The non-discernible bank (NDB) is usually less than 3 ft above mean high water. Since the base of bank is difficult to define, the measurement of shore zone features which depend on base of bank make assessments problematic. Alternative structures or land use changes may be more appropriate to address the stabilization of NDBs, particularly if flooding rather than erosion is the primary concern.

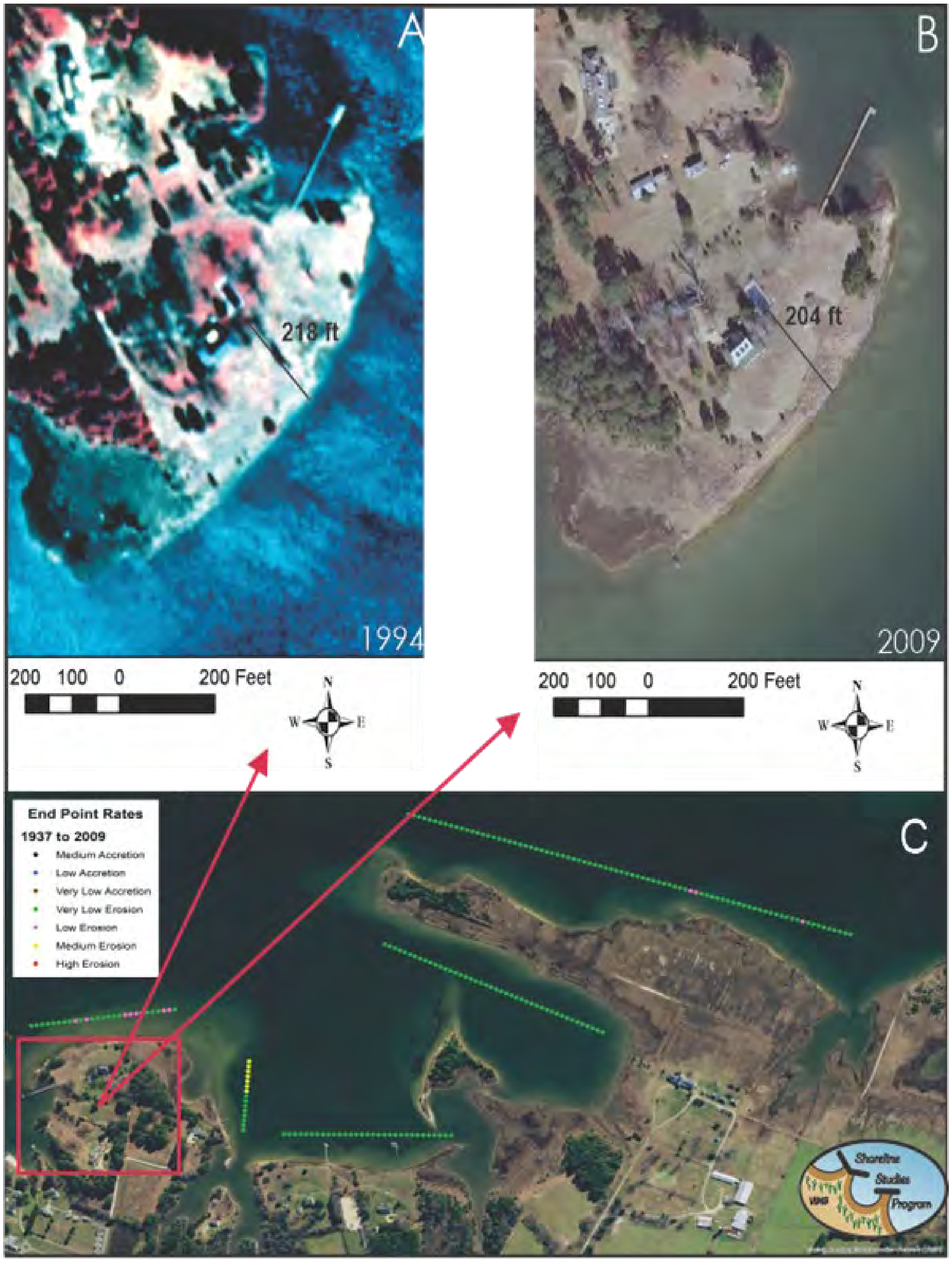

Figure 2-7. Determining rate of change along the shoreline. Aerial photos of a site in Gloucester County in A) 1994 and B) 2009. C) The end point rate of shoreline change determined between 1937 and 2009. Rates are visualized as different colored dots and show the variability of rates of change along small sections of shore (from Milligan et al., 2009)

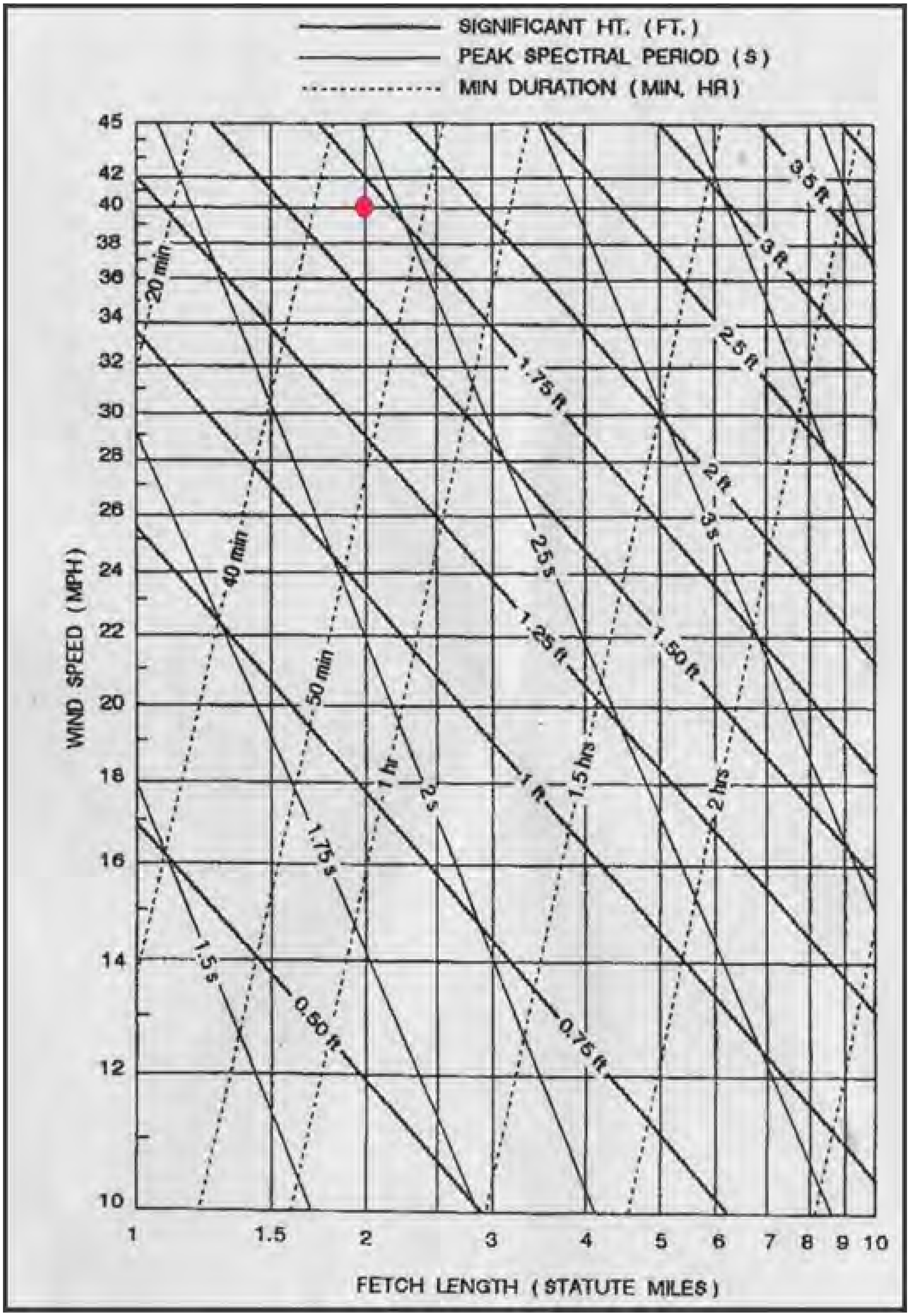

Figure 2-8. Wave height and period estimation using wind speed, duration, and fetch. Appendix 13B-1 from VDOT (2017).

F. Bank Composition

It is difficult to determine the composition of bank sediments unless the soil is exposed or borings are taken. Bank exposure would generally indicate at least some wave induced erosion and period of high water acting on the base of bank. Hard marls and tight clays are more erosion resistant than unconsolidated sand banks. Other types of bank material will have more intermediate erosion rates (Miller, 1983). Knowing the bank composition is also important to design slope vegetation improvements. Standard soil tests can be performed to determine the soil pH and other important growing condition parameters for plant species selection and soil amendment requirements.

Another reason to determine bank composition is to determine if the material can be used in a living shoreline system design. Sandy upland soil can be mined from the bank and used as the planting substrate for created tidal marshes. The preferred material for beach nourishment and planted tidal marshes should contain no more than 5 percent passing the number 200 sieve and no more than 10 percent passing the number 100 sieve. The material shall consist of rounded or semi-rounded grains having a median diameter of 0.6 mm (+/-0.25 mm). In order to determine bank sediment grain size a channel sample should be taken along a section of the bank. Once the sample is mixed up to make it homogenous, it can be compared to a geotechnical gauge (search in Google for geotechnical gauge to see an example) to determine approximate grain size. Certain laboratories in the region will process a sediment sample and provide an accurate grain size distribution of the sample.

G. Riparian Buffer Vegetation

The type and amount of vegetation growing on the bank in the upland riparian buffer indicate erosion potential and what actions may be effective. The density and type of bank vegetation help determine if bank grading and shoreline construction access are feasible. The native and invasive plant species present will guide landscape designs for bank restoration.

Stable bank faces are indicated by mature trees of various ages growing vertically, regardless of bank slope. Multiple layers of canopy trees, understory trees, shrubs, **herbaceous** plants, and ground covers also indicate stability. An indiscernible transition from wetland to upland vegetation moving upslope from the shoreline is another indicator of a stable bank.

Dead, dying, severely leaning and undercut trees indicate bank erosion and a potential for tree fall. Herbaceous plants only without any woody trees or shrubs may indicate periodic erosion or bank slumping with gradual re-colonization. These intermediate conditions indicate a transitional bank face.

Unstable banks may have bare exposed soil and a relative absence of bank vegetation due to active erosion or unconsolidated sediments too loose for plants to grow. The absence of vegetation also may result from previous disturbances, such as clearing, grading, or herbicide use. Trees of uniform age, stands of invasive, colonizing species such as Asian privet or Japanese honeysuckle, and tree stumps are indicators of human disturbance, rather than natural erosion conditions. In some cases, simply allowing the native riparian vegetation to recover naturally is effective for reducing erosion. The riparian buffer conditions on adjacent shorelines and across the water also may help explain observed conditions.

Tools to assist with the evaluation of the existing native plant community include field guides and regional native plant guides made available on the Plant Virginia Natives web site (https://www.plantvirginianatives.org/). Expert advice about existing native plants and landscape designs for riparian buffers can be obtained from Certified Chesapeake Bay Landscape Professionals. A directory of these native plant experts is available on their web site (https://cblpro.org/).

H. Intertidal Shore Zone Width and Elevation

The intertidal shore zone is usually dominated by two features, beach and/or low, intertidal marsh. The beach is measured from MHW to the beginning of upper marsh or dune-type vegetation (Figure 2-10). If a project area is dominated by a sandy beach feature, then beach nourishment may be a viable option to improve protection. A shore dominated by low marsh (*Spartina alterniflora*) extends from the seaward limit of the marsh (usually mean tide level [MTL]) to just above MHW, where the upper high marsh or backshore zone begins. The living shoreline design options most suitable for project areas dominated by low tidal marshes include existing marsh expansion or new planted marshes with sills. Sometimes the intertidal shore zone may be composed of patchy marsh headlands with small pocket beaches between. Sometimes a wide, protective marsh is experiencing erosion along the marsh edge and reducing marsh edge erosion may be a desired stabilization strategy. An accurate assessment and mapped location of existing intertidal marsh and beach features will help guide project planting plans, plus they are necessary for permit applications. The VIMS tidal marsh inventory provides maps to compare with on-site evaluations, especially during late fall and winter when many tidal marshes are not visible above ground. These maps are available in the AdaptVA interactive map viewer under the category Natural

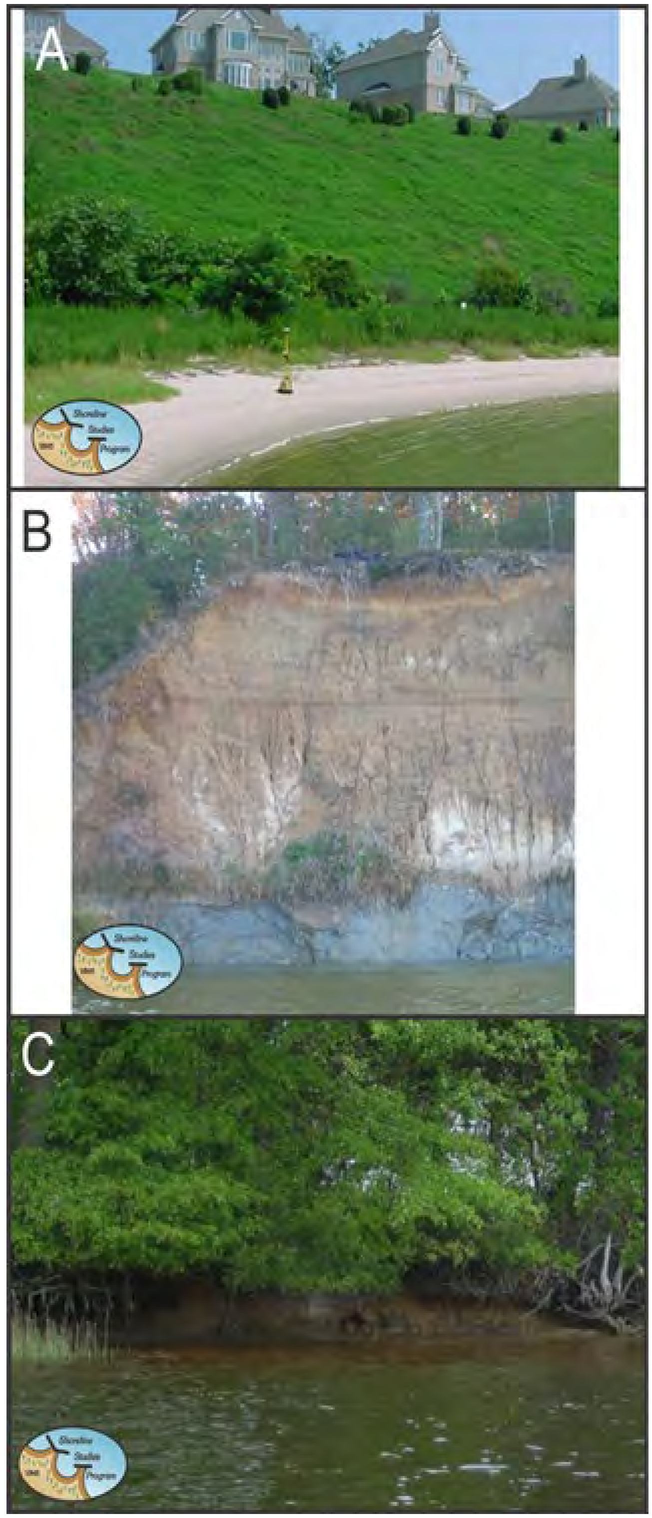

Figure 2-9. Bank condition example photos A) A stable base of bank and bank face that has been graded and planted with vegetation; B) An unstable base of bank and bank face. The different colored layers indicate different types of material; C) An undercut bank.

Resources (http://cmap2.vims.edu/AdaptVA/adaptVA_viewer.html).

Beaches and marsh fringes serve the same basic purpose which is to attenuate wave action. If the marsh fringe or beach and backshore are narrow or nonexistent then waves can generally act directly on the base of an upland bank causing chronic erosion. The wider these features the more wave dampening will occur. How much wave energy is reduced before reaching the upland bank during storm periods of high water and wave action will determine the stability of the bank face. Knutson et al. (1982) studied the effect of *Spartina alterniflora* on wave dampening. This research showed that the first 8 ft of the marsh would dissipate about 50% of small waves, not higher than the plants. All of the wave energy would be dissipated within 100 ft of marsh.

I. Backshore Zone Width and Elevation

The backshore zone is usually higher in elevation than the intertidal shore zone and is the last natural wave attenuating feature before the base of bank is reached. It usually is an upper or high marsh, a sandy backshore terrace with upland grasses and trees, or a dune environment. The backshore zone is measured from the beginning of the upper marsh, where the low marsh ends just above MHW, to the base of bank. The sandy backshore terrace or dune is measured from where the beach intertidal shore zone stops and the upland or dune vegetation begins, to the base of bank. Once again it can be difficult to characterize and accurately measure the intertidal shore zone and backshore zones. The combined, interconnected width of these features should be evaluated.

J. Boat Wakes

The presence and effect of boat wakes along a given shoreline will often be difficult to ascertain. It is the cumulative effect of many boat passages that result in shoreline erosion and change. Some local knowledge of how the adjacent waterway is used throughout the year and observing or video

recording how boat wakes interact with the shoreline is helpful. Shorelines next to navigational channels would most likely be directly affected by boat wakes including No Wake Zones (Zabawa and Ostrom, 1980; Fonseca and Cahalan, 1992). The occurrence of marinas and docking facilities and the number of visible piers nearby are indicators of potential boat traffic. The main point is whether there is enough boat activity to adversely affect the shoreline based on whether the boats are small with planing hulls designed to ride on top of the water, or if there is frequent passage of boats with displacement hulls that ride in the water pushing it to the side as they move forward. The number and frequency of very large displacement hulls like tanker ships, and trawlers, may be a factor that influences project design. Often in very narrow waterways high boat traffic of any kind will produce a severe wave climate that would not otherwise exist from wind driven waves. Therefore, a judgement call is required to determine the importance of this parameter.

K. Existing Shoreline Access & Defense Structures

The location of existing piers, boathouses, decks, stairs, paths, and other waterfront access structures should be identified. Waterfront recreation uses should also be noted, such as swimming beaches, boat ramps and mooring areas, and canoe-kayak launch sites. If shoreline defense structures

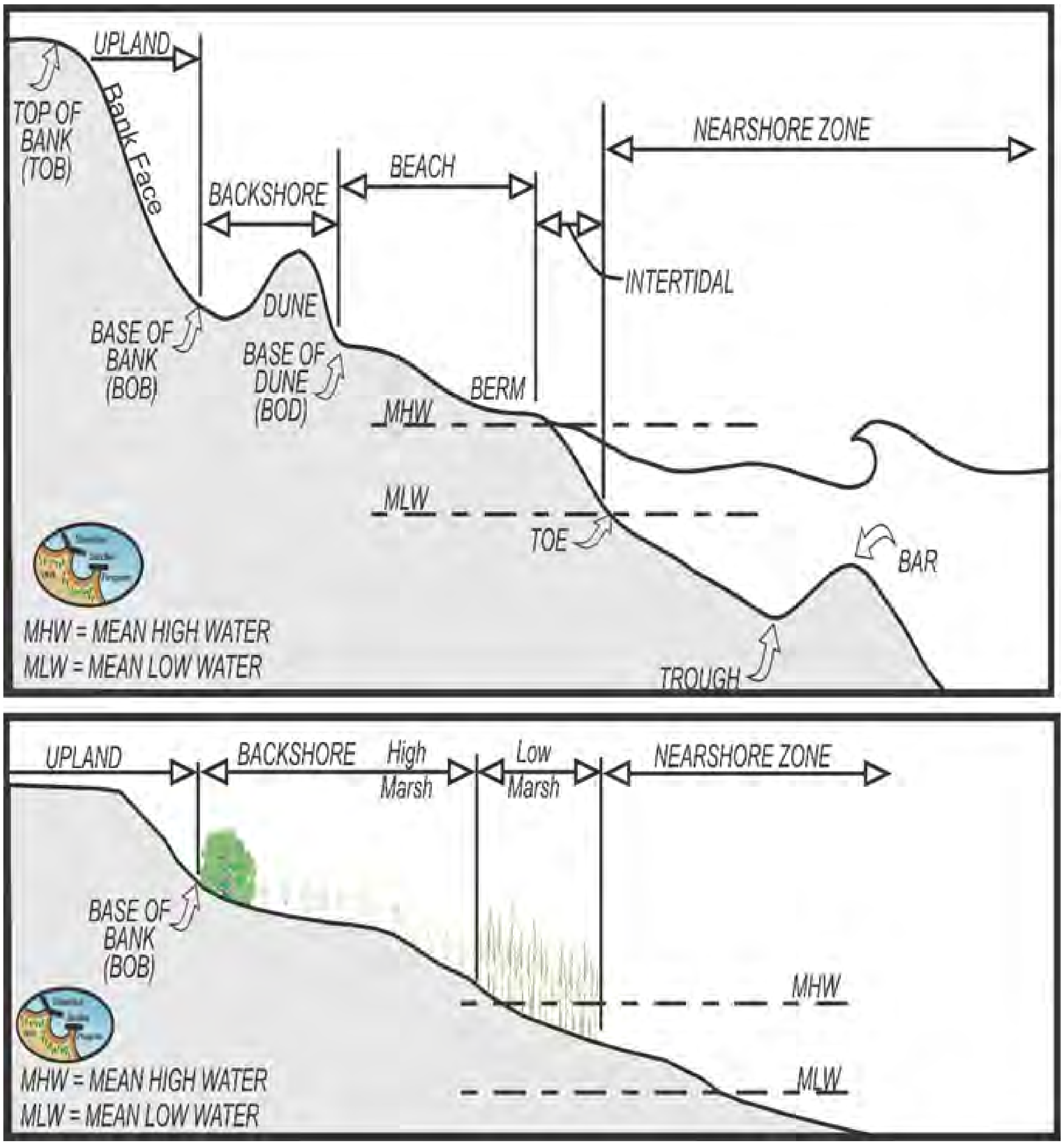

Figure 2-10. Terminology used to identify sections of the shore and backshore zones.

such as bulkheads, revetments, groins, marsh sills, or offshore breakwaters are already present, their condition, and effects on shoreline processes should be considered. Old structures might indicate previous attempts to address erosion. If the structure is undamaged or easy to repair with no erosion in the vicinity, then maintaining the current defense may be suggested. Existing defense structures on adjacent properties may also affect choices for the target shoreline, especially if the adjacent structures are trapping sand or preventing sediment movement along the shoreline.

Failed or deteriorating defense structures that are no longer providing shoreline protection do not necessarily have to be replaced if other parameters indicate no need for structural defense. If the structures are flanked by erosion around the ends or over the top, this may indicate inadequate design or structure type for the site conditions. For example, undersized revetments that are overtopped and damaged during storm events can sometimes be rebuilt as marsh sills. The amount of sand trapped between groins and located next to revetments and bulkheads may indicate the amount of sand available and which direction it moves. Very narrow intertidal areas next to existing revetments and bulkheads may indicate abrupt changes in nearshore water depths.

L. Nearshore Stability

It also is important to assess the nearshore bottom stability, whether firm or soft. The substrate must support the weight-bearing load of any proposed project elements, like stone, sand and reef materials to avoid undesirable settlement below target design heights which can compromise the intended level of protection. The nearshore morphology provides an indicator of whether or not the bottom is suitable for living shoreline projects, however, it should be confirmed during a site visit. A rule of thumb is if the bottom can support a person's weight without sinking or going "quick," then it probably will support sills and other features. Going "quick" is a term used to describe sediment that is so saturated with water that it is a mushy mixture of sediment and water that cannot support weight. If the nearshore is mushy or quick, the project designer and contractor must address potential settlement. For example, a 200 lb man standing with his feet together might represent 200 lbs/square foot. Calculate the lbs/square feet of a potential rock structure, technically a gravity structure, and compare results. Field verify during a site visit using the described estimation method or with the use of a soil compaction tester or a standard penetration test (SPT).

2.2 Coastal Profile

Once the map and site visit parameters above have been summarized to determine the site-specific conditions, a coastal profile can be developed. Shoreline management considers how different shoreline habitats and structures at any given location interact to provide erosion protection, water quality and habitat functions. For Chesapeake Bay shorelines, this means considering how the upland land uses, riparian buffers, tidal wetlands, beaches and shallow water habitats, when combined, affect local conditions in a holistic ecosystem approach (Figure 2-11).

Developing a gradual, vegetated coastal profile is the key to designing a successful living shoreline system. Each element of the system works in some way to reduce stormwater runoff and incoming wave energy impacting the upland. The coastal processes that occur between these zones should also be evaluated, especially those that may contribute to the level of protection achieved by a living shoreline project. This includes allowing for natural ecological succession over time and tolerating physical changes, such as lateral and landward habitat shifts in response to accretion or storm event recovery (Bilkovic et al, 2016). Developing a coastal profile also helps predict necessary habitat tradeoffs in order to improve wave attenuation characteristics of the profile. Accounting for human land and water uses in the coastal profile is also important for living shoreline project designs.

The word riparian refers to anything connected with or immediately adjacent to the banks of a stream or other water body. Creek-side woodlands are riparian forests. These riparian buffers trap and filter sediments, nutrients, and chemicals from surface runoff and shallow groundwater. The framework of tree roots stabilizes the creek bank and microbes in the organic forest soils convert nitrate (especially from agricultural land) into nitrogen gas through denitrification.

Chesapeake Bay riparian buffers along tidal creeks and rivers occur above the zone of tidal wetlands and are typically occupied by scrub/shrub and trees. Riparian buffers often erode as the upland banks recede, as evidenced by displaced and fallen trees along the shoreline. When shoreline erosion strategies are employed, interfacing with the riparian buffer must be considered. If the bank face is relatively stable, the riparian buffer might remain as is. If the bank face is fully exposed and actively eroding or large trees are leaning over threatening to fall, then selective tree removal or entire bank grading might be required. Graded banks should be replanted with the proper native vegetation.

Along the Bay's higher energy shorelines, beaches interact with dunes and serve as habitat of animals and plants living on or in the sand. Dunes themselves are a transitional area between marine and terrestrial habitats providing essential habitat and are protective barriers from flooding and erosion resulting in decreased sediment and nutrient input. Marshes provide habitats for both aquatic and terrestrial animals and reduce erosion by intercepting runoff, filtering groundwater, and holding sediment in place (CCRM, 2007).

Natural features in the nearshore zone that contribute to wave attenuation include submerged aquatic vegetation (SAV), sand bars, tidal flats and shellfish reefs. A broad, shallow nearshore zone will attenuate waves more than a steeply sloped nearshore with deep water (> 3 ft, 30 ft channel ward from MLW) even though the fetch distance may be the same. Submerged aquatic vegetation beds reduce wave energy, trap sediment, and produce dissolved oxygen for better water quality, in addition to providing habitat for numerous species. SAV wrack is produced annually and may be deposited in the intertidal zone covering marsh and beach plants. Nearshore sand bars provide a sediment source for shoreline marshes and beaches if the onshore movement and deposition of sand is not interrupted. Productive shellfish reefs and bars in the nearshore and intertidal zones indicate natural recruitment potential and may need to be avoided. Table 2-1 provides a summary of the potential natural coastal profile features in each habitat zone, plus the human uses and activities that should be evaluated to create a combined coastal profile.

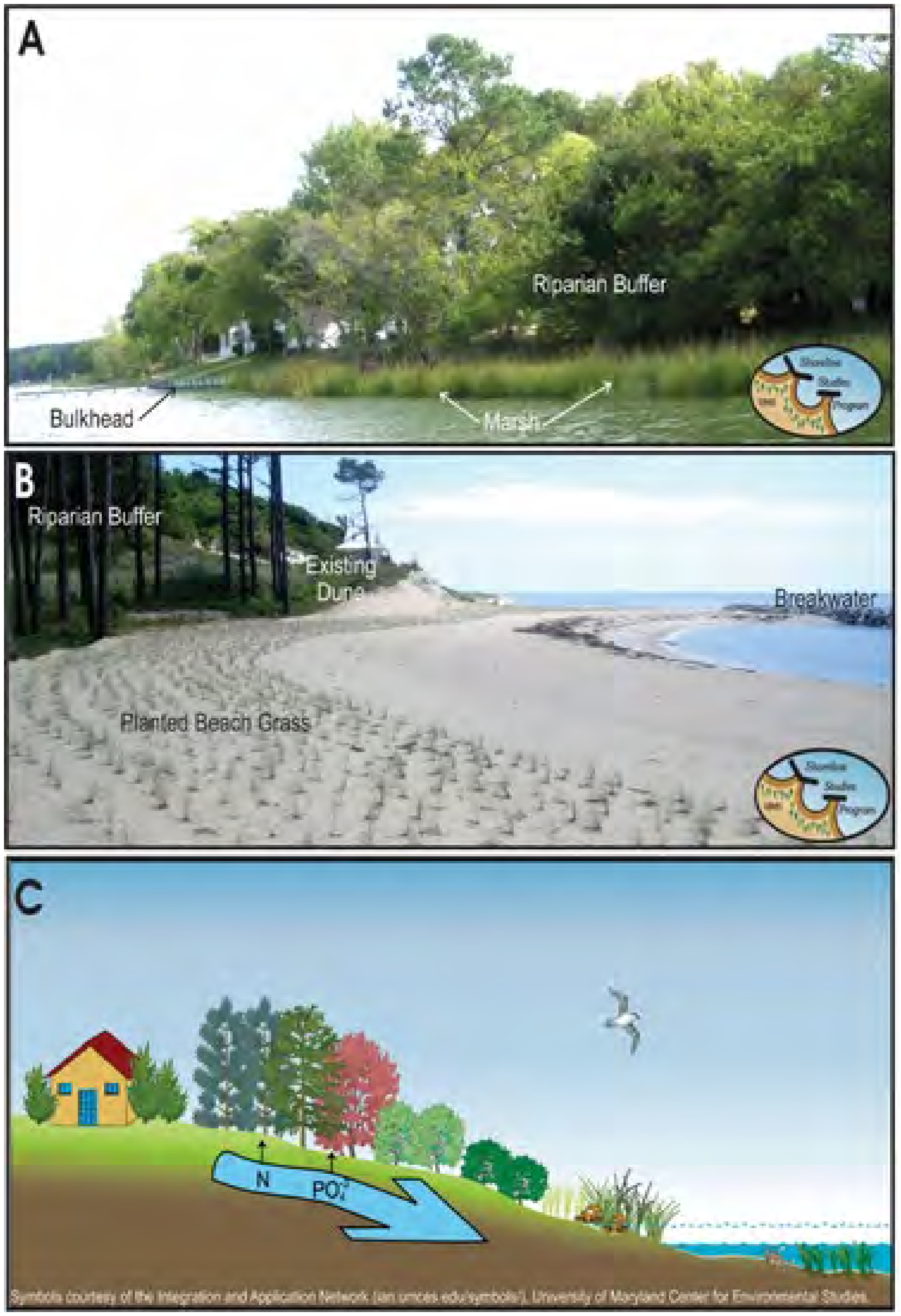

Figure 2-11. Photos depicting aspects of the coastal profile for A) a low-medium energy marsh shoreline and B) a high energy beach shoreline. C)diagram of a connected shore zone shows different landscape elements. C is reprinted courtesy of the University of Maryland Center for Environmental Studies N = Nitrogen, PO4-3 = Phosphate.

Table 2-1. Potential natural features and human uses included in a coastal profile.

	Riparian Buffer & Bank	Backshore	Intertidal	Nearshore
Natural Features	Forested - undisturbed	High marsh	Low marsh	SAV
	Forested – disturbed	Dune	Beach	Shellfish reefs
	Herbaceous only	Upland trees – grasses	Marsh & beach	Sand bars
	Bare soil			Tidal flats
	Developed			Deep water
Human Uses	Visible infrastructure	Existing defense structures		Boat mooring areas
	Underground infrastructure	Recreation improvements & uses		Navigation channels
	Stormwater management	Water access improvements & uses		Boat wakes
	Riparian access structures			

3 Design Considerations

3.1 Selecting Shore Management Strategies

Shoreline management is the act of dealing with actual and potential coastal erosion in a planned way. Recent scientific studies that examined shoreline management practices found measurable impacts as a result of prolific shoreline armoring throughout the Chesapeake Bay estuary. Large-scale ecosystem disruption is occurring as a result of incremental shoreline alteration with a loss of valuable ecosystem services that coastal communities benefit from (Bilkovic et al., 2016). This growing body of scientific evidence has led to changes in how estuarine shorelines are managed. Shoreline management practices to reduce erosion are typically not very effective as flood mitigation strategies. Yet concerns for coastal community resilience are now driving shoreline management policies and practices in Virginia to protect valuable shoreline habitats, while also dealing with more frequent and intense storms and more frequent tidal flooding. Shoreline management practices that can endure with expected rates of sea-level rise or be modified as needed in the future are also becoming more important.

Living shorelines are deliberate shoreline management projects that create or enhance vegetated shoreline habitats with a natural ability to abate shoreline erosion while maintaining or improving habitat and water quality. Public policy in the Commonwealth of Virginia and other coastal states now require the use of living shoreline projects as the preferred shoreline management practices wherever they can be successfully implemented. Choosing which living shoreline technique to use may not be straightforward and living shoreline management alternatives are not always appropriate or feasible depending on the risk and level of protection required.

After a project site has been evaluated, the nature of the erosion is understood, and a site-specific coastal profile has been developed, the next step is performing a shoreline management alternatives analysis with an emphasis on various living shoreline practices. The No Action alternative is the first to be considered. Many sites in low fetch creeks may have an undercut bank, but they may not have a true erosion problem because the rate is very low. Others may have very low erosion rates that, if allowed to continue, would not impact the property significantly. For properties with significant flooding risk, adaptation strategies other than shoreline stabilization probably need to be considered. However, if an erosion problem truly exists and the erosion risk cannot be tolerated, then determining a strategy that best suits the site's particular coastal profile is essential.

Except for the very low fetch areas, it is important to remember that shore protection is the primary consideration of the project with habitat and recreational benefits secondary considerations. In lower fetch creeks, generally less than 0.5 mile, where very little erosion is occurring, habitats might be the primary consideration since they can provide erosion protection for the bank. These areas can be protected by non-structural options including oyster reefs where suitable shellfish growing conditions exist. However, with the advent of various types of oyster reef material and designs, some eroding shorelines in slightly higher fetch areas could be protected with oyster reef structures.

Shore protection method selection will be determined by, in general, the level of protection versus the impinging wave climate. Wave energy typically increases with increasing fetch, and, therefore, the level of protection needed at the site requires that a revetment be built higher and living shorelines both higher and wider (Figure 3-1). Fetch generally can be used as a proxy for the hydrodynamic forces impacting a site. Generally, the higher the wave energy, the higher and wider the structure. Sills can be used along low and medium energy shorelines. Beach and marsh combinations using both breakwaters and sills, also called **brills**, can be located along medium and high energy shorelines (Milligan et al, 2021). The backshore can be either a marsh or a beach depending where the project sits. Breakwaters are versatile and can be sized for medium, high, and very high energy sites. The parameters outlined in Figure 3-1 are guidelines only and all sites need to be designed by experienced coastal professionals.

On the land side, the bank height is important. A higher bank may require grading on more wave-exposed sites depending on the proximity of vegetation cover, upland infrastructure and land use. The project might have to encroach both channelward and landward in order to establish a gentle, fully vegetated coastal gradient. More than one technique might be appropriate to achieve this target profile such as stormwater management and riparian buffer enhancements in the upland plus a planted tidal marsh or created sand beach feature with wave attenuation and containment structures in the intertidal and nearshore zones.

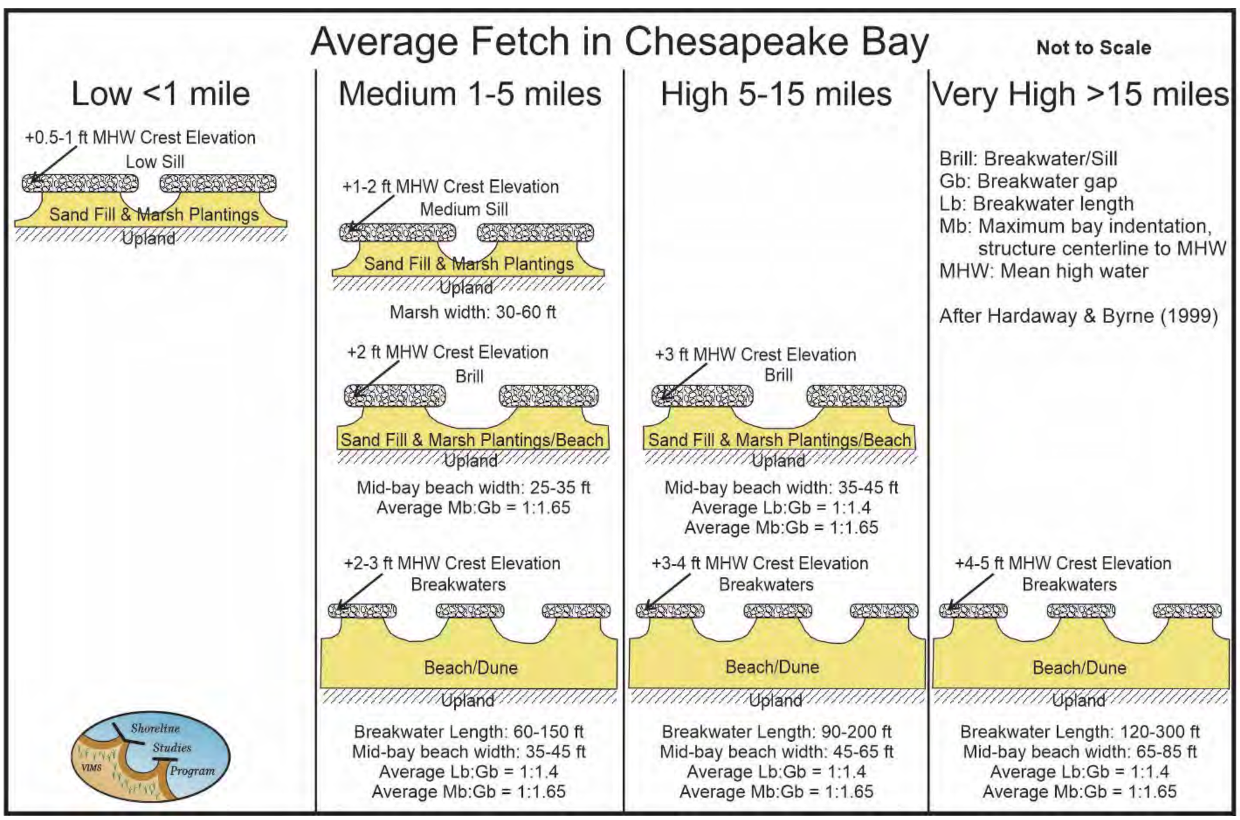

Figure 3-1. Conceptual shore protection strategies for hybrid living shoreline systems with rock, sand, and plants. Average fetch is used to determine site suitability. The parameters outlined shown are guidelines only, and all sites need to be designed by experienced coastal professionals. From Milligan et al. (2021), after Hardaway and Byrne (1999).

The VIMS Center for Coastal Resources Management has developed online decision tools to assist with choosing the most effective and least environmentally harmful shoreline management practices. The Shoreline Management Model is a spatial model that determines preferred practices using available GIS data for bank vegetation cover, bank height, the presence or absence of natural vegetation buffers (riparian forest, tidal marshes, wide beaches), nearshore water depth and slope, fetch, and the proximity of coastal development to the shoreline. The model output of best shoreline practices is displayed in the AdaptVA interactive map viewer under the Shoreline Management category (http://cmap2.vims.edu/AdaptVA/adaptVA_viewer.html). An interactive Shoreline Decision Support Tool combines the decision flow paths of the Shoreline Management Model with on-site observations (https://cmap2.vims.edu/LivingShoreline/DecisionSupportTool/).

The Virginia Marine Resources Commission has an online database of permit records (https://webapps.mrc.virginia.gov/public/habitat/). This database can be useful to look at what shore stabilization strategies have been proposed in different locations. Applications can be searched by watershed and immediate waterway as well as by year. Typical cross-sections, which generally are included in the application, may be a guide for strategies that might be appropriate for a particular shoreline location.

The following sections describe various living shoreline practices and the site-specific design considerations that need to be made to determine if they are feasible and how to make the practice successful. Any one practice alone may be all that is needed for solving a particular erosion problem. Generally, more than one practice combined will achieve the best integrated slope and vegetated zones for stormwater runoff interception, tidal flooding and wind-wave attenuation, sediment capture and accretion, plus the resulting water quality and habitat benefits.

3.1.1 Stormwater Management

The objective of stormwater management practices is to reduce the volume and flow rate of stormwater runoff heading toward the shoreline and over the top of the bank that contributes to an erosion problem or may complicate the successful establishment of other living shoreline practices. Reducing the direct input of stormwater runoff also improves water quality by decreasing the input of fertilizers, upland sediment, and the toxic metals, chemicals and bacteria that attach to sediment particles carried by stormwater runoff.

Stormwater management practice selection is based on the site needs, conditions, and property owner objectives. Improving the stormwater conveyance system, rainwater harvesting to collect and reuse it, land use changes to reduce impervious surfaces and pollutant generation, or a combination of these practices may be appropriate and feasible. Stormwater management practices near the shoreline might be small-scale residential type best management practices (BMPs), or they could involve larger-scale practices for runoff coming from paved parking lots, roads, or large institutional buildings.

For example, roof gutters connected to pipes that discharge directly into the adjacent tidal waterway can be disconnected and re-directed into dry wells or sheet flow across an expanse of turf grass or planted vegetation. Low earth berms or terraces can be installed to slow down the rate of runoff down slope. Converting waterfront turf to conservation landscaping areas with native plants is another technique to intercept stormwater runoff.

Footpaths through the riparian buffer to access the waterfront and piers can be modified with steps or cross-slope angles. New conveyance channels or changing from impervious to pervious materials can be considered for vehicle access routes and boat ramps. New upland landscaping features can be added to intercept runoff and allow for percolation or to slow down the runoff rate. This might include rain gardens, mulched beds, or creating areas for natural leaf litter to accumulate and conservation landscaping areas with native plants.

3.1.2 Riparian Buffer Vegetation Management and Restoration

Riparian buffer management refers to maintaining, enhancing, or restoring the health and density of vegetation near the top of the bank and on the bank face. The strategic planting and management of riparian buffer vegetation can be used to slow down upland runoff, stabilize slopes, reduce the risk of falling trees, and to create densely vegetated storm surge buffer areas at the toe of the bank. The target area for riparian buffer management should extend at least 100 feet back from the top of bank to the backshore zone.

Shoreline tree management includes assessing the health and remaining life expectancy of large, mature trees. Preserving intact, stable mature forested areas is generally good for erosion protection and water quality. This means avoiding unnecessary tree and understory removal and incidental tree damage during project construction. Selectively removing dead, dying and severely leaning or undercut trees may reduce the risk of trees falling and enhance the growth of understory vegetation. Pruning branches hanging over the shoreline can reduce the weight-bearing load on the trees and increase sunlight for tidal marsh and beach plants. The need for regular pruning as part of a routine maintenance plan should be factored in. Proper pruning techniques for each tree species should be used with advice from a certified arborist if needed, especially arborists with a Tree Risk Assessment specialty for evaluating if trees pose a hazard or not.

Previously cleared riparian buffer areas can be restored through selective re-generation and with the addition of new plantings. Native plants adapted to local soil, wind, tide range and flooding conditions should be the foundation of a riparian buffer planting plan. The best native plants to use for this purpose are the native species found growing in undisturbed riparian buffers in the local area. Other non-invasive, non-native plants can be included that are suitable for the growing conditions. Sometimes healthy canopy trees are present and only the understory has been removed. Adding native understory trees and shrubs might be all that is needed. In other cases, a more comprehensive planting plan is needed to restore multiple vegetation layers such as when waterfront turf is converted to a conservation landscaped area with native herbaceous grasses and perennials, shrubs, understory and canopy trees. Removing and controlling non-native invasive species that are present should follow integrated pest management and best practices for the particular species.

The timing and maintenance requirements to reach establishment for riparian buffer management strategies should be considered to determine their feasibility. It is important to identify responsible parties for installation, monitoring, and maintenance including temporary irrigation, grazing protection and protection from adjacent mowing activity. Compatibility with the property owner's objectives, land uses, and recreation activities is also an important consideration.

3.1.3 Bank Grading

Bank grading reduces the steepness of the bank slope. A more gradual slope will improve vegetation growing conditions on the bank face, allow for wave run-up at the toe instead of undercutting, and create space and a suitable slope for future landward migration of the adjacent tidal wetland in response to sea-level rise. Bank shaping refers to only grading the top or bottom of the bank where erosion is occurring to achieve increased stability while avoiding disturbance to stable bank vegetation or non-erosive sediments.

The feasibility to grade a bank may be limited by upland improvements and underground utilities, dense vegetation and many large trees, excessive bank height, grading equipment access restrictions, existing shoreline defense structures, and/or adjacent property conditions. The removal of existing trees and other vegetation may be required. Existing vegetation removal should be limited to situations where the long-term benefits of a more stable slope outweigh the loss of the existing vegetation cover. This determination may require professional judgement and consultation with local environmental officials.

Bank grading can be done in a landward direction from the bank toe into the adjacent upland. Channelward encroachment with bank grading can be considered if there is not enough space in the upland for the desired slope. The bank soils need to be suitable for placement into tidal wetlands and shallow water habitats to create or enhance the intertidal zone marsh or beach in these cases. Potential water quality impacts plus the target slopes and width for the intertidal zone need to be considered with channelward bank grading.

The target grade is usually at least 3:1 or flatter where possible or terracing the bank may be feasible. Bank terracing is another option to consider if a uniform grade cannot be achieved for the entire bank slope. The type of soil material present, its cohesive properties, and how the material will be handled need to be determined. Grading and excavation will expose soil layers that may be highly erodible or not suitable for a planting medium.

Temporary erosion and sediment control measures are required to protect the new slope and prevent excessive sediment runoff into the adjacent waterway. Once the target grade is achieved, biodegradable netting and erosion control blankets can be used in addition to seeding and planting to re-establish a vegetation cover. Surface and sub-surface runoff controls may be needed to maintain slope stability while vegetation becomes established.

Banks that are graded should be stabilized afterward with a variety of native plants placed at appropriate elevations relative to the tide range. The site wetness, flooding potential, and shade also need to be considered for plant selection. Soil amendments may be necessary depending on the ambient soil condition after grading and the desired re-vegetation plan. A planting plan will be needed that includes plant species and quantities, planting zones above and below the spring high tide elevation, and the ideal planting times which are different for warm-season grasses and perennials (spring-early summer) compared to woody vegetation (fall).

Seed mixes with a variety of native, drought-tolerant warm-season grasses with deep root systems can be combined with plugs of other herbaceous plants for the most immediate cover. Native trees and shrubs that are tolerant of local salt spray and wind conditions can be planted above the spring high tide line. Consulting with a Chesapeake Bay Landscape Professional or other shoreline landscape designer might be helpful. Additional information and guidance are available from a USDA Natural Resources Conservation Service web site about coastal and shoreline plants (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/plantmaterials/technical/publications/?cid=stelprdb1044303).

3.1.4 Sand Fill and Beach Nourishment

Sand fill can be used in different ways for living shoreline projects such as filling in bank erosion areas, replacing soil lost from fallen or removed trees in the riparian buffer, filling in erosion areas within existing marshes, raising the elevation of the intertidal zone to plant new marshes, or adding sand to improve the protection level of a sand beach feature (beach nourishment). Sand fill and beach nourishment are usually combined with other living shoreline design features such as planted marshes and dunes and containment structures like sills and breakwaters.

Beach nourishment alone may be a desirable strategy where swimming, canoe and kayak launching, or other activities are desired and these activities will prevent the sustained growth of shoreline vegetation. Beach nourishment is a suitable practice where an existing beach is present with a gently sloping shoreline and where natural offshore sand transport mechanisms exist to help maintain the beach.

Potential material sources include upland sand mines, selective mining of bank grading materials, and the beneficial use of dredged material. Presently, only sandy dredge material is being placed along the shoreline as beneficial use. No guidelines exist for placement of the placement of muddier dredge sediments in Virginia’s marshes. Generally, the preferred fill material for beach nourishment and planted tidal marshes contains coarse-grained sands so it is not easily carried away from the project site and provides a suitable growing medium for tidal marsh and dune plants to become established. Imported materials with a high clay content are more difficult to grade and may drain poorly; these materials will not support robust growth of tidal marsh and dune plants. Beach nourishment material should be similar to the sand on the existing beach and without toxic contaminants, solid waste, and invasive plant species. For low salinity and freshwater locations, the material requirements may need to be tailored differently based on similar natural habitats in the local area.

After a suitable material source is identified, methods for transporting the material to the site and stockpiling on site need to be considered. Pipeline routes for hydraulically pumped dredged material may need to be designated. The sand grain size needed for the project is the same regardless of salinity. Periodic replacement of sand fill and beach nourishment material may be necessary if the necessary slope profile or vegetated habitats fail to persist over time, so adequate access routes for future installments may need to be available.

The construction grade for sand fill is typically not the final beach profile, only the initial condition. For sand fill and beach nourishment placed in the active wave zone of the intertidal area, a settling period of at least two weeks is recommended for acclimation to local environmental conditions before any planting is completed. Storms, tidal currents, freshwater inflows, and boat wakes may gradually change the original profile over time. This type of dynamic habitat is considered acceptable for living shoreline projects, yet the movement of sand in the project area might also interfere with boating and navigation. These potential use conflicts should be anticipated and considered during the design process.

3.1.5 Tidal Marsh Planting and Management

Marsh management is usually used in very small, narrow creeks (fetch less than about 1,000 ft) where the existing marsh fringe is narrow or absent resulting in an exposed base of bank (Figure 3-2). If the erosion rate is minimal, no action may be needed. If the narrowing of the marsh is due to shading by trees, the overhanging branches possibly can be trimmed. Bare areas of existing intertidal substrate can be planted with marsh grass, usually *Spartina alterniflora* between Mean Tide Level (MTL) and Mean High Water (MHW) if there is a sufficient amount of sunlight during the summer. Periodic removal of tidal debris that may be smothering marsh plants is another marsh management practice.

Sand fill is often needed to widen the created marsh fringe to provide an effective wave buffer that reduces bank erosion. Plants are the primary component from a wave attenuation and habitat perspective. Two main wetland plant species are typically used in salt marsh fringe creation, *Spartina alterniflora* and *Spartina patens*. The *Spartina alterniflora* grows in the low intertidal marsh zone between Mean Tide Level and Mean High Water. *Spartina patens* is planted above mean high water in the high marsh zone. *Spartina alterniflora* may also grow above MHW in areas where more frequent and higher inundation occurs, and an intermixing zone between the two species can be planted above and below the elevation of MHW. Additional salt marsh plants usually appear naturally over time because of the stabilizing presence of these two foundation plant species. For low salinity and freshwater tidal marshes, other foundation plant species can be used such as *Spartina cynosuroides*, *Panicum virgatum*, *Carex stricta*, *Juncus effuses* and others.

Therefore, it is critical to know the tide range and where MHW will reside in the new sand fill substrate upon which the plants will be installed. In tidal creeks, nearby natural marsh fringes can be used as a biologic benchmark. The *Spartina alterniflora/Spartina patens* elevation is critical. The lower limit of *Spartina alterniflora* is too variable to be used as a MTL marker but once MHW is known, then MTL can be determined. The wetland-upland transition elevation is also important but there are some plants that grow well in both the high marsh and adjacent riparian buffer like *Spartina patens, Panicum virgatum, Baccharis halimifolia*, and *Morella* spp. These are good choices for planting across the high marsh-riparian buffer transition zone for storm surge and extreme high tide protection.

Most of the common planted marsh species can be purchased from wetland plant nurseries. Nursery stock is recommended because these plants are healthy and ready for growing as soon as they are planted. The project site salinity must be given to the nursery grower in advance so the plants can be gradually brought up to the target salinity.

Wild harvest from donor marshes might be feasible for small planting projects, but it can be difficult to extract plants from dense natural marshes. Eroded marsh clumps can be easily salvaged and transplanted. Transplanted vegetation will need time to acclimate and overcome transplant shock at the new growing site.

Planting labor includes professional service companies with experience planting large wetland areas or volunteers can be used. If volunteer labor will be part of the project, then the design and project sequence need to allow time for recruitment, training, coordination, and oversight. While volunteer planting projects are enjoyable, it is essential for a qualified responsible party to follow up volunteer planting events with routine inspections and quality control.

The spacing between plants typically is 1.5 ft on center, but it can range from 1-2 ft apart depending on the area to be planted and how rapidly the marsh needs to be established. Experimentation is underway with planting in clusters rather than in straight rows. Clustered marsh vegetation has been shown to be more resilient to wave action with fewer washed out plugs but there are no established guidelines yet for how best to arrange marsh grass clusters except to mimic natural marshes in the local vicinity.

Temporary measures to protect new tidal marsh plants from grazing pressure are usually required wherever Canada geese, mute swans, deer, and wild horses are known to occur and may be attracted to the new planting area. There are several designs for temporary grazing exclusion systems depending on the project size, available labor, and budget. The project design should include these extra materials and the labor required for installation and removal. The materials used for temporary grazing exclusion can and should be removed after the new marsh is well-established with healthy root growth.

It is not difficult to achieve a well-established marsh after just one growing season provided the new elevations are suitable, the marsh is gently sloped to allow for full drainage and exposure of the marsh surface during ebb tides, and the substrate allows for the spread of underground roots and rhizomes. The indicators of a well-established marsh include grasses going through the full reproductive cycle with flowers and then seeds appearing in late summer-early fall. The linear appearance of new grass shoots between planted plugs indicates rhizome growth and expansion.

The main reasons planted marshes fail to 'take' or become well-established are because the elevation of the planted area is too low or there is incomplete drainage at low tide. Ponding areas within the planted area suggest an inadequately graded slope from the backshore to the nearshore. The complete disappearance of planted marsh grasses may indicate excessive flow stresses, wave energy or stormwater runoff or inadequate packing of soil around the new plants. New plugs can easily wash out if they are not packed in tightly enough and follow-up inspections are not conducted often enough to replace washed out plugs. Excessive foot traffic and recreation activities can also compromise new planted areas.

3.1.6 Coir Logs and Mats: Other Temporary Growing Materials

Coir fiber logs and mats are manufactured products that provide temporary stabilization at upland and wetland planting areas and where existing vegetation needs to be disturbed, such as bank grading projects, tree removal areas, and planted tidal marshes (Figure 3-3). Coir logs and mats are designed to support plant growth and should be used in combination with vegetation planting and management. They are used in single layer applications or stacked to gain elevation. Other similar temporary growing materials are also being introduced to the living shoreline market constructed with

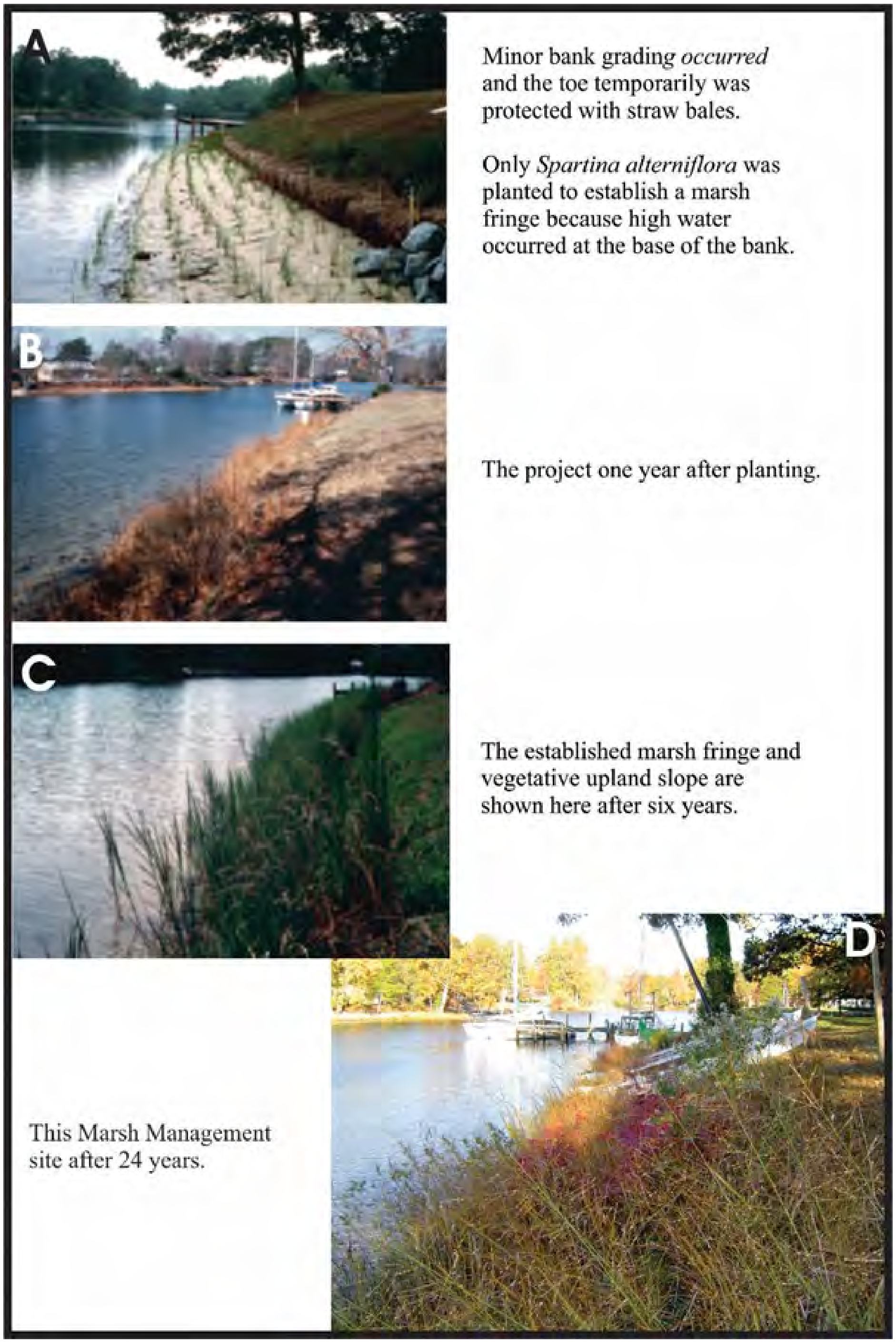

Figure 3-2. Marsh planting A) after planting, B) after one year, C) after 6 years, and D) after 24 years of growth. (Reprinted from Hardaway et al., 2010).

organic and artificial geotextiles. The introduction of plastic materials should be avoided to limit adverse impacts to fish and wildlife from ingestion, bacteria and toxic adhesion to plastics, and other negative effects of microplastic pollution.

These products are typically not designed to attenuate wave energy and are usually not effectively used without a combined vegetation practice. Since most are bio-degradable, these products will gradually decay within 3-5 years in tidal settings. While the products are undergoing decay, the adjacent vegetation becomes established and usually grows into the material. It is the planted or existing vegetation that provides shoreline protection over time, not these products themselves.

Coir logs and mats are most effective above the mid-tide level landward from regular wave action and inundation in low energy settings with only minor boat wake action. Premium grade products have proven to be worth the extra expense at moderate energy sites. They are especially useful for high marsh, beach-dune, and riparian buffer applications. Full contact with the ground along the entire length of these products is critical, especially where they will encounter wave or runoff forces. They should be aggressively anchored to the ground with hardwood stakes placed in an X across the top of the log and tied down with durable cotton-based twine with breaking strength greater than 800 lbs. Every turn of the twine around the stake can be knotted for more durability. Coir logs should not be tucked against vertical erosion scarps where waves are abruptly reflected.

Living shoreline projects that include coir products or other temporary growing materials might also need to include sand fill to create suitable elevations. Waiting for natural accretion then planting is a possible strategy as long as they remain firmly anchored and flush with the ground. The faster the sediments fill in, the less likely the installation will fail. Sand fill should be included if the local sediment supply is limited. Indicators of local sediment supply include accretion against large woody debris or shoreline structures and over wash deposits or sand berms adjacent to the intertidal area. Jumpstarting the accretion process with introduced sand fill will require construction access to put the sand in place.

Figure 3-3. Coir logs and mats placed at toe of a graded bank for temporary stabilization while planted tidal marsh and riparian buffer become established. Photos by P. Menichino.

Planting into coir logs has had mixed results. In most cases, the adjacent vegetation becomes easily incorporated into the coir material and planting into the logs is not necessary. Saturation is important for wetland plants. While regularly flooded low marsh plants plugged into coir logs tend to survive, high marsh and upland plants may need irrigation during dry spells. Some of these products come with pre-drilled planting holes because creating planting cells in the dense fiber material is difficult. Planting into coir mats is effective if the roots will have contact with soil beneath the mats.

Regular inspection and replacement of dislodged coir logs and mats is essential. Responsible parties for this maintenance task should be identified early in the design process. The persistence of the planted or existing vegetation after the coir products decay is the ultimate objective for this practice. The most successful projects over time are those where property owners and project managers accept and understand the limitations of coir products and recognize it is the vegetation that needs to be taken care of over a longer time span.

3.1.7 Sills with Planted Marshes

The stone sill has been used extensively in Chesapeake Bay over the years, especially in Maryland. Rock sill systems consist of a line of rock placed just offshore of an eroding shoreline/coast with a sand fill placed between the back of the sill and the eroding bank. Marsh grasses are planted on the sand fill to create a protective marsh fringe. The wider and higher the sill system, the greater the ability to provide shore erosion control (Figure 3-4). The elevation of the fill at the bank (which is determined by the desired level of protection) and the local tide range generally govern the dimensions of the sill system. The sand fill slopes on about a 10:1 slope from the bank to the back of the sill. Typically, the sand fill intersects with the back of the sill at about mid tide level. This allows for planting of *Spartina alterniflora* in the intertidal zone.

The Maryland nonstructural program implemented in the mid and late 1980s provided match funding for landowners to build marsh systems for shore erosion control. These included sand fill with groins and sill systems. A typical design of these early systems is shown in Figure 3-5A; the overall general design has remained fairly constant through time. Hardaway and Byrne (1999) describe average marsh widths and **armor stone** size needed for sills in low and medium environments. In low energy environments armor stone needs to be at least 300-900 lbs. In medium energy environments, marshes need to be at least 40-70 ft wide and should use armor stone that is at least 400-1,200 lbs.

Although generally effective at erosion control and marsh fringe creation, sills are non-native rock structures placed in the aquatic environment. Sill placement along the marsh edge impacts the benthic habitat underneath the structure and also affects the adjacent nearshore habitat, although recent studies suggest not as significantly as larger rock revetments placed at the upland bank (Bilkovic et al 2016). Openings or gaps in the sill are encouraged to allow access for marine fauna to utilize the created marsh fringe, particularly turtles and fish. Sills with crest heights above mean high water might also need openings to allow more tidal flushing. This creates problems because as the sill is opened to allow for tidal exchange and marine fauna ingress and egress, the local wave climate will impact the marsh fringe and shoreline as well.

Two common effects occur at sill openings, 1) the waves could impact the upland bank the sill was designed to protect and 2) the waves would create a berm around the perimeter of the opening thereby closing the marsh fringe off and reducing access to the marsh. In fact, sill openings could create small pocket beaches which are, themselves, important estuarine habitat. These factors are addressed by installing numerous creative opening designs including varying the opening or gap, turning the sills offshore to create small spurs, using cobbles instead of sand adjacent to the openings and monitoring them (Hardaway et al., 2007). The results of one study indicated that access to the fringe marsh actually occurs in three ways, through the sill gaps, the macro-pores or interstitial spaces in the sill, and by overtopping by tidal waters (Hardaway et al., 2007).

No research has been performed to determine optimum gap widths and numbers for sills. A general empirical guide is to include gaps in the system at some interval, but the final decision should be left to the designer so that shoreline turns, offsets, upland drainages, recreational access, or geomorphic opportunities can be incorporated as necessary. Gaps and openings should be designed for the site's geomorphic setting.

One important management question from the Virginia Marine Resources Commission has been how far these systems must encroach onto state bottoms to provide the desired shore protection. Hardaway et al. (2009) addressed the question for three pertinent elements: 1) level of protection desired 2) return intervals of the design storm, and 3) required width of sill system needed to attain that level of protection. To minimize encroachment, systems should be designed to the needed level of protection elevation and then graded on an average slope (8:1 or 10:1) to

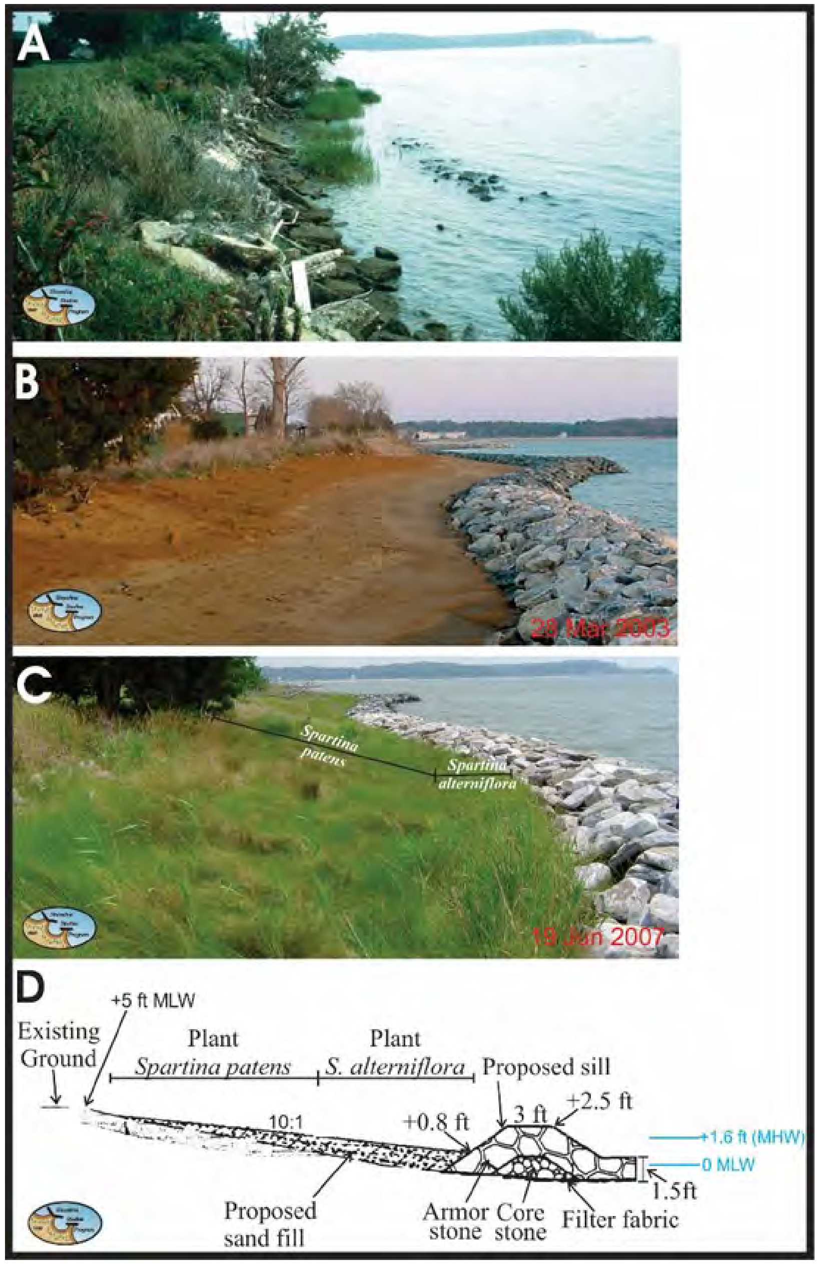

Figure 3-4. Sand fill with stone sills and marsh plantings at Webster Field Annex, St. Mary's County, Maryland A) before installation, B) after installation but before planting, C) after four years, and D) the cross-section used for construction (Hardaway et al., 2010).

the back of the sill (Hardaway et al., 2009) (Figure 3-5B).

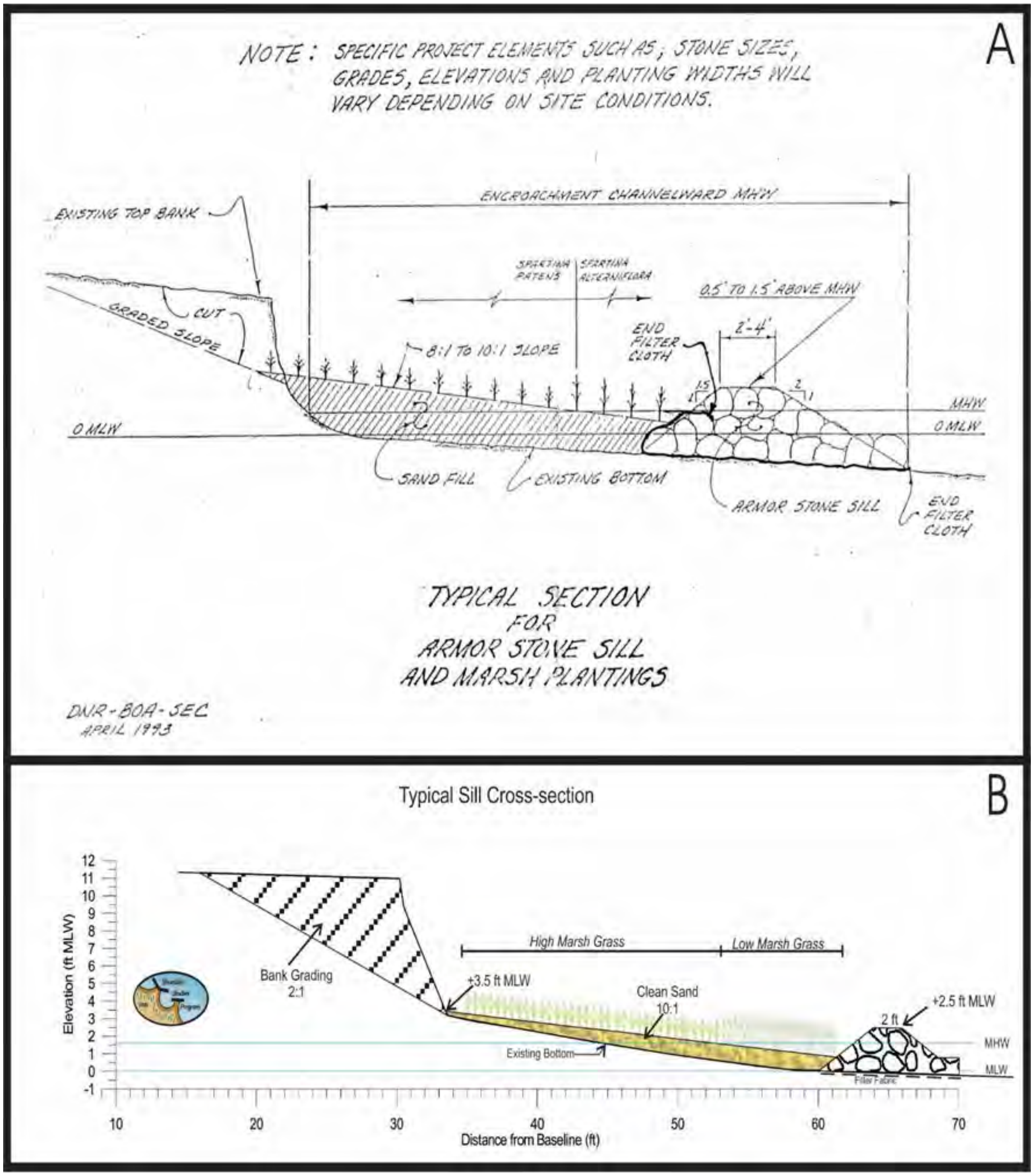

Figure 3-5. Typical sill cross-section A) created by Maryland Department of Natural Resources for their non-structural program and B) designed for Robin Grove Park in Colonial Beach. The mean tide range is 1.6 ft, so mid-tide level is 0.8 ft MLW. The level of protection in this case is +3.5 ft MLW, so the sand fill should be graded on a 10:1 slope from the bank to the back of the sill. The upland bank should also be graded and re-vegetated.

3.1.8 Marsh Toe Revetment/Sill

An existing marsh that is functioning as shore protection can be maintained with a freestanding, trapezoidal-shaped structure (i.e. sill). These marsh toe revetments can be used where existing marshes have eroding edges and scarps, or where upland bank erosion is present in spite of the marsh being present (Figure 3-6). These are low stone structures placed near the channelward marsh edge. The stone height can be near mean high water in low energy settings or if the marsh is already more than 15 ft wide. The height can be raised 1 foot above mean high water in moderate energy settings or if the marsh is less than 15 ft wide.

Marsh toe revetments should be offset from the existing marsh edge near or channelward from mean low water. They should not be placed immediately next to or directly on the marsh surface. The low marsh zone between the marsh edge and mean low water should not be completely covered with stone. Tidal gaps can be strategically placed at natural marsh channels or where the total length of a marsh toe revetment is greater than 100 ft.

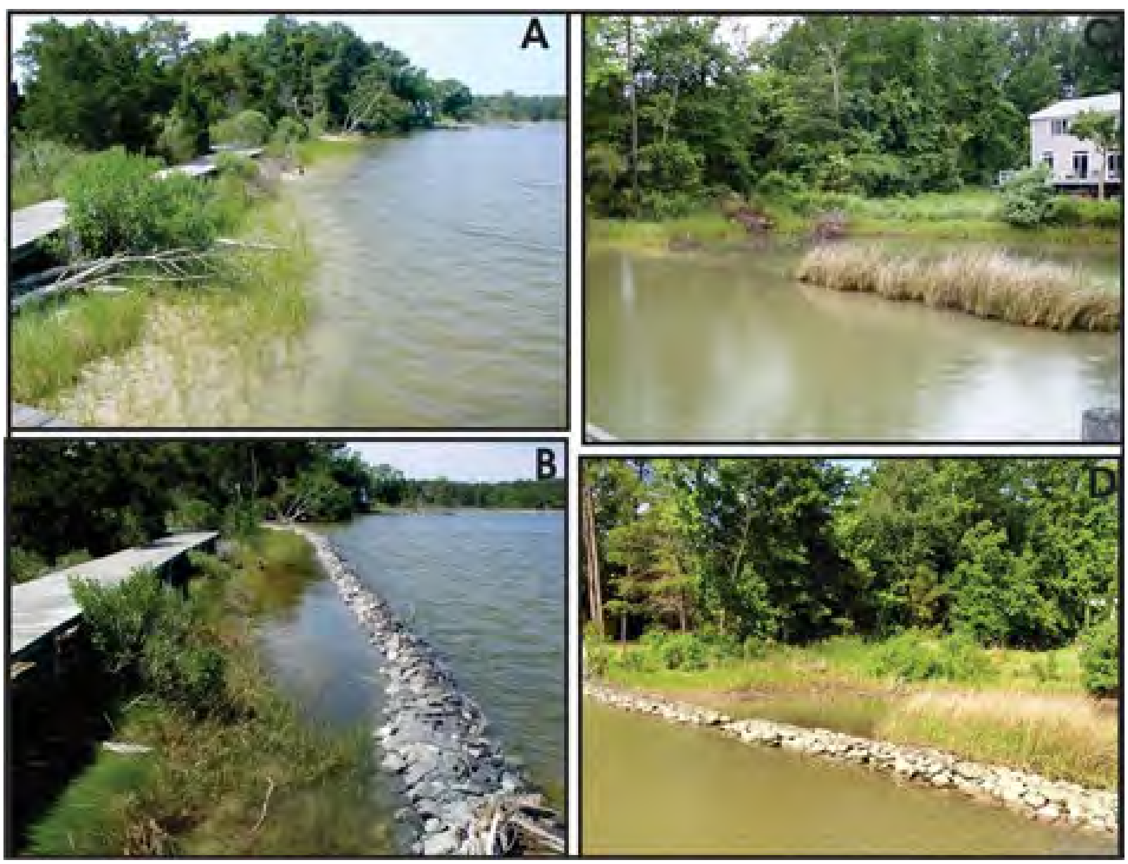

Figure 3-6. Photos showing marsh toe revetments A) before and B) after a project on Cranes Creek in Northumberland County and C) before and D) after a project on Mosquito Creek in Lancaster County, Virginia.

3.1.9 Intertidal Oyster Reef Sills

Oyster reefs have been used in living shoreline projects as a substitute for stone sills in front of marshes or in addition to other practices to increase habitat diversity. Oyster reef applications include loose shell, bagged shell, oyster mats, and a variety of pre-cast reef structures. While loose oyster shell (shell plant) is highly suitable for oyster restoration reef building, it is usually not effective for reducing wave height and energy by itself except for very low energy settings. Placing shell into some type of containment bags then stacking the bags to achieve a desired height creates a more rigid reef structure that intercepts incoming waves (Figure 3-7). Different types of pre-cast structures designed to support the settlement and growth of shellfish are also being used for living shoreline applications. Selection of alternative substrates for oyster restoration reflects differing project goals, scales, outlooks, challenges, and limitations (Goelz *et al*., 2020). Both ecosystem and economic benefits must be considered when selecting an alternative substrate, and in the end, the specific goals of specific restoration projects will dictate the choice of the substrate.

Interest in oyster reef structures has been revived to not only promote oyster growth, provide habitat, and improve water quality, but also to provide shore protection. Though oyster reefs have been studied for habitat creation, only recently have studies been occurring on sites that specifically use them for shore protection (Morris *et al*., 2021). In Chesapeake Bay, using oyster shell bags to create sills for shore protection has been in practice for about 10 years. Typically, these oyster shell bags are placed in front of marshes with no fill. However, several installations included sand fill and marsh grass plantings. These living shoreline reefs are most successful at locations with evidence of a healthy natural oyster population already present, which tends to be in lower reaches of tidal tributaries where the salinity remains above 10 ppt. Oyster bags offer habitat and reduce wave action so that the marsh can flourish. Milligan *et al.* (2018) reviewed the effectiveness of existing oyster bag sill sites in Chesapeake Bay. The oldest site examined had been in the water for seven years at the time of the study.

Overall, the assessment of existing bagged shell sill sites that have been in place for several years indicates that in low fetch situations (<1 mile), oyster bag sills can provide shore protection through the creation or stabilization of marsh (Milligan *et al*., 2018). The design of the sill should be site specific; larger fetches should have larger structures, and the bags should be placed closer to the eroding marsh scarp particularly along sites with a sand platform. When placed farther from the eroding marsh scarp, the top bags tended to roll toward the shoreline. No bag movement occurred on the sills that consisted of 6 bags. Sites that were filled with sand and planted with grass had thriving marshes. However, the landward side of the sill is covered by sand thereby reducing the area that can be covered in oysters. Oyster shells are a limited resource so perhaps, the design could accommodate other substrates behind the oyster bags. Initial monitoring of several oyster bag sills installed without sand fill and marsh plantings indicates that sediment can be deposited behind the structure allowing marsh grass to grow riverward.

The incidental effects of shell containment on reef evolution, such as the creation of microplastics from the shell bags, however, is not well studied or understood in the Chesapeake Bay region. The bags are damaged and broken open during storms and Predation can be an issue because the predators open the bags which can lead to scatter (Milligan *et al*., 2018). Only clean, sun-dried shells from the local region should be used for this purpose to avoid spreading shellfish diseases.

Growing oysters on the sill structure is assumed to be a critical part of the shore protection capabilities of the system and as such, the structures must be placed correctly for shellfish growth. Few studies have investigated what happens to hydrodynamics once the sills are fully colonized by oysters (Morris *et al..* 2019). These intertidal structures display the same vertical zonation in community structure as natural rocky intertidal habitats. Specifically, the upper intertidal (above MHW, Mean High Water) is dominated by barnacles, which are adapted to the severe physical stress (e.g., heat/cold exposure and desiccation) in the high intertidal (Seitz *et al*., 2019). The only exception is when the high intertidal zone is shaded, such as under docks, where oysters and mussels can penetrate part of the high intertidal. In the low intertidal (below MLW, Mean Low Water) algae, tunicates, sponges and bryozoans are dominant by outcompeting oysters and being less susceptible to predators. The "sweet spot" for oysters (and ribbed mussels) is the mid-intertidal between MHW and MLW and when the reef experiences greater than 50% inundation (Morris *et al*., 2021). Below the low intertidal, the shallow subtidal can harbor dense oyster and hooked mussel assemblages. Thus, living shoreline oyster reefs should span from just above MHW (but higher under portions of living shorelines that cross under docks) through the shallow subtidal (Seitz *et al*., 2019).

The ideal arrangement, placement, height or width and adaptive ability of self-sustaining oyster reef sills for shoreline protection requires more investigation. The placement of oyster reef structures in a living shoreline project also depends on what other practices are being implemented plus the bottom type, nearshore slope and tide range (Howie & Bishop, 2021). Intertidal reefs placed above mean low water will need to withstand wave action, wave overtopping, and extreme temperature stresses during exposure. Wave and current-induced turbulence caused by bagged shell and other reef materials may affect recruitment and spat settlement (Morris *et al*., 2019). Subtidal reefs placed below mean low water typically have more productive oyster growth, but may become navigation or safety hazards if water-based recreation activities also occur in the project area. Hard sand bottom will result in less settling of the reef and less siltation over the reef compared to muddy sediments. Siltation and heavy biofouling interfere with successful recruitment of oyster spat. Access and permission for monitoring and maintenance of oyster reef structures should also be factored in during the design process.

Other reef-building alternatives are pre-cast products designed to be suitable for oyster spat settlement and growth. These manufactured products come in different shapes and might be proprietary designs. This type of living shoreline reef is typically placed in an array channelward from a natural or planted tidal marsh. The performance effectiveness for long-term shore protection of all oyster reefs that are used for wave attenuation, sediment accretion, and resulting erosion reduction is still uncertain. These living shoreline reefs for shore protection are presently considered to be experimental approaches still under investigation for more specific design criteria.

However, many different materials and designs have been used to construct living shorelines and studied for oyster growth, some of which can serve as effective oyster reefs (Burke, 2010; Lipcius & Burke, 2016; Goelz *et al.,* 2020; Burke & Lipcius, 2020). Burke (2010) examined the suitability of granite, concrete, limestone marl, concrete modules and reefballs as living shoreline oyster reefs through reef surveys and experiments in the Lynnhaven River of Chesapeake Bay. After 2.5 y, all reefs had high oyster density and biomass and sustainable accretion rates. Similarly, Burke and Lipcius (2020), in a long-term study lasting 5 years, examined various types of living shoreline oyster reefs, including granite mounds, concrete pyramids, reefballs, concrete tables, and oyster shell in the Elizabeth and Lafayette Rivers of Chesapeake Bay. After 5 years, all reef types performed exceptionally well in terms of oyster density, oyster biomass, macrofaunal biomass, reef accretion, and multi-year oyster age structure, except for two sites in a polluted area. In South Carolina, numerous types of living shorelines, including oyster reefs, were examined as to their efficacy in protecting and restoring salt marsh, and in promoting oyster and macrofaunal populations under low-energy and high-energy conditions.

The collective conclusion from these studies is that various alternative substrates can be used to promote development and persistence of oyster populations and possibly as living shoreline reefs for shore protection. However, Morris *et al*., (2021) found that it may be difficult to achieve both ecological and engineering goals because wave transmission increased with decreasing freeboard height of the reef crest above water level, yet provision of oyster habitat depends on frequency of inundation. A critical threshold for intertidal oyster reef establishment is 50% inundation duration, i.e., living shorelines that spent less than one-half of the time inundated were not considered suitable habitat for oysters but were effective for wave attenuation. Reefs that experienced >50% inundation (i.e. lower structures) were suitable for oyster habitat but less effective for wave attenuation. Wave attenuation can increase over time due to oyster growth, but intertidal reefs generally attenuated more waves during shallow water conditions (<2.5 ft). Under deeper water levels (>3 ft), less than 15% of the waves were attenuated (Hogan & Reidenback, 2021; Wiberg *et al.,* 2019)).

Continued research into other reef parameters should be investigated for optimizing wave attenuation, e.g., width below target inundation threshold instead of height so that a certain level of shore protection can be assured. In addition, as sea level rises, the oyster reefs will need to grow higher in elevation to continue attenuating waves and protecting marshes. Though recent research (Bost et al., 2020) demonstrated that natural intertidal reefs can keep up with sea-level rise, they also suggested that a young restored reef, positioned low in the tidal zone, grows rapidly with 20–40% aerial exposure and takes between 20 and 50 years to equilibrate with mean sea level. Only time will determine if artificial reefs will be able to be maintained and provide shore protection into the future.

Figure 3-7. An example of the construction of oyster reef bags with sand fill and marsh grasses planted behind the structures. Top left: Shoreline prior to the project on 26 May 2016; Top right: after the sand fill was placed May 2017; Middle left: after bags were placed in May 2017; and Middle Right: after the grass was planted in July 2017. Photo credit: Walter Priest.
Bottom right and left: Site about 1.5 years after construction.

3.1.10 Breakwaters

The use of breakwaters along Virginia shorelines began in 1985 with the installation of Drummond Field on the James River. Since then, numerous projects have been built all over Chesapeake Bay in various physical settings (Hardaway and Gunn 2000). The breakwater system constructed at the Virginia Institute of Marine Science in 2010 protects a great deal of infrastructure and provides a recreational area and research platform (Figure 3-8).

The basic theory is to establish stable pocket beaches between fixed headlands. Breakwaters are considered to be offensive structures (as opposed to defensive structures such as revetments) because they alter the incoming wave climate before it reaches the upland. The breakwater "breaks" the force of the wave and dissipates the energy so the waves do not erode the beach or upland banks (Hardaway and Byrne, 1999). However, the use of breakwaters takes an advanced knowledge of coastal processes in order to understand the performance expectations and potential impacts. It is possible to build the structures too small for the site's wave climate and not take into consideration potential impacts to adjacent shorelines. They are included in this guidance to complete the available methods but should not be attempted without a thorough understanding of their use, which requires experience.

Figures 3-9 and 3-10 show the typical design parameters for a breakwater system. Primary parameters are breakwater length (Lb), distance offshore (Xb), the gap between breakwater units (Gb), the maximum embayment indentation distance (Mb), and the minimum beach width (Bm) required for shoreline protection (Hardaway and Byrne, 1999). Research developed empirical relations for these parameters (Hardaway and Gunn, 2000) which have become useful guidelines for headland breakwater design in Chesapeake Bay, but site- specific conditions, including geomorphic setting, access, and property lines, can influence breakwater and beach position along the shore. For Chesapeake Bay, the overall average Mb:Gb is 1:1.65 and the overall Lb:Gb is 1:1.4. Other design concerns include addressing potential impacts to the adjacent coast, ensuring breakwater length approaches two times the wave length, and using coarse sand.

Hardaway and Byrne (1999) describe the mid-bay beach widths and size of **armor stone** that are necessary under medium and high energy regimes. When a site is exposed to a medium wave climate, the mid-bay beach width needs to be at least 35-45 ft wide from MHW to the base of bank. Armor rock should be a minimum of 800-2,000 lbs. In high energy environments, the mid-bay beach width should be 45-65 ft wide from MHW to the base of the bank with an elevation of three to four ft above MHW where the backshore meets the bank. Armor stone should be a minimum of 1,000-2,500 lbs., but a better range is 2,000-5,000 lbs. (Hardaway and Byrne, 1999). Extreme energy environments, such as those on the southern shore of Chesapeake Bay, should have even larger stone.

Figure 3-8. Aerial photos of breakwaters at the Virginia Institute of Marine Science campus on the York River. While the physical characteristics of breakwater sites differ, the goals are the same: protect the upland bank/marsh with a wide recreational/ protective beach.

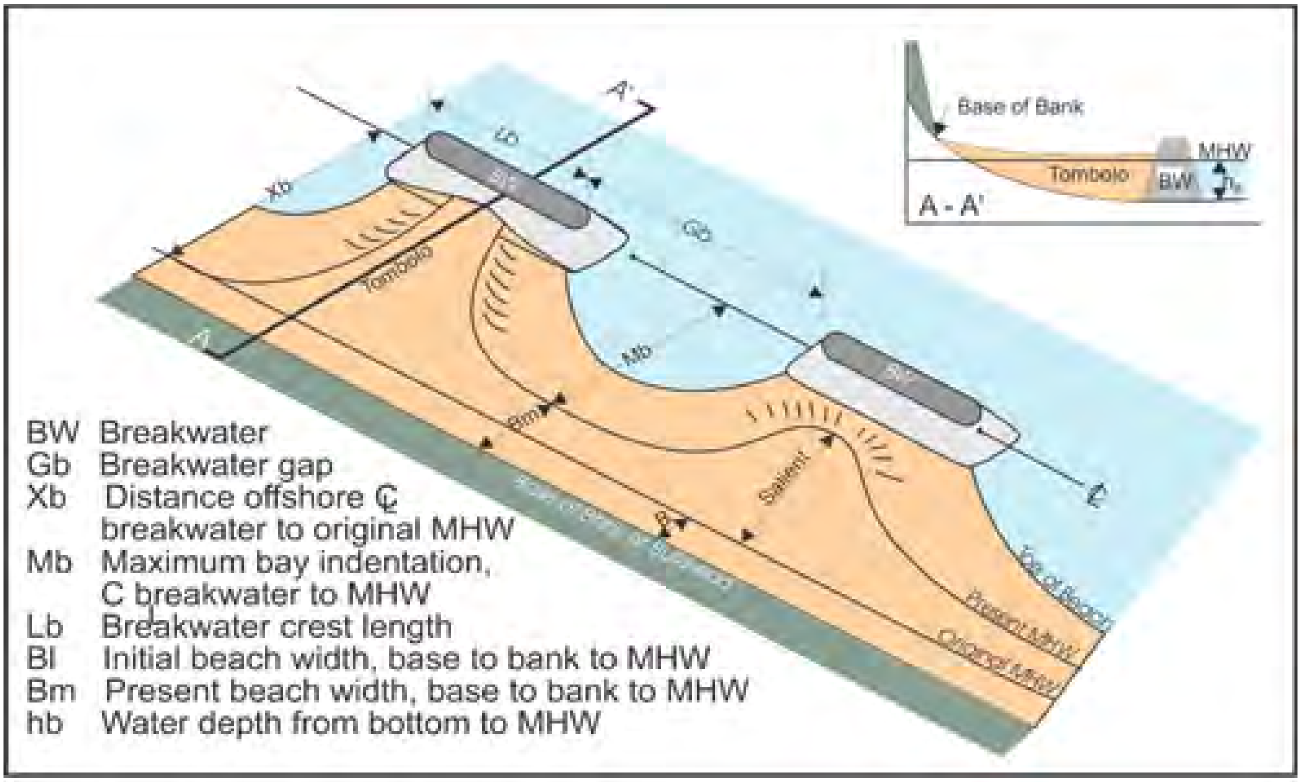

Figure 3-9. Breakwater design parameters (after Hardaway and Byrne, 1999).

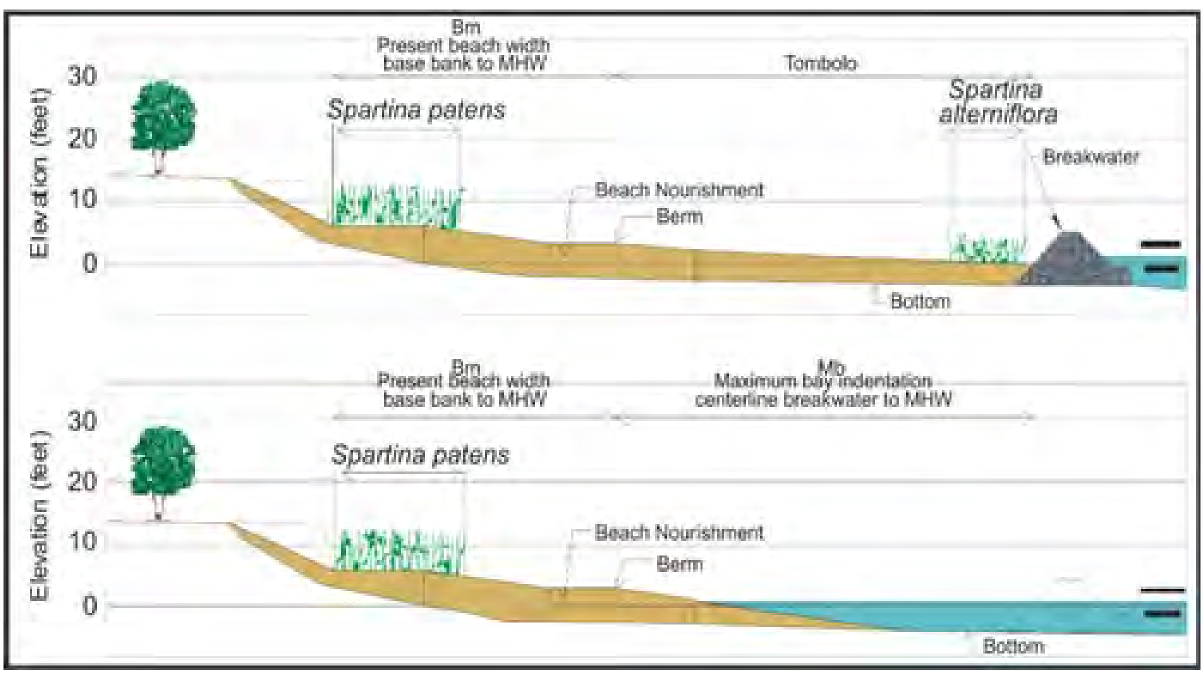

Figure 3-10. Typical tombolo with breakwater and bay beach cross sections (after Hardaway and Byrne, 1999).

3.2 Level of Protection

The level of protection is a necessary part of the overall discussion of desired shoreline management strategies with a landowner. The maximum wind- wave climate from which the shoreline needs protection will determine the level of protection as will an analysis of site conditions. Quantifying the design storm waves and the storm surge will provide the horizontal and vertical dimensions necessary to protect the coast from erosion during a design storm. However, it may not be economically feasible to design for the largest storms. Landowners need to be made aware of those situations and related expectations.

When the design storm is exceeded, then so is the level of protection. Overtopping a revetment by surge and wave may only create a wave cut scarp across the adjacent bank or bluff (Figure 3-11) like what occurred along the James River during Hurricane Isabel. Has the level of protection been exceeded? The revetment is very much intact and as long as the stability of the bank face and consequently any infrastructure is not threatened, then probably not. If the structure itself fails, particularly early during the storm event, then a more serious problem will result. If the structure fails, the bank fails and the infrastructure can be threatened or damaged. No erosion occurred of the graded bank just upriver from this particular revetment where the beach is wide behind a headland breakwater. The revetment crest elevation is +8 ft MLLW which was three feet less than water and wave heights in that area of the James River.

Figure 3-11. Revetment on the James River that was overtopped by storm surge and waves during Hurricane Isabel. Photo dates 21 October 2003.

When creating living shorelines, the level of protection will increase as the fill is raised thereby increasing the system's elevation and moving it farther landward or farther offshore. It may not be cost effective to protect against a large storm, such as Hurricane Isabel with a 1% probability of occurring in any given year, unless the bank is graded (Figure 3-5B). The level of protection will translate to the amount of risk or damage the property owner is willing to accept or incur. This usually relates to costs but some level of damage may be deemed acceptable in light of the size of the shore protection project and what is being protected. In other words, if a house is close to the shoreline, it may require more protection than a farm field and therefore a higher level of protection, and usually a higher cost.

3.3 Encroachment

When living shoreline projects are considered, it must be understood that there are habitat tradeoffs. Subaqueous bottom has ecological value; however, the additional benefits of an intertidal fringe marsh versus subaqueous bottom have basically been accepted by the regulatory frame work in Chesapeake Bay (i.e., Maryland and Virginia). The rationale is that if an erosion problem exists, a shore protection structure will be built. While a living shoreline may replace subaqueous bottom with a marsh fringe or beach, it is considered a better alternative to hardening the shoreline as long as the project has a substantial biological component.

That said, reducing the encroachment of shore protection systems both landward and seaward must be a consideration in the design. Landward encroachment is necessary when the site-specific conditions allow or require bank grading. However, a good grading plan can reduce the landward encroachment and even provide additional habitat by planting vegetation on the newly-graded bank. The amount of encroachment on state-owned bottom will be a function of 1) existing gradient, 2) the sand fill level required plus, 3) the holding device (for this discussion, a stone sill) (Hardaway et al., 2009).

1. The existing gradient is a function of local geomorphology, but an erosion problem generally develops when the protective natural marsh fringe is not wide enough to offer a sustained wave buffer. When we look at “typical” tidal creeks and rivers, it is evident that stable upland banks reside behind a continuous wide marsh fringe. How wide these marshes are is a function of shore orientation, nearshore gradient and fetch exposure. Along the main stems of these water bodies, the fetches vary from 0.5 to 2.0 miles and protective fringes (those with stable upland banks) generally are 10 to 20 ft wide from the marsh edge to the base of the bank. As a fringe becomes narrower over the years to less than 5 ft to no fringe, the upland bank will often be impacted and bank erosion will ensue. The shore gradient at that point may have MHW either at the base of bank or within five to 10 ft of it. The position of MLW on a non-vegetated intertidal zone is a function of the intertidal slope. This varies but may be an 8:1 to a 10:1 slope. The distance from MLW to MHW therefore is a function of tide range (Hardaway et al., 2009).

2. The level of protection will vary, but once determined, it should be set against the base of the eroding upland bank. This is the simplest way to assign the critical elevation remembering that with greater fetch exposure, large storm waves must be attenuated across the sill system. That is why in very fetch limited areas (<0.5miles), one might place this elevation only a foot or so above MHW because the impinging waves are small and even a little scarping is infrequent. In larger fetch exposures (> 2.0 miles), an elevation of 2 ft MHW or more might be more prudent. The bank height is

also a function of the level of protection. If bank grading is possible then the sand fill elevation could be lower. From the level of protection of the sand fill, the sand is graded on a 10:1 slope (average) to MTL at the back of the sill. The level of protection might be different along similar shore reaches because of land use. Waterfront property with no improvements might utilize a lesser level of protection than improved property. At this point, the first encroachment distance is set (Hardaway et al., 2009).

3. The sand fill holding device (a sill, in this case) is placed according to where MTL occurs at the water side of the sand fill grade. The average back slope of the sill is 10:1 but may vary with time often getting steeper (Hardaway et al., 2009). The sill height and, consequently, its width and front slope complete the encroachment scenario. It may be more a result of many years of sill installations in Maryland and Virginia, but having a sill that is more than 2 ft above MHW moves the structural definition toward a breakwater. A long, high, semi-continuous line of rock is not envisioned as aesthetic or supportive of maintaining wetland-aquatic habitat connections. In very fetch-limited areas, a MHW sill might work while on more open shores, a 0.5 to 1.5 ft MHW sill is more appropriate. This tradeoff has evolved over the years and is the basis for this encroachment discussion. The second encroachment distance is set resulting in the total encroachment for the selected sill system (Hardaway et al., 2009).

3.4 Coastal Resiliency

Coastal resilience means creating the ability for a community to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, health, the economy and the environment (Virginia Coastal Resilience Master Plan Framework, 2020). This capability can prevent a short-term hazard event from turning into a long-term community-wide disaster. From a shore protection perspective, bulkheads and stone revetments are as effective as living shorelines and have less maintenance issues. However, they may provide less resiliency at the site because they can be impacted and overtopped causing structural failure, particularly when events exceed design dimensions. The more continuous coastal profile created by living shorelines, on the other hand, provide ample opportunities to mitigate wave energy during storms. Living shoreline systems dominated by vegetated habitats tend to be submerged during extreme storm events, yet can recover naturally after the storm surge recedes, making these systems more resilient to major storm events. Due to their ability to stabilize the shoreline with minimal impact to the ecology while being resilient themselves, living shorelines are considered a method to increase coastal community resilience to sea level rise (e.g., Sutton-Grier, Wowk, & Bamford, 2015; Van Slobbe et al., 2013).

For existing sites, the process of determining how to adaptively manage living shorelines for morphologic resiliency should occur over the life of the system. Ongoing maintenance of the site informs this process. However, for new projects, the question becomes when should the system incorporate how increased sea level will impact a site? For rock structures, when is the addition of rock and sand to the living shoreline most timely so that the system maintains is ability to protect the shore under higher water levels? Should it be done when it is needed or should the system be overdesigned for present conditions. The former would increase the cost of the system now but may save money over the long-term (Milligan *et al.,* 2021).

The anticipatory strategy includes designing crest elevations to reduce impacts of future or grading property for marsh migration. However, this is a risk because of the uncertainty in the future. They may not be needed in the future or they may cost more now than adaptive strategies in the future. Reactive strategies wait to react until the project is in dire jeopardy generally due to short-term storm events. At that time, it may be more difficult to act due to lack of preparation. In addition, costs may be more expensive by waiting until action is needed immediately. The shore protection plan should consist of strategies such as adding rock, sand, and plants to the system to enhance adaptability. Another option is to raise the level of protection significantly at time of construction. This provides increased protection from sea-level rise, but it also increases project costs (Milligan *et al.,* 2021).

Typically, morphologic resiliency of shoreline protection measures is often couched in terms of habitat impacts, diversity, and what existing ecosystem was replaced before the measure was installed. In terms of habitat, stone revetments are better than bulkheads, and living shorelines are better than revetments. However, when utilizing living components to mitigate hazardous events, measures to provide shoreline erosion control must be robust enough for the particular energy conditions at the site and designed for a certain level of protection and given scenario of sea-level rise.

For hybrid living shorelines that include rock, sand, and plants, in the simplest terms, resiliency is tied to the elevation of the structure and whether or not the marsh can migrate up slope and accrete sediment to maintain vertical elevation within the tidal range. If a living shoreline system gradually shows signs of too much water depth and inundation frequency such that the vegetated habitats cannot persist, then adding rock and sand to the system is a viable alternative to extend the life of these shore protection projects by increasing the elevations of both the structure and the marsh (Hardaway et al., 2018 & 2019; Milligan et al., 2021).

Determining a shore protection system's capacity for morphologic resiliency should occur during the design phase for new systems and throughout the life of the project especially for those that are already installed. Adaptive management strategies can be incorporated into ongoing monitoring to determine the capacity for morphologic resilience at specific sites (Milligan et al., 2021). Identifying when action is needed is an important component of adaptive management. The effectiveness of a shore protection system may decrease over time due to an increase in sea level, frequency and depth of tidal inundation, a lack of maintenance, and changes in vegetation that compromise wave attenuation. The project's decline in performance and increased erosion may happen slowly over time so that it is not easily recognized, or it may happen quickly during a storm. Developing a monitoring plan for projects to watch for erosion evidence and significant and persistent vegetation changes over time will enhance the life expectancy of a living shoreline.

3.5 Costs

Can your proposed strategy be built cost-effectively? Living shoreline project costs can generally be categorized into: design, permitting, materials, transportation and shipping, site access preparation, installation including labor, site work, restoration of access areas, mitigation for impacts (covering state bottom, tree removal), maintenance and monitoring. Overall project cost will vary project by project and contractor to contractor. Design costs depend on how much specific information is required and the complexity of the project. Labor costs vary depending on how many professional services are required and how much volunteer labor is available. For structural living shoreline projects like sills and breakwaters, the largest cost is typically the installation of rock and sand including both materials and transportation costs. The cost also will vary depending on the type of specifications in the design. Fewer specifications may lower the cost, but it may lead to a less successful project (i.e., undersized rock, the rock is dumped rather than placed, value-engineering to save labor costs).

In their locality-based shoreline management plans, Hardaway et al. (2016) provides a general guideline for costs of rock sills and breakwaters. The range of the typical cost/foot (Table 3-1) are strictly for comparison and do not consider design work, bank grading, access, permits, and other costs. An additional 20%-25% could be added to the material charges for mobilization and demobilization (if applicable) and the costs associated with the previous list of items. The feasibility of transport of material to the site must be considered. If the site is too shallow for the material to be barged in and has to be trucked to the site, the costs will vary based on the number of trips required. If sensitive or soft habitats occur between the stockpile site and the shoreline and logging mats are needed, the additional cost can be significant and must be included in the cost estimate. These costs may have changed recently due to supply chain interruptions, labor shortages and other factors resulting from the global pandemic.

Table 3-1. Approximate typical structure cost per linear foot. From Hardaway et al. (2016).

Type of Structure	Estimated Cost per Linear Foot*
Low Sill	$150-$250
High Sill	$250-$400
Breakwater	$600-$1,000
*Based on typical cross-section. Cost includes only rock, sand, and plants. It does not include design, permitting, mobilization or demobilization.	

To calculate the costs associated with a specific project, the amount of material needed to complete the project must be determined as does the cost per unit of the material. For coir logs and mats, the cost will vary depend on product types selected with premium products for extended life expectancy costing more. The cost for oyster reef projects will depend on the available sources for shell and the labor required to fill and place containment bags. For sills and breakwaters, the volume of rock, reef materials and sand needed is calculated from the typical cross-sections. Once the volume needed for the entire project is determined, it can be multiplied times the cost per foot (installed) of the material. For bank grading projects, the costs for removing excess material and temporary erosion and sediment control measures need to be included. Tidal marsh plants are typically planted on a 1.5 ft grid and the area covered is calculated from the typical cross-section. This will determine the number of marsh plants needed and should be specific to their location in regard to tide level. A cost per plant should include the cost of the plant, the fertilizer needed, the goose fencing, and stakes. For riparian buffer plantings, the costs for trees, shrubs, herbaceous plants and temporary staking materials need to be factored in and will vary depending on the number of suppliers and labor required for installation.

3.6 Permits

Local, state and federal laws require permits for development and other activities in environmentally sensitive areas. The laws relating to the marine resources of Virginia include a permit review process for human uses of tidal shorelines, tidal wetlands, beaches, and shallow water habitats (Figure 3-12). The permit process for tidal shoreline projects in Virginia is important because any action on one shoreline has the potential to impact adjacent shorelines and natural resources. A well-designed living shoreline project must incorporate standards established by the regulatory program. This section describes important permitting criteria that should be considered early during the design process.

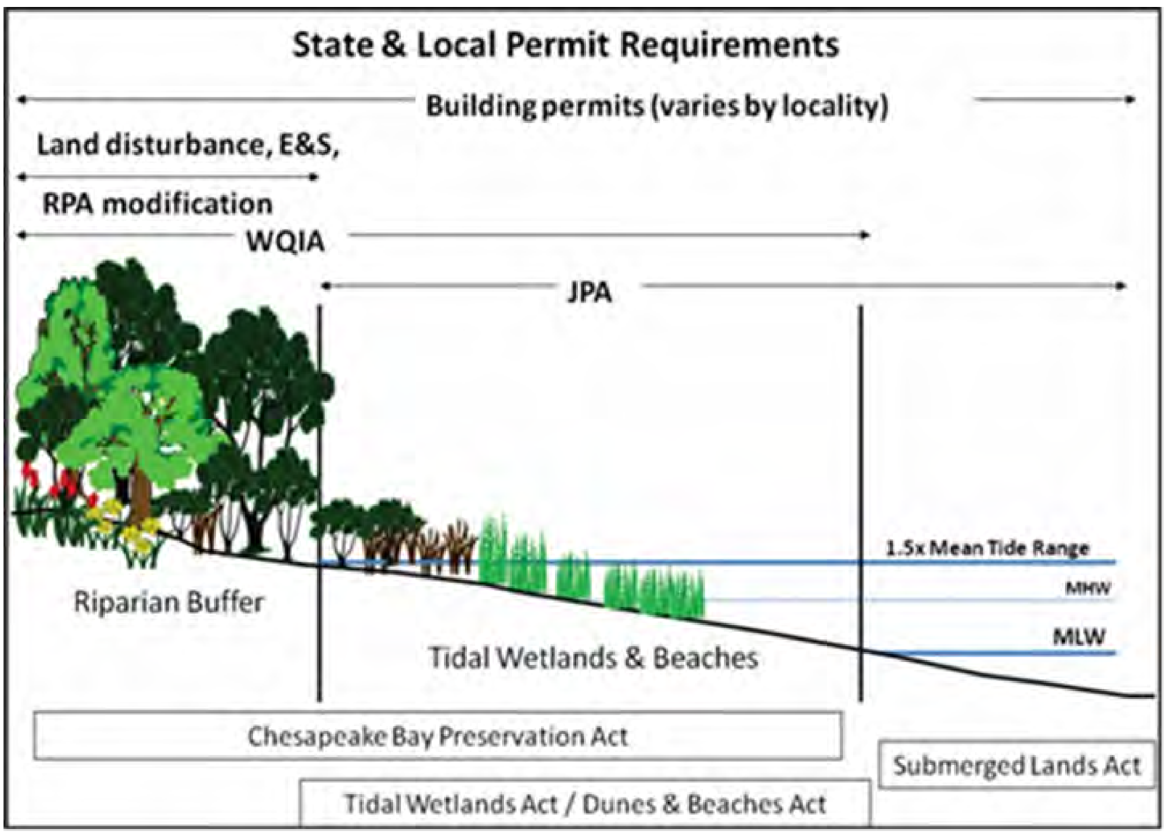

Figure 3-12. Graphic depicting the shore zone habitats and Virginia's permitting requirements in each zone.

The permit process is designed to balance public and private benefits of shoreline uses with the potential public and private detrimental effects. The Code of Virginia vests ownership of "all the beds of the bays, rivers, creeks, and shores of the sea in the Commonwealth to be used as a common by all the people of Virginia." All projects that encroach onto state-owned bottomlands or potentially impact water quality are reviewed for their potential impact on public trust resources and the rights of others to use the same waterway.

Some of the regulated areas are private property, but the Commonwealth has authority to regulate private uses of wetlands and shorelines because of the anticipated impacts those uses might have on the public's health, safety, and welfare. For example, filling wetlands to create private upland property removes important ecosystem services provided by those wetlands that benefit everyone. Created wetlands in living shoreline projects might need to be designed within jurisdictional wetland boundaries. Erosion control structures including living shoreline projects may prevent adverse property loss but also may create new, adverse erosion problems on adjacent properties and contribute marine debris if they are improperly designed or constructed.

Virginia Living Shoreline Laws & Policies

Chesapeake Bay Preservation Act (CBPA) § 62.1-44.15:72, as amended 2020

Living shoreline projects that include land disturbance, clearing, grading, or vegetation removal within designated Chesapeake Bay Preservation Areas will require Bay Act approval from local governments. This approval process may include submission of a Water Quality Impact Assessment (WQIA), which identifies potential impacts on water quality and Resource Protection Areas, plus steps to minimize or mitigate potential water quality impacts of the land disturbance.

This process is separate from the Joint Permit Application process that authorizes work in tidal wetlands and shallow water habitats. Local government staff should be contacted early in the living shoreline design process for on-site delineation of Bay Act jurisdictional areas and to ensure that the final project design and construction meets all applicable CBPA requirements.

Proposed living shoreline project designs should include descriptions of existing vegetation within Resource Protection Areas, including tidal wetlands, tidal shores, nontidal wetlands connected by surface flow and contiguous to tidal wetlands, water bodies with perennial flow, and a 100-foot buffer area adjacent to and landward from these natural resources. All proposed land disturbance, construction activity, vegetation clearing, tree and vegetation protection measures, all proposed planting, and erosion and sediment control measures should be described.

Tidal Wetlands Act amendments §§ 28.2-104.1, 28.2-1301, 28.2-1302, and 28.2-1308 effective July 2020

Amendments to sections of the Code of Virginia related to living shorelines were enacted by the General Assembly of Virginia in 2020. The Virginia Marine Resources Commission and local wetlands boards shall permit only living shoreline approaches to shoreline management unless the best available science shows that such approaches are not suitable. If the best available science shows that such approaches are not suitable, the Commission shall require the applicant to incorporate, to the maximum extent possible, elements of living shoreline approaches into permitted projects. Joint Permit Applications must include a statement indicating whether the use of a living shoreline is not suitable, including reasons for the determination.

Additional amendments specify that standards set by the Commonwealth for the protection and conservation of wetlands ensure protection of shorelines and sensitive coastal habitats from sea level rise and coastal hazards. This prompted the Virginia Marine Resources Commission to promulgate updated Tidal Wetlands Guidelines to incorporate these additional standards.

Virginia Tidal Wetlands Guidelines updated May 2021

The 2021 revision of the Tidal Wetlands Guidelines provides minimum standards and guiding principles to administer the latest amendments related to living shorelines, sea level rise and coastal hazards. Tidal wetland types are re-defined and simplified. Criteria related to living shorelines are identified including preferred shoreline management options in the event best available science shows that a living shoreline approach is not suitable. Best available science is relayed through the Virginia Marine Resources Commission Habitat Management Division. The Virginia Institute of Marine Science (VIMS) is designated as the Commonwealth's science advisor on coastal and marine natural resource-related issues. VIMS serves as the arbiter in situations in which the best available science is in question. The entire document containing the revised guidelines is available from the Virginia Marine Resources Commission (https://mrc.virginia.gov/regulations/Final-Wetlands-Guidelines-Update_05-26-2021.pdf).

Code of Virginia Living Shoreline Definition effective 2011

'Living Shoreline' means a shoreline management practice that provides erosion control and water quality benefits; protects restores or enhances shoreline habitat; and maintains coastal processes through the strategic placement of plants, stone, sand fill, and other structural and organic materials. (Code of Virginia, §28.2- 104.1)

Virginia Living Shoreline Permit Incentive Programs

State and federal permit incentive programs specifically for living shoreline projects are being applied in Virginia. Projects must meet specific design criteria in order to qualify for permit issuance under these programs. However, it is also important to design projects based on the site conditions and risk factors present, rather than compromising a design just to meet expedited permit criteria. The qualifying criteria and additional information for each of these programs is summarized below:

Living Shorelines Group 1 General Permit VAC 20-1300-10 ET SEQ. effective September 1, 2015

The purpose of this general permit is to provide a streamlined permitting process as an incentive to encourage property owners to use a living shoreline approach as appropriate to manage shoreline erosion, and promote the planting and growth of tidal wetland vegetation to restore or enhance ecosystem services. This general permit authorizes the placement of certain specified sand fill, fiber logs, fiber mats, shell bags, and temporary grazing protection in tidal wetlands landward of mean low water to improve growing conditions for wetland vegetation.

The specific design criteria that living shoreline projects must meet in order to qualify for this general permit include, but are not limited to:

• Maximum fetch < 0.5 mile in any direction

• Sand fill cannot exceed the elevation of jurisdictional tidal wetlands (1.5 times the mean tide range above mean low water)

• Appropriate wetland vegetation shall be planted in all suitable sand fill areas

• Fiber logs, fiber mats and shell bags may be used to create a sill or otherwise support vegetation growth; if available biodegradable materials are encouraged

• Temporary grazing protection may be used & shall be removed after establishment

• Brief monitoring report at the end of first full growing season following planting and after the second year of establishment

• Replanting and sand fill to address problem areas and restore the originally proposed elevation are allowed

The entire regulation authorizing this general permit is available from the Virginia Marine Resources Commission: (http://www.mrc.virginia.gov/regulations/MRC_Scanned_Regs/Habitat/FR1300_09-01-15.pdf)

Living Shorelines Group 2 General Permit VAC 20-1330-10 ET SEQ. effective November 1, 2017

The purpose of this second general permit is to provide a streamlined permitting process for another group of living shoreline type projects that manage shoreline erosion and promote the planting and growth of tidal wetland vegetation and sand dunes and beaches. The allowable activities include structural design elements not covered by the Group 1 general permit plus treatments that encroach into state-owned submerged lands.

The specific design criteria that living shoreline projects must meet in order to qualify for the Group 2 general permit include, but are not limited to:

• There is clear evidence of active detrimental erosion at the project site and the maximum fetch does not exceed 1.5 miles in any shore angle direction.

• The maximum water depth at the sill location shall not exceed 2 feet at mean low water and the landward edge of the sill shall not be located further than 30 feet channelward of mean low water.

• The project shall include an existing or created tidal wetland with a minimum total width of 8 feet.

• For unaltered shorelines, the proposed living shoreline components are the only shoreline protection structures proposed along the specific shoreline segment.

• Marsh toe revetments and sills shall be constructed of riprap or alternative materials…The materials shall be of sufficient weight or adequately anchored to prevent being dislodged by anticipated wave action.

• Marsh toe revetments, sills, and associated fill shall not be placed on submerged aquatic vegetation.

• Sills shall be designed and constructed with a minimum of one 5-foot wide gap or window per property and per 100 linear feet.

The entire regulation authorizing this Group 2 general permit is available from the Virginia Marine Resources Commission: (http://www.mrc.state.va.us/regulations/MRC_Scanned_Regs/Habitat/FR1330_11-01-17.pdf)

Nationwide Permit 54 Living Shorelines US Army Corps of Engineers effective March 19, 2017

A federal nationwide permit (NWP) specifically for living shoreline projects was authorized in March 2017. The US Army Corps of Engineers, Norfolk District administers this permit in Virginia. A living shoreline under this permit program has a footprint that is made up mostly of native material and must have a substantial biological component, either tidal fringe wetlands or oyster or mussel reef structures. It incorporates vegetation or other living, natural "soft" elements alone or in combination with some type of harder shoreline structure (e.g., oyster or mussel reefs or rock sills) for added protection and stability. Living shorelines should maintain the natural continuity of the land-water interface, and retain or enhance shoreline ecological processes.

The specific design criteria that living shoreline projects must meet in order to qualify for this federal nationwide permit include, but are not limited to:

• Structures and sand fill cannot extend into the waterbody more than 30 feet from the mean low water line in tidal waters, unless the District Engineer waives this criterion

• Project length is no more than 500 feet unless waived by the District Engineer

• Coir logs, coir mats, stone, native oyster shell, native wood debris, and other structural materials must be adequately anchored, of sufficient weight, or installed in a manner that prevents relocation in most wave action or water flow conditions

• If sills, breakwaters, or other structures must be included, they must be the minimum size necessary to protect the project's fringe wetlands

• Sills must have at least one 5-foot gap per property and per 100 linear feet of sill, the sill height should be a maximum of +1 foot above mean high water, unless waived by the District Engineer

• Regional conditions for the Norfolk District apply to projects in sensitive environmental areas, e.g., SAV, anadromous fish use areas, federally listed species habitats

• Proper maintenance is allowed and required to correct any minor deviations

The entire list of permit conditions and regional conditions for Nationwide Permit 54 – Living Shorelines is available from the US Army Corps of Engineers, Norfolk District: (http://www.nao.usace.army.mil/Portals/31/docs/regulatory/nationwidepermits/Nationwide%20Permit%2054.pdf?ver=2017-04-12-115820-837)

4 Living Shorelines Performance Case Studies

4.1 Marsh Management

4.1.1 Poole Marsh: Tabbs Creek, Lancaster County, VA (37°39’13.86” N, 76°21’19.17” W)

Introduction

The Poole site is part of a vegetative erosion control (VEC) project where marsh fringes were planted in front of eroding upland banks in order to reestablish what was once there. In 1982, Poole was planted with *Spartina alterniflora* in front of a graded bank with straw bales placed along the base of the bank (Figure 3-2). This site was used in Section 3 as a successful example of vegetative plantings. However, recent review of the site indicates that conditions have changed in the last several years.

Site Setting

The Poole site is a very low-energy shore with a high graded bank on the north shore of Tabbs Creek. The tide range (MLW to MHW) in Tabbs creek is 1.1 ft. The shore faces south-southwest with an average fetch of only 240 ft with a minimal historic erosion rate. However, an exposed erosional bank face existed before grading, indicating active erosion (Hardaway *et al*., 1984). After grading, hay bales were placed along the base of the bank, and the graded slope was planted with tall fescue.

A narrow intertidal beach, composed of fine silty sand, extended riverward from the hay bales for about 12 ft. Most of the sediments that support the beach probably came from the erosion of the previously- exposed bank. Natural stands of *Spartina alterniflora* (smooth cordgrass) occurred next to the site where there appeared to be less shading from trees on the bank.

Design Elements and Construction

The Poole site was first planted with *Spartina alterniflora* (smooth cordgrass) in the spring of 1982 between MLW to MHW. This site was not too complicated because the 12-ft upland bank was already graded and had straw bales staked along its base. High water occurred at the base of the straw bales, and the upper intertidal zone was about 5 ft wide. This only allowed the use of a low marsh plant *Spartina alterniflora* to establish the marsh fringe. *Spartina alterniflora* was planted on the usual 1.5 ft x 1.5 ft grid with one ounce of Osmocote fertilizer placed under each plug.

Performance

A significant reduction in marsh area and width occurred by August of 1982 where the lower limit was naturally established at mean sea or mean tide level. Some increase in width was seen over the 1982/83 winter as well as some base of bank scarping due to deterioration of the hay bales. Maintenance planting was done in the spring of 1983. The planting was extended to its original limits of the initial 1982 planting. By late August 1983, the lower limit had retreated to its previous position at MTL.

A slight loss of sediment within the intertidal fringe occurred over the winter of 1983-84. By the spring of 1984, a slight increase in marsh area and width was observed. Rhizome-spread had begun as early as mid- March from the fringe where the lower limit corresponded almost exactly to MTL.

The Poole site has been able to maintain a stable upper tidal and thick continuous *Spartina alterniflora* fringe through time. Although slight bank erosion has occurred, the site generally was considered successful by the end of the monitoring period in 1984 (Figure 3-2). The site has remained intact for more than 25 years as evidenced by the following series of photographs (Figure 3-2). This type of treatment is viable when there is only a narrow upper intertidal zone for planting. The need for sunlight also is critical for establishing fringes up the numerous tidal creeks where bank orientation, height and shading by trees are factors to consider.

A review of performance in 2016 indicated that the marsh fringe had deteriorated. A site review by the Virginia Department of Conservation and Recreation Shoreline Erosion Advisory service in 2016 found that erosion on the property was caused by elevated water levels and waves associated with storms (Figure 4-1). Due to tree loss and other erosion concerns, a riprap revetment was constructed above mean high water to protect the bank and allow the existing marsh grass to continue to grow (Figure 4-1).

Figure 4-1. The Poole site in 2016 (top) showing the loss of much of the intertidal marsh fringe, and in 2018 (bottom) after the construction of a riprap revetment along the bank above mean high water. Photos from the VMRC permit (#20160366) report.

4.2 Intertidal Oyster Reef Sills

Captain Sinclair Recreational Area: Severn River, Gloucester County, VA (37°19'28.3"N 76°25'51.0"W)

Introduction

2,000 oyster shell bags were placed along the eroding edge of a large tidal marsh at the Captain Sinclair Recreational Area site in August, 2017 by VIMS, Shoreline Studies Program personnel with the assistance of representatives from the Department of Conservation Shoreline Advisory Service and the Virginia Marine Resources Commission. In addition, several local teens and young adults volunteered to help build the sill. On the southwest-facing shoreline, a three-bag design was used, and on the southeast-facing shoreline, a six-bag design was used (Figure 4-2). The six-bag reef has fared very well, but the three-bag structure has had mixed results.

Site Setting

The Captain Sinclair Recreational Area is located on the northern shore of the southeast branch of the Severn River between School Neck Point and Turtle Neck Point. The existing marsh at CSRA had a scarped, eroding edge. The marsh point has two directions of face that have two relatively different fetches. The southwest facing shoreline has an average fetch of about 0.85 miles and the southeast facing shoreline has an average fetch of about 1.02 miles. Oyster bags were placed along shore in gapped sections of sill. Lengths ranged from 80-100 ft long. The permit was received from the Corps of Engineers on July 31, 2017.

Design Elements and Construction

The 2,000 oyster bags were placed on August 15-16, 2017. Oyster bags filled with shell were loaded offsite and brought by boat to the marsh for placement. The bags were placed directly adjacent to the eroding marsh in deeper areas and slightly offshore at the base of the sand slope in more

Figure 4-2. Construction of the 3-bag sill (left) and 6-bag sill (right) in August 2017. From Milligan et al. (2018). *Photo credit: Linda Tjossem*

shallow areas so that the structure was at approximately low water. This would provide an intertidal range for the sill.

Performance

The site was monitored for biologic impact on April 3, 2018 by students in the Christopher Newport University's Invertebrate Zoology class in cooperation with Dr. Heather Harwell, assistant professor in the Department of Organismal and Environmental Biology. Although the site only had a fall and winter on the ground, a diverse group of macrofauna inhabited the sill. Both live and dead oysters, as well as ribbed mussels, were present on and in the bags.

The site was surveyed by real time kinematic global positioning system on September 8, 2017 and April 3, 2018. The as-built survey shows that the oyster bags were placed similar to what was designed (Figure 4-3). However, only three sections of sill were built on the southeast facing shoreline while 5 sections were built on the southwest facing shoreline. The 6-bag sill was wrapped around the southernmost point very close to the marsh to provide additional protection to the area with the

Figure 4-3. Captain Sinclair's Recreational Area oyster bag sill. The three-bag sill (top) that was placed on the southwest-facing shoreline has not been as stable. The top bag of some sections were rolled toward the shoreline. The six-bag sill (bottom) on the point and the southeast-facing shoreline has remained intact. From Milligan et al. (2018).

largest erosion rate. Overall, the 6-bag sill has remained intact over the past several years (as shown by Google Earth 2021 imagery) and is maintaining the marsh edge. The 3-bag sill has had mixed results. The sections of sill that are farther north, and therefore are more protected, remained intact as did those that were placed close to the marsh. However, the top bag on the 3-bag sills that were placed farther from the marsh at the base of the gentle sand intertidal slope tended to roll. No definitive data has determined whether or not the change in structure will affect the role the bags play in shore protection.

4.3 Marsh Toe Revetment/Sill

Hollerith Marsh Toe Revetment: East River, Mathews County, VA

(37°23'8.73"N, 76°20'1.24"W)

Introduction

The Hollerith site is located on the East River in Mathews County. This marsh toe revetment was installed in 2001 (Figure 4-4). The site had an existing wide fringing marsh with an eroding edge and low upland bank erosion. A marsh toe revetment with tidal gaps was used to reduce wave action into the existing marsh and restore severely eroded pockets within the fringing marsh.

Site Setting

The Hollerith site is located along about 860 ft of shoreline on the East River with an historic erosion rate of about 1 ft/yr. The shoreline faces about due west with fetch exposures to the west and northwest of about 0.5 mile and 1.5 miles, respectively. A long fetch to the southwest of about 8.0 miles exists. The tide range in the East River is about 2.5 ft.

This is a moderate-energy setting with a low, upland bank that transitions southward to an upland and marsh spit. The upland bank had an undercut base and was occasionally overtopped during storms. The existing fringing marsh was greater than 25 ft wide with pockets of severely eroded marsh and non-vegetated areas (Figure 4-4). The nearshore is a wide, shallow, sandy habitat with persistent submerged aquatic vegetation (SAV) beds.

Design Elements and Construction

Marsh and upland bank erosion plus a desire to maintain and restore the marsh were the main design elements. The wide fringing marsh had a "scalloped" edge with variable marsh widths, yet the marsh toe revetment was placed in a straight alignment. This allowed the non-vegetated and eroded marsh areas to become colonized with low marsh plants, particularly *Spartina alterniflora*. The objective was to restore a fringing marsh with a uniform width of 35 ft that included both low and high marsh zones.

Two marsh toe revetment sections at +3.0 MLW were designed near the mid-tide level with crest lengths of 450 ft and 360 ft. A revetment was used between the marsh toe sections where the level of protection needed was greater for a large house and the fringing marsh was very narrow. Tidal openings were located at the ends of both sections only; there were no tidal gaps within either section.

Upland access for construction in the summer of 2001 was not limited. The average stone weight was 25 lbs. for core material and 75 lbs. for armor layers for a total weight of ¾ tons per foot.

Performance

This site was surveyed in 2004 and 2005 for a marsh toe revetment study. No evidence of scattered stones, settling or other structural integrity problems due to Hurricane Isabel was found. The low marsh had expanded into previously bare areas and both low marsh and high marsh zones were densely covered with high species diversity for a continuous wide fringing marsh.

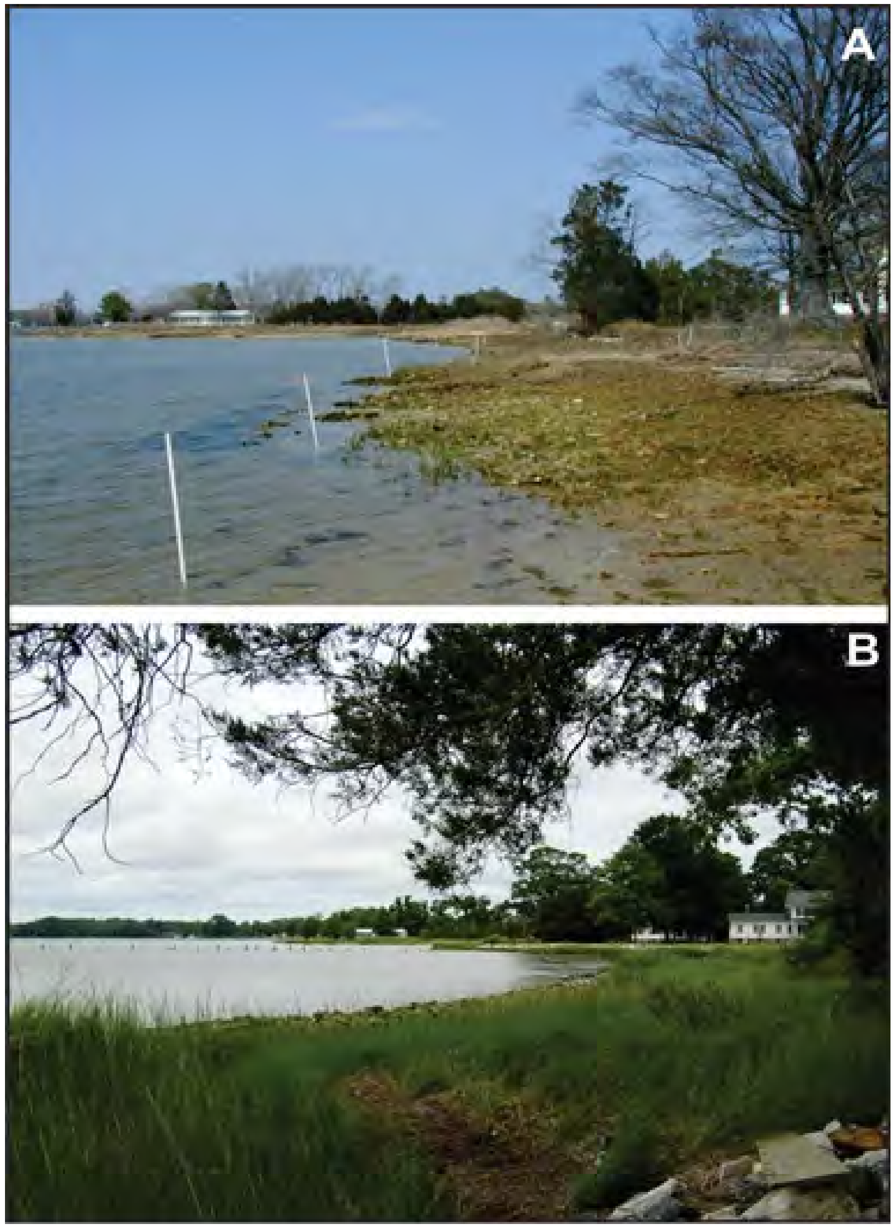

Figure 4-4. Hollerith marsh toe revetment/sill site A) before project with eroding fringing marsh in winter and B) after construction.

Upland bank erosion continued to be a concern behind the southern marsh toe revetment. The height was increased by 1 ft (+4.0 MLW). The reason why upland bank erosion continued in spite of marsh enhancement and a long continuous marsh toe revetment structure has not been determined. The frequency and duration of extreme high tide flooding above the living shoreline system might be a factor. A more recent look at aerial imagery from Google Earth and the Virginia Base Mapping Program show that though the marsh may have expanded initially, many areas of what was once low marsh has been converted to tidal flat in 2021. A more detailed look at this site is warranted to determine its effectiveness as sea level continues to rise.

4.4 Sills

4.4.1 Poplar Grove: East River, Mathews County, VA

(37°23’49.93” N, 76°20’11.52” W)

Introduction

Poplar Grove is a plantation established the late 18th century on the North River in Mathews County. The property owner had contacted VIMS regarding shore protection on the more exposed southern shoreline. She chose a revetment and sill system as provided by the contractor (Figure 4-5).

Figure 4-5. Sill system at Poplar Grove on the East River in Mathews County, Virginia six years after completion. A) The sill and marsh fringe provide a wide buffer between the water and the upland. B) The wide gap in the sill provides a pocket beach access area along the shoreline. C) The project zones are clearly visible: stone sill, S. alterniflora, S. patens, and upland/wooded. D) The old mill sits close to the shoreline. In this area, a revetment was chosen to protect the shoreline.

Site Setting

Poplar Grove is located on the East River in Mathews County, Virginia. The project shoreline is about 1,500 ft long and faces almost due south with a long fetch exposure of almost 16 miles in that direction. The long fetch to the south was a concern. The tide range is 2.7 ft MLW (NOAA station). The eastern 250 ft of the project shoreline occurs as a narrow peninsula on the East River. An old mill is perched on the bank, and old broken concrete occurred along the bank face (Figure 4-5D). The shoreline extended westward about 900 ft as a low eroding bank which transitions into a low, sand-faced marsh spit.

Design Elements

Access to the site was across an open field. The project includes a low revetment to protect the old mill peninsula. The existing broken concrete was incorporated into the bedding of the revetment

(Figure 4-6). The revetment transitions westward into a low, wide-crested sill with a pocket beach and a sill window incorporated into the system. The upland was excavated behind the opening for the pocket beach in order to accommodate the distance needed for a stable beach planform. The sill ends where the upland transitions into marsh, then a short breakwater is placed about 150 ft from the end of the sill to hold a marsh point (Figure 4-7). Sand nourishment was placed along the open shore between the sill and the breakwater to enhance the spit and provide access to build the breakwater.

The revetment was built to the top of the existing bank and placed on a 1.5:1 slope. The sill was designed as a low wide sill with an elevation at +3 ft MLW and crest width of 4 ft which was needed for the proposed armor stone required to address the long, southern fetch. The sand fill was placed on a 10:1 slope beginning near the top of the low bank and extending to the back of the sill at about MTL. This provided for a maximum planting zone of 12 ft of *Spartina alterniflora* and 16 ft of *Spartina patens* (Figures 4-6 and 4-7).

Construction and Performance

The project was installed in 2003 and took about two months to complete. The site has experienced numerous storm events beginning with Hurricane Isabel and the Veteran's Day Northeaster. Water levels during the Veteran's Day Northeaster in 2009 were more than 4 ft higher than a normal high tide. Storm waves essentially rolled over the project area and were effectively attenuated with no signs of bank scarping. A slight offset has developed at the beach between the sill and the small breakwater but that was expected and appears to have reached a state of shore planform equilibrium.

Google Earth imagery (November 2015) shows a stable system that has changed little since construction. However, imagery from May 2021 may indicate that some areas of the low marsh may have been converted to tidal flat behind the two sills to the west. Looking at this site in detail may determine whether adaptive management is needed at the site.

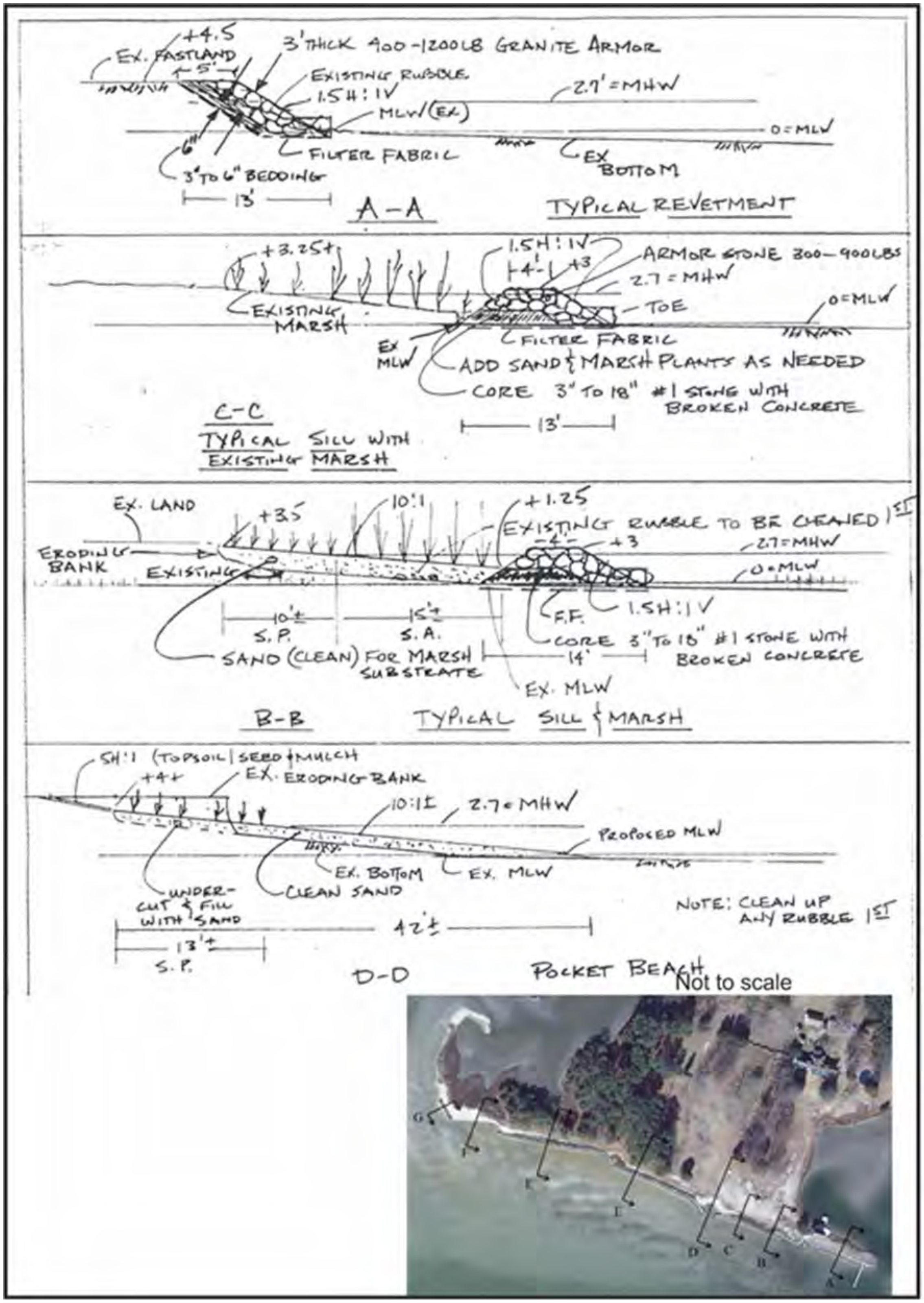

Figure 4-6. Typical cross-sections of the Poplar Grove shore protection system including the revetment, sill and marsh and pocket beach. Permit drawings by Coastal Design & Construction, Inc.

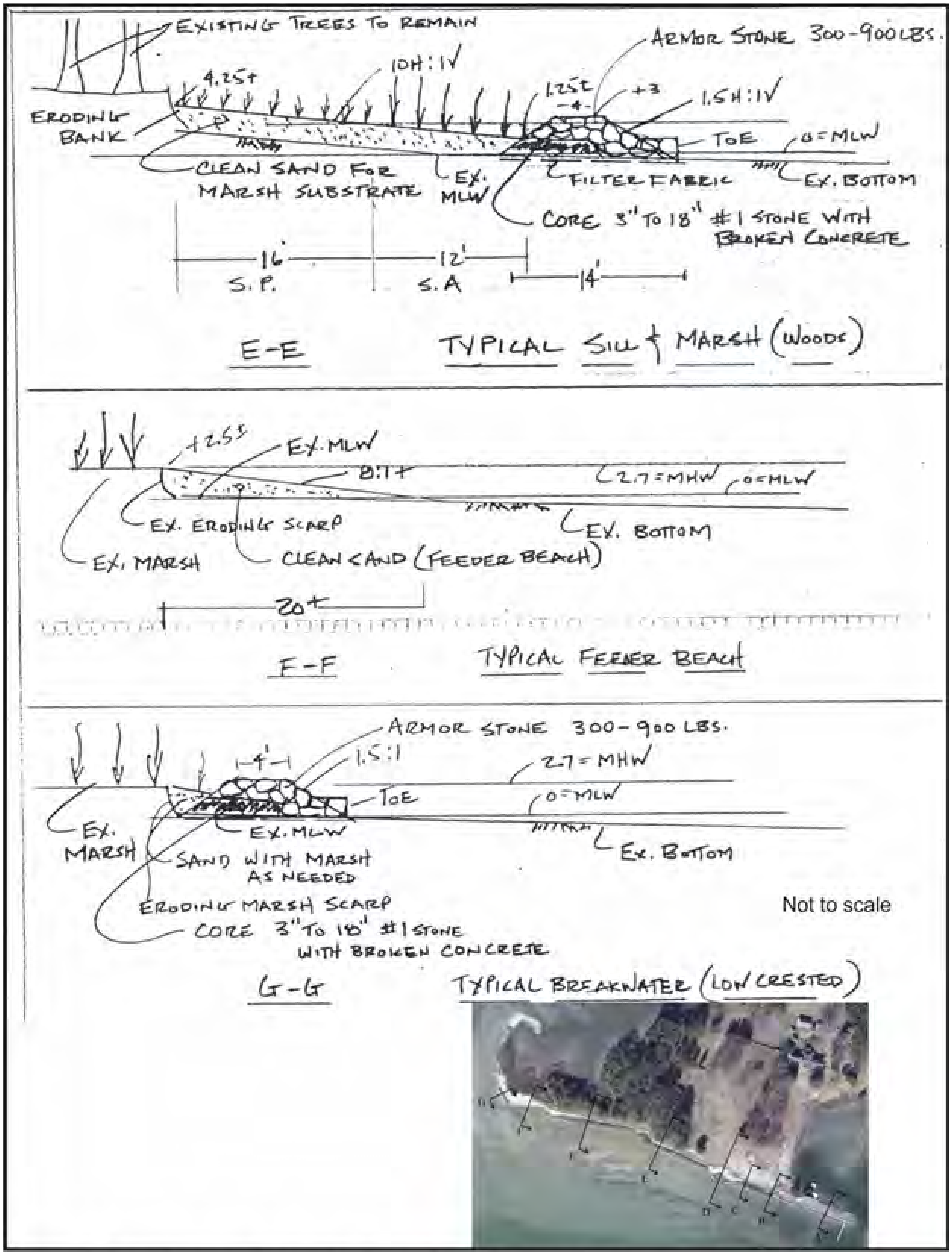

Figure 4-7. Typical cross-sections of the Poplar Grove shore protection system including the sill and marsh, feeder beach, and breakwater. Permit drawings by Coastal Design & Construction, Inc.

4.4.2 Hull Springs Farm: Lower Machodoc Creek, Westmoreland County, VA (38°7’35.35” N, 76°39’13.41” W)

Introduction

Hull Springs Farm was obtained by Longwood University in 2000 to serve as a research venue for various subjects including shoreline processes, habitat, and management. Longwood obtained a grant from NOAA in 2005 to develop a GIS- based shoreline management plan for Lower Machodoc Creek including the approximately two miles of tidal shoreline around Hull Springs Farm. Most of the shoreline at Hull Springs Farm has small fetches and sheltered coasts except for the shoreline in front of the “Manor House” which was actively eroding (Figure 4-6A).

Site Setting

The Hull Springs Farm sill was built in 2008 along about 300 ft of shoreline on Lower Machodoc Creek. This coast is on the distal end of a neck of land between Glebe Creek and Aimes Creek (Figure 4-8). Recent (1994-2007) changes at the site indicate that the shore is eroding between -1 and -2 ft/yr. The site has fetches to the north, northeast, and east of 700, 7,500, and 800 ft, respectively. The north and east fetches are small relative to the northeast, which has more than one mile of fetch out the mouth of Glebe Creek and across Lower Machodoc Creek and is the primary cause of shore erosion during storms. The tide range is 1.8 ft (NOAA). The shoreline occurs as a high upland bank composed of basal clay overlain by some very sandy strata. The base of the bank is generally erosive along the project site while the bank face is erosive to transitional to stable (Figure 4-9A).

The existing marsh fringe and backshore varies from nonexistent, to about 5 ft wide at about mid-neck, and widening southward to about 10 to 15 ft wide. The instability of the base of the bank is related to the narrowness of the fringe, which in turn is related to fetch. A short, concrete seawall on the north end is the remnant of a wall that once extended southward along the eroding upland (Figure 4-9A). Its presence is evidence of previous efforts to abate bank erosion at the project site. The bank is graded behind the standing wall. Northward, from the end of the wall, no marsh fringe exists and the base of bank is erosive, but the bank face is stable. Regular high tides reach the base of bank. In some areas, vegetation obscured the scarp at the base of bank.

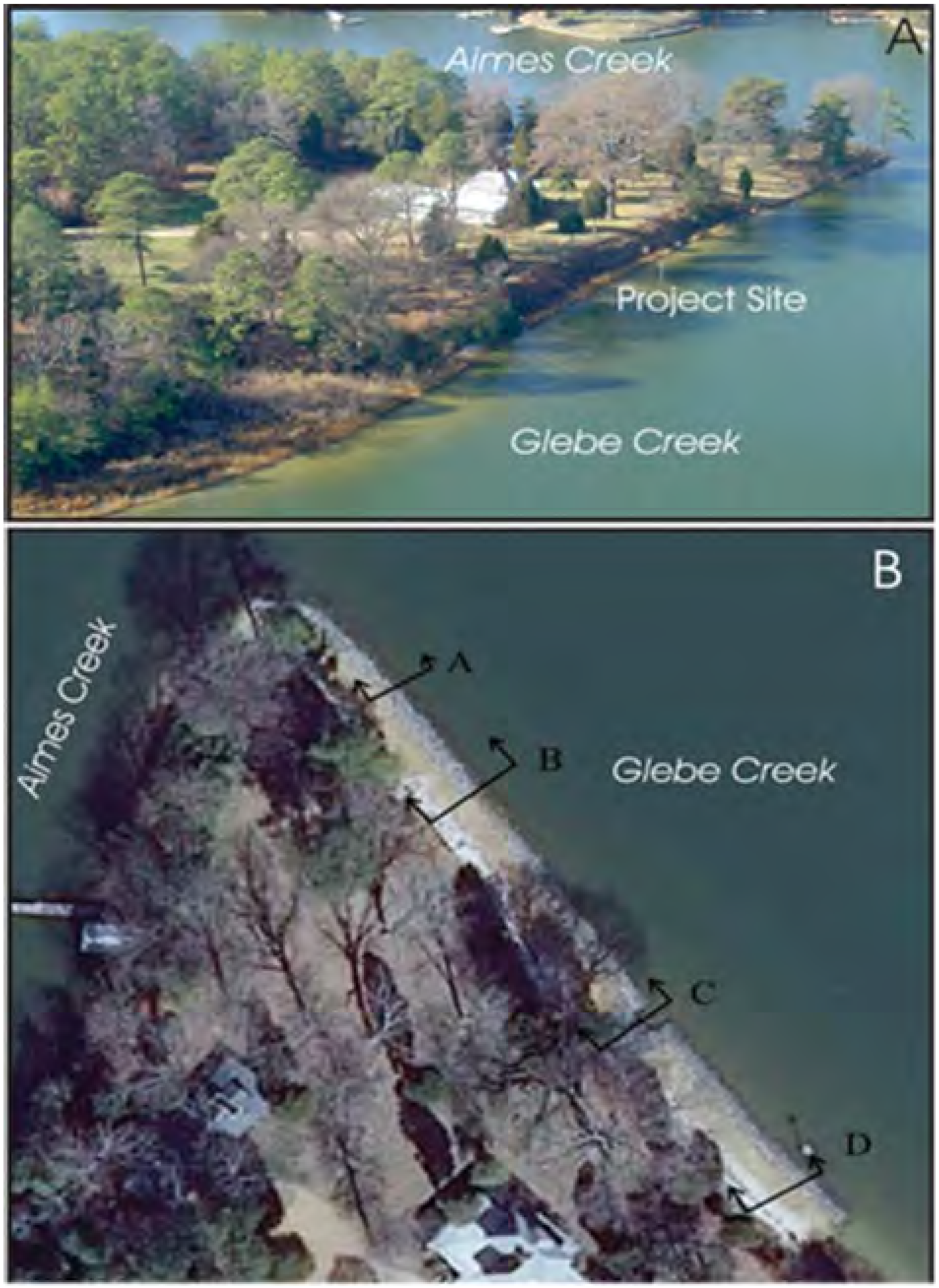

Figure 4-8. Longwood University's Hull Springs Farm on Glebe Creek. A) Before the shoreline project, the bank is eroding in front of the Manor House. B) After the project, the shore zone was widened with sand behind the sills.

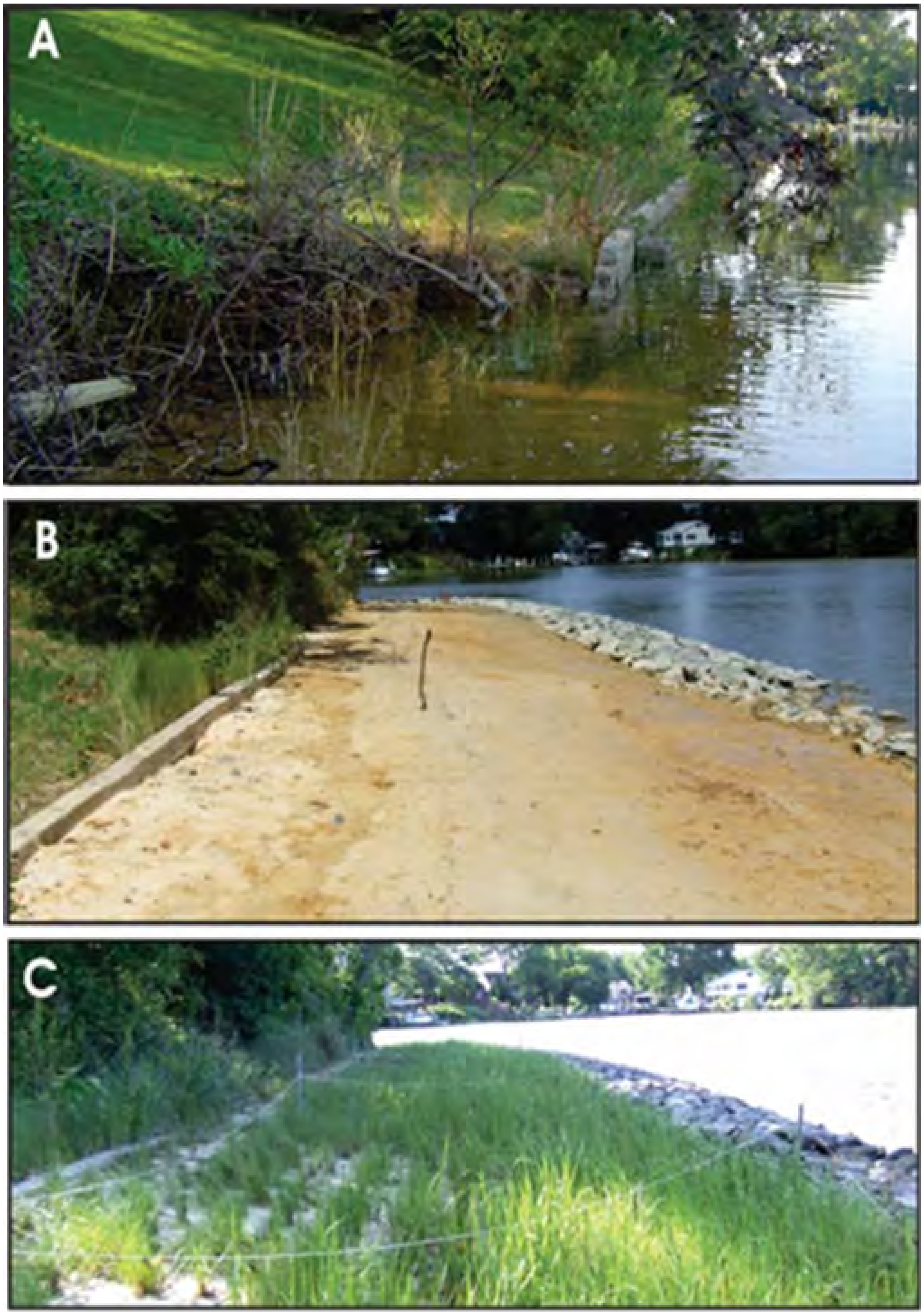

Figure 4-9. Hull Springs Farm shoreline A) before construction, B) after construction of the sill and placement of sand, and C) after planting.

Design Elements and Construction

The presence of a large oak tree about 25 ft from the top of bank was one reason for dealing with the erosion. Longwood University also wanted to demonstrate the Living Shoreline approach to shoreline management. VIMS determined that the bank condition, nearshore bottom condition, and fetch indicated that this would be an appropriate Living Shoreline application site. A low sill with sand fill and marsh plants was designed (Figures 4-10 and 4-11).

Due to Tropical Storm Ernesto in 2006, the base of bank was significantly impacted, and the nature of the long-term erosion was dramatically revealed. The wave cut bank scarp from the storm was 6 ft high and eroded one to 2 ft in some areas. It was evident that the proposed sill was not sufficient for immediate protection of the base of bank since continued erosion would threaten the old oak tree on top of the bank. The design was modified to include a stone revetment in the vicinity of and adjacent to the old oak. The sill was still built in front (waterside) of the revetment (Figure 4-11).

The sand fill begins at +3 ft on the bank and old bulkhead and extends on a 10:1 slope to about mid- tide (+0.8 ft) at the back of the sill (A-A, Figure 4-10). This provides planting widths of about 10 ft for *Spartina alterniflora* and 12 ft for *Spartina patens*.

The revetment was set at +6 ft MLW, the approximate top of scarp resulting from Ernesto. The sill, as originally planned, began at the northernmost end of the neck and extended southward across the upland bank area of active erosion. A low weir section was designed in the sill at the bulkhead (B-B, Figure 4-10) and an open window was designed in front of the revetment. In order to keep the window open, a cobble pavement was proposed instead of sand (C-C, Figure 4-11). Less sand fill was needed toward the south end of the project and only as an amendment to the existing marsh fringe. The revetment was built first, then the sill system. The revetment was built along about 400 ft of shoreline in front of the large oak tree.

Construction and Performance

The sill system was built in August 2008 and soon after 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 but appear to have reemerged intact. Photos taken in May 2015 show a robust marsh behind the sill (Figure 4-12). Some bare spots do occur near the base of the bank, but scrub/shrub plants are colonizing the marsh and should eventually fill in these areas.

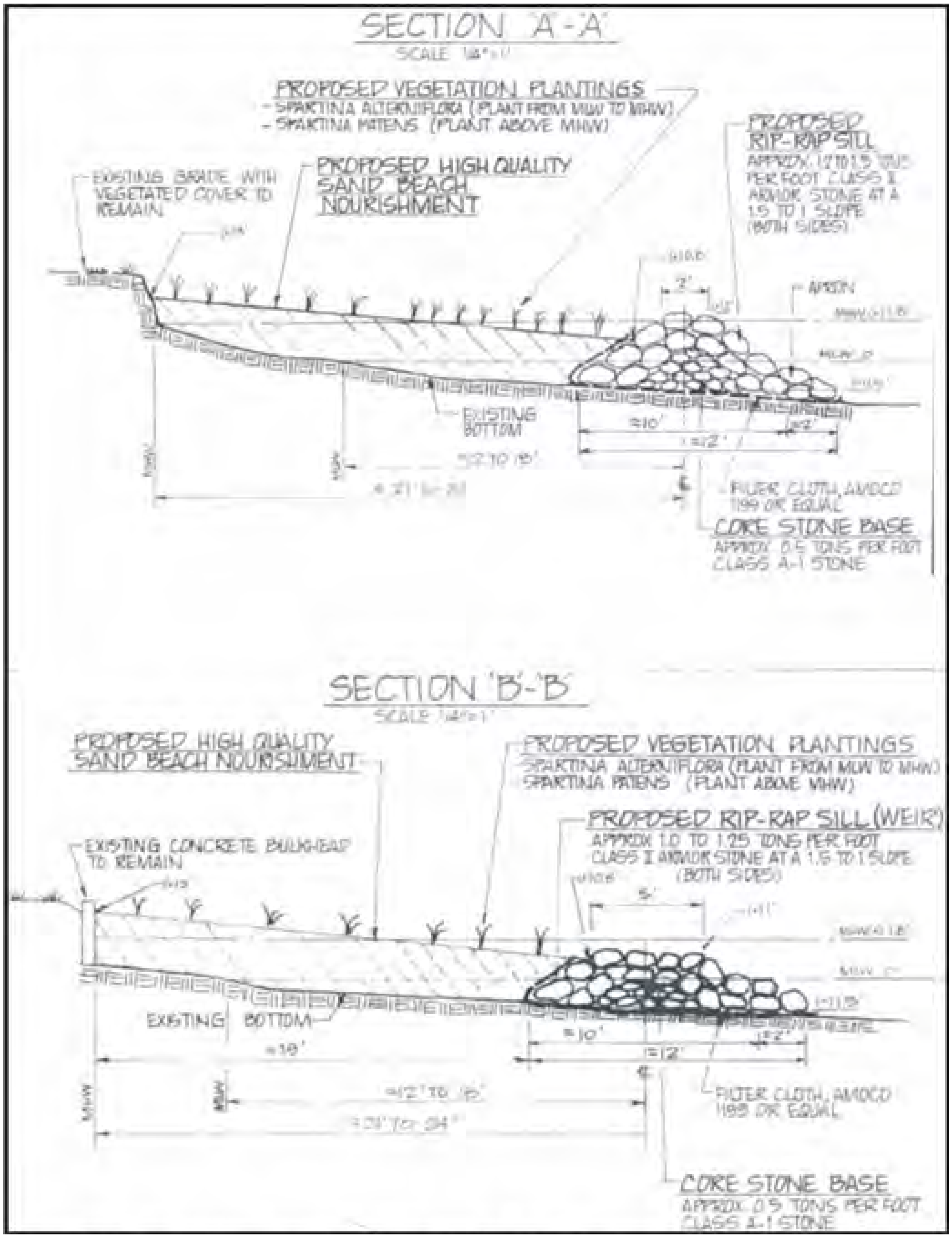

Figure 4-10. Typical cross-sections for sill built at Hull Springs Farm. Section locations are shown on Figure 4-8B.

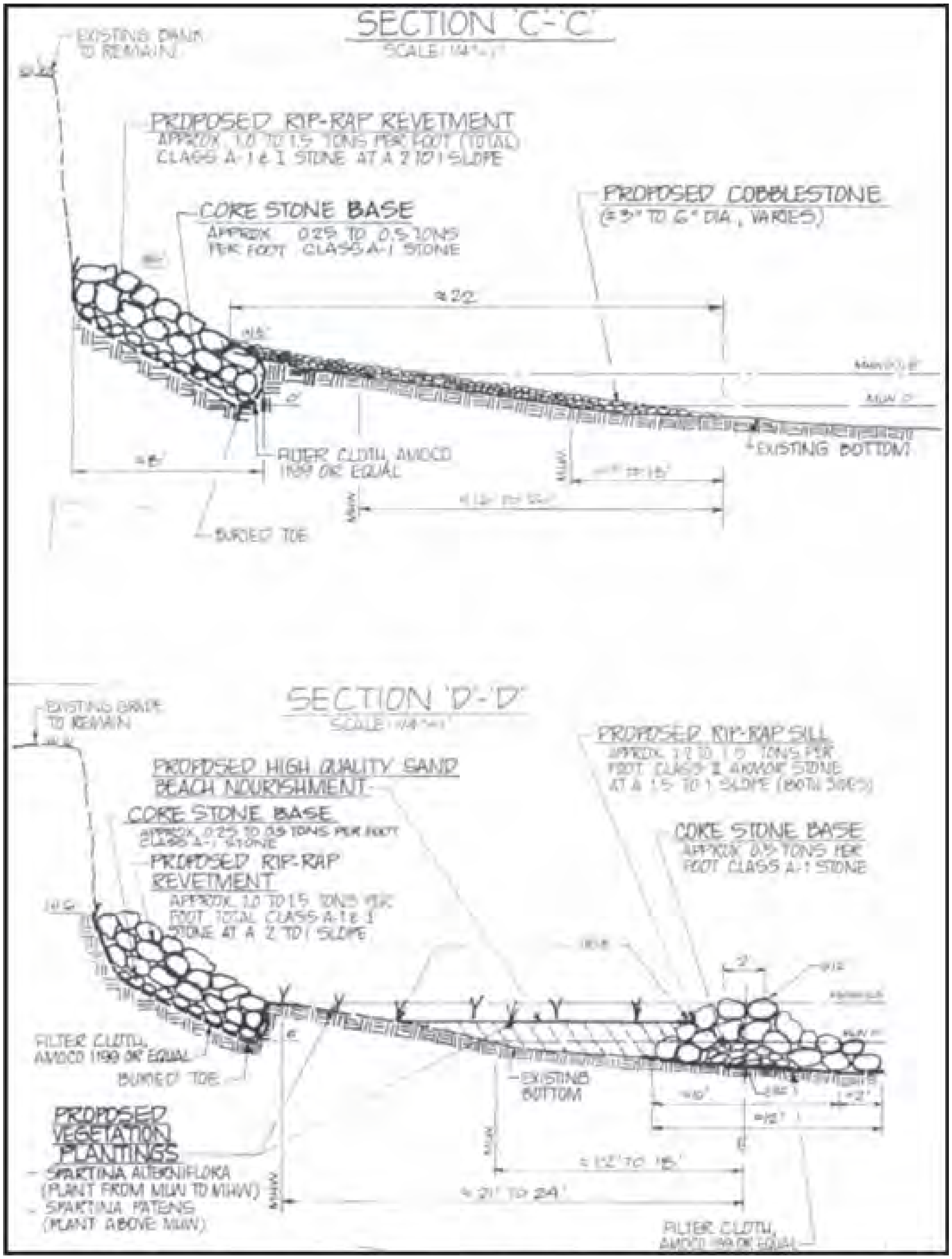

Figure 4-11. Typical cross-sections for sill built at Hull Springs Farm. Section locations are shown on Figure 4-8B. Permit drawings by Bayshore Design, LLC.

Figure 4-12. Photos of Hull Springs Farm in May 2015, seven years after construction.

4.5 Breakwaters

Van Dyke: James River, Isle of Wight County, VA (37°2'8.47" N, 76°36'50.12" W)

Introduction

Van Dyke is located on the south shore of the James River in Isle of Wight County, Virginia. It is a privately- owned site that had severe erosion of its 50 ft banks due, in part, to its exposure to a long fetch to the north of more than 12 miles (Figure 4-13).

Site Setting

The site is impacted with wind/waves from the northwest, north, and northeast and is defined as a bimodal site. The site's bimodal wave climate and sand rich bank called for a breakwater system which utilized the bank sand for beach fill. Long-term erosion averaged -3.5 ft/yr.

Design Elements and Construction

Several factors were important considerations in the design; these were impacts to adjacent properties and the coordination of 15 property owners with varying degrees of support for, and input to, the project. The overall purposes of the project were to provide shore protection and access to the James River.

Performance

The 2,300 ft project was installed in 1997. The system consisted of eight headland breakwaters ranging in size from 90 ft to 160 ft with an open upriver boundary and a low short 50 ft interfacing breakwater and revetment downriver (Figure 4-13). The project also included beach fill and wetland plants. Beach fill sand was selectively mined from adjacent 40-foot upland banks when they were graded. Since the original project was installed, additional breakwaters have been installed on either end of the project.

Impacts from Hurricane Isabel were documented by Hardaway et al. (2005). They found that while a landward shift in the positions of both the shoreline and base of bank occurred due to the storm, post-storm recovery showed the shore planform has returned to approximately their pre-storm configuration. Generally, the base of bank was relatively stable, but erosion of the bank did occur behind several bays (Figure 4-14). However, the combination of storm surge and wave height exceeded 11 ft MLLW, about 3 ft higher than project design. Ground photos taken before and after Hurricane Isabel show the extent of the upland bank scarping which likely was caused by the combination of storm surge and wave impacts (Figure 4-14). The retreat of the base of bank was generally more severe in the embayments than behind the breakwaters and associated tombolos. Also, base of bank impact was minimal where the interface between the backshore and base of bank had a less steep gradient.

Recent aerial imagery from Google Earth (Figure 4-13) shows the state of the beach in November 2016, about 20 years since installation. The longer breakwaters on the ends of the project have created larger beach and backshore regions. However, in the center of the project, several breakwaters are shorter and farther offshore and no longer have a subaerially- attached tombolo. Homeowners installed a revetment in 2013 along this 400-foot stretch of shoreline in the central section of the project to provide additional protection because these upland banks were impacted by Hurricane Isabel. This illustrates the need for long term monitoring and maintenance of shore protection strategies especially along high wave energy estuarine coasts.

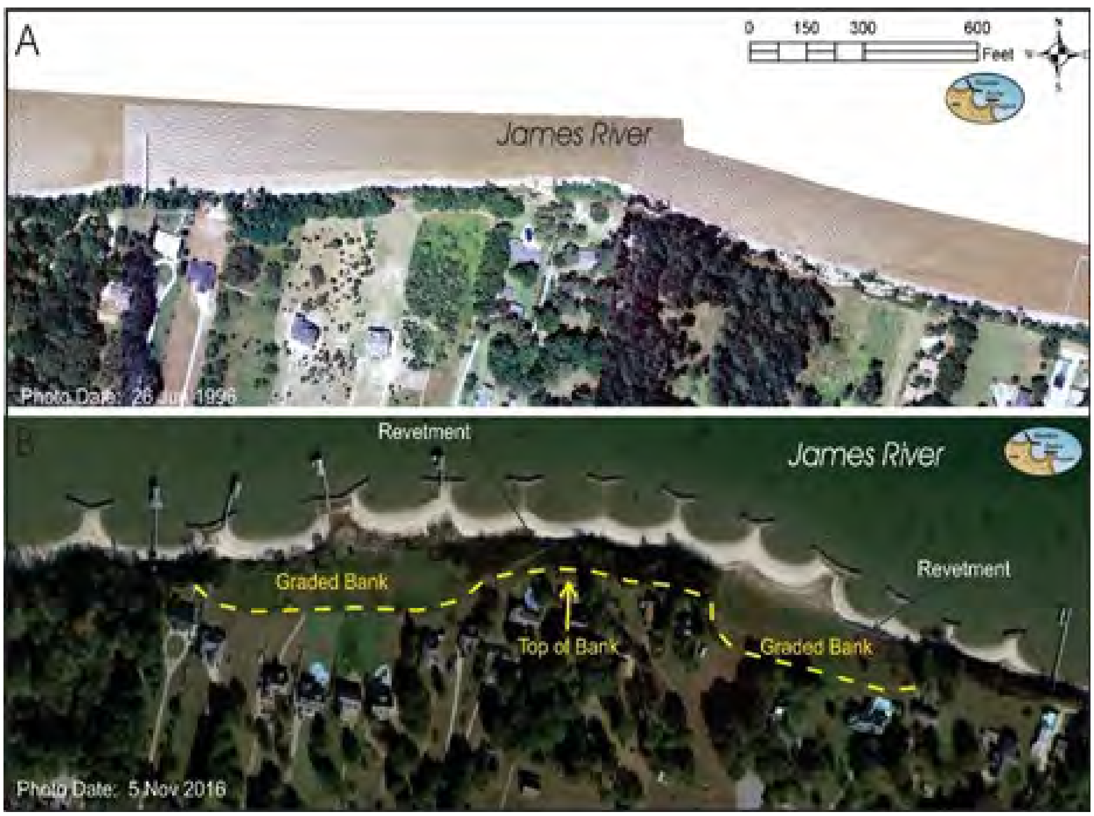

Figure 4-13. Photos of Hull Springs Farm in May 2015, seven years after construction.

Figure 4-14. Photos of Hull Springs Farm in May 2015, seven years after construction.

5 Living Shoreline Design Examples

5.1 Occohannock on the Bay

Introduction

Occohannock on the Bay is located near the mouth of Occohannock Creek in Accomack County, Virginia. It is a Methodist church camp that had been experiencing shoreline erosion for years. Funding from The Nature Conservancy allowed for design, permitting, and construction of this sill system that is one of only a few Living Shoreline demonstration sites in Accomack County, Virginia.

Setting

Occohannock on the Bay resides on the distal end of a neck of land at the confluence of Tawes Creek and Occohannock Creek (Figure 5-1). It is a west facing shoreline with two different fetch exposures. The shoreline in Tawes Creek has a fetch of less than 1,000 ft. The shoreline facing Occohannock Creek has a larger fetch and has a long fetch of over 20 miles to the southwest across Chesapeake Bay (Hardaway et al., 2008). The project shoreline is about 600 feet long with an historic erosion rate of 0.5-1 ft/yr (Hardaway et al., 2008).

The Occohannock on the Bay shoreline, in 2013, was a low eroding upland bank along the southern section of the project area with a very narrow marsh fringe which gave way to an actively eroding low, clayey bank where the camp shoreline access road was located (Figure 5-2). The coast then transitioned to a marsh fringe associated with a small tidal creek, then back to low eroding upland. A small beach was used for canoe launching just as the bank rose to about 15 ft MLW along the

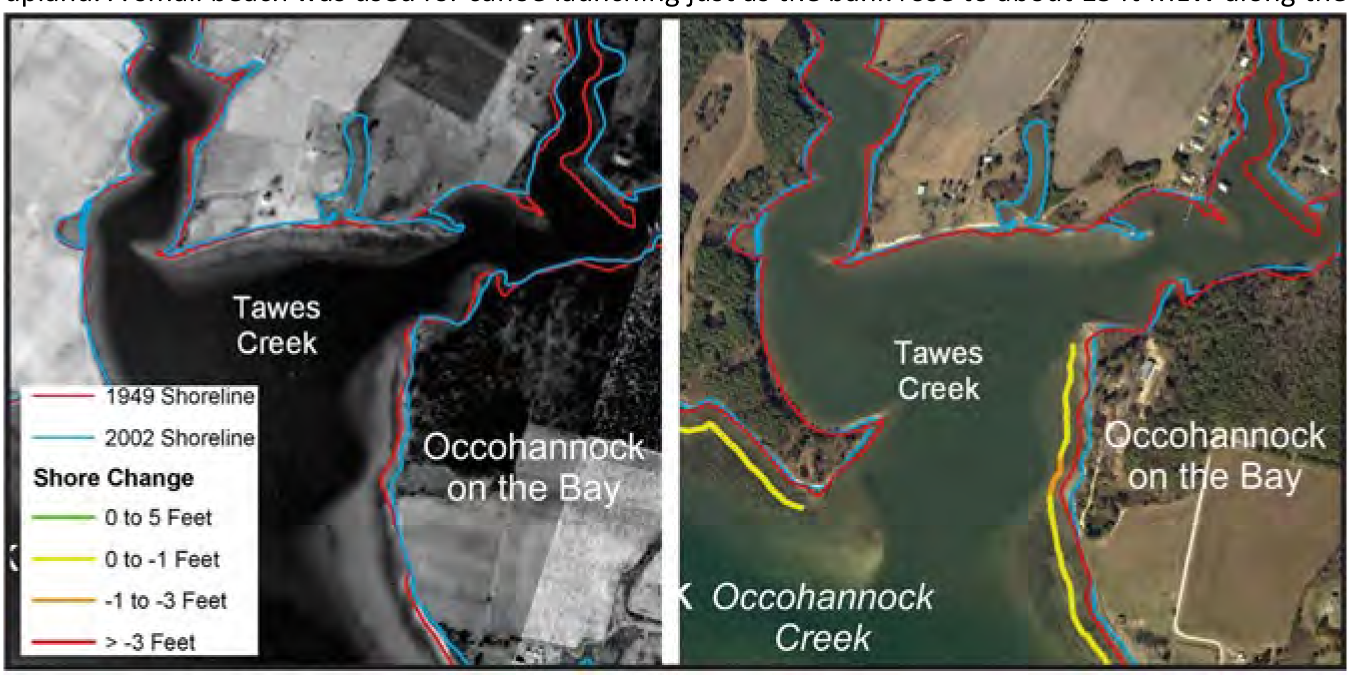

Figure 5-1. Shoreline change at Occohannock on the Bay (from Hardaway et al., 2008).

north section. The high upland bank was sandy, mostly vertically exposed and actively eroding with a very sparse *Spartina alterniflora* fringe along the shoreline. A residence occurred about 60 ft from the top of bank, and a high wood bulkhead had been installed on the very north section of the high bank shoreline.

The nearshore was relatively shallow with abundant SAV (widgeon grass) beds that came very close to shore, especially along the low bank south coast of the project site where aquaculture cages are located across the nearshore region. The SAV beds did not extend south past the small tidal creek where the nearshore continued as a very shallow tidal flat.

The tide range is 1.7 ft with a storm surge frequency of the 10, 50, and 100-year event of 4.4 ft, 4.9 ft, and 5.2 ft MLLW, respectively (FEMA, 2015). The shallow flats along the project shoreline and the extensive sand bars along the mouth of Occohannock Creek attenuate much of the Bay-centric wind driven waves from the southwest. The low bank shoreline is impacted during high water events, but the southwest storm wind/wave climate causes pulse erosion to the high bank coast.

Design

Three distinct treatment segments were designed on the original Occohannock on the Bay Shore Plan (Figure 5-4):

Figure 5-2. Considerations for shore protection design along the project area.

1. Approximately 405 feet of cobble sill was designed to protect and enhance the existing high marsh (S. patens) fringe which was actively eroding along the water's edge (Figure 5-3, Section AA). This marsh partially protected the adjacent upland from moderate storm waves. However, portions of the low upland bank were eroding because the fringe was becoming narrower. Existing SAV beds were within a few feet of MLW and thus disallowed encroachment into the nearshore. The plan called for additional planting of S. patens to enhance the existing high marsh fringe. This section was not built due to a lack of funding.

2. Approximately 185 feet of stone revetment was designed to protect the actively eroding upland and access path. The revetment had to be swapped out for a robust stone sill due to funding requirements that all components of the plan be Living Shoreline best management practices (Figure 5-3, Section BB and ZZ).

3. Approximately 480 feet of stone sill consisting of three sill units was built where no SAV is present (Figure 5-4). Sill 1 was 100 ft in length and protected a low eroding marsh edge (section CC). Bay A was the opening to the small unnamed tidal creek. Sill 2 continued on the up-creek side of the tidal inlet for 120 feet and protected the low eroding upland bank (Section DD). Bay B was 40 feet wide between Sill 2 and Sill 3 and was the location of the kayak and canoe access beach. The added sand fill was designed to provide a protective beach for the adjacent low upland bank. Sill 3 continued for 220 feet and protected the adjacent actively eroding upland bank (Section EE). The upland bank increased from +5 ft MLW to +12 ft MLW along the length of Sill 3 and bank grading was proposed as shown. It should be noted that the Sill 3 sand nourishment covered approximately 5,980 sq. ft of existing low marsh that was not wide or robust enough for adequate shore protection. This project created 6,900 sq. ft of intertidal marsh and 9,120 sq. ft of high marsh.

Construction

The project was completed in 2014 including bank grading, construction of the sills and sand nourishment to create the vegetative planting terraces (Figure 5-5). Pre- and post- construction for the sill along the shoreline access road and the larger sill is seen in Figure 5-6. All material was brought in by land and locally sourced when possible. The permitting process in Virginia required the calculation of the impacts to the existing site conditions. This includes the amount of habitat created and the habitat tradeoffs as shown in Table 5-1. Volunteer labor helped reduce costs associated with planting.

Performance

Overall, after three growing seasons the structures built and the grasses planted have fared very well at the site (Figure 5-7). The grasses have taken hold and other plants (pine trees) are beginning to colonize the upper marsh and upland transition zone. The access road is no longer threatened due to erosion. However, one small section of planted marsh behind Sill 3 did not fill in (Figure 5-8). The bare spot was a concern so, in July 2017, additional low marsh plants were planted at the site.

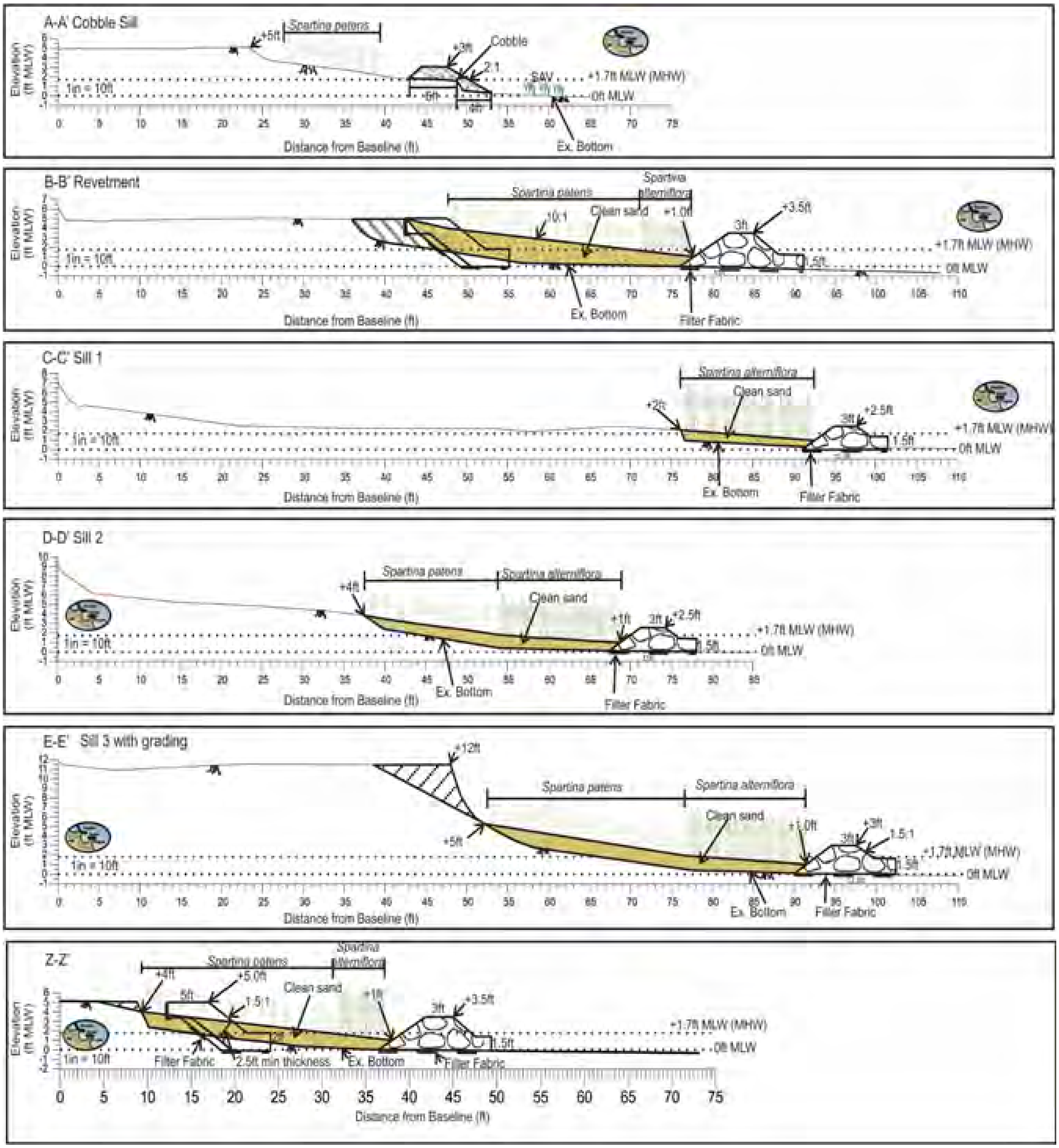

Figure 5-3. Typical cross-section of shore protection structures proposed at Occohannock on the Bay.

Table 5-1. Habitat created and impacts of the Occohannock on the Bay shore project

			Habitat Created		Impacts: Rock					Impacts: Sand					
		Length	Sa (ft²)	Sp(ft²)	Max	Max	Vegetated	Nonveg	Subaqueous	Fill	Veg.	Volume		Area	
Typical	Structure				MHW	MLW	Wetlands	Wetlands	Bottom		Wetlands	<MLW	>MLW	<MLW	>MLW
X-Section	Type	(ft)			(ft)	(ft)	(ft²)	(ft²)	(ft²)	(cy)	(ft²)	(cy)	(cy)	(ft²)	(ft²)
A-A'	Cobble Sill	320			12	3	1,920	1,280	50			none			
B-B'	Revetment	145			10	0	290	1,160	0			none			
C-C'	Sill	100	1,500		30	12		100	1,200	60		0	5	0	1,500
Bay A	Bay											none			
D-D'	Sill	120	1,800	1,800	50	25		660	660	192	100	1	70	20	3,600
Bay B	Bay									68	0	1	65	200	1,800
E-E'	Sill	220	3,300	5,500	45	20		5,280	2,640	484	612	1	242	20	8,360
Total		905	6,600	7,300	**147**	**60**	**2,210**	**8,480**	**4,550**	**804**	**712**	**3**	**382**	**240**	**15,260**

Figure 5-4. Design for shore structures at Occohannock on the Bay.

Figure 5-5. Construction of the shore structures at Occohannock on the Bay.

Figure 5-6. Occohannock on the Bay shoreline before (top) sill construction and after (bottom) construction.

Figure 5-7. Photos of the project three years after installation in May 2017. The marsh behind the sill is expansive (left) and the access road is no longer threatened (right).

Figure 5-8. Photos showing a bare spot behind the sill (left) in May 2017, and the grasses replanted in July 2017 (right).

5.2 Captain Sinclair's Recreational Area: Severn River, Gloucester County, VA (37°19'28.17" N, 76°25'40.77" W)

Introduction

Captain Sinclair's Recreational Area (CSRA) is located near the mouth of the Severn River in Gloucester County, Virginia (Figure 5-9). In 2013, almost 100 acres of property was gifted to the Middle Peninsula Chesapeake Bay Public Access Authority (MPCBPAA). The Middle Peninsula Planning District Commission (MPPDC) partnered with the Public Access Authority to develop a management framework for the property. The MPPDC partnered with the Shoreline Studies Program at VIMS and received a NFWF Small Watershed grant in order to accomplish the Shoreline Management Plan for the property as well as develop a living shoreline demonstration site and educational outreach program.

Site Setting

CSRA is set within the low-lying landscape that surrounds the Mobjack Bay. The tidal shoreline is a wide, eroding marsh dominated by *Spartina patens* and black needle rush (Figure 5-10). Significant shore recession has occurred along the edge of a large tidal marsh area in front of the main house which has erosion rates of about 0.6 ft/yr (Hardaway et al.,2017).

The tide range is 2.5 feet at the mouth of the Severn River. The proposed project was designed to address shoreline erosion along the marsh edge which is exposed to a fetch to the west of about 2.5 miles and the southwest of 1.8 miles, low medium energy exposure. A new pier recently was built for recreation access.

Design Elements

This living shoreline project consisted of four sills with three windows and sand fill which were built to protect the existing eroding marsh (Figure 5-11). The upper elevation of sand fill was set at +3.0 ft MLW and extended over the top of the eroding peat scarp (Figure 5-12). Placing the sand on top of the marsh was designed for two reasons. First, planting in the sand fill overtop the existing marsh created a smooth transition between the existing marsh and the planted marsh. Second, SAV existed in the nearshore at the site. To avoid placement of the structures on the SAV, the design called for the structures to be placed at or above existing MLW. Designing the maximum elevation to occur slightly inland of the existing marsh scarp allowed the sand fill to extend on a 10:1 slope to about mean tide level at the back of the proposed stone sills (Figure 5-12). A 10:1 slope typically provides the optimum balance between upper and lower marsh creation at a site. Core stone generally is placed in the center of the sill structure, but at this site, it was moved landward to help perch the sand behind the structure. Once established the project will provide a gradually sloped marsh edge that is no longer retreating landward and will provide shore protection.

Figure 5-9. Captain Sinclair's Recreational Area pre-construction.

Construction Elements

The project was bid by the Virginia Institute of Marine Science in November 2015 in accordance with Commonwealth guidelines. The winning bid for $93,900 was to complete the Captain Sinclair Living Shoreline in accordance with the plans and specification. Because the plants were planted by volunteers, they were not included in the bid cost. To purchase the plants, fertilizer, stakes, and goose fencing cost an additional $1,700.

Construction of the project began in January 2016 and was completed in February 2016 by Coastline Design and Construction, Inc. of Gloucester (Figure 5-13). Adjustments had to be made during the construction process because the marsh was too wet for the machinery to travel across. Logging mats had to be placed across the marsh, and a smaller, lighter machine to transport the material from the stock pile to the shoreline had to be used. Grasses were planted by Gloucester High School students in April/May 2016. Approximately 3,200 sq. ft of low marsh (*Spartina alterniflora*) and about 2,500 sq. ft of high marsh (*Spartina patens*) were created (Table 5-2).

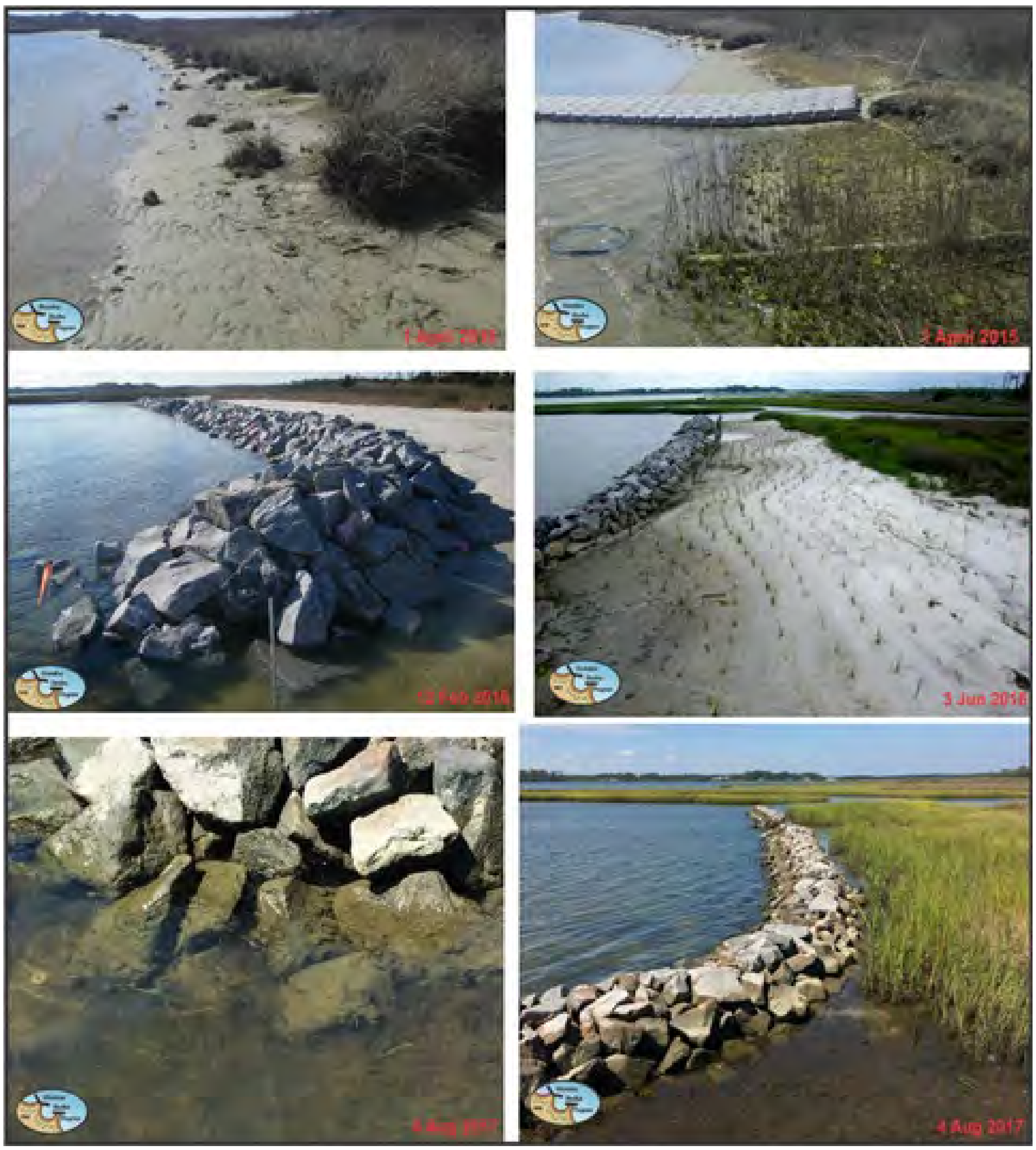

Figure 5-10. Captain Sinclair's Recreational Area pre-construction (top), post-construction (middle), and a year later (bottom). The marsh grasses are lush, SAV has grown behind the structure, and fauna are utilizing the rocks and the marsh.

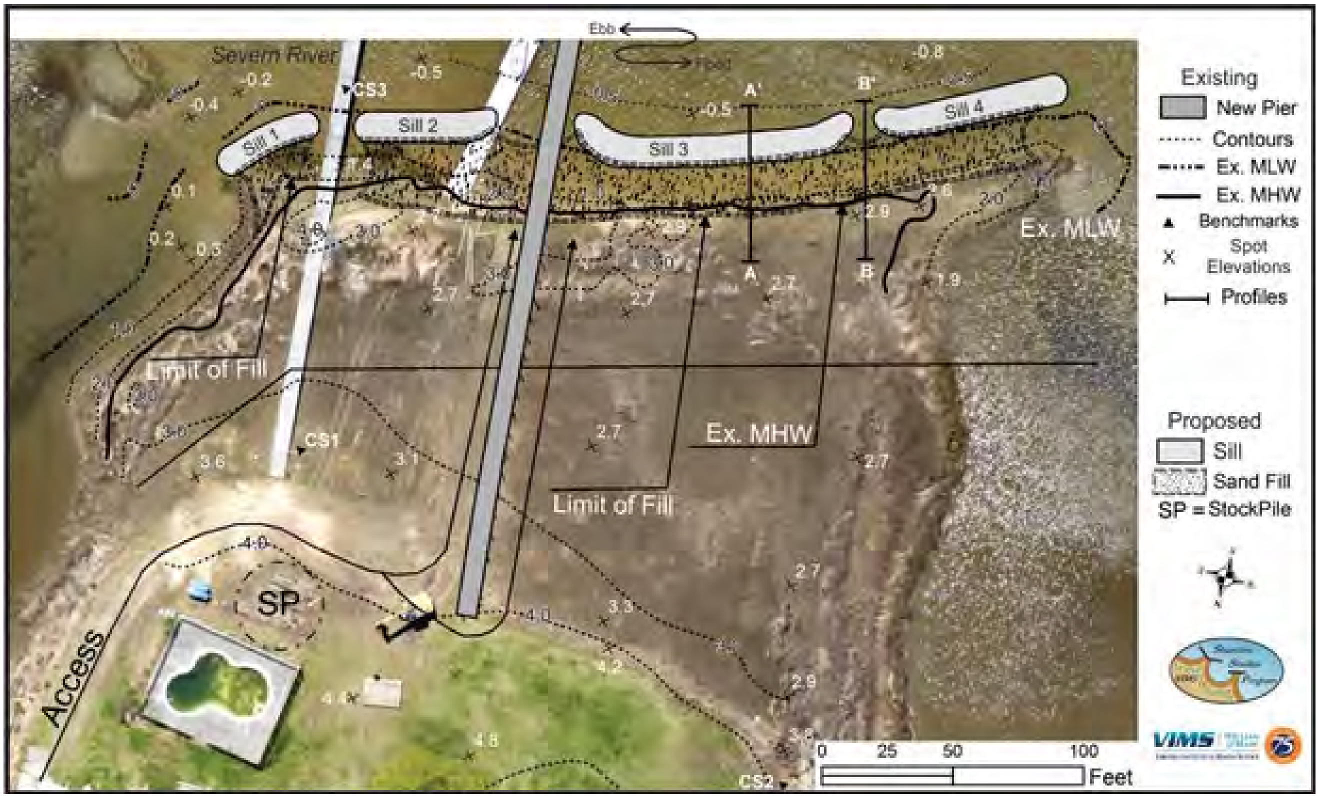

Figure 5-11. Plan design for Captain Sinclair's Recreational Area.

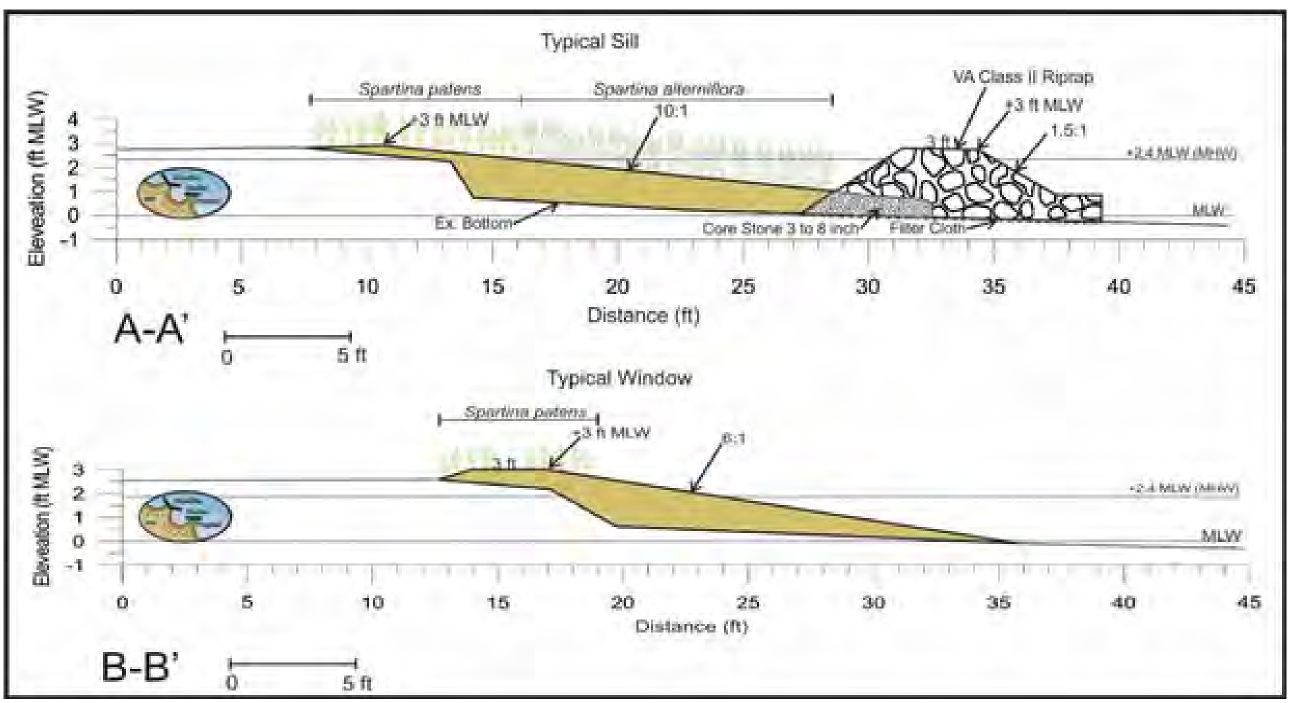

Figure 5-12. Typical cross-section of shore protection structures proposed at Captain Sinclair's Recreational Area.

After a year and a half since construction, the planted marshes have filled in behind the sills with a smooth transition into the natural marsh edge. Although equipment access along the marsh edge was avoided, the recovery of pre-existing fauna (e.g. ribbed mussels) along the natural marsh edge is still in progress after sand fill disturbance (Figure 5-10). Other flora and fauna are using the living shoreline. Oysters are growing on the rocks, SAV has colonized in the bays, and small fish have been observed using the shallow areas in the bay and near the rocks. The path through the marsh next to the pier used by the heavy equipment has not completely recovered. Four years after installation (Figure 5-14) the sills are still attached and has marshes growing behind the structures.

5.3 Design Examples Summary

These design examples illustrate how effective living shoreline project designs for shore protection in Virginia's estuarine environments start with an understanding of how the project shoreline has evolved in the past. The present-day hydrodynamic setting, recent storm impacts and storm surge levels, plus site-specific shoreline variables are then factored into project designs. Sustainable shore protection into the near future also requires forecasting sea level rise trends and expected responses of living habitats included in the design. The protection and creation of valuable natural resources and natural erosion buffers should be combined with property owner interests and land uses as part of the design alternatives analysis.

Selecting the best living shoreline management strategy might involve just one or a combination of methods depending on the conditions identified during the development of a site-specific coastal profile. Early identification of the problems to be solved will help set realistic expectations for project construction sequencing and project changes over time, plus determine if and when a project is successful. Long-term performance tracking of constructed projects in Virginia reveals the importance of considering stormwater runoff as well as the incoming wave climate during the design process. Early considerations of regulatory requirements during the design process is also suggested. There may be a temptation to let construction costs and expedited permit programs influence project designs, but achieving the original level of protection desired should not be discounted in the process.

The case studies and design examples described in these guidelines demonstrate how a deliberate alternatives analysis, thoughtful construction sequence planning, ongoing monitoring and maintenance, plus patience on the part of landowners all contribute to successful and sustainable living shoreline project designs. It is true that living shoreline strategies might not be appropriate or feasible in some locations. Yet recent evidence and project performance has proven that these approaches can and do provide long-term shore protection in many locations and situations while simultaneously providing larger-scale habitat and water quality co-benefits.

Figure 5-13. Photos taken during construction at Captain Sinclair's Recreational Area on 29 Jan 2016.

Table 5-2. Habitat created and impacts for Captain Sinclair's Recreational Area Living Shoreline project

			Habitat Created		Encroachment		Impacts: Rock			Impacts: Sand						
		Length	Sa (ft^2)	Sp(ft^2)	Max	Max	Vegetated	Nonveg	Subaqueous	Fill	Veg.	Nonveg	Volume		Area	
Structure	Structure				MHW	MLW	Wetlands	Wetlands	Bottom		Wetlands	Wetlands	<MLW	>MLW	<MLW	>MLW
Name	Type	(ft)			(ft)	(ft)	(ft^2)	(ft^2)	(ft^2)	(cy)	(ft^2)	(ft^2)	(cy)	(cy)	(ft^2)	(ft^2)
Sill 1	Sill	42	312	212	20	0	0	443	0	42	379	0	0	42	0	379
Bay A	Bay	13								0	0	0	0	0	0	0
Sill 2	Sill	55	750	425	35	10	0	366	256	55	642	295	0	55	0	937
Bay B	Bay	30		255						31	0	1,454	1	30	45	1,454
Sill 3	Sill	106	1,312	892	38	12	0	209	1,089	107	297	1,485	1	106	32	1,782
Bay C	Bay	8		68						11	42	401	3	8	84	443
Sill 4	Sill	75	812	595	35	17	0	0	859	80	117	786	5	75	130	903
Total		329	3,186	2,447			**0**	**1,018**	**2,204**	**326**	**1,477**	**4,421**	**10**	**316**	**291**	**5,898**

Figure 5-14. Drone imagery of the Captain Sinclair sills taken about 4 years after project installation (12 May 2020).

6 Post-Construction Considerations

The effectiveness of a shore protection system may decrease over time due to an increase in sea level, a lack of maintenance, and changes in vegetation. The project's decline in performance may happen slowly over time so that it is not easily recognized, or it may happen quickly during a storm. Understanding the short-term and long-term effects of hazardous events on the living shoreline is crucial to determining when action is needed. Short-term events can result in a reactive approach to resiliency because there is usually little time before the event to address potential impacts (Milligan et al., 2020).

6.1 Monitoring

Monitoring of shoreline stabilization projects with wetland restoration like living shorelines can be designed to accomplish many different tasks including information on their structural and functional aspects. Natural resource managers and homeowners generally want to establish the effectiveness of their living shoreline for shoreline stabilization. Milligan, Priest, & Hardaway (2019) developed a quick and easy monitoring protocol that uses metrics that document sand retention, movement and elevation variability, tidal inundation, evaluate the success of the plantings and, where necessary, provide information for remedial actions (https://scholarworks.wm.edu/reports/2070/). Most property owners generally only want to know are the measured parameters improving? staying the same? or deteriorating?

Milligan et al. (2019) describes how to develop a monitoring plan for living shoreline projects that is applicable to the various types of shoreline protection systems that are installed throughout Chesapeake Bay. It is designed to be easy to use and is aimed primarily at Virginia's natural resource managers and interested homeowners who do not have access to sophisticated equipment, laboratory facilities, or funding for a more extensive monitoring project as described by other frameworks. Following this protocol will allow the practitioner to determine basic characteristics of the structural effectiveness, functional success, and overall stability of the project. It also can provide an assessment of deficiencies that require remedial attention such as excessive sand loss or plant mortality.

6.2 Maintenance

Maintenance is critical for the success of a living shoreline project. Keeping the shore protection system at its most effective is the best way to negate impacts from short-term hazardous events. Regularly maintaining the site will provide needed information to determine when the system's effectiveness needs to be addressed.

The erosion resistant marsh and dune grasses are an important component of the living shoreline. Maintaining these are crucial to the success of the overall system. Routinely replanting vegetation as needed, trimming tree branches to reduce shade on the marsh (depending on the native vegetation's sunlight requirements), removing debris that can smother grasses, and removing any invasive species, such as *Phragmites australis* are all items that need to be addressed by the property owner.

Phragmites australis (common reed) is one of the most widespread invasive species in wetland habitats of North America. It can tolerate a wide range of salinities allowing it to spread to many areas of the Bay. Sciance et al. (2016) found that agricultural land use and shoreline armoring were significant predictors of *Phragmites* occurrence. The prolific and resilient *Phragmites* may require diverse treatments, such as mowing, grazing, and burning, or active revegetation. If spraying *Phragmites* is the only option, research results suggest that herbicide treatment must continue in perpetuity (Hazelton, 2018). Elsey-Quirk and Leck (2020) found that planting native vegetation to outcompete *Phragmites* seedlings and total removal of *Phragmites* to cut off the seed supply may be necessary for successful longer-term restoration and establishment of native species.

7 References

Avila, L.A. & Cangialosi, J. (2012). Tropical Cyclone Report: Hurricane Irene. National Hurricane Center. Retrieved from http://www.nhc.noaa.gov/data/tcr/AL092011_Irene.pdf

Beven, J., & Cobb H. (2003). Tropical Cyclone Report Hurricane Isabel, National Hurricane Center, 16. Retrieved from http://www.nhc.noaa.gov/data/tcr/AL132003_Isabel.pdf

Bilkovic, D., Mitchell, M., Mason, P., & Duhring, K. (2016). The Role of Living Shorelines as Estuarine Habitat Conservation Strategies. Coastal Management vol. 44, no. 3, 161-174.

Bilkovic, D., Mitchell, M., Davis, J., Andrews, E., King, A., Mason, P., Herman, & J., Tahvildari, N. (2017). Review of boat wake wave impacts on shoreline erosion and potential solutions for the Chesapeake Bay. STAC Publication Number 17-002, Edgewater, MD.

Blake, E.S., Kimberlain, T.B., Berg, R.J., Cangialosi, J.P., & Beven, II, J.L. (2013). Tropical Cyclone Report Hurricane Sandy, National Hurricane Center, 12. Retrieved from http://www.nhc.noaa.gov/data/tcr/AL182012_Sandy.pdf

Boon, J.D. (2004). Secrets of the Tide: Tidal and Tidal Current Analysis and Applications, Storm Surges and Sea Level Trends. Chichester, UK: Horwood.

Boon, J.D., Hepworth, D.A, & Farmer, F.H. (1992). Chesapeake Bay Wave Climate Wolf Trap Wave Station Report and Summary of Wave Observations November 6, 1989 through August 2, 1990. VIMS Data Report no. 42. Department of Physical Sciences. Gloucester Point, VA: Virginia Institute of Marine Science.

Boon, J.D., Brubaker, J.M., & Forrest, D.R. (2010). Chesapeake Bay land subsidence and sea level change: An evaluation of past and present trends and future outlook. Special report in Applied Marine Science and Ocean Engineering No. 425. Gloucester Point, VA: Virginia Institute of Marine Science.

Boon, J.D., Kimball, S.M., Suh, K.D., & Hepworth, D.A. (1990). Chesapeake Bay Wave Climate Thimble Shoals Wave Station Report and Summary of Wave Observations September 27, 1988 through October 17, 1989. VIMS Data Report no. 32. Division of Geological and Benthic Oceanography. Gloucester Point, VA: Virginia Institute of Marine Science.

Bost, M.C., Rodriguez, A.B., Ridge, J.T., Miller, C.B., & Fegley, S.R., (2021). Natural intertidal oyster reef growth across two landscape settings and tidal ranges. Estuaries and Coasts https://doi.org/10.1007/s12237-021-00925-2

Burke R.P., (2010). Alternative substrates as a native oyster (Crassostrea virginica) reef restoration strategy in Chesapeake Bay. Ph.D. Dissertation. The College of William and Mary. 286 p.

Burke, R.P & Lipcius, R.N., (2016). Monitoring at the Elizabeth River and Hoffler Creek oyster reef sites (CIEE). Christopher Newport University.

Burke, R.P & Lipcius, R.N., (2020). Monitoring at the Elizabeth River and Hoffler Creek oyster reef sites (CIEE), year five. Christopher Newport University.

Buzzanga, B., Bekaert, D. P., Hamlington, B. D., & Sangha, S. S. (2020). Towards sustained monitoring of subsidence at the coast using InSAR and GPS: An application in Hampton Roads, Virginia. Geophysical Research Letters, 47(18), 1-9, Article e2020GL090013. https://doi.org/10.1029/2020GL090013

CCRM (2007). Introduction to the Integrated Guidance Concept. *Rivers & Coast* 2(1): 1-5. https://publish.wm.edu/reports/218/Chesapeake Bay Foundation (2017). Facts & Figures. Retrieved from https://www.chesapeakebay.net/discover/facts

Church, J.A. & White, N.J. (2006). A 20th century acceleration in global sea-level rise. Geophysical Research Letters, 33, LO1602.

Chesapeake Bay Foundation (2017). Facts & Figures. Retrieved from https://www.chesapeakebay.net/discover/facts

Eggleston, J. & Pope, J. (2013). Land subsidence and relative sea-level rise in the southern Chesapeake Bay region. U.S. Geological Survey Circular 1392. http://dx.doi.org/10.3133/cir1392.

Elsey-Quirk, T. & Leck, M.A., 2020. High Reinvasion Potential of Phragmites australis in a Delaware River (USA) Tidal Freshwater Marsh Following Chemical Treatment: the Role of the Seedbank. Wetlands (2021) 41: 12. https://doi.org/10.1007/s13157-021-01398-6

Engelhart, S.E., & Horton, B.P. (2012). Holocene sea level database for the Atlantic Coast of the United States: Quaternary Science Reviews, v. 54, p. 12–25.

FEMA (2015). Flood Insurance Study: Accomack County, Virginia and Incorporated Areas. Federal Emergency Management Agency # 51001CV000B.

Fonseca, M.S. & Cahalan, J.A. (1992). A preliminary evaluation of wave attenuation by four species of seagrass. Est. Coast Shelf Sci. 35, pp. 565–576.

Goelz, T., Vogt, B., and Hartley, T. (2020). Alternative substrates used for oyster reef restoration: a review. J. Shellfish Res. 39, 1–12. doi: 10.2983/035.039.0101

Hardaway, Jr., C.S. (2017). Design elements: Marsh sills and breakwaters. Contractor training class presentation. Gloucester Point, VA: Virginia Institute of Marine Science.
http://www.vims.edu/research/departments/physical/programs/ssp/shoreline_management/living_shorelines/class_info/index.php

Hardaway, Jr., C.S., & Anderson, G.L. (1980). Estuarine shore erosion control (Educational series No. 31). Gloucester Point, VA: Virginia Institute of Marine Science.

Hardaway, Jr., C.S. & Byrne, R.J. (1999). Shoreline Management in Chesapeake Bay. Special Report in Applied Marine Science and Ocean Engineering Number 356. Gloucester Point, VA: Virginia Institute of Marine Science. http://web.vims.edu/physical/research/shoreline/docs/ShorelineErosionInCBay.pdf

Hardaway, C.S. & Gunn, J.R. (2000). Shoreline Protection: Design Guidelines for Pocket Beaches in Chesapeake Bay, USA. Proceedings, Carbonate Beach 2000. ASCE, December 5-8, 2002, Key Largo, FL. p. 126-139.

Hardaway, C.S., Jr., Milligan, D.A., Wilcox, C.A., Meneghini, L.M., Thomas, G.R., & Comer, T.R. (2005). The Chesapeake Bay Breakwater Database Project: Hurricane Isabel Impacts to Four Breakwater Systems. Gloucester Point, VA: Virginia Institute of Marine Science.

Hardaway, Jr., C.S., Milligan, D.A., O'Brien, K.P., Wilcox, C.A., Berman, M., Killeen, S., Rudnicky, T., & Nunez, K. (2008). Occohannock Creek Shoreline Erosion Assessment and Living Shoreline Options Report. Gloucester Point, VA: Virginia Institute of Marine Science. https://publish.wm.edu/reports/232/

Hardaway, Jr., C.S., Milligan, D.A., O'Brien, K.P., Wilcox, C.A., Shen, J., & Hobbs, III, C.H. (2009). Encroachment of Sills onto State-Owned Bottom: Design Guidelines for Chesapeake Bay. Gloucester Point, VA: Virginia Institute of Marine Science. https://publish.wm.edu/reports/561/

Hardaway, Jr., C.S., Milligan, D.A., Hobbs, III, C.H., Wilcox, O'Brien, K.P., & Varnell, L.M. (2010). Mathews County Shoreline Management Plan. Gloucester Point, VA: Virginia Institute of Marine Science. https://publish.wm.edu/reports/178/

Hardaway, Jr., C.S., Milligan, D.A., Wilcox, C.A., Berman, M., Rudnicky, T., Nunez, K., & Killeen, S. (2016). Gloucester County Shoreline Management Plan. Gloucester Point, VA: Virginia Institute of Marine

Science. https://publish.wm.edu/reports/256/
Hardaway, Jr., C.S., Milligan, D.A., & Wilcox, C.A. (2017). Shoreline Studies Program shoreline evolution interactive map database 1937-2009. Retrieved from http://www.vims.edu/research/departments/physical/programs/ssp/gis_maps/index.php
Hardaway, C., Milligan, D. A., & Wilcox, C. A. (2018). Living Shoreline Sea-Level Resiliency: Performance and Adaptive Management of Existing Sites. Virginia Institute of Marine Science, William & Mary. https://doi.org/10.25773/nnbj-m745
Hardaway, C., Milligan, D. A., Wilcox, C. A., & Milligan, A. C. (2019). Living Shoreline Sea Level Resiliency: Performance and Adaptive Management of Existing Breakwater Sites, Year 2 Summary Report. Virginia Institute of Marine Science, William & Mary. https://doi.org/10.25773/jpxn-r132
Hardaway, C.S., Jr., Reay, W.R., Shen, J., Lerberg, S.B., Milligan, D.A., Wilcox, C.A., & O'Brien, K.P. (2007). Performance of Sills: St. Mary's City, St. Mary's River, Maryland. Gloucester Point, VA: Virginia Institute of Marine Science. https://publish.wm.edu/reports/560/
Hardaway, Jr., C.S., Thomas, G.R., Zacherle, A.W., & Fowler, B.K. (1984). Vegetative Erosion Control Project: Final Report. Prepared for Virginia Division of Soil and Water, Technical Report. Gloucester Point, VA: Virginia Institute of Marine Science.
Hazelton, E.L.G., K.M. Kettenring, R. Downard, M.K. McCormick, and D.F. Whigham. 2018 Spatial and temporal variation in brackish wetland seedbanks: implications for wetland restoration following Phragmites control. Estuaries and Coasts. https://doi.org/10.1007/s12237-017-0289-z
Hogan, S., & Reidenbach, M.A., (2021). Quantifying tradeoffs in ecosystem services under various oyster reef restoration designs. Estuaries and Coasts. https://doi.org/10.1007/s12237-021-01010-4
Horan, J., D. Bilkovic, N. Gardner, J. Greiner, L. Karrh, K. Sellner, Q. Stubbs. 2014. Designing Sustainable Coastal Habitats. STAC (Chesapeake Bay Program Scientific and Technical Advisory Committee) Publ. #14-003), Edgewater, MD. 74 pp.
Howie, A.H. & Biship, M.J., (2021). Contemporary Oyster Reef Restoration: Responding to a Changing World. Frontiers in Ecology and Evolution 9. DOI=10.3389/fevo.2021.689915
Knabb, R.D., & Mainelli, M. (2006). Tropical Cyclone Report Hurricane Ernesto The National Hurricane Center, (AL052006). https://www.essie.ufl.edu/~uriah/Kraken/ernesto/TCR-AL052006_Ernesto.pdf
Knutson, P.L., Seeling, W.N., & Inskeep, M.R. (1982). Wave dampening in *Spartina alterniflora* marshes, Wetlands 2, pp. 87–104.
Koch, E.W. (1996). Hydrodynamics of a shallow *Thalassia testudinum* bed in FL, USA. In: Kuo, J., Phillips, R.C., Walker, D.I., Kirkman, H. (Eds.), Proc.Int.Workshop on Seagrass Biology, pp. 105–109.
Lindsey, R. (2021, January 25). Climate Change: Global Sea Level. Retrieved from climate.gov.
Lovett, R.A. (2013, Apr 19). Hurricane may have triggered earthquake aftershocks. Nature. doi:10.1038/nature.2013.12839
Marisa, 2021. Mid-Atlantic Regional Integrated Sciences and Assessments website. Retrieved from www.midatlanticrisa.org.
Miller, A.J. (1983). Shore Erosion Processes, Rates and Sediment contributions to the Potomac Tidal River and Estuary, Dissertation, Baltimore, MD: Johns Hopkins University.
Miller, J. K., Rella, A., Williams, A., & Sproule, E. (2016). Living Shorelines Engineering Guidelines. Report prepared for the New Jersey Department of Environmental Protection. Stevens Institute of Technology Report No. SIT-DL-14-9-2942. Revised February 2016.
Milligan, D. A., Hardaway, C., Wilcox, C. A., & Priest, W. I. (2018) Oyster Bag Sill Construction and Monitoring at Two Sites in Chesapeake Bay. Virginia Institute of Marine Science, William & Mary.

https://doi.org/10.25773/n2v0-td81
Milligan, D. A., Hardaway, C., Wilcox, C. A., & DiNapoli, N. J. (2021) Living Shoreline Sea-Level Resiliency: Performance and Adaptive Management of Existing Sites Year 3 Summary Report. Virginia Institute of Marine Science, William & Mary. https://doi.org/10.25773/sfsv-bc33
Milligan, D. A., O'Brien, K.P., Wilcox, C., & Hardaway, Jr., C.S. (2010). Shoreline Evolution: Gloucester County, Virginia, York River, Mobjack Bay, and Piankatank River Shorelines. Gloucester Point, VA: Virginia Institute of Marine Science. https://publish.wm.edu/reports/567/
Milligan, D. A., Priest, W. I., & Hardaway, C. (2019) Leesylvania State Park Living Shoreline Project Monitoring Protocol. Virginia Institute of Marine Science, William & Mary. https://doi.org/10.25773/znwn-qd37
Morris, R. L.; Bilkovic, D.M., Boswell, M. K.; Bushek, D., Cebrian, J., Goff, J., Kibler, K.M., La Peyre, M.K, McClenachan, G., Moody, J., Sacks, P., Shinn, J.P., Sparks, E.L., Temple, N.A., Walters, L.J., Webb, B.M., Swearer, S.E., (2019). The application of oyster reefs in shoreline protection: Are we over-engineering for an ecosystem engineer? Journal of Applied Ecology, 56(7), 1703-1711. https://doi.org/10.1111/1365-2664.13390
Morris, R. L., M. K. La Peyre, B. M. Webb, D. A. Marshall, D. M. Bilkovic, J. Cebrian, G. McClenachan, K. M. Kibler, L. J. Walters, D. Bushek, E. L. Sparks, N. A. Temple, J. Moody, K. Angstadt, J. Goff, M. Boswell, P. Sacks, and S. E. Swearer, (2021). Large-scale variation in wave attenuation of oyster reef living shorelines and the influence of inundation duration. Ecological Applications 31(6): e02382. 10.1002/eap.2382
NOAA (2021). Tides and Currents website. Retrieved on June 8, 2021 from https://tidesandcurrents.noaa.gov/sltrends/
Nowacki, D.J., Beudin, A., & Ganju, N.K., (2017). Spectral wave dissipation by submerged aquatic vegetation in a back-barrier estuary. Limnology and Oceanography 62: 736-753. doi: 10.1002/lno.10456
Sciance, M.B., C.J. Patrick, D.E. Weller, M.N. Williams, M.K. McCormick, and E.L.G. Hazelton. 2016. Local and regional disturbances associated with the invasion of Chesapeake Bay marshes by the common reed Phragmites australis. Biological Invasions 18: 2661–2677. https://doi.org/10.1007/s10530-016-1136-z.
Seitz, R. D., Aguilera, S., Wood, M. A., & Lipcius, R. N. 2019. Production and vertical distribution of invertebrates on riprap shorelines in Chesapeake Bay: A novel rocky intertidal habitat. Estuarine, Coastal and Shelf Science, 228. https://doi.org/10.1016/j.ecss.2019.106357
Stewart, S.R. (2017) Tropical Cyclone Report Hurricane Matthew, National Hurricane Center, 7 April 2017. Retrieved from http://www.nhc.noaa.gov/data/tcr/AL142016_Matthew.pdf
Sutton-Grier, A. E., Wowk, K., & Bamford, H. (2015). Future of our coasts: The potential for natural and hybrid infrastructure to enhance the resilience of our coastal communities, economies and ecosystems. Environmental Science & Policy, 51, 137–148. https://doi.org/10.1016/j.envsci.2015.04.006
Takagi, H., Kashihara, H. Esteban, M., & Shibayama, T., 2011. Assessment of Future Stability of Breakwaters under Climate Change. Coastal Engineering Journal, 53(01). https://doi.org/10.1142/S0578563411002264
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 No. 48. p89-99.

VDOT (2017). Drainage Manual. Retrieved from http://www.virginiadot.org/business/locdes/hydra-drainage-manual.asp
Van Slobbe, E., de Vriend, H. J., Aarninkhof, S., Lulofs, K., de Vries, M., & Dircke, P., (2013). Building with nature: In search of resilient storm surge protection strategies. Natural Hazards, 66(3), 1461–1480. https://doi.org/10.1007/s11069-013-0612-3
Varnell, L.M. (2014). Shoreline Energy and Sea Level Dynamics in Lower Chesapeake Bay: History and Patterns. Estuaries and Coasts (2014) 37: 508-523. Springer.
VMRC (2021). Habitat management permits and applications. Retrieved from https://mrc.virginia.gov/links.shtm
Wiberg, P.L., Taube, S.R., Ferguson, A.E., Kremer, M.R., & Reidenbach, M.A., (2019). Wave attenuation by oyster reefs in shallow coastal bays. Estuary and Coasts (42): 331-347. https://doi.org/10.1007/s12237-018-0463-y
Zabawa, C., & Ostrom, C. (Eds.). (1980). Final report on the role of boat wakes in shore erosion in Anne Arundel County, Maryland. Annapolis, MD: Maryland Department of Natural Resources.
Ziegenfelder, (2009). November 11-13th 2009 Northeaster. Retrieved on June 28, 2010 from http://www.frf.usace.army.mil/vets/Wakefield_NWS_NovemberNoreaster.pdf

8 Glossary

Armor Stone - Large, heavy rocks used to build sills, breakwaters, and revetments.

Benthic - Relating to the bottom of a water body or to the organisms that live there. The benthic region begins at the shoreline (intertidal zone) and extends downward along the bottom of the water body.

Biologic Benchmarks – The maximum and minimum elevations of the distinct zones in which tidal marsh plants will grow. Biologic benchmarks are based on empirical data and direct observation of natural plant communities whose establishment is based on frequency and duration of inundation. *Spartina alteniflora* is found between mid-tide and extends up to mean high water (MHW). *Spartina patens* picks up from there and occurs between mean high water (MHW) and mean higher high water (MHHW) or spring tide. Both of these species do not vary more than 0.1 feet in elevation from these tidal zones. They are very precise about where they will live.

Erosion - The process of weathering and transport of solids (sediment, soil, rock and other particles) in the natural environment.

Fetch - The distance along open water over which wind blows.

Geomorphology - the scientific study of landforms (physical feature) and the processes that shape them. Geomorphologists seek to understand landform history and dynamics, and predict future changes through a combination of field observation, physical experiment, and numerical modeling.

Glacial Rebound – also called glacial isostatic adjustment is the flexing of the Earth's crust in response to glacier formation and melting. During the last ice age, the weight of the ice sheets that existed across the Northern United States pushed the land under them downward which created a bulge in areas south of the sheets. The southern Chesapeake Bay was pushed upward during the last ice age, but as the glaciers melted, the Earth's crust in the region began sinking. This region is still sinking as other areas to the north are moving upward.

Great Diurnal Tide Range - Also known as Spring Range. The difference in height between mean higher high water and mean lower low water.

Herbaceous - Having little or no woody tissue and persisting usually for a single growing season.

Hydrodynamics - The study of liquids in motion. For this document, it typically refers to the effects of tides, storm surge, and waves on the shoreline.

Mean Higher High Water (MHHW) - The average of the higher high-water height of each tidal day observed over the National Tidal Datum Epoch.

Mean High Water (MHW) - The average of all the high-water heights observed over the National Tidal Datum Epoch.

Mean Low Water (MLW) - The average of all the low water heights observed over the National Tidal Datum Epoch.

Mean Lower Low Water (MLLW) - The average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch.

Mean Tide Range - The difference between mean high and mean low water levels.
North American Vertical Datum 1988 - Known as NAVD88, it is the vertical control datum established for vertical control surveying in the United States of America.

Refraction - The process by which the direction of a wave moving in shallow water at an angle to the bottom contours is changed. The part of the wave moving shoreward in shallower water travels more slowly than that portion in deeper water, causing the wave to turn or bend to become parallel to the contours.

Riparian - Anything connected with or immediately adjacent to the banks of a stream or other water body.

Sea Level - The average height of the water's surface.

Significant Wave Height - The average wave height (trough to crest) of the one-third largest waves.

Shore Orientation - The compass direction the shoreline faces.

Scarp - A low, steep slope along a beach caused by wave erosion.

Terrace - A terrace is a geological term for a step-like landform that borders a shoreline or river floodplain and represents the former position of either a floodplain or the shoreline of a lake, sea, or ocean. A terrace consists of a flat or gently sloping geomorphic surface that is typically bounded one side by a steeper ascending slope, which called a "riser" or "scarp", on one side and a steeper descending slope (riser or scarp) on its other side.

Tidal Constituents - Tides are created by the gravitational forces of the Moon and Sun, acting upon the waters of the Earth. Those gravitational forces change as the relative positions of the Earth, Sun, and Moon change. Each of these changes is cyclical, repeating over time; and each change also has a measurable effect on the tides we experience on the ocean's coast. These motions or "constituents" are in a set of harmonic constants whose mathematical value describes the effect that cyclical motion of the Earth, Sun, Moon system has on the tides. There are 37 which normally have the greatest effect on tides and are used as the tidal harmonic constituents to predict tidal conditions for a location. For example:
M2 – The largest lunar constituent – is related to the direct gravitational effect of the Moon on the tides. The Earth rotates on its axis every 24-hours, but the Moon is orbiting in the same direction as the Earth's rotation. It takes a location on the Earth an additional 50 minutes to "catch up" to the Moon. This results in a tidal signal (M2) which has 2 peaks every 24-hours and 50 minutes.
S2 – The largest solar constituent – is related to the direct gravitational effect of the Sun on the tides. The Earth rotates on its axis every 24-hours. This results in a tidal signal (S2) which has 2 peaks every 24-hours.
SA – Solar Annual constituent – is related to the changing positions of the Earth and Sun on an annual basis, every 365.25 days.

Wave Climate - The distribution of wave conditions, defined by wave height, period, and direction, over a time period. As waves are generated by winds, wave climate reflects both the seasonal winds as well as those caused by extreme storms.

Wave Crest - The highest part of the wave or that part of the wave above still water level.

Definitions were obtained from:

- Hardaway, Jr., C.S. and R.J. Byrne, 1999. Shoreline Management in Chesapeake Bay. Special Report in Applied Marine Science and Ocean Engineering Number 356. Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, Virginia. http://web.vims.edu/physical/research/shoreline/docs/ShorelineErosionInCBay.pdf
- Merriam-Webster online: http://www.merriam-webster.com/dictionary
- NOAA Tides and Currents Website: http://tidesandcurrents.noaa.gov/datum_options.htm
- Glossary of Coastal Terminology: http://www.csc.noaa.gov/text/glossary.html
- Coastal Research Group Glossary, Department of Physical Geography, Utrecht University, the Netherlands: http://www.coastalresearch.nl/glossary/5/view
- Wikipedia: http://en.wikipedia.org
- https://swampschool.org/biological-benchmarks/

Appendix A: Site Evaluation Worksheet

Site Evaluation

Site Name_______________ Date ________________________________
Site Locality _____________ Body of Water ______________________

Pre-Visit Parameters

1. Shore Orientation(s): N NE E SE S SW W NW

Site Length: ____________________(ft)

2. Average Fetch(es):
   Very High (> 15 miles) High (5-15 miles) Medium (1-5 miles)
   Low (0.5-1 miles) Very Low (< 0.5 miles)

Longest Fetch:__________________ miles

3. Shore Morphology: Pocket Straight Headland Irregular
4. Depth Offshore: ___________
5. Nearshore Morphology: Bars ____ Tidal Flats ____
6. Nearshore Aquatic Vegetation:___________
7. Tide Range: ______________
8. Storm Surge: 10 yr_________ 50 yr________ 100 yr __________
9. Erosion Rate:

   Very High Accretion (> +10 ft/yr) High Accretion (+10 to +5 ft/yr)
   Medium Accretion (+5 to +2 ft/yr) Low Accretion (+2 to +1 ft/yr)
   Very Low Accretion (+ 1 to 0 ft/yr) Very Low Erosion (0 to -1 ft/yr)
   Low Erosion (-1 to -2 ft/yr) Medium Erosion (-2 to -5 ft/yr)
   High Erosion (-5 to -10 ft/yr) Very High Erosion (<-10 ft/yr)

10. Design Wave: Height______Period_______

Notes:

Site Visit Parameters

1. Site Boundaries:

2. Site Characteristics:
   Upland Land Use

   Proximity to Infrastructure

   Cover

3. Bank Condition:

   Bank Face- Erosional Stable Transitional Undercut
   Bank of Bank - Erosional Stable Transitional

4. Bank Height: ______

5. Bank Composition:

6. RPA Buffer:

7. Shore Zone: Sand ________Marsh_______

   Width

   Elevation

8. Backshore Zone: Sand ___________Marsh_______

   Width

   Elevation

9. Boat Wakes a Problem:

10. Existing Shoreline Defensive Structures:

11. Nearshore Stability: Firm _________Soft_________

Appendix B: Data Links

Data Links

Google Earth http://earth.google.com/

VIMS Google Earth applications – mean & spring tide ranges, NAVD88 to MLW, Bathymetry contours http://www.vims.edu/research/departments/physical/programs/ssp/shoreline_management/living_shorelines/class_info/index.php

VIMS Submerged Aquatic Vegetation (SAV) Inventory http://web.vims.edu/bio/sav/

VIMS Shoreline Evolution - shoreline change map & reports http://www.vims.edu/research/departments/physical/programs/ssp/shoreline_evolution/index.php

NOAA Office of Coast Survey navigational charts https://www.nauticalcharts.noaa.gov/

NOAA Tides & Currents https://tidesandcurrents.noaa.gov/

NOAA Office for Coastal Management, Digital Coast https://coast.noaa.gov/digitalcoast/

FEMA Flood Map Service Center https://msc.fema.gov/portal

Living Shoreline Design & Monitoring Guidelines

VIMS Living Shoreline Design Guidance http://www.vims.edu/research/departments/physical/programs/ssp/shoreline_management/living_shorelines/class_info/index.php

Stevens Institute Living Shorelines Engineering Guidelines http://www.nj.gov/dep/cmp/docs/living-shorelines-engineering-guidelines-final.pdf

A Framework for Developing Monitoring Plans for Coastal Wetland Restoration and Living Shoreline Projects in New Jersey 2016 https://s3.amazonaws.com/delawareestuary/2016_NJMonitoringFramework_v1_04_06_2016_FINAL.pdf

Decision Support Tools

VIMS Shoreline Studies Program Living Shoreline Design Guidance, Class Information, and Tools

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

VIMS Shoreline Studies Program Publications http://www.vims.edu/research/departments/physical/programs/ssp/publications/index.php

VIMS Shoreline Studies Program Shoreline Change Online Mapping

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

VIMS Shoreline Best Management Practices http://www.vims.edu/ccrm/ccrmp/bmp/index.php

VIMS Comprehensive Coastal Resource Management Portals
http://www.vims.edu/ccrm/ccrmp/index.php

NOAA Guidance for Considering the Use of Living Shorelines 2015
https://www.habitatblueprint.noaa.gov/living-shorelines/

Commonwealth of Virginia Regulatory Agencies & Permit Process

Local Wetlands Boards - http://www.vims.edu/ccrm/wetlands_mgmt/lwb/index.php

VA Marine Resources Commission (VMRC), Habitat Management Division
http://www.mrc.state.va.us/hmac/hmoverview.shtm

VA Marine Resources Commission (VMRC) Permit Records
https://webapps.mrc.virginia.gov/public/habitat/

U.S. Army Corps of Engineers (USACOE) Norfolk District Regulatory Branch
http://www.nao.usace.army.mil/Missions/Regulatory.aspx

Joint Permit Application http://www.nao.usace.army.mil/Missions/Regulatory/JPA.aspx

VA Game and Inland Fisheries (DGIF) - Fish & Wildlife Information Service http://vafwis.org/fwis/

VA Department of Historic Resources (DHR) Division of Review & Compliance
http://dhr.virginia.gov/review/orc_home.html

VA Department of Health (VDH) Division of Shellfish Sanitation
https://www.vdh.virginia.gov/environmental-health/environmental-health-services/shellfish-safety/about-us/

U.S. Fish and Wildlife Service (USFWS) Ecological Services, Virginia Field Office
http://www.fws.gov/northeast/virginiafield/

General Living Shorelines Web Sites

VIMS – Center for Coastal Resources Management
http://www.vims.edu/ccrm/outreach/living_shorelines/index.php
VIMS – Shoreline Studies Program
http://www.vims.edu/research/departments/physical/programs/ssp/shoreline_management/living_shorelines/index.php
Living Shorelines Academy https://livingshorelinesacademy.org/

NOAA Living Shorelines https://www.habitatblueprint.noaa.gov/living-shorelines/