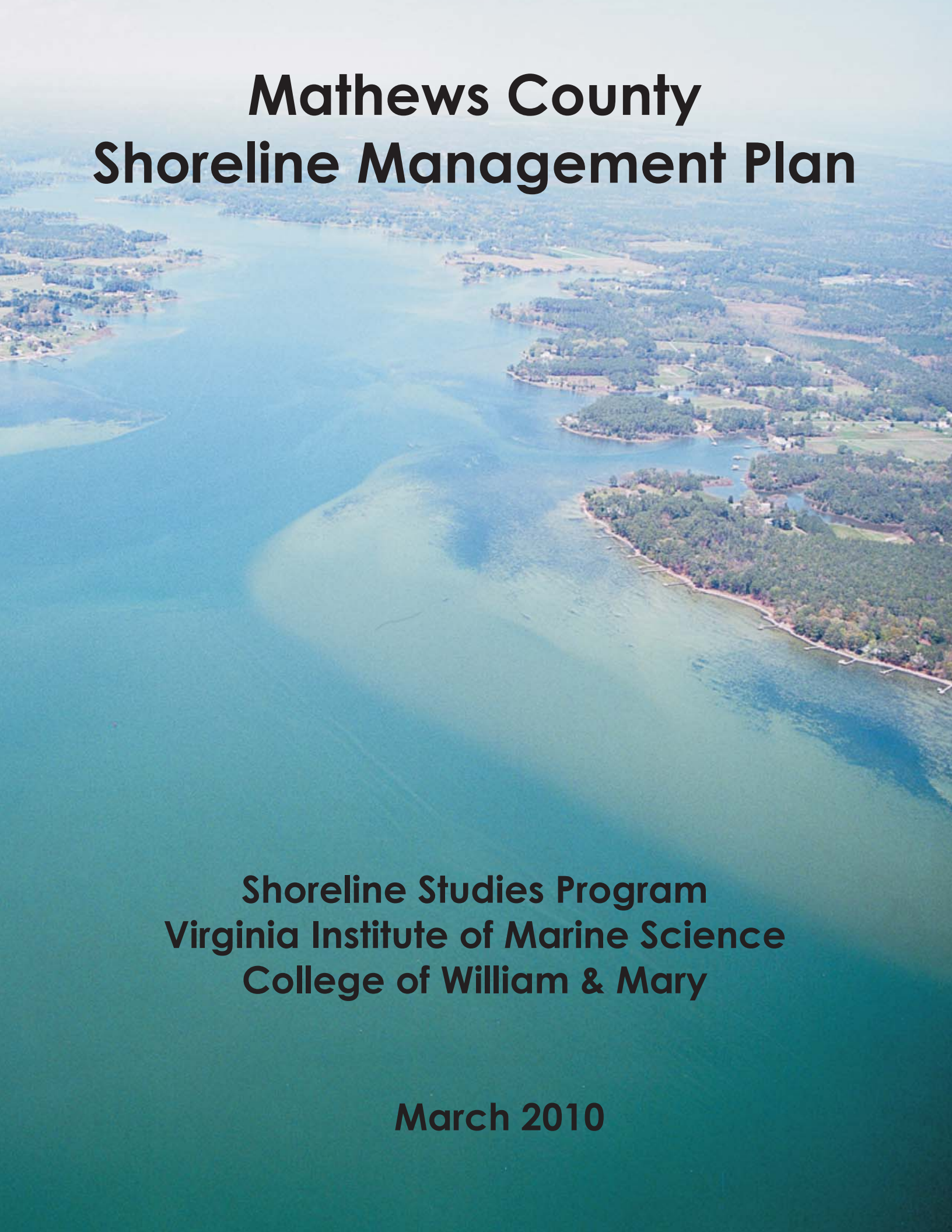


An aerial photograph of a large body of water, likely a reservoir or lake, with numerous small, forested islands and peninsulas. The water is a deep blue-green color, and the surrounding land is covered in dense green trees. The sky is a pale blue.

Mathews County Shoreline Management Plan

**Shoreline Studies Program
Virginia Institute of Marine Science
College of William & Mary**

March 2010

Mathews County Shoreline Management Plan

Prepared for
Mathews County
and the
National Fish and Wildlife Foundation

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Project Summary

The Mathews County Shoreline Management Plan (Plan) is the result of cooperative work between Mathews County and the Shoreline Studies Program and the Center for Resource Management at the Virginia Institute of Marine Science. The work was funded by the National Fish and Wildlife Foundation through their Chesapeake Bay Small Watershed Grants Program. The goal of the project is to create an easy-to-use Plan that landowners in Mathews County can use to initiate shore management strategies that stabilize their shoreline in an environmentally-friendly way.

This report has several sections. [General coastal zone management considerations](#) and [existing conditions](#) along the Mathews County shoreline are discussed. The overall Mathews shoreline was divided into three reaches: [Reach 1, Piankatank River, Hills Bay, and Queens Creek](#); [Reach 2, New Point Comfort to Gwynn's Island including Milford Haven](#); and [Reach 3, Mobjack Bay, East River, and North River](#). Each reach is discussed in terms of specific shore conditions as well as design considerations and shore stabilization recommendations. Reach 2 is slightly different from the other reaches in that it includes the high energy Chesapeake Bay shoreline. For this section of shore, recommendations were made at both the lot-by-lot level as well as for the larger subreach. Specific areas where the larger, subreach shoreline strategies were recommended are: [Gwynn's Island](#), [Rigby Island/Festival Beach/Bethel Beach](#), [New Point Campground/Sandy Bank](#), [Chesapeake and Bavon Beaches](#). The maps portraying the recommended strategies are in Appendix B. The [index map](#) will locate the appropriate plate for the shoreline section of interest. A table listing the characteristics of each site and the recommended strategies follow each map.

An integral part of the strategy recommendation is the accompanying typical cross-section. These cross-sections provide a starting point for consultants and/or designers and an approximate estimated cost per linear foot for the property owner. The table below lists the strategies recommended for each reach and their approximate cost. Marsh management cost is often tree trimming and planting on existing bottom. An approximate cost is provided for breakwaters and beach fill; however, these types of projects can be built in phases and so costs are difficult to accurately determine per linear foot.

Data developed for this report is discussed in the appendices. [Appendix A](#) shows the rate of change along Mathews shoreline between 1937 and 2007. [Appendix C](#) describes, in detail, Mathews' geologic history and its implication in sea level rise. [Appendix D](#) shows marine resource data available through existing databases, and [Appendix E](#) maps orthorectified aerial photo mosaics and digitized shorelines for 1937, 1953, 1968, 1978, 1994, 2002, and 2007. Appendix E is large and as such is only available digitally.

The strategies recommended for each reach in the Mathews County Shoreline Management Plan and their approximate cost.

Reach	Strategy	Cost per Linear Foot of Shoreline*
1	marsh management	<\$50
<i>Piankatank River, Hills Bay</i>	small low sill	\$125-\$175
<i>and Queens Creek</i>	low sill	\$150-\$195
	medium sill	\$190-\$240
2 - Lower energy areas	marsh management	<\$50
<i>Milford Haven and</i>	small low sill	\$125-\$175
<i>associated creeks</i>	low sill, narrow-crest	\$200-\$275
2 - Higher energy Bay Shoreline	breakwaters and beach fill	\$500-\$1,000
3	marsh management	<\$50
<i>Mobjack Bay, East River</i>	small low sill	\$125-\$175
<i>and North River</i>	low sill, narrow-crest	\$200-\$275
	low sill, wide-crest	\$250-\$350

*Costs are approximate and were determined in Spring 2010. They typically include the materials and installation of rocks, sand, and plants. Other work, such as permitting, gaining access, and other site work can vary considerably by site and is not included in the estimated cost.

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1 Introduction

Erosion control throughout Virginia's coastal communities usually consists of isolated actions taken on a parcel-by-parcel basis when waterfront property owners contact consultants or contractors to address erosion concerns along their shorelines. In this way, management of Virginia's shorelines can be characterized as response-structured, since resource managers are involved only in review and permitting after the project has been proposed by the owner. Prior to the property owner's investment in the permit process, managers generally cannot influence or educate waterfront property owners on whether or not they have an erosion problem, the magnitude of erosion if it exists or about alternative approaches that are more beneficial to the property owner and the local environment. With approximately 85 percent of the Chesapeake Bay shoreline privately owned, a critical need exists to increase awareness of erosion potential and the choices available for shore stabilization that enhances the land-water connection. The National Academy of Science recently published a report that spotlights the necessity of developing a shoreline management framework (NRC, 2007). It suggests that improving awareness of the choices available for erosion mitigation, considering cumulative consequences of erosion mitigation approaches, and improving shoreline management planning are key elements to mitigating shore erosion on sheltered coasts in an environmentally-friendly way.

Since most of Mathews County's perimeter is formed by its 350 mile long shoreline, a large percentage of the County's population and tax base are vulnerable to coastal impacts. Actions taken by waterfront property owners to stabilize the shoreline can affect the health of the Bay as well as adjacent properties for decades. With these long-term implications, managers on the local level should have a more proactive role in how shorelines are managed. Mathews County recognizes this, and while the County presently does not have a cohesive regional approach to shoreline management, its Comprehensive Plan (2000) recognized the potential for expanding its economy by utilizing and protecting its existing local resources, particularly its shorelines. Other components of the Comprehensive Plan are that any new development along the shoreline will be encouraged to use natural methods such as marshes and beaches, rather than hardened structures, to prevent or diminish shoreline erosion and that all areas identified with a high rate of erosion will have stronger regulations for development. Such requirements may be in the form of more stringent setback requirements, stricter building codes, and more environmentally sensitive erosion control measures. In addition, all new shoreline development must have a Shoreline Protection Plan detailing the steps being taken to control erosion. Wherever possible, vegetative approaches are preferred over hard structures.

These Comprehensive Plan goals certainly are achievable; however, managers, homeowners, and consultants/contractors need the accurate, site-specific information readily available. The shores of Mathews County range from open bay to very sheltered creeks, and the nature of shoreline change can vary accordingly. Therefore, shore management must be tailored to existing conditions and account for bank height and type, severity of erosion, fetch, littoral transport, proximity to other marine resources, sea-level rise, and potential for flooding. This type of information generally is not available at the local level, especially in a comprehensive format.

A shoreline management plan is useful for evaluating and planning shoreline management strategies appropriate for the Bay, creeks and rivers of Mathews County. It ties the physical and hydrodynamic elements of tidal shorelines to the various shoreline protection strategies. These shoreline management strategies are balanced against shore protection, environmental concerns, and zoning and permitting regulations to provide the recommendation for shore reaches along the tidal shorelines of the County. In addition to these concerns, cost is considered by regulatory agencies and property owners. The Mathews County Shoreline Management Plan (MCSMP) outlines unique shoreline situations on various scales and presents stabilization alternatives that optimize the balance of habitat value and effective erosion control. These strategies, along the cost estimates provided, can be used during the project development stage to promote the most reasonable and beneficial approach to shoreline stabilization.

Specifically, the MCSMP identifies shoreline types at multiple scales, from individual lots to large reaches, and determines whether or not they are actively eroding, describes the geology and morphology of Mathews County, determines historical and recent shoreline and land use changes, assesses existing marine resources, and analyzes general wave climate, storm surge, and sea-level rise. A detailed site analysis also is provided. This accurate and detailed information at the appropriate scale is the basis for shore protection recommendations.

The recommended shoreline strategies provide effective shore protection but also have the added distinction of creating, preserving, and enhancing wetland, beach, and dune habitat. These habitats are essential to addressing the protection and restoration of water quality and natural resources with the Chesapeake Bay watershed. Recommendations were made along eroding residential properties or those susceptible to development since these are the areas where shore structures likely will be constructed. Property types other than these may not receive a recommendation.

The final MCSMP is an educational and management reference for the County and its landholders. Much of Mathews County's shoreline is suitable for a "Living Shoreline" approach to shoreline management. However, many landowners do not realize that there are alternatives to bulkheads and riprap or are unsure of the viability of living shorelines. This management plan, its public presentation, its availability in both printed and digital format, and its use in zoning, planning, and permitting will provide excellent alternatives for landowners to make informed shoreline management decisions.

2 General Coastal Zone Management Considerations

2.1 Coastal Profile

Mathews County, Virginia is located at the eastern tip of the "Middle Peninsula" between the York and Piankatank Rivers on Chesapeake Bay (Figure 2-1). The County is a broad peninsula of land bordered on the west by the North River, south and southwest by Mobjack Bay, the east by Chesapeake Bay, and the north by the Piankatank River (Figure 2-2). The shorelines of Mathews County are variable from very low uplands and marsh coasts along the North and East Rivers to open-bay barrier beaches and marshes along the eastern coastline, to high upland banks along the Piankatank River. Most of the 350 miles of tidal shorelines in Mathews County occur in narrow, small creeks and rivers that have short distances over which wind can blow which limits wave energy. Marsh fringes can occur up these creeks and rivers while more expansive marsh complexes generally occur along the eastern, Bay side of the County.

Marshes can be either remnants of once broader marsh plains or more recently developed on sediment that allows marsh grasses to colonize in the upper intertidal zone. Both types will attenuate storm waves and help protect adjacent uplands from wave attack. The coastal profile that has a wide, gentle gradient will allow the high water and high wave energy to attenuate across its slope. Where there is a natural, stable upland bank, there is usually a wide beach or marsh that buffers it from wave action.

Erosion is the process by which wind-driven waves impact the coast and cause the bank sediments to be undercut and transported away from the source. As the marshes and beaches become more narrow and the coastal profile steepens, storm waves can reach the base of upland and initiate erosion. The result is a landward retreat of the bank, berm, or line of vegetation which further steepens the profile. The process is more severe during periods of high water and high winds, *i.e.* a storm, when wave energy is highest and impacts to upland banks are the greatest. Generally, shore erosion on a daily basis is minimal.

The narrowing or loss of the protective fringing marsh often results in undercutting or scarping of the base of the upland bank due to waves and, sometimes, boat wakes. Continued undercutting and scarping of the base of bank can lead to the failure of the bank face (Figure 2-3A). This is a natural process but the response to loss along residential properties is often hardening with bulkheads or stone revetments (Figure 2-3B and C). In low energy creeks, they may be entirely unnecessary as bank erosion is usually minimal. These defensive strategies are effective shore protection but often cause loss of intertidal wetlands, both vegetated and non-vegetated, since they intersect the coast profile and make it difficult to establish a connected shore zone as shown in Figure 2-4A. Instead, re-establishing the wave buffer, *i.e.* fringe marsh, and reducing the steepness of the coastal gradient can enhance the coastal profile.

Figure 2-4B describes an idealized coastal profile in the Bay watershed whose segments include upland, riparian buffer, banks, intertidal, and subaqueous habitats. This water quality

and habitat model integrates habitat features through a cross-section of the coastal zone and depicts the preferred use from an environmental perspective (CCRM, 2007). More natural landuse (shown in green) helps stabilize the bank thereby reducing erosion and sediment introduction into the waterway and provides native or unaltered habitat for animals and birds. Natural landscapes generally have larger plant and animal diversity whereas coastal areas that have been altered may not have suitable habitat for a wide variety of creatures. In addition, vegetation in coastal habitats take up the nitrogen (N) and phosphorus (PO_4^{3-}) in ground water which reduces their input to the waterways.

Creek-side woodlands are riparian buffers that trap and filter sediments, nutrients, and chemicals from surface runoff and shallow groundwater. The tree roots stabilize the creek bank, and microbes in forest soil convert nitrate (especially from agricultural land) into nitrogen gas. The riparian buffers along the smaller creeks and river in Mathews County occur above the zone of tidal wetlands and are typically occupied by scrub/shrub and trees. Downed trees along the shore is an indicator that the bank is eroding and that the riparian buffer is being impacted (Figure 2-3A).

In the intertidal zone, marshes provide habitat for aquatic, avian, and terrestrial animals and reduce erosion by absorbing wave energy, intercepting run-off, filtering groundwater, and holding sediment in place. Along Mathews' higher energy shorelines, beaches and dunes create habitat for animals, birds and plants and are protective barriers from flooding and erosion resulting in decreased sediment and nutrient input. In the subaqueous zone, submerged aquatic vegetation (SAV) and oyster reefs continue to face restoration challenges in Chesapeake Bay and the surrounding watersheds. They are important components of the coastal ecosystem for a wide variety of estuarine species and also can dampen waves and stabilize nearshore sediments.

2.2 Shoreline Strategies

Over the past 20 years, more habitat-friendly management strategies, which utilize the creation of marshes and beaches for shore protection rather than hardening the coast, have been implemented around the Bay. These approaches include creating marsh fringe by direct planting of the existing substrate, adding sand, and adding sand with stone groins and sills. Where the fetch is long, stone is needed to resist waves. On more open coasts, breakwaters and beach fill can be built to achieve a stable sandy habitat of beach and dunes. These "Living Shoreline" strategies can, if properly designed and constructed, provide shore protection as well as create a viable vegetated fringe that 1) restores natural functions and 2) provides water quality buffer, two main Chesapeake Bay restoration goals. The descriptive term "Living Shoreline" readily conveys the image of a shoreline characterized by wetlands and sand beaches and may include submerged aquatic vegetation, mud flats, and/or oyster reefs that provide living spaces for a broad array of aquatic and terrestrial organisms. The fundamental objective of the living shoreline approach is to protect eroding shorelines while also enhancing water quality and habitat for living resources in the Bay.

In developing the Shoreline Management options for effective shore stabilization, the following objectives (Hardaway and Byrne, 1999) should be given consideration:

- Prevention of loss of land and protection of upland improvements.
- Protection, maintenance, enhancement, and/or creation of wetlands habitat: both vegetated and non-vegetated.
- Management of upland runoff and groundwater flow through the maintenance of riparian and vegetated wetland fringes.
- For a proposed shoreline strategy, address potential secondary impacts within the reach which may include impacts to downdrift shores from a reduction in the sand supply or the encroachment of structures onto subaqueous land and wetlands.
- Provision for access to and/or creation of recreational opportunities such as beaches.
- Abatement of sedimentation through erosion control.
- Longevity of the shore stabilization strategy.

These objectives are best assessed initially in the context of a shoreline reach. While all objectives should be considered, they will not carry equal weight. In fact, satisfaction of all objectives for any given reach is not likely as some may be mutually exclusive. Suitable shoreline management strategies for Mathews County are listed below.

- 1) Marsh 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 2-5). 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* in Mathews.
- 2) Add sand with groins: As fetch exposure increases beyond about 1,000 ft and the intertidal marsh width is not sufficient to attenuate wave action, the addition of sand can increase the intertidal substrate as well as the backshore region (Figure 2-6). The simple addition of sand usually is not enough because the sand often will be transported away from the site. This usually requires the inclusion of some sand retaining structures such as short groins or a low sill. A T-head, so named because the groin now resembles a T, can be added to the end of a groin in order to hold the fill. Any addition of sand or rock seaward of mean high water (MHW) requires a permit. A permit may be required landward of MHW if the shore is vegetated.
- 3) Stone sills: The stone sill has been used extensively in Chesapeake Bay over the years especially in Maryland (Figure 2-7). It is a rock structure placed parallel to the shore so that a marsh can be planted behind it. 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.

- 4) Breakwater System: Although single breakwaters can be used, two or more are recommended to address several hundred feet of coast (Figure 2-8). For breakwaters, the level of protection changes with the system dimensions such that larger dimensions generally correspond to bigger fetches and where a beach/dune shoreline is desired.
- 5) Revetments: Many bulkheads and revetments exist along the Mathews County coast, some of which are in need of repair or extensions (Figure 2-9). Stone revetments may be the preferred method for shore erosion control along north facing shorelines with high banks and heavy tree cover and other areas where it may be difficult to establish a protective marsh fringe.
- 6) Spurs: A spur is a structure that is connected either to the land or another structure. For the purposes of this management plan, spurs can be connected to groins to try and maintain a certain beach width or at the end of sills or breakwaters to mitigate downdrift impacts.

The overall goal of effective shoreline strategies, other than defensive structures, is to create a less steep coastal gradient. On the landward side, this reduces erosion from runoff and on the seaward side, waves energy is reduced before it impacts the bank. However, creating these more gradual slopes can involve encroaching into landward habitats (banks, riparian, upland) through grading and into nearshore habitats by converting existing sandy bottom to marsh or rock.

Balancing the encroachment is necessary for overall shoreline management. Bank grading may be necessary for unstable banks to reduce their slope and minimize the risk of bank failure. Newly graded slopes should be re-vegetated with different types of vegetation including trees, shrubs and plants. Marshes are generally constructed on slopes between 8:1 and 14:1, but average about 10:1 (for every 10 ft in width, the elevation changes by 1 foot). Steeper systems have less encroachment into the nearshore but may not successfully stabilize the bank because the marsh may not attenuate the waves enough before they impact the bank. Shallower, wider systems have more encroachment but also have the advantage of creating more marsh and attenuating wave energy more effectively. Determining the system's level of protection, *i.e.* height and width, is the encroachment.

2.3 Permitting

Any type of fill onto state bottom requires a series of permits since the Commonwealth holds in trust all lands below mean low water and are responsible for their management. Disturbances to the riparian buffer also require permits. Jurisdictional boundaries are shown in Figure 2-10A and can be referred to as the jurisdictional coastal zone with as many as 15 Federal, state, and local agencies in play. A Local/State/Federal Joint Permit Application typically needs to be submitted for all shoreline erosion control projects. The application will be concurrently reviewed by the Mathews County Wetlands Board, the Virginia Marine Resources Commission (VMRC), the U.S. Army Corps of Engineers, and possibly other regulatory agencies in conformance with applicable local, state, and federal regulations.

The jurisdictional coastal zone (JCZ) extends both landward and seaward from the shoreline. The jurisdictional shoreline (JS) is defined by two tidal datums, MHW and mean low water (MLW) both of which have different agencies responsible for their management. The landward limit of the JCZ is defined by local zoning, primarily by the Chesapeake Bay Preservation Act (Bay Act) (http://www.dcr.virginia.gov/chesapeake_bay_local_assistance/index.shtml). The Bay Act has two land use jurisdictions, the resource protection area (RPA) and the resource management areas (RMA). The Resource Protection Area focuses importance on a functional upland buffer and allow for fully functional tidal and nontidal wetlands and tidal shores (CBLA, 2008). It establishes a buffer 100 ft wide located adjacent to and landward of these areas (Figure 2-10B). The buffer usually begins at the most landward edge of the protected habitats (Figure 2-10B). The RMA includes land types that, if improperly used or developed, have a potential for causing significant water quality degradation or for diminishing the functional value of the Resource Protection Area (CBLA, 2008) including floodplains, highly erodible or permeable soils and nontidal wetlands not included in the RPA. The RMA is contiguous to the entire inland boundary of the RPA (Figure 2-11). In accordance with the Chesapeake Bay Preservation Act, Mathews County adopted a zoning ordinance amendment that established both Resource Protection Areas and Resource Management Areas such that they encompass almost 30,000 acres or slightly more than one-half of the area of the County.

The seaward limit of the JCZ may go to the 3 miles boundary off the Virginia coast. All submerged lands seaward of MLW are under the jurisdiction of the VMRC and the U.S. Army Corps of Engineers. The Corps has jurisdiction from MHW seaward which includes the intertidal zone between MLW and MHW. The intertidal zone is defined as a non-vegetated wetland and is regulated by the local wetlands board. The local wetlands board in turn has jurisdiction from MLW to the landward limit of vegetated wetlands, and in some cases beaches and dunes.

3 Existing Conditions

3.1 Natural Shore Types

The status of the existing shoreline is the basis for the type of shoreline management strategy that is recommended. The state of the upland bank, whether it is stable, erosional or transitional is the primary parameter for strategy recommendations (Figure 3-1). Two components of the upland bank exist: the base of bank and the bank face or slope. Generally, if the base of bank is erosional then the bank face eventually will become erosional. It likely will evolve from a stable bank face to transitional to erosional over time. A naturally stable base of bank is usually “protected” by a wide marsh or beach/dune. Marsh shorelines tend to erode slower than adjacent upland banks because they are over-topped during storm events whereas the upland banks are directly impacted. When the marsh or beach erodes and becomes too narrow to abate storm wave action against the upland, then bank erosion ensues. It can be a very gradual process or occur relatively fast during a severe storm. Generally, the greater the fetch, the more severe the bank erosion. Once bank erosion begins, it will continue until stabilizing conditions return or a structure is built to protect it.

Bank height will affect the nature of erosion (Figure 3-2). While waves will impact the base of any eroding bank, the long-term fate of the bank slope will depend on bank height and composition. During severe storms, the waves may actually be active across the top of a low bank while at the same level they would be acting on the bank face of a higher bank. The processes of upland runoff and freeze thaw tend to be more active on the higher bank shorelines (Figure 3-3). In Mathews, most of the banks are low (< 5ft MW) from North River around to Milford Haven. They slowly increase in elevation to about +10 ft MLW in Queens Creek up to Ginny Point and increase up to 20 ft MLW up the Piankatank River (Figure 3-4).

3.2 Shoreline Structures

The Comprehensive Coastal Inventory Program (CCI) at VIMS has described the existing shoreline conditions along Mathews County’s tidal shoreline (Berman *et al.*, 2000; Berman *et al.*, 2009). The assessment used Global Positioning Systems (GPS), and Geographic Information Systems (GIS) to collect, analyze, and display shoreline conditions. These protocols and techniques have been developed over several years, incorporating suggestions and data needs conveyed by state agency and local government professionals (Berman and Hershner, 1999) and were used to describe the presence of shoreline structures for shore protection and recreational purposes. For detailed methodology and additional data, see the Mathews County Shoreline Inventory (Berman *et al.*, 2009).

Almost 50 miles of Mathews County’s shoreline has structures (Table 3-1). That accounts for about 14 percent of the total shoreline length. These structures vary from large breakwaters systems to unconventional structures/debris such as broken concrete revetments or old tires. Of the 50 miles, only about 3.1 miles are breakwaters or marsh toe revetments/sills which are considered to have habitat benefits. Groins are present along an additional 5 miles and

while these structures can accumulate sand, it is rare in Mathews County for them to create a beach wide enough to enable a dune system.

Table 3-1. Existing structures along Mathews County's shoreline (Berman *et al.*, 2009).

Type of Structure	Count	Length in Feet (Miles)
Breakwater	19	3,366 (0.6)
Bulkhead	242	43,767 (8.3)
Debris	70	6,675 (1.3)
Dilapidated Bulkhead	37	4,709 (0.9)
Groin Field	27	28,192 (5.4)
Jetty	13	1,815 (0.3)
Marina <50 slips	17	5,726 (1.1)
Marina >50 slips	4	4,486 (0.9)
Marsh_Toe	77	13,096 (2.5)
Riprap	577	140,111 (26.5)
Unconventional	48	7,112 (1.4)
Wharf	9	2,374 (0.5)
Total	1140	261,430 (49.5)

Between 1999 and 2008, structures were built along about 17 miles of Mathews shoreline (Table 3-2). The majority, almost 12 miles, of shoreline hardening was through the use of riprap revetments or bulkheads. During this time, only about two miles of breakwaters and marsh toe revetments/sills were constructed.

Table 3-2. Change in the length of shoreline between those that did not have a structure on it in 1999 and what structures were placed on the shoreline in the intervening nine years (Berman *et al.*, 2009).

1999 Shore Designation	2008 Shore Designation	Shore Length Change feet (miles)
No Structure	Breakwater	1,945 (0.4)
No Structure	Bulkhead	15,476 (2.9)
No Structure	Debris	4,379 (0.8)
No Structure	Dilapidated Bulkhead	1,507 (0.3)
No Structure	Groin Field	9,164 (1.7)
No Structure	Jetty	741 (0.1)
No Structure	Marsh_Toe/sills	7,448 (1.4)
No Structure	Riprap	46,194 (8.7)
No Structure	Unconventional	3,057 (0.6)
	Total	89,912 (17.0)

3.3 Tide and Storm Surge

The tide range varies across County shorelines (Figure 3-5). The mean tide range, which is the difference between high and low water levels is nearly a foot larger in the North and East Rivers and Mobjack Bay than farther north at Gwynn's Island and along the Piankatank River (Table 3-3). The spring range, which is the difference between high and low tidal levels during the periods of increased range around the full and new moons, in the North River is nearly double the range along the Piankatank River. Tide range is an important factor in effective shore stabilization strategies.

Table 3-3. Tide Ranges around Mathews County from the 2009 NOAA Tide Tables, <http://tidesandcurrents.noaa.gov/tides09/tab2ec2c.html#56>.

Location	Mean Range (ft)	Spring Range (ft)	Mean Tide Level (ft)
Belleville, North River	2.48	3.00	1.36
East River, Mobjack Bay	2.40	2.90	1.30
New Point Comfort*	2.3	2.8	1.2
Wolftrap Light*	1.60	1.94	0.90
Cherry Point, Gwynn's Island*	1.2	1.4	0.7
Dixie, Piankatank River	1.30	1.57	0.72

*These data came from NOAA's 2007 published tide tables.

The coastal areas of Mathews County are vulnerable to tidal flooding from both hurricanes and northeasters, both of which have the potential to produce winds which push large volumes of water (and thus energy) against the shore. The amount of flooding depends on the topography of the area, rate of rise of flood waters, the depth and duration of flooding, and the exposure to wave action (FEMA, 2007). Floods caused by hurricanes are usually of much shorter duration than northeasters. The timing of the maximum storm surge with normal high tide is an important factor in determining the amount of tidal flooding. FEMA (2007) indicates that the stillwater elevations that could be expected during a 10-yr, 50-yr, 100-yr and 500-yr event are 5.8 ft mean lower low water (MLLW), 7.3 ft MLLW, 8.1 ft MLLW, and 10.1 ft MLLW, respectively. For a 100-yr event, the maximum stillwater and wave hazard elevation is 11.8 ft MLLW (FEMA, 2007). Figure 3-6 shows those areas closest to the water that would be flooded and vulnerable to damage during a 100-yr event. Inland, where waves will not impact, the areas that would be flooded by the stillwater level also are depicted. During a 500-yr event, most of the eastern most sections of Mathews would be flooded.

Three recent storms have impacted Mathews' coast. On September 18, 2003, Hurricane Isabel passed through the Virginia coastal plain. The main damaging winds, with gusts up to 69 mph at Gloucester Point (Figure 2-1), began from the north and shifted to the east then south.

The highest water level recorded at nearby Gloucester Point tide gauge was 8.2 ft above MLLW, and 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 20 mph and a peak gust of 27 mph with water levels rising above 6.0 ft above MLLW at the Yorktown USCG Training Center tide station (NOAA, 2009). The Veterans Day Northeaster on November 11, 2009 had water levels of 6.9 ft above MLLW with wind speeds at 48 mph with gusts at 58 mph (NOAA, 2009).

The impact of the Veteran's Day Northeaster on Mathews' Chesapeake Bay coast was documented through beach profiling at Bavon Beach (Figure 2-2). Post-storm profiles at Bavon showed dune retreat along the south end of over 30 ft (Figure 3-7A) while massive amounts of sand were pushed onshore at Bethel Beach. Sand loss and undermined structures are scattered along Gywnn's Island (Figure 3-7B). The breakwater at Festival Beach (Figure 2-8A) performed admirably with no appreciable loss of beach sand.

3.4 Sea-Level Rise and the Response of Marshes and Beaches

The level of the sea is rising at a rate of 1.25 ft/century (Figure 3-8). One of the most simple consequences of sea-level rise is that the shoreline will move landward as low areas are inundated. Others are that storm tides will reach farther inland; erosion will accelerate; some septic systems in low areas will fail; some wells will start to yield brackish water; tidal marshes will change and beaches may be lost. Reed *et al.* (2006) found that the wetlands of Mathews County should be able to keep pace with sea level rise at a rate of 0.12 in/yr and may not be converted to open water. However, they also indicated that if the sea level rate increases by just 0.3 inches/yr, the marshes very well could be lost. Unfortunately, the actual rate of rise at Gloucester Point is 0.15 in/yr (Table 3-1) indicating that marshes could be impacted sooner than expected. A detailed analysis of Mathew's geology and sea-level rise rates are found in [Appendix C](#).

The response of a tidal marsh to sea-level change is complex. In areas where the marsh is relatively thick, it can be even more complex as the marsh can compact, or settle, under its own weight (Kaye and Barghoorn, 1964; Pizutto and Schwendt, 1997; among others). This results in a lowering of the marsh surface and an increase in the relative sea level. Being able to sustain the surface of a tidal marsh largely depends upon the balance between the rate of sea-level rise and the rate at which the marsh surface collects sediment. There are two primary sources of material to the marsh surface: decomposition of local marsh plants and sediments carried in with the tide. If the upward growth of the marsh surface through accumulation of newly deposited material, accretion, is in balance with the local rate of sea-level rise, the marsh will experience little change; the marsh might expand landward across a gently sloping shore and the outer edge of the marsh could move landward or seaward or could remain in place depending upon other factors.

If, however, sea-level rise exceeds the accretion of the marsh surface, the entire marsh sequence will migrate landward. Marsh plants have to tolerate both saline waters and

submergence. The species of plant changes along a transect across the marsh from the open water to the upland. Different plants have different tolerances to the frequency, duration, and depth of submergence. If the area immediately inland from the marsh slopes gently, as the overall sea level rises and tidal waters reach farther inland, new marsh can grow on the newly flooded lands. Depending on what occurs at the water side of the marsh, this might or might not result in an increase of marsh area. The outer edge of the *Spartina alterniflora*, saltmarsh cordgrass, which will be inundated too deeply and for too long, will die and the shoreline will retreat. The plants of the main marsh surface also may die if the *S. alterniflora* could not colonize the areas formerly occupied by higher marsh plants. Should this occur, it is most likely that marsh areas would become open water.

The fate of marshes is important because so much of Mathews County is mudflat, tidal marsh, or very low ground that abuts the marsh. The complex response of marshes to sea-level rise in Mathews is shown in [Figure 3-9](#). In section 1 on [Figure 3-9](#), the face of the marsh has eroded between 1937 and 2007, however, the decline in trees in the upland indicates that the marsh has been able to migrate landward. In section 2 on [Figure 3-9](#), the tree line is relatively unchanged indicating that the marsh has not been able to move into the upland area. Not only has the face of the marsh eroded, but also the marsh itself cannot keep up with sea-level rise and is being converted to open water. The marshes behind Bethel Beach, in and near Winter Harbor are very much at risk both to degradation as a consequence of inundation and to physical erosion that is occurring due to the collapse of the Bethel Beach barrier ([Figure 3-10](#)).

The very thin strands of sand extending in a line along the Chesapeake Bay shore of Mathews from Gwynn Island continuing through Rigby Island and Bethel Beaches are barrier islands. Even as fragile as they are today, these islands protect the marshes in the lagoons behind them and the mainland from assault by waves in the Bay. According to Pilkey (2003), there are five conditions that must be met for barrier islands to exist. Sea level must be rising (1) over a gently sloping mainland surface (2). There must be an adequate supply of sand (3), energetic waves (4), and a low to intermediate tidal range (5). The Bay shore of Mathews meets all of these conditions except, it appears, the adequate supply of sand.

The lack of sand has manifested itself in several ways. The barrier islands and beaches have not been able to grow such that they contain a reserve volume of sand sufficient to maintain them through strong storms. Although there are some small areas that contain very small sand dunes, the dunes are so diminutive that many people would not recognize them as “sand dunes.” During a severe storm with an elevated water level, the storm waves wash fully over much of the thin barrier. As the waves push across the barrier, they transport sand from the front and main body of the island to the marsh or lagoon. That sand is lost from the barrier and cannot help rebuild it. As sea level rises, it encroaches on both sides of the barrier with the result that the barrier becomes thinner. This makes the barrier even more fragile. These circumstances work together so that the barriers along the Bay shore of Mathews have degraded and are collapsing ([Figure 3-10](#)).

Should the barriers disappear completely, storm waves will directly attack the marshes and mud flats in Winter Harbor and the newly exposed shore elsewhere. Areas with a easterly or northeasterly exposure to the Bay across the eastern portion of Milford Haven and The Hole in the Wall will be subjected to increased erosion.

3.5 Existing Marine Resources

Marine resources, both natural and aquacultural areas, are shown in GIS through existing databases ([Appendix D](#)). They are included as a layer in the existing conditions element of the plan. No new data has been created for this report. The source data are:

Tidal Wetlands Inventory - VIMS, Center for Coastal Resources Management, 1988

Tidal wetland data were collected through site visits to all tidal marshes in Virginia using aerial photography for assistance. The geographic boundaries of tidal marshes were digitized from USGS 7.5 minute topographic quadrangle maps (scale = 1:24000). Aerial photography was used to correct for obvious discrepancies in the boundaries observed. The community structure and composition were described through site visits to all tidal marshes in the Tidewater region of Virginia. Composition was based on estimated percent cover of wetland species observed during site visits. http://ccrm.vims.edu/gis_data_maps/data/index.html

Aquaculture Vulnerability Model (AVM) - VIMS, Center for Coastal Resources Management, completed in 2007 but consists of data extracted from existing sources.

The purpose of the AVM was to model risks to shellfish aquaculture. The model first considers basics physical and biological conditions necessary for aquaculture success, and second, the impacts that current land use and proposed local zoning have on suitable growing areas. The study used data from federal, state, and local government sources to derive salinity, bathymetry, submerged aquatic vegetation (SAV) distribution, water quality, land use, and local zoning. A vulnerability index is scaled to reflect current and projected conditions and the resulting impact to shellfish growing. http://ccrm.vims.edu/gis_data_maps/data/index.html

Blue Infrastructure - VIMS, Center for Coastal Resources Management

This online mapping tool integrates important aquatic resources that have been compiled for the coastal zone of Virginia using GIS technology. The data used for this tool represents archives from a variety of agencies and programs. Data from VIMS's Comprehensive Coastal Inventory Program (CCI) and Submerged Aquatic Vegetation (SAV) Program were layers plotted on the maps as were layers from the Dept. of Conservation and Recreation, the Dept. of Game and Inland Fisheries, Virginia Marine Resources Commission, and Virginia Commonwealth University. Layers include: aquaculture sites (hard clams and oysters) and mud flats. http://ccrm.vims.edu/gis_data_maps/interactive_maps/blueinfrastructure/disclaimer_bi.html

SAV - VIMS, Submerged Aquatic Vegetation (SAV) Program

The 2007 Chesapeake Bay SAV Coverage was mapped from 1:24,000 black and white aerial photography. Each area of SAV was interpreted on-screen from the rectified photography and classified into one of four density classes by the percentage of cover. Data on the final 2006 SAV distribution is stored as ArcInfo GIS coverages. <http://www.vims.edu/bio/sav/>

4 Methods

4.1 Shore Change

In order to understand the suite of processes that alter shorelines, knowledge of the history of shoreline change is essential. Images of Mathews from 1937, 1953, 1968, 1978, 1994, 2002, and 2007 were used in the analysis. Chesapeake Bay and Piankatank River orthorectified historical and recent imagery, and digitized shorelines exist for Mathews County (Hardaway *et al.*, 2005). Using the same procedures, the photos showing the smaller creeks and rivers flowing into Mobjack Bay were rectified. The 1994 imagery was orthorectified by the U.S. Geological Survey (USGS) and the 2002 and 2007 imagery was orthorectified by the Virginia Geographic Information Network (VGIN).

The 1937, 1953, 1968, and 1978 images were scanned at 600 dpi and converted to ERDAS IMAGINE (.img) format. They were orthorectified to a reference mosaic, the 1994 Digital Orthophoto Quarter Quadrangles (DOQQ) from USGS. The original DOQQs were in MrSid format but were converted into .img format. ERDAS Orthobase image processing software was used to orthographically correct the individual flight lines using a bundle block solution. Camera lens calibration data were matched to the image location of fiducial points to define the interior camera model. Control points from 1994 USGS DOQQ images provide the exterior control, which is enhanced by a large number of image-matching tie points produced automatically by the software. A minimum of four ground control points was used per image, allowing two points per overlap area. The exterior and interior models were combined with a digital elevation model (DEM) from the USGS National Elevation Dataset to produce an orthophoto for each aerial photograph. The orthophotographs that cover each USGS 7.5 minute quadrangle area were adjusted to approximately uniform brightness and contrast, and were combined using the ERDAS Imagine mosaic tool to produce a 3 ft resolution mosaic also in Imagine (*.img) format. To maintain an accurate match with the reference images, it was necessary to distribute the control points evenly. This can be challenging in areas with little development. Good examples of control points are manmade features such as corners of buildings or road intersections and stable natural landmarks such as easily recognized isolated trees. The orthorectified photo mosaics are available in digital format only ([Appendix E](#)).

Once the aerial photos were orthorectified and mosaicked, the shorelines were digitized in ArcMap with the mosaics in the background. Digitizing the shoreline is particularly challenging in the smaller creeks and rivers of the County. Vegetation, narrow shore features, and small rates of change can challenge the accuracy of digitized shoreline. For this reason, in some areas, only the 1937 and 2007 shorelines were digitized. In a few cases, the 1937 photos were considered too inaccurate to include in the data set. In these cases, the photos are useful to determine land use change but could not be used to determine a rate of change.

The toe of the beach or the edge of the marsh was delineated as the shoreline. These features approximate low water. In some areas where the shoreline was not clearly identifiable on the aerial photography, the location was estimated based on the experience of the digitizer.

The displayed shorelines are in shapefile format. One shapefile was produced for each year that was mosaicked.

Horizontal positional accuracy is based upon orthorectification of scanned aerial photography using USGS DOQQs. Vertical control is the USGS 100 ft DEM. The 1994 USGS reference images were developed in accordance with National Map Accuracy Standards (NMAS) for Spatial Data Accuracy at the 1:12,000 scale. The 2002 and 2007 VGIN images were developed in accordance with the National Standard for Spatial Data Accuracy (NSSDA). Horizontal root mean square error (RMSE) for historical mosaics was held to less than 20 ft. These standards for the individually orthorectified images.

Once the images are combined to a mosaic and a shoreline digitized, it becomes necessary to determine a meaningful measure of the error in the calculated rate of shoreline change. The cumulative error in photo orthorectification, control source, DEM, and digitizing was estimated to provide an estimate of total maximum shoreline position error (Morton *et al.*, 2004; FGDC, 1998). Since each data source and method for orthorectifying each data set is different, they have different estimated shoreline positions errors. The orthorectified data sets (1937, 1953, 1968 and 1978) have an estimated total maximum shoreline position error of ± 20.0 ft which means that the shoreline can be up to 20 ft on either sides of the digitized position. The total shoreline error for the three existing data sets are estimated at ± 18.3 ft for USGS and ± 10.2 ft for VGIN. Using the methodology of Morton *et al.* (2004), these result in a maximum annualized error for the shoreline data of ± 0.7 ft/yr.

These numbers are the maximum potential error; in reality, the actual error likely is far less. The largest errors in the calculation comes from the error inherent in rectifying the images. In most cases, the quality control checks indicate that the accuracy of the rectified photos was far better than the maximum potential error.

The End Point Rate of Change was determined between the 1937 and 2007 shorelines along the larger creeks, river and the Bay. Using procedures developed for the series of Shoreline Evolution reports created by Shoreline Studies Program (Hardaway *et al.*, 2005), rates of change calculated, categorized, and plotted. In some areas, a net change in shore position is indicated as 0 ft/yr. This does not mean that the shoreline has not changed in 70 years. It simply means that any positive (accretionary) shoreline changes are offset by negative (erosional) changes over this time period resulting in no net change.

4.2 Wave Climate

The wave climate describes the overall wave energy that impacts the shoreline through time. The wave climate along any given shoreline is a function of fetch and nearshore bathymetry. Fetch is defined as the distance over water that wind can blow and generate waves and was determined for each site where a recommendation was given. The 2007 VGIN image mosaic and its corresponding shoreline were used to determine the starting point of each fetch location, while a bay wide shoreline from National Oceanic and Atmospheric Administration

(NOAA) and a 30 meter bathymetric DEM from NOAA were used to establish the end shoreline locations. At each of the fetch locations, the length of each fetch line was computed along with the direction of the longest fetch line, the direction of the center fetch line and the effective fetch for each location. The shoreline and fetch center line shapefiles and the DEM information were input to an Arc Macro Language (AML) program running in ArcInfo Workstation which produced two sets of six additional vectors for each fetch location. The additional vector lines were spaced at six degree intervals on either side of the original centerline, starting at the same point as the corresponding centerlines and extending to the opposite shoreline.

In order to model the wave height and period associated with specific storms, the Nearshore Evolution MODELing System was used (NEMOS). NEMOS simulates the long-term planform evolution of the beach in response to imposed wave conditions, coastal structures, and other engineering activity. NEMOS is part of the Coastal Engineering Design and Analysis System (CEDAS) (Veri-Tech, Inc., 2009). Specifically, the grid generator was used to develop a bathymetric grid over which wave conditions were modeled.

Georeferenced soundings and depth contour information were obtained from NOAA's Electronic Navigational Charts (NOAA ENC) online database. These data were used to create a grid of the Chesapeake Bay near Mathews County (Figure 4-1). STWAVE was used to model storm waves across this grid. STWAVE uses a finite-difference representation of a simplified form of the spectral balance equation to simulate near-coast, time-independent spectral wave energy propagation. This model simulated wind-driven storm waves from the northeast, east, and southeast resulting only from a persistent high winds during two different storm conditions, the 50 year and 100 year events for the Bay coast of Mathews. Wind speeds modeled were 40 miles/hour (mph) and 50 mph for the 50 year and 100 year, respectively. The storm surges are based on the predicted levels in FEMA (1987) and are 6.5 ft NGVD and 7.3 ft NGVD for the 50 year and 100 year, respectively. Based on tidal datums at Gloucester Point, NGVD is 0.80 ft above MLLW. Since the bathymetric grid is at MLLW, the water elevations were converted to MLLW for use in the model, 7.3 ft MLLW and 8.1 ft MLLW.

4.3 Shore Management Strategy Development

Living Shoreline strategies are recommended for each section of identified, actively-eroding coast. The initial analysis was made from a small, shallow draft vessel, navigating at slow speeds parallel to the shoreline during seven field days between May and December 2008. Strategies were coded into handheld GPS unit, the GeoExplorer XH, and written on maps which were transcribed in the office. The GPS data were downloaded, processed as raw data and in GIS to display the management strategies. Once the data were compiled and evaluated, the preferred strategies were subjected to further analysis utilizing other collected data, including the condition of the bank face and toe, marsh width, landscape type, and GPS-referenced photos.

The primary erosion control approaches displayed in this Plan, therefore, are based on a comprehensive analysis of all geological, physical, and biological factors influencing the shoreline dynamics. Future ecological impacts also are considered as well as future threats from

sea-level rise. These strategies are considered to be the optimized on-site approach and should be viewed as the preferred science-based recommendation. Protection of personal capital and investment is the primary objective of the property owner when dealing with an eroding shoreline. The fundamental purpose of this Plan is shoreline stabilization, and although there certainly are other options for erosion control, the recommendations presented in this Plan, if properly constructed and maintained, will protect the upland for many years to come as well as create the living connection to the shoreline that enhances living on the waterfront.

The decision to apply a primary shore stabilization approach is based on the condition of the upland bank at the time of the survey. The erosive force operating on the upland banks varies with fetch. The base of bank and bank face can be erosive, transitional (from stable to erosive or visa versa) or stable. Stable banks do not receive a recommendation since they are either already protected with a structure or have a sufficiently wide marsh fringe. If the shore protection is failing or inadequate then a note is made with a possible recommendation.

The base of bank condition is the key. If it is erosive, undercut, scarped or slumping then the potential exists for bank face instability. The bank condition reflects the seriousness of the problem. When shoreline erosion strategies are applied, the interface with the riparian edge also 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 necessary. Graded banks should be replanted with the proper native vegetation.

Geomorphic opportunities were used whenever possible to develop optimized shoreline protection strategies. For example, a naturally embayed shoreline between two headlands may see the structures recommended to protect the headlands with the intent that the shore between will stabilize. Other opportunities include recommending additional structures, such as spurs, attached to existing structures to enhance the shoreline protection.

The recommendations are of types listed in [Section 2.2](#) of this report. Cross-sections for most of the recommended structures were created. These cross-sections show the slope of the created marsh/beach, the size of the structure in relation to the tide range, bank interface, as well as an estimated cost per linear foot of shoreline. The cost is an estimate of the installation cost of the rock, sand and plants. It does not include any additional work necessary such as obtaining site access, project cleanup, permit preparation, etc.

It should be noted that not all eroding coasts receive recommendations and not all eroding coasts may be identified. Factors such as vegetative cover and tide level may have hidden erosion of the bank or front of marsh. Some areas of land that are not and likely will not be developed, such as the extensive marshes in the eastern section of the County, may be eroding, but they did not receive a recommendation as they are unlikely to ever be developed. Depending on tide level during the site visit, the front edge of fringe marshes may not have been identified as eroding.

For ease of discussion, three reaches were created for the Plan. Reach 1 is located along

the Piankatank River while Reach 2 includes Gwynn Island, Milford Haven and Mathews Chesapeake Bay shoreline. Reach 3 includes the Mobjack Bay shoreline as well as the East and North River shorelines.

5 Reach 1: Piankatank River, Hills Bay, and Queens Creek

5.1 Shore Conditions

Reach 1 includes almost 40 miles of shore along the Piankatank River including Hills Bay (west of the bridge to Gwynn's Island) and Queens Creek (Figure 5-1), and has some of the highest elevations in Mathews. Along the Piankatank River from Holland Point to Ginney Point, the banks reach elevations of 20 ft above MLW (Figure 5-2A) and are eroding at -0.5 to -2 ft/yr (Appendix A-1 and A-2). Sections of this shore are slightly accretionary, which could be attributed to the influence of structures along the shoreline, slumping of the banks and transport alongshore, or error in the orthorectified images since the rates of change are so minimal. From Ginney Point to Iron Point closer to Hills Bay (Figure 5-2B), the banks are lower (about 10 ft) and much of the shoreline contains numerous structures. These shorelines have higher erosion rates generally varying between -1 to -5 ft/yr (Appendix A-3). The shorelines along Cobbs Creek are typical of the fetch-limited creek shorelines throughout Mathews (Figure 5-2C). Trees typically shade the banks which results in the a reduction or elimination of the fringe marsh, thereby exposing the base of bank and increasing its vulnerability to erosion. The general erosion rate is minimal along these shores, but the perception of an eroding bank often leads to structure placement. The nearshore along the Piankatank River varies from fairly deep in the nearshore in the area around the Route 3 bridge (Figure 5-1) to wider nearshore areas with broad shoals such as off Warehouse Cove and Burton Point.

Along Queens Creek, much of the shore zone is generally between +5 and +10 ft MLW (Figure 5-2D). It is a narrow, fetch-limited creek with minimal erosion rates (Appendix A-3). The banks along the southern shore of Hills Bay are low, about 5 ft MLW, and much of the unaltered shorelines are eroding (Figure 5-2E and F). The nearshore is wide and shallow upstream of the bridge. The Queens Creek entrance channel has been dredged five times since 1967 with the most recent in 2009. The mostly sandy material from the channel has been placed along several sections of the Hills Bay shore.

The mouth of the Piankatank River was included in the wave climate analysis (Figure 4-1). The results show that the northeast waves affect this reach the most (Table 5-1) Station 1 is located off Burton Point and showed that during an event with a water level at 7.3 ft MLLW and a sustained 50 mph wind, an almost 3 ft wave would occur along the Hills Bay shoreline. Station 2, in addition to being very sheltered, was placed too close to shore to provide an accurate prediction of wave conditions during these modeled events.

5.2 Design Considerations and Recommendations

A variety of structures already exist along this reach (Appendix B-1 to B-8), some of which are more effective than others. Shore protection using non-standard materials (Figure 5-2G) may be effective in the short-term, but they can be unattractive and hazardous in the long-term if they fail. On the Piankatank River at the mouth of Cobbs Creek, a high, alongshore sill is providing protection for a fringe marsh (Figure 5-2H). However, it provides only modest

protection for the bank face continues to erode. In order to be effective for bank erosion control, a sill system should provide an effective base elevation for to attenuate storm surge. As shown in [Figure 5-3](#), the interface between the marsh and bank should be less steep either through bank grading or fill placement. At Warehouse Cove on the Piankatank River, a low sill effectively stabilizes the marsh ([Figure 5-2I](#)) that faces southeast and has a shorter fetch. On this same property, as the shoreline turns to face the northeast and is exposed to a longer fetch, a bulkhead and a riprap revetment were built.

Bank height and the variation in fetch along the shoreline are considerations for determining the type of structures recommended for this Reach ([Appendix B](#)). The recommended structures are summarized in [Table 5-2](#) and include site recommendations 268 to 352. The typical cross-sections are shown in [Figure 5-3](#). There are 85 site recommendations along Reach 1 covering over 7 miles of shoreline.

The high bank shorelines (>20ft) along the Piankatank River range from stable to erosional. Many are erosional bases of bank with relatively stable bank slopes. The landuse is residential and/or wooded with the potential for development. Although erosion rates are low and banks relatively stable, shore hardening, usually with stone revetments, occurs both with grading ([Figure 5-4A](#)) and without ([Figure 5-4B](#)). Therefore, when base of bank conditions warrant a recommendation, a living shoreline alternative is provided, usually a low to medium sill system. This subreach has 41 recommendations numbered 310 to 352 ([Appendix B-1 through B-4](#)) which include low sills, medium sills, revetments and breakwaters. Six medium sill sites are recommended because of the high banks. The decision to grade the bank should be addressed at the site design level.

The Godfrey Bay/Hills Bay subreach includes sites numbered 303 to 310 which mostly address eroding upland banks of about +10 to +15 ft MLW. Much of this coast has been hardened. Chapel Creek is considered one site (309) and the Plan recommends marsh management around the perimeter of the creek that has many undercut banks, overhanging trees and narrow intertidal exposures. Sites 308 and 309 are residential properties that have relatively stable, but very exposed, shorelines on residential properties; they are good candidates for breakwater systems.

The Queens Creek subreach is mostly +10 ft upland banks with little or no marsh fringe, undercut and erosional bases of bank, and stable to transitional bank slopes. Recommendations are numbered 268 to 310 and include small low sills, low sills, and marsh management.

About 7.4 miles of recommendations are made for the shoreline within Reach 1 ([Table 5-1](#)). Numerically, low sill had the most recommendations, but marsh management had longer sites such that the total site length was nearly double that for low sills.

Table 5-1. Wave data model output for a idealized 50-yr and 100-yr events with northeast, east, and southeast winds.

Station Number	Northeast						East						Southeast					
	50-yr event			100-yr Event			50-yr event			100-yr Event			50-yr event			100-yr Event		
	Hmo	T	Dir	Hmo	T	Dir	Hmo	T	Dir	Hmo	T	Dir	Hmo	T	Dir	Hmo	T	Dir
1	2.8	5.3	236	2.9	5.7	236	2.4	5.3	241	3.1	5.7	241	1.6	5.00	241	2.4	5.9	256
2	0.2	4.5	184	0.2	4.5	181	0.1	4.5	185	0.1	4.7	185	0.8	4.8	185	0.1	4.5	184
3	3.1	5.3	213	4.0	5.7	216	3.8	5.3	242	4.7	7.0	241	3.7	5.0	256	5.1	5.9	256
4	4.2	5.3	241	5.3	5.7	238	4.3	5.3	263	5.5	5.7	265	3.1	5.0	281	4.3	5.9	279
5	3.8	5.3	238	5.2	5.7	241	4.6	5.3	263	5.8	5.7	264	3.2	5.0	284	4.4	6.2	281
6	4.5	5.3	236	5.9	5.7	238	4.3	5.3	261	5.8	5.7	265	2.6	5.0	281	3.8	5.9	277
7	4.5	5.3	238	5.7	6.2	236	4.7	5.3	264	5.9	7.0	269	4.0	5.3	304	5.2	6.2	299
8	4.2	5.3	237	5.2	6.2	242	4.2	5.3	270	5.3	5.7	259	3.1	5.3	296	4.1	5.9	296
9	4	5.3	237	5.1	5.7	241	4.3	5.3	261	5.4	5.7	259	3.6	5.3	295	4.6	5.9	296
10	4.4	5.3	237	5.8	5.7	236	4.5	5.3	263	5.7	5.7	269	4.2	5.3	303	5.4	5.9	296
11	4.4	5.3	237	5.7	6.2	238	4.8	5.3	270	6.1	7.0	265	4.4	5.3	299	5.8	6.2	298
12	4.2	5.3	237	5.5	6.2	231	4.9	5.3	267	6.3	7.0	279	5.0	5.3	304	6.5	6.2	299
13	3.8	5.3	242	5.1	5.7	250	4.4	5.3	259	5.7	5.7	279	4.7	5.6	307	6.1	5.7	304
14	2.7	5.0	261	3.5	6.2	261	4.3	5.3	284	5.6	5.7	281	4.1	5.3	307	5.3	5.7	304
15	3.1	5.0	253	4.2	5.7	256	4.2	5.3	327	5.2	5.7	273	3.9	5.6	298	5.2	5.7	290
16	3.0	5.3	256	3.9	5.7	259	3.9	5.3	282	4.9	5.7	284	4.2	5.3	310	5.4	6.2	300
17	3.3	5.0	250	4.3	5.7	250	4.6	5.3	277	5.8	5.7	279	4.6	5.3	311	6.0	5.7	300
18	3.7	5.0	326	5.7	5.7	276	4.5	5.3	296	5.5	5.7	299	4.1	5.3	324	5.3	5.7	326
19	3.1	5.6	320	4.0	6.2	284	3.4	5.3	305	4.1	7.0	306	2.6	5.6	324	3.1	6.2	324
20	3.1	5.6	324	4.1	6.2	281	3.3	5.3	287	3.9	7.0	284	2.7	5.6	307	3.4	6.2	307
21	1.2	5.0	310	0.2	6.2	342	0.3	5.3	346	0.6	7.0	342	0.3	5.6	336	0.6	6.2	339
22	1.1	5.6	317	0.2	6.2	338	0.3	5.3	330	0.4	7.0	333	1.1	4.5	347	1.6	4.5	328
Average	3.3	5.24	256.07	4.2	5.85	253.20	3.6	5.26	274.66	4.6	6.13	273.57	3.3	5.24	295.44	4.3	5.84	292.68

Hmo = Significant wave height (ft)

T = Period (seconds)

Dir = Wave heading direction (°TN)

50-yr input: wind speed = 40 mph, surge = 6.5 ft

100-yr input: wind speed= 50 mph, surge = 7.3 ft

Table 5-2. Recommended strategies for Reach 1.

Type of Structure	Total Number of Recommended Strategies	Total Site Length (feet)	Average Site Fetch (feet)
Marsh Management	11	16,930	210
Beach Fill	1	270	2,890
Spur	3	390	28,530
Small Low Sill	23	3,410	770
Low Sill	29	9,720	5,480
Medium Sill	6	1,830	4,450
Revetment/RipRap	4	420	1,520
Breakwaters with Beach Fill	10	6,090	41,300
Total	87	39,060	

6 Reach 2: New Point Comfort to Gwynn's Island including Milford Haven

6.1 Shore Conditions

The total shoreline length from New Point Comfort to Cherry Point, around Gwynn's Island, Milford Haven, and inside Winter and Horn Harbors is about 170 miles. The conditions along this reach vary from small, fetch-limited creeks to the open Bay shore (Figure 6-1). The open Bay coast from Cherry Point to New Point Comfort is considered separately (as a subreach of Reach 2) due to the disparity in onshore energy potential.

6.1.1 Gwynn's Island and the Bay Coast of Mathews

The eastern side of Mathews County from New Point Comfort to Cherry Point has the most exposed shorelines in the county. The longest fetches to the northeast, east, and southeast are 35 miles, 15 miles, and 18 miles, respectively. However, a long fetch to the north up most of Chesapeake Bay can impact the upper reaches of this shoreline. In addition, the lower reaches of this shore can be exposed to oceanic waves coming through the mouth of the Bay. The overall reach has transformed from a relatively continuous sandy barrier island chain from Gwynn's Island to Horn Harbor to one that has been breached and fragmented (Figure 2-2).

Developed areas occur along the few scattered uplands along the Bay subreach of Reach 2. Most development occurs at Gwynn's Island, New Point Campground/Sandy Bank, and Chesapeake & Bavon Beaches (C&BB) with a few houses at Bethel Beach and one north of Winter Harbor (Figure 6-1). The barrier island segment known as Rigby Island is all but eroded away (Appendix A-6). At Hole in the Wall where properties on Point Breeze and Lilley's Neck have become exposed to open Bay conditions, the shorelines have been hardened with stone revetments (Figure 6-2). The properties along the old Whites Creek shoreline presently have some protection from open Bay conditions due to the remnant of Rigby Island, but as the Island continues to erode, they will be subjected to increased wave action (Appendix A-9).

Overall, this subreach has medium to high erosion (-2 to -5 ft/yr and -5 to -10 ft/yr) (Appendix A-5, A-6, A-9 to A-11). Just north of the entrance to Winter Harbor, the end point rate of shore change shows accretion. This is due to the placement of dredge spoil over time from the Harbor (Appendix A-11 and A-12). Dredge material was also placed north of Dyer Creek (Appendix A-13). Very high erosion (-10 to -14 ft/yr) has been occurring at New Point Comfort (Appendix A-14). When finished in 1805, the New Point Comfort Lighthouse was on a 75 acre peninsula (Hardaway *et al.*, 2008). Even as long ago as 1853, erosion had segmented the shore and left the lighthouse on an island. That island was much smaller by 1937 and by 1960, erosion had left the lighthouse isolated in Chesapeake Bay (Figure 6-3).

Gwynn's Island

The northwest-facing side of Gwynn's Island, which is much less dynamic than the Bay side, has had minimal change between 1937 and 2007 ([Appendix A-5](#)) mainly due to the construction of shore-stabilization structures ([Figure 6-4](#)). Various types of shore structures, both constructed and dumped, exist along the shore. Most bulkheads and revetments are built to withstand certain storm conditions. Other types of structures such as the undersized riprap ([Figure 6-4C](#)) or broken concrete ([Figure 6-4F](#)) are not built to specifications but are simply dumped along the shore. These typically are less effective at shore stabilization than properly built structures. Bank erosion still occurs along sections of the shore even though they are fronted by a "structure". This threatens the main access road to the island.

The Bay coast of Gwynn's Island is the most developed along this reach. Many of the properties have some form of erosion control in the form of groins alongshore backed by a bulkhead or stone revetment ([Figure 6-5](#)). Shoreline hardening occurs on 68% of Gwynn's Bay coast. Only about 4,300 ft out of 13,600 ft of shoreline have no structures. The effectiveness of the structures and the beach in front varies along the shore. When only a narrow beach and intertidal zone exists, vegetation cannot become established ([Figure 6-5](#)) reducing the overall effectiveness of the beach as shore protection. The numerous groins along Gwynn's Island were built to trap sand and can help maintain sand in front of revetments and bulkheads. However, they tend to restrict sand movement alongshore and onto adjacent properties ([Figure 6-5](#)) and may accelerate sand loss during storms. Along Gwynn's Island, groins may bound non-hardened properties creating small pocket beaches where sand accumulates and dunes evolve enhancing storm protection.

Beaches in front of hardened structures can disappear after a large storm and may subsequently recover, but it is important that the structure be designed and built to withstand the sand loss, scour, and potential undercutting. With few exceptions, the non-hardened shore segments have a beach and dune profile that can offer protection against moderate-sized storms. However, as witnessed during Hurricane Isabel and, more recently, the Veteran's Day Storm, the sand beaches and dune can be carried landward as overwash. Post-storm recovery may allow the dunes to re-establish themselves. This can be accelerated with the use of sand fencing and grass plantings. During storms, Gwynn's Island is impacted by waves that can be up to 6 ft high ([Table 5-1](#)). Stations 6 and 7 have the largest waves when the wind blows from the northeast and east.

Coastal surveys of Gwynn's Island as far back as 1863 show how erosion of the upland region provides sand to the short northern spit and the much elongated southern spit. This geomorphic "discrepancy" indicates not only a net movement to the south but also a divergence zone on the northeast side where sediment transport would go north then south. ([Figure 6-6](#)). By 1937, the southern spit had shortened by 3,000 ft and the northern spit lengthened by about 700 ft. Shoreline change for four segments of Gwynn's Island is shown for time periods 1853 to 1937 and 1937 to 2007 ([Figure 6-6](#)). Shore recession rates for the earlier time period are relatively consistent and average about 7.5 ft/y while the later time period averages about 3.4

ft/yr, less than half. Shore recession on Section D is about the same for both time periods. The erosion rate along the main island coast (Sections A, B, and C) has significantly decreased due, in part, to hardening of the shoreline.

Rigby Island/Festival Beach/Bethel Beach

South of Gwynn's Island is a stretch of coast that consists of the remnants of the barrier islands of Sandy Point and Rigby Island. Sandy Point became an island when it detached from Gwynn's Island in 1979. The channel between Sandy Point and Rigby Island to the south was called the "Hole in the Wall". Rigby Island was semi-attached on the south end until 1960 when it breached into White's Creek and became a true island.

Festival Beach has long been a publicly-used area just south of Rigby Island. Various erosion control structures have been placed on the shore over time including wood posts and other experimental structures. It was not until 2000 that a large headland breakwater with beach fill system was installed which provided long-term stability. This subreach of shoreline down to Horn Harbor is composed of broad sandy washovers, similar to barrier islands, that migrate landward across the adjacent tidal marsh complex.

South of Festival Beach, about 3,000 ft, one single residential property is on the Bay and 4,000 ft farther south is Bethel Beach with three cottages. In between is the old inlet to Garden Creek that has filled with sand. Two more cottages existed on the south end of Bethel Beach, but they have succumbed to erosion. South of Bethel Beach is a major breach in the low barrier islands that formed 1978 as a small tidal inlet ([Figure 3-10](#)). Since then, the breach has widened to over 2,700 ft which resulted in another break in the alongshore, littoral transport system that allows sand to become trapped in the new embayment.

The navigation channel at Horn Harbor requires "regular" maintenance and the sandy dredged material is placed along the north coast. This has resulted in a very wide beach and dune system that has become a good habitat for the threatened northern beach tiger beetle.

New Point Campground/Sandy Bank

The New Point Campground/Sandy Bank shoreline is south of Doctors Creek ([Appendix A-13](#)) and about 3,000 ft long. It has evolved as a pocket beach between two large marsh headlands. There are extensive sand bars in the nearshore. Unfortunately, the northern marsh headland has almost completely eroded, and once gone, the relative stability of this beach will be compromised. This reach also had a commercial pier extending from Route 602 into the Bay as seen in aerial imagery as early as 1937 and up to 1978. The reach had an intermittent marsh and beach shoreline in 1937 that subsequently has evolved into mostly beach. By 1978, New Point Campground and Sandy Bank homes were established.

The residents of Sandy Bank, which occupies the north half of the subreach, responded to recent storms and floods by building stone revetments. Four have been built to date, and these

protective structures rest upon the uplands but also encroach upon the adjacent beach making it narrower.

This southern half of this subreach is New Point Campground which has received sandy dredge material from Horn Harbor intermittently over the years. This has provided a wide beach and shore protection. Sand fencing had been placed along the backshore to encourage dune growth.

Chesapeake and Bavon Beaches

The Chesapeake and Bavon Beaches subreach is a relatively dynamic beach dune complex that is about 5,800 ft long. The northern section has been relatively stable recently while the southern portion has eroded significantly ([Appendix A-14](#)). Development began in earnest in the late 1970s as farm and maritime forest were built upon. The reach is controlled in large part by the nearshore sand bars which attach, detach, and migrate along shore. Two marsh headlands acted as littoral boundaries through the mid-1980s. The northern point was hardened in 1988 with a stone sill and spurs ([Figure 6-7B](#)). This helped keep beach sands from migrating northward and out of the reach. The southern point is a marsh headland that persists today and acts as a littoral boundary to sand movement to the south. However, impacts from Hurricane Isabel in September 2003, the Fall 2006 northeaster, and mostly recently, the Veteran's Day Northeaster in November 2009 have exacerbated dune erosion along the entire reach.

Prior to this latest northeaster, homeowners normally installed extensive dune fencing and planted dune grass along the shoreline after storms ([Figure 6-7A](#)). Installing and maintaining sand fencing also was employed by homeowners to create protective dunes. On the northern end, this method worked well due to a relatively wide beach. However, on the southern end, the shoreline has continued to erode. The C&BB community developed a collective shore stabilization plan in the 1990s which was revised in 2005 ([Figure 6-7C](#)). This plan was prepared by a local engineering firm experienced in headland control for shoreline stabilization. The plan consisted of a series of headland breakwaters placed strategically at beach salients along the shore with fill to provide a wide stable protective beach. The plan was not feasible at the time due to economic constraints. However, the same philosophy still applies and is the most reasonable method to address the issues facing the homeowners at C&BB. Before the Veteran's Day Northeaster, the main problem was dune erosion along the southern end where the beach and dune system had been significantly impacted. These landowners, whose properties have been impacted, have filed permit applications for revetments.

6.1.2 Tidal Creeks of Reach 2

Milford Haven, Stutts Creek, Billups Creek, Winter Harbor, Horn Harbor, and Dyer Creek have similar shoreline conditions. These primarily are low shorelines (< 5ft MLW) with intermittent marsh fringes and few areas where sand accumulates. Fetch is short, generally less than 1,000 ft, with more open fetches on Milford Haven and at the creek mouths. Land use is a

mix of wooded and residential with some wooded riparian buffers adjacent to lawns. Erosion occurs along the base of bank and bank face. Further up the creeks, undercut bases of bank occur due to overhanging trees that shade out the marsh fringes. Shore erosion along the tidal creeks of Reach 2 is relatively low except for the more open shorelines on Milford Haven and at the mouths of the creeks. Rates of change were not calculated in Winter Harbor. The rates are relatively low since marsh is more resistant to erosion than sand. However, as the breach continues to widen and deepen, marsh habitat will continue to erode ([Appendix A-11](#)). Tide range is about 1.1 ft in the Milford Haven region increasing to about 1.8 ft in Winter Harbor and Horn Harbor. This difference can effect storm surge even across these short distances.

6.2 Design Considerations and Recommendations

6.2.1 Gwynn's Island and the Bay Coast of Mathews

From a shoreline management perspective, it is much more cost effective to address shore erosion on a reach basis. However, this is often difficult due to multiple landowners who have varying opinions and resources to address the issue. Often the erosion process must be confronted on a lot by lot basis requiring individual permits and actions by the landowner. For the various reaches along the Bay coast, both of these approaches will be discussed..

The Bay coast of Mathews has several isolated populations of the threatened northern beach tiger beetle on Gwynn's Island, Festival Beach, Bethel Beach, and the beaches north of Winter Harbor and Bavon. These are beach and dune environments that have been reduced through time as the beaches became fragmented and eroded. Any permit application along the coast will have to address the impacts to the tiger beetle. Therefore, projects that enhance or create beaches will be encouraged.

Gwynn's Island

The west coast of Gwynn's Island is mostly hardened but geomorphic opportunities exist at sites 256 and 257 for spur breakwaters and beach fill ([Appendix B-7 and B-9](#)). The road along the west coast should be repaired with, at a minimum, more armor stone in a way that insures long-term integrity.

At the subreach and lot level of management, less expensive methods can be employed ([Figure 6-8](#)). The methods and results will vary depending on the dimensionality of the effort. At the lot level, shoreline management recommendations for the Bay coast of Gwynn's Island include maintaining or enhancing existing revetments, bulkheads, and groins, many of which have been in place for years. This can be done by adding more armor stone to revetments and sand to groin fields and placing T-heads and/or spurs at the end of the groins to increase their capability to hold sand. Sand fencing and dune grass plantings on appropriate shore segments also are beneficial. In addition, groin integrity must be maintained by rebuilding deteriorated structures and/or replacing wood groins with stone. Recommendations for using spur and short breakwaters at strategic locations are based on recent shoreline geomorphology. Also, after the

Veteran's Day Northeaster, it is evident that some of the bulkheads should be replaced with properly-sized stone revetments, especially directly in front of waterfront homes. The plan (Figure 6-8) includes 17 spurs with beach fill and 20 T-head of select groin fields (consisting of 2 or more groins). This does not preclude adding groins and sand to other groins cells as conditions warrant.

However, the Bay coast of Gwynn's Island is best protected by a comprehensive strategy. An overall management plan consisting of an extensive breakwater and beach nourishment system has been developed for the purpose of illustrating how a long term reach approach would appear (Appendix B-9). The breakwater units are 200 ft long with gaps between them of about 400 ft along the southern end and about 300 ft at the northern end (Figure 6-9A). The gaps are relatively wide because there is an existing system of hardened shores, groins and beaches that will act as the landward boundary for the system. This proposal would require more detailed engineering and construction funding. A lot-by-lot series of recommendations also is provided for this reach. It is noteworthy to reiterate that several landowners or groups of landowners working together will allow for a more cost effective approach to shoreline management along the Bay coast of Gwynn's Island.

Although generally more expensive than the more traditional erosion control structures, a properly designed and constructed headland breakwater system would provide long term shore protection and expansive beach and vegetated dune habitat as shown in Appendix B, plate B-5 and B-6. This is a conceptual plan consisting of 27 breakwater units and about 100,000 cubic yards (cy) of clean beach fill. Construction costs could be \$10 to \$14 million depending on the source of sand fill. Sand could be obtained from navigation channels or even sand mining off the Mathews coast. This plan could be phased or done piecemeal as funding would allow. The permitting of such a headland breakwater system would also require time and possible conservation easements. It could be viewed as positive to certain federal, state and local agencies because of the potential habitat benefits to the tiger beetle, diamondback terrapins, horseshoe crabs, and sensitive water fowl including the least tern and piping plover.

Rigby Island/Festival Beach/Bethel Beach

Rigby Island is rapidly disintegrating, which poses a threat to a great deal of shoreline behind it in Milford Haven. In order to preserve the island in its present state, a series of 13 breakwaters is proposed to protect its Bay side and 10 sills to protect the lee side (Appendix B-11, Figure 6-9B). Waves from Milford Haven can impact the back side of the Island and must be accounted for in the design. While the breakwaters at Festival Beach have done a good job holding the shoreline position, updrift and downdrift shorelines continue to erode. A series of seven breakwaters with beach fill will address this reach (Appendix B-17). A great deal of sand will be needed for beach fill for these projects. Dredging from Mathews shallow draft channels or sources offshore may be needed to make these designs feasible.

Farther south at Garden Creek two breakwaters and a spur are proposed to take advantage of geomorphic opportunities (Appendix B-19). In addition, spurs on the existing groins will help

maintain a wider beach that will provide more protection to the upland structures.

New Point Campground/Sandy Bank

In order to maintain a wide protective beach along this reach, seven breakwaters with beach fill are proposed ([Appendix B-25](#)). Breakwater 1 on the northern end will hold the headland and “set” the system. Structures 2-4 will maintain a beach to provide protection to the upland. Breakwaters 5-7 are more closely spaced in order to protect the dense population of structures closer to the shoreline.

Chesapeake and Bavon Beaches

At the lot-by-lot level of management, recommendations for this reach include maintaining the dune fencing where feasible and allowing for beach recovery to continue, which historically has occurred on the northern end of the site. Stone revetments might be needed on the Bay side of beach homes on the southern end if beach recovery is not adequate. Stone revetments should be high enough and buried deep enough to withstand overtopping and scour. Stone size should be Virginia Class III riprap or bigger. Detailed design should be done by an experienced engineer or contractor.

Beach nourishment also is recommended, but absent the holding capabilities of breakwaters, periodic re-nourishment may be necessary. The sand fill should be at least as coarse, if not coarser, than the existing beach material. Management on a reach basis consists of eight breakwaters with beach fill ([Appendix B-27](#)). Breakwaters should be at least 150 ft long and of similar design as proposed in 1990 and 2005. The backshore should be planted with dune grasses along with sand fencing to promote dune growth.

6.2.2 Tidal Creeks of Reach 2

Milford Haven, including shorelines on back side of Gwynn’s Island and Lane Creek, has 36 sites numbered 231 to 266. Stutts Creek, Morris Creek, Billups Creek and adjacent tidal waters include sites 191 to 230. In this region, three small breakwater systems, sites 195, 228, and 257 are recommended. However, most of the recommendations for shore erosion control in these areas are marsh management, small low sills, and low sills ([Figure 6-10](#)).

Low sills can be effective on more open fetch shorelines (>3000 ft), but sand fill should reach to the top of the eroding bank face ([Figure 6-10A](#)). Minor bank grading might be needed with consideration for the existing trees and riparian buffer. The small low sill is employed when the fetch is smaller, there is little or no upper tidal zone to plant, and sand fill is required to satiate that need.. The small low sill for the tidal creeks of Reach 2 is shown in [Figure 6-10B](#) with the fill beginning at + 3 to + 4 MLW and extending on a 10:1 to mid-tide at the back of the sill. These dimensions should be adapted to site conditions where the fill slope could be more or less depending on nearshore water depths.

Marsh management generally is recommended when trees shade out the marsh fringe resulting in an undercut upland bank. Tree shading is common particularly in areas with a small fetch (<500 ft). Proper tree trimming and planting with *Spartina alterniflora* in the upper tidal zone can be effective over time (Figure 6-10C). Bank grading usually is not needed because of the slow erosion processes acting on a very low upland bank.

Winter Harbor and Horn Harbor, sites 175-190, have similar shore conditions as Milford Haven, but the tide range is larger by about 0.5 ft. This increased range makes the sand fill for both the small low sills and low sills slightly wider. Low sills, breakwaters and revetments are included in the recommendations. Revetments are recommended at sites 186 and 187 at the mouth of Winter Harbor where the nearshore is too deep for a sill.

The recommended strategies for Reach 2 are summarized in Table 6-1. Overall, the small low sill and low sill are the most numerous recommendations. These recommended structures make up 60% of the recommendations for this reach as well as almost 60% of the shoreline length. These strategies account for about 3.7 miles of shoreline in Reach 2. When the fetch of the site is averaged within each site recommendation group, the result shows that structure size increases with increased fetch.

Table 6-1. Recommended strategies for Reach 2.

Type of Structure	Total Number of Recommended Strategies	Site Length (feet)	Average Site Fetch (feet)
Marsh Management	18	2,740	380
Sand with Groins	2	290	2,070
Spur	2	480	9,550
Small Low Sill	23	4,210	1,070
Low Sill	34	7,050	2,310
Medium Sill	1	510	9,990
Revetment/RipRap	5	890	2,070
Breakwaters with Beach Fill	5	3,120	32,560
Total	90	19,290	

7 Reach 3: Mobjack Bay, East River, and North River

7.1 Shore Conditions

There are 143 miles along Reach 3 which includes the Mobjack Bay, East River and North River shorelines. It starts at New Point Comfort and includes Harper, Davis, Pepper, and Sloop Creeks as well as the East and North River and their tributaries. This reach is characterized by low upland banks and marsh fringe shorelines (Figure 7-1 and 7-2). The East River runs about north and south and branches both northwest and northeast. The northeast reach becomes Put in Creek that leads to Mathews Courthouse. The North River begins in the upper reaches of the North End Branch and Burke Mill Stream. These are narrow tidal creeks whose channels occur as a series of meanders until opening up at the upstream end of the North River. Here the shore processes go from tidal dominated to wave dominated as the fetch opens up. This geomorphic transition point (T) occurs at the upper reaches of the major tidal creeks and rivers (Hardaway and Byrne, 1999). Down river of point T, the coast is a series of headlands and embayments, point bars and meanders of the ancient fluvial North River, now a flooded estuary.

Erosion rates tended to be higher along Mobjack Bay at the mouths of the East and North Rivers (Appendix A-16, A-20). The shorelines of the East and North Rivers generally are slightly erosional with a few areas of accretion. The banks along the North and East Rivers are low uplands averaging about +5 ft MLW (Figure 7-3). They are composed of silty fine sands and clays. As they erode they can provide sediments for narrow beaches and may also help re-establishment of marsh fringes. The shorelines along the Mobjack are even lower with areas of intermittent marsh fringes and broad marsh complexes.

Most of the marshes along the North and East Rivers are fringing marshes along the adjacent uplands or small pocket marshes in coves (Silberhorn 1974). These are composed of saltmarsh cordgrass, black needle rush, with saltmeadow hay, big cordgrass, and salt bush at the higher elevations before transitioning onto the adjacent uplands. In the intertidal zone, saltmarsh cordgrass dominates; at elevations above this, washed by spring tides, is the saltbush community which is the transition zone between upland vegetation and the marsh (Silberhorn, 1974).

The nearshore region (0 to -6 ft MLW) is relatively narrow (Figure 7-2) in the upper reaches of the North River above Cradle Point, the point at which the north turns sharply eastward. The shore zone (within 30 ft to 50 ft laterally from mean low water) is greater than 2 ft deep in some areas. From Cradle Point eastward to Roys Point and the mouth of Blackwater Creek, the nearshore region becomes wider with the region just west of Roys Point the most shallow with about 1,000 ft to the -6 ft contour. The upper reaches of Blackwater Creek, like the North River, can be deep in the shore zone. The consequence of a deep shore zone is that a proposed sill system will require more stone to maintain the desired crest elevation. On the other hand, these are very protected shores.

The North River coast from Blackwater Creek southward down the southwest side of Whites Neck has nine tidal creeks with established mouths. The land is low and the nearshore widens from about 700 ft to about 1,500 ft at Cedar Point then widens to a broad shoal over 3,500 ft off Minter Point. Along the Mobjack Bay portion of this reach, the shore zone is relatively shallow and appears as tidal flats. Only a few residences occur on the open Mobjack Bay along this reach; most development is along the tidal creeks.

The Mathews County side of the North River extends southward and is intersected by numerous smaller tidal creeks. Erosion rates vary along this reach with higher rates, up to -7 ft/yr along the more fetch-exposed shorelines of Mobjack Bay. From the headwaters of the North River to Blackwater Creek, most of the shorelines eroded at less than -2 ft/yr with a very few showing slight accretion. Erosion rates are generally less than -0.5 ft/yr up the smaller creeks. The East River has the same general geomorphology and shore types as the North River. However, the East River is more developed with numerous shoreline hardening structures along the coast.

7.2 Design Considerations and Recommendations

As noted earlier, many structures exist along this reach. While many are riprap or wood bulkheads, some other types of shore protection have been placed. Along the East River, marsh management is occurring. As shown in [Figure 7-4A](#), intertidal and upland planting of marsh grasses may eventually take hold and stabilize the shore. A very low structure is in the nearshore. Its ability to protect the grasses from incoming waves may be inhibited by low elevation of the crest. Coir logs (coir (coconut) fiber logs covered by coir netting) and marsh grasses have been used along the shore in [Figure 7-4B](#). These may eventually take hold, but sections of the shore appear to be shaded which will make marsh establishment difficult. Trimming the upland vegetation may help. Also, the coir logs will eventually decay and the marsh may not be able to maintain itself without them.

Gabion basket breakwaters were placed along the North River ([Figure 7-4C](#)). Gabion baskets have the advantage of using smaller rock contained in coated wire baskets which make them “easy” for homeowners to construct or place themselves. However, sand either was not placed between the gabions and the shore during the construction or it has eroded. Upland erosion continues as indicated by the onsite situation and the additional riprap along the bank. Eventually, these gabions may rust and fall apart. The rock inside is not big enough to stay in the nearshore and will be scattered by storms. Other types of non-engineered structures occur along the shore ([Figure 7-4D](#)). These structures may not provide adequate protection during storms.

One structure that has been successful is “Granddaddy” sill along the East River. Anecdotal evidence suggested that a sill was built along the East River in Mathews County in the late 1800s. The present owner, whose family has owned the land for more than 100 years, has stated that the sill was built using ballast stone. Comparing the shoreline position taken from aerial photos in 1937 to the shore position today suggests that a sill has indeed been in place

since at least that time (Figure 7-5). This structure has maintained a shoreline that hasn't changed in at least 70 years (Appendix A-17).

There are 174 site recommendations for Reach 3, which includes marsh management and small low sills up the narrow creeks and small low sills, breakwaters and spurs on the more open coasts including Mobjack Bay (Table 7-1). These coasts are very low, and during storms, sand in these systems can be carried landward as overwash. Maintenance (replacing sand and replanting the marsh or dune grasses) may be required after major storms.

Typical cross-sections are shown in Figure 7-6. The 2.4 foot tide range and 10:1 slope for low sills provides an opportunity to create a wider *Spartina alterniflora* marsh fringe. Existing marsh can be allowed to remain in some instances when sand fill can be applied behind the fringe and planted. Small low sills are effective where small sand fills can enhance the intertidal zone for planting marsh grasses creating a narrow but effective fringe. Sand alone may be sufficient to inhibit erosion; however, erosion control may be problematic if sand is transported away from the site by the same physical processes causing the bank to be undercut or erode. Therefore a small line of rock with gaps (to allow for free tidal exchange) is recommended to hold the sand and provide long term stability to the planted marsh. The small low sill may be for very protected properties or those that are non-residential where the landowner would like to abate minimal erosion.

Low sills provide the needed marsh width and stability for the marsh fringe. The sand fill is placed against the bank from +3 ft MLW up to +4 ft depending on bank height, fetch and nature of the landuse. Low to medium sill systems are required for eroding residential shorelines. The low sill can also have a narrow crest (2') or wide crest (3 to 4') (Figure 7-6C and D) with the latter more appropriate for more fetch exposed (>3miles) residential property. A low sill with a wide crest was built at Poplar Grove on the East River; it is shown in the photo in Figure 7-6D. This sill has been very effective at maintaining a wide marsh and neither the marsh nor upland was damaged during the Veteran's Day Storm.

Table 7-1. Recommended strategies for Reach 3.

Type of Structure	Total Number of Recommended Strategies	Site Length (feet)	Average Site Fetch (feet)
Marsh Management	37	8,130	570
Beach Fill	1	590	3,140
Sand with Groins	4	750	300
Spur	7	320	4,980
Small Low Sill	66	11,670	1630
Low Sill	56	15,990	570
Breakwaters with Beach Fill	3	920	37,780
Total	174	38,370	

8 Summary

The shoreline in Mathews County is highly variable in terms of its physical characteristics. The shoreline types range from fetch-limited creeks to open Bay shorelines to very high eroding banks to very low extensive marshes. Almost 50 miles of Mathews' 350 miles of shoreline already has shore protection; 35% (or 17 miles) of which have been built in the last 10 years. The vast majority of these structures (70%) are riprap revetments or bulkheads. While revetments and bulkheads are efficient erosion control structures, they generally adversely impact the connection between upland and nearshore environments, resulting in reductions of natural buffers, *i.e.* beaches and marshes, that help to filter upland runoff of sediments, nutrients, and other types of pollution, and maintain a natural habitat continuum.

However, living shorelines have been used effectively for shore stabilization over the last 20 years. These strategies create beaches and marshes, with and without structures, to enhance and protect shorelines. This Plan makes recommendations that will effectively stabilize the shoreline while maintaining an environmental edge. The 351 recommendations cover 18 miles of shoreline and are science-based using available information including site visits to create a strategy specific to each section of eroding shoreline. The Plan does not make recommendations where the upland is not eroding or areas of large, generally uninhabited marshes. Some sections of eroding shorelines may have been missed in the original assessment or shoreline conditions may have changed; in these cases, recommendations for nearby properties may provide suitable guidance.

By far the three largest categories of recommendations are marsh management, small low sills and low sills (Table 8-1). Marsh management requires no structures and is recommended for the most narrow creeks of the County. Small low sills are generally used to create marshes in the smaller creeks and rivers of the County that have less than one mile of fetch. These small low structures strike a balance between effective shore stabilization, cost, and ecosystem function. Low sills are slightly larger than the small low sills and are used in areas where the fetch is greater than 1 mile. The average site fetch (Table 8-1) for the low sills is 2.6 miles. This average is skewed upward by 11 sites on Mobjack Bay, North River, and Hills Bay that have large fetches. In the case of Mobjack Bay and the North River, the sites are south facing so even though they have a large fetch, a low sill can provide adequate protection. In Hills Bay, the wide shallow nearshore as well as Gwynn's Island will limit the wave energy that would impact these sites. Typically, the shoreline on which low sills have been recommended have a low bank and are residential. Medium sills are larger than low sills and are used primarily for areas of the coast that are residential and have a high bank. In Mathews, these are generally only recommended along the Piankatank River. Revetments are recommended at 9 sites in Mathews (Table 8-1), usually in areas that have existing structures that could be extended to cover the eroding shoreline or in a few areas where the nearshore is too deep to cost-effectively build a sill.

Generally, alternative shore stabilization strategies were not recommended for shorelines that are already protected with structures. Exceptions to this occurred, and recommendations were included if a structure was deemed ineffective or failing. Gwynn's Island is another

notable example. Most of the Bay shoreline along Gwynn's Island has shore protection, usually groins and a bulkhead. While these structures may not fail until a big storm, they generally are not scaled to create effective shore protection against large storms. Effective shore stabilization measures seek to reduce the slope of the coast. This can be achieved by creating a wider shore zone through marshes, beaches, and dunes and/or grading the upland. By creating a less steep slope, wave energy will be reduced as the waves travel across it. Along Gwynn's Island, the beach and backshore created by the groins may not always be wide enough to provide the necessary level of protection. The most effective erosion control for this section of shore would be the installation of breakwaters and beach fill along the entire reach. As that requires a great deal of cooperation and funding, additional lot-by-lot recommendations, generally T-heads or spurs added to the existing groins, were made in order to help each homeowner maintain as stable a beach as possible.

Overall, this MCSMP is an educational and management reference for the County that provides guidance to managers and landowners alike. These recommendations are the minimum that a landowner should consider to be confident that their shore is protected. If the property owner chooses, they can increase their level of protection. For those sites where a small low sill has been recommended, a larger sill can be built to provide additional protection. If all of the recommended marsh management, small low sill, low sill, and medium sill strategies were constructed, nearly 40 acres of *Spartina patens* upper marsh and 30 acres of *Spartina alterniflora* intertidal marsh would be created County-wide.

Table 8-1. Overall summary of recommended strategies for Mathews County, Virginia.

Type of Structure	Total Number of Recommended Strategies	Site Length feet (miles)	Average Site Fetch feet (miles)
Marsh Management	66	27,797 (5.3)	461 (0.1)
Beach Fill	2	861 (0.2)	3,016 (0.6)
Sand with Groins	6	1,039 (0.2)	280 (0.1)
Spur	12	1,193 (0.2)	11,844 (2.2)
Small Low Sill	112	19,313 (3.7)	1,336 (0.1)
Low Sill	119	32,747 (6.2)	13,485 (2.6)
Medium Sill	7	2,342 (0.4)	5,238 (1.0)
Revetment/RipRap	9	1,308 (1.3)	1,826 (0.4)
Breakwaters with Beach Fill	18	10,228 (1.9)	35,205 (6.7)
Total	351	96,828 (18.3)	

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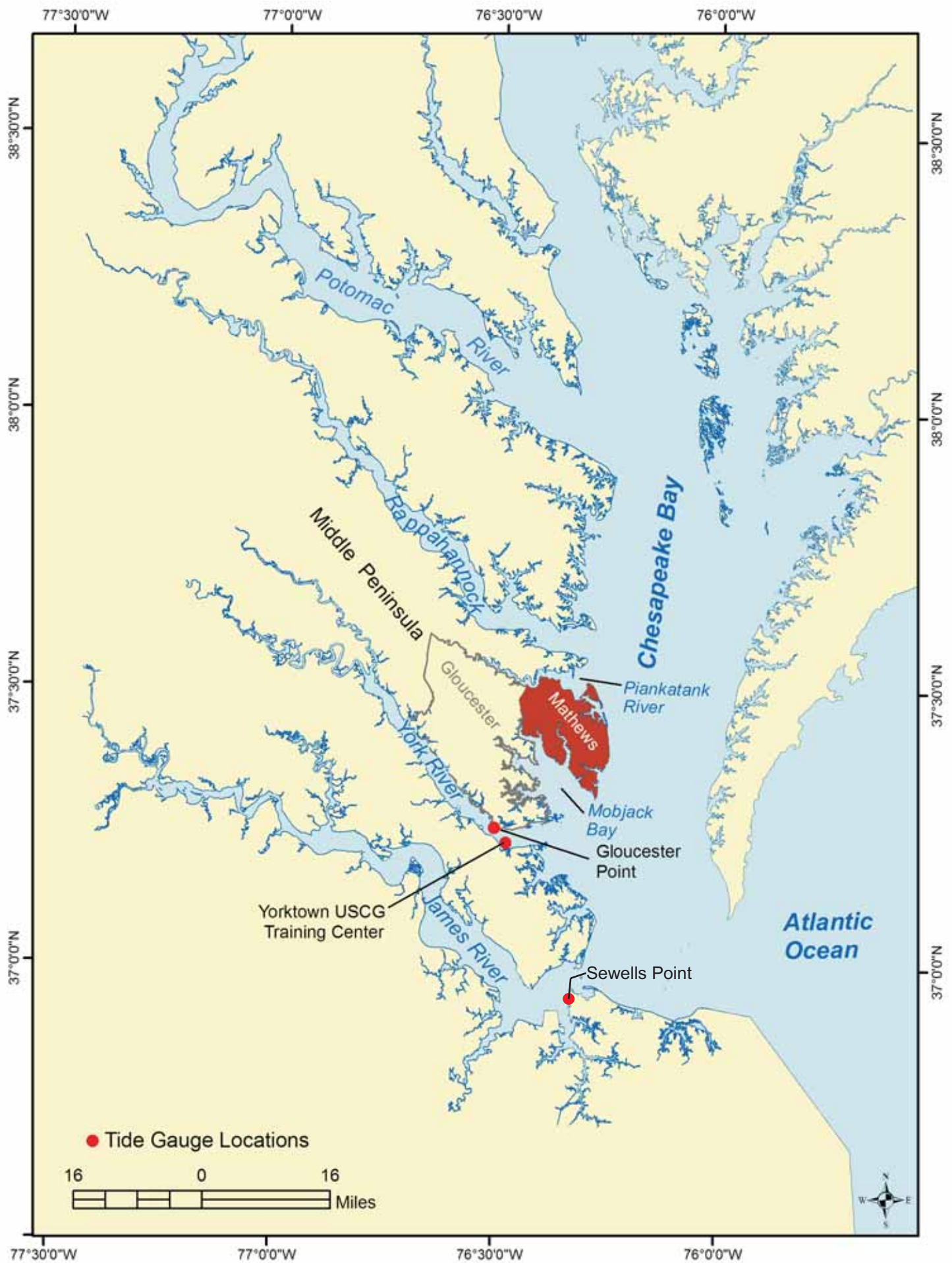


Figure 2-1. Location of Mathews County, Virginia within the Chesapeake Bay estuarine system.



Figure 2-2. Image of Mathews County, Virginia with locations and Reaches designated.

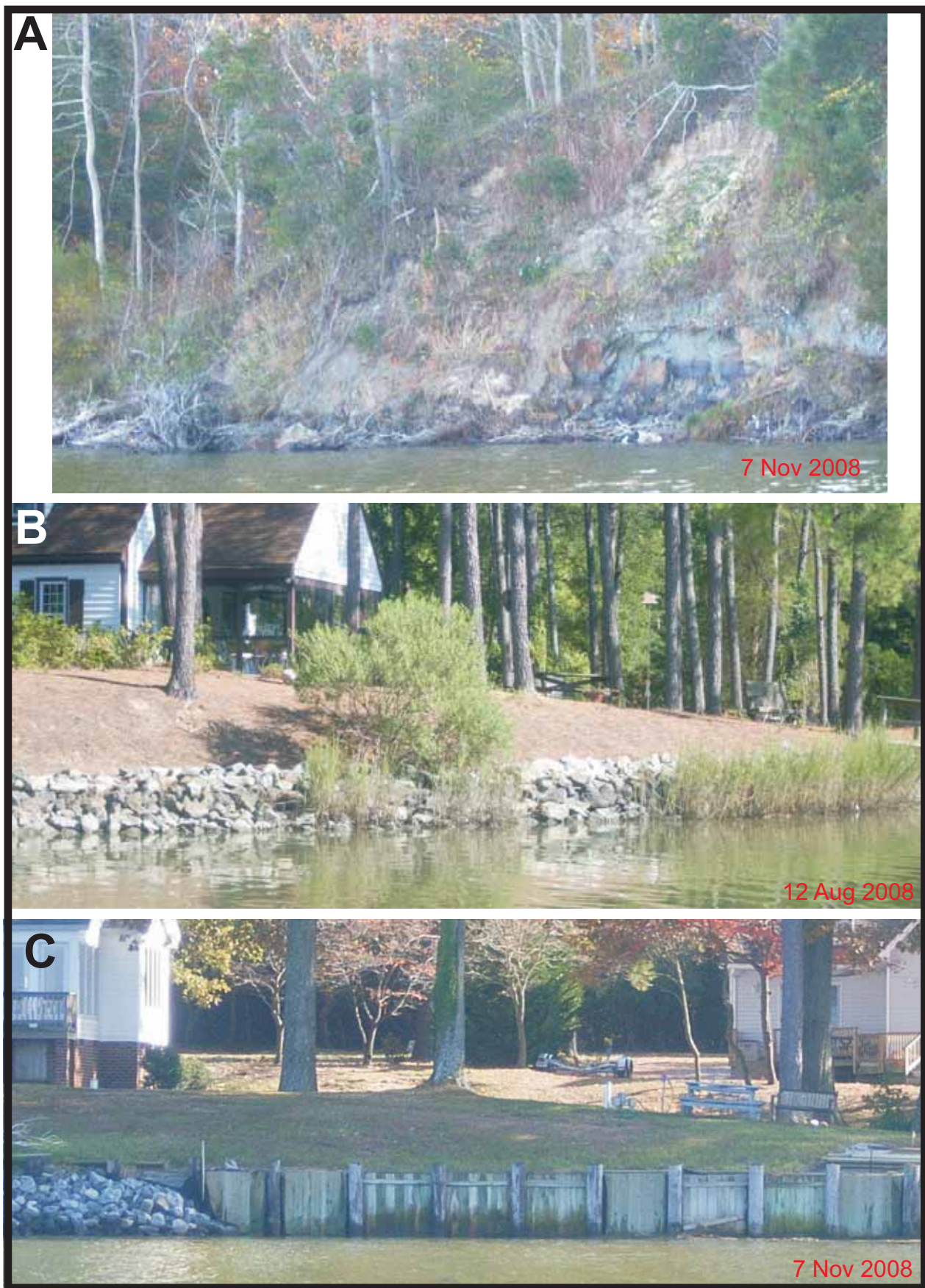
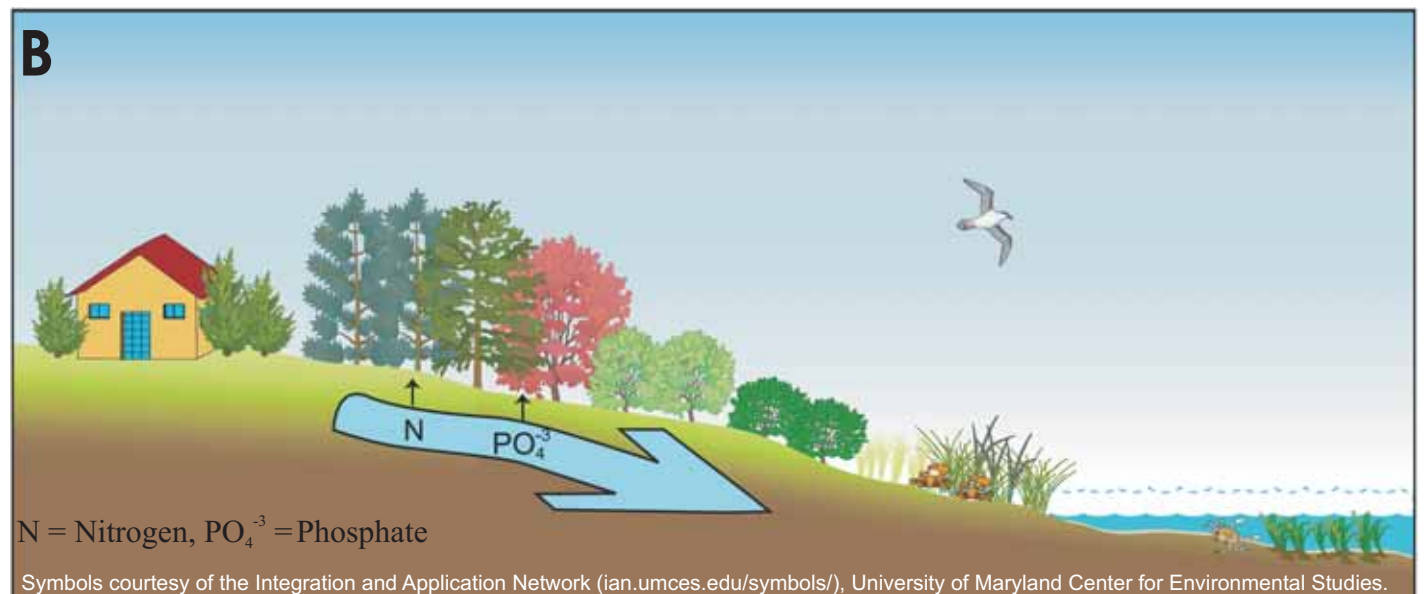
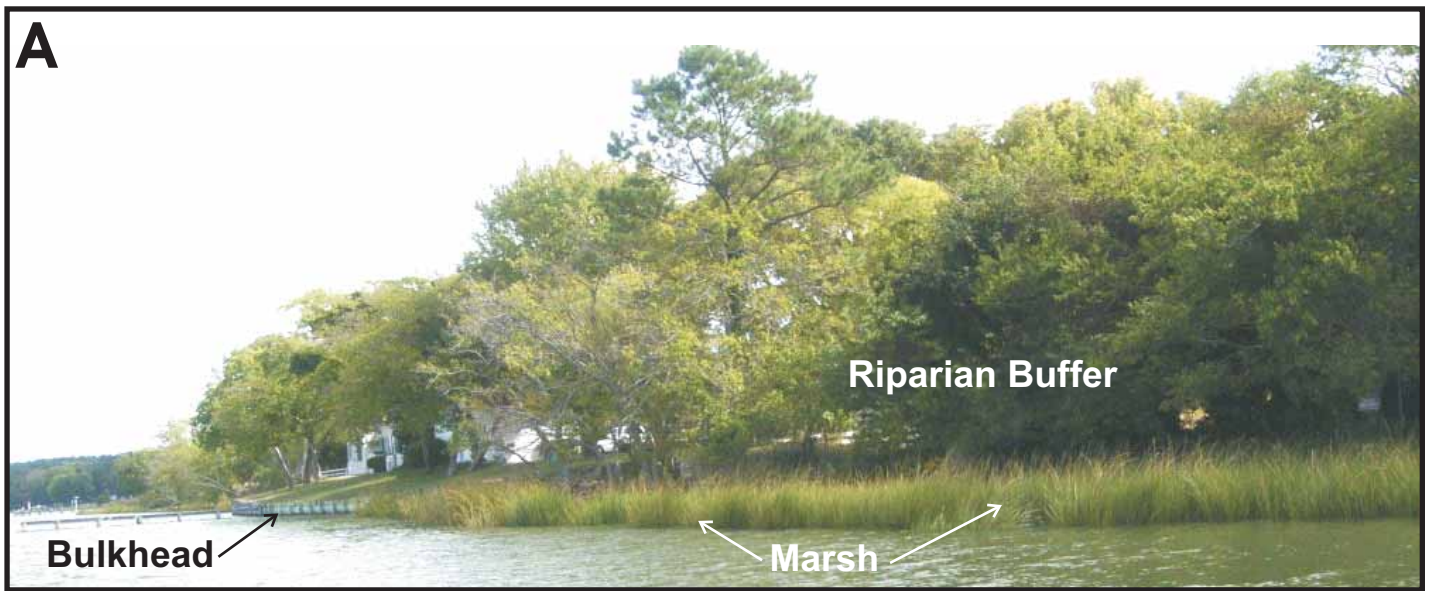


Figure 2-3. A) An undercut bank that has resulted in slumping of the bank face on the Piankatank River, B) A narrow marsh fringe in front of a rock revetment on the East River. The existing marsh indicates that a fringe likely could have been established to protect the bank. C) Rock revetment is replacing a failing wood bulkhead on the Piankatank River.



Upland Landuse	Riparian Landuse	Banks	Intertidal Zone	Subaqueous Lands
(+) Trees, shrubs, tall grass	Trees, shrubs, tall grass	Vegetated, Stable	Marshes, Phragmites	Seagrass (SAV)
		Partial vegetation	Coastal Sand Dunes	Oyster Reefs
Agriculture	Residential, Agriculture	Undercut	Riprap, Bulkheads	Aquaculture
(-) Residential, Commercial	Industrial	Bare, Unstable	Boat ramps	Marinas

Figure 2-4. A) Photo taken along Occohannock Creek, Virginia depicting aspects of the coastal profile, and B) a connected shore zone water quality model that shows how different landscape elements affect water quality and habitat, from positive (**diverse habitat opportunities and improved water quality**) to negative (**few habitat opportunities and reduced water quality**). Plants in the buffer zone can take up nitrogen and phosphorus (from commercial and residential fertilizers) which are two common types of non-point source pollution. B is reprinted courtesy of VIMS Center for Coastal Resources Management.



Minor bank grading *occurred* and the toe temporarily was protected with straw bales.

Only *Spartina alterniflora* was planted to establish a marsh fringe because high water occurred at the base of the bank.



The project one year after planting.



The established marsh fringe and vegetative upland slope are shown here after six years.

This Marsh Management site after 24 years.



Figure 2-5. Marsh planting along Occohannock Creek, Northampton County, A) after planting, B) after one year, C) after 6 years, and D) after 24 years of growth. (After Hardaway and Byrne, 1999).

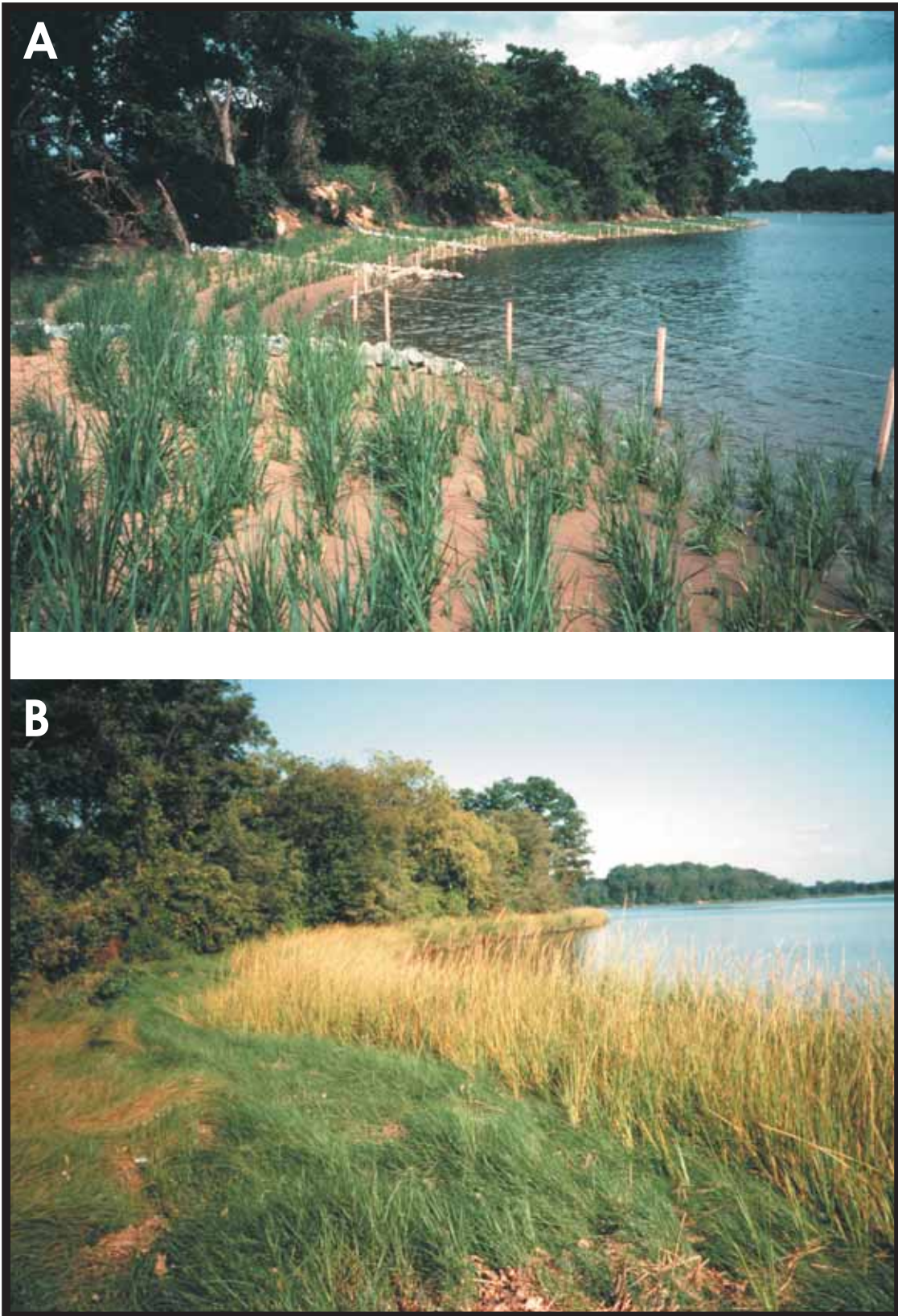


Figure 2-6. Marsh grass plantings with sand fill and short stone groins at Wye Island, Kent County, Maryland A) three months after installation and B) four years after installation (reprinted from Hardaway and Byrne, 1999).

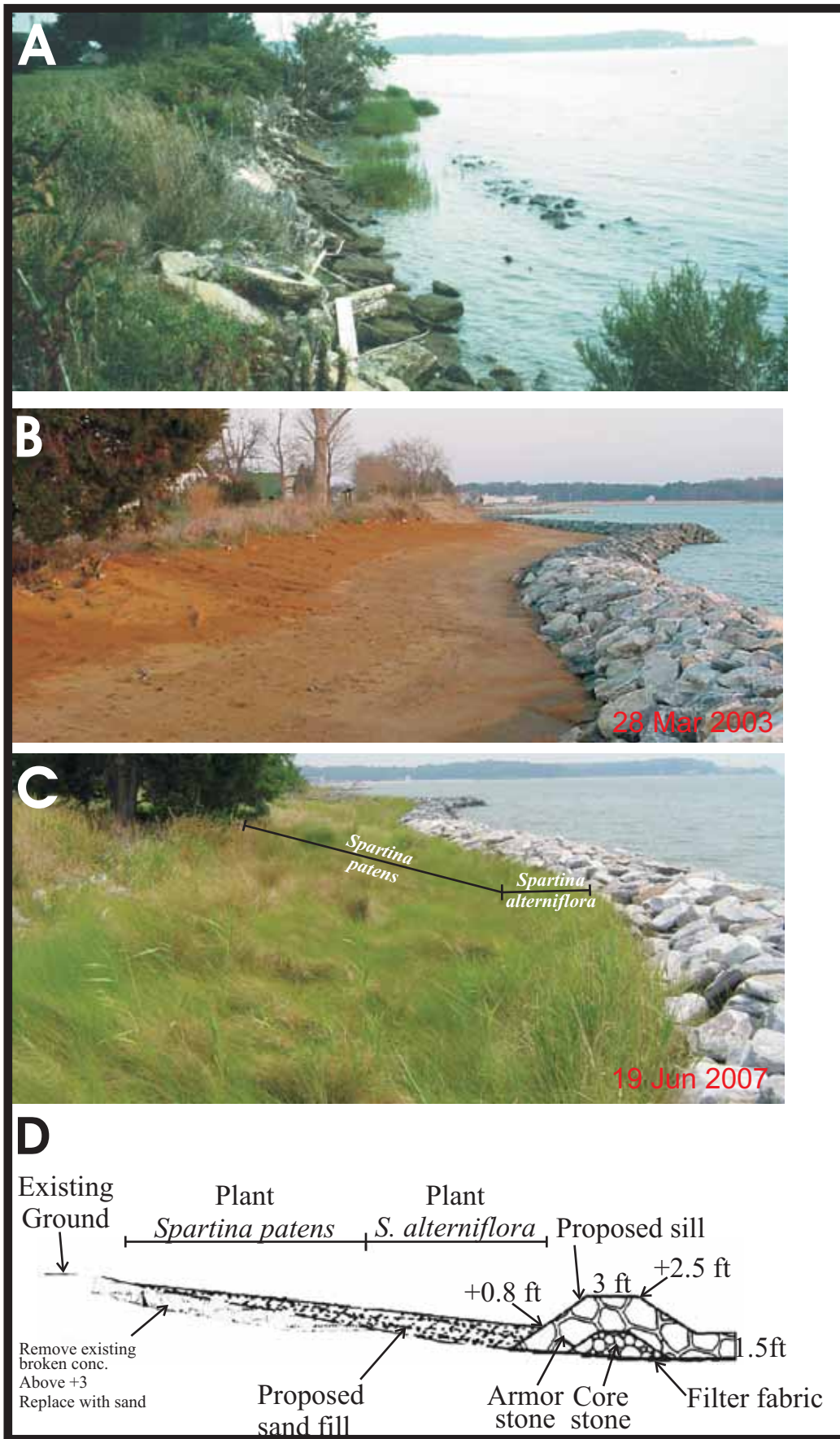


Figure 2-7. Sand fill with stone sills and marsh plantings at Webster Field Annex, St. Mary's County, Maryland A) before installation, B) after installation but before planting, C) after four years, and D) the cross-section used for construction.

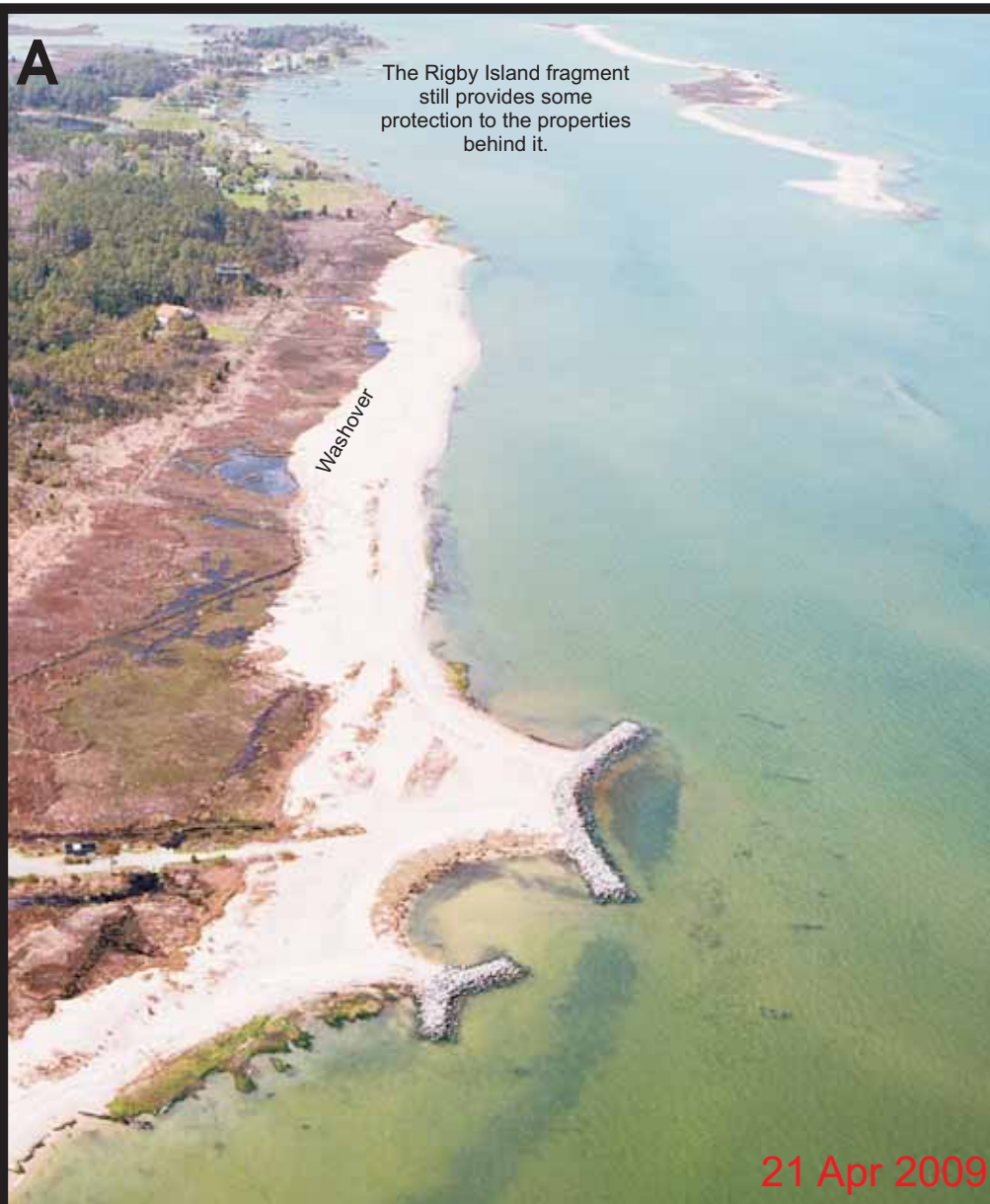


Figure 2-8. A) Breakwaters built on Chesapeake Bay at Festival Beach, Mathews, Virginia and B) breakwaters built on the York River in Gloucester, Virginia.

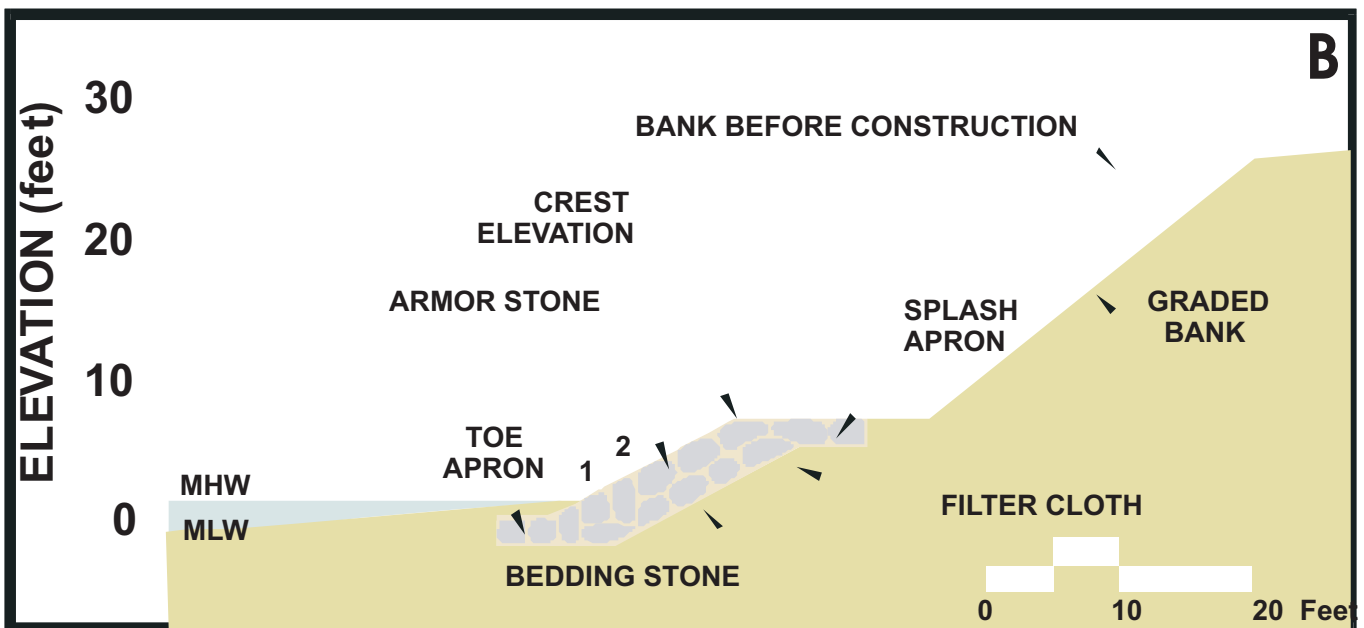


Figure 2-9. A) Stone revetment shortly after construction on the Potomac River, Virginia, and B) cross-section of the elements necessary for proper stone revetment design (Hardaway and Byrne, 1999).

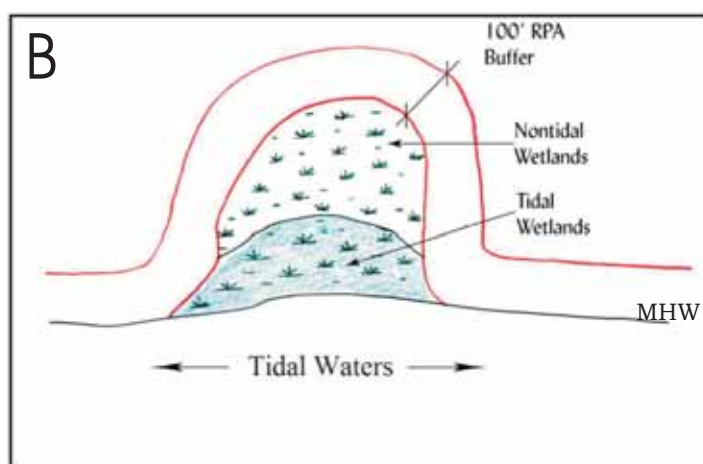
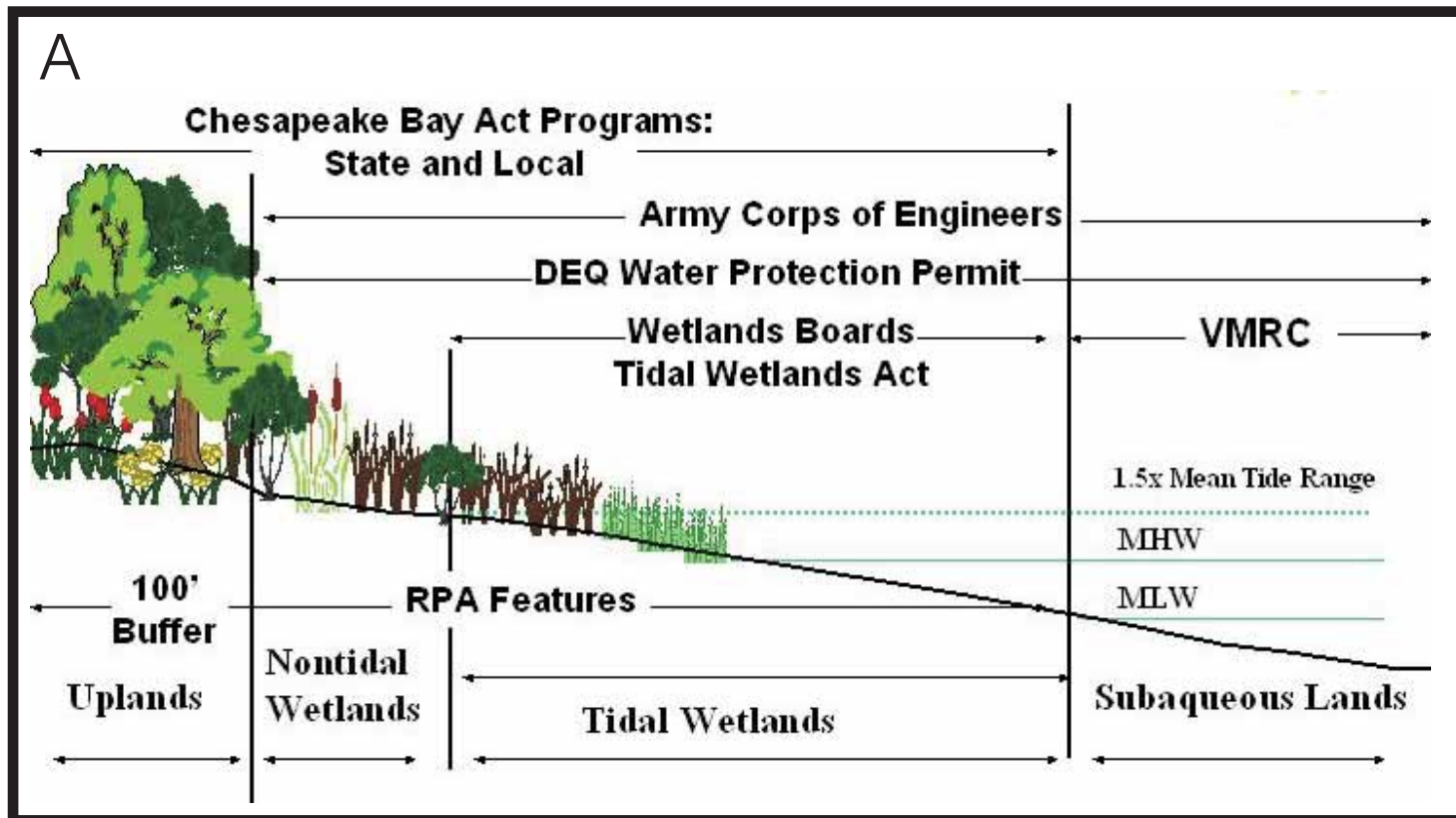


Figure 2-10. A) Shore zone jurisdictional limits (reprinted courtesy of CCRM) and B) graphic depicting how the Resource Protection Area is determined from various shore zone habitats.

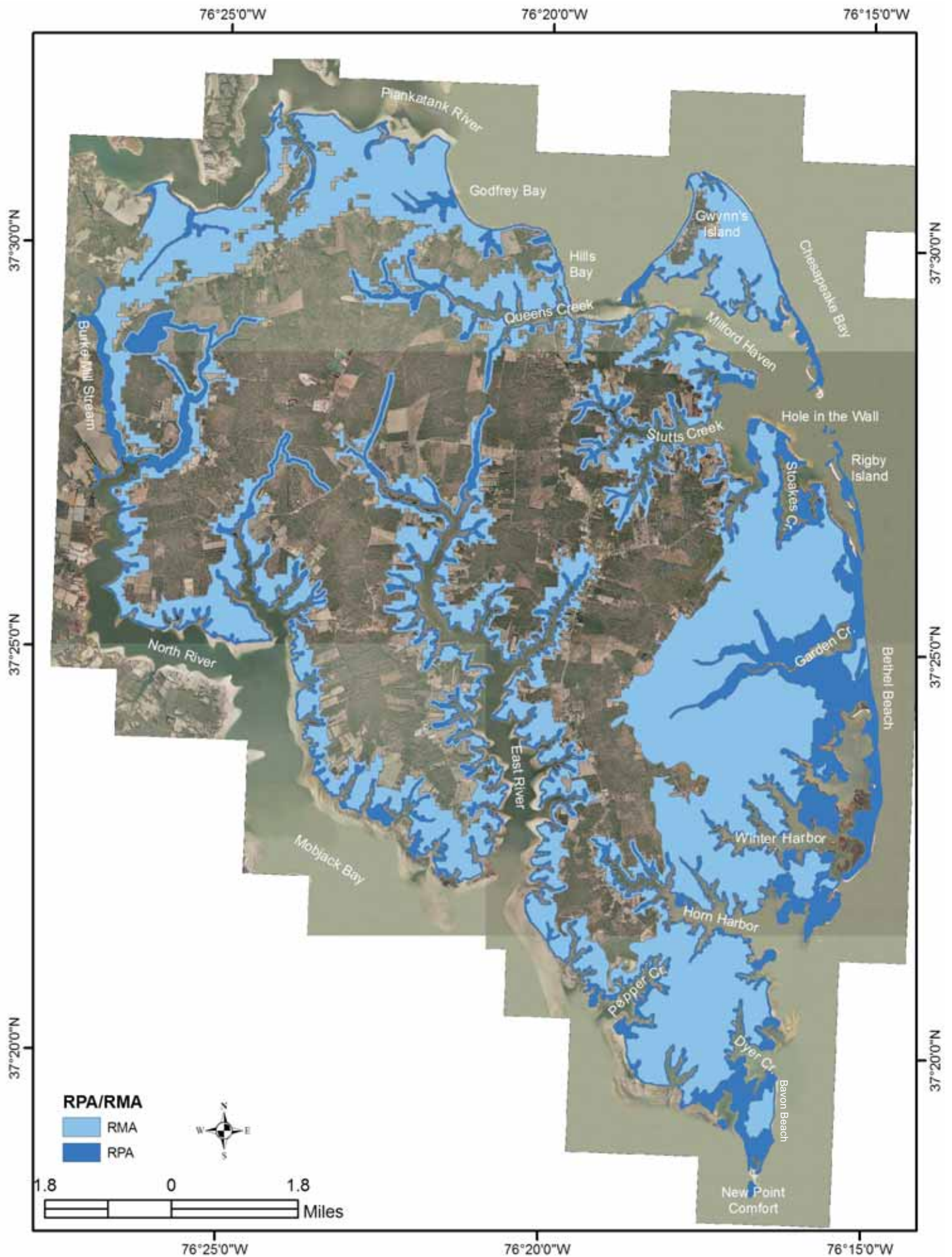


Figure 2-11. The mapped extent of the Resource Protection Areas and Resource Management Areas in Mathews, Virginia. (Data received from Vanasse Hangen Brustlin, Inc.).



Figure 3-1. These Mathews County shorelines are characterized as A) stable, B) transitional and erosional, and C) erosional.



Figure 3-2. These Mathews County shorelines have a A) low bank and B) high bank.



Figure 3-3. These Mathews County shorelines depict base of bank and bank face erosion. A) The dense vegetation as well as lower fetch environment has maintained a stable bank face while the base of the bank shows erosion primarily due to the loss of a vegetated fringe probably due to shading. B) Bare spots on the bank indicate that the sediments on the bank face are unstable. Protecting the base of bank with rock will not stabilize the bank face.

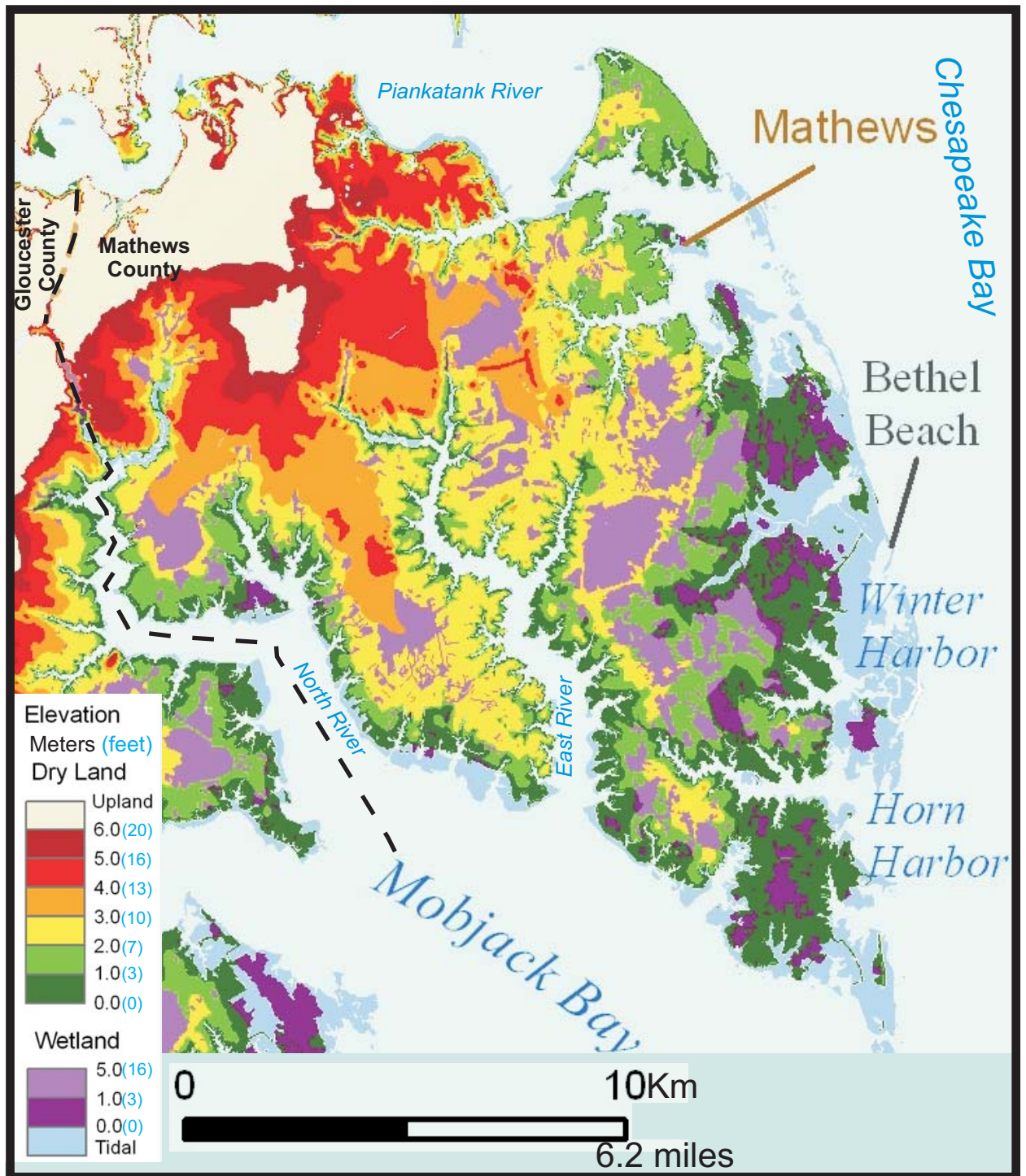


Figure 3-4. Elevations of lands close to sea level. Elevations are above spring high water which is the approximate inland boundary of tidal wetlands (from Titus and Wang, 2008).

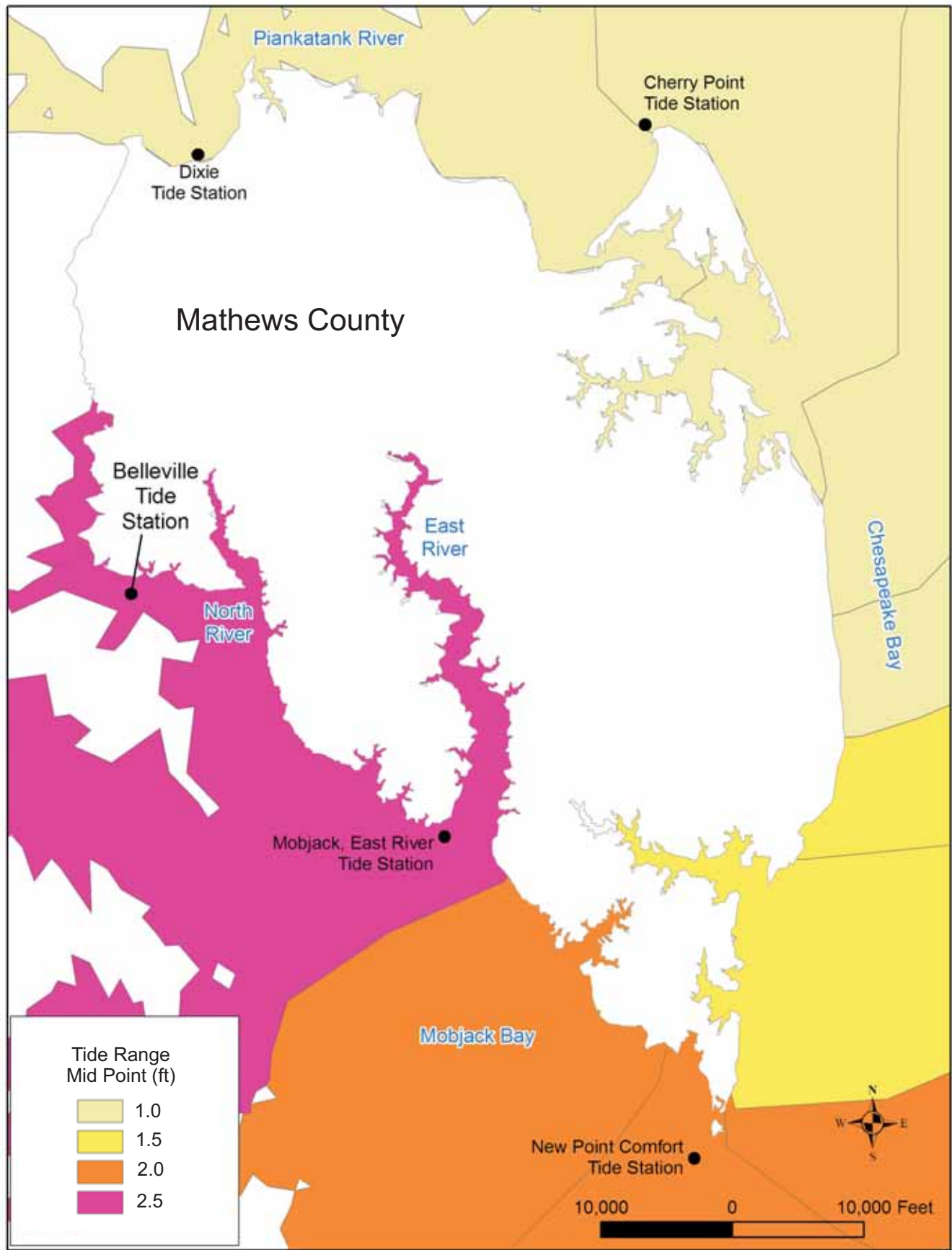


Figure 3-5. Approximate tide ranges around Mathews County and the location of tide stations. Ranges were interpolated between tide stations. The actual tide range can be slightly more or less than the mid-point.

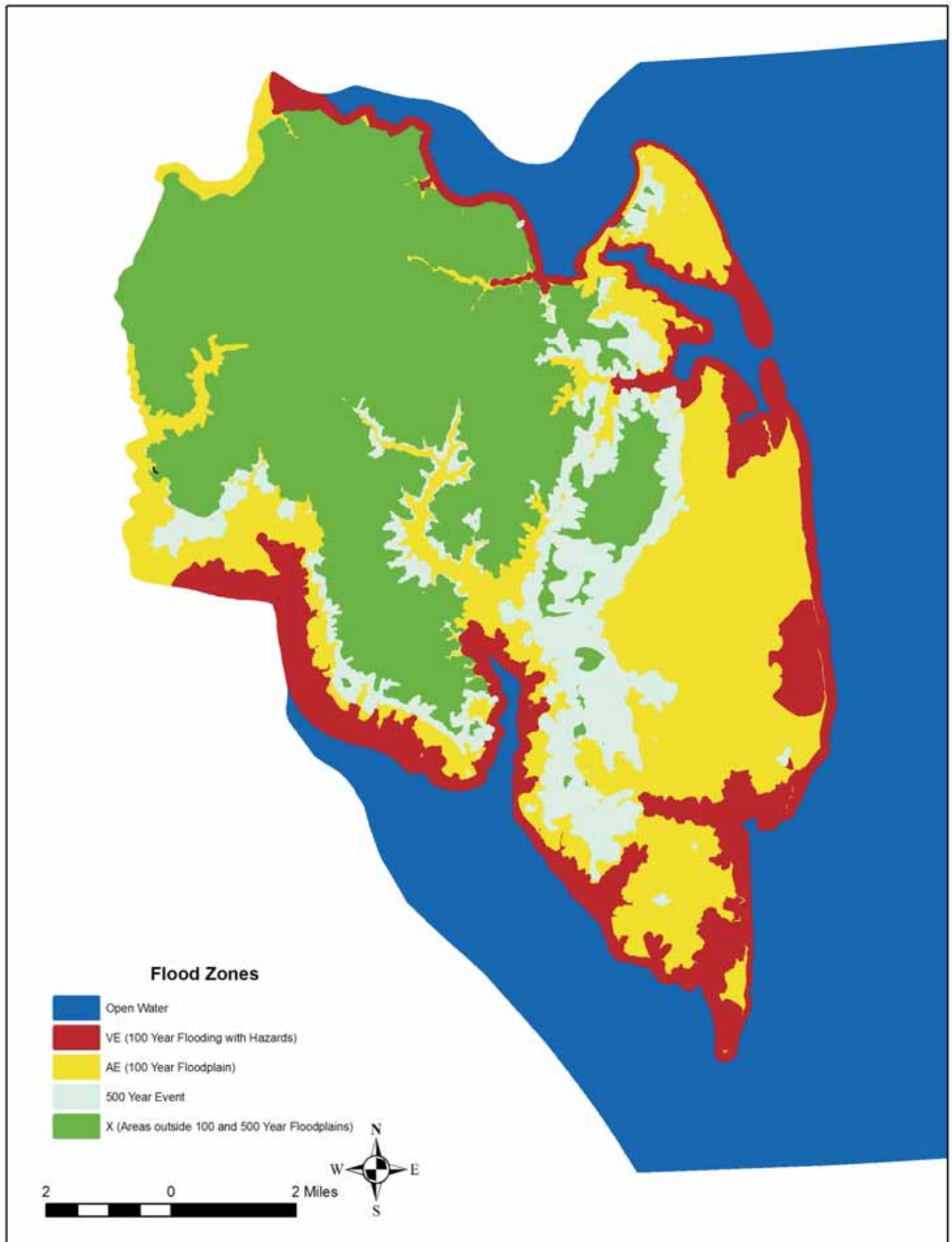


Figure 3-6. Mathews County flood zones determined by the Federal Emergency Management Agency (FEMA).

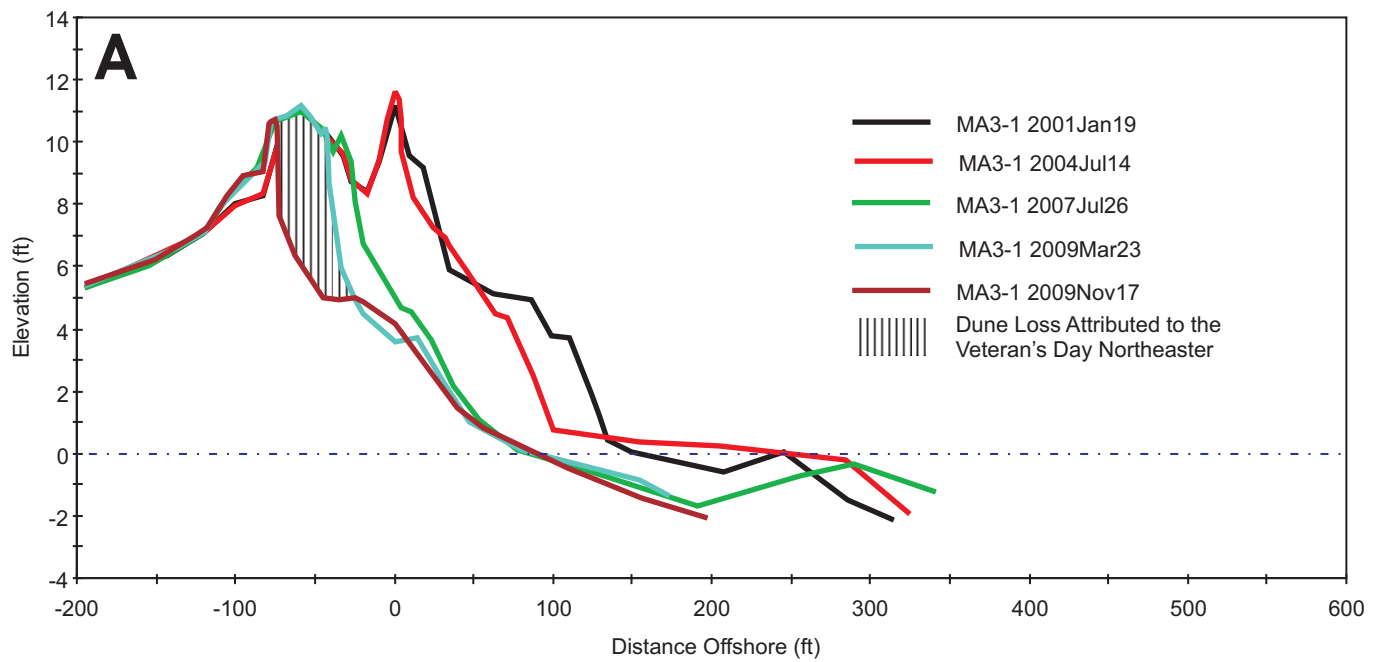


Figure 3-7. Impacts of the Veteran's Day Northeaster along select Mathews County shoreline. A) Profile data taken along the southern end of Bavon Beach showed that the beach had a large amount of erosion. B) Structures along Gwynn's Island failed and the shoreline eroded. C) A sill on the East River had no significant impact from the increased water levels and waves.

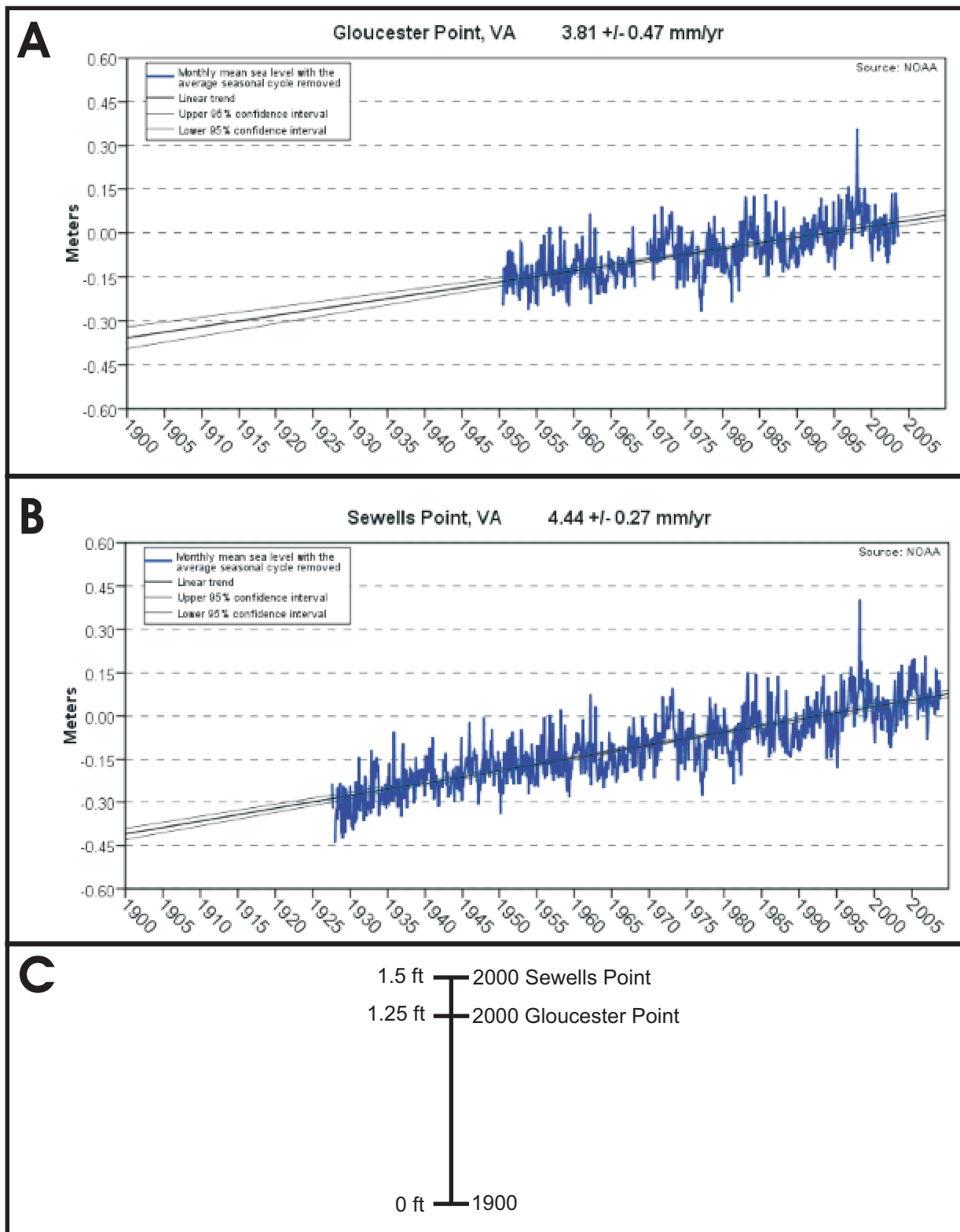


Figure 3-8. Graphs of sea level rise as indicated by monthly mean sea levels at A) Gloucester Point and B) Sewells Point, Virginia (NOAA, 2009). C) Also shown is the cumulative change in water level at these sites over 100 years. Sea level rise occurs at different rates around Chesapeake Bay due to varying geology.

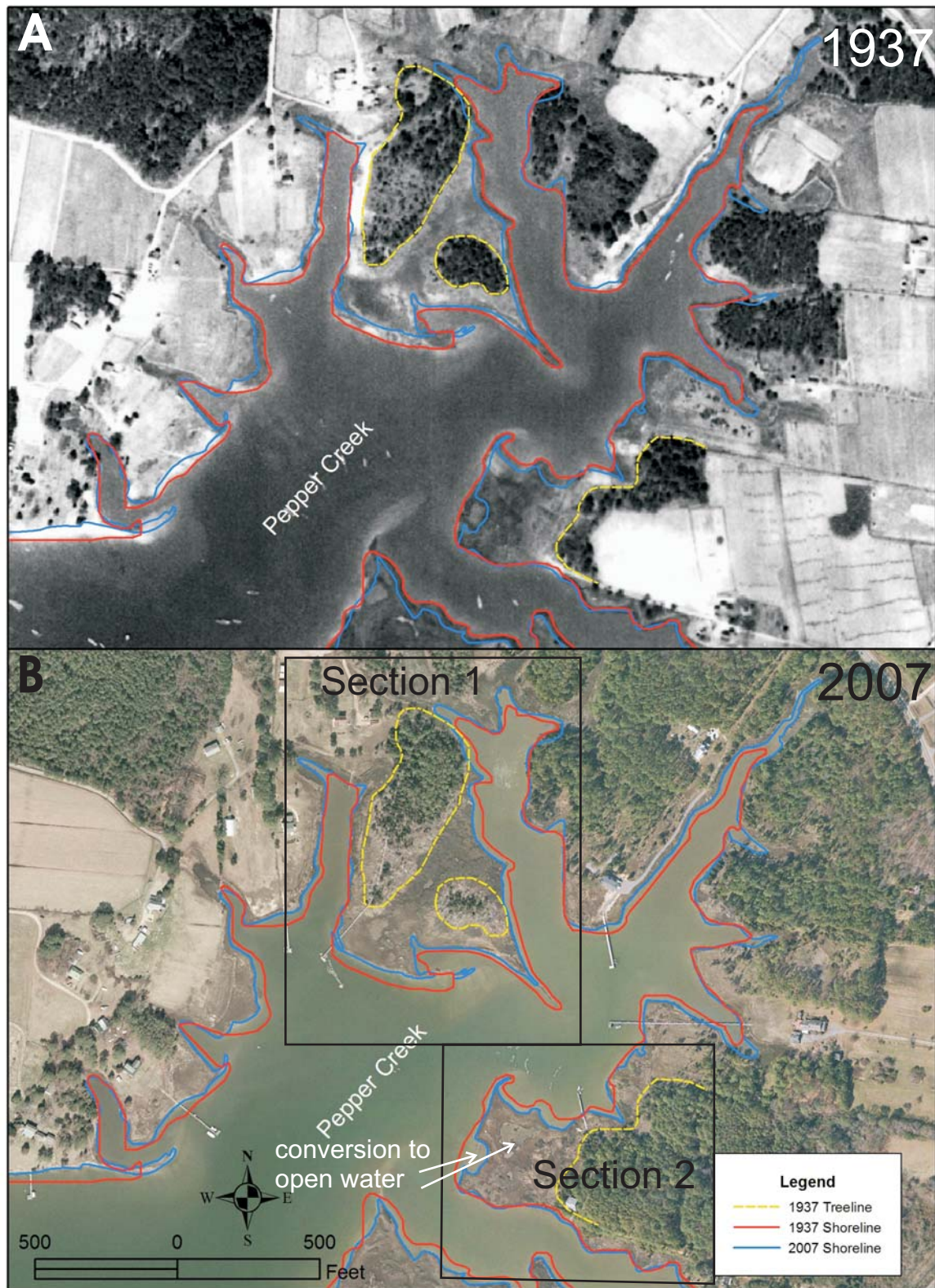


Figure 3-9. Aerial photo taken in A) 1937 and B) 2007 showing the change in the marsh due to sea-level rise. As sea level becomes higher, water moves farther inland allowing the marsh to migrate landward in low areas. However, this also can lead to the loss of upland vegetation (trees and shrubs) and marsh. Upland plant loss is due to flooding with salt water. Marsh on the seaward edge is lost due to erosion and submersion.

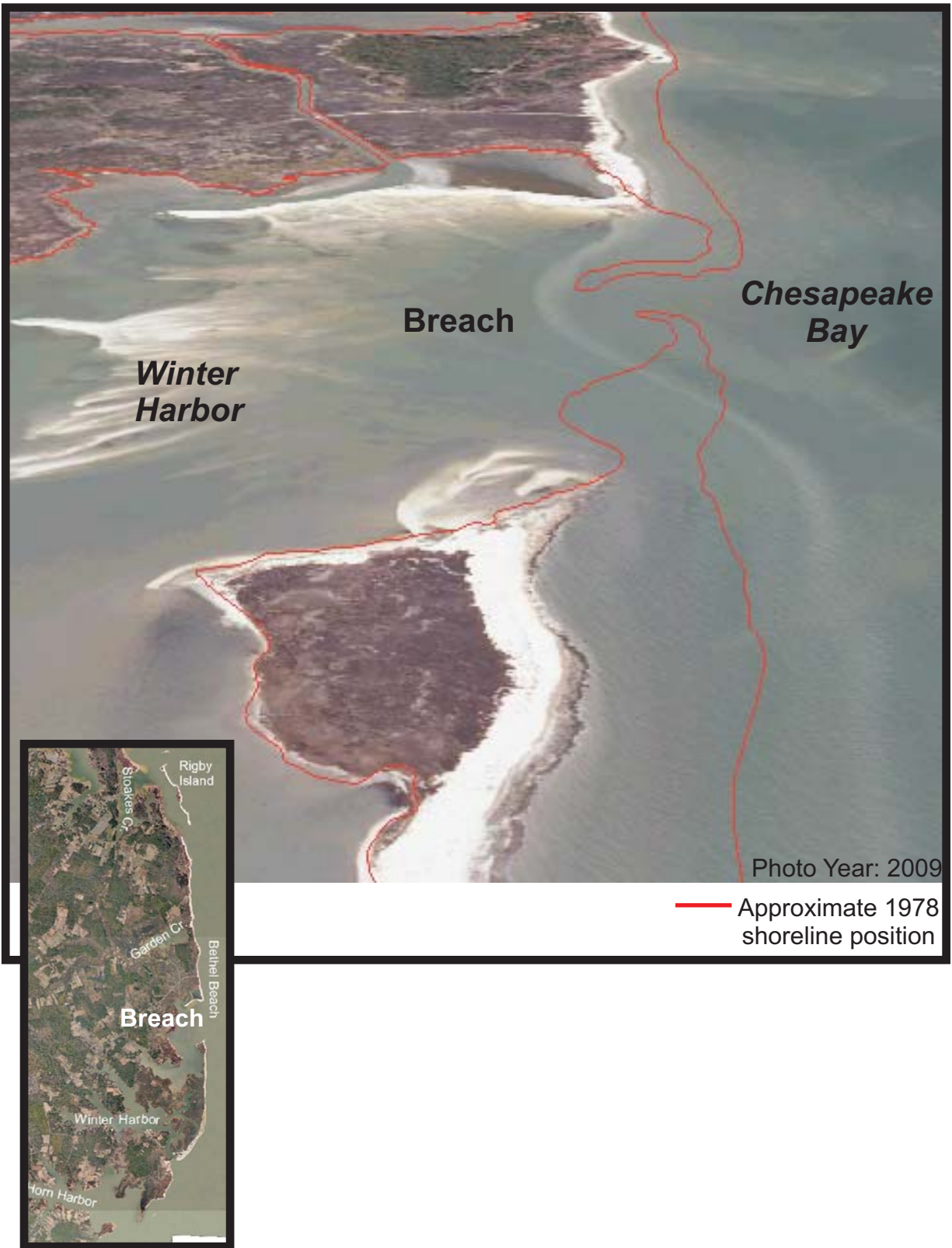


Figure 3-10. Barrier beach breach at Bethel Beach into Winter Harbor.

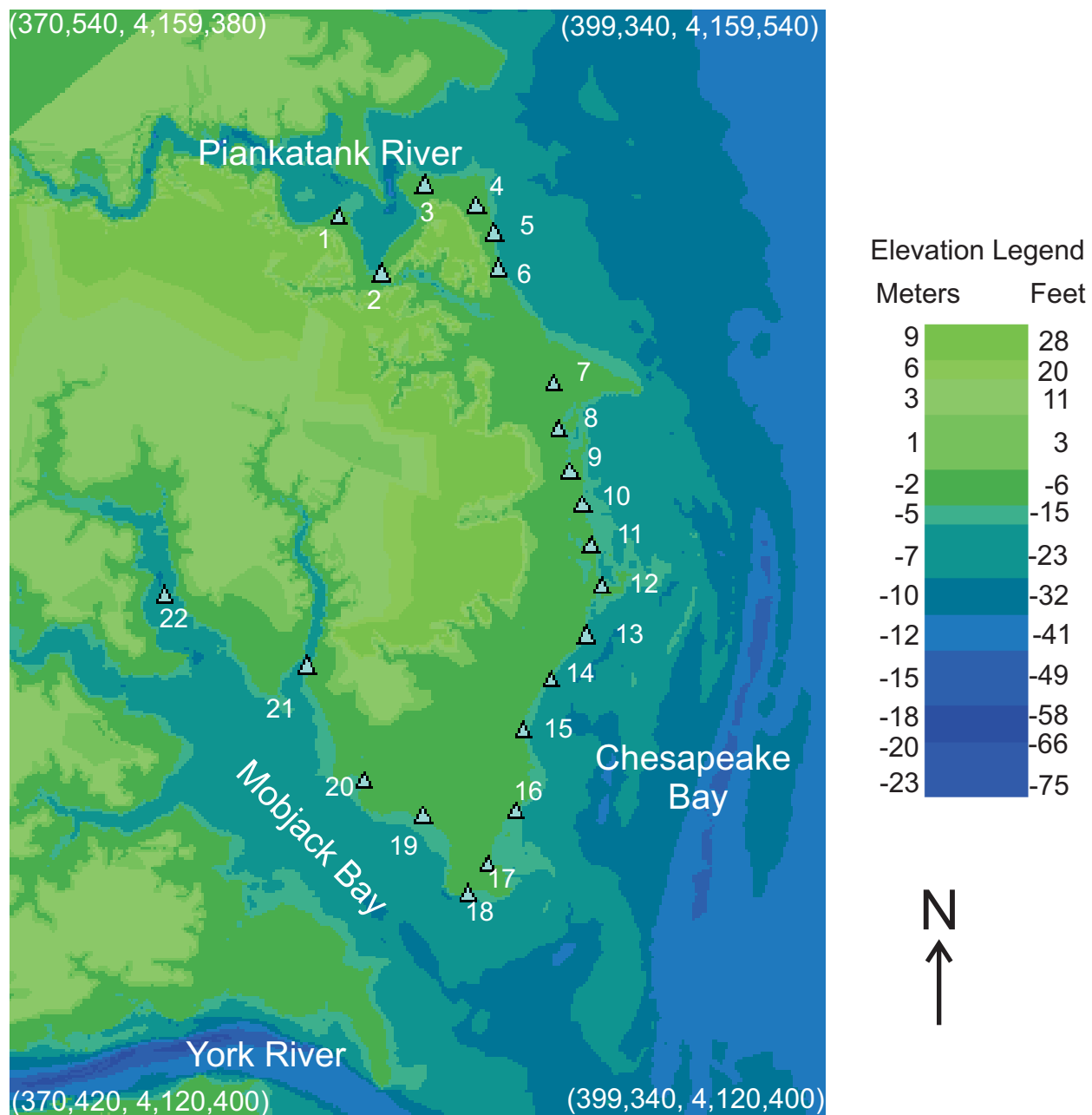


Figure 4-1. Gridded bathymetry of the waterways of Mathews County and locations of STWAVE output stations. Horizontal datum is UTM, NAD83 zone 18N, meters. Vertical datum is approximately mean low water. Bathymetry retrieved from NOAA's ENC database.

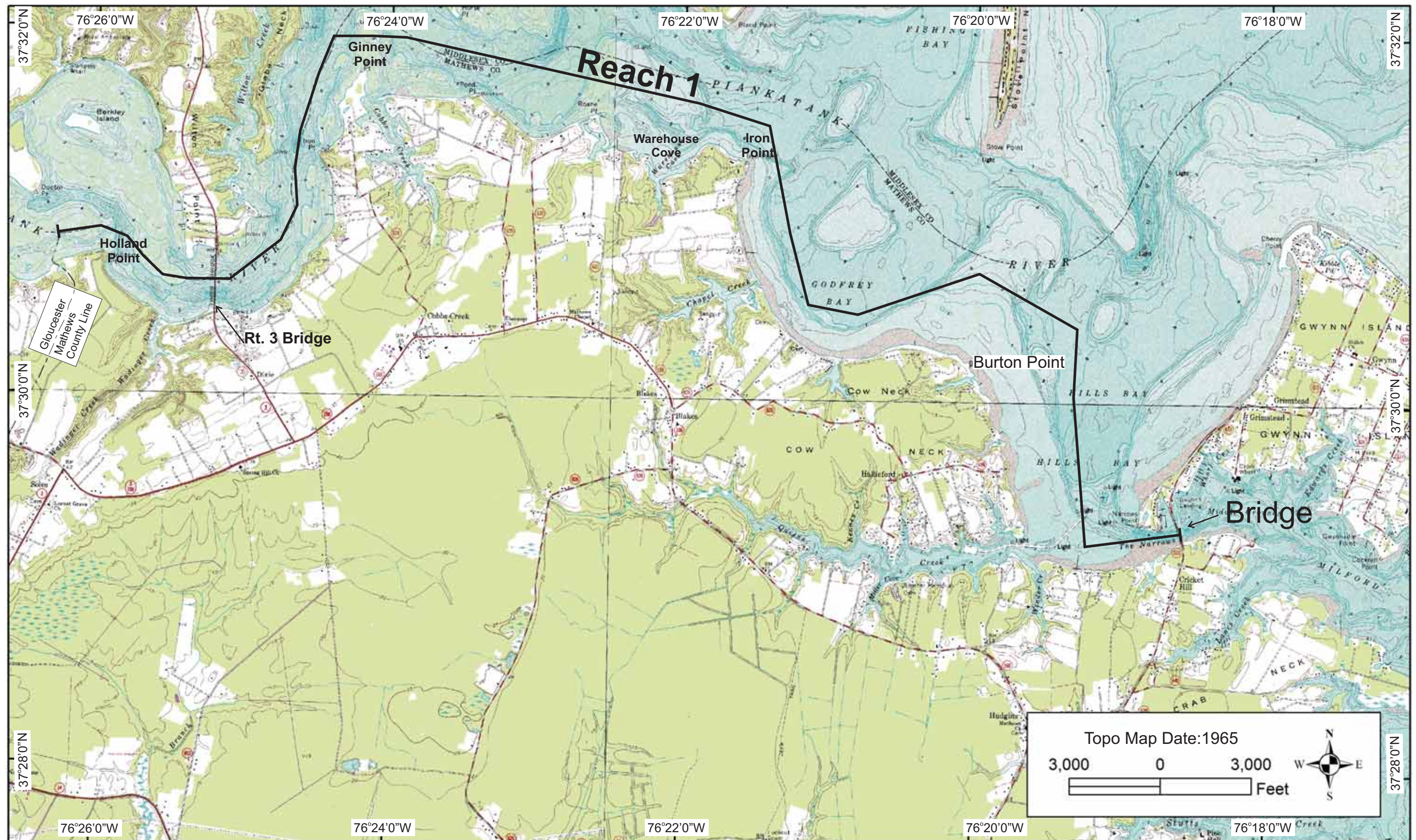


Figure 5-1. Topographic map of Reach 1 along the Piankatank River, Hills Bay, and Queen Creek.

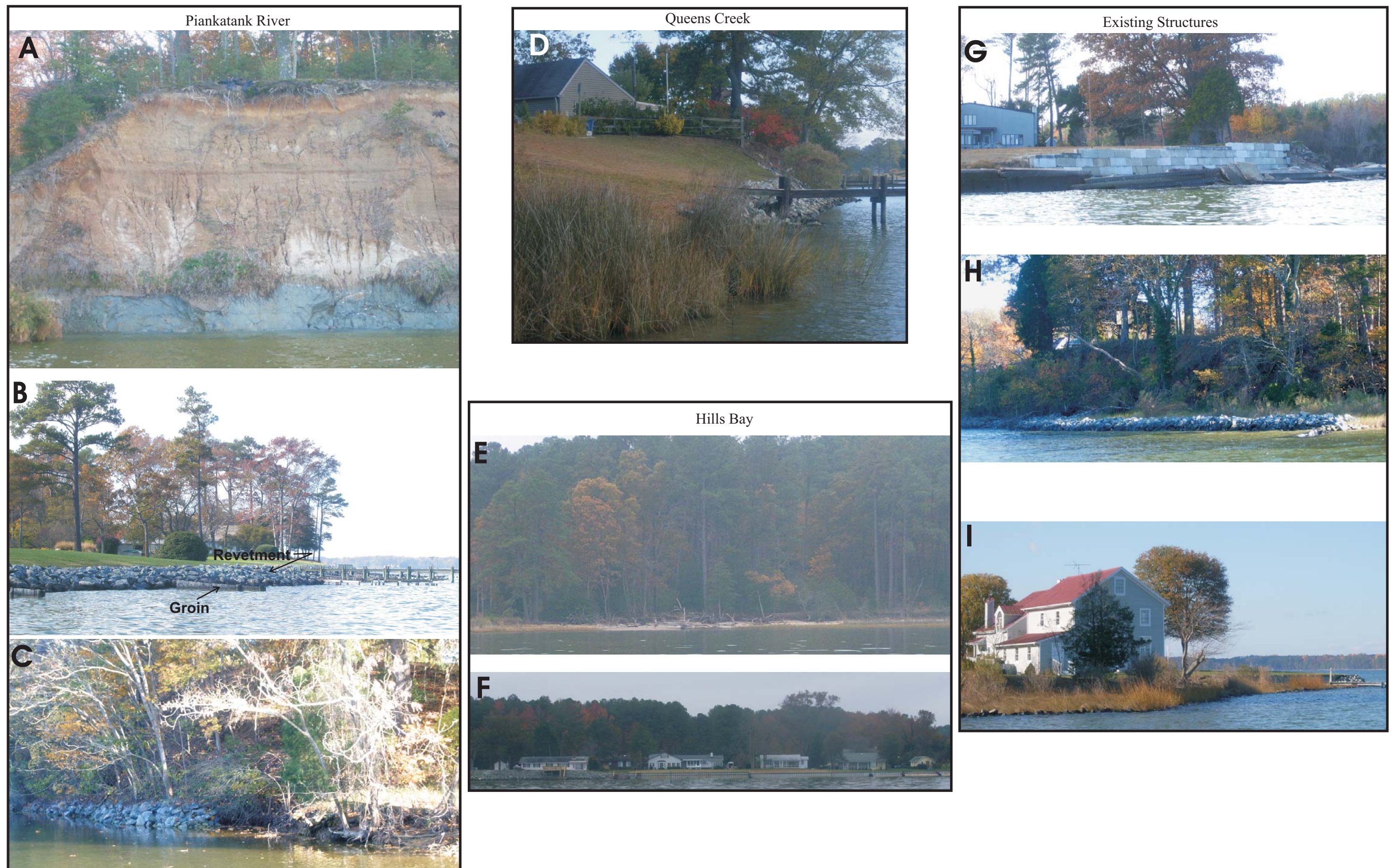


Figure 5-2. Photos of Reach I showing the Piankatank River (A, B, C), Hills Bay (E, F), and Queens Creek (D) shorelines as well as some existing structures in this reach (G, H, I).

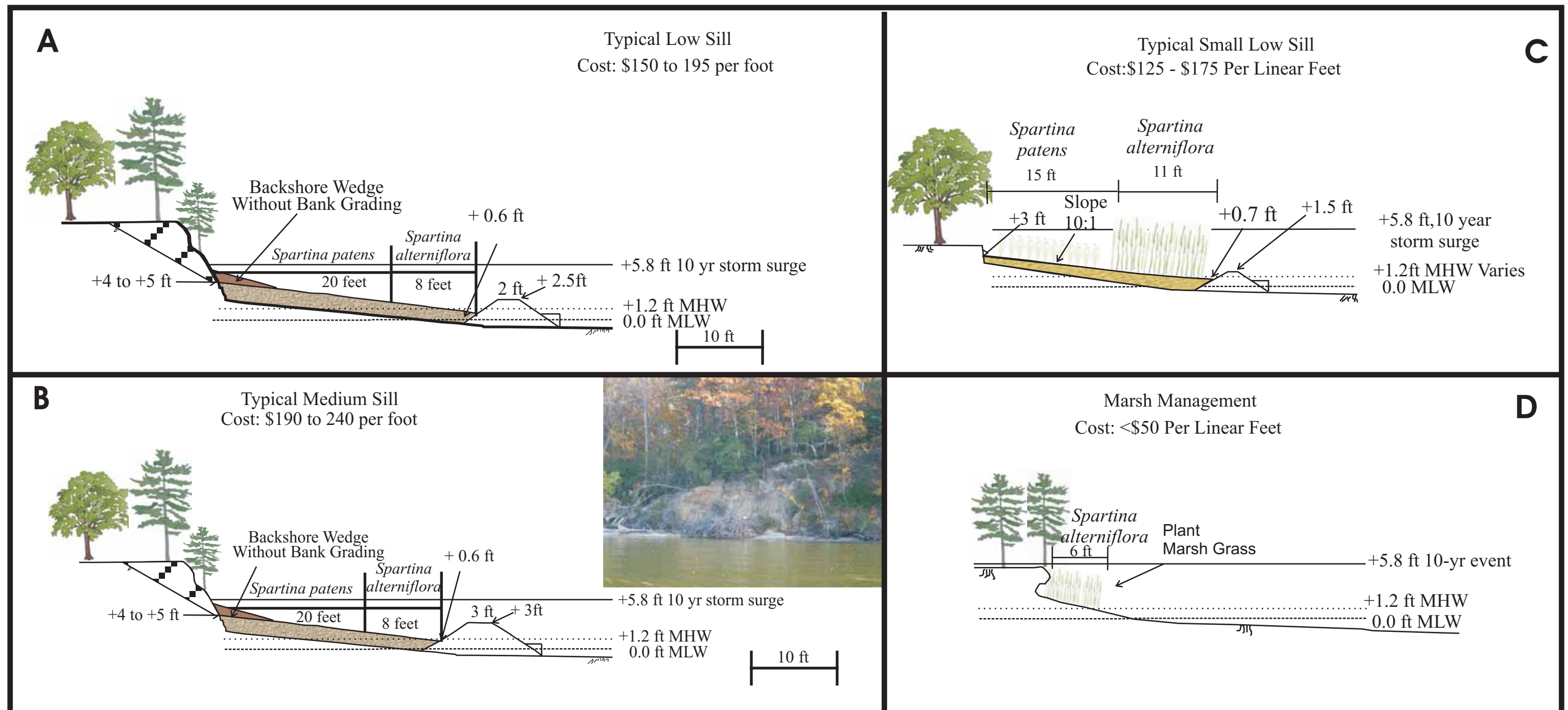


Figure 5-3. Typical cross-sections for Reach 1, Piankatank River, Hills Bay, and Queens Creek of A) a low sill, B) a medium sill, C) a small low sill, and D) Marsh Management proposed for Reach 1. Costs are estimated and typically include the materials and installation of rocks, sand, and plants. Other work, such as permitting, gaining access, etc, can vary considerable by site and is not included in the estimated cost.

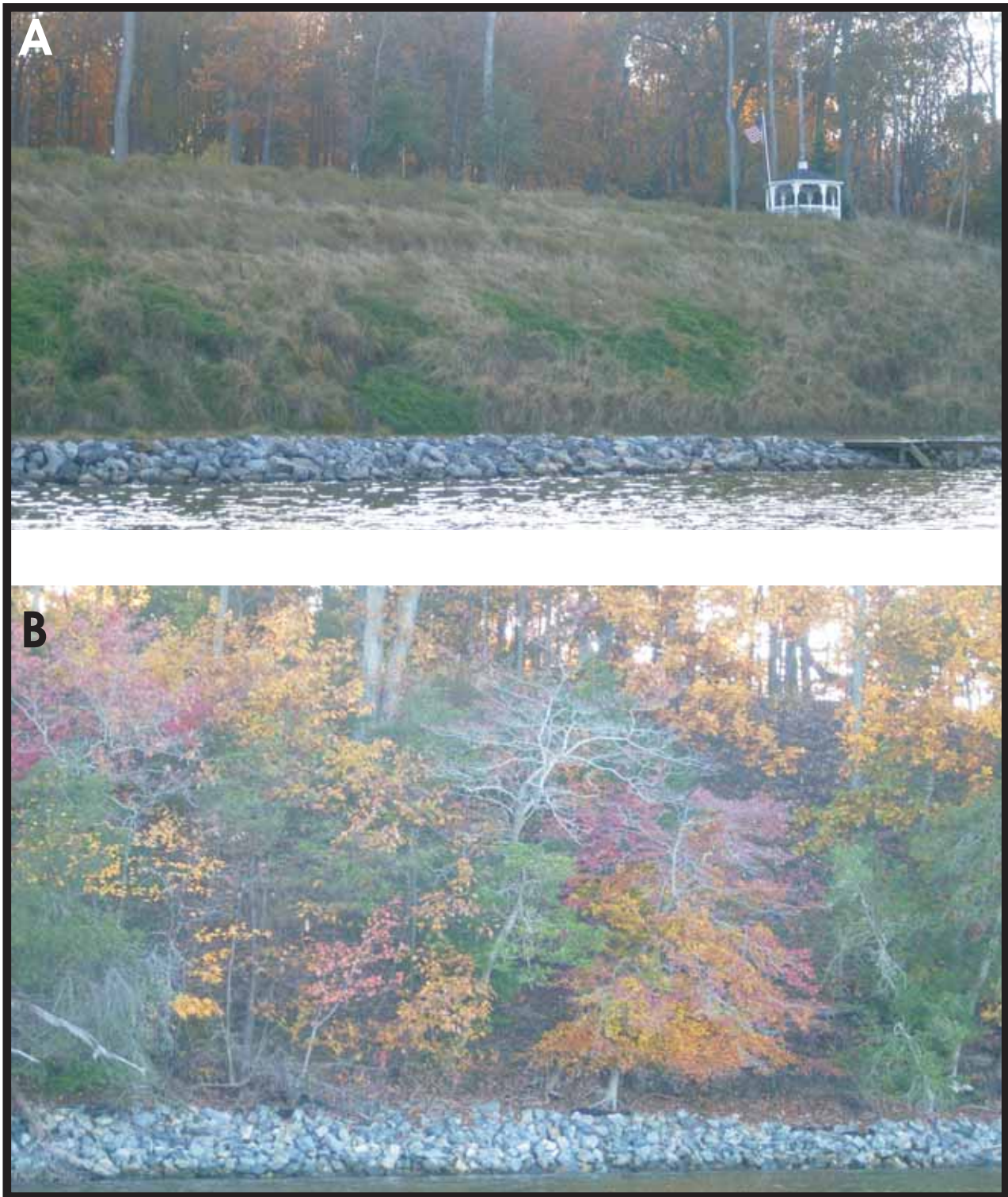


Figure 5-4. Existing riprap revetments along the base of bank with a A) graded bank, and B) ungraded bank.

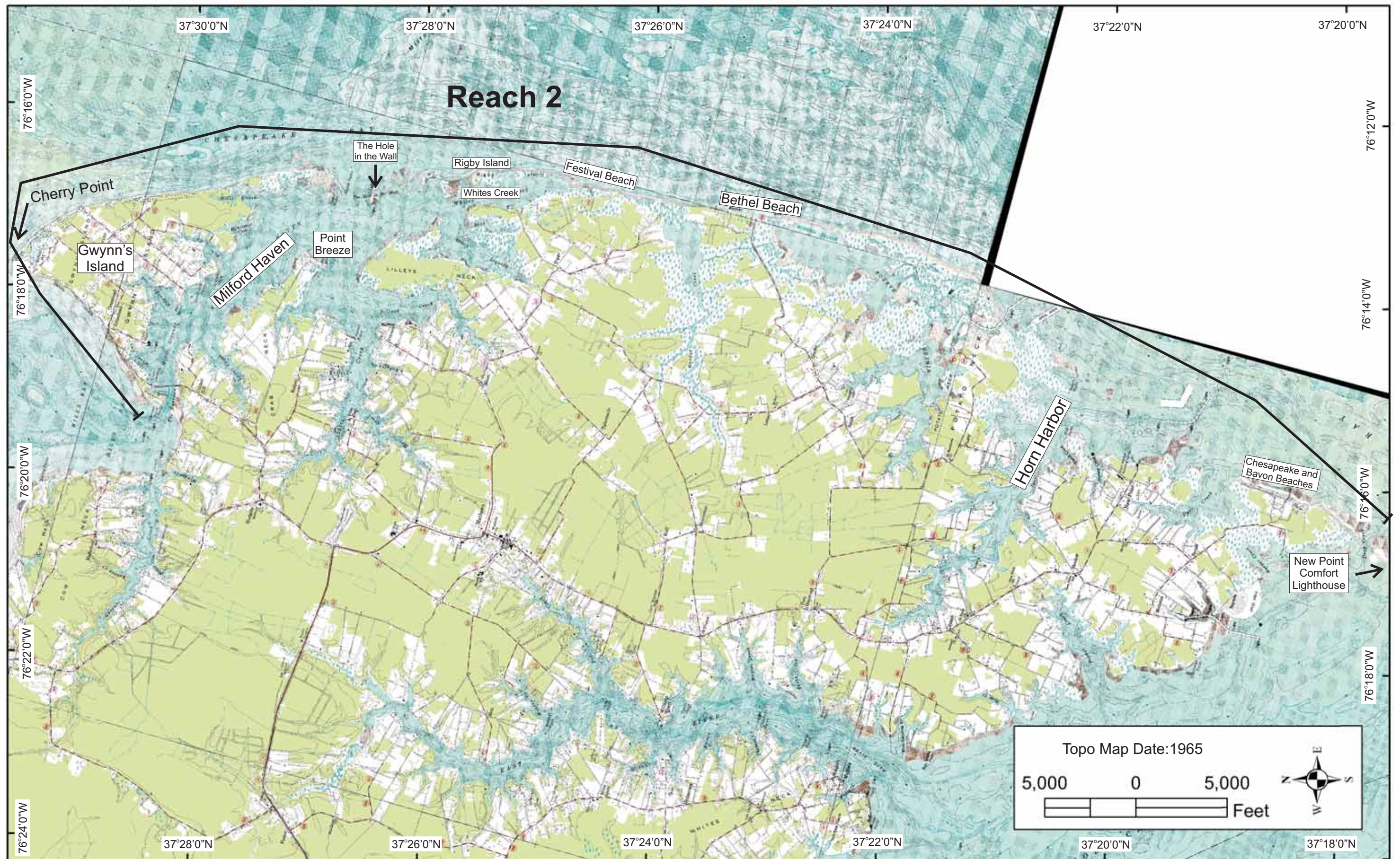


Figure 6-1. Topographic map of Reach 2 along the Chesapeake Bay, Milford Haven, Winter Harbor and Horn Harbor.

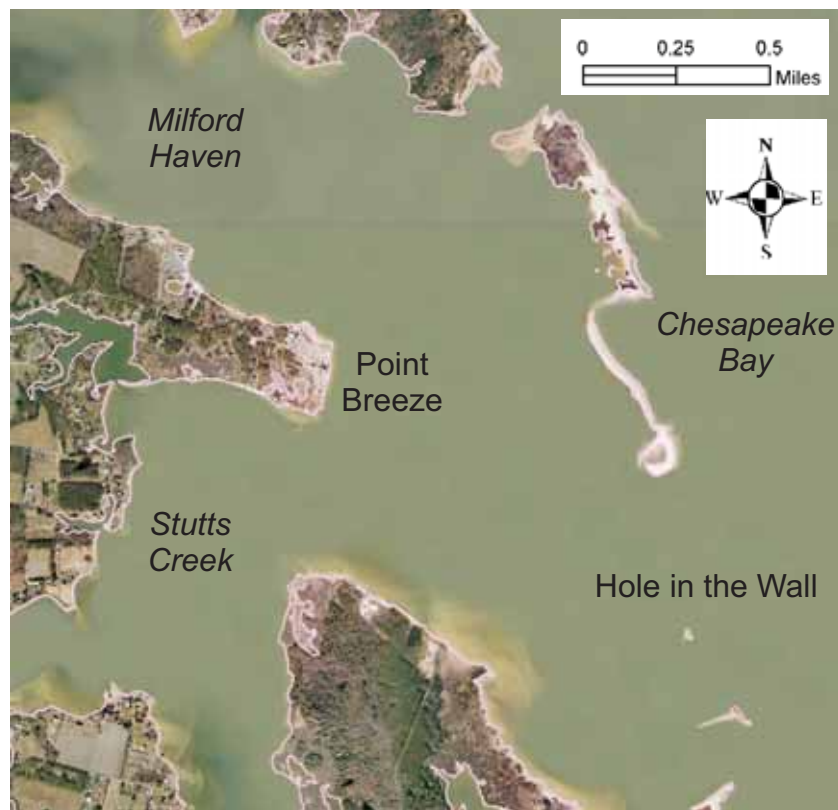


Figure 6-2. Point Breeze in Milford Haven is exposed to open Bay conditions due to the deterioration of Rigby Island. As a result, a stone revetment was constructed to stabilize the shoreline.

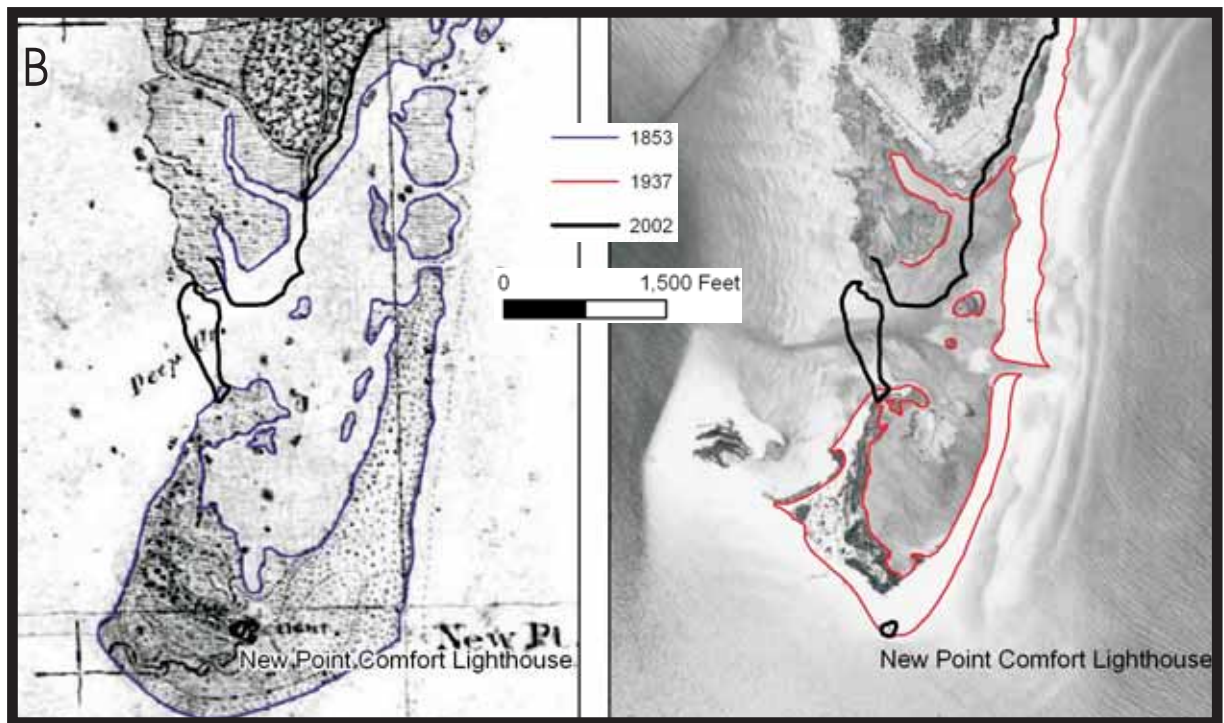
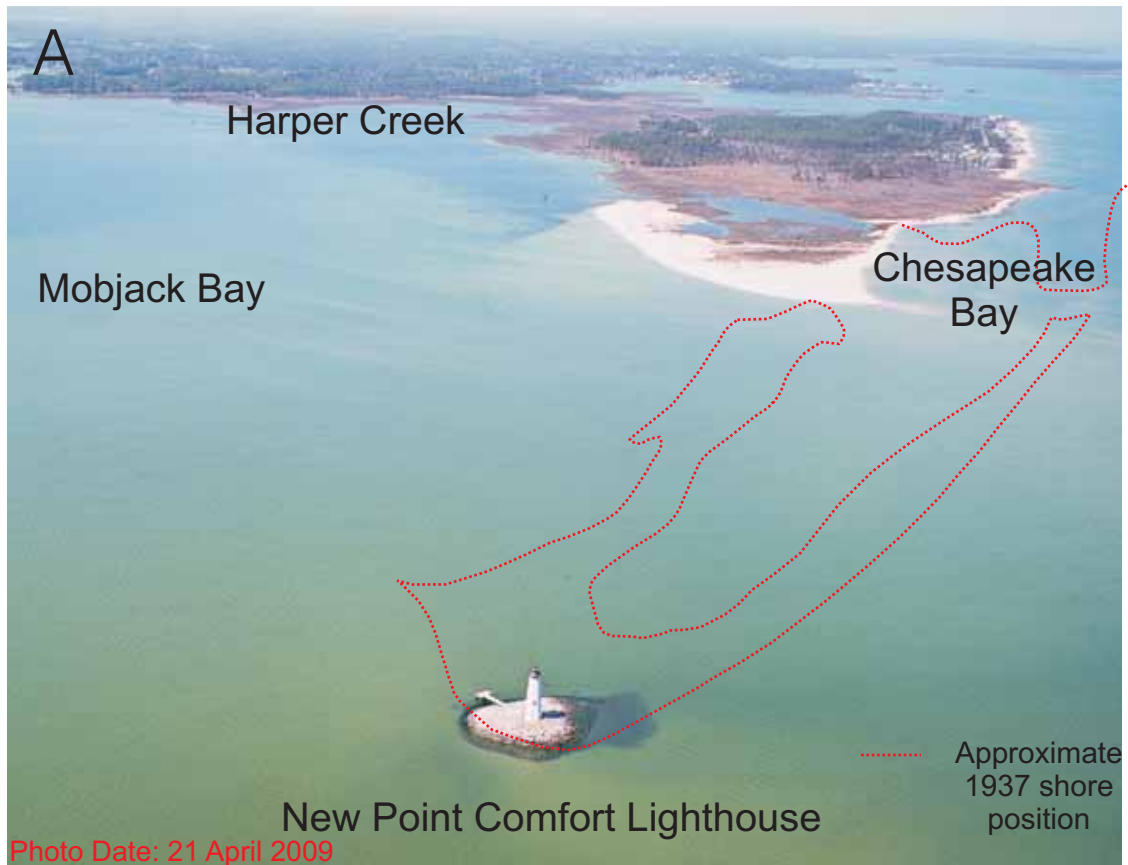


Figure 6-3. A) New Point Comfort Lighthouse looking north showing the approximate extent of the 1937 shoreline. B) Images showing an 1853 map and 1937 aerial photo with digitized shorelines (from Hardaway *et al.*, 2008).

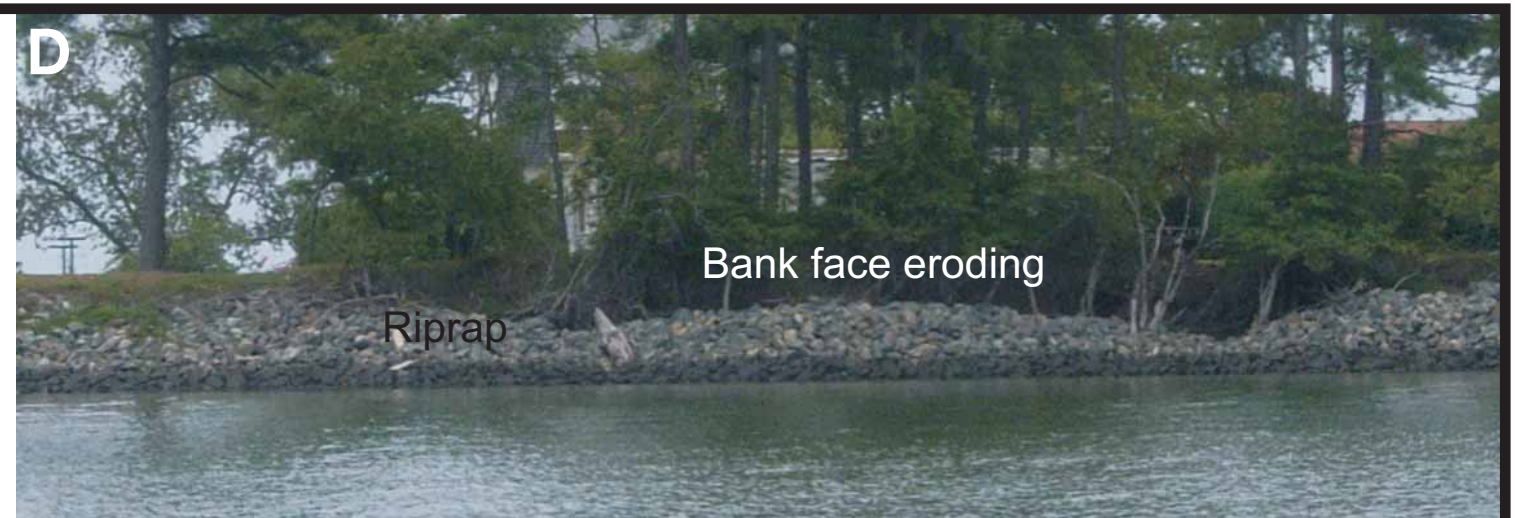
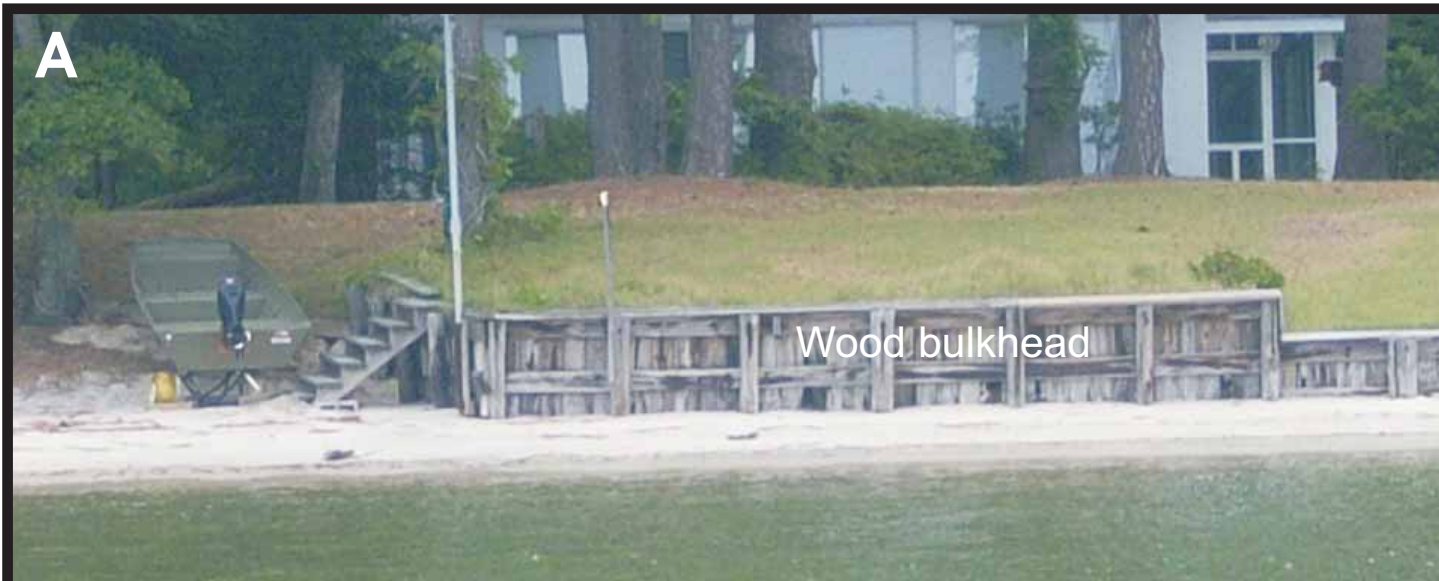


Figure 6-4. The northwest side of Gwynn's Island has many types of structures for shore stabilization A) bulkheads, B) groins and revetments, and C) riprap. In addition, along the main road onto Gwynn's Island broken concrete and poured concrete have been dumped along the shore in order to protect the road.



The beach and backshore are too narrow to allow the growth of vegetation.



Sand is deposited on the updrift side of the groin reducing the downdrift alongshore sand transport.



Pocket beaches develop on natural shorelines downdrift of hardened shorelines.



Figure 6-5. Photos of Gwynn's Island, Mathews, Virginia.

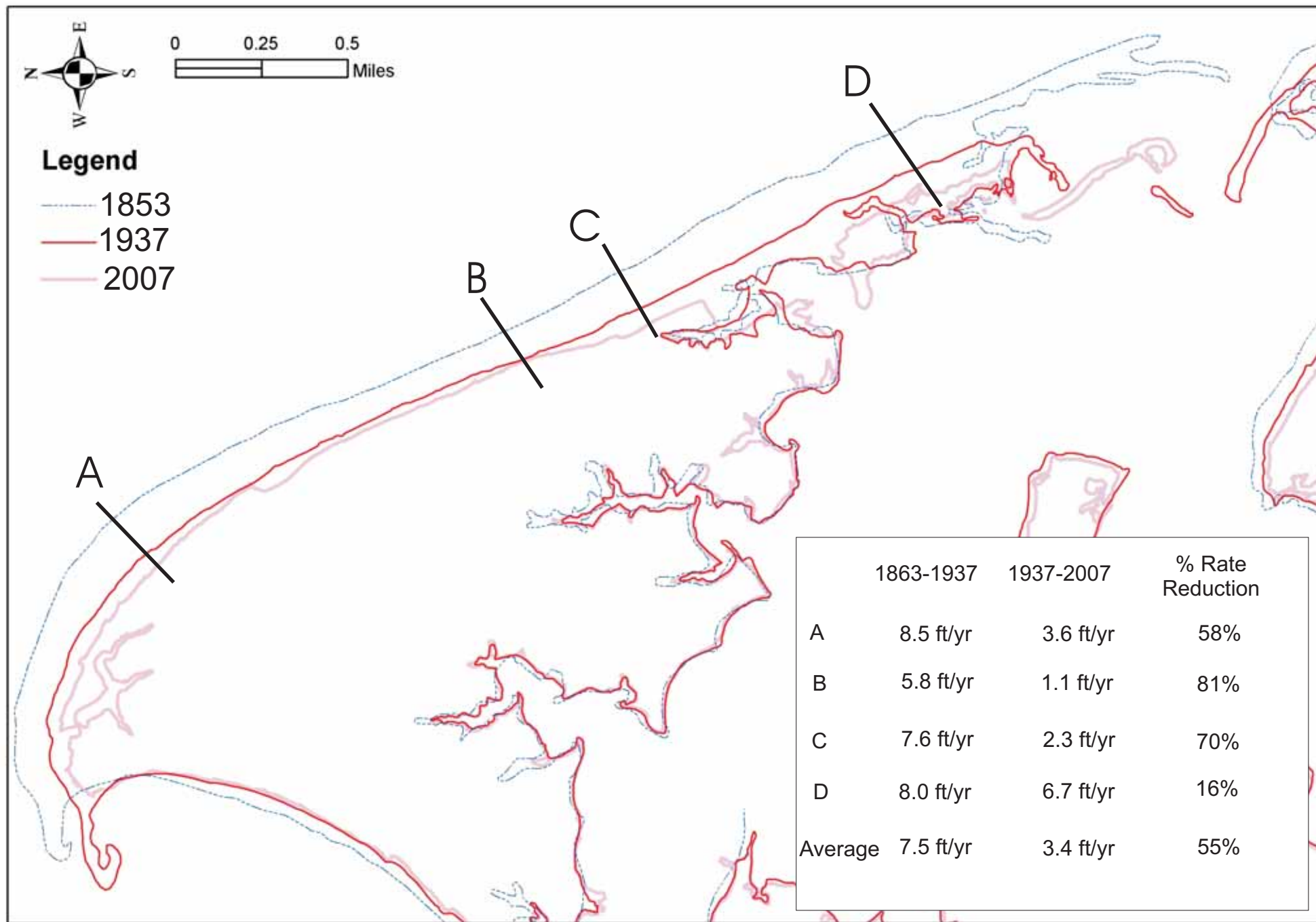


Figure 6-6. Rates of change for Gwynn's Island, Virginia.



Figure 6-7. Chesapeake and Bavon Beaches showing A) extensive dune fencing, B) an alongshore view looking south toward New Point Comfort, and C) The stabilization plan developed for this shoreline reach.

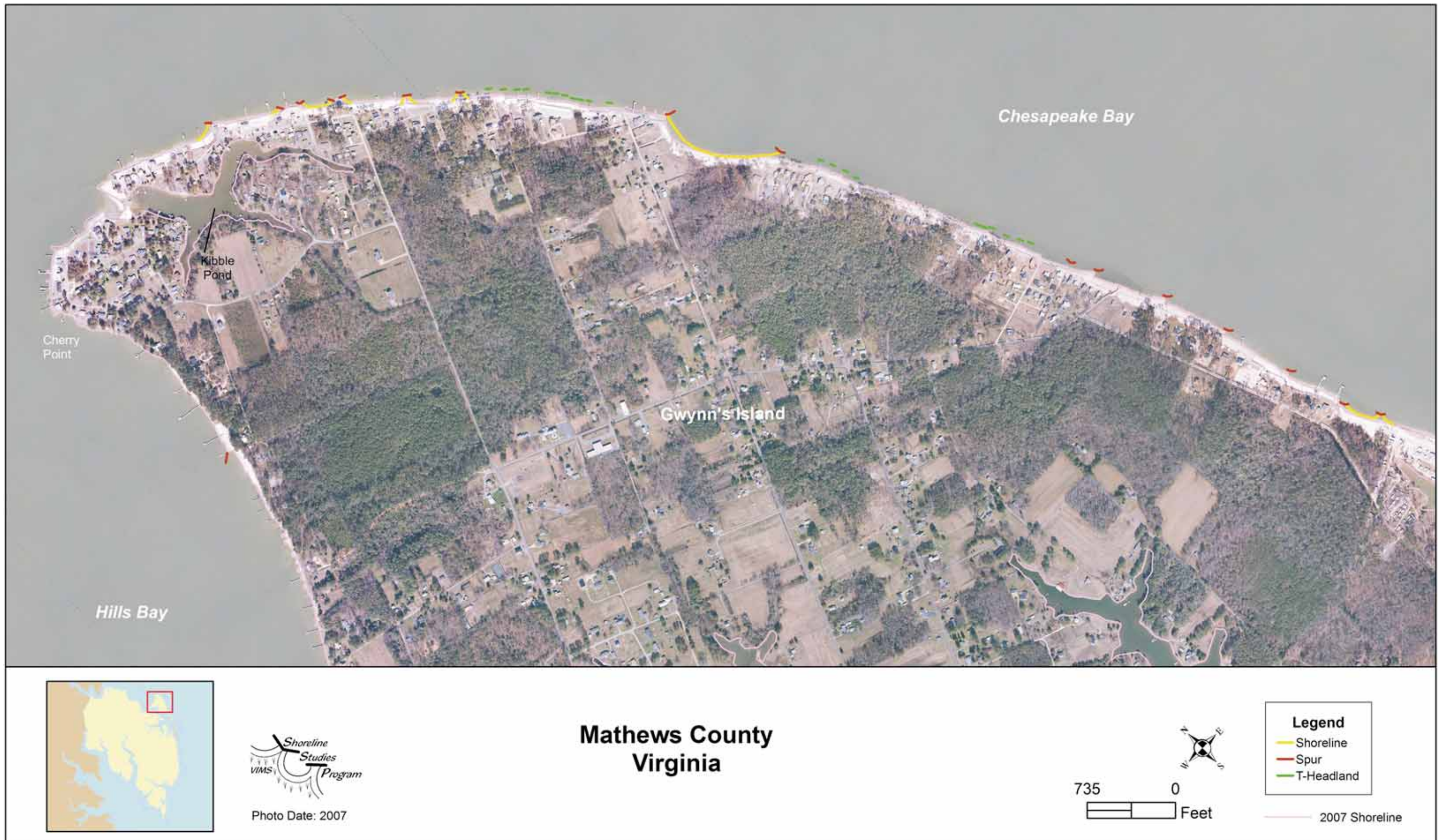


Figure 6-8. Management recommendations for Gwynn's Island, Virginia on a lot-by-lot basis rather than by reach.

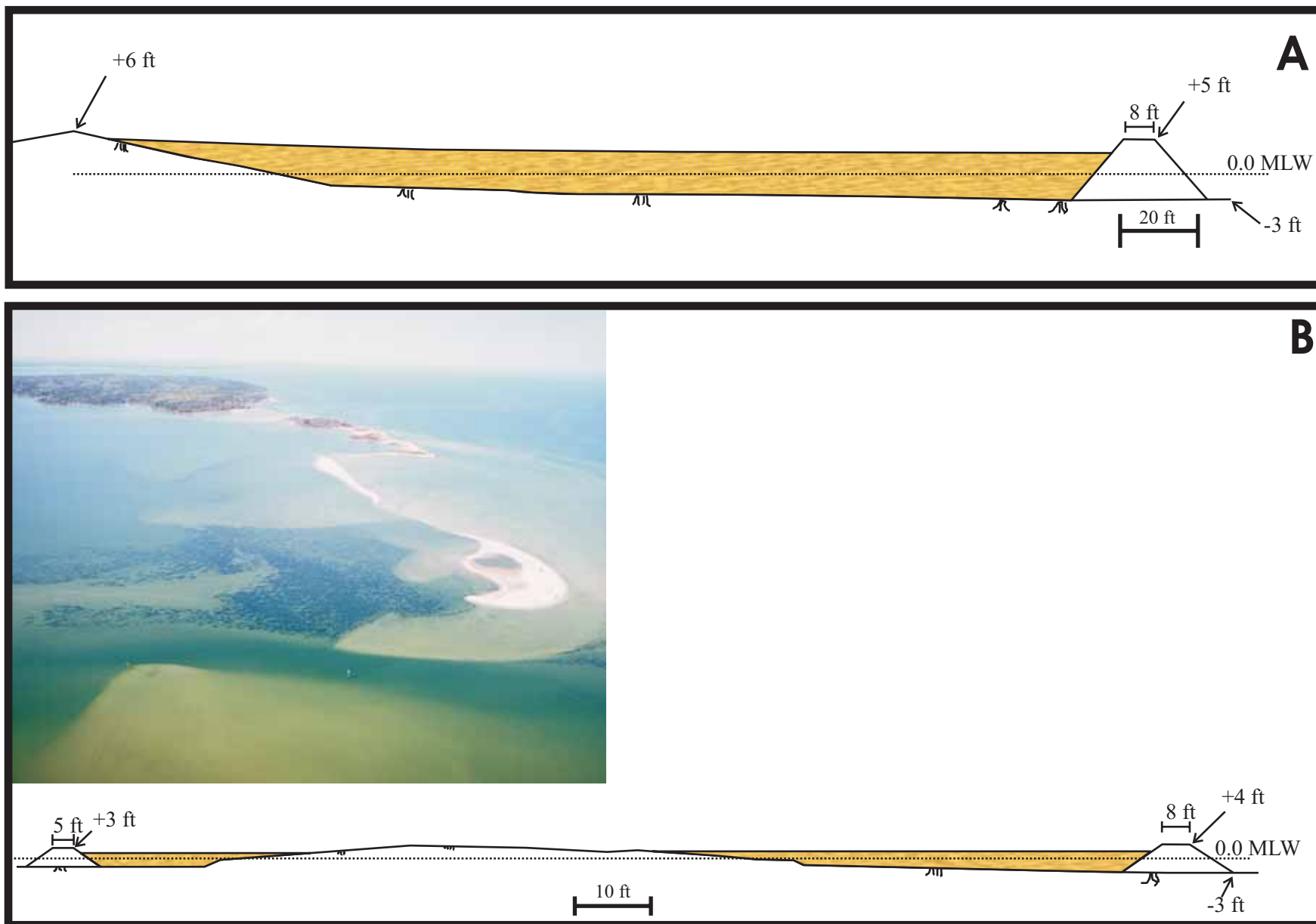
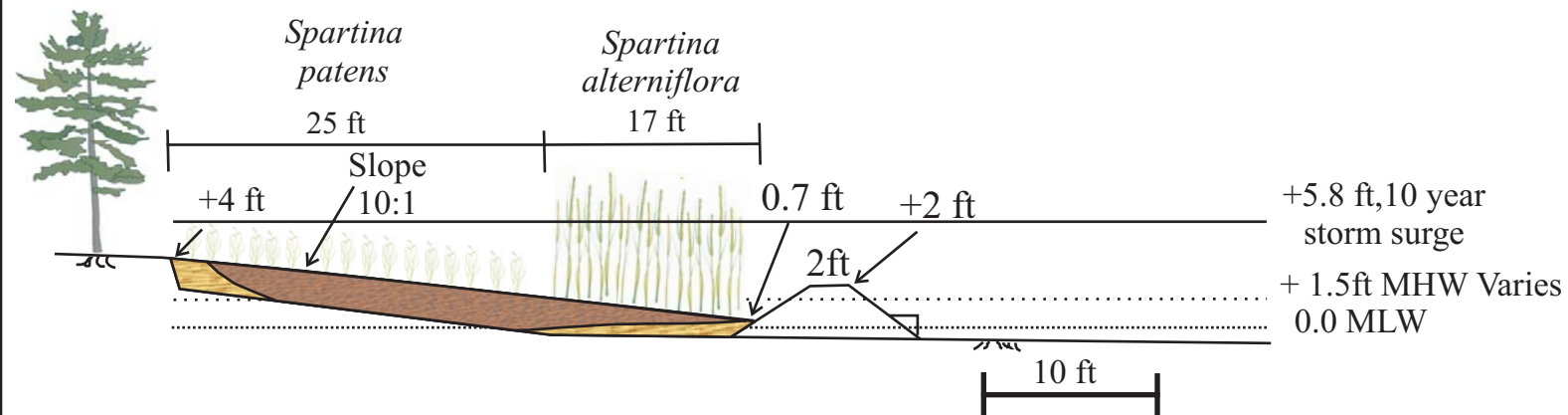


Figure 6-9. Typical cross-sections of breakwaters and beach fill for A) for the Bay coast of Mathews and B) for Rigby Island which requires protection on both the Bay side and lee side in Milford Haven.



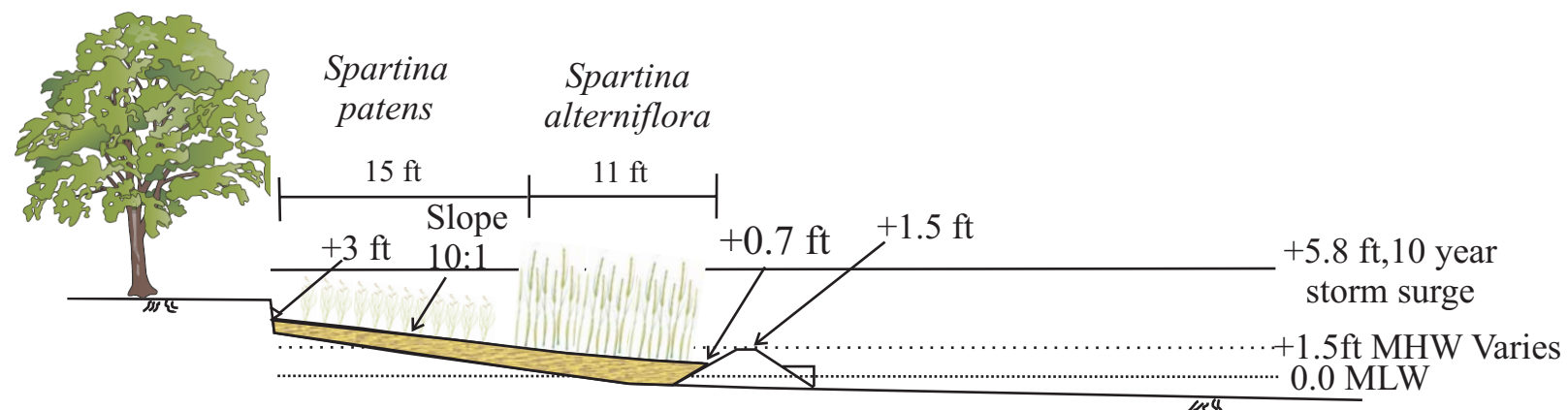
Typical Low Sill - Narrow Crest
Cost: \$200 - \$275 Per Linear Feet

A



Typical Small Low Sill
Cost: \$125 - \$175 Per Linear Feet

B



Marsh Management
Cost: <\$50 per linear foot

C

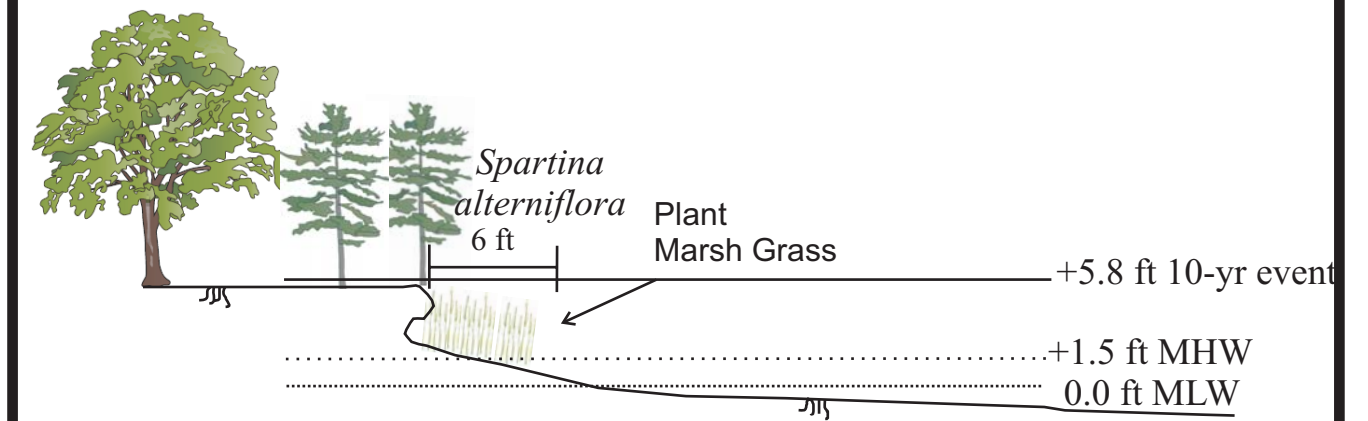


Figure 6-10. Typical cross-sections for the relatively lower energy shores of Reach 2 showing A) a low sill, B) small low sill, and C) marsh management. Costs are estimated and typically include the materials and installation of rocks, sand, and plants. Other work, such as permitting, gaining access, etc, can vary considerable by site and is not included in the estimated cost.

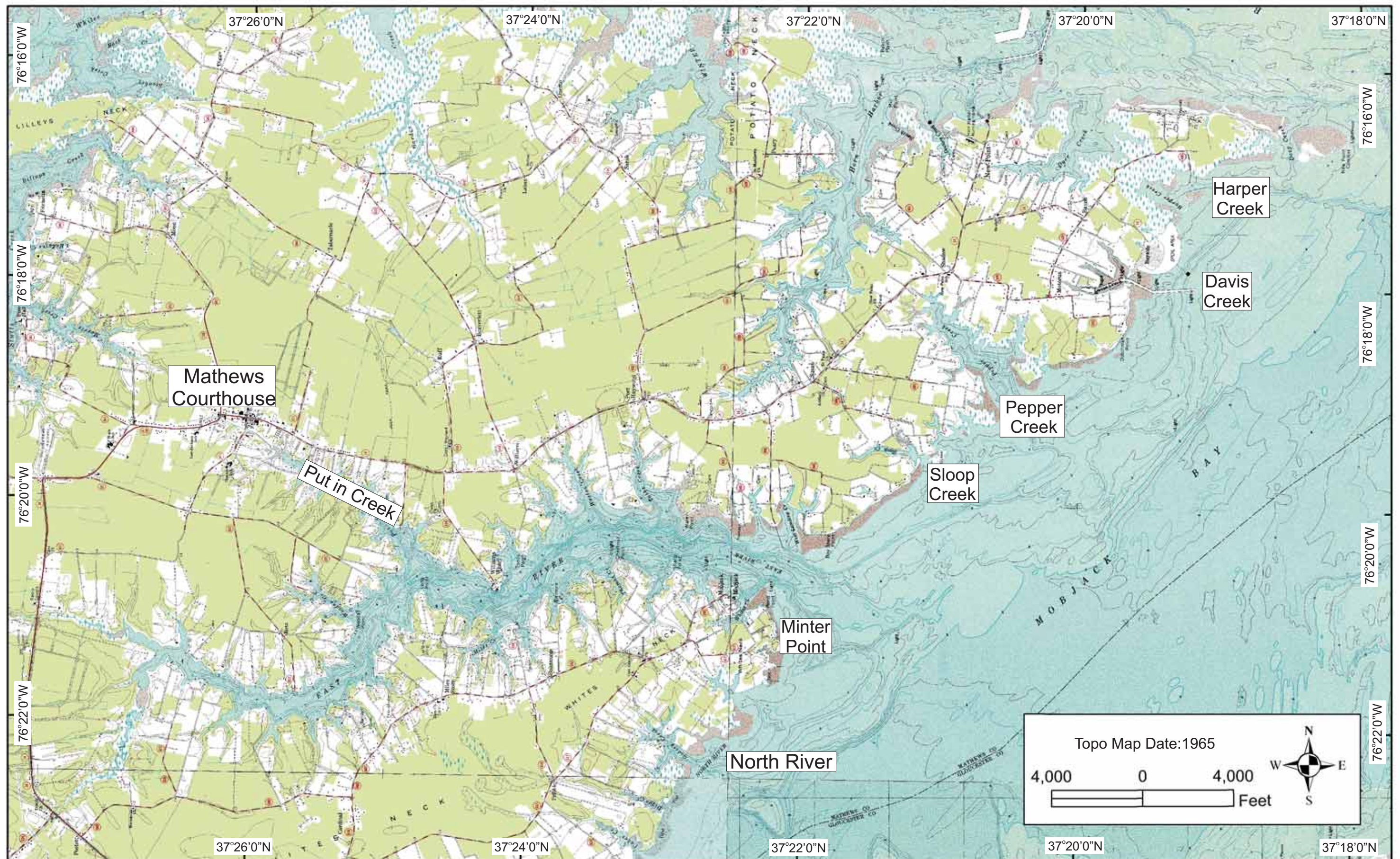


Figure 7-1. Topographic map of Reach 3 along the East River, Put in Creek and Horn Harbor.

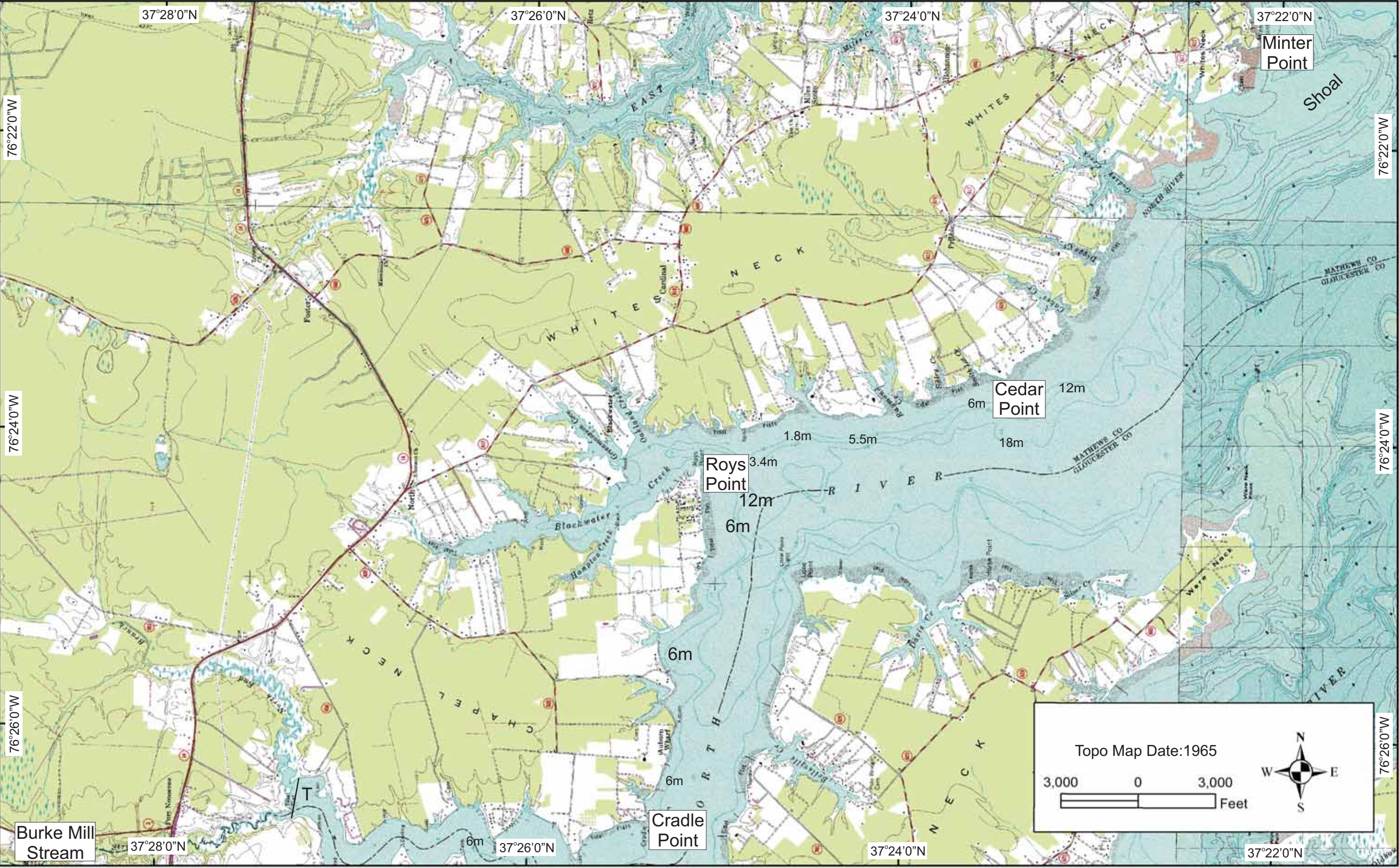


Figure 7-2. Topographic map of Reach 3 along Mobjack Bay and the North River.



Figure 7-3. Shorelines along the East River (A, B, and C), the North River (D and E), and along Mobjack Bay (F).



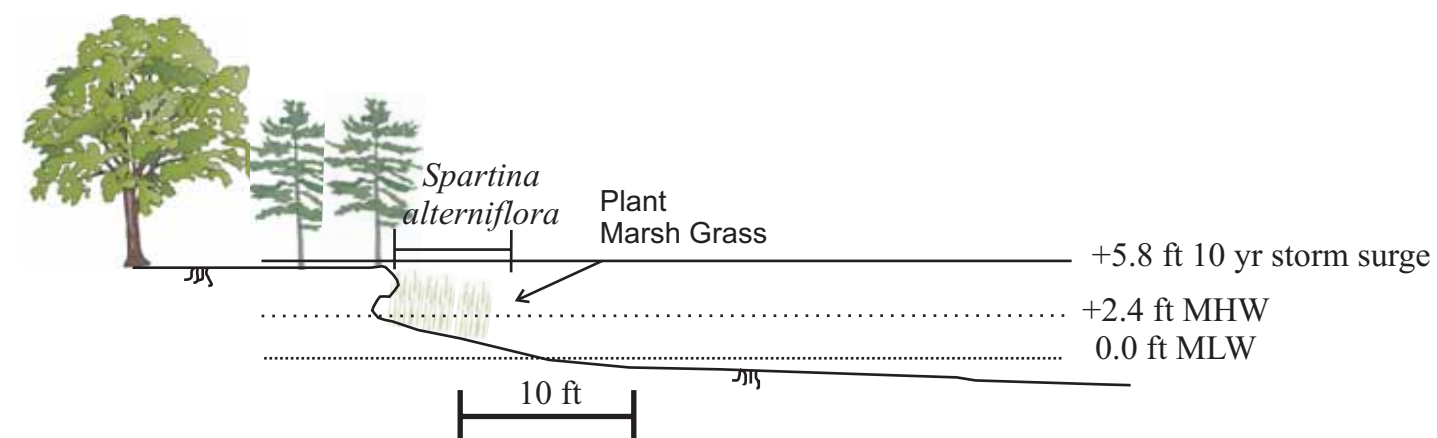
Figure 7-4. Photos of existing projects along Reach 3.



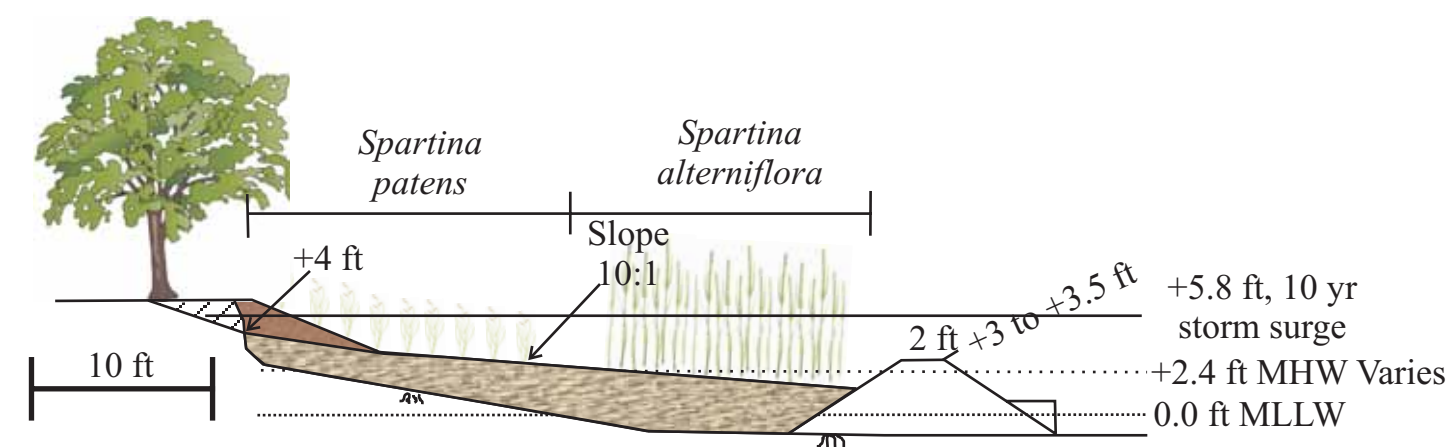
Figure 7-5. “Granddaddy sill” along the East River. Anecdotal evidence suggests this structure was placed along the shore in the late 1800s. Since that time, it has maintained the fringe marsh in front of the upland.



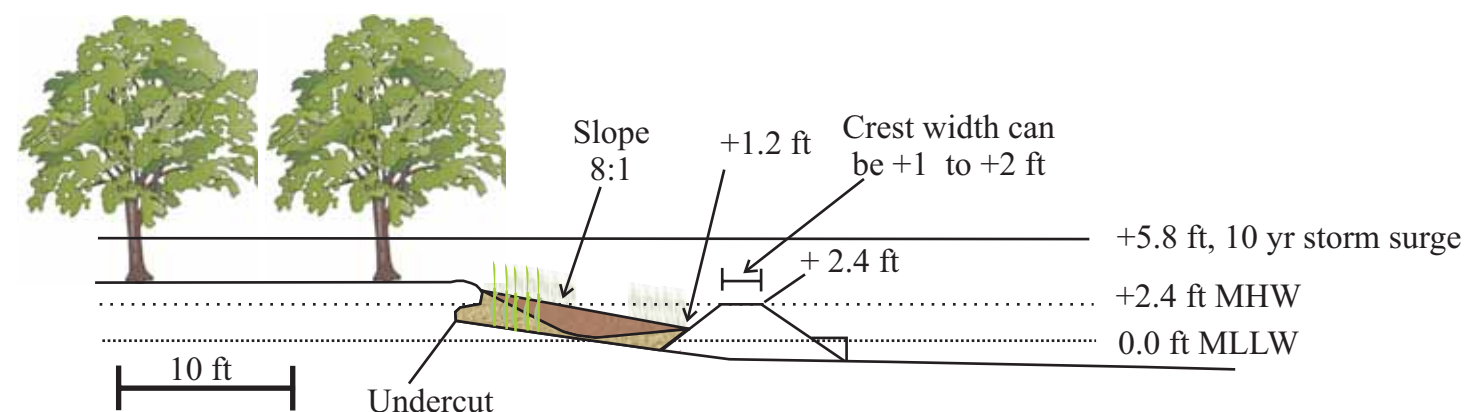
A
Marsh Management
Cost: <\$50 Per Linear Foot



C
Typical Low Sill- Narrow Crest
Cost: \$200 - \$275 Per Linear Foot



B
Typical Small Low Sill
Cost: \$125 - \$175 Per Linear Foot



D
Typical Low Sill - Wide Crest
Cost: \$250 - \$350 Per Linear Foot

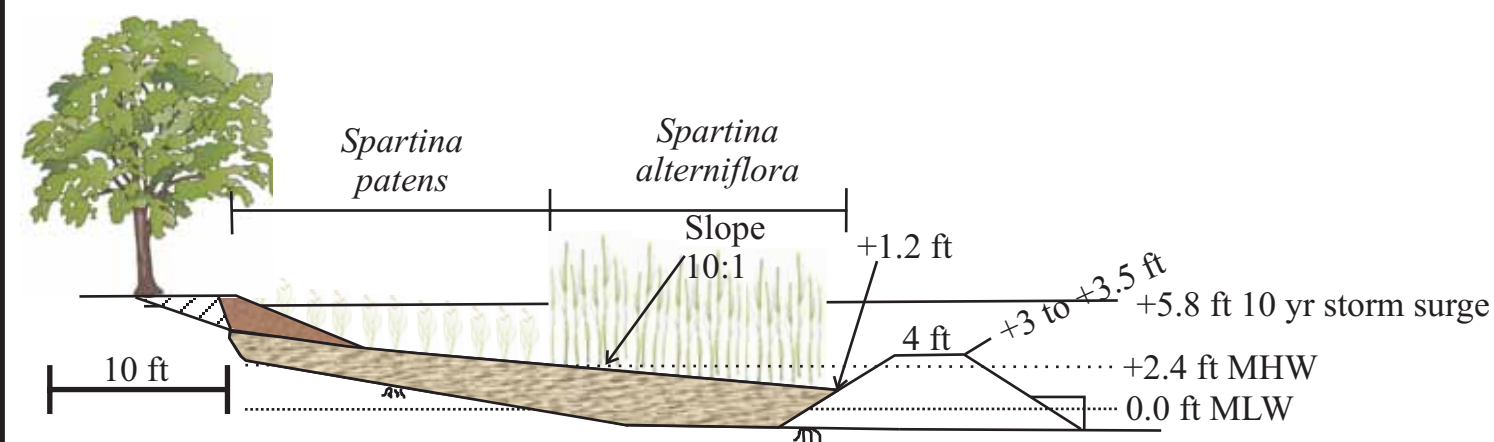


Figure 7-6. Typical cross-sections for Reach 3 along the North and East Rivers. Costs are estimated and typically include the materials and installation of rocks, sand, and plants. Other work, such as permitting, gaining access, etc, can vary considerable by site and is not included in the estimated cost.

Appendix E

Historical Shoreline Index Maps

1937	1968	1994	2007
1953	1978	2002	