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

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Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Statement of the Problem and Purpose

Most shorelines in Virginia's Chesapeake Bay estuarine system are eroding. Since the end of the last ice age 18,000 years ago, **sea level** has been rising with ocean waters flooding the lands adjacent to the Bay and the rivers and creeks that flow into it. As the water moves continually higher, the boundary between the land and water moves inland. This process is known as shore recession or **erosion**.

In more recent history, since the end of World War II and the advent of "leisure" time, people have been moving to the shoreline increasing the coastal population. The Chesapeake Bay has about 10 million people living along its shores (Chesapeake Bay Foundation, 2010) and about 85% of the shoreline is privately-owned (Chesapeake Bay Program, 2010). As communities developed along the shore, the continual shore retreat became a problem. Then as it is today, when land along the shore show signs of erosion, property owners tend to address it. Since the advent of laws regulating the coastal zone, land owners typically contact consultants or contractors who can design and build shore protection structures first. In the past, shore stabilization strategies generally were stone revetments or wood bulkheads.

However, these strategies, while effective at shore stabilization, create a disconnect between the upland and the water and provide few natural habitats along the shoreline. In fact, between 1993 and 2004, approximately 230 miles of new, "hard" erosion protection measures were permitted in Virginia (Moon, 2007). In Mathews County, alone, more than 15 miles of shoreline were "hardened" between 1999 and 2008 (Hardaway *et al.*, 2010). In the past 20 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.

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 (Moon, 2007). 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 are meant to address the need to educate consultants, contractors, and other professionals in the use of living shoreline strategies. 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 marsh fringes but also touch on the use of 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.

1.2 Chesapeake Bay Shorelines

1.2.1 Physical Setting

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 were havens to storms and open water.

The Atlantic Ocean has come and gone numerous times over the Virginia coastal plain over 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, beaches and dunes.

During the 20^{th} century, global sea level rose at about 0.56 ft per century (1.7 mm per year)(Church and White, 2006). 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. 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). It likely is the result of ongoing compaction of buried sediments and the resulting settlement of the surface.

Table 1-1. Rate of sea-level rise at selected sites in the mid-Atlantic. Data from NOAA (2009).

Location	mm per year	ft per century
Colonial Beach, VA	4.78	1.57
Lewisetta, VA	4.97	1.63
Gloucester Point, VA	3.81	1.25
Kiptopeke, VA	3.48	1.14
Chesapeake Bay Bridge Tunnel, VA	6.05	1.98
Sewells Point, VA	4.44	1.46
Portsmouth, VA	3.76	1.23

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. 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, 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, 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 amounts.

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 *et al.* (1984) categorized wave energy acting on a shoreline into three general categories based on a fetch. Low energy shorelines have average fetch exposures of less than 6,000 ft and often are found along tidal creeks and small tributary rivers. Medium-energy shorelines typically occur along the main tributaries and have average fetch exposures of 6,000-30,000 ft (1-5 miles). High-energy shorelines occur along the main stem of the Bay and at the mouth of tributaries. Hardaway and Byrne (1999) further refined average fetch exposures such that they 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, 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).

Tide range is an important factor in effective shore stabilization strategies since structures 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,** also known as the 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).

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 to design since higher water levels allow waves to travel farther inland or impact higher on a bank. The highest water levels at Lewisetta on the Potomac River are shown in Table 1-3.

Three recent storms, which have impacted various sections of Virginia's coast, 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 three to five ft above normal tide levels were observed over the central portions of the Chesapeake Bay and five to 6.5 ft above normal tide over the southern portion of the Bay in the vicinity of Hampton Roads, Virginia. High surges also were observed at the headwaters of the tributaries, reaching 8.2 ft above normal levels in Richmond City and nearly 5.5 ft above normal in Washington, D.C. (Beven and Cobb, 2003) The highest water level recorded at the Gloucester Point tide gauge was 8.2 ft above MLLW, and data from the gauge indicated the water level was still rising when the station was destroyed (NOAA, 2009).

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 ft 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 ft at the Chesapeake Bay Bridge Tunnel and more than 2 ft in the middle to upper Bay regions (Knabb and 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 ft above MLLW, which was 5 ft higher than the predicted tide. This ranks it as the 5th highest water elevation on record since 1930 and was just 0.2 ft 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 ft 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.

Table 1-2. Summary wind conditions at Norfolk Airport between 1960-1990.

		WIND DIRECTION								
Wind Speed (mph)	**Mid Range (mph)**	**South**	**South west**	**West**	**North west**	**North**	**North east**	**East**	**South east**	**Total**
< 5	3	5497* 2.12+	3316 1.28	2156 0.83	1221 0.47	35748 13.78	2050 0.79	3611 1.39	2995 1.15	56594 21.81
5-11	8	21083 8.13	15229 5.87	9260 3.57	6432 2.48	11019 4.25	13139 5.06	9957 3.84	9195 3.54	95314 36.74
11-21	16	14790 5.70	17834 6.87	10966 4.23	8404 3.24	21816 8.41	16736 6.45	5720 2.20	4306 1.66	100572 38.77
21-31	26	594 0.23	994 0.38	896 0.35	751 0.29	1941 0.75	1103 0.43	148 0.06	60 0.02	6487 2.5
31-41	36	25 0.01	73 0.03	46 0.02	25 0.01	162 0.06	101 0.04	10 0.00	8 0.00	450 0.17
41-51	46	0 0.00	0 0.00	0 0.00	1 0.00	4 0.00	4 0.00	1 0.00	0 0.00	10 0.00
Total		41989 16.19	37446 14.43	23324 8.99	16834 6.49	70690 27.25	33133 12.77	19447 7.50	16564 6.38	259427 100.00

*Number of Occurrences +Percent

Table 1-3. Maximum water levels above mean lower low water and associated storm event at Lewisetta, Virginia tide gauge between April 1974 and 2007 (data from NOAA website, 2007).

Date	Elevation (ft MLW)	Comment
1-Sep-2006	5.65	Tropical Storm Ernesto
19-Sep-2003	5.47	Hurricane Isabel
5-Feb-1998	3.84	Twin Northeasters
1-Nov-1991	3.73	Halloween Storm
31-Oct-1991	3.66	Halloween Storm
7-Sep-1996	3.59	Hurricane Fran
16-Sep-1999	3.51	Hurricane Floyd
8-Oct-2006	3.49	Tropical Storm
22-Sep-1994	3.39)	Northeaster
19-Mar-1983	3.36	Northeaster
15-Jun-2007	3.36	Northeaster
28-Jan-1998	3.35	Twin Northeasters

2 Site Evaluation

2.1 Shoreline Variables

In order to determine the appropriate course of action, if any, along the tidal shorelines of the Commonwealth, 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 and site visit parameters.

Map Parameters
fetch, depth offshore, shoreline geometry, shoreline orientation, nearshore morphology/stability, submerged aquatic vegetation (SAV), tide range, storm surge frequency, erosion rate, design wave determination

Site Visit Parameters
fastland bank condition, bank height, bank composition, 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, and existing shoreline defense structures

Specific characteristics of the site visit parameters are discussed in the next section, but a Project Sheet (Appendix A) has been developed to help standardize data collection for each site. Map parameters can be determined from a variety of available, online resources.

The CCRM at VIMS has online tools to evaluate existing shoreline conditions. One such tool is the Shoreline Assessment Mapper (http://139.70.26.131:8008/ShorelineAssessmentMapper/) which provides bank conditions, existing structures, marine resources and bathymetric contours. 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.

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 rate. In addition, custom applications, developed by Shoreline Studies Program and available on their website, were created for some parameters such as tide range and bathymetry.

Navigational charts are available from the National Oceanic and Atmospheric Administration's (NOAA) Office of Coast Survey. Their Booklet Charts (http://ocsdata.ncd.noaa.gov/bookletchart/) are navigation charts split into sections so that they can be printed on letter-sized paper. These are convenient for determining depth offshore and nearshore morphology.

2.1.1 Map Parameter Measurement

1. **Shoreline Orientation**

The shoreline orientation is the direction the shoreline faces and is measured normal to the shore strike. If shore orientations vary significantly along the length of the subject shoreline, they should be measured separately. 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 create a shaded shoreline if the bank is high and/or trees are present. This might restrict the ability to create a marsh fringe.

2. **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 22.5º 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 to the farthest shore. This measurement can be important to determine possible conditions during storms when water levels 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 (> 15miles) 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.

3. 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. 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.

4. Depth Offshore

The nearshore gradient will influence incoming waves. 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 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 three and 6 foot contours in Chesapeake Bay.

The very nearshore depth where possible sills or breakwaters may be recommended 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 might be the preferred alternative.

5. Nearshore Morphology/Stability

This parameter evaluates the occurrence or lack of offshore tidal flats and sand bars. These features often are associated with a shallow nearshore region as indicated in parameter #4. 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 water (Figure 2-4). Navigational charts also will show the existence of tidal flats along tidal shorelines and could be used to support field observations.

It also is important to assess the nearshore bottom stability, whether firm or soft. The substrate must support the rock and sand of any proposed structure. The nearshore morphology provides an indicator of whether or not the bottom is suitable for structures, 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 the structure. Going "quick" is a term used to describe sediment that is so saturated with water that it is a mushy mixture of sand and water that cannot support weight. If the nearshore is marshy or quick, the contractor must address potential settlement.

6. Nearshore Submerged Aquatic Vegetation (SAV)

Nearshore SAV, where present, can have a significant effect on wave attenuation (Figure 2-4). Seagrass beds efficiently attenuate waves before reaching the shoreline (Fonseca and Cahalan, 1992; Koch, 1996). In fresh water, cypress trees along the shore act as breakwaters and, where abundant, also will act to reduce wave energy (Bellis *et al.,* 1975). The distribution of SAV within Chesapeake Bay is available at VIMS (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 is located offshore of a project site, it can affect the acceptability of certain structures.

7. Tide Range

The local tide range can be found at NOAA Tides and Currents website or in Figures 1-3 and 1-4. This parameter is important to determining the size of the structure and the width of the created marsh fringe.

8. Storm Surge

Storm surge return frequencies can be found in FEMA's Flood Insurance Studies for all localities in Virginia. Knowing the predicted water level during certain storms will provide the level of protection that a structure 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. (http://msc.fema.gov/webapp/wcs/stores/servlet/FemaWelcomeView?storeId=10001&catalogId=10001&langId=-1&userType=G).

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 2-5 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 SSP custom Google Earth application shows the elevation difference between NAVD88 and MLLW around the Bay.

9. Erosion Rate

Long-term erosion rates indicate how critical shore stability is at a site. Some sites may have undercut banks but almost immeasurable rates of change. This may indicate a landscaping issue rather than a shore erosion issue. The easiest way to determine shoreline change rates is to use the Shoreline Studies Program's (SSP) databases of shore evolution reports. These exist for various localities on the SSP website - Accomack, Gloucester, Hampton, Lancaster, Mathews, Middlesex, Newport News, Northampton, Northumberland, Norfolk, Poquoson, Virginia Beach, Westmoreland, and York. Portsmouth, Isle of Wight, Suffolk, and James City will be finished late in 2010. Not all shorelines have been completed in each locality. However, SSP is adding localities and updating others. Generally, the shore rate reported in the evolution reports is the long-term rate of change, usually determined between 1937/38 and 2002/2007.

If the site does not exist in the SSP database, the time slider in Google Earth is an alternative. 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 the shore erosion rate. For instance, if photos dated 1994 and 2009 are available (Figure 2-6A 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).

10. 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 systems, particularly rock size. A simple, straightforward method to determine a design wave comes from the U.S. Army Corps of Engineers (1977). By using their forecasting curves for shallow-water waves, a wave height and period can be estimated based on wind speed and fetch (Figure 2-7).

Figure 2-7 has forecasting curves for waves in 5 ft (Figure 2-7A) and 10 ft (Figure 2-7B) water depths. Most sites in the creek and rivers of the Bay can be estimated using one of these charts. In order to determine which forecasting curve to use, the tide range and design storm surge (elevation above MHW) must be added together. For example, at a site with a tide range of 1.5 ft, the water level may increase an additional 3.5 ft above MHW during a small storm so the 5-ft curve can be used. In more energetic areas with a larger tide range, the 10-ft curve may be more appropriate. For instance, a site with a 2.5 ft tide range that has a 6.2 surge may more appropriately use the 10-ft curve to overestimate the design wave rather than underestimate it.

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 6,000 ft fetch with a storm that has a 40 mph onshore wind that will use the 10 ft curve, the design wave is roughly-estimated at about 1.7 ft. For these same conditions except that the fetch increases to 3 miles (15,840 ft), the wave height at the shore could 2.3 ft. These are **significant wave heights** which are defined as the average of the highest 33% of the wind/wave field. Wave heights for the highest 10% also should be noted in wave energy considerations for the determination of rock size.

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. They can be used for this purpose as well.

2.1.2 Site Visit Parameters

1. Site Boundaries

Knowing the boundaries of the site is an important aspect in determining what strategies are necessary. End effects as well as downdrift impacts of structures must be considered.

2. Site Characteristics

In order to determine if bank grading is feasible, knowing the upland land use, the proximity of the shoreline to infrastructure, as well as the amount of 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 may affect the level of protection needed and/or construction access and staging.

3. Bank Condition

The condition of the fastland bank is the best indication of how frequently wave action reaches the base of bank. Other factors, such as upland runoff, freeze/thaw and groundwater seepage, can make significant contributions, but storm waves are the main cause of most shore erosion in Chesapeake Bay. Stable banks are indicated by relatively gentle bank face slope with abundant vegetative cover and no undercutting along the base of bank (Figure 2-8A). The other extreme is the vertically exposed bank may be slumping and generally lacks stabilizing vegetation (Figure 2-8B). 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 2-8C). In fetches larger than 0.5 miles undercutting and exposed base of bank reveals potential long-term instability of the bank slope.

4. Bank Height

Bank height can be measured from a chart, 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, 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 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.

5. Bank Composition

It is difficult to determine the composition of the base of bank unless it 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. Types of bank material between these two extremes will have more intermediate erosion rates (Miller, 1983).

Another reason to determine bank composition is to use the material in system design. Sandy upland banks can be mined from the bank and used as the planting substrate behind the sill. The material 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).

6. Resource Protection Area (RPA) Buffer

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 is feasible. The native 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 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 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.

7. Shore Zone Width and Elevation

The shore zone usually is dominated by two features, beach and/or low, intertidal marsh. (In fresh water, these could be cypress trees). The beach is measured from MHW to the beginning of upper marsh or dune-type vegetation (Figure 2-9). A shore dominated by low marsh (*Spartina alternifora*) extends from the seaward limit of the marsh (usually mean tide level [MTL]) to just above MHW, where the upper marsh or backshore zone begins. Sometimes the shore zone may be composed of patchy marsh headlands with small pocket beaches between.

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 small waves, not taller than the plants, would dissipate about 50% of their energy within the first 8 ft of the marsh. All of the wave energy would be dissipated within 100 ft of marsh.

8. Backshore Zone Width and Elevation

The backshore zone usually is higher in elevation than the shore zone and is the last natural wave attenuating feature before the base of bank is reached. It usually is an upper 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, to the base of bank. The sandy backshore terrace or dune is measured from where the beach shore zone stops and the upland or dune vegetation begins, to the base of bank. Once again it is often difficult to characterize and accurately measure the shore zone and backshore zones. The combined, interconnected width of these features should be evaluated.

9. Boat Wakes

The effect of boat wakes along a given shoreline will often be difficult to ascertain. Some local knowledge of how the adjacent waterway is used throughout the year is helpful. Shorelines next to navigational channels would most likely be directly affected by boat wakes (Byrne *et al.* 1980). The occurrence of marinas and docking facilities and the number of visible piers nearby is indicators of potential boat traffic. The main point is whether there is enough boat activity to adversely affect the shoreline. Often in very narrow waterways high boat traffic will produce a severe wave climate that would not otherwise exist from wind driven waves. Therefore, a judgement call is required to the importance of this parameter.

10. Existing Shoreline Defense Structures

If shoreline defense structures are already present, their condition and effects on shoreline processes should be considered. Old structures 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.

Failed or deteriorating 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.

2.2 Coastal Profile

Once the 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 and shallow water habitats, when combined, affect local conditions in a holistic ecosystem approach (Figure 2-10). Developing a gradual, vegetated coastal profile is the key to designing a successful living shoreline system. Each element of the system works to reduce wave energy impacting the upland.

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.

The riparian buffers along the smaller 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 trees along the shoreline. When shoreline erosion strategies are employed, interfacing with the riparian edge must be considered. If the bank face is relatively stable, the riparian edge might remain as is, but if the bank face is fully exposed and actively eroding, then 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).

3 Design Considerations

3.1 Selecting Shore Management Strategies

When an experienced contractor or consultant arrives on a site, the shoreline situation and coastal setting are determined relatively quickly. For instance, standing on the upland bank, a vertically-exposed bank is obvious with a minimal, existing marsh fringe. The fetch exposure across the creek is north with a long fetch to the northeast. This information is quickly processed, and the need to fix the erosion is apparent. What then? Are there options? Of course, but often the primary option offered is an approach that the contractor/consultant is most familiar or comfortable with. Assuming the do nothing option is not desired, the next step is to select a shoreline management strategy.

Now that the site has been evaluated and the nature of the erosion is understood, what are the ramifications of doing nothing? 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. However, if a problem truly exists, determining a strategy that best suits the site's particular property is essential. While living shorelines are preferable from an environmental and recreational perspective, is one economically feasible at the site? Do site conditions warrant hardening the shoreline? What will the impacts be to adjacent shorelines and/or the nearshore? 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 miles, where very little erosion is occurring, habitats can be the primary consideration since the marsh provides the protection for the bank.

A "standard" fix for eroding shorelines is often a stone revetment. When properly designed and installed, it provides long-term shore protection. However, it does not provide the connection to the water that originally drew many property owners to the waterfront. Living shoreline strategies can be used to provide shore stability and to create the natural connection between the upland and the water. With a revetment, property owners can stand at the top of the bank to look at the water, but with a living shoreline, they can cross the marsh or beach and dip their toes in the water.

Shore protection method selection will follow, in general, the level of protection versus the impinging wave climate. Wave energy 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. 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 upland infrastructure and land use. The project encroaches both bayward and landward in order to establish a gentle, fully vegetated coastal gradient.

The VIMS's Center for Coastal Resources Management has an online database of permit records (http://ccrm.vims.edu/perms/newpermits.html). 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 structures that might be appropriate for a watershed.

3.1.1 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 3-1). 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 can be trimmed. Bare areas of existing intertidal substrate can be planted with marsh grass, usually *Spartina alterniflora* between MTL and MHW. Periodic removal of tidal debris that may be smothering marsh plants also is included.

3.1.2 Sills

Rock sill systems consist of a line of rock placed just offshore of an eroding shoreline/coast with a sand fill placed between the sill and the eroding bank upon which marsh grasses are planted to create a protective marsh fringe. The wider and higher the sill system the greater the ability to provide shore erosion control (Figure 3-2). The cross-section shows the sand for the wetlands substrate is on about a 10:1 slope from the base of the bank to the back of the sill. The elevation of the intersection of the fill at the bank and tide range will determine, in part, the dimensions of the sill system.

The stone sill has been used extensively in Chesapeake Bay over the years, especially in Maryland. 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 3-3A; 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. 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.

Sand fill widens the created marsh fringe and provides a wave buffer. Plants are the primary component from a wave attenuation and habitat perspective for sill systems. Two main wetland species are used in marsh fringe creation, *Spartina alterniflora* and *Spartina patens*. The *Spartina alterniflora* grows between MTL and MHW. *Spartina patens* grows above that. *Spartina alterniflora* will grow above MHW and an intermixing zone between the two species usually occurs at the elevation of MHHW. 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. Both species can be purchased from wetland plant nurseries. The spacing between plants typically is 1.5 ft, 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. More detailed information on designing tidal wetlands is found in Appendix B.

Although generally effective at erosion control and marsh fringe creation, the sill was still considered by managers to be a line of rock, a hardening of the shore. Openings or gaps in the sill were encouraged to allow access for marine fauna to utilize the created marsh fringe, particularly turtles and fish. This created problems because as the sill is opened to allow marine fauna ingress and egress, the local wave climate will impact the shoreline as well. The result was twofold, 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 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 about every 100 ft, 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.

One important management question from the Virginia Marine Resources Commission has been how far do these systems have to 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 the back of the sill (Hardaway *et al.*, 2009) (Figure 3-3B).

3.1.3 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 3-4). 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.

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.

3.1.4 Breakwaters

The use of breakwaters along the shores of the Commonwealth began in 1985 with the installation of Drummond Field on the James River (Figure 3-5A). Since then, numerous projects have been built all over Chesapeake Bay in various physical settings. A more recent breakwater installation was at Festival Beach in Mathews County (Figure 3-5B). These breakwaters were built on Chesapeake Bay to stop erosion of the marsh landward of the beach as well as to create a recreational opportunity.

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 3-6A and B 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 is1:1.65 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.

3.2 Level of Protection

The level of protection is a necessary part of the overall discussion of desired 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 3-7) such as 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 are threatened or damaged. No erosion occurred of the graded bank just upriver from the 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.

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, unless the bank is graded (Figure 3-3B). 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 shore protection structures are considered, it must be understood that there are habitat tradeoffs. Subaqueous bottom has ecological value; however, the additional benefits of a 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.

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 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 bottoms 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 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 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. 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 trade off 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 Costs

Can your proposed strategy be built cost-effectively? Costs can be categorized into: design, permitting, materials (rock, sand, and plants), site access preparation, installation, site work, restoration of access areas, mitigation for impacts (covering state bottom, tree removal). Overall project cost will vary contractor by contractor; however, generally, the primary cost is the installation of rock and sand. 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 lesser product (i.e., the rock is dumped rather than placed).

3.5 Permits

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 3-8). 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.

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 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. Erosion control structures 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. More detailed information on the permitting agencies and requirements is found in Appendix C.

4 Living Shorelines Case Studies

4.1 Marsh Management

4.1.1 Poole Marsh: Tabbs Creek, Lancaster County, Virginia

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 3-1).

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 *Spartina alterniflora* to establish the marsh fringe. *Spartina alterniflora* was planted on the usual 1.5 ft x1.5 ft grid with one ounce of Osmocote fertilizer.

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 3-1). The site has remained intact for more than 25 years as evidenced by the following series of photographs (Figure 3-1). This type of treatment is viable only when there is a narrow upper intertidal zone for planting. The need for sunlight also is critical for establishing fringes up the numerous tidal creeks in the Commonwealth where bank orientation, height and shading by trees are factors to consider.

4.1.2 Lee Marsh: Corrotoman River, Lancaster County, Virginia

Introduction

The Lee is a demonstration site established in 1982 and represented a north-facing, high upland bank with a limited fetch. Mr. Lee was quite helpful in helping plant and monitor the site over the many years since the marsh was planted and re-planted. Alas, limited sunlight kept the marsh from reaching full potential and a small stone revetment was finally installed in 1999 (Figure 4-1).

Site Setting

The Lee marsh site is a low energy, high fastland bank which faces north-northeast with an average fetch exposure of 3,650 ft. It is located on the south side of the Western Branch of the Corrotoman River just downriver from the Merry Point Ferry. The historical erosion rate is less than one ft/yr. The bank slope in 1981 was relatively stable with abundant vegetation including vines, small trees and grasses. At that time, Mr. Lee had built a house and thinned some of the trees allowing sunlight to reach the shore. Before that, little or no marsh fringe existed, and the base of the bank was undercut. Over time, continued undercutting would lead to minor slumping.

Prior to planting, the beach was composed of medium to coarse-grained sand and gravel, the source being primarily the adjacent eroding banks. The beach/backshore extends from the base of the bank, which occurs at about +1 ft, out about 20 ft to the coarse-grained toe. The tide range is 1.3 ft.

Design Elements and Construction

The planting consisted of the two species, *Spartina alterniflora* and *Spartina patens* (saltmeadow hay) and was initially planted in May 1981. *Spartina patens* was planted from the base of the bank to MHW and *Spartina alterniflora* from MHW to MLW. Losses through the first growing season were mostly the area of *Spartina alterniflora* planted below MTL. *Spartina patens* lost about 50% of the original plants from what appeared to be excessive shading.

Performance

The intertidal fringe gained sediment during the winter of 1981-1982 with no base of bank erosion. A standing crop of *Spartina alterniflora* existed during the winter months which helped deter wave attack. The marsh fringe expanded over the summer and fall of 1982. The *Spartina patens* maintained the backshore elevation. Only minor bank erosion was noted as a result in October 1982. Little change occurred over the winter of 1982-1983. Minor maintenance planting was done in the spring of 1983 to fill a small void.

The marsh fringe continued to expand through the summer of 1983 with minor base of bank erosion. By the spring of 1984, bank erosion was immeasurable, the backshore was stable and the intertidal fringe had trapped more sediments even with a slight decrease in marsh area. Between 1981 and 1984, no loss of bank occurred due to slumping or undercutting. The top of bank and bank face remained very stable.

After 20 years of intermittent maintenance, Mr. Lee finally opted for a small stone revetment. A few shoots of *Spartina alterniflora* remain, but no viable fringe (Figure 4-1). This site provided the opportunity to monitor a north-facing high bank with a planted marsh fringe. It takes ongoing maintenance and shade control for a viable marsh fringe along north facing shorelines.

4.2 Marsh Toe Revetment/Sill

4.2.1 Hollerith Marsh Toe Revetment: East River, Mathews County, Virginia

Introduction

The Hollerith site is located on the East River in Mathews County. This marsh toe revetment was installed in 2001 (Figure 4-2). 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 4-2). 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 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.

Upland bank erosion continued to be a concern behind the southern marsh toe revetment. The height was increased by 1 ft (+4.0 MLW).

4.3 Sills

4.3.1 Foxx: Sturgeon Creek, Middlesex County, Virginia

Introduction

The Foxx site is located on Sturgeon Creek in Middlesex County and was installed in 2005. Pre-project consultations with the Shoreline Studies Program helped the contractor is his design effort for establishing a Living Shoreline using a sill system. Certain other elements deemed necessary by Mr. Foxx were a graded bank and thinning of the dense small tree and shrubs along the top (Figure 4-3). The base of bank also was undercut which could eventually lead to bank failure.

Site Setting

The Foxx site resides along about 250 ft of shoreline on Sturgeon Creek with an historic erosion rate of about 0.6 ft/yr. The shoreline faces about due east with fetch exposures to the northeast, east and southeast of about 300 ft, 500 ft, and 700 ft, respectively. One long fetch to the east-northeast is about 1,500 ft. The tide range is Sturgeon Creek is 1.2 ft (at Windmill Point).

The coastline occurs as a high upland bank along the northern half of the shoreline that transitions southward to a lower bank, then a marsh spit. The upland bank had an undercut base of bank and a relatively stable bank face. The upper bank has a layer of sandy material. A narrow, intermittent marsh fringe that varied from zero to 3 ft wide did not provide enough wave damping capability (Figure 4-3). High water occurred at the base of the high bank. Overtime, the erosion of the upland bank and subsequent littoral transport has lead to the creation of the marsh spit.

Design Elements and Construction

The access, bank sands, and desire for a marsh were the main design elements. The bank has good quality sand such that, when graded, it provided the bulk of the sand fill for the project. Three sill sections at +2.2 MLW with windows were designed with crest lengths of 100 ft, 100 ft and 75 ft (Figure 4-4). The southern unit transitions southward across the marsh spit for 125 ft at about MHW. The sand fill is in front the high bank was set at +3 MLW and extended to MTL on the back of the sill on about a 10:1 slope. This provided for an average planting width of 10 ft for *Spartina alterniflora* and 14 ft for *Spartina patens*. The access to the shoreline was over the bank where the upland transitions from a high bank to low bank.

Performance

The planted marsh was quickly established in the first growing season after construction. The marsh width gradually decreased at the tidal opening. It has weathered various storms and protected the base of the graded bank. Wrack can be seen on the bank face, evidence of the latest storm surge.

4.3.2 Poplar Grove: East River, Mathews County, Virginia

Introduction

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

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 (NOAA station). The upland bank height along the project shoreline averages about four to 5 ft MLW. 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 most recently the Veteran's Day Northeaster. Water levels during the Veteran's Day Northeaster 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.

4.3.3 Hull Springs Farm: Lower Machodoc Creek, Westmoreland County, Virginia

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 4-8A).

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. High water hits the base of bank. In some areas, vegetation obscured the scarp at the base of bank.

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. 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 on the bank and old bulkhead and extends on a 10:1 slope to about mid-tide (+0.8) 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 recently 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 the past winter but appear to have reemerged intact.

4.4 Breakwaters

4.4.1 Van Dyke: James River, Isle of Wight County, Virginia

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 4-12).

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 4-12). 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.

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 4-13). 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 4-13). 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 impacts were minimal where the interface between the backshore and base of bank had a less steep gradient.

5 Design Examples

Examples of the thought process and data used in Living Shoreline design are examined in this section. For this document, we are creating a scenario which will be used to illustrate how design of the system may progress. These projects do not exist and are being used only for illustrative purposes. The structures presented in this section are options that will manage shore erosion, but are, by no means, the only solution for these or other sites. It is important to use professional judgement for site-specific conditions.

For our purposes, the property owner is prepared to act and wants to abate the erosion, and desires a living shoreline, either a sill or breakwater, but a stone revetment also can be considered for the site. Costs will play a role as well as permitting.

5.1 Medium Sill, Site 349, Piankatank River, Mathews, Virginia

Introduction

Site 349 was identified in the Mathews County Shoreline Management Plan (Hardaway *et al.*, 2010) as an erosional site that could be stabilized with a medium sill which would address the severely eroding uplands. Presently the site is wooded, but it has a large potential for development.

Site Setting

Site 349 of the Mathews County Shoreline Management Plan is located on the south shore of the Piankatank River (Figure 5-1). The project length is about 900 ft long and faces approximately north-northwest with an average fetch exposure in that direction of about 4,600 ft. Straight line fetch exposures to the west, northwest, north, and northeast are 3,850 ft, 2,650 ft, 3,945 ft, and 3,560 ft, respectively. The longest fetch is to the west-northwest of 3.5 miles. The tide range is 1.2 ft, and the distance to the -6 ft MLW contour is about 750 ft. No marine resources are shown in existing databases (Hardaway *et al.*, 2010). The nearshore is sandy and firm.

The project shoreline occurs as a curvilinear headland on the west side of a major point of land, known as Holland Point and has a shore change rate on the western end of -0.85 ft/yr and on the eastern end of 1.7 ft/yr (between 1937 and 2007). The bank height varies from about +4 ft MLW water at either end and increases to about +20 ft MLW along the majority of the site (Figure 5-2). The low banks are heavily treed as is the top of the bank. The high bank is vertically-exposed and actively eroding (Figure 5-2B). The bank is composed of a basal gray clay layer up to about + 4 ft MLW and overlain by a sandy substrate possibly suitable for a sand fill.

Design Elements

To start the design process, the following assumptions are made: the landowner does not consider "doing nothing" as an option and would prefer a living shoreline. Whatever is chosen, bank grading will be necessary. An example site evaluation sheet has been created for this project (Figure 5-3).

While a breakwater system could be built, the nearshore is relatively deep, and depths greater than 3 ft MLW at about 75 ft from shore probably makes this option cost ineffective. However, if constructed, a breakwater system would have the minimum beach (pocket beach) requirement for a medium energy shoreline of about 35 to 45 ft from MHW or about 45 to 55 ft from MLW (Hardaway and Bryne, 1999). However, if the beach starts at +7 ft MLW then the distance to MLW, on a 10:1 slope, is 70 ft. A 90 ft gap between breakwaters yields a Mb of 55 ft, which with the 70 ft, means that the breakwaters need to be placed 125 ft offshore in water that is about 3ft deep. The rule of thumb for the minimum breakwater crest length is 60 ft (Hardaway and Byrne 1999). However, an offshore position in -3 ft MLW with a +2 ft tombolo attachment at mid-structure would require a crest length of 80 ft and a crest elevation +3.5 ft MLW.

For the sake of this analysis, only a sill and a revetment are considered. The final decision on structure type will be made by the landowner. Table 5-1 lists the approximate material and installation costs of the shore management strategies described below. These will help the landowner in their decision-making process.

The level of protection desired is for the 25-year event. In this section of the Piankatank River, the storm surge frequency and levels for the 10, 25, 50 and 100- yr storms are 4.4 ft, 5.4 ft, 5.9 ft and 6.7 ft MLW, respectively. A stone revetment would have to be at about +6.0 ft MLW to accommodate the 25-year return frequency (Figure 5-4). In comparison, the proposed sill will require a sand fill to be about the same elevation graded on a 10:1 slope to MTL (0.6 ft) for a distance of 50 ft. The sill elevation recommendation from the Mathews County Management Plan (Hardaway *et al.*, 2010) was for a +3 ft crest for the main sill along the high eroding bank face. As the bank drops toward each end to about +4 ft MLW, the sill elevation also can drop to about + 2 ft MLW crest elevation. The sand fill would extend from the top of the low bank and go riverward to about MTL, a distance of about 35 ft (Figure 5-4). The overall design planform is shown in Figure 5-5.

To determine potential wave energy against the proposed system, we will use a 60-mph wind from the longest fetch coupled with the +6 MLW storm surge. At -3 ft MLW, the total water depth is 9 ft, say 10 ft. Referring to Figure 2-7B, using the 9,500 ft fetch measurement to the west-northwest and a 60 mph in 10 ft of water, the estimated significant wave height is about 2.7 ft with a wave period of 3.3 seconds. However, the greatest impact to the sill structure at +3.0 ft in 2 ft of water results in a water depth of 5 ft. Using Figure 2-7A, the impinging **significant wave height** on the structure is 1.75 ft with a period of 3.0 seconds.

The significant wave height is defined as the average of the highest 33% of the wind/wave field. Wave heights for the highest 10% also should be noted in wave energy considerations and determination of rock size. For significant wave heights for 2.7 ft and 1.75 ft, the corresponding 10% wave heights are 3.4 ft and 2.3 ft, respectively (USACE, 1977).

Given the wave height analyses, Virginia Class II stone for the sill armor should be used and Class II can be used for the revetment, especially if on a 2:1 slope. The stone should be durable quarry stone that is hard and angular, free from either laminations, weak cleavages or undesirable weathering, and of such character that it will not disintegrate from the action of air, salt water, or handling. Sedimentary stone will generally be unacceptable. Filter cloth should be used as an underlayment and filter for both the stone revetment and the sill and should have a minimum burst strength of 500 psi.

The sand for the planting substrate behind the sill 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). The material in the bank meets this requirement.

The wetlands plants should consist of *Spartina alterniflora* and *Spartina patens* and planted on 1.5x1.5 ft centers. The *Spartina alterniflora* should be planted from MTL to SHW (+1.5 MLW; *Spartina alterniflora* will grow above MHW) and the *Spartina patens* from +1.5 MLW to the base of the bank. In looking at the initial grade for the +3 ft sill, there is only about a 10-foot wide *Spartina alterniflora* planting width. If more *Spartina alterniflora* is desired, the grade from MTL (back of the sill) can be changed to a 20:1 slope up to about +1.5 ft MLW which gives us a 18 foot swath of *Spartina alterniflora* and does not threaten the integrity of the fringe. This can be done for the lower +2 ft sills at either end as well. The graded slope also must be planted with appropriate riparian plants, especially deep-rooted grasses and shrubs in the potential wave strike zone at the base of the bank.

Deciding on a strategy ultimately comes down to cost. Referring to cross-section (Figure 5-4), the quantity of stone in both the revetment and sill is about 3.7 tons/foot (Table 5-1). When designing a revetment, it is important to try balancing the cut and fill for the subgrade. The sand required for the vegetative planting subgrade of the sill is about five cy/ft, of which, at least half can be mined from the bank using sand from the 2:1 cut. An additional 2.5 cy/ft may have to be hauled. However, a box cut might provide the additional balance required, but there are construction hazards with this type of mining. Costs shown in Table 5-1 assume all necessary sand for the revetment comes from the bank. So for the additional bank work, the sill costs are comparable with the revetment but with the vastly improved habitat.

Costs for a revetment or sill along the low bank on either end of the site also are shown in Table 5-1. Less rock per foot is needed for the designed sill than for the revetment. Two options for sill costs are presented for these lower bank areas since the cost of the sand will depend on how much sand can be removed from the bank during grading. If enough sand occurs in the bank, the sill is less expensive than the revetment. However, if sand has to be brought in from offsite, the cost per foot of the sill will be slightly higher than the revetment.

Construction Elements

The construction elements and the design elements are linked by costs and access. This site can be accessed on each end or by water. The bank grading provides a working bench for both revetment and sill applications. The stockpile area should be in the uplands if possible with protections for trees to be preserved. Some trees will have to be removed as part of the construction process but should be kept at a minimum. Replanting an equal number of select trees and shrubs will be required across the newly graded slope. Curlex or other erosion control fabric should be used to help stabilize the slope.

During construction the proper erosion and sediment control devices should be employed to prevent sedimentation. This includes a silt fence around upland stockpiles and accesses and a turbidity curtain along the waterside of the project. All disturbed areas should be seeded and mulched after construction.

Table 5-1. Approximate cost of materials for both the proposed sill and proposed revetment.

	Amount of Material (tons or cubic yards)	Cost per Ton	Cost per cubic yard	Cost per foot	Total Cost per foot*
High Bank					
Revetment					
Rock	3.7	$70		$259	**$309**
Sand	5		$10	$50	
Sill					
Rock	3.7	$70		$259	**$309**
Sand from Bank	5		$10	$50	
Low Bank					
Revetment					
Rock	2.8	$70		$196	**$236**
Subgrade with Sand from Bank	4		$10	$40	
Sill - Option 1					
Rock	2	$70		$140	**$169**
Sand from Bank	2.9		$10	$29	
Sill - Option 2					
Rock	2	$70		$140	**$242**
Sand from Offsite	2.9		$35	$102	

*Total cost only includes materials installed and does not include other costs such as plants, permitting, site work, access, or mitigation.

5.2 Small Low Sill, Site 118, East River, Mathews, Virginia

Introduction

A second site was selected from the Mathews County Shoreline Management Plan (Hardaway *et al.*, 2010). Site 118, located on the East River in Mathews, Virginia (Figure 5-1), received a small, low sill recommendation.

Site Setting

Site 118 is set within a longer reach of shoreline that extends from a small tidal creek just upriver southward for about 1,000 ft to a point (Figure 5-6). The project shoreline, where the erosion is occurring, is about 250 ft long. This site transitions to a more stable area to the north where a low shoal protects the shoreline and to the south where the coast has a wider marsh fringe. This fringe is wide enough to protect the adjacent low upland from wave action and the upland bank is mostly stable there (Figure 5-6B).

The average fetch exposure is to the west-southwest and is about 1,500 ft with a long fetch exposure to the west of about 2,400 ft. A second long fetch is to the south-southwest and is about 2,200 ft. The more frequent wind/wave climate comes from the southwest and west (Table 1-2). The site has a 2.4 foot tide range and the distance to the 6-ft contour is about 300 ft.

The site has a low, undercut, and erosive upland bank with a sparse marsh fringe (Figure 5-6C and 5-6D). Tree shading and wind-wave action from the west and southwest appear to be the primary causes of bank erosion. The site has a wooded fringe about 30 to 40 ft wide that extends along this shore segment which borders an agricultural field. Erosion is not severe, but chronic, and the landowner would like to know some options. The agricultural field is a prime candidate for development because of limited tree cover.

Design Elements

No upland improvements exist, and the erosion rate is relatively low, less than -0.5 ft/yr. A do nothing option is quite reasonable. Trimming the trees and planting *Spartina alterniflora* in the bare areas (Marsh Management) also is an option, and over time, the planting may expand and provide some wave attenuation capabilities. For a long-term solution, building a small low sill would be the next step. Sand fill would be brought in and planted with *Spartina alterniflora* and *Spartina patens*. Tree trimming also would be required. Access to the site would be relatively easy across and along the agricultural field. A small stone revetment also is an option.

Why a small low sill and not a higher structure? If this had a house or lawn on the property, a higher structure may be warranted. We know that if we can provide a stable marsh fringe then the erosion should be adequately abated. Wave action against the bank would be worst with storm surges at about +4 ft MLW, typically occurring several times a year but with southwest winds. Undercutting of the bank is no doubt more frequent under lesser wind/wave and water levels and chronic as shown by the sparse marsh fringe. Based on fetches, a significant wind wave from the west-southwest could reach between 1.0 ft and 1.5 ft given a 50-mph wind at +4 ft MLW. Storm water levels for the 10, 25, 50 and 100 year events are 5.8, 6.8, 7.3, and 8.1 ft, respectively. So the site is under water during just about any significant storm. Therefore, providing a gentle wave attenuating coastal gradient is desired.

The sill design would start with establishing a typical cross-section (Figure 5-7). The level of the sand against the bank should be determined. In this case, the fill might go up to near the top of the bank, say +3.5 ft MLW. The top of the bank can be graded slightly after removal of dead and threatened trees. Care needs to be taken to leave nearby trees and minimize impacts to the riparian buffer. The sand gradient should be on a 8:1 slope down to approximately mid-tide or +1.2 ft MLW at the back of the proposed sill. This provides a wetland planting terrace of about 23 ft with *Spartina alterniflora* planted from +1.2 ft MLW to about MHW (+2.4 ft) and the *Spartina patens* landward of that. Sand should be clean, with no more the 10% passing the 100 sieve and with minimum D50 of 0.25 mm.

The small low sill has an elevation of about MHW, slightly higher or lower depending on fetch. In this case it should be at least MHW. Virginia Class I rock (50 to 150 lbs.) should be sufficient in this hydrodynamic setting. Filter cloth should be used under the sill.

How many windows should be included in the sill? This is a question with a variety of opinions because many think that windows are required for access to the newly created marsh fringe by marine fauna and they improve flushing. Potential impacts to adjacent properties can be addressed by turning the ends of the sill outward as a short spur has shown to interface well with adjacent marsh fringes. This should be done on both ends of the structure.

Construction Elements

Access must be gained through the woods and onto the shore. A construction road can be built from the driveway through the agricultural field to the shore. Sand could be brought in to provide a building access alongshore. Dead trees and overhanging limbs would be removed as the shore access road is built.

A stockpile area generally is required and should be located near the project shore on some portion of the adjacent agricultural field out of the riparian buffer zone. Erosion and sediment control devices like a silt fence and a turbidity curtain should be used where potential sedimentation during construction might occur.

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7 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.

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.

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 direct 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.

Wave Climate - the distribution of wave conditions, defined by wave height, period, and direciton, 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.

Wave Ray - A ray is a line extending outward from the source and representing the direction of propagation of the wave at any point along it. Rays are perpendicular to wave fronts.

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.html

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

8 Links for Additional Information

Living Shorelines

VIMS, CCRM http://ccrm.vims.edu/livingshorelines/index.html

VIMS, SSP http://web.vims.edu/physical/research/shoreline/Publications-Other.htm

Shore Management Planning and Strategies

VIMS, SSP - Publications
http://web.vims.edu/physical/research/shoreline/Publications-ShoreMgt.htm

VIMS, CCRM - Decision Tree

http://ccrm.vims.edu/education/workshops_events/april2010/index.html

NOAA - http://coastalmanagement.noaa.gov/initiatives/shoreline_ppr_planning.html

Data Links

Google Earth 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 rate.

Erosion rates are available for many Bay localities in Shore Evolution Reports published by the Shoreline Studies Program at VIMS. These reports used ortho-rectified historical and recent aerial photos to determine the long-term rate of change (usually between 1937/1938 and 2002/2007). Not all areas are presently available, but the work is ongoing. (http://web.vims.edu/physical/research/shoreline/Publications-Dune.htm).

The Submerged Aquatic Vegetation (SAV) program at VIMS (http://web.vims.edu/bio/sav/) maps the location and amount of SAV in the nearshore for Chesapeake Bay.

Navigational charts are available from the National Oceanic and Atmospheric Administration's (NOAA) Office of Coast Survey. Their Booklet Charts (http://ocsdata.ncd.noaa.gov/bookletchart/) are navigation charts split into sections so that they can be printed on letter-sized paper. These are convenient for determining depth offshore and nearshore morphology.

Tide range is shown in Figures 1-3 and 1-4. These data were obtained from NOAA's online database (http://tidesandcurrents.noaa.gov/).

Storm surge levels are determined by the Federal Emergency Management Agency (FEMA) in their Flood Insurance Studies (FIS). These studies are available online at FEMA's Map Service Center under their product catalog (http://msc.fema.gov/webapp/wcs/stores/servlet/FemaWelcomeView?storeId=10001&catalogId=10001&langId=-1&userType=G).

Permit Process Links

Local Wetlands Boards - http://ccrm.vims.edu/permits_web/guidance/local_wetlands_boards.html

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

VA Institute of Marine Science (VIMS) - Permit Database http://ccrm.vims.edu/

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

VA Department of Historic Resources (DHR) Environmental Review http://www.dhr.virginia.gov/review/section_106.htm

VA Department of Health (VDH) Shellfish Sanitation http://www.vdh.virginia.gov/EnvironmentalHealth/Shellfish/index.htm

Joint Permit Application http://www.nao.usace.army.mil/technical%20services/Regulatory%20branch/JPA.asp

U.S. Army Corps of Engineers (USACOE) (link to Norfolk District wetland permits)

http://www.nao.usace.army.mil/technical%20services/Regulatory%20branch/homepage.asp

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

NOAA Coastal Services Center, Decision Support Tools http://www.csc.noaa.gov/tools.html

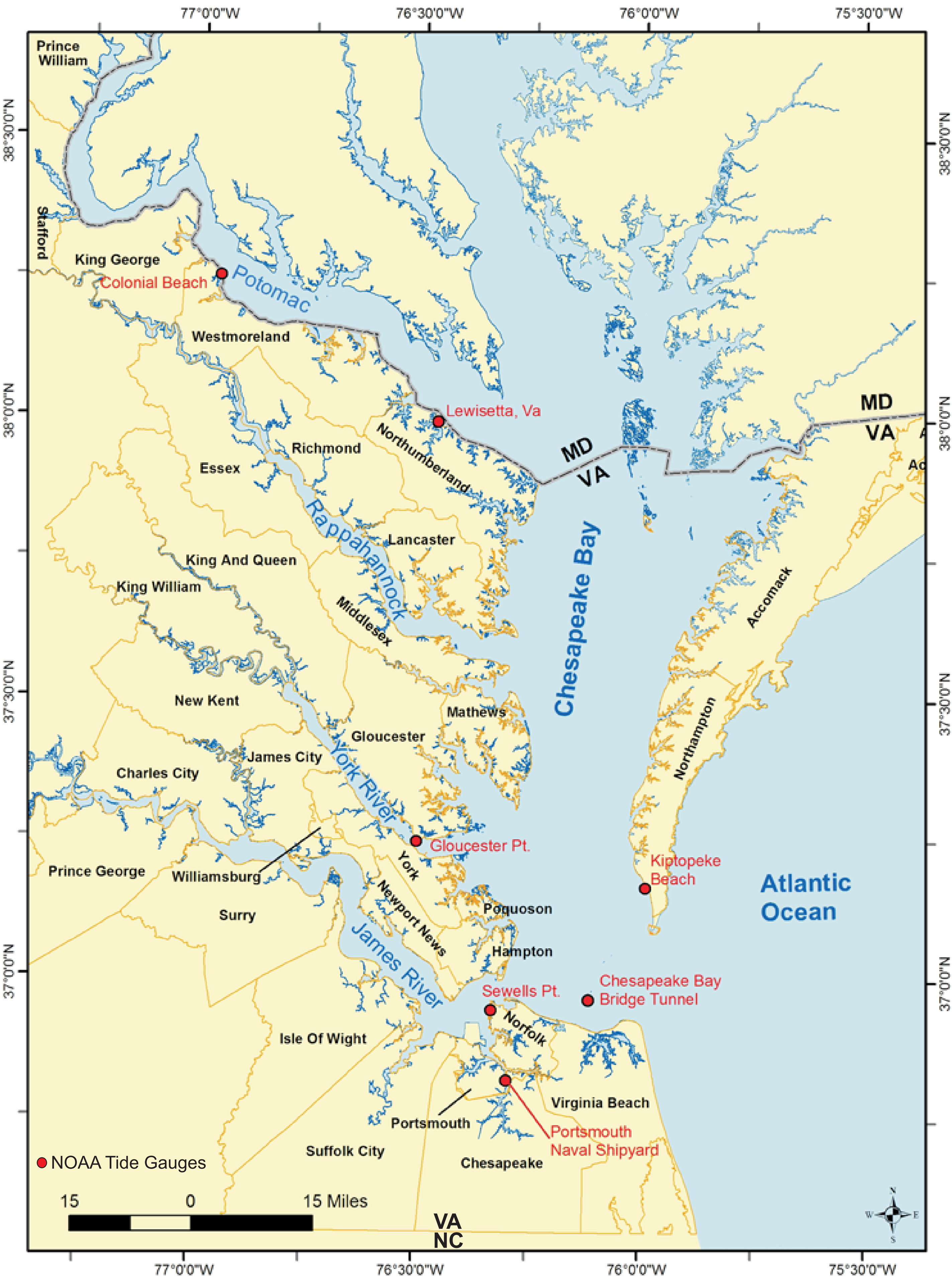


Figure 1-1. Virginia portion of the Chesapeake Bay estuary and location of tide gauges.

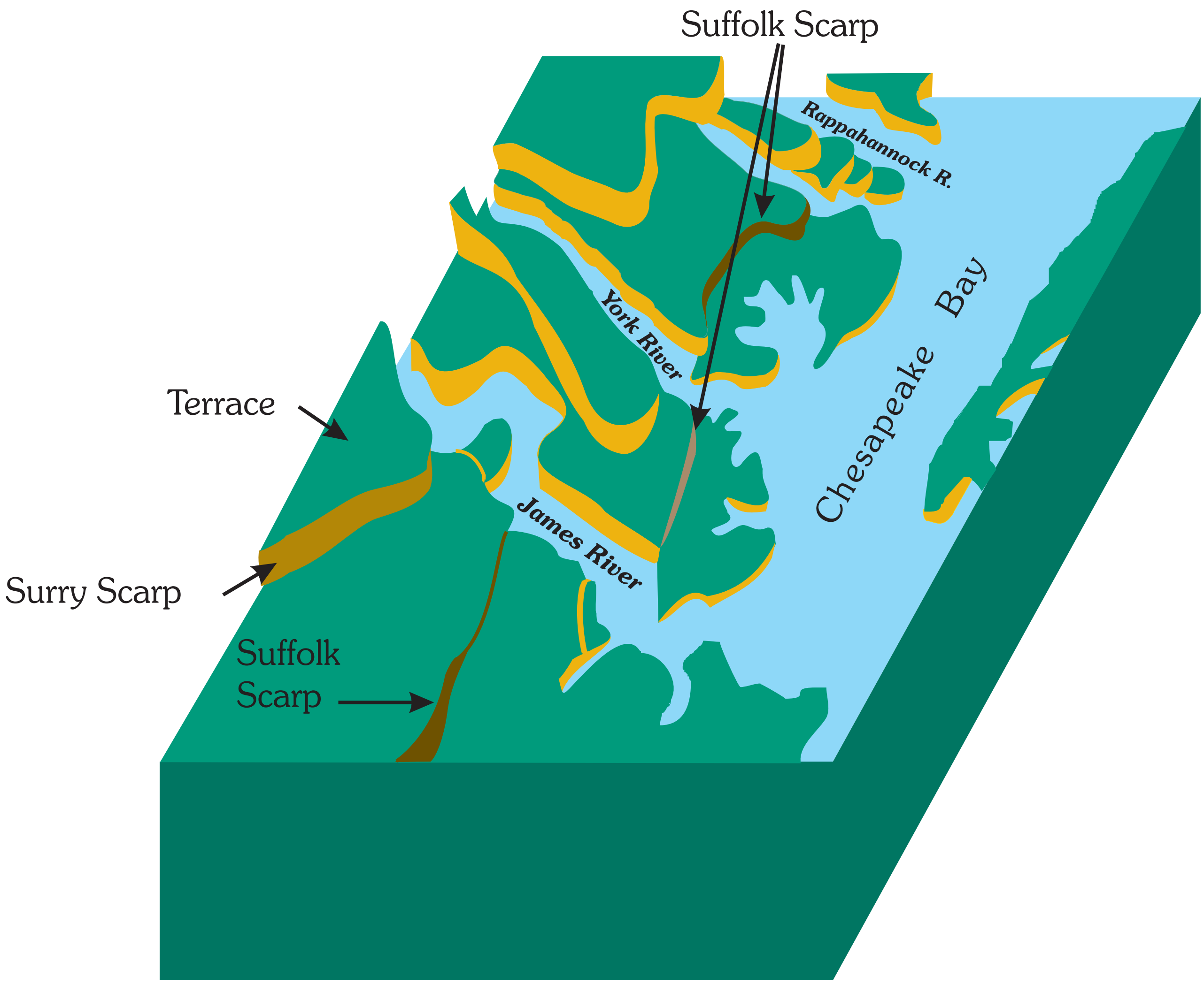


Figure 1-2. Ancient scarp features of the Virginia Coastal Plain (after Peebles, 1984).

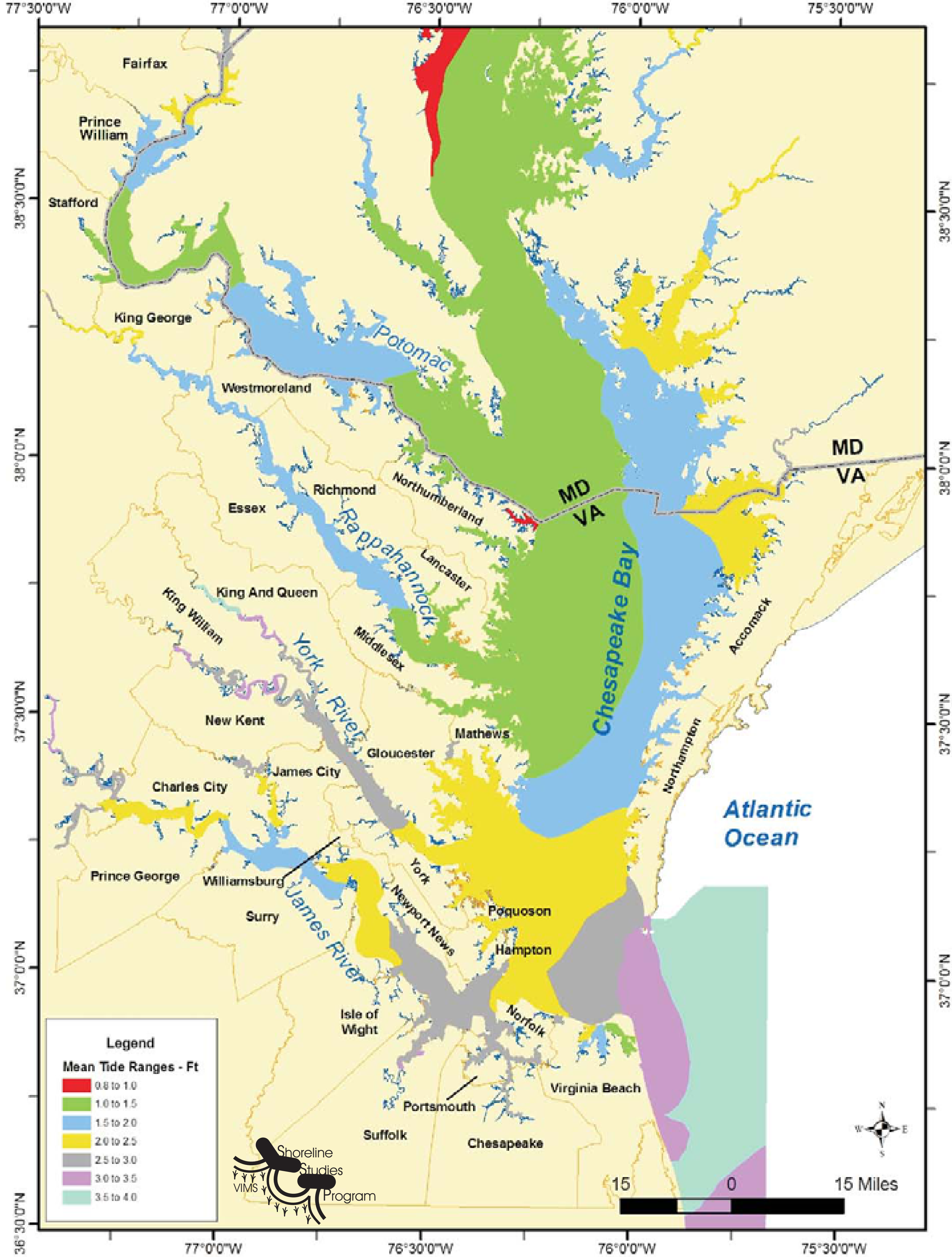


Figure 1-3. Mean tide ranges in Chesapeake Bay. Tide range polygons interpolated in ArcGIS from data points obtained from NOAA Tides & Currents online.

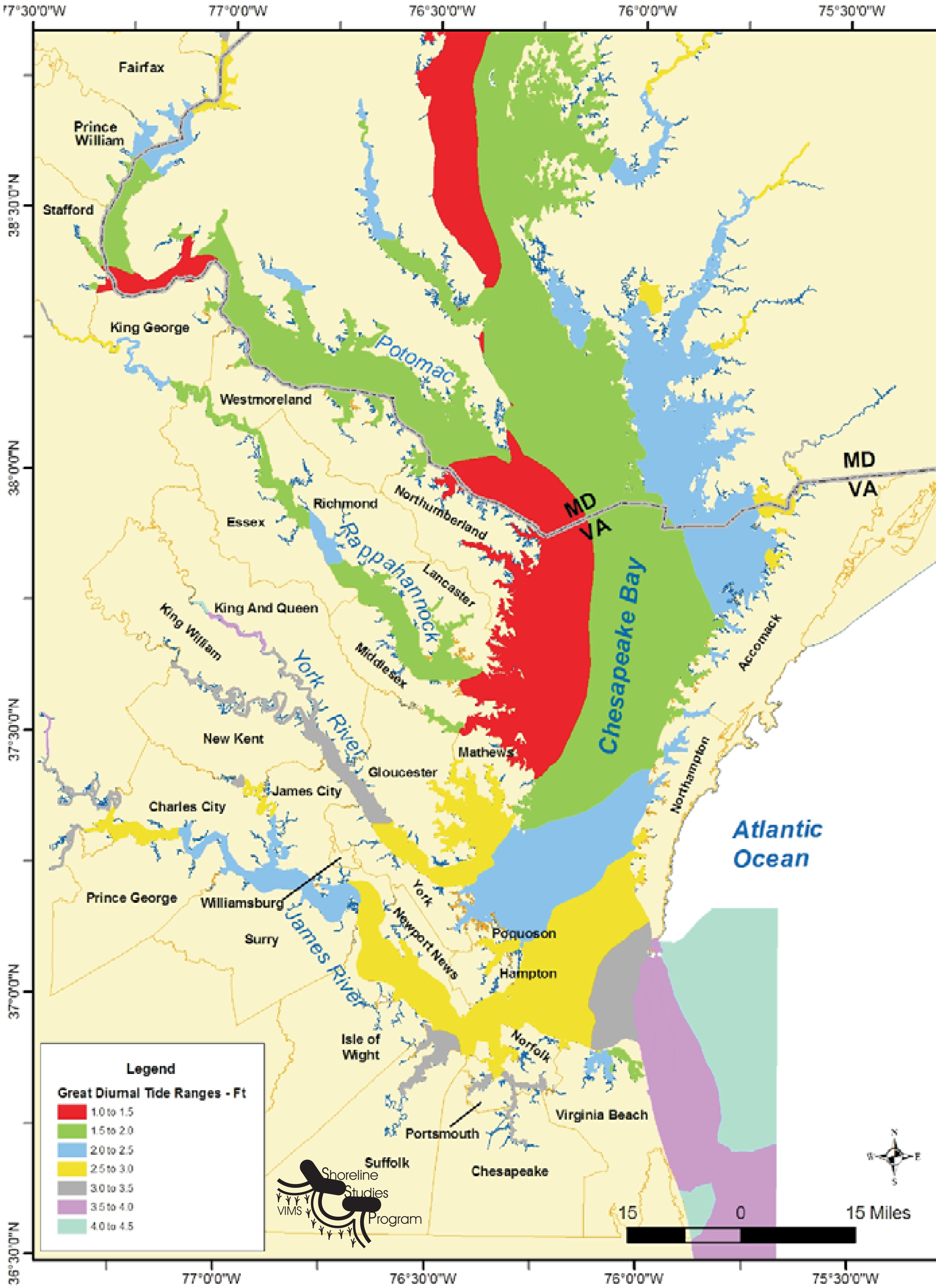


Figure 1-4. Great diurnal (spring) tide ranges in Chesapeake Bay. Tide range polygons interpolated in ArcGIS from data points obtained from NOAA Tides & Currents online.

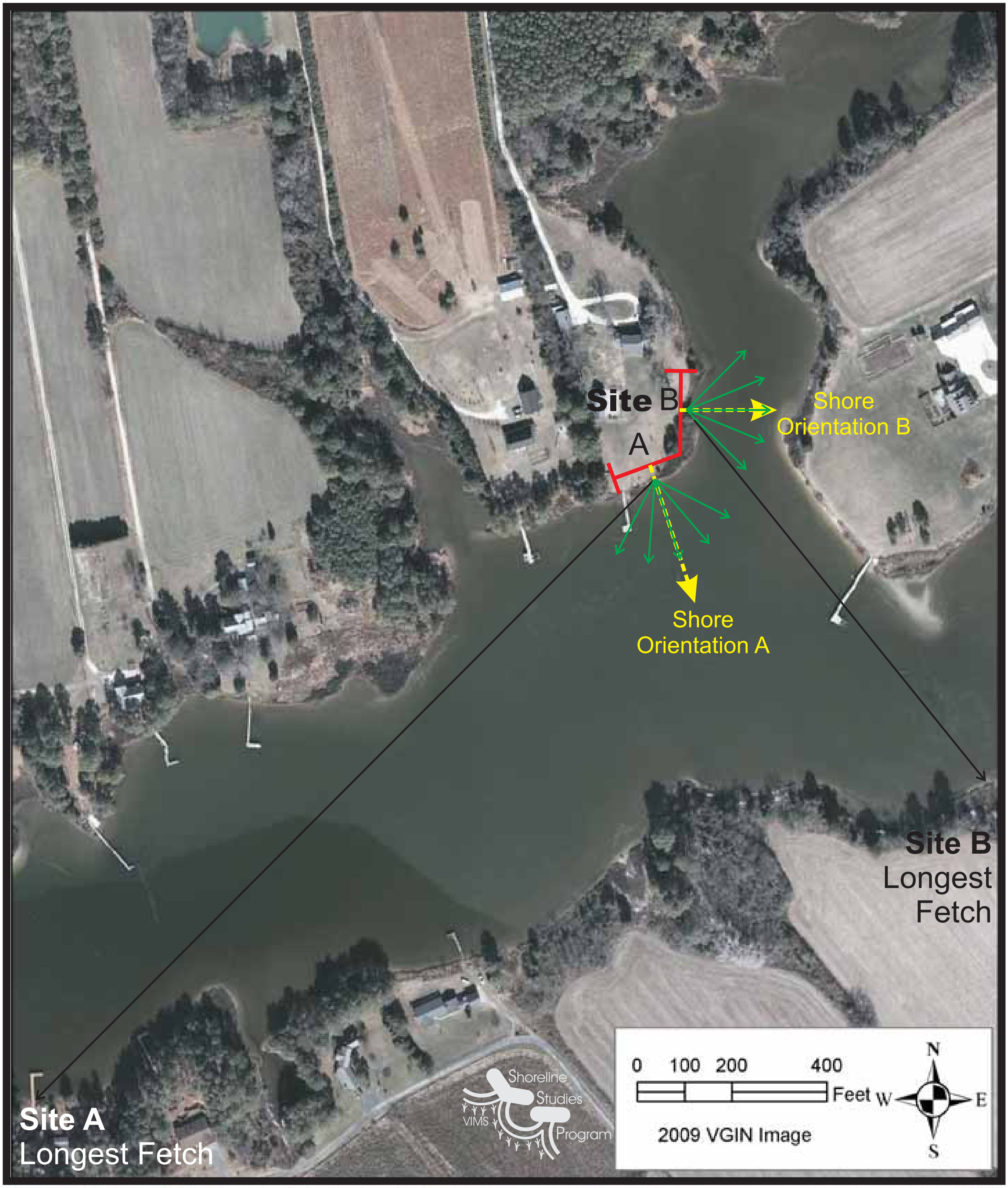
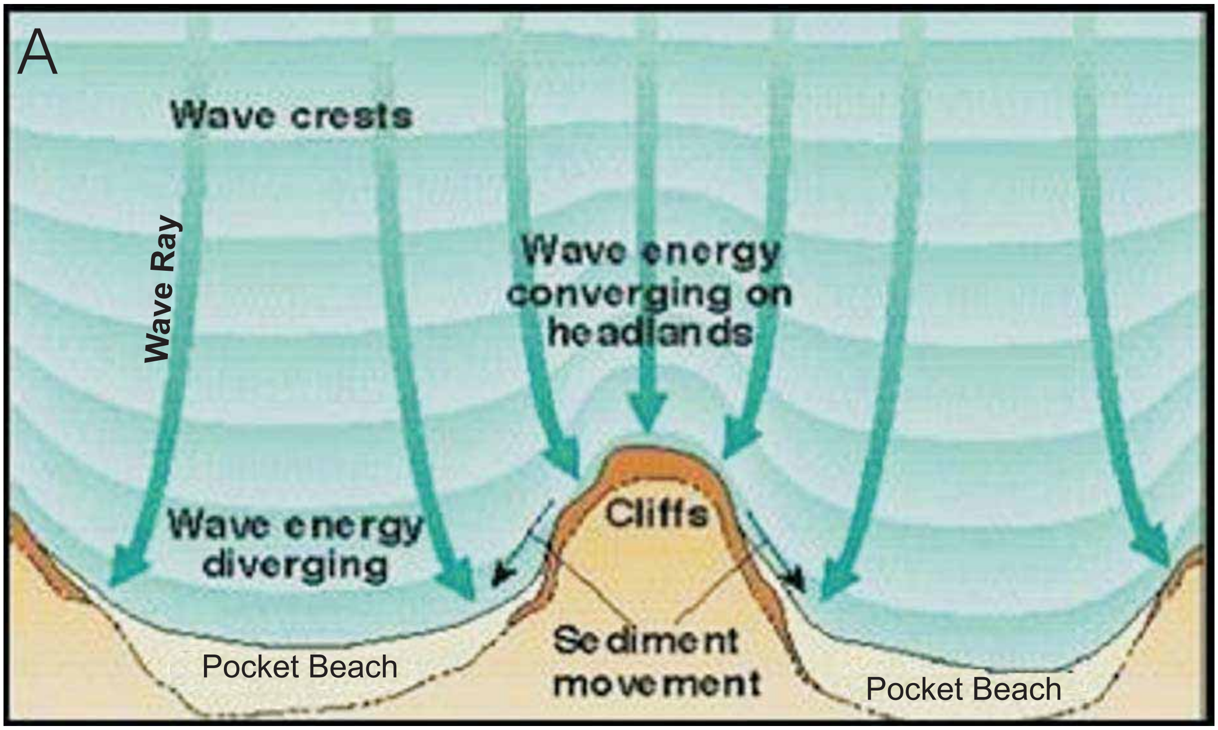


Figure 2-1. Photo depicting the longest fetch for two sections of a site. Section A's shore orientation (direction of face) is southeast while Section B's orientation is east. The green arrows show the vectors measured to determine average fetch while the black arrows show the vector of the longest fetch.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

Figure 2-2. Photos illustrating four different types of shore morphology within Chesapeake Bay.



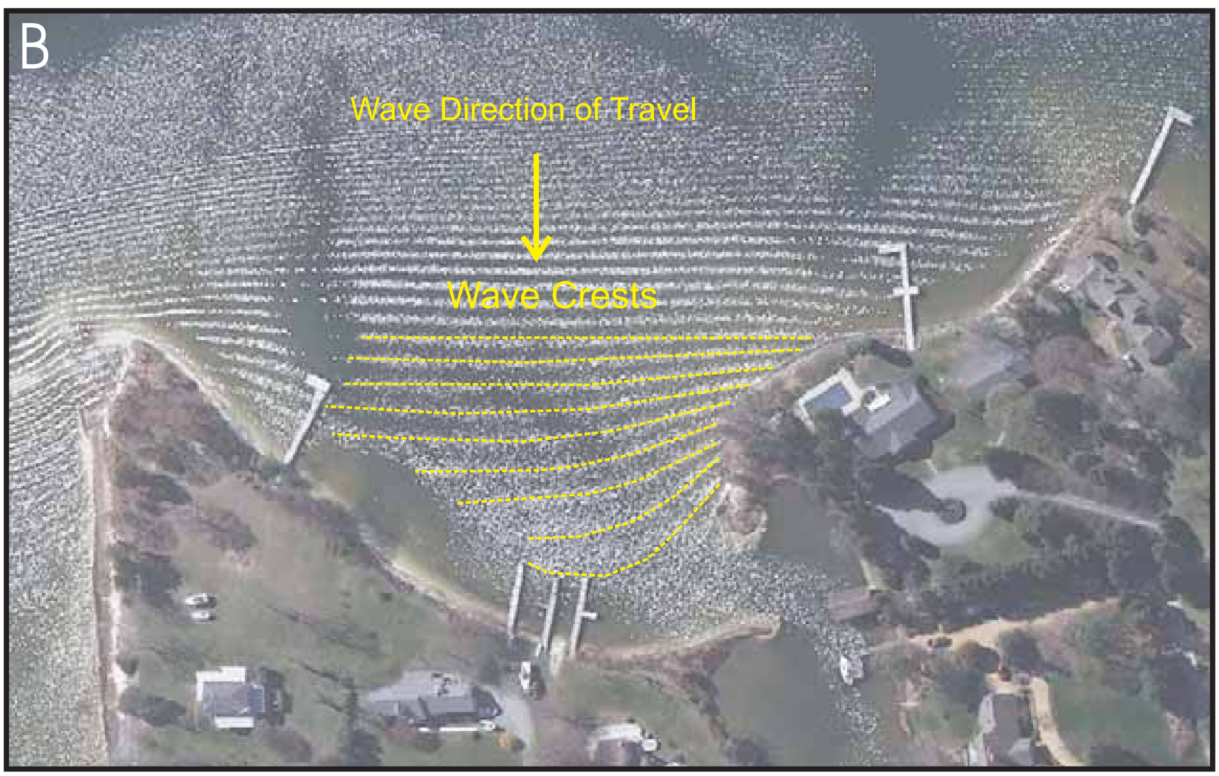


Figure 2-3. Refraction of incoming waves occurs due to changes in depth contours. A) Waves are refracted within a pocket beach such that they diverge or spread but converge or concentrate on the outside edges and at headlands (from http://www.crd.bc.ca/watersheds/protection/geology-processes/Waves.htm). B) Waves are refracted at a pocket shoreline at Tabbs Creek, Lancaster, Virginia.

Figure 2-4. Photos showing nearshore bars and submerged aquatic vegetation. A) A VGIN 2009 photo shows the channel into Cranes Creek in Northumberland County, Virginia. 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. B) A VIMS aerial photo of Pond Point on the East River in Mathews, Virginia (dated 21 April 2009) showing extensive SAV in the nearshore, as well as sand bars.

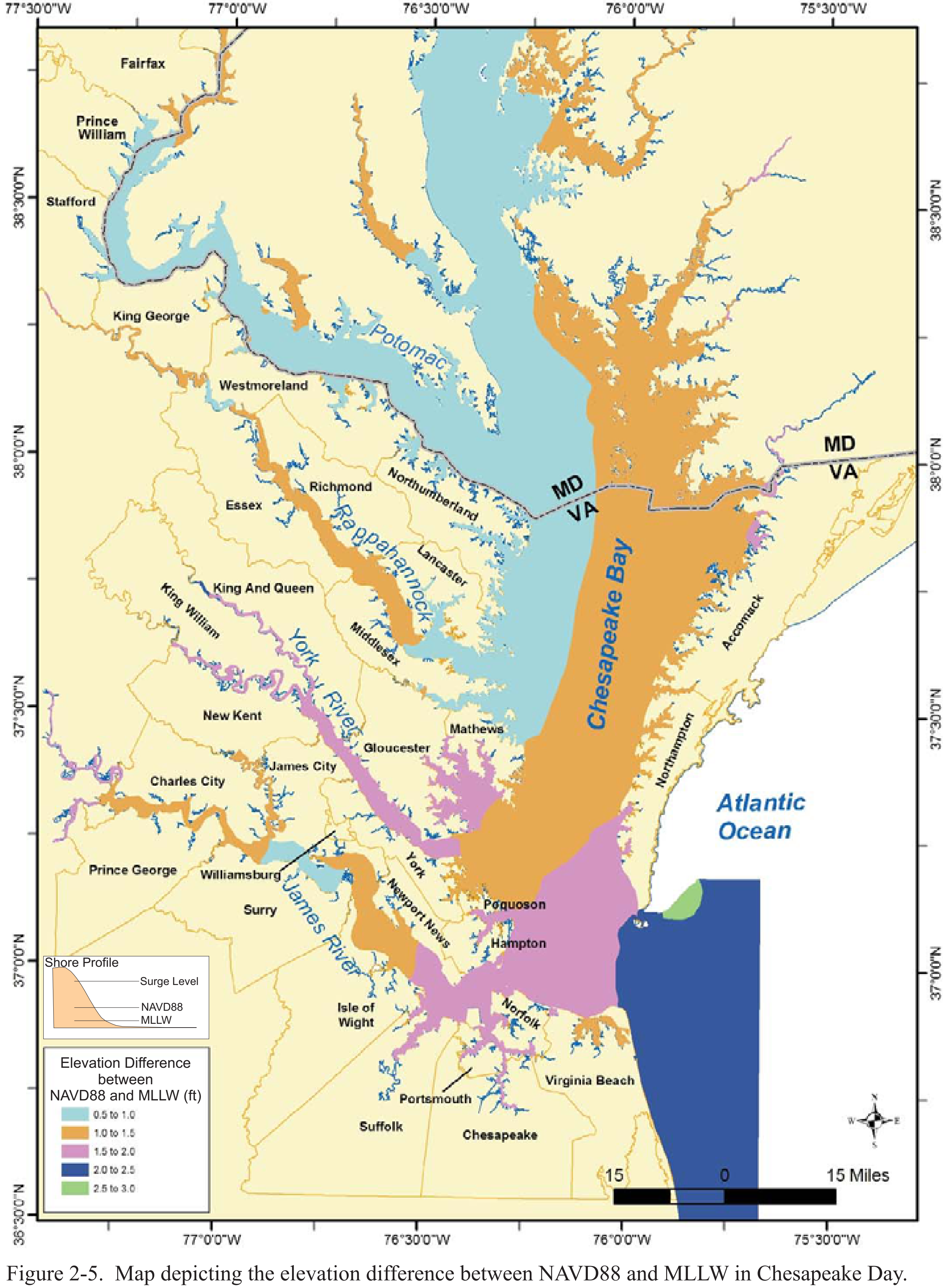


Figure 2-5. Map depicting the elevation difference between NAVD88 and MLLW in Chesapeake Day. Data calculated using NOAA's VDATUM grids. Datum transformation grid TSS was subtracted from the MLLW datum transformation grid (http://vdatum.noaa.gov/dev/gtx_info.html) to obtain the elevation differences.

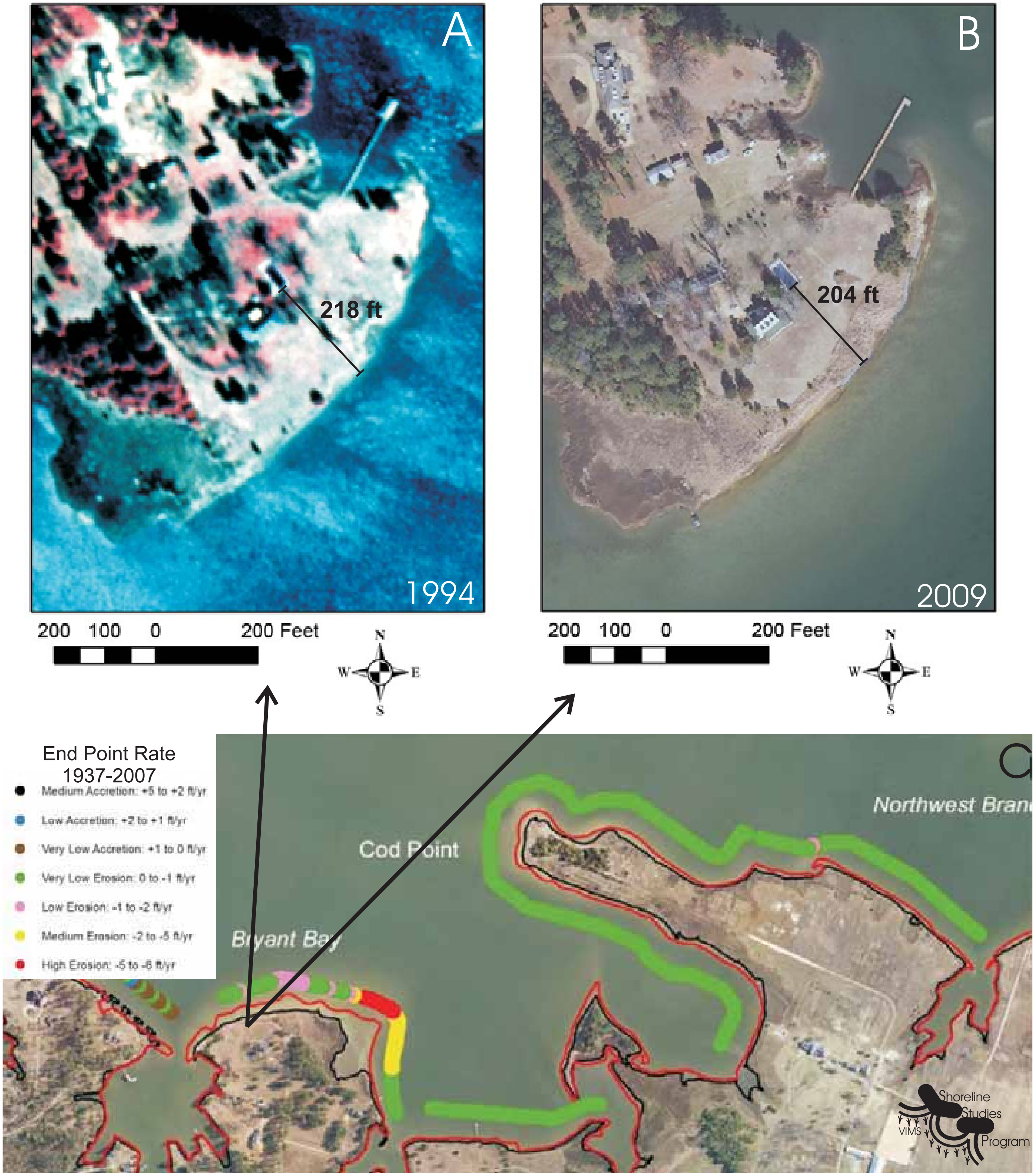
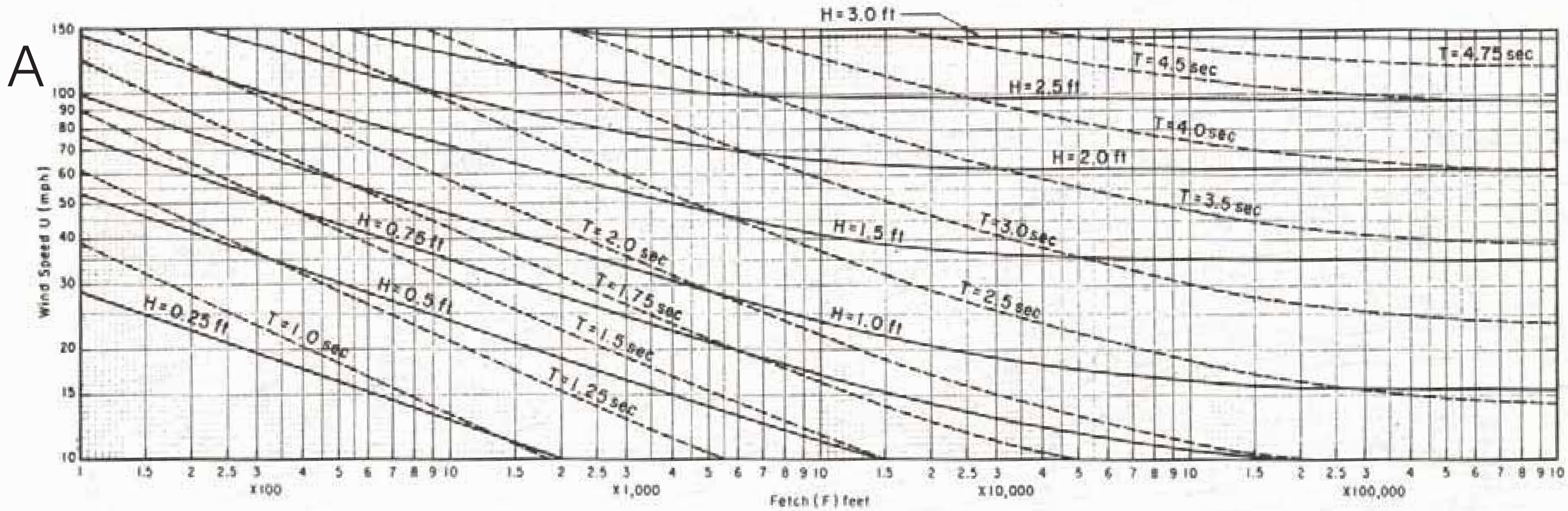
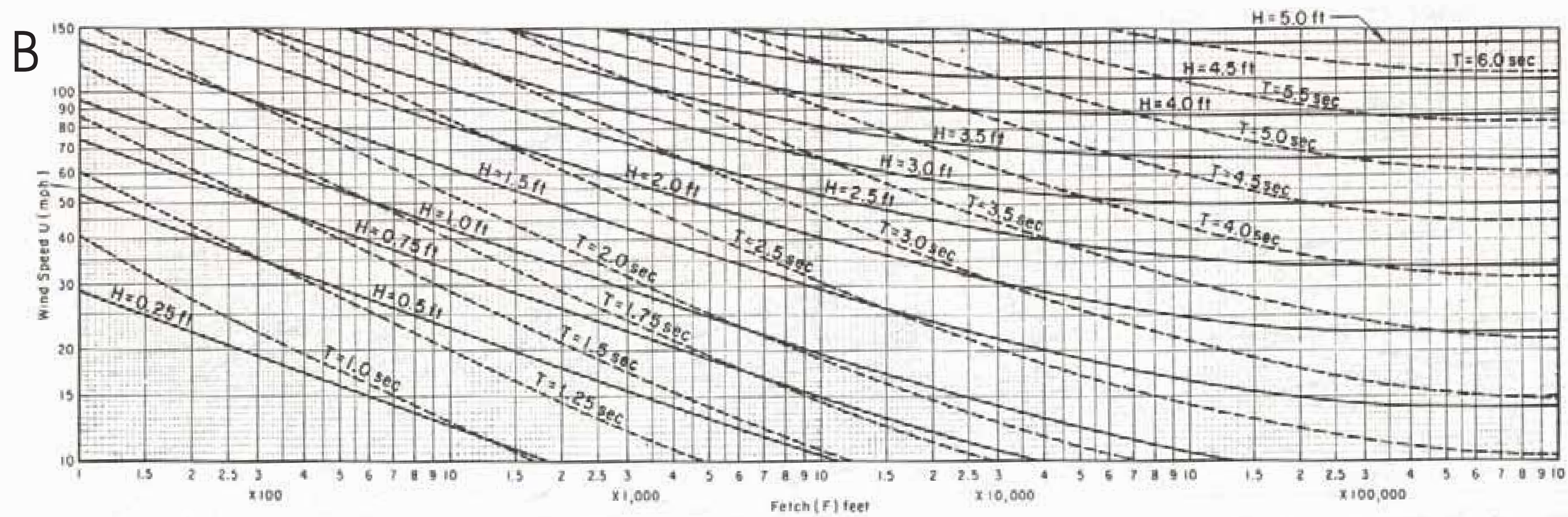


Figure 2-6. Determining rate of change along the shoreline. Aerial photos of a site in Gloucester County in A) 1994 and B) 2009. C) The end point rate of shoreline change determined between 1937 and 2007. Rates are visualized as different colored dots and show the variability of rates of change along small sections of shore (from Milligan *et al*., 2009)

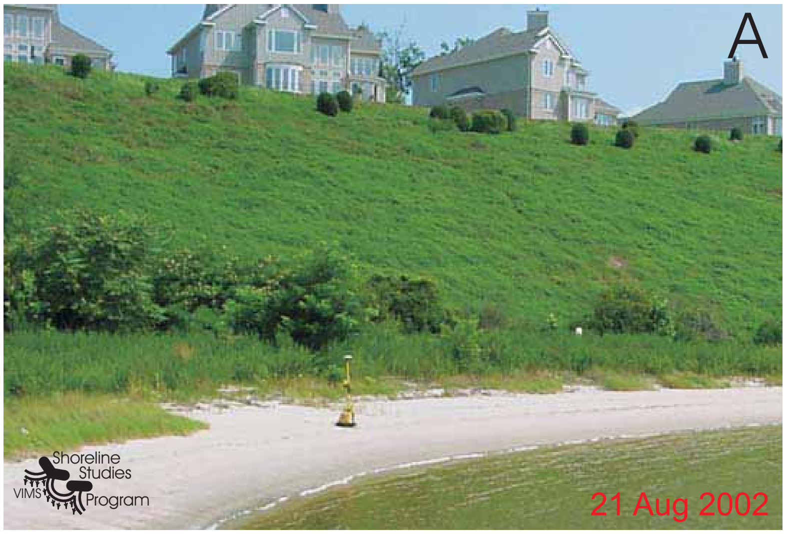


Constant Depth = 5 feet.



Constant Depth = 10 feet.

Figure 2-7. Forecasting Curves for Shallow-Water Waves. From USACE, 1977.



A stable base of bank and bank face that has been graded and planted with vegetation.
James River, Virginia

An unstable base of bank and bank face. The different colored layers indicates different types of material.
Piankatank River, Virginia

An undercut bank on the East River, Virginia.

Figure 2-8. Bank condition example photos.

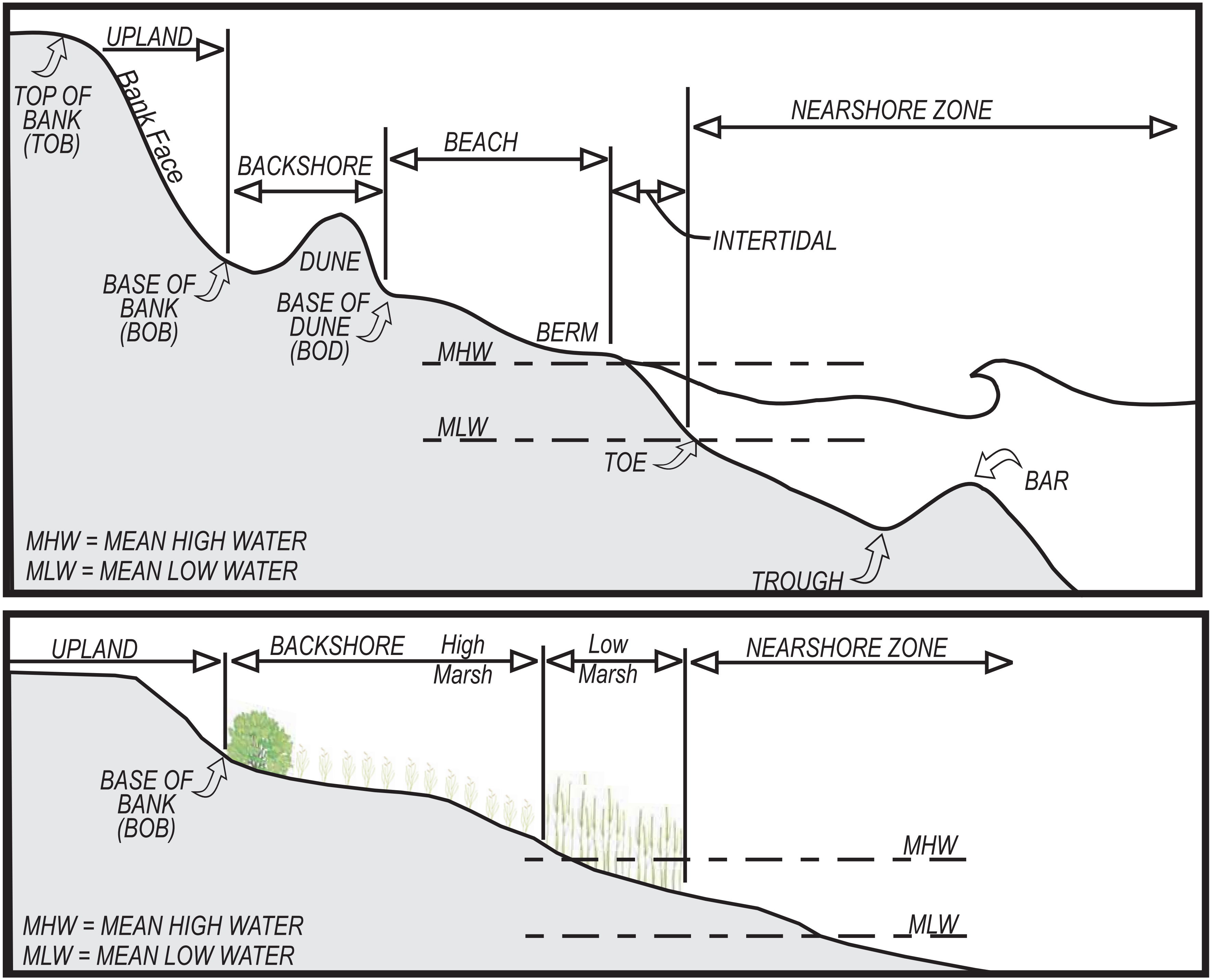


Figure 2-9. Terminology used to identify sections of the shore and backshore zones.

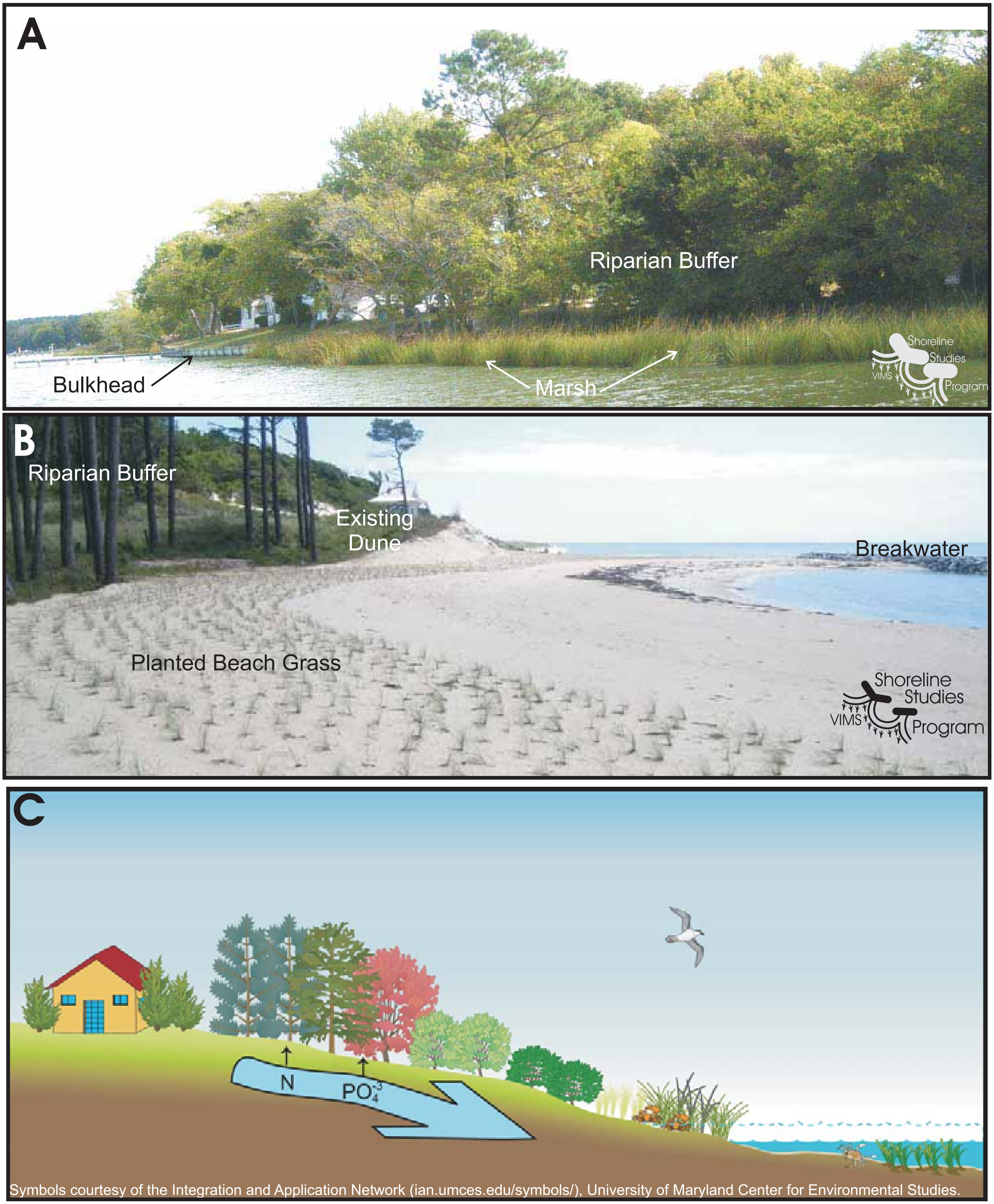


Figure 2-10. Photos depicting aspects of the coastal profile for A) a low-medium energy marsh shoreline and B) a high energy beach shoreline. C) diagram of a connected shore zone shows different landscape elements. C is reprinted courtesy of the VIMS Center for Coastal Resources Management. N = Nitrogen, PO_4^{-3} = Phosphate.

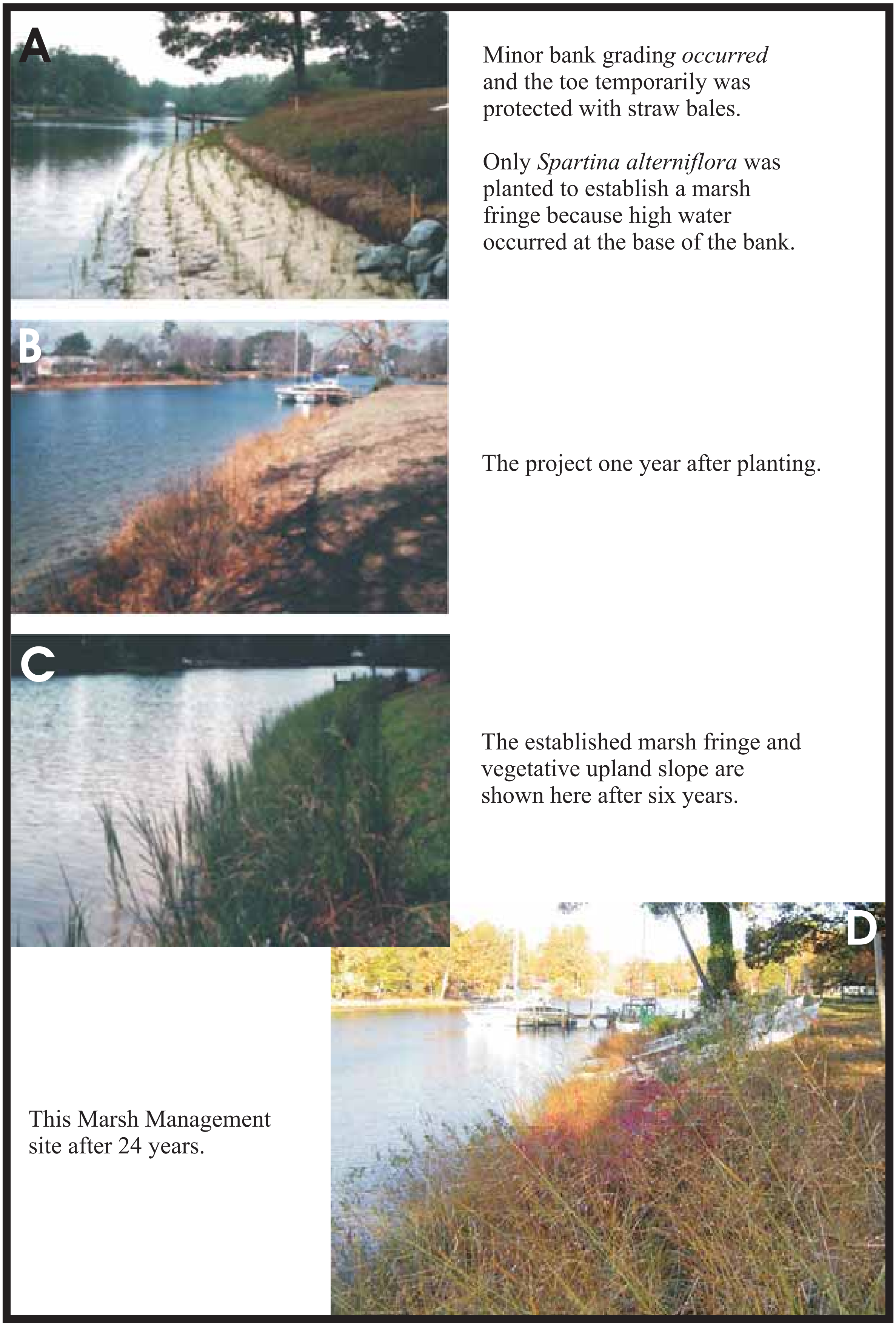


Figure 3-1. Marsh planting A) after planting, B) after one year, C) after 6 years, and D) after 24 years of growth. (Reprinted from Hardaway *et al*., 2010).

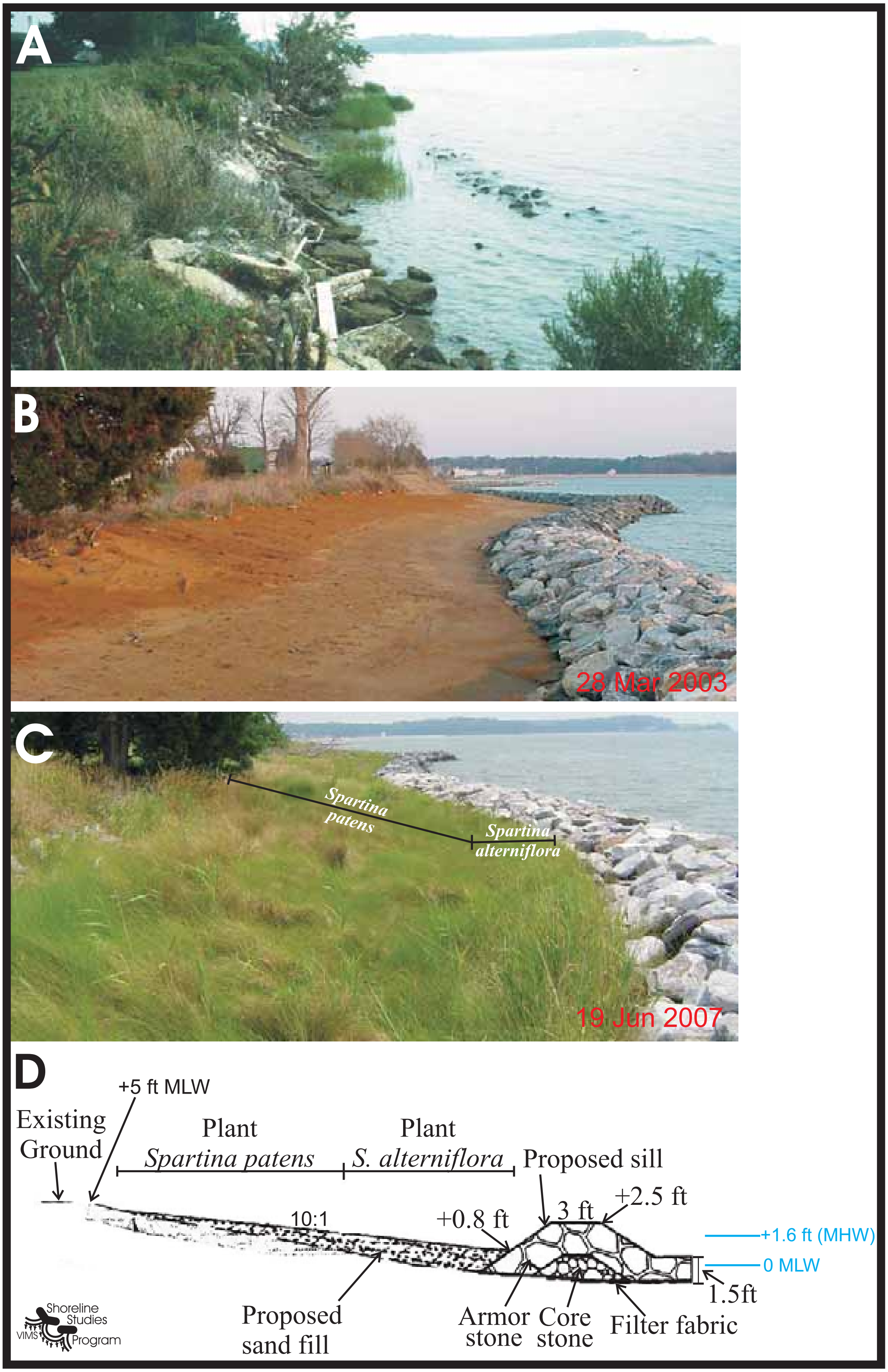


Figure 3-2. Sand fill with stone sills and marsh plantings at Webster Field Annex, St. Mary's County, Maryland A) before installation, B) after installation but before planting, C) after four years, and D) the cross-section used for construction (Hardaway *et al*., 2010).

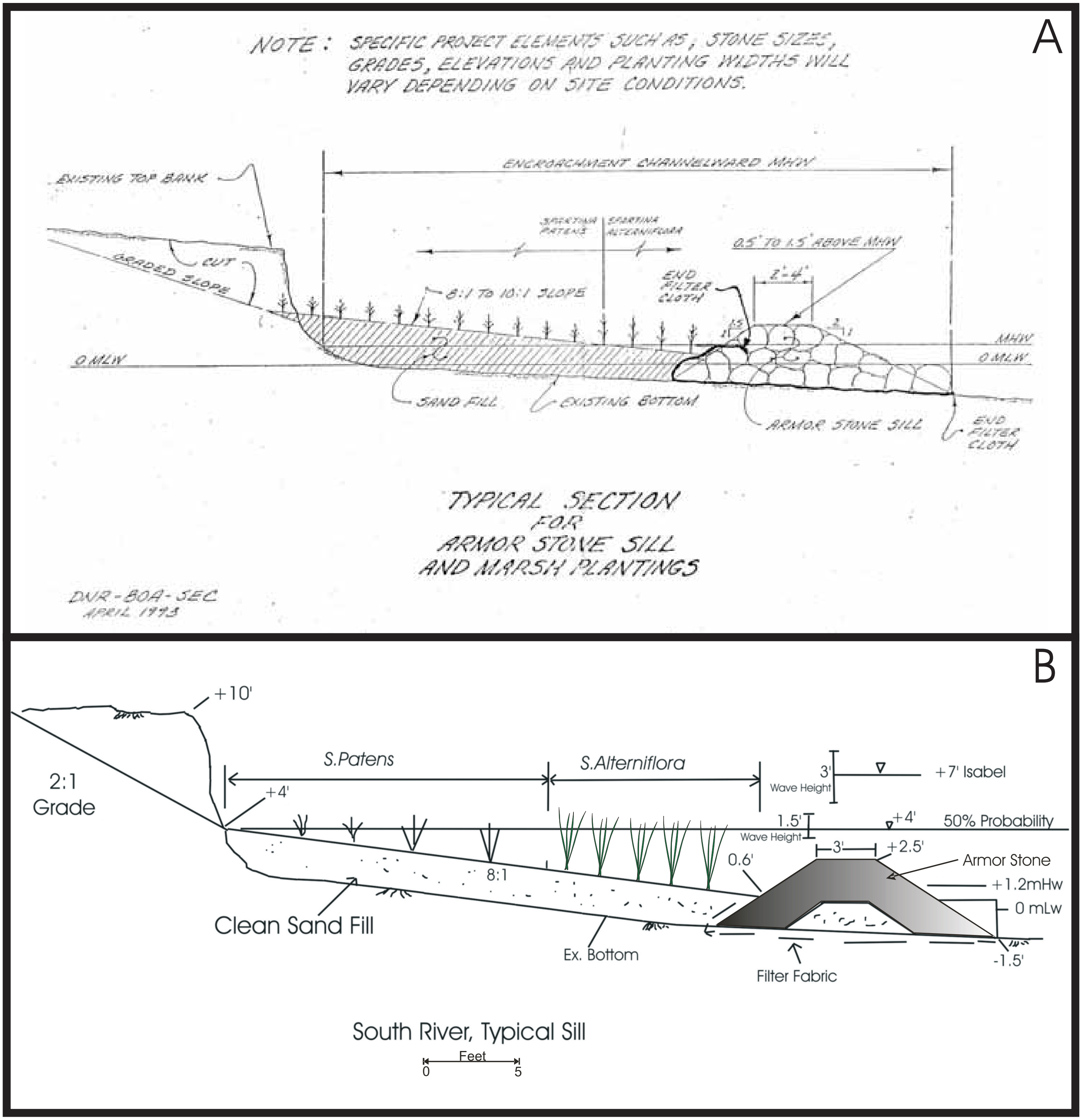


Figure 3-3. Typical sill cross-section A) created by Maryland Department of Natural Resources for their non-structural program and B) for the South River which shows the 2-yr event (50% probability) storm tide elevation with design wave height (1.5 ft) as well as the storm tide elevation during Hurricane Isabel (2003) with associated wave height (3 ft). The mean tide range is 1.2 ft, so mid-tide level is 0.6 ft MLW. The level of protection in this case was +4 ft MLW, so the sand fill was graded on an 8:1 slope from the bank to the back of the sill. The upland bank was also graded and re-vegetated.

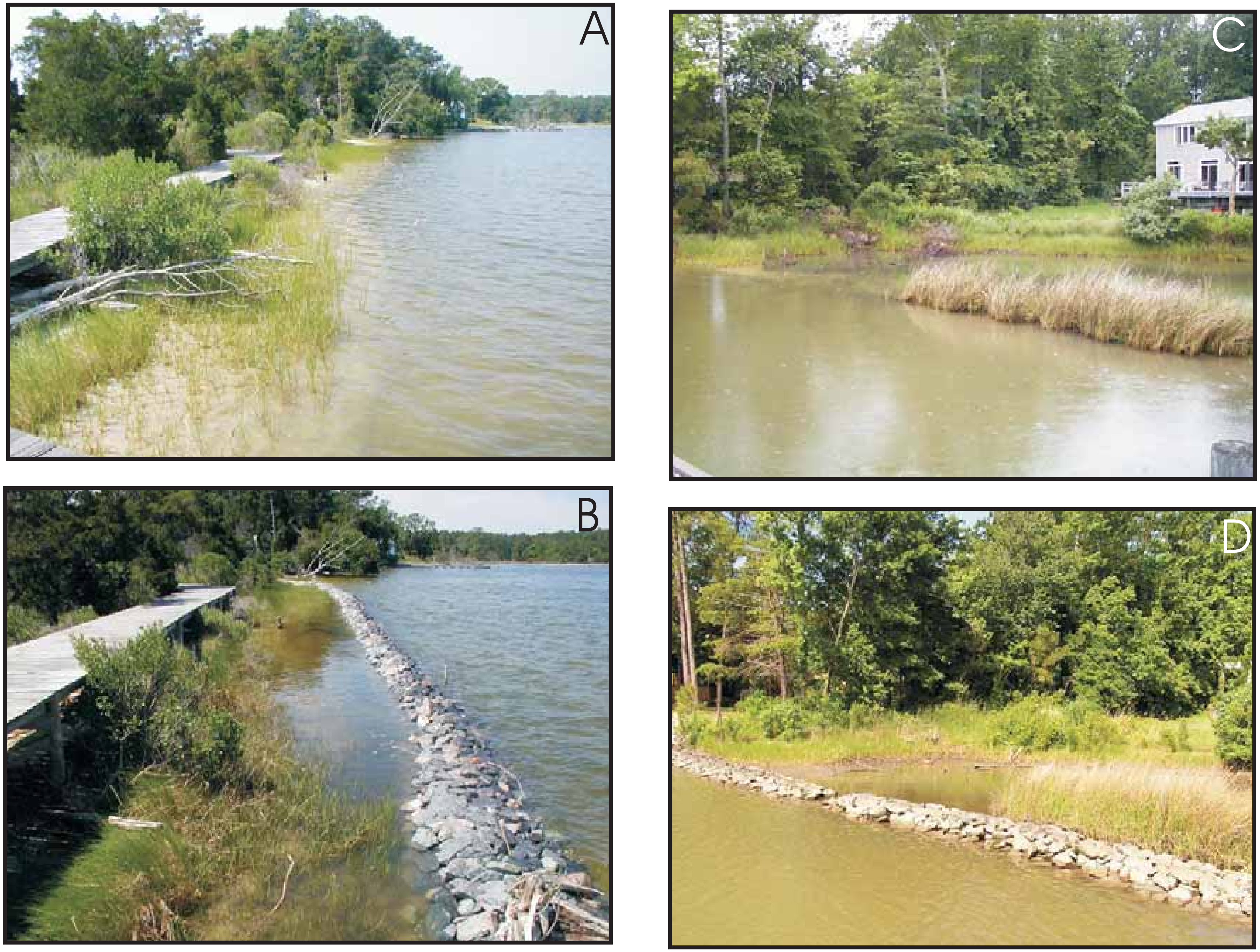


Figure 3-4. Photos showing marsh toe revetments A) before and B) after a project on Cranes Creek in Northumberland County and C) before and D) after a project on Mosquito Creek in Lancaster County, Virginia.

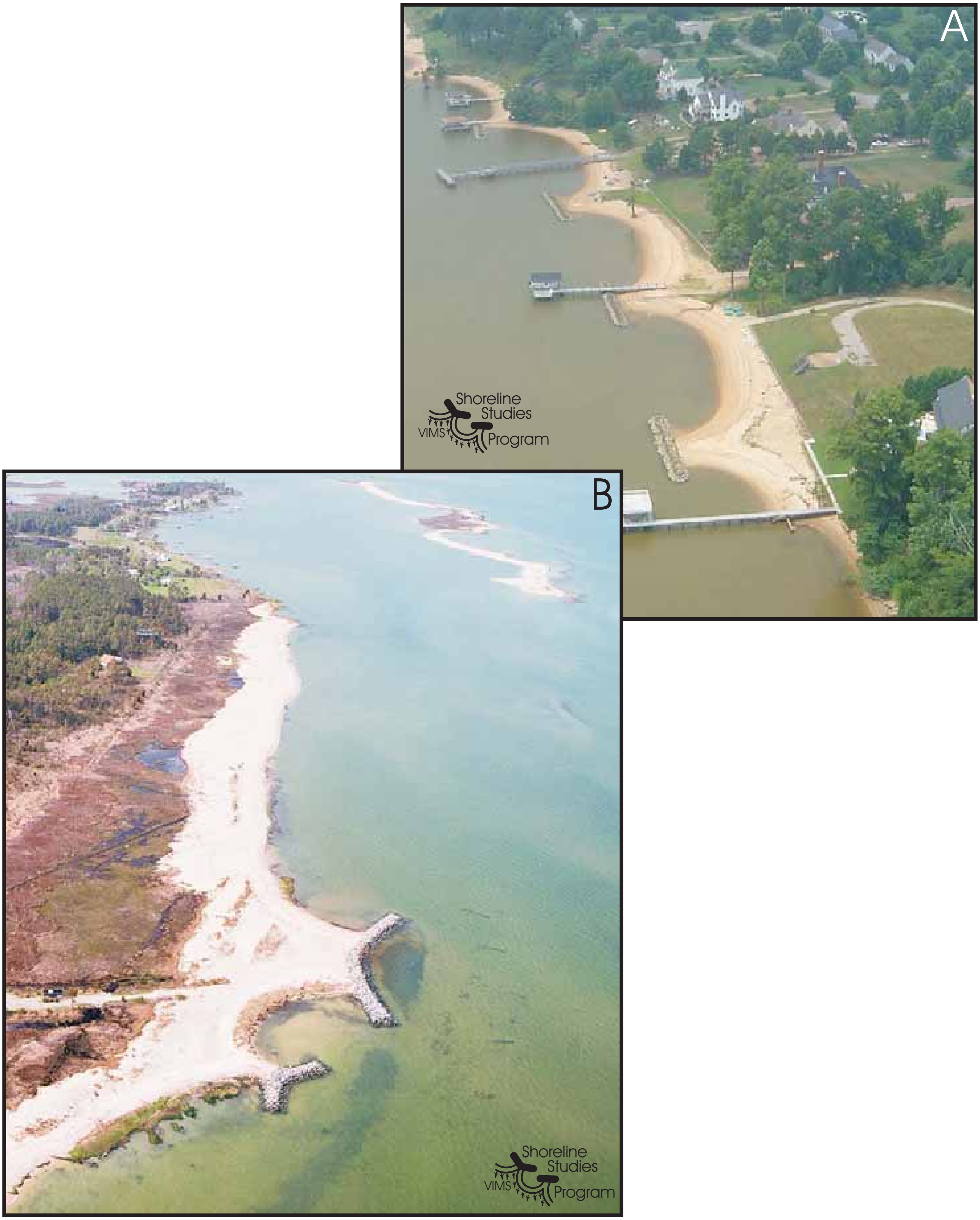


Figure 3-5. Aerial photos of A) Drummond Field breakwaters (June 30, 2005) on the James River, and B) Festival Beach on Chesapeake Bay (April 21, 2010). While the physical characteristics of each site differ, the goals are the same: protect the upland bank/marsh with a wide recreational beach.

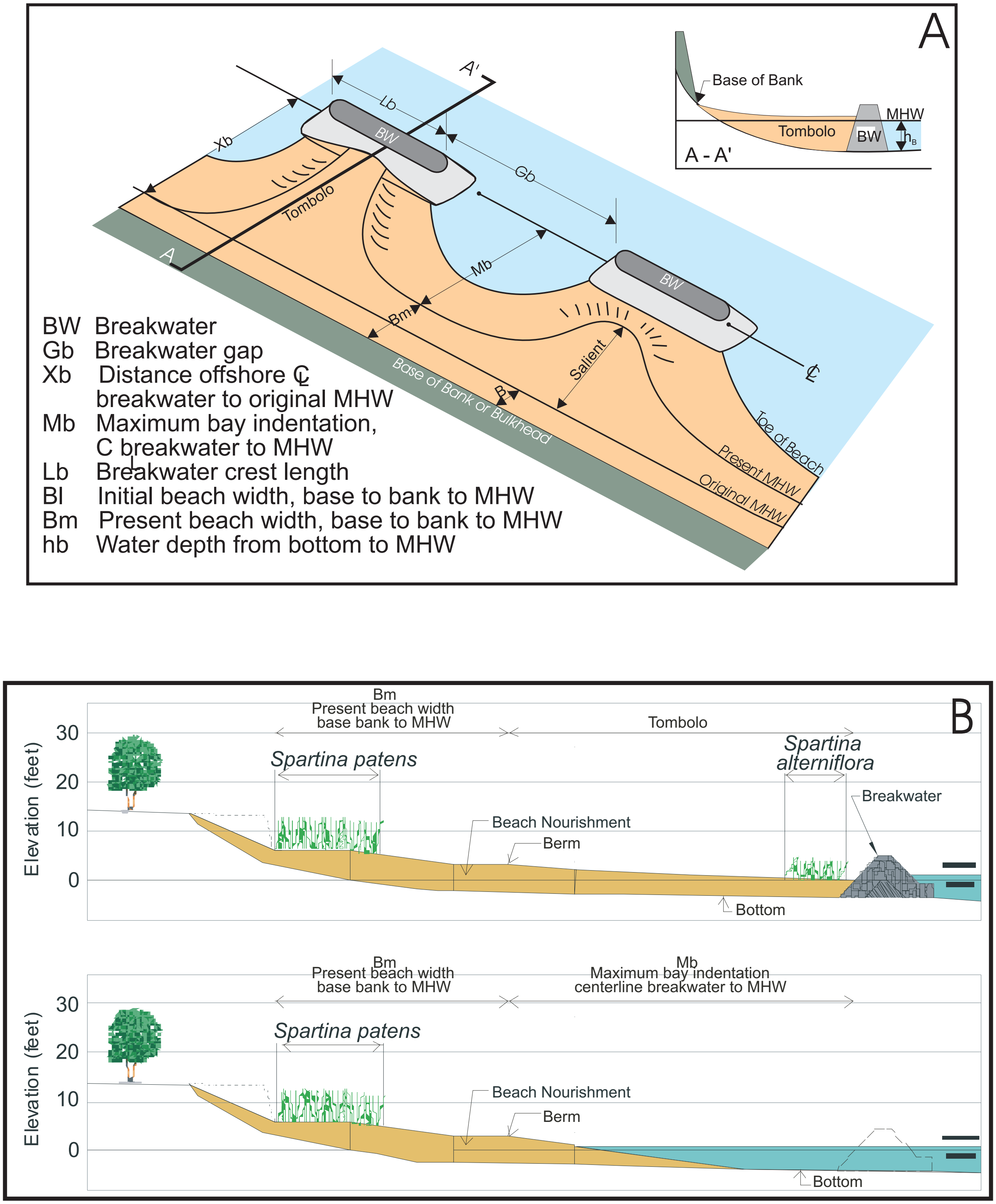


Figure 3-6. A) Breakwater design parameters and B) typical tombolo with breakwater and bay beach cross sections (after Hardaway and Byrne, 1999).

Figure 3-7. Revetment on the James River that was overtopped by storm surge and waves during Hurricane Isabel. Photo dates 21 October 2003.

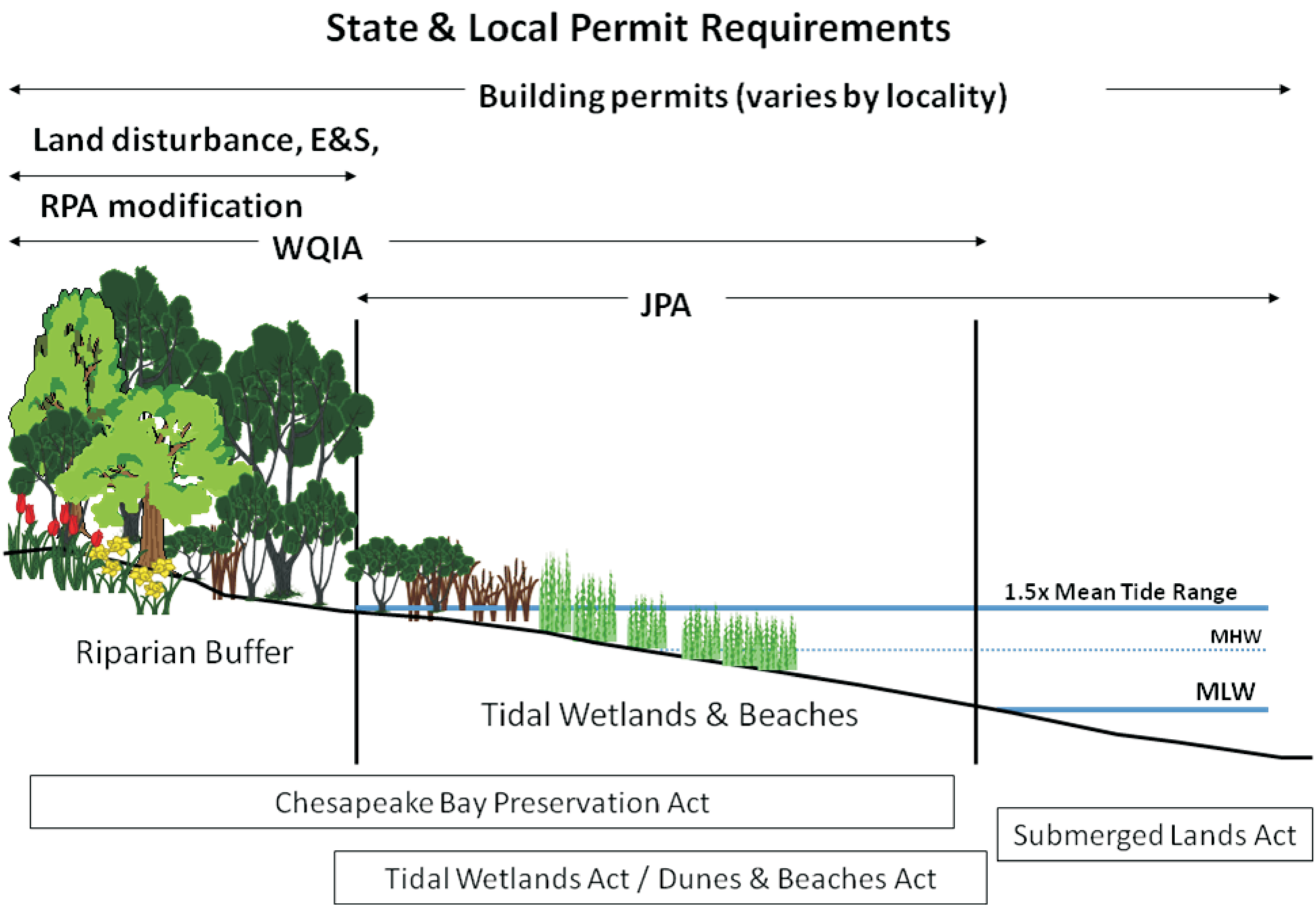


Figure 3-8. Graphic depicting the shore zone habitats and Virginia's permitting requirements in each zone.

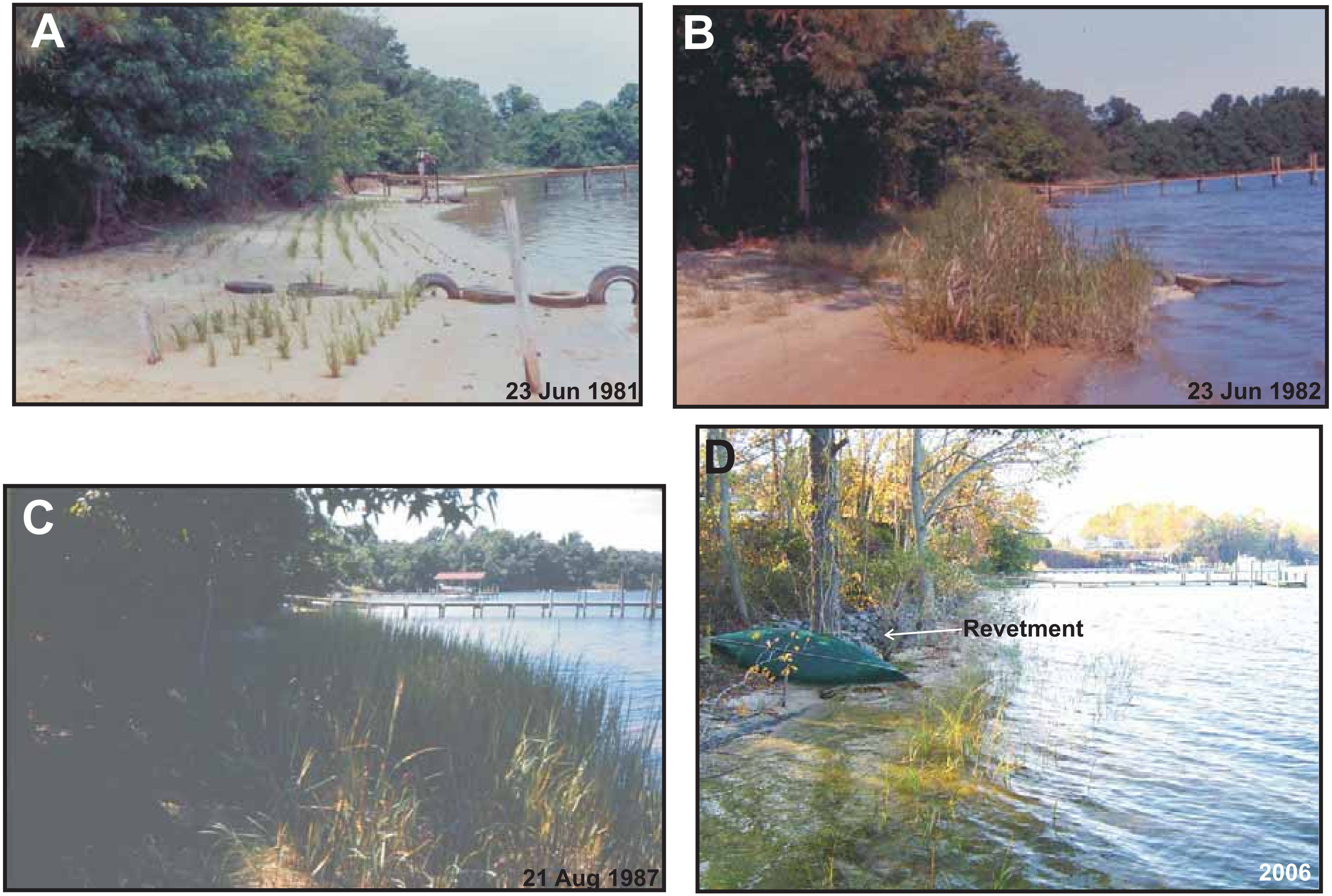


Figure 4-1. Lee marsh management site A) just after installation, B) a year later, C) six years after installation, and D) 25 years after construction.

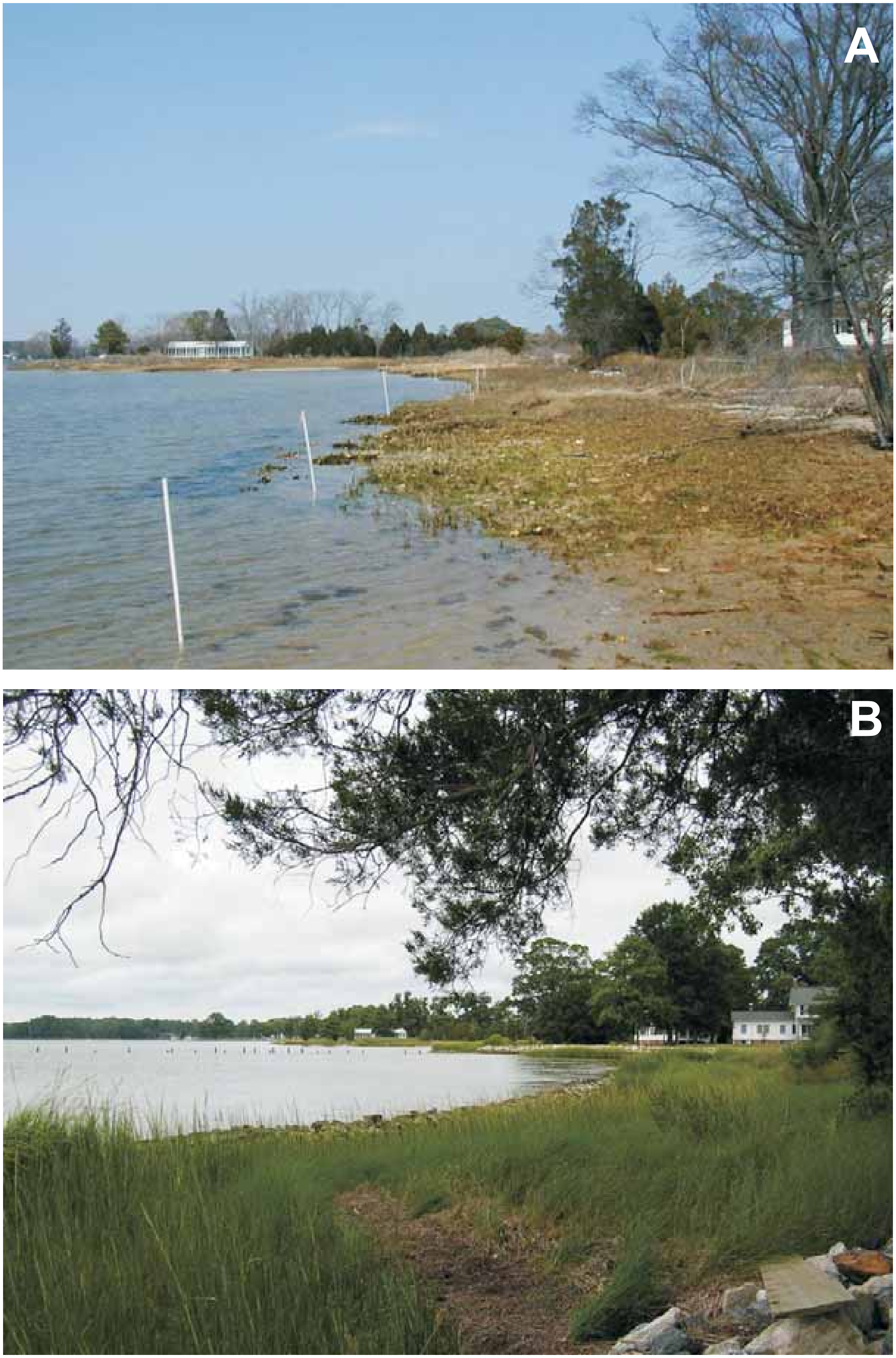


Figure 4-2. Hollerith marsh toe revetment/sill site A) before project with eroding fringing marsh in winter and B) after construction.

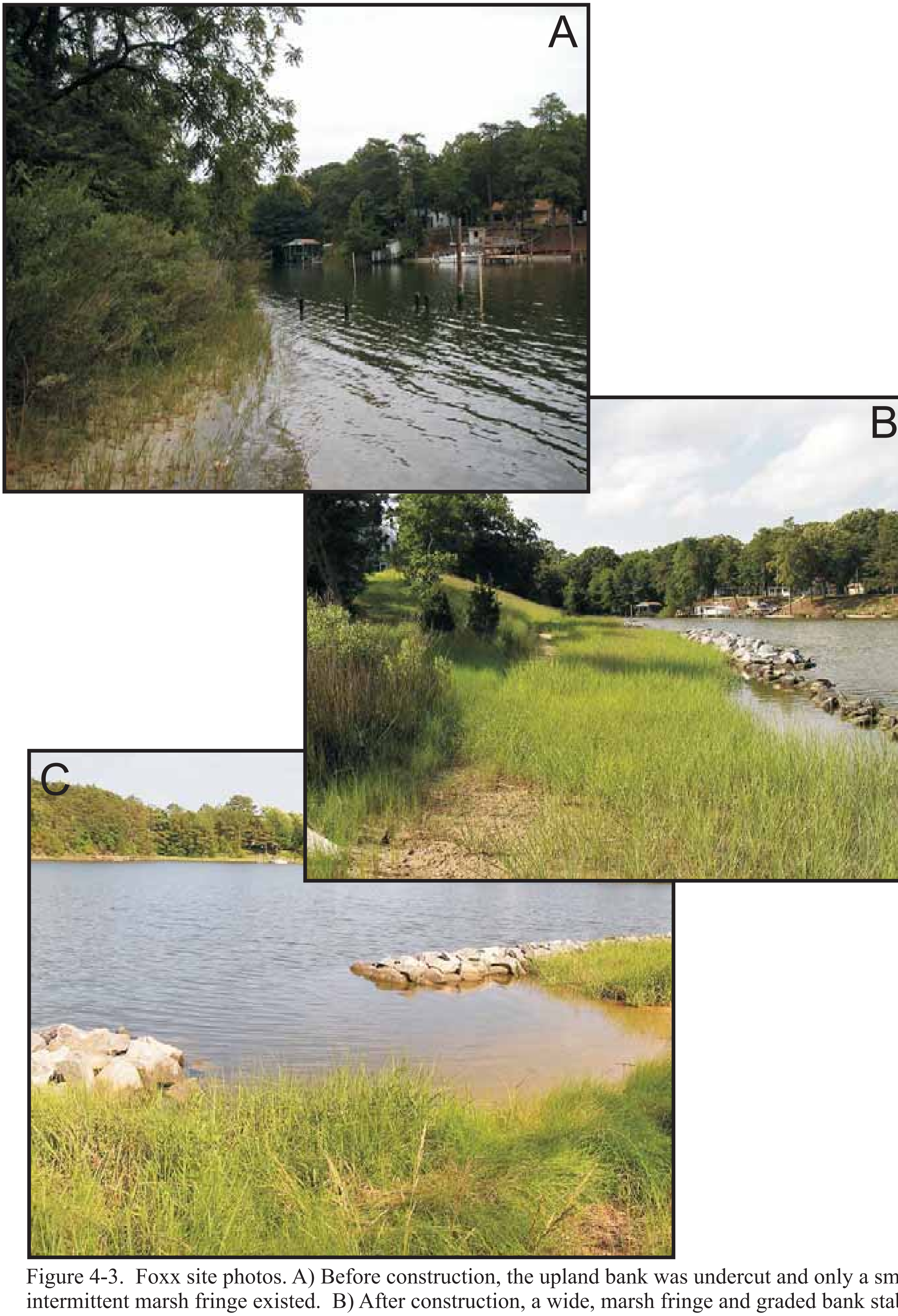
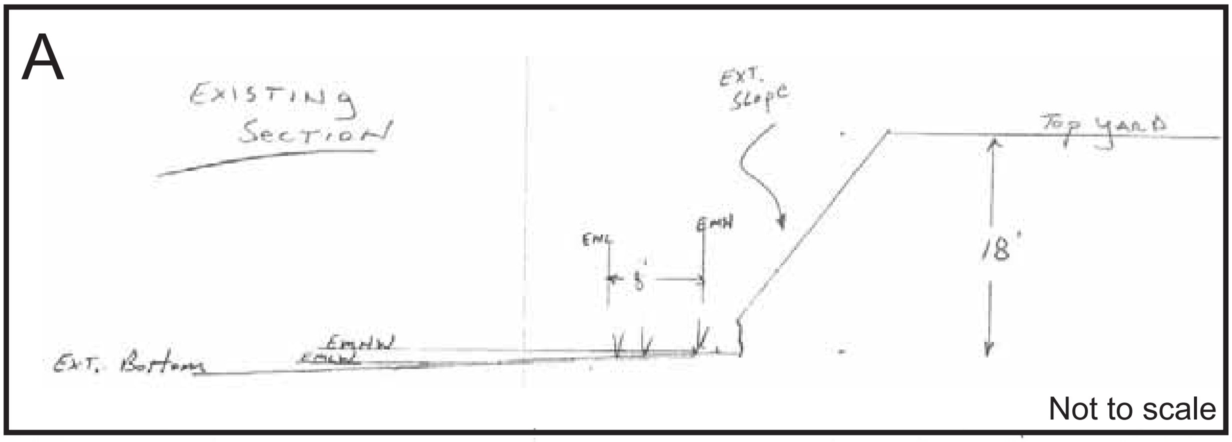
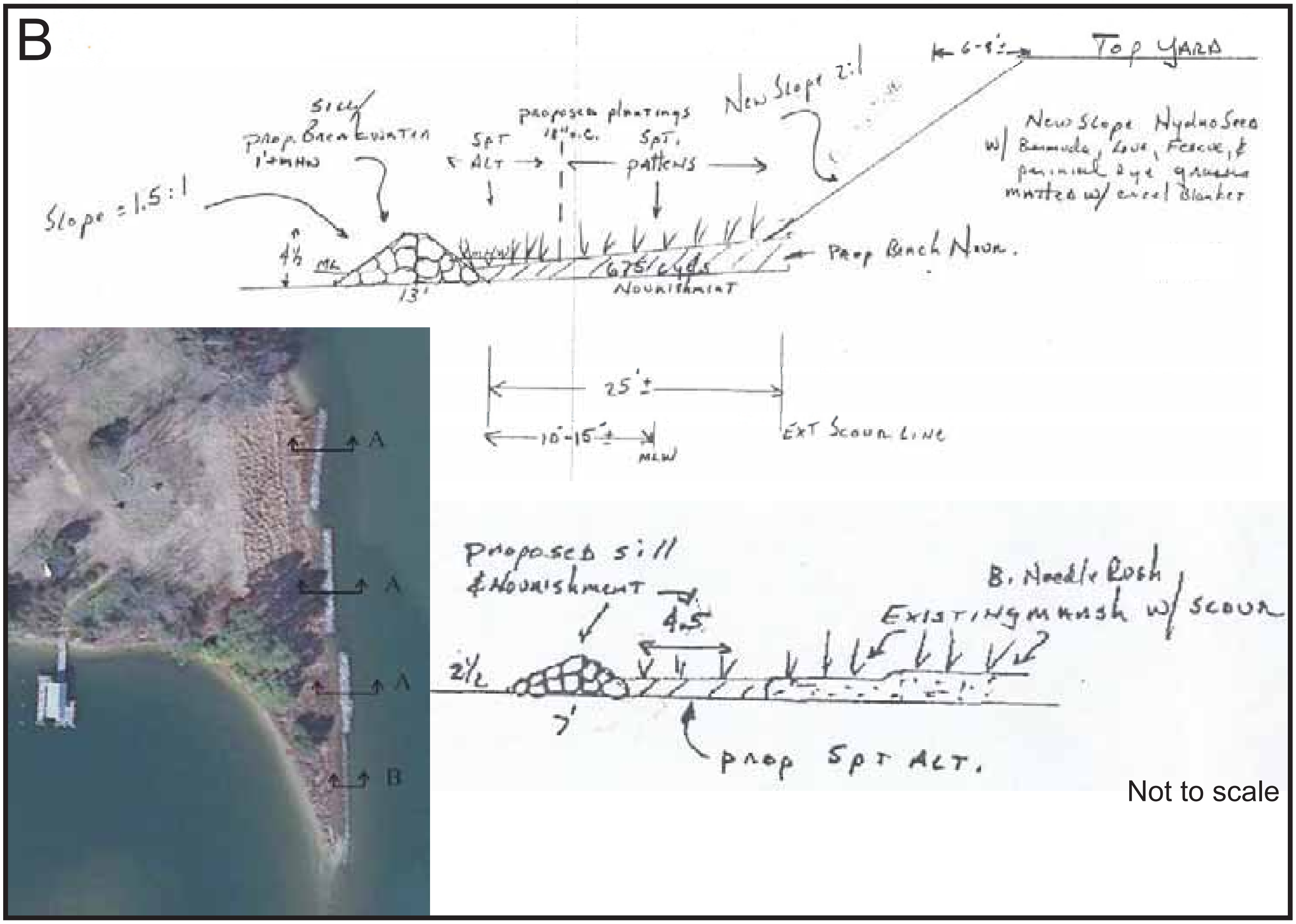


Figure 4-3. Foxx site photos. A) Before construction, the upland bank was undercut and only a small intermittent marsh fringe existed. B) After construction, a wide, marsh fringe and graded bank stabilized the site. C) Gaps in the sill allow waves in, reducing the width of the marsh there.





Planting Schedule

C

-Planting to occur April-June 2003.
-Planting to be monitored quarterly for survivorship over a three year period.
-Any replanting will occur within 15 days.
-Applicant and contractor will submit a yearly letter of assessment to all agencies.

Figure 4-4. Permit drawings submitted for the Foxx project. A) The pre-existing conditions are shown in cross-section. B) Typical cross-sections of the structures as shown in the photo. C) List of the planting schedule for the project. Permit drawings done by Riverworks, Inc., Gloucester, Virginia.

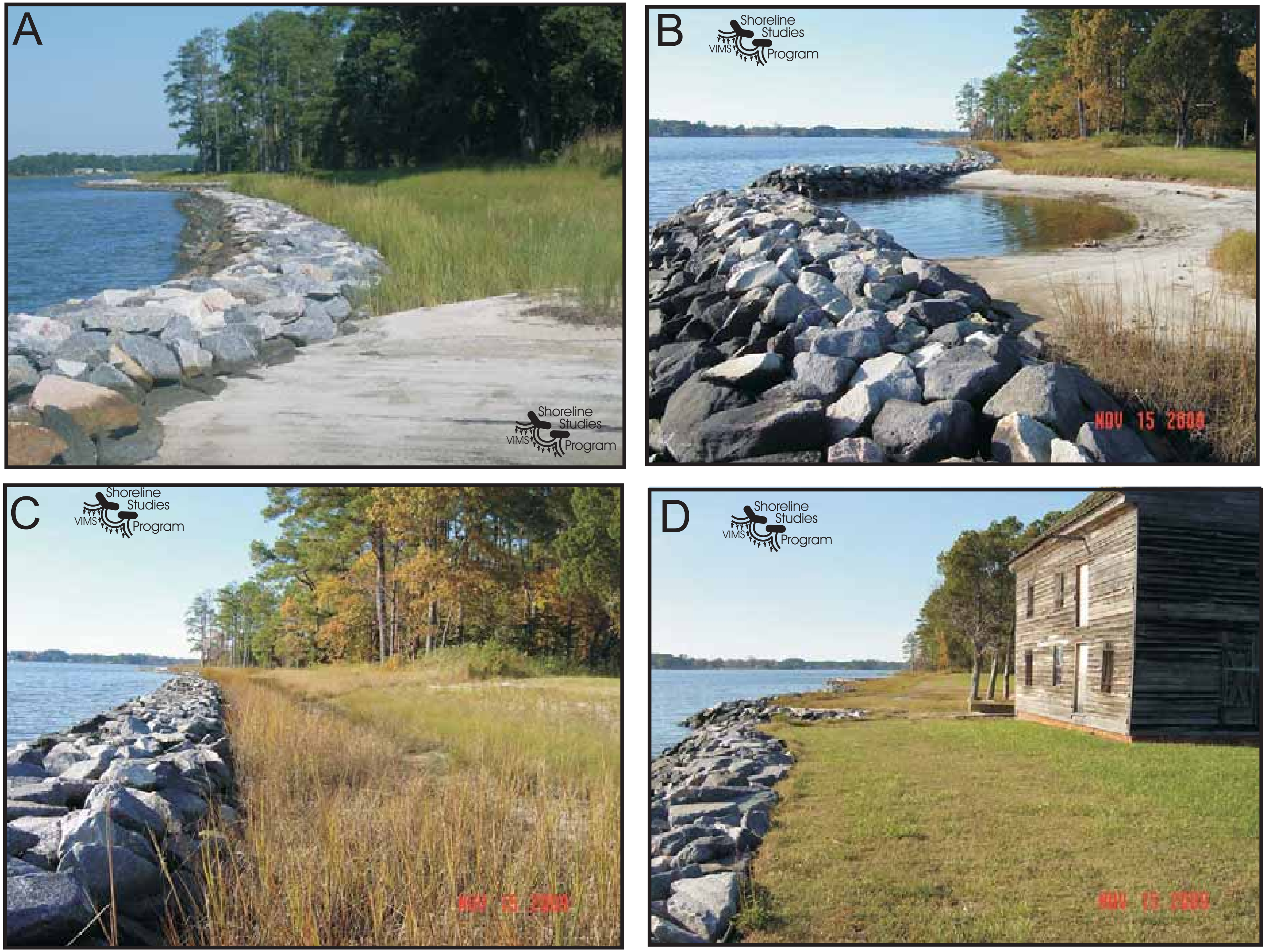
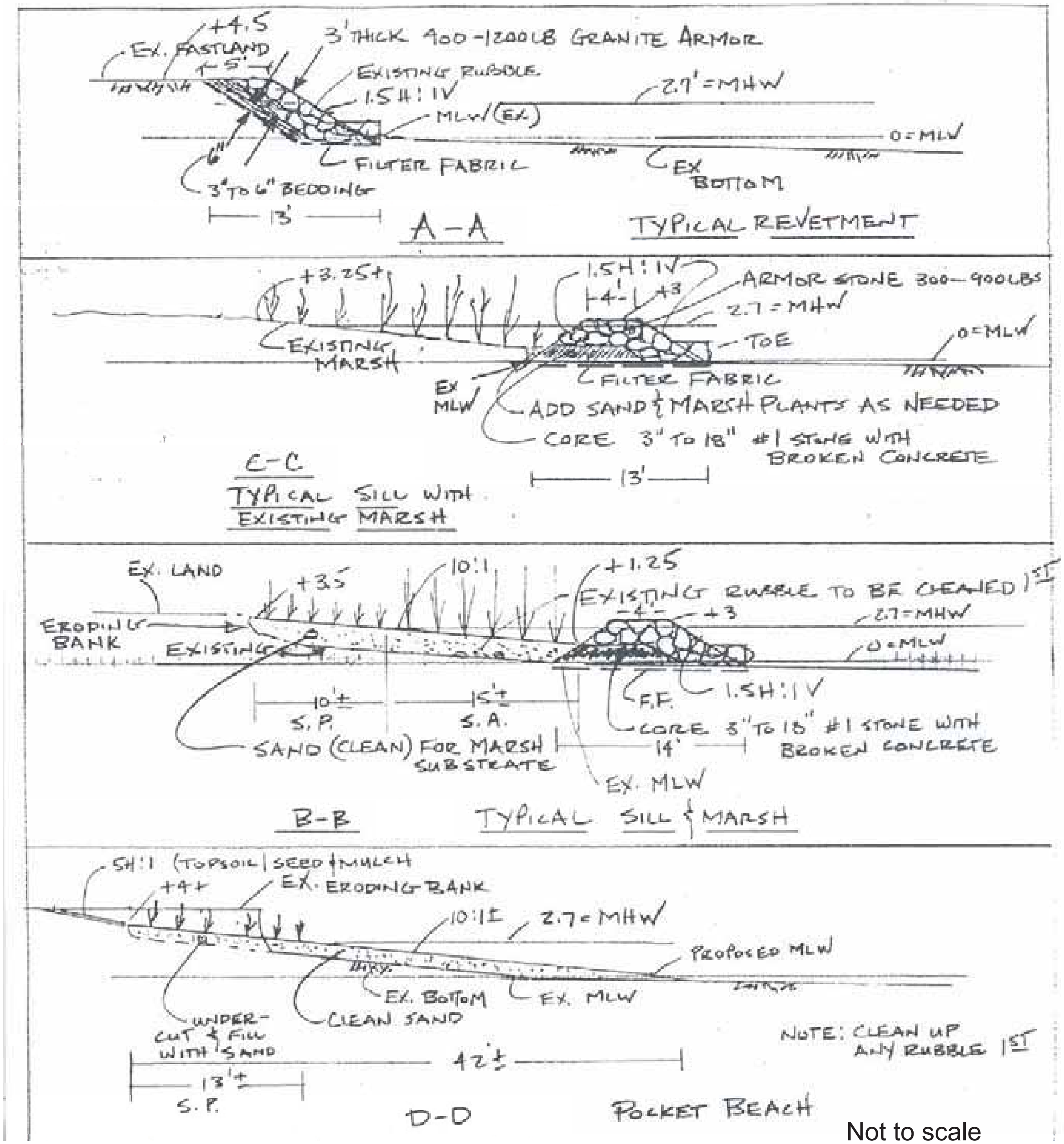


Figure 4-5. Sill system at Poplar Grove on the East River in Mathews County, Virginia six years after completion. A) The sill and marsh fringe provide a wide buffer between the water and the upland. B) The wide gap in the sill provides a pocket beach access area along the shoreline. C) The project zones 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.



Not to scale

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.

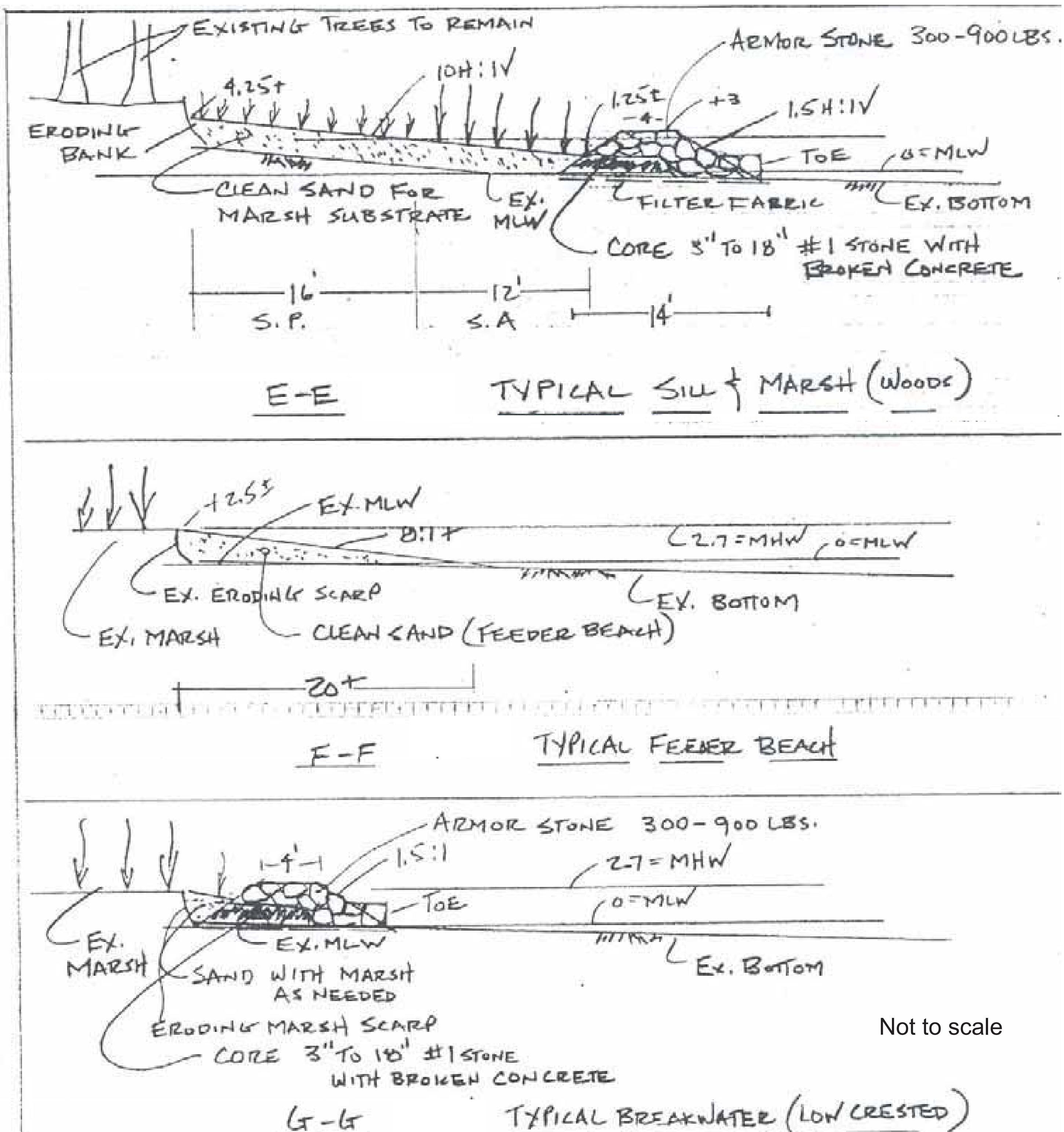


Figure 4-7. Typical cross-sections of the Poplar Grove shore protection system including the sill and marsh, feeder beach, and breakwater. Permit drawings by Coastal Design & Construction, Inc.

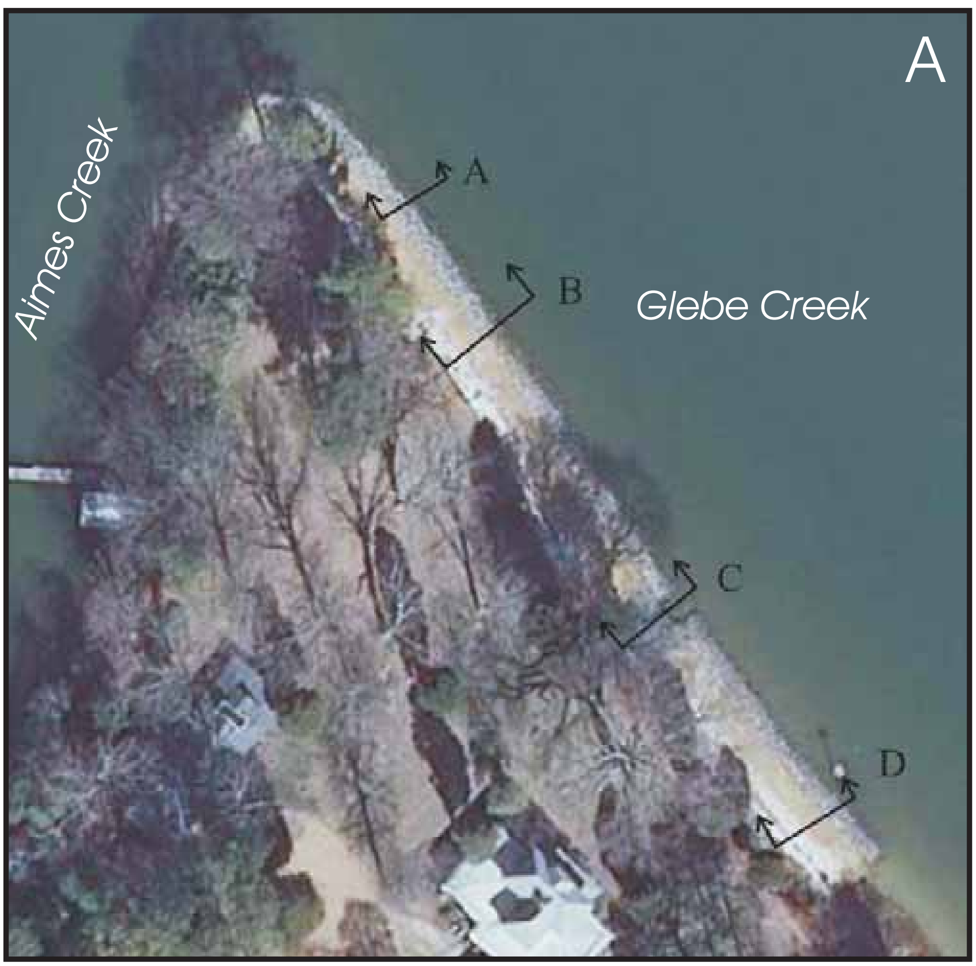


Figure 4-8. Longwood University's Hull Springs Farm on Glebe Creek. A) Before the shoreline project, the bank is eroding in front of the Manor House. B) After the project, the shore zone was widened with sand behind the sills.

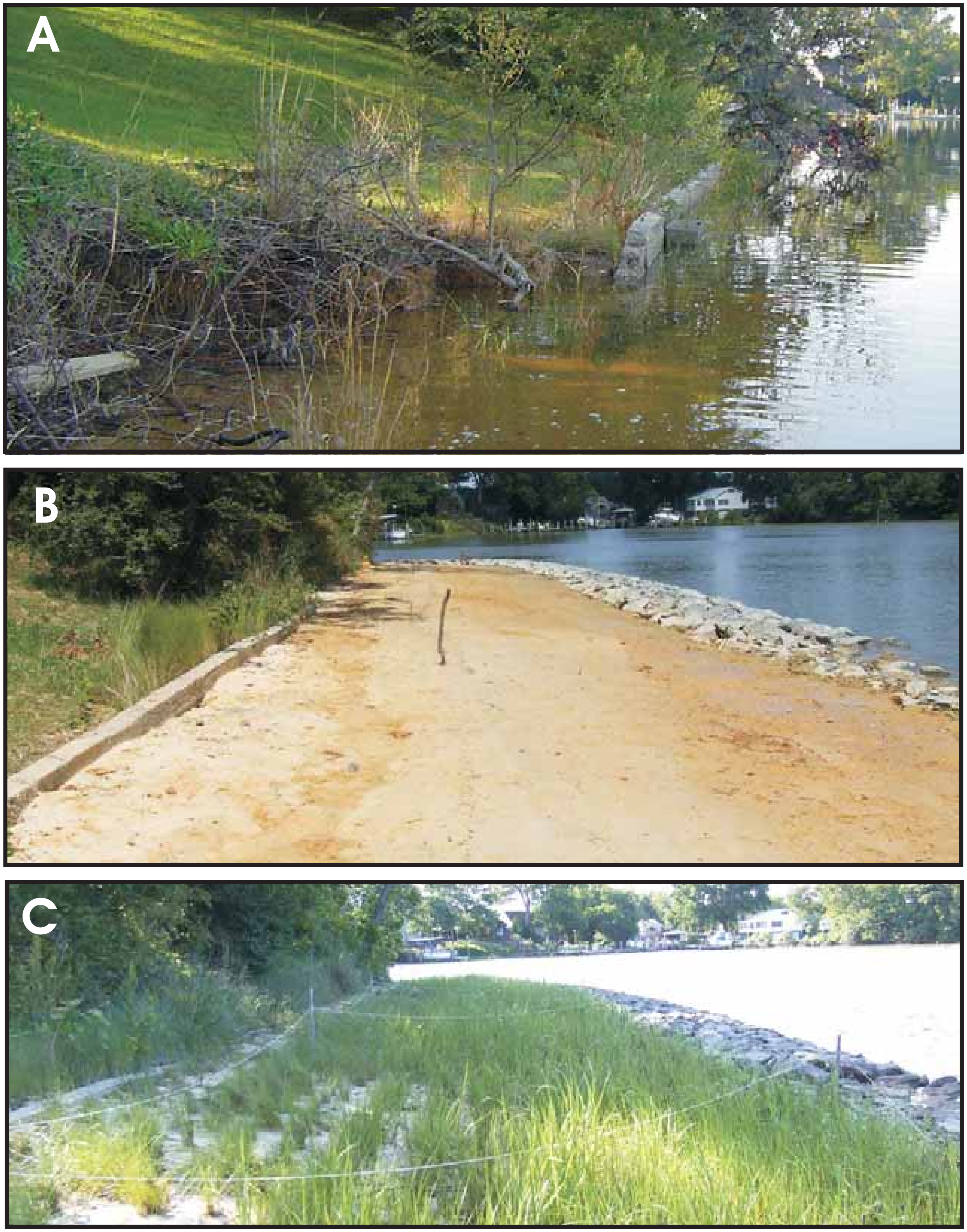


Figure 4-9. Hull Springs Farm shoreline A) before construction, B) after construction of the sill and placement of sand, and C) after planting.

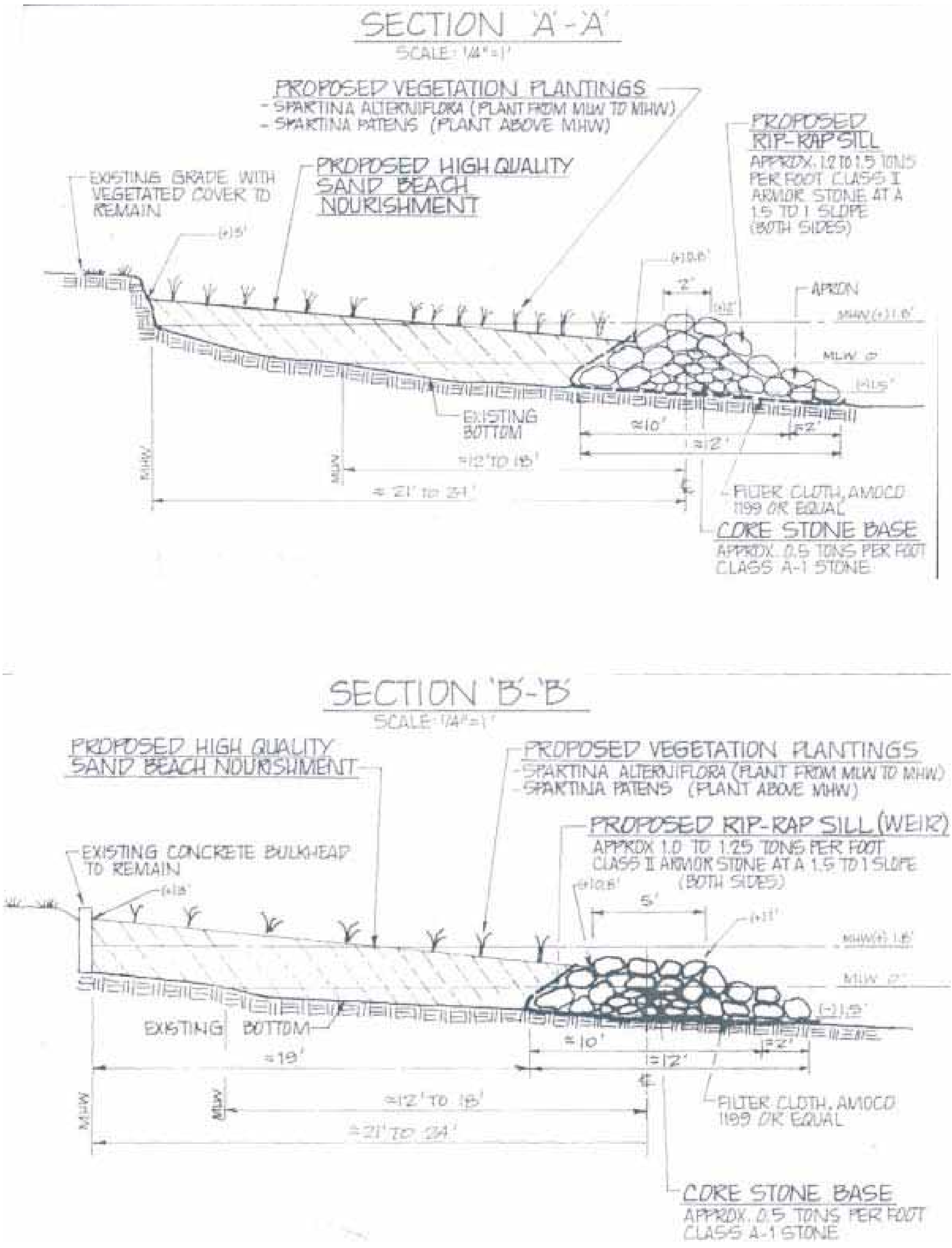


Figure 4-10. Typical cross-sections for sill built at Hull Springs Farm. Section locations are shown on Figure 4-8B. Permit drawings by Bayshore Design, LLC.

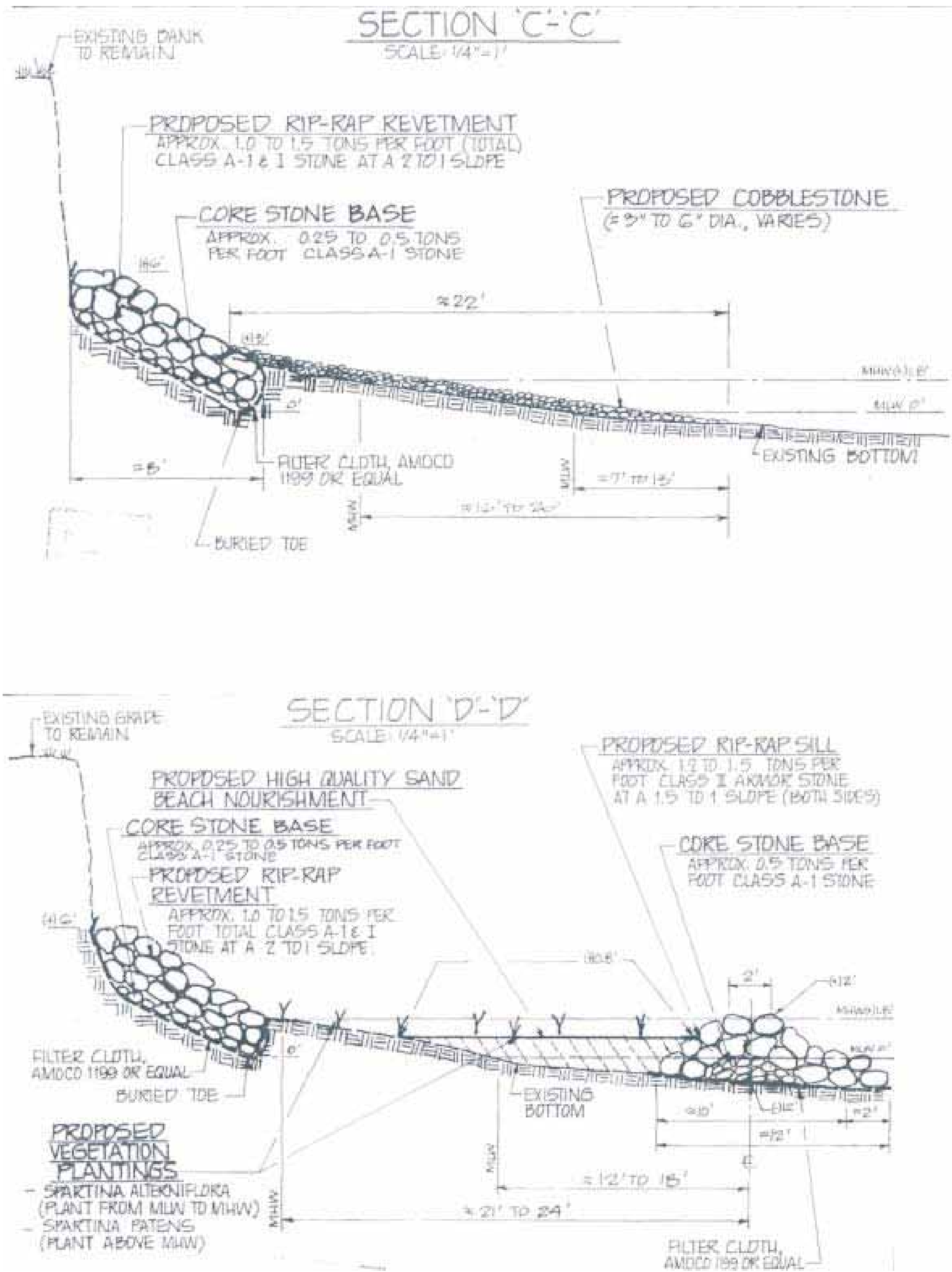


Figure 4-11. Typical cross-sections for sill built at Hull Springs Farm. Section locations are shown on Figure 4-8B. Permit drawings by Bayshore Design, LLC.

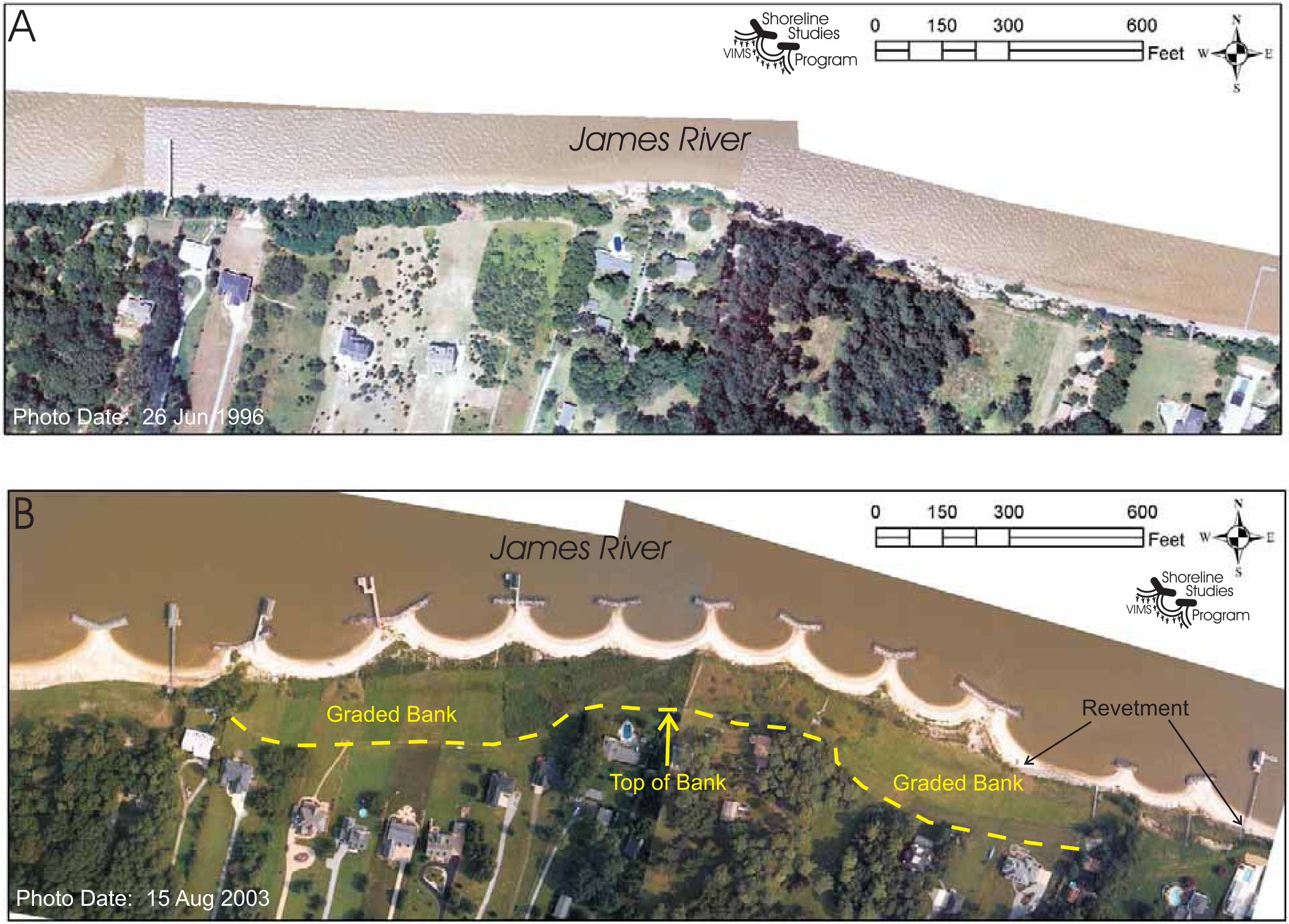


Figure 4-12. Rectified aerial photography of Van Dyke breakwater site A) before construction and B) five years after construction, just before Hurricane Isabel.

Figure 4-13. Van Dyke ground photos before and after Hurricane Isabel (from Hardaway *et al.*, 2005).

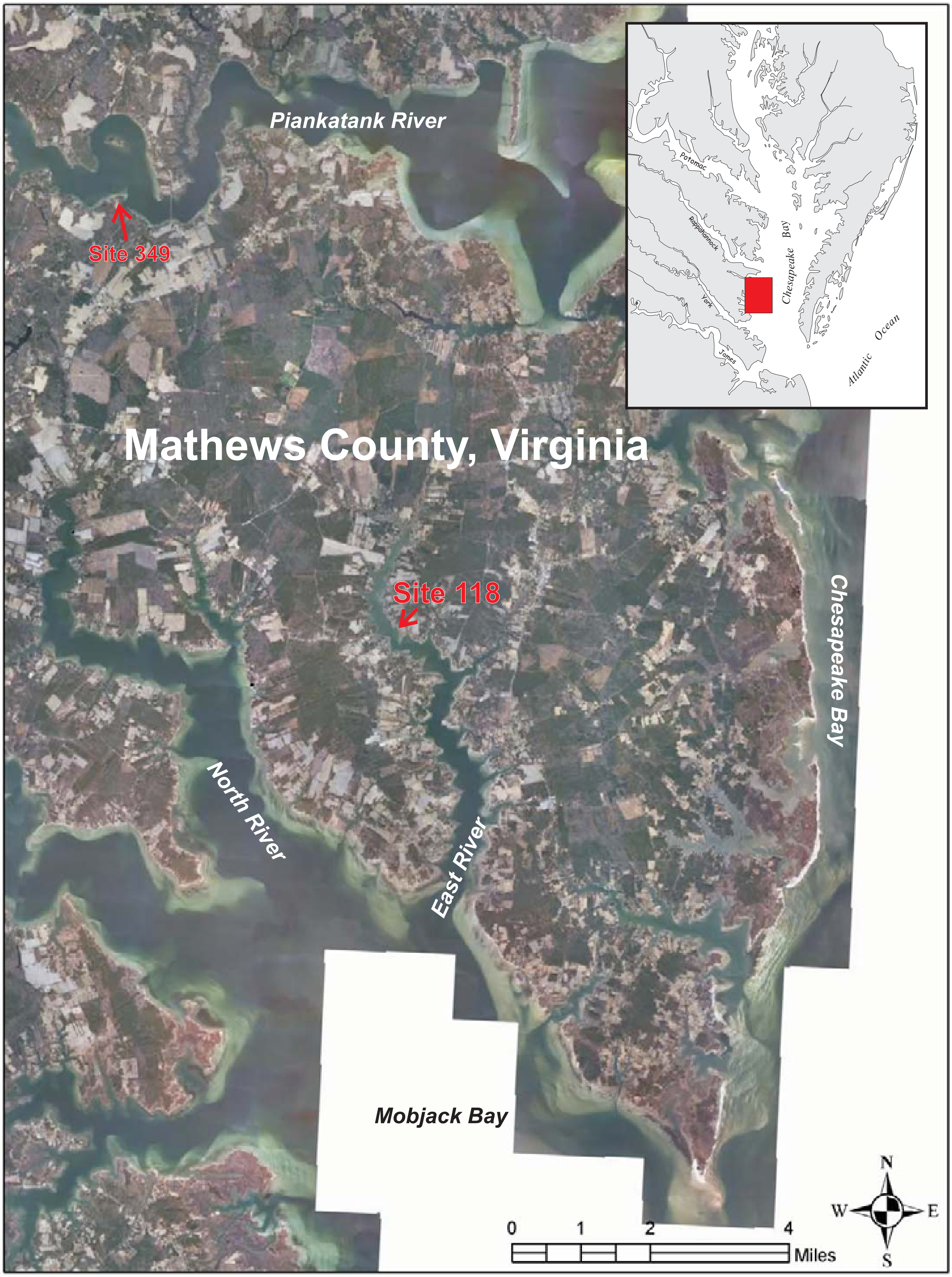


Figure 5-1. Location of design example sites 349 and 118.

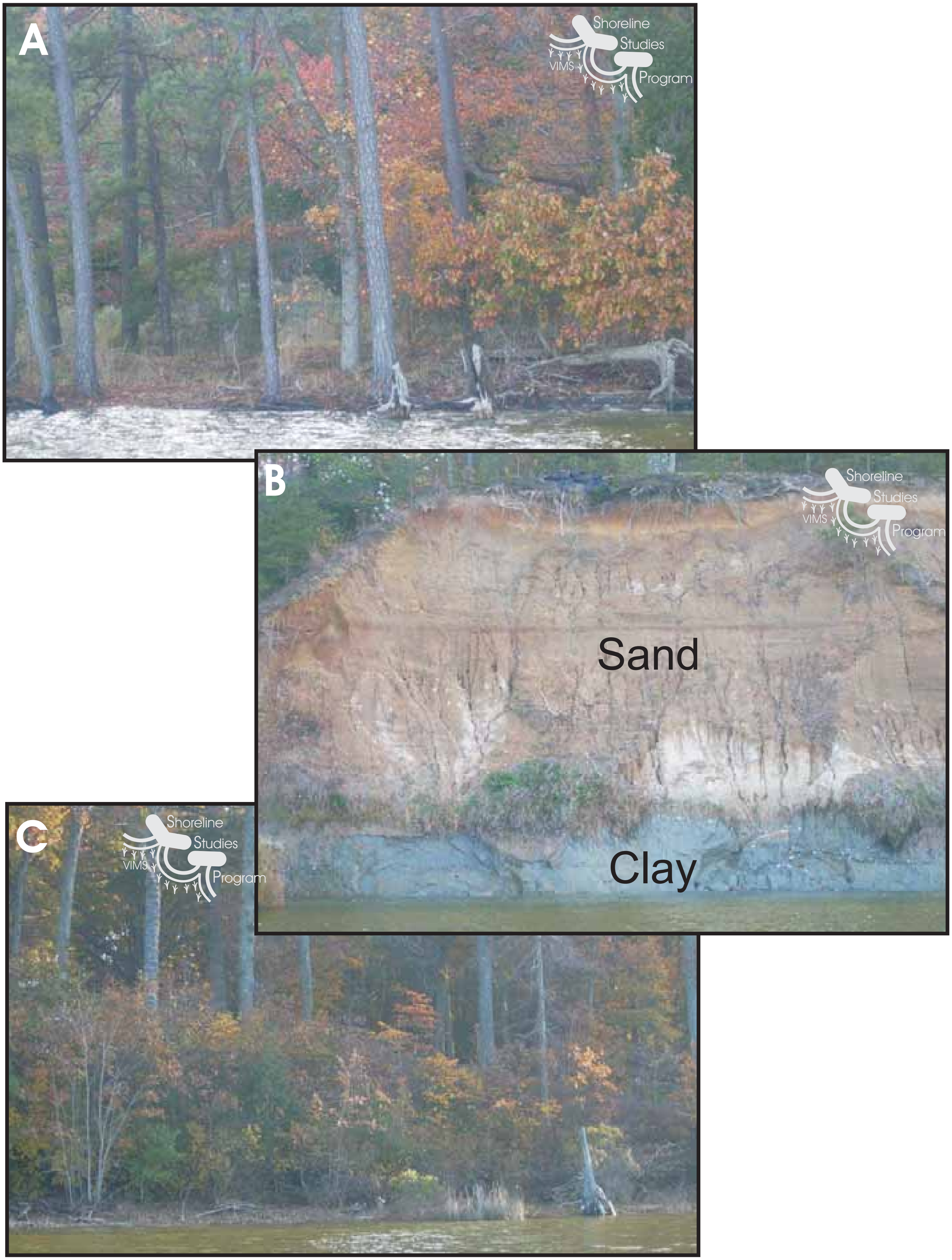


Figure 5-2. Site 349, as identified in the Mathews County Shoreline Management Plan, on the Piankatank River. A) The eastern end of the site is low, wooded and eroding. B) the high banks along the site are vertically-exposed and eroding. C) The western end of the site also is low, wooded and eroding.

Site Evaluation

Site Name #349 | Date July 2010
Site Locality Mathews | Body of Water Piankatank R.

Pre-Visit Parameters

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

Site Length: 900 (ft)

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: 3.5 miles to the WNW

Shore Morphology: Pocket (Straight) Headland Irregular

Depth Offshore: 250 ft min, 750 ft max

Nearshore Morphology: Bars no Tidal Flats no

Nearshore Aquatic Vegetation: none

Tide Range: 1.2 ft

Storm Surge: 10 yr 4.4 50 yr 5.9 100 yr 6.7 ft MLW

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)) – West End
East End – (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)

Design Wave: Height_____ Period_____

Notes:
* no actual field work took place.
This is an example

Site Visit Parameters

Site Boundaries:
Creek boundary on right

Site Characteristics:
Upland Land Use
wood residential
Proximity to Infrastructure
160 ft to house
Cover
wooded

Bank Condition:
Bank Face- (Erosional) Stable Transitional Undercut
Bank of Bank (Erosional) Stable Transitional

Bank Height: 4 ft to 20 ft

Bank Composition: upper sand, lower clay

RPA Buffer:

Shore Zone: Sand ✓ Marsh_____
Width 15 ft
Elevation at bank ~2 ft MLW

Backshore Zone: Sand_____ Marsh_____
Width none
Elevation

Boat Wakes:

Existing Shoreline Defensive Structures: no

Figure 5-3. Site evaluation for site 349. This data was filled in for the purpose of the examples give in this report. No actual field visit occurred.

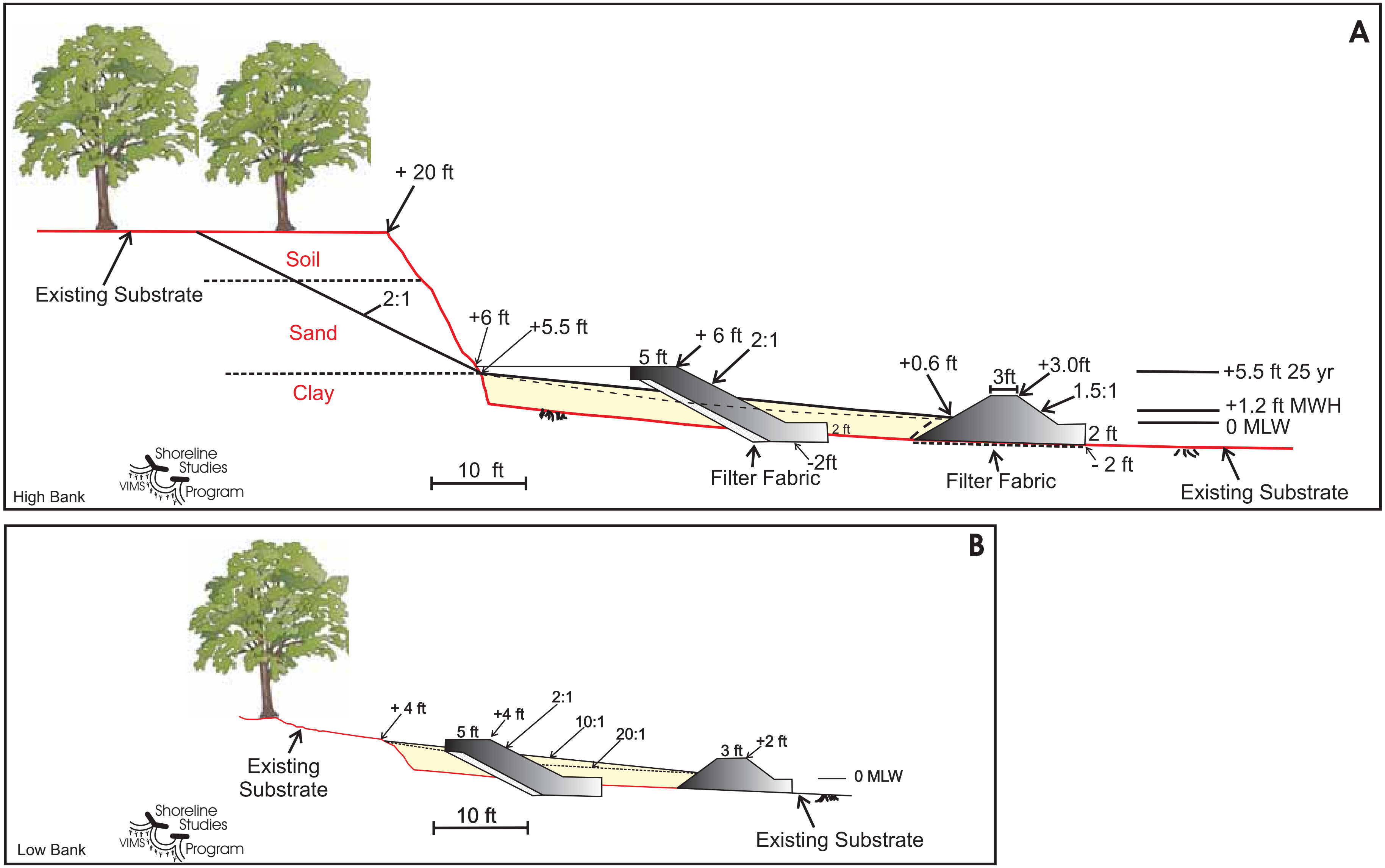


Figure 5-4. Typical cross-sections for Site 349 on the A) high bank section of shore and B) on the low bank section of shore.

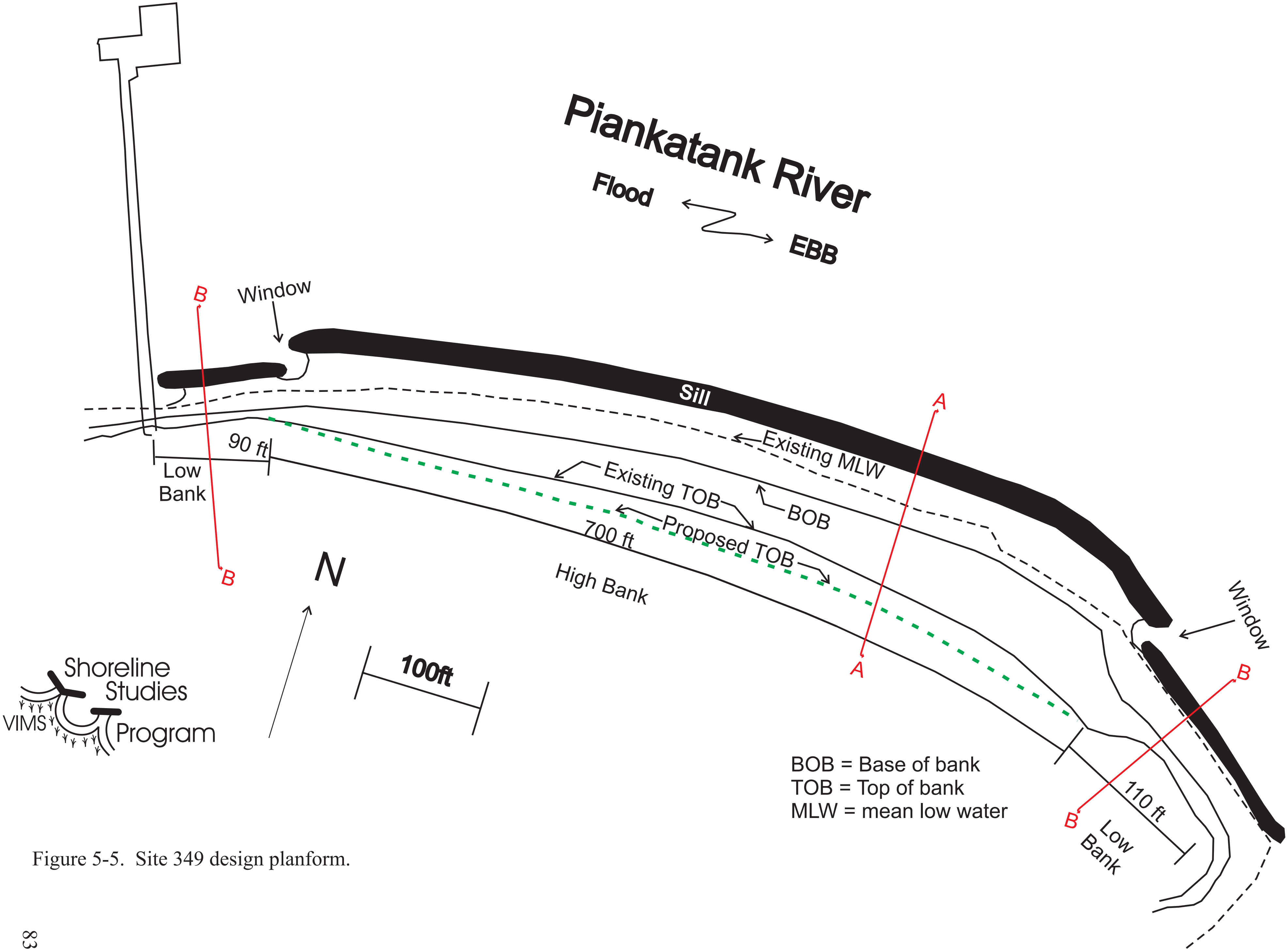


Figure 5-5. Site 349 design planform.

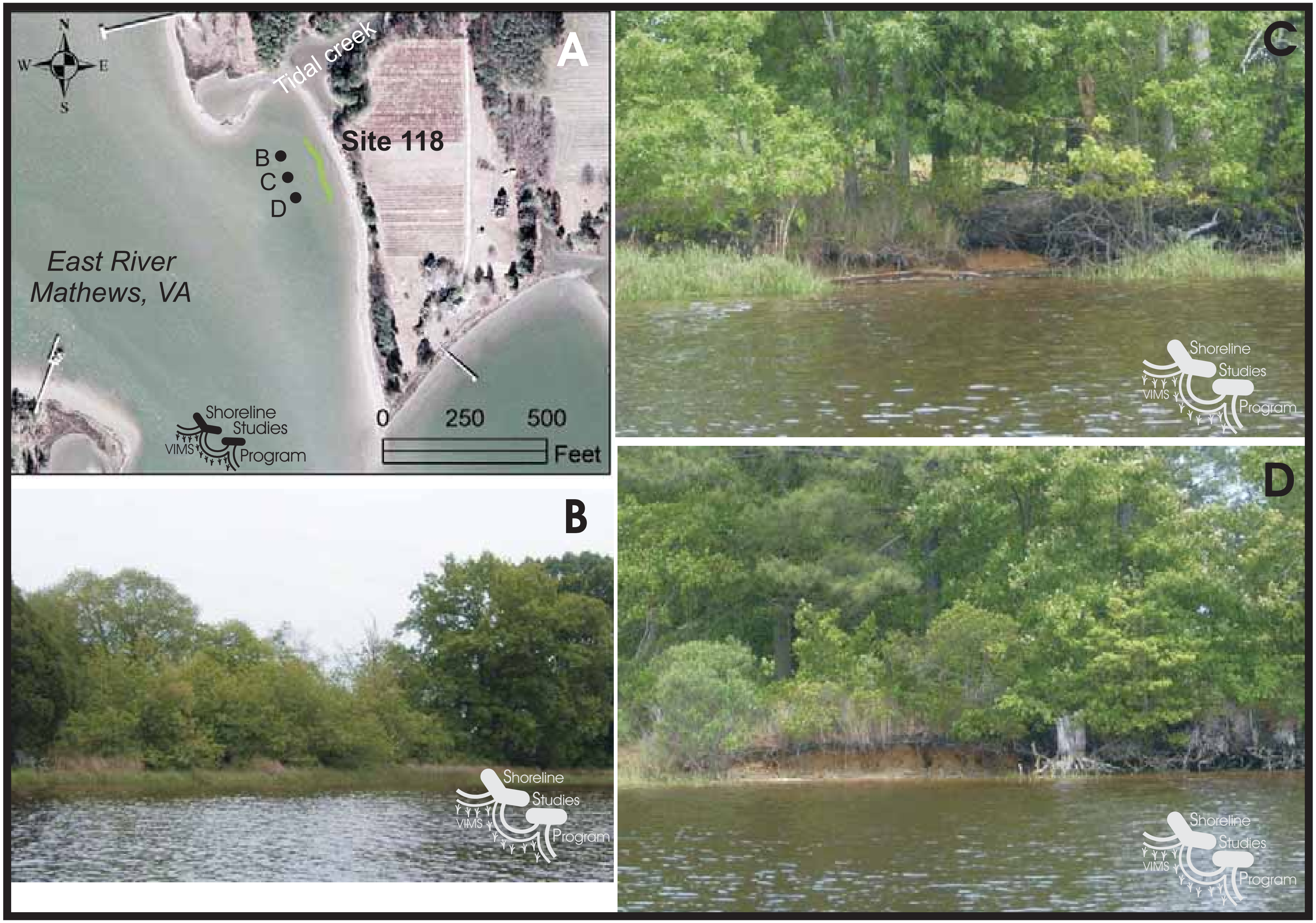


Figure 5-6. Location and site photos of design example 118 on the East River in Mathews, VA as identified in Hardaway *et al.* (2010).

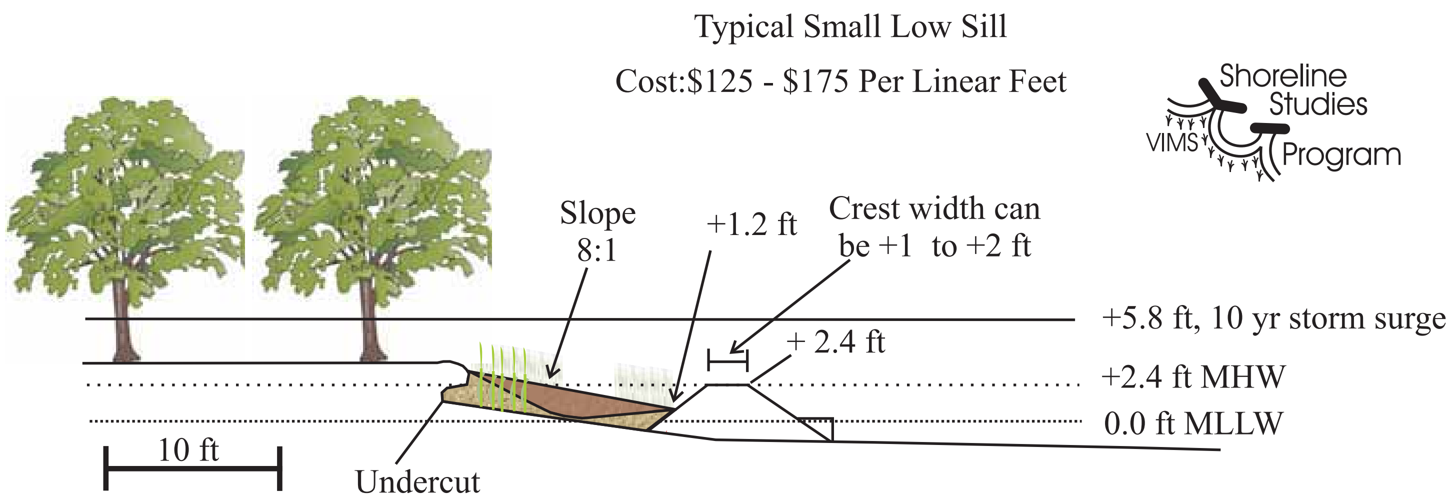


Figure 5-7. Typical cross-section of the small, low sill proposed at Site 118 in the Mathews County Shoreline Management Plan (Hardaway *et al*., 2010).

Appendix A

Site Evaluation Worksheet

Site Evaluation

Site Name______________ Date ______________________________
Site Locality ____________ Body of Water ______________________

Pre-Visit Parameters

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

Site Length: ___________________(ft)

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

Shore Morphology: Pocket Straight Headland Irregular

Depth Offshore: __________

Nearshore Morphology: Bars ____ Tidal Flats ____

Nearshore Aquatic Vegetation:___________

Tide Range: _____________

Storm Surge: 10 yr_________50 yr________100 yr ______

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)

Design Wave: Height______Period_______

Notes:

Site Visit Parameters

Site Boundaries:

Site Characteristics:

Upland Land Use

Proximity to Infrastructure

Cover

Bank Condition:

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

Bank Height: ______

Bank Composition:

RPA Buffer:

Shore Zone: Sand ________Marsh_______

Width

Elevation

Backshore Zone: Sand ____________Marsh_______

Width

Elevation

Nearshore Stability: Firm_________Soft_________

Boat Wakes:

Existing Shoreline Defensive Structures:

Appendix B

Design Criteria for Tidal Wetlands

by

Walter Priest

Management, Policy, Science, and Engineering of Nonstructural Erosion Control in the Chesapeake Bay

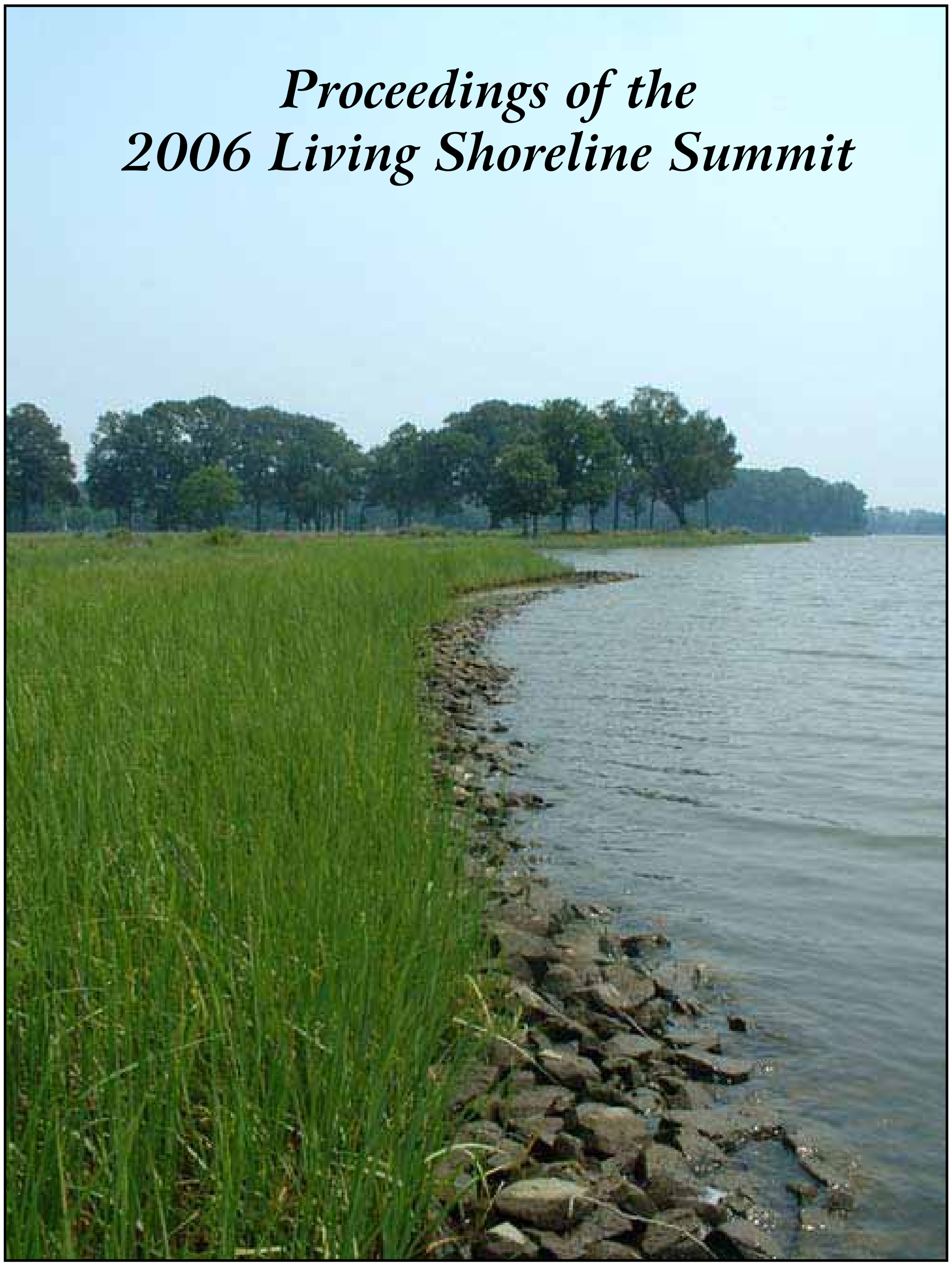


Photo credit: Jana Davis, Chesapeake Bay Trust

CRC Publ. No. 08-164

http://www.vims.edu/cbnerr/_docs/ctp_docs/ls_docs/06_LS_Full_Proceed.pdf

Design Criteria for Tidal Wetlands

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ABSTRACT

The design and construction of tidal wetlands can often be a perplexing, mystifying process. Many of the techniques are solely the domain of practicing professionals which leaves many individuals and organizations at a loss when contemplating a project. This paper attempts to present practical guidelines that can be used by the lay person as well as restoration practitioners for the successful construction of tidal wetlands. These include screening criteria for site selection that will help avoid inherent problems with a particular site and design criteria to guide the development of wetland hydrology and the successful establishment of wetland vegetation.

INTRODUCTION

During the course of a number of wetland construction projects over the years, a number of guiding principles have emerged. Incorporation of these guiding principles or design criteria into a project can have a profound/major impact on the success of a particular project. These principles are applicable to Living Shorelines as well as other wetland restoration situations.

Development of general guidelines for Living Shorelines has been a joint effort of numerous practitioners such as Edward Garbisch with Environmental Concern in Maryland (1,2), Stephen Broome at North Carolina State University (3), and others who have pioneered the science of wetlands restoration. They have shared their successes and failures in numerous publications that have benefited many others in the field. James Perry (4) and C. Scott Hardaway (5) at the Virginia Institute of Marine Science (VIMS) have freely shared their experiences as well.

When embarking on a wetland construction project, it is critically important to focus on the objective of the project whether it is shoreline protection, habitat development, restoration, mitigation, or stormwater treatment. Each of these objectives involves slightly different features or approaches that can drive the design. For example, if one's goal is stormwater treatment, emphasis might be on stormwater residence time while a habitat restoration project might emphasize community diversity and fish access. These characteristics would likely result in different wetland configurations and landscape positions. Living Shorelines designed predominantly to provide erosion protection while also providing desirable ecological functions and values might have increased width and height of the fringing marsh for erosion protection and also habitat for fish and crabs.

I have organized these criteria into a number of categories that should be considered when planning any type of wetland including screening (considered prior to design) and design (addressed during design and construction) criteria. This paper is not intended to be an exhaustive treatise, but rather a detailed checklist of the most important considerations necessary when designing a tidal wetland. Furthermore, it has been my intent to present the information in terms that will be useful to the experienced practitioner as well as the novice.

SCREENING CRITERIA

The first step in the design is a general evaluation to ensure that a project is possible at the site in general, and no undue impacts will occur as a result of the project.

- Are there contamination issues at the site?
- Are endangered species an issue?
- Are cultural resources an issue?
- In urban areas, are underground or aerial utilities an issue?
- Is there adequate construction access to the site?
- Will valuable existing habitat, such as a mature hardwood forest, have to be destroyed to construct the wetland?

All of these questions need to addressed and resolved prior to proceeding with any detailed design.

DESIGN CRITERIA

Landscape Position

The most important aspect of this criterion is fetch, a measure of the exposure of the site to wave action. Generally when the fetch exceeds one mile, the chances of success without some type of structural protection are limited. Between one and 0.5 miles, chances improve but some minimal structure, such as biologs, is advisable to help the marsh become established. When the fetch is <0.5 mile, chances of success without structural toe protection, such as a rock sill, are good. If water quality improvement is part of the restoration objective, it is important that the runoff from the adjacent watershed be directed into or through the wetland as opposed to a simple excavated basin with a limited watershed.

Elevation

The critical elevations for tidal wetlands establishment are mean low water (MLW), the average low water at the site, mean high water (MHW), the average high water level at the site, mean tide level (MTL), roughly halfway between MLW and MHW, and the upper limit of wetlands (ULW), approximately 1.5 times the mean tide range at the site. These are the important elevations that will dictate the various planting zones within the new marsh.

Design elevations need to be based on a tidal datum such as the National Ocean Service (NOS) MLW and not strictly on a geodetic datum like the North American Vertical Datum of 1988 (NAVD 88). Tidal datums are based on water level observations over a 19 year period (a tidal epoch) where all of the high tides and low tides are averaged to determine MHW and MLW. NAVD 88 is based on the elevation of a fixed point in Canada and is not directly related to tidal elevations. Relationships between tidal and geodetic datums have been established for many locations but can vary widely. The NOS MLW datum used should also be based on the 1983-2001 tidal epoch to help ensure recent sea level rise has been taken into account. More information on tidal elevations and datums can be found at http://tidesandcurrents.noaa.gov/.

Biological benchmarks (BBM) are elevations established by surveying the elevations of representative plant communities in an adjacent reference marsh. These elevations can then be corroborated with the tidal datum to cross reference the design elevations for the wetland. The advantage of incorporating biological benchmarks into the design is that these elevations integrate any vagaries in the local hydrology that might influence the distribution of plant zonation. For example, if there is a hydrologic constriction that prevents the area from draining completely, it can result in a perched mean low water and a concomitant compression of the tide range that will affect the success of the plantings.

Slope

Flat slopes in the new marsh are important because they help maximize the plantable area within the intertidal zone and, where applicable, help dissipate wave energy and reduce erosion potential. Very often the slopes will be dictated by the size of the site, but, where possible they should at least 10:1 (H:V), preferably flatter if possible. In some situations, the intertidal area can be maximized by creating a bench between the creek and the upland that is very flat from MTL to MHW followed by a steeper slope from

MHW to the adjacent upland. The slope of this transition zone should also be kept as flat as site conditions will allow. In higher wave energy sites where there is steep upland transition, some type of structure may be necessary to stabilize this slope. It is also important for the slopes to provide positive drainage for the site at low tide. If the site does not drain completely and there are large areas of standing water within the area to be planted, plant survival can be compromised. I generally recommend that areas of standing water greater than 100 square feet be avoided unless they are an intentional feature of the design to increase habitat diversity.

Hydrology

Hydrology is the most important factor in successfully establishing a wetland. Several of the other important factors, e.g., elevation and slope, can have a direct influence on hydrology as well. To put it simply, to effect wetland hydrology in a tidal wetland, the area must be under water at high tide and dry at low tide. This may sound overly simplistic but it is the essence of tidal wetland hydrology. It is also the easiest way to explain the grading plan to an equipment operator.

Being dry at low tide is just as important as being wet at high tide. The reason that vegetation only grows down to MTL instead of MLW is that the roots need to breathe at low tide in order to survive. The dominant salt marsh plants do not grow well in permanently standing water. If the elevations and drainage, i.e. hydrology, in your planted marsh mimic the hydrology in the connecting waterway, the plants will adjust accordingly.

If the tidal connection to your site is highly convoluted or culverted, it can produce a phase lag in the hydrology. A phase lag usually results from having too much friction in the discharge channel which does not allow the site to drain effectively. Imagine a typical tidal cycle. At high tide because of the force of the incoming tide, the water levels within your site and those of the connecting waterway are equal. As the tide ebbs, it ebbs more slowly within the site because friction slows down the flow of water to the creek. Consequently, when it is low tide in the creek, there might still be a considerable amount of water waiting to drain from the site. As the tide begins to flood in the creek, it will rise to the level of the still ebbing water from the marsh. This level effectively determines the low water elevation because, from this point, the water begins to rise again within the marsh. The ultimate result of this situation is a higher MLW and a compressed tide range in the new marsh. This can have a dramatic impact on the survivability of the plants if the tidal levels from the adjacent creek, and not the site itself, are the main determinants for the planting elevations. In this regard, projects that involve pipes, tide gates, or other plumbing devices should be carefully evaluated.

Substrate

When constructing a new marsh you need to think of the substrate, first and foremost, as the medium for growing plants. There are other factors such as the amount of organic carbon in the soil that govern functions, like denitrification. However, in the beginning, it is more important to establish the vegetation as rapidly as possible. To do this, the best medium is sand. It provides a good anchor for the plants, allows for rapid root growth and effective drainage. In exposed conditions, coarser sand should be used to minimize transport by wave action. Silt-clay and peat can work but they make planting more difficult and are not as effective at anchoring the plants. Heavy plastic clays should be avoided because of planting difficulties and the impediments to root growth. Likewise, organic amendments, topsoil, and mulch should be avoided in brackish tidal marshes. Once they become wet, they are difficult to plant because they often do not effectively anchor the plants which naturally float and tend to be dislodged by tidal and wave action.

When excavating a new marsh from upland, it is critical that borings be made to the proposed planting elevation to identify the type of substrate that will be exposed for planting. If the substrate at grade is not suitable because of plastic clay, rubble, or *Phragmites* roots, it will be necessary to over-excavate the site and bring in at least a foot of good clean sand to bring the site back up to the desired elevation.

Shade

Most wetland plants require a minimum of six hours of direct sun during the growing season. They require large amounts of energy to cope with the stress of salinity and inundation twice a day. When planting fringing areas, this may require the judicious pruning of the lower branches of adjacent trees to allow for additional sunlight. Trees should only be removed when absolutely necessary. The design should also take into consideration shading from nearby structures and north facing shorelines which can induce unwanted shade. North facing shorelines, particularly forested, tend to receive less sunlight because of the low angle of the sun during the winter, spring, and fall.

Salinity Considerations

Site selection should also include an analysis of the local salinity regime. Consideration needs to be given to annual variation from lower spring to higher summer salinities. Do not depend on a single salinity measurement to be indicative of a site unless you are intimately familiar with the area. Also, be mindful of flashiness in the system, particularly in head water areas that are susceptible to freshwater pulses following major rain events. Plant selection must be reflective of this salinity regime. Natural vegetation in adjacent similarly situated marshes should be used as a guide to recommend species most likely to be successful. It is also important that the nursery stock to be planted is conditioned to site salinity levels. Plants grown in freshwater at the nursery and planted in high salinity areas can have a difficult time adjusting, delaying effective establishment of the stand. It can also lead to failure of the planting.

Zonation and Salinity Regimes

A general overview of planting zones and salinity tolerances for some of the more commonly planted species is provided in Table 1. This is neither exhaustive nor definitive and should be only used as a guide to be tempered by local conditions. Almost anyone will be able to find exceptions to these recommendations, but they will work in a vast majority of situations. It is critical to the success of a project to effectively match plant material, planting zones, and salinity regimes.

Species	Inundation Zone	Salinity Range
Spartina alterniflora	MTL – MHW	5 – 30 ppt
Spartina patens	MHW – ULW	5 – 30 ppt
Spartina cynosuroides	MHW – ULW	0 – 5 ppt
Distichlis spicata	MHW – ULW	10 – 30 ppt
Scirpus americanus	MHW – ULW	0 – 15 ppt
Juncus roemarianus	above MHW	10 – 25 ppt
Iva frutescens	near ULW	5 – 30 ppt
Baccharis halimifolia	near ULW	0 – 30 ppt
Panicum virgatum	above ULW	0 – 25 ppt
Myrica cerifera	above ULW	0 – 30 ppt

Table 1. *Zonation and salinity levels for common wetland plants (see text for zone abbreviations).*

Planting Materials and Methods

The preferred method of planting is nursery grown plants. These plants are readily available and have an excellent success record. The plants are typically grown in plastic cell packs with 72 plants per flat. The leaves should be a uniform green color with roots that are white and appear to be actively growing. Depending on the age of the plant, it may appear pot bound which is acceptable. Sometimes when the plants are received, the leaves have all been clipped to a uniform height. This is usually done on older plants to facilitate transport. It can also help with plant establishment by reducing initial demands on the root system. When planting, it is important to get the bottom of the plant at least 4 inches deep to effectively anchor the plant. The plants should also be firmly compacted into the soil to eliminate any air pockets. When explaining the planting process to volunteers, it is important to emphasize that the plants are not delicate and cannot be planted too deep or packed down too hard.

Transplants from an existing marsh can be used but are not generally recommended except for small projects with a viable donor marsh. Transplant excavation is a very labor intensive operation because of the dense root system of most plants. When excavating transplants, care must be taken to spread out the plugs removed so as to not unduly impact the donor marsh.

Seeding of brackish marshes can be a viable option under the right circumstances. It requires a knowledgeable contractor, a very protected site, and a substrate firm enough to support planting vehicles and implements. In tidal freshwater systems, the seed bank of the existing marsh substrate can be a highly effective seed source. In this case, marsh sediments are salvaged during construction, for example from an entrance channel. Once grading is complete, these sediments and seed bank can be incorporated into the new substrate as a means of revegetation.

Volunteers can often be used to do the planting. This works best when working in firm sand and is less successful in soft mucky conditions. The key is the demonstration of the proper planting technique and adequate supervision.

Fertilizer

It is very important to get the planted vegetation established as quickly as possible. The faster it becomes established, the sooner it can begin functioning within the system. Consequently, the limited use of high nitrogen, slow release fertilizer is typically recommended, e.g., Osmocote 18-6-12. These fertilizers are placed in the planting hole at the time of planting. Normally, an application of one-half ounce (one tablespoon) per plant is sufficient to establish the plant. Time release is temperature and moisture dependent and different release periods are available. Timing should be based on the amount of growing season remaining, e.g., nine month release for spring planting, six for summer, and three for fall.

Planting Times

The best time for planting is spring because the plants have the entire growing season to get established. But as with any planting, there is always a measure of risk. When planting in the early spring (March), the plants tend to be smaller unless they have been carried over from the previous year. Also, there is a greater chance a spring storm could dislodge the plants. April, May, and June typically are the lowest risk times. Planting in the summer, July, August and much of September, can be risky for high marsh plants with irregular inundation, if there is insufficient rainfall to sustain the plantings and irrigation is not available. Low marsh plants should do well except for a slightly shorter growing season. Fall plantings, September and October, are typically successful in protected settings but take longer to achieve complete cover. Plantings in late fall and winter, November, December, January, and February, can also be successful in protected settings, but the risk of damage from storms and winter ice can be significant. The planting of large shrubs and trees should be done in the fall and winter to minimize transpiration stress. Smaller size shrubs typically do better in spring than summer. In short, tidal wetlands can be established during most of the year, but the degree of risk varies substantially. If using optimum planting, fertilizing (see above), spacing, and maintenance (see below) techniques, plants can become established quickly (e.g., Fig. 1a,b).

<u>Spacing</u>

1. 1 foot centers – very rapid cover
2. 1.5 foot centers - rapid cover
3. 2 foot centers – average conditions
4. 3 foot centers – large areas
5. Alternate species in transition areas
6. Plant above and below predicted elevations

Typical plant spacing for restoration projects is 2’ on center. This will usually give complete cover in two full growing seasons. Mitigation projects or those requiring faster cover are normally planted on 1.5’ centers. Closer spacing is seldom necessary and rarely recommended. When planting large areas where rapid cover is not necessary or when cost is a significant issue, a 3’ on center spacing can be effectively used with a resulting delay in reaching full cover.

When planting in transitional areas, like in the vicinity of MHW or ULW, it is advisable to alternate species along the rows both above and below the juncture. This allows the right plants to be available to help accommodate minor variations in topography at critical breaks in slope and community transitions.

Maintenance

Many maintenance issues and problems can be very complex and require the services of wetland professionals. These are beyond the scope of this paper. The use of water control structures, pipes, weirs, tide gates, etc. should be avoided unless absolutely necessary. Wetlands should be designed as self-sustaining natural systems. This simplicity is compromised anytime a structure is required that needs maintenance to function properly. Notable exceptions are forebays which are small settling basins typically located where high volume discharges from adjacent watersheds enter a constructed wetland. These structures can help contain large sediment loads and help modulate flows. However, they do need to be maintained to function effectively.

It is very important to maintain effective erosion control in newly established wetlands due to wave action or upland erosion. The effects of a storm event on a newly planted marsh can easily be mitigated with additional plantings. Significant upland erosion that deposits large amount of sediments into a new established wetland can smother plantings. It can also cause hydrological modifications and alter elevations within the wetland that would alter vegetative communities and, perhaps facilitate the invasion of *Phragmites*.

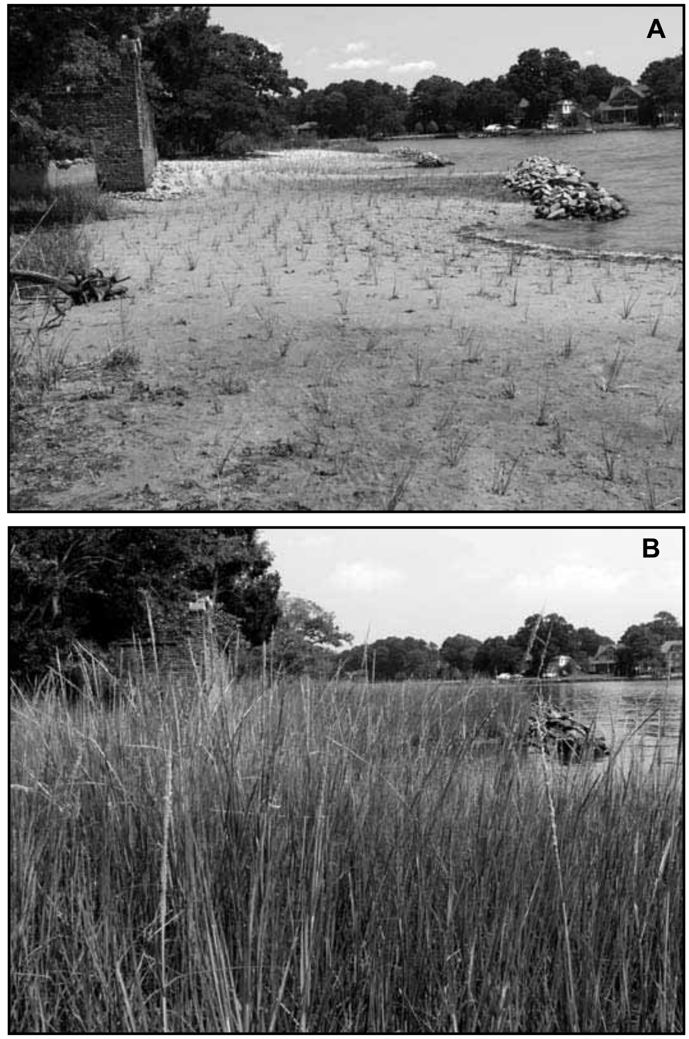

Figure 1. *Living shoreline using a segmented sill design at the Hermitage site in Virginia (a) immediately after planting (May 2006) and (b) the following summer (August 2007).*

In areas with populations of the common reed *Phragmites australis*, extraordinary measures are often necessary to eliminate existing stands and prevent recolonization. While there are no guarantees, there are a number of techniques which can help limit the risk. Whenever possible, existing stands should be sprayed with an appropriate herbicide prior to construction. During construction, every effort should be made to excavate and remove from the site as much of the *Phragmites* as possible. This should include over-excavation of at least a foot of material and backfill with clean sand. It is also important to design the majority of the site below MHW. In areas of moderate to high salinity, this can be a very effective deterrent. The creation of a subtidal ditch around the perimeter of the site can also help deter recolonization by rhizomes from adjacent stands. *Phragmites* control is an issue that requires continuing vigilance including at least semi-annual inspections and a comprehensive plan to treat future infestations. This is a very complex issue and consultation with a wetland professional is highly recommended.

Herbivory or the unwanted consumption of newly planted marshes is an emerging problem due to the burgeoning populations of resident Canada geese. These animals relish new stands of *Spartina alterniflora* and can quickly devastate plantings. They can, however, be effectively excluded by intensive fencing practices. They are not a threat to be underestimated, and again, a wetland professional should be consulted if geese are perceived as a threat.

The accumulation of debris, flotsam and jetsam, as well as wrack material, *Spartina* stems, and eelgrass leaves, can smother and devastate newly planted marshes. Care needs to be taken on any windward shore, particularly in coves facing the dominant wind direction. The only remedy is constant surveillance and judicious removal.

CONCLUSION

The purpose of this paper has been to outline some of the critical elements in the design of tidal wetlands. Due to the nature of this paper, the treatment of some elements has been necessarily cursory. Hopefully, though, it will precipitate intelligent questions during the design process and lead to better designed marshes that can effectively function as productive components of the estuarine system.

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Appendix C

Additional Permit Information

More information on Virginia's shoreline permitting process

Local, state and federal government agencies participate in the shoreline permit process in three different ways, including regulatory, oversight and advisory roles. Regulatory agencies are responsible for reviewing applications, issuing permits, enforcing permit conditions and investigating code violations. Oversight roles include monitoring the implementation of local government ordinances for consistency and compliance with state codes. Some agencies serve only advisory roles by providing technical information and objective recommendations that are not binding, yet it may be legally required to consider the advice given.

This section will briefly describe the various local, state, and federal agencies and their role in the process. Additional information about the regulations they are responsible for administering is provided in the next section.

Local government programs are regulatory agencies for administration of the Chesapeake Bay Preservation Act, Erosion and Sediment Control law, Tidal Wetlands Act and the Coastal Primary Sand Dunes/Beaches Act. Local government offices are usually located in one or more of the following departments: Planning, Zoning, Building and Zoning, Codes Compliance, Environmental Program or Division, Development Services, Wetlands, Waterfront Development.

Commonwealth Agencies include:

VA Marine Resources Commission (VMRC) - A regulatory agency responsible for administration of the Wetlands, Coastal Primary Sand Dunes and Beaches Act and Submerged Lands Act .

Department of Conservation and Recreation (DCR), Chesapeake Bay Local Assistance - A local government oversight agency for administration of the Chesapeake Bay Preservation Act.

Virginia Institute of Marine Science (VIMS) - An advisory agency responsible for providing independent, objective scientific evaluations and guidelines, and decision support tools.

VA Department of Game and Inland Fisheries (DGIF) An advisory agency responsible for providing information about protected species, anadromous fish and other wildlife resources of concern.

Department of Conservation and Recreation (DCR), Soil and Water Conservation - A local government oversight agency for administration of the Erosion and Sediment Control Act.

VA Department of Historic Resources (DHR) - An advisory agency responsible for providing information about cultural and historic resources that may be impacted by proposed projects.

VA Department of Environmental Quality (DEQ) - A regulatory agency responsible for administration of the Virginia Water Protection Program, which regulates activities with impacts on water quality.

Federal Agencies are:

U.S. Army Corps of Engineers (USACOE), Norfolk District - A regulatory agency responsible for administration of the Clean Water Act and the Rivers and Harbors Act which regulate activities with impacts on waters of the United States.

U.S. Fish and Wildlife Service (USFWS) - An advisory agency responsible for providing information about federally protected species and other wildlife resources of concern.

Regulations for Chesapeake Bay shorelines

Chesapeake Bay Preservation Act (Title 10.1 - Chapter 21, Code of Virginia)

The Chesapeake Bay Preservation Act, commonly known as "The Bay Act", was adopted by the Virginia General Assembly in 1988. The Bay Act is designed to improve water quality in the Chesapeake Bay and its tributaries by requiring the use of effective conservation planning and pollution prevention practices when using and developing environmentally sensitive lands. It grants local governments authority to manage water quality and establishes a specific relationship between water quality protection and local land use decision-making.

Each locality designates certain lands within their jurisdictions called Chesapeake Bay Preservation Areas, which if improperly used or developed may result in substantial damage to water quality. These special areas are further divided into Resource Protection Areas (RPAs), Resource Management Areas (RMAs), and Intensely Developed Areas (IDAs) (Figure 3-8).

Resource Protection Areas (RPAs) are lands adjacent to water bodies that have an intrinsic water quality value due to the ecological and biological processes they perform, or they are sensitive to impacts which may result in significant water quality degradation. RPA features include tidal wetlands, tidal shores, non-tidal wetlands connected by surface flow and contiguous to tidal wetlands or water bodies with perennial flow, and other lands considered by the local government to meet the provisions of the Bay Act.

The Resource Protection Area also includes a buffer area not less than 100 feet in width located adjacent to and landward of all RPA features and along both sides of any water body with perennial flow. This buffer area is commonly referred to as the "RPA buffer" or "100-ft buffer". The extent of the RPA buffer is determined by the location of the associated RPA feature.

Resource Management Areas (RMAs) are land types adjacent to Resource Protection Areas that have potential for causing significant water quality degradation if improperly used or developed. Examples of RMAs include floodplains, highly erodible soils, steep slopes, and nontidal wetlands not included in the RPA. For some localities, the entire town, city or county is designated as a RMA.

Intensely Developed Areas (IDA) may be designated where development has severely altered the natural state of the area. These areas of existing development are targeted for redevelopment and infill sites with less stringent water quality protection measures. For example, the 100-ft buffer may or may not be required and regulated in designated IDAs.

Bay Act Performance Criteria for Shoreline Erosion Control Projects

Local government Bay Act programs are required to review shoreline erosion control projects for compliance with the regulation. Most shoreline erosion control projects require land disturbance within Resource Protection Areas and associated 100-ft buffers. Each locality must verify that all aspects of the project meet the requirements of the Bay Act before allowing land disturbance or removal of vegetation within the RPA. If any of the following criteria are not met, local governments should not allow removal of vegetation from the RPA buffer, regardless of whether or not wetland permits have been issued for shoreline erosion control structures:

- The proposed shoreline erosion control measure is necessary
- The erosion control measure will employ the best available technical advice
- Indigenous vegetation will be preserved to the maximum extent practicable
- The proposed land disturbance will be minimized
- Appropriate mitigation plantings are proposed that will provide the required water quality functions of the buffer area
- The project is consistent with the locality's comprehensive plan
- Access to the project will be provided with the minimum disturbance necessary
- The project complies with erosion and sediment control requirements

Water Quality Impact Assessment (WQIA)

The Bay Act program review of shoreline erosion control projects is typically done through a Water Quality Impact Assessment (WQIA). The purpose of the WQIA for shoreline projects is to identify the potential impacts on water quality and lands in the RPAs, and identifies steps to minimize or mitigate potential water quality impacts of the land disturbance.

Each local program has its own application form and requirements for the WQIA. Typical WQIA components include:

- Reach assessment - an evaluation of the shoreline setting where the project will take place. It may include the physical extent or limits of the shoreline type, historical rates and patterns of erosion and accretion, source and volume of local sand supply, effective wave climate, littoral drift direction, estimating potential project impacts on adjacent properties, and estimates of other erosion causing factors (surface runoff, groundwater discharge, boat wakes, etc.)

- Indigenous vegetation preservation and removal plan - species type, size, and location of all woody vegetation on the site and what vegetation will be impacted or removed

- Construction access plan - preferred method of access and limits of clearing and grading

- Erosion and sediment control plan - required for all shoreline projects with more than 2,500 square feet of land disturbance, must demonstrate compliance with the local E&S laws

- Mitigation planting and maintenance plan - species type, size and location of all vegetation to be restored on the site; some local governments may require a performance guarantee

Contact the local government Bay Act program coordinator for more information specific to the project location.

Wetlands Act (Title 28.2 - Chapter 13, Code of Virginia)

The Wetlands Act was first adopted by the Virginia General Assembly in 1972 to protect tidal wetlands along estuarine shorelines. It was later amended in 1982 to include non-vegetated tidal wetlands. A Wetlands Mitigation-Compensation Policy was added in 1989 and then updated in 2005 to include private and commercial projects. The primary objective of Virginia's Tidal Wetlands Act is "to preserve the wetlands, and to prevent their despoliation and destruction and to accommodate necessary economic development in a manner consistent with wetlands preservation." (Section 28.2-1301).

Tidal wetlands in the Commonwealth of Virginia are located landward from the mean low water elevation (Figure 3-8). This is the legal boundary that separates public state-owned submerged lands from private property and the reason why Virginia is referred to as a "mean low water" state. The tidal wetland areas covered by this Act fall into two categories: non-vegetated and vegetated. Non-vegetated tidal wetlands are also referred to as intertidal flats, sand flats or mud flats. Non-vegetated tidal wetlands mean unvegetated lands lying contiguous to mean low water and between mean low water and mean high water. Vegetated tidal wetlands are also referred to as marshes, salt marshes and tidal swamps. Vegetated tidal wetlands means lands lying between and contiguous to mean low water and an elevation above mean low water equal to the factor one and one-half times the mean tide range at the site of the proposed project, and upon which is growing any of 37 listed wetland plant species.

The Wetlands Act gives local governments an option to adopt their own (tidal) Wetlands Zoning Ordinance. If they choose not to adopt this ordinance for a local program, then the Virginia Marine Resources Commission will administer the Act for that locality. Most of the Tidewater localities have adopted their own tidal wetlands ordinance and permit program. This includes a Local Wetlands Board comprised of citizen volunteers appointed by the Board of Supervisors.

The Local Wetlands Boards (or the Commission) must hold a public hearing for every permit application that includes tidal wetland impacts. The public hearing process requires the direct notification of adjacent property owners and various agencies. Legal advertisements for wetlands board hearings are typically published in local newspapers. Permit approval or denial is granted by the Local Wetlands Board through a majority vote, with at least 3 affirmative votes required for approval.

Wetlands Board approval at the public hearing is not equivalent to receiving a permit. There is a 10 day waiting period after the public hearing for VMRC review. Every decision rendered by individual boards is reviewed by the governor appointed Marine Resources Commissioner to ensure uniformity. The local government will issue a final permit document if there will be no review of the case by VMRC.

The Commissioner will recommend a review of the local decision by the full Commission where he believes the local board failed to fulfill its responsibilities under the wetlands zoning ordinance. The Commission also hears and decides all wetland appeals that are filed by either an aggrieved applicant or 25 or more freeholders of property within the locality.

Tidal Wetlands Act Performance Criteria for Shoreline Erosion Control Projects

Proposed projects on tidal shorelines are supposed to meet both general and specific criteria. Generally, shoreline alterations are allowed to gain access to navigable waters and to protect property from significant damage or loss due to erosion provided marine fisheries, wetlands and wildlife resources are not unreasonably detrimentally affected.

Specifically, shoreline protection structures are justified only if:

- there is active detrimental erosion which cannot be otherwise controlled, or
- there is rapid sedimentation adversely affecting marine life or impairing navigation that cannot be corrected by upland modifications, or
- there is a clear and definite need to accrete beaches.

Other permit review criteria consider how various methods will interfere with natural shoreline processes. These considerations include:

- the use of integrated vegetation buffers on gradual slopes is preferred for shorelines experiencing mild to moderate erosion
- the use of offshore structures combined with marsh or beach areas is preferred when an erosion control structure is deemed necessary
- Placing structures directly against the upland bank should be a last resort where offshore structures with marsh or beach are not feasible, such as small shoreline sections, shorelines with limited sand supply or navigation conflicts, etc.
- Sloped rock structures are preferred over vertical bulkheads
- Quarry stone is preferred as a construction material, except where alternative materials have a proven track record of effective performance
- Filling in wetlands should be limited to creating marshes or beaches, or for water-dependent or otherwise necessary actions that cannot be accommodated in the uplands
- Living shorelines projects should improve ecological conditions without any adverse affect on nearby or adjacent properties, fisheries resources, other uses of state waters, water quality, wetlands and submerged aquatic vegetation.

Wetland Mitigation and Compensation Policy

Most local wetlands boards now require compensation for unavoidable, permanent loss of tidal wetlands pursuant to the Commonwealth's “no net loss” wetland mitigation and compensation policy. Each local government program adopts its own policies and procedures for this requirement. One option available in many locations is an in-lieu fee system that accepts money in place of actual wetland construction. The rationale is that the collection of fees from many individual projects to fund fewer large compensation projects is likely to produce more successful compensation (CCRM, 2005).

Compensation may be required for living shorelines projects that include tidal wetland impacts. There may be existing wetland vegetation that needs to be filled in order to achieve target grades. The Virginia Institute of Marine Science has advised wetlands boards that most wetland conversions associated with properly designed and sited living shorelines projects are beneficial and compensation should not be required.

Coastal Primary Sand Dunes / Beaches Act (Title 28.2, Chapter 14 Code of Virginia)

Another regulation applies to sandy shorelines on Virginia's ocean coast and Chesapeake Bay shorelines (Figure 3-8). This Act recognizes the unique characteristics and economic benefits of beach and dune habitats that serve as protective barriers to coastal hazards. It was first adopted in 1980 for eight localities and then revised in 2008 to apply to all tidal Virginia localities.

The administration of this law is similar to the Wetlands Act where local governments have the option to adopt their own implementing ordinance. In many cases, the Local Wetlands Board has the authority to review applications and issue permits for projects that impact jurisdictional beaches and dunes. The Marine Resources Commission will review all beach/dune decisions made by the local boards or administer the permit program where the locality has not adopted their own ordinance.

Living shorelines projects on beaches and dunes include beach nourishment, dune enhancement or restoration, and offshore breakwaters with beach nourishment. The permit process for these projects is very similar to the Wetlands Act with special considerations for minimizing impacts to the habitats involved. These permit review standards include:

- Limit impacts to activities that must occur on beaches/dunes and that cannot be accommodated elsewhere
- Minimize alteration of natural dune contours
- Avoid damage to vegetation growing on the dune

Activities contrary to these standards will be permitted only if the wetlands board or Commission finds there will be no significant adverse ecological impact, or that granting a permit is clearly necessary and consistent with the public interest.

Submerged Lands Act (Title 28.2 - Chapter 12 Code of Virginia)

The Submerged Lands Act defines ownership and regulates uses of state-owned bottomlands (Figure 3-8). It is administered by the Marine Resources Commission (VMRC). Small projects may receive administrative permits. Larger and controversial projects may require a public hearing in front of the full Commission.

Acceptable submerged lands projects that receive permits are determined to be in the public interest. This includes the necessity for the project, there are no reasonable alternatives requiring less environmental disruption, and that adverse effects do not unreasonably interfere with other private and public rights to use the waterways and bottomlands. Particular emphasis has been applied to reducing unnecessary filling of state-owned bottom, including living shorelines projects.

When determining whether to grant or deny a permit for the use of state-owned bottomlands, the Commission considers both public and private benefits of the project and its effects on the following:

- Other reasonable and permissible uses
- Marine and fisheries resources
- Adjacent and nearby properties
- Water quality
- Submerged aquatic vegetation (SAV)

Royalties

The Marine Resources Commission has the authority to assess rents and royalties for certain activities permitted on state-owned bottomlands. This includes activities associated with living shorelines projects, such as the placement of sand fill and offshore containment structures. Some fees and royalties are defined by statute while others are within the discretion of the Commission. Royalties are due and payable only after the project is approved.

Federal Regulations

The Regulatory Branch of the U.S. Army Corps of Engineers (Norfolk District) issues permits under the authority of Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act of 1899 for regulated activities throughout Virginia. The regulated areas include tidal marshes, rivers, bays and streams. Similar to the local and state permit process, this agency is responsible for protecting aquatic resources while allowing reasonable and necessary development to occur.

The U.S. Fish and Wildlife Service serves as an advisory agency in the federal permit process. This agency is responsible for assisting the U.S. Army Corps of Engineers with enforcing the Endangered Species Act. For living shorelines projects, this may include special considerations for the northeastern beach tiger beetle, sea turtles and marine mammals and other protected species.

The U.S. Army Corps of Engineers must also consider the presence of historic and cultural resources. The Virginia Department of Historic Resources has an Environmental Review process to help determine if a project will impact properties on the National Register of Historic Places and other designated resources. Potential issues that arise with living shorelines projects are the presence of artifacts that cannot be excavated with bank grading and historic cemeteries that cannot be disturbed.

The most common type of permit issued by the U.S. Army Corps of Engineers for living shorelines projects is a Regional Permit. This is a general permit that lists specific individual activities that are authorized with general and specific conditions to protect the public interest. No public notice or public hearing is required. For living shorelines projects, Regional Permit 08-RP- 19 authorizes activities over which the VA Marine Resources Commission and/or the local wetlands board have regulatory authority, including submerged sills and associated beach nourishment, low breakwaters and associated beach nourishment, and bioengineering projects to prevent erosion (among others).

In order for this RP-19 to be valid, the applicant must obtain state and/or local approvals prior to commencement of such work in waters of the United States. The activities that qualify for this RP meet the requirements of DEQ Virginia Water Protection Permit Regulation provided that the permittee abides by the conditions of RP-19.

Permittees should ensure that their projects are designed and constructed in a manner consistent with all state and local requirements pursuant to the Chesapeake Bay Preservation Act (Virginia Code 10.1-2100 et seq.) and the Chesapeake Bay Preservation Area Designation and Management Regulations (9 VAC 10-20-10 et seq.). Those activities on the Potomac River extending beyond the mean low water line must be authorized by the VMRC, the Maryland Department of Natural Resources and/or the Potomac River Fisheries Commission in order to comply with this regional permit.

Activities do not qualify for this regional permit unless they satisfy ALL of the special and general conditions listed for each individual activity. For living shoreline type projects, important conditions to note include but are not limited to:

1. The total amount of vegetated wetlands which may be filled, in square feet, may not exceed the length of the activity along the shoreline in linear feet (e.g. 100 square feet maximum for a 100-foot long marsh sill).

2. For projects where bioengineering is to be utilized in lieu of bulkheading or riprap, grading or excavating wetlands shall be limited to one square foot of vegetated wetlands per linear foot of shoreline.

3. Only clean, non-metallic, non-organic, non-floatable fill obtained from an upland source may be used as backfill material

4. Any temporary fills must be removed in their entirety and the affected areas returned to their pre-existing elevation (e.g. staging and stockpile areas, access roads)

5. Submerged sills may be constructed of riprap, gabion baskets, or concrete. Alternative materials may be considered for use during the permit review process. The materials should be of sufficient weight or adequately anchored to prevent their being dislodged and carried by wave action. Asphalt and materials containing asphalt or other toxic substances shall not be used in the construction of sills.

6. Submerged sills and breakwaters may not be connected to the upland or constructed in conjunction with groins or other erosion control structures. Such structures will require individual Department of the Army review.

7. Beach nourishment is allowed landward of sills and breakwaters provided the nourishment is for erosion control (and not solely recreational activities). Planting of vegetation to stabilize the nourishment area may be required. The maximum beach nourishment area within waters of the United States that can be authorized under this Regional Permit is one acre.

8. All beach nourishment material must be of grain size comparable with the existing beach. All material will be obtained from either an upland source, a borrow pit, or a dredging project approved by the Corps.

9. The beach nourishment material will not be placed in or affect any vegetated wetlands, submerged aquatic vegetation, or shellfish beds.

10. Beach nourishment may result in the creation of suitable habitat for various federally listed threatened or endangered species. If this occurs and the applicant proposes to either add to or replenish the area, the Corps will consult with the Fish and Wildlife Service to ensure the work does not adversely affect or jeopardize a federally listed or proposed threatened or endangered species.

11. Low breakwaters constructed close to shore for the purpose of erosion protection are authorized by this RP. This permit does not include high breakwaters constructed for the purpose of creating quiet water for the protection of a boat harbor.

Visit this web site for a complete list of all activities and the general and specific conditions contained in Regional Permit 19 for living shorelines projects.
http://www.nao.usace.army.mil/technical%20services/Regulatory%20branch/08-RP_LOP_Final/08-RP-19%20Permit.pdf

Permit Application Process

The permit process includes multiple regulations and government agencies. The first point of contact is normally the local government where the project is located. The local government offices responsible for administering the Chesapeake Bay Preservation Act and Wetlands Act should be contacted to determine what the requirements and procedures are for compliance with land use, zoning, land disturbance, landscape restoration and wetlands or beaches permitting. There will be application forms and other documents required by the local government to legally describe and document the proposed project.

A Joint Permit Application (JPA) is required for all projects that include impacts to tidal wetlands, beaches or submerged lands. There are two versions of the JPA, one for routine erosion control projects in the Tidewater region and another longer version for dredging and other types of projects. The application form includes a series of Appendices that must be completed for each activity type included in the project.

The VMRC acts as a clearinghouse for JPA submittal. This agency will distribute copies to all regulatory and advisory agencies, including the federal government. After the JPA is submitted, additional information may be requested by one or more of the reviewing agencies to clarify project information and impact assessments. The applicant's signature on the application grants permission for site visits by the reviewing agencies for official project review purposes. These site visits are not always announced or scheduled with the property owner or permit agent. Each agency will inform the applicant separately what requirement s remain before work can begin.

The federal permit review process is concurrent but separate from the local and state process. Only one Joint Permit Application needs to be submitted, but after receipt of the application, the federal process is independent. It is the applicant's responsibility to ensure receipt of all required local, state and federal authorizations before starting work. If the local government and VMRC approvals are obtained, but if the US Army Corps of Engineers does not grant approval, then the project cannot legally be constructed.

Summary of Applications and Permits

Summary of information for permit applications.

	Local	State	Federal
Applications / Forms	Water Quality Impact Assessment		
	Landscape Restoration Agreement		
	Joint Permit Application		
Permits	Land Disturbance Permit	Submerged Lands Permit	Regional or Individual Permit
	Local Wetlands Board permit		
	Building Permit		

Summary Guidelines for Permit Process

- Design projects based on shoreline conditions & desired level of protection, adjust as needed to satisfy regulatory agencies
- Habitat tradeoffs associated with living shorelines projects must be considered on a case-by-case basis
- Rough concept plan
- all proposed activity from beyond most landward limit to beyond most channelward limit)
- Establish mutual understanding among stakeholders about project, approval process, and responsibilities
- Allow at least 2 months from submitting application to permit issuance; more likely 4-6 months for complicated projects
- Do not assume permit exemptions or qualifications; get authorizations and permit waivers in writing
- Check with local county or city environmental office BEFORE doing ANY shoreline work

Permit Process Checklist

1. Rough Concept Plan
    - from beyond channelward limit to beyond landward limit of project activities project dimensions (estimated)

- existing habitat types and condition, especially accurate representation of all vegetated wetlands affected by the project
- potential impact areas
- construction access requirements
- construction sequence estimates

2. Draft Impact Assessments (WQIA, tidal wetlands, subaqueous lands)

3. Pre-Application Contact with Local Government

   - Local Bay Act program coordinator - allowable tree removal and land disturbance, forms and procedures for WQIA
   - Wetlands Board staff - timeline for permit review, compensation policy

4. Pre-application contact with adjacent property owners

   - immediately adjacent
   - across waterway(s)
   - Obtain signed APO forms, follow-up if project is modified

5. Pre-application contact with State Government (if necessary)

   - VA Marine Resources Commission (VMRC), Habitat Management Division Ask about Joint Permit Application process, Leased Grounds, Royalties
   - VA Institute of Marine Science (VIMS) Evaluate resources in project vicinity with VIMS GIS Tools, including SAV, shoreline evolution reports, shoreline assessment mapper

VA Game and Inland Fisheries (DGIF) Request DGIF Fish & Wildlife Information Search

- VA Department of Historic Resources (DHR) Request DHR environmental review if needed

6. Pre-application contact with Federal Government

   - U.S. Army Corps of Engineers (USACOE) Submit pre-application review request form, request permit type determination (regional or individual)

7. Pre-application contact with other stakeholders (as needed)

   - navigation interests
   - community and property associations

- shellfish lease holders
- financial supporters

8. Document Site Conditions - conduct necessary or suggested environmental studies
    - tree survey, tree preservation and removal plan
    - wetland delineations, tidal and non-tidal
    - Refine topography and bathymetry
    - Mean Low Water survey,
    - sediment samples, subtidal, intertidal, upland bank
    - protected species

9. Modify project concept plan as needed based on pre-application review and environmental studies

10. Permit process plan - develop plan for simultaneous agency permit process, submission and review requirements, what to expect, steps in the process, sequence, timeframe, public hearing requirements

11. Communicate with property owner(s) to establish realistic expectations and understanding of what the process entails including unannounced site visits by various parties, who will be responsible for what (e.g. representation at public hearings, tolerance for project modifications, sureties if required)

12. Prepare various applications as required, use most recent forms available
    - Prepare Erosion and Sediment Control Plan, land disturbance permit application
    - Prepare Water Quality Impact Assessment (WQIA)
    - Prepare Joint Permit Application and drawings in 8.5x11 inch format
    - Prepare Landscape restoration plan

13. Submit applications, project drawings and supporting documents to local government and VMRC (as required)

Acronyms

E & S	Erosion & Sediment control
RPA	Resource Protection Area
CBPA	Chesapeake Bay Preservation Act
WQIA	Water Quality Impact Assessment
JPA	Joint Permit Application (local, state, federal)
NWP	Nationwide Permit (federal)
RP	Regional Permit (federal)
VMRC	Virginia Marine Resources Commission
VIMS	Virginia Institute of Marine Science
USACOE	US Army Corps of Engineers