Encroachment of Sills onto State-Owned Bottom: Design Guidelines for Chesapeake Bay

Virginia Institute of Marine Science
College of William & Mary

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C. Scott Hardaway, Jr.
Donna A. Milligan
Kevin P. O'Brien
Christine A. Wilcox
Jian Shen
Carl H. Hobbs, III

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

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1 INTRODUCTION

1.1 Statement of the Problem

Recent efforts have sought to expand the use of "Living Shorelines" by waterfront property owners in Virginia and Maryland to combat tidal shoreline erosion. Living shorelines represent a shoreline management option that combines various erosion control methodologies and/or structures while at the same time restoring or preserving natural shoreline vegetation communities. Some regulatory agencies and non-governmental organizations prefer living shorelines over "traditional" shore hardening using bulkheads or stone revetments because these structures create a "barrier" or disconnect between the upland and marine environments.

Typically, creation of a living shoreline involves the placement of sand, planting marsh flora, and, if necessary, construction of a rock structure on the shoreline or in the nearshore (Figure 1). When any type of material, sand and/or rock, is placed below/beyond mean high water (MHW) two situations could occur: 1) encroachment onto regulated lands necessitates a permit and 2) one habitat is traded for another -- non-vegetated wetlands and/or nearshore bottom for marsh fringe and rocky substrate. Encroachment beyond mean low water (MLW) in Virginia (MHW in Maryland) is onto state-owned bottom. This latter point is of concern to the Virginia Marine Resources Commission (VMRC) which manages this region. Its concern is the determination of how much encroachment onto public state bottom is necessary for a shore protection project. The Virginia Chesapeake Bay Local Assistance Program (CBLA) regulates the area above MHW and the landward limit of tidal wetlands. They are concerned about how much encroachment landward is required for bank stabilization. The goal of this report is to offer some guidance toward these concerns, most particularly as it pertains to state bottom. Specifically, it is the intent of this report to look at encroachment primarily bayward of MHW/MLW for sill-type systems installed for shore protection.

1.2 Defining Encroachment

Whenever shore protection is undertaken, impacts to the existing habitat are possible both bayward and landward of the project. Bayward of MHW these habitats include:

- existing marsh fringe, if present
- existing non-vegetated wetland which is the intertidal zone between MHW and MLW
- existing nearshore subaqueaous, bottom/tidal flats/bars below MLW

Landward form MHW, impacts might include:

- backshore regions (beaches and dunes)
- eroding bank grades
- riparian buffers
- infrastructure

These habitats may be impacted but they are replaced both bayward and landward by an engineered, coastal profile capable of shore protection consisting of one or more of the following:

- vegetated upland slope, allowing for storm wave runup
- enhanced marsh fringe or beach, providing wave attenuation
- hard rocky substrate by revetment, sill or breakwaters protecting the enhanced marsh and or beach,

The following example illustrates encroachment. A site on a large tidal creek is eroding at the base of bank and on the bank face. The site has an average fetch of 2 miles (3.2 km) with a bank height of 20 feet (6 m) and a narrow sand beach. The level of shore protection for a 25 year storm is +5 feet (1.5 m) mean low water (MLW), and the mean tidal range is 2.0 feet (0.6 m). With a proposed sill project, the intersection of the sand fill and the base of the bank is a key point (Figure 1). The sand is placed on a slope of 10:1* see note (Luscher and Hollingsworth, 2006) and intersects the landside of the sill at about +1.0 foot (0.3 m) MLW or mean tide level (MTL). The amount of encroachment beyond mean high water (MHW) and MLW depends on the pre-existing profile. If the bank is graded, the encroachment landward is a function of bank height where grading begins at +5 feet (1.5 m) MLW and goes 30 feet (9 m) landward on 2:1 grade. The resulting graded bank will be vegetated and might represent an improved upland buffer compared to the previously eroding bank.

* note When slope is expressed as 10:1, it means that for every ten feet in the horizontal direction, there is one foot of change in the vertical direction. So as the first number decreases, the slope becomes steeper. A grade of 2:1 is much steeper than 10:1.

1.3 Defining Living Shoreline Types

Living shoreline approaches for lower energy environments in the rivers and creeks of the Virginia portion of Chesapeake Bay include the establishment of marsh fringes and beaches to provide shore erosion control. They have been used for many years and broadly include:

- marsh planting on existing substrate (Figure 2)
- sand fill with groins and marsh plantings (Figure 3)
- sand fill with stone sills and marsh plantings (Figure 4)
- sand fill with breakwaters and marsh and dune plantings (Figure 5)

An erosion problem can be perceived as being more severe than it is, particularly up very fetch-limited tidal creeks where shade from trees prevents the marsh fringe from growing (Figure 6). Nevertheless, landowners often view any loss of land as undesirable and wish to fix it, usually with a revetment or bulkhead. Once the marsh dies or a bulkhead or revetment is installed, the buffer between the upland and the adjacent water body is lost. In contrast to bulkheads and revetments, living shorelines offer a vegetated coastal buffer zone and an equally effective means of controlling shore erosion.

When creating fringe marshes for erosion control, use of one to three basic components is considered based primarily on wave climate. The three components are plants, sand, and rock. It also is possible to use only one component, rock, in protecting an eroding marsh that is wide enough and currently protecting the adjacent upland with a marsh toe revetment or sill (Duhring *et al.*, 2006). Otherwise the following order of encroachment would logically be:

- **One component**: Planting the existing substrate with intertidal marsh species, usually *Spartina alterniflora*, is inexpensive and easy and does not require a permit. However, one must first determine why there is no marsh and if the bank really is eroding. If the reason is not wave-related then it could be shading by over hanging trees and limbs. This is common on very fetch-limited tidal creeks where the average fetch is less than 500 feet (150 m).

- **Two components** (sand and plants): Adding sand to enhance and widen the intertidal zone to be planted may be necessary as fetches increase beyond about 1,000 feet (300 m). When a site does not face the dominant direction of wave approach, the sand fill will tend to move along the shoreline and off-site. Boat wakes also can be an issue. When this occurs, some type of wave damping device or structure is required to attenuate the impinging waves and hold the sand fill in place. This sends us to the next component scenario.

- **Three components** (sand, plants, and rock): For long-term shore stabilization requiring groins or sills, rock is the best choice. This is necessary where the fetch is 1,000 feet (300 m) or more. However, sills may be necessary in areas with shorter fetches. When fetch exceeds 5 miles (8 km), sills can still be used but a breakwater system might be more appropriate. It's best to use breakwaters along several hundred feet of shoreline. Because of their larger scope, breakwaters are not considered in these encroachment guidelines.

1.4 Encroachment Guidelines in Erosion-Control Policy

This study provides technical guidance for the use of sills to control erosion of tidal shorelines. These recommendations provide information for the analyses of, and decisions on, environmental impacts and ecological trade-offs. The design criteria, when applied on a case-by-case basis and fitted to the particular shoreline situation, can provide managers, property owners, and agents/contractors with data on the area of subaqueous bottom that would be lost and on the composition and characteristics of the alternative shoreline habitat.

A literature search reveals an extensive historical base of research showing the functions and values of tidal marshes and the nonvegetated nearshore. However, research specific to tidal fringe marshes and the nonvegetated nearshore adjacent to eroding scarps (most relevant to the shorelines at question) is less robust than studies on expansive marshes or tidal marsh basins (*i.e.* creek intertidal headwaters and similar areas). Since neither ecosystem comparison nor

decision-making structure is the focus of this study, this report does not incorporate the costs and benefits of the complex combination of factors included in weighing the value and method of controlling upland erosion against the value-trades of various structural and non-structural options. These factors include the benefits of protecting upland property, erosion control, possible benefits of allowing erosion to continue, the value(s) of the affected subaqueous bottom on local and regional ecological scales, the degree of impacts to the local and regional subaqueous environment from a cumulative perspective, the potential effects upon adjacent/local properties and estuarine habitats and other concerns that may be relevant. Instead, once a decision has been made to protect a stretch of shoreline, this report provides scientifically-based guidelines on the how to create a functioning system with minimum encroachment onto existing habitats. Therefore, as an element of this report, an exhaustive review and discussion of tidal wetlands' functions and values would be of little value. However, a list of supporting studies is included for reference in Appendix A.

2 ASSESSMENT OF EXISTING SILL SITES

2.1 Data Collection

2.1.1 Physical Assessment

In order to determine the encroachment of the sill site on subaqueous areas and the overall performance, three sites were examined. They were selected for review based upon the availability of pre-construction data, design data, and the length of structures. They represent sill installations in low, (fetch <1 miles (0.6 km)), medium (1-5 miles (0.6 - 8 km)) and high energy (>5 miles (8 km)) environments. The sites are St. Mary's, Jefferson Patterson Park & Museum (JJPM), and Webster Field Annex, respectively (Figure 7). St. Mary's was surveyed in 2007 and JPPM and Webster Field in 2008. These projects were constructed in 2002, 1999, and 2003, respectively.

New shoreline and nearshore surveys were conducted at each site for this study in order to document the present conditions. The survey data are presented in Appendix B. A Trimble 4700 Real-Time Kinematic Global Positioning System (RTK-GPS) was used to set control points and to acquire shore data. The system utilizes dual-frequency, real-time technology to obtain centimeter accuracy in surveying applications. In addition, a Trimble 5600 Robotic Total Station was used to acquire data in the nearshore. Generally, the surveys included the following elements:

1. Dimensions of the sill;
2. Mean High Water (MHW) and Mean Lower Low Water (MLLW); survey extends to approximately the -2 feet (0.6 m) MLLW contour; and
3. Base of bank, where appropriate and possible. In addition, the conditions of the base of banks were assessed in terms of stability/wave scarping since the sites were impacted by Hurricane Isabel in September 2003.

At St. Mary's and Webster Field, pre- and post-construction field surveys were available. Where available, benchmarks from the older surveys were incorporated into the new surveys so that all the data could be converted to the present horizontal and vertical datums and used for comparison. The pre-construction data for JPPM was slightly more problematic; the older digital data could not be accurately aligned with the new data. However, we were able to obtain a reasonable estimate of the pre-construction profile by manually measuring from the plans created for the project. While these profiles are not as accurate as the other pre-existing data, it was important to at least estimate the encroachment of the system. Datum conversion information is located in Appendix B.

The encroachment distance of the system was quantified as was the slope of the fringe marsh behind the sill. The width of the *Spartina alterniflora* and *Spartina patens* zones behind the sills was determined from the survey where it was possible to do so. Geographic Information System (GIS) was used in some analyses. In addition, aerial imagery and ground photos provided information for a detailed analysis of performance at each sites.

2.1.2 Hydrodynamic Assessment

High water levels during a storm often result in shoreline erosion and can affect the performance of erosion control efforts at a managed site. A numerical model simulation of hurricanes was combined with observation data to analyze the influence of storm surge and waves on shoreline erosion at three sites. Hurricane Isabel and Tropical Storm Ernesto were used as examples.

Storm Description

Hurricane Isabel made landfall in eastern North Carolina on September 18, 2003 (UTC 17:00). It then weakened as it moved across eastern North Carolina, southern Virginia, and western Pennsylvania (Beven and Cobb, 2003). Sustained winds of approximately 100 miles per hour (46 m/s) and a pressure drop of approximately 56 mb were measured before landfall. The hurricane traveled at a speed of approximately 24 miles per hour (39 km/hr) after it made landfall. Hurricane Isabel is considered to be one of the most significant tropical cyclones to affect portions of northeastern North Carolina and east central Virginia since Hurricane Hazel in 1954 and the Chesapeake-Potomac Hurricane of 1933. Storm surges of 3 to 5 feet (1.0-1.4 m) above normal tide levels were observed over the central portions of the Chesapeake Bay and 5 to 6.5 feet (1.5-2.0 m) above normal tide over the southern portion of the Bay in the vicinity of Hampton Roads, Virginia. In the upper regions of the Chesapeake Bay, near Annapolis and Baltimore, Maryland, surge of 5.5 to 6.5 feet (1.7-2.0 m) above normal tide were observed. High surges also were observed at the headwaters of the tributaries, reaching 8.2 feet (2.5 m) above normal levels at the Richmond City locks along the James River in Virginia and nearly 5.5 feet (1.7 m) above normal along the Potomac River in Washington, D.C. The surge and inundation caused a great deal of damage in the region. Many flooded areas are located in the low-lying area of the tributaries.

On August 30, 2006, Tropical Storm Ernesto made landfall at Plantation Key, Florida, in the upper Florida Keys around 03:00 UTC. The storm made a second landfall, around 05:00 UTC on the Florida mainland in southwestern Miami (Dade County) (Knabb and Mainelli, 2006). The storm moved northward and reached the North Carolina/Virginia border at about 18:00 UTC on September 1, 2006. The storm had diminished to an extratropical cyclone. By 18:00 UTC, September 2, Ernesto was centered near Washington, D.C. A pressure of 988.5 mb was measured at Kinston, North Carolina. The strongest sustained wind measured by an official surface-based anemometer in North Carolina was 57 miles per hour (25.7 m/s) at the National Ocean Service (NOS) station at Wrightsville Beach (Johnny Mercer Pier), where a gust of 73 miles per hour (32.9 m/s) was reported (Knabb and Mainelli, 2006). A large area of high pressure was centered over southeastern Canada as Ernesto advanced northward. The combined pressure system produced sustained gale-force winds near the coasts of Virginia, Maryland, Delaware, and New Jersey. The sustained wind measured at Chesapeake Bay Bridge Tunnel (CBBT) was about 56 miles per hour(25 m/s) as the storm approached the lower Bay area. The storm generated a surge of about 3.2 feet (1.0 m) at the Chesapeake Bay Bridge Tunnel and more than 2 feet (0.6 m) in the middle to upper Bay regions.

Storm Wind and Water

Data on the wind speed and direction during the two storms were obtained from the National Oceanic and Atmospheric Administration (NOAA) stations in the upper Bay area. During the first phase of Isabel, the wind was from northeast which generated a storm surge in the lower portion of the Bay (Shen *et al.*, 2006). During the second phase of the storm, the wind direction changed from northeast to southeast and then to the south. The strong southerly wind was dominant during the last phase of the storm and generated the large surge in the upper Bay. Figure 8 shows the wind distribution at two NOAA stations. The meteorological station at Solomon's Island failed during the second phase of the storm. During Ernesto, wind direction changed from northeasterly to southerly (Figure 9). However, the maximum wind speed was less than Isabel (Table 1). Figure 10 shows the water levels at the NOAA stations at Solomon's and Lewisetta. The storm tide at these stations were very similar at the two stations during Isabel and Ernesto. The maximum storm tide was 5.5 and 5.8 feet MLLW (1.7 and 1.8 m MLLW) at Lewisetta for Isabel and Ernesto, respectively. At Solomon's, the maximimum water level was 4.5 feet MLLW (1.4 m) during both events. However, it should be noted that during Isabel, the tide guage at Solomon's stopped working while the tide was rising. It is likely that the maximum water level was slightly higher than 4.5 feet MLLW (1.4 m).

Table 1. Summary of wind conditions at Solomon's Island, Maryland and Lewisetta, Virginia as recorded at NOAA stations during Hurricane Isabel and Tropical Storm Ernesto. The instruments at Solomon's Island failed during the second phase of Isabel. N/A means not available.

Storm Event	**Date and Time (UTC)**		**Solomon's Island**		**Lewisetta**	
			Wind speed (mph)	Direction (° TN)	Wind speed (mph)	Direction (° TN)
Isabel						
Phase 1 NE Wind	9/18/2003 (12:00-16:00)	Maximum	37	46	46	69
		Mean	33	57	36	63
Phase 2 SE Wind	9/18/2003 (16:00) to 9/19/2003 (8:00)	Maximum	N/A	N/A	53	121
		Mean	N/A	N/A	34	152
Ernesto						
Phase 1 NE Wind	9/1/2006 (0:00-23:00)	Maximum	43	61	43	78
		Mean	25	49	35	82
Phase 2 SE/SW Wind	9/1/2006 (23:00) to 9/2/2006 (18:00)	Maximum	19	121	16	260
		Mean	15	125	11	247

Storm Surge Simulation

The Unstructured, Tidal, Residual Intertidal, and Mudflat model (UnTRIM) was used to model the storm tide for both storms for all of the sill sites. A large model domain and grid (Figure 11) was used as for the study as they will yield more accurate results by including the remote wind effect on the surge development inside the Bay (Shen and Gong, in press). The UnTRIM model, developed by Casulli (Casulli and Zanolli, 1998; Casulli and Walters, 2000), is a general three-dimensional model. The model domain is covered by a set of non-overlapping convex triangles, or polygons. Each side of each polygon is either a boundary line or a side of an adjacent polygon. A center point exists in each polygon such that the segment joining the centers of two adjacent polygons is orthogonal to the side shared by the two. The model preserves all the advantages of the previous TRIM model but uses an orthogonal, unstructured grid with mixed triangular and quadrilateral grids (Cheng *et al.*, 1993; Cheng and Casulli, 2002). The z-coordinate is used in the vertical. The Eulerian-Lagrangian transport scheme was used for treating the convective terms and a semi-implicit finite-difference method of solution was implemented in the model (Casulli and Zanolli, 1998). Because the Eulerian-Lagrangian transport scheme is implemented in the model, a large model timestep can be used. Thus, very fine model grid cells can be used to represent the model domain without reducing computational efficiency (Shen *et al.*, 2006). Detailed model descriptions can be found in Casulli and Zanolli (1998) and Casulli and Walters (2000).

Wave Estimation

Since erosion during storms is controlled by the wind-generated waves, storm-specific wave conditions were estimated. The observed wind, mean depth, and fetch at selected sites were used to calculate storm wave characteristics using empirical equations suggested by Young and Verhagen (1996). The dominant wind was from northeast and then from south in both Isabel and Ernesto; therefore, the wave characteristics were estimated based on the northeasterly and southerly wind and the fetch at each site. Both maximum and mean wind speeds were used to estimate the wave for the period.

2.2 Site Description

2.2.1 St. Mary's City

St. Mary's City is located on the St. Mary's River in St. Mary's County, Maryland (Figure 7). The project site lies along a curvilinear portion of the coast where fetch varies slightly along the length of the project. The site has very high upland banks and had a narrow, gravelly beach before construction. Erosion was occurring at the base of the bank causing intermittent slumping. Shore recession averaged about 1 feet (0.3 m) per year between 1848 and 1994 (http://www.mgs.md.gov/coastal/maps/schangepdf.html). No shore protection structures were present before construction of the sill system.

The fetches from about mid-site are to the west, northwest and north of 0.9, 0.9, and 0.6 miles, (1.4, 1.4, 1.0 km) respectively. The tidal range at Lewisetta, the closet tide gauge, is 1.2 feet (0.37 m) whereas the tidal range at St. Mary's City is 1.5 feet (0.46 m). The ten highest water levels from post-construction to the present are shown in Table 2.

The gapped sill at St. Mary's City was built in 2002 and has about 1,000 feet (300 m)of shoreline (Figure 12). The main purpose of the St. Mary's Shoreline Project was shoreline erosion control which was achieved with a combination of the stone sill and marsh fringe. Sand fill was placed at about +2.9 feet MLLW (tidal epoch 1983-2001) against the base of the bank and graded on an 8:1 slope to the back of the sill just below mean tide level, +0.4 feet MLLW. The sill height was set at +2.4 feet (0.88 m) MLLW, about a foot (0.3 m)above MHW, typical of many sill systems installed in Maryland (Bosch *et al.*, 2006). As discussed in Hardaway *et al.* (2007), the project was designed as a demonstration of various types of sill openings.

Table 2. List of maximum water levels above mean lower low water and associated storm event at Lewisetta, Virginia tide gauge since April 1974 (NOAA website, 2007).

Date	Elevation (feet (m)MLW)	Comment
1-Sep-2006	5.65 (1.72)	Tropical Storm Ernesto
19-Sep-2003	5.47 (1.67)	Hurricane Isabelle
5-Feb-1998	3.84 (1.17)	Twin Northeasters
1-Nov-1991	3.73 (1.14)	Halloween Storm
31-Oct-1991	3.66 (1.12)	Halloween Storm
7-Sep-1996	3.59 (1.09)	Hurricane Fran
16-Sep-1999	3.51 (1.07)	Hurricane Floyd
8-Oct-2006	3.49 (1.06)	Tropical Storm
22-Sep-1994	3.39 (1.03)	Northeaster
19-Mar-1983	3.36 (1.02)	Northeaster
15-Jun-2007	3.36 (1.02)	Northeaster
28-Jan-1998	3.35 (1.02)	Twin Northeasters

2.2.2 Jefferson Patterson Park & Museum

JPPM is located on the north shore of the Patuxent River beginning at Petersons Point and extending over 2 miles (3 km) upriver (Figure 7). Their shoreline is protected by several projects built in phases since 1986. Because of availability of pre-, and post construction surveys, this study concentrates on Phase 4 which was built in 1999 (Figure 13 and Figure 14).

Overall, this shoreline has historic erosion rates of about 1 feet (0.3 m) per year (http://www.mgs.md.gov/coastal/maps/schangepdf.html). The shoreline has as an intermittently eroding bank that averages about +25 feet (7.6 m) MLW with several low drainages. The middle

drainage occurs within the Phase 4's limits. A small line of stone which acted as a very low sill existed at the site, but it did not offer long-term shore protection for the failing upland banks. One of the main reasons for the project was to protect valuable archaeological resources contained in the banks. Another feature was the paleontonlogical resources along the base of the bank, an indurated highly fossiliferous marl (Figure 15).

This site has fetches to the northwest, west, southwest, south, and south-southeast of 1.3 miles (2 km), 2.5 miles (4 km), 1.9 miles (3 km), 1.3 miles (2 km), and 4.0 miles (6.4 km), respectively. The tide range is assumed the same as at the tide gauge at Solomon's Island, which is 1.2 feet (0.37 m) (Appendix B). Storm surge frequencies at Solomon's Island according to Boon *et al.* (1978) are 4.0 feet (1.22 m), 4.7 feet (1.43 m), 5.4 feet (1.65 m), and 6.1 feet (1.86 m) above MLW for the 10, 25, 50 and 100-yr storms. Hurricane Isabel had an estimated maximum storm surge of just over +4.5 feet (1.37 m) MLW placing it arguably in the 25-year return range for this particular site.

Phase 4 was designed primarily as a sill system but numerous spurs and small breakwaters were constructed at "strategic" morphologic opportunities (Figure 13). Only the section of Phase 4 that was monitored for this study is shown. The site includes the low drainage area which consists of intermittently inundated marshes with marsh peat and thin sandy beaches. The area in the nearshore of this drainage is quite soft and unable to support stone structures and sand fill.

The overall design philosophy was to address subtle headlands with breakwaters or large sills and utilize gapped sills along the adjacent shorelines. The transition between different structures types is accomplished with spurs and side pocket beaches. The gaps or windows between sill segments address the dominant northwest winds and waves with a short spur on the south side of each window "turning" into the wind.

The typical sill (Figure 16A) was designed to address the 25-year event. Since the bank would not be graded due to archaeological concerns, the sand fill was brought up to +6 feet (1.8 m) MLW at the base of the bank then graded down on about 3.5:1 to +4 feet (1.2 m) MLW. From there, the fill followed about a 10:1 slope to about MTL (0.6 feet MLW) intersecting the back of the sill structure. The typical sill crest was set at +2.0 feet (0.6 m) MLW. This provided about 50 feet (15 m) of sand and sill from the intersection of the sand fill with the base of the bank to the outside edge of this stone sill. Other structural units were used to address headlands, structural transitions to pocket beaches and windows.

Breakwater #3 was placed in front of a subtle headland with a pocket beach that transitions both up and down river into gapped sills including sill #3 (Figure 16A). A larger and broader headland was addressed with sill #4, a high, continuous sill bounded by spurs (Figure16B). This headland was the result of a basal, indurated fossil layer that was more erosion resistant than adjacent conditions. Beyond the middle watershed the remaining shore was addressed with breakwater #4 and sill #5.

2.2.3 Webster Field Annex

Webster Field is located on the St. Mary's River at Priest's Point (Figure 7). The sill and breakwater portion of the project shoreline extends about 1,200 feet (365 m) both upriver and downriver from Priest's Point proper (Figure 17) for a total of about 2,400 feet (730 m) of sill/breakwater. These two shore segments were part of the Webster Field Shore Protection Project, the southwest facing coast and the northwest facing coast adjacent to Priest's Point. With a long fetch to the south, long-term shoreline erosion has been between 0.7 and 1.4 feet/yr (0.2 and 0.42 m/yr) . The northwest coast has had intermittent shore change averaging about -0.5 feet/yr (0.15 m/yr) (http://www.mgs.md.gov/coastal/maps/schangepdf.html). However, the northwest side advanced between 1853 and 1958, possibly due to infilling by the Navy.

The upriver section is more sheltered, faces approximately northwest and has fetch exposures to the west, northwest, and north of 1.3, 1.4, and 1.2 miles (2.1, 2.2, and 1.9 km), respectively. The down river section faces southwest and has fetches to the southeast, south, and southwest of 1.2, 5.3, and 4.6 miles (1.9, 8.5, and 7.4 km). Tidal range is 1.5 feet (0.26 m).

Priest's Point is the site of the earliest colonization of Maryland by Jesuit priests and has a very high archaeological significance. The shoreline along the southwest facing shore begins as a low bank at Priest's Point proper at elevation +5 feet (1.5 m) MLW (Figure 18). It slowly rises to about +8 feet (2.4 m) MLW southeastward from Priest's Point while the elevation drops back down to about +4 feet (1.2 m) MLW just south of the breakwaters. The upland is mostly lawn with a narrow line of trees. Old attempts to abate the erosion included bulkheads and broken concrete placed along the bank. In addition, a low line of small stone was placed offshore, and while a narrow marsh had established itself over the years, it was not large enough to control erosion of the upland banks.

Up the St. Mary's River from Priest's Point, the shoreline is an upland bank rising to about +7.5 feet (2.3 m) MLW with a narrow marsh fringe (Figure 18). Broken concrete also had been dumped along the base of this upland bank. The upland then drops down about +3 feet (0.9 m) as the shoreline becomes a narrow, sandy barrier fronting a broad drainage with a small pond that drains to the river. This low sandy bank and marsh fringe abuts the next upland which rises up to about +8 feet (2.4 m) MLW. This upland continues for about 800 feet (245 m) and had a large amount of broken concrete dumped across it over the years. A long pier that is shown in the distance on photos 13 and 14 (Figure 18) also occurs along his reach.

The typical cross-sections of the designed structures (Figure 19) show that existing structures, including broken concrete and a nearshore sill, existed prior to installation of the system and had to be incorporated into the project (Figure 20). In addition, the existing intermittent marsh on the southwest facing shore was not covered but included in the design. The level of protection for this project was +5 feet (1.5 m) MLW.

3 RESULTS

3.1 Project Encroachment and Performance Evaluation

3.1.1 Physical Assessment

Analysis of survey data and ground and aerial photography reveals durable, well-built systems that have withstood several severe storms. The sill systems were designed to protect banks that were eroding and in some cases, had existing "structures." Encroachment onto existing habitats was relatively similar in all three sites (Table 3). At St. Mary's, the average amount of intertidal habitat covered for the project was 9 feet (2.7 m) in the cross-shore direction while the average amount of submerged lands covered was 21 feet (6.4 m). At JPPM and Webster, the average amount of intertidal habitat converted to fringe marsh was 7 feet (2.1 m) and 9 feet (2.7 m), respectively. The amount of submerged land converted was 40 feet (12.2 m) and 36 feet (11 m), respectively for JPPM and Webster. The St. Mary's system is built closer to shore because it is subject to less energetic conditions.

The average change in slope is shown in Table 4. The three sites have responded differently because of their wave climates. St. Mary's has become less steep than the design slope going from 8:1 to 10:1. JPPM had the reverse trend becoming steeper on average. At Webster, the site was designed for a 10:1, but post-construction profiles show it was built at an average of 11:1. Five years later, it has become even shallower at 14:1, on average.

Cross-shore profiles at each site are shown in Figure 21, Figure 22, and Figure 23. Using the 2008 survey data, additional cross-shore analysis showed that at JPPM, the average distance of *S. alterniflora* from the sill is 6 feet (1.8 m). The design cross-section (Figure 16) shows that between 7 feet (2.1 m) and 8 feet (2.4 m) of *S. alterniflora* was planted behind the sill. This corresponds with the change in slope. As the area behind the sill gets steeper, the *S. alterniflora* has a reduced area in which to grow. Along the southwest facing shore at Webster, the average distance of *S. alterniflora* from the sill is 7 feet (2.1 m) and the measured width of the *S. patens* area is 17 feet. (5.2 m). However, the design cross-section shows that *S. alterniflora* was planted at about 13 feet wide (3.9 m) and *S. patens* at 20 feet (6.1 m) wide. Where the slope got shallower, the average width of the plant areas decreased. Along the northwest facing shore, the measured average width of *S. alterniflora* and the design width for plantings was 10 feet (3 m).

Table 3. The amount of encroachment by the sill systems at each site due to the project.

	St. Mary's Habitat Covered		JPPM Habitat Covered		Webster Habitat Covered	
	Intertidal	Nearshore	Intertidal	Nearshore	Intertidal	Nearshore
	feet (m)	feet (m)	feet (m)	feet (m)	feet (m)	feet (m)
Mean	9 (3)	21 (6)	7 (2)	40 (12)	9 (3)	36 (11)
Minimum	3 (1)	14 (4)	3 (1)	21 (6)	2 (1)	11 (3)
Maximum	12 (4)	34 (10)	13 (4)	87 (27)	26 (8)	96 (29)
Range	10 (3)	20 (6)	7 (2)	34 (10)	7 (2)	30 (9)

Table 4. Design and measured slopes behind sills at each site.

	St. Mary's		JPPM		Webster		
	Design Slope	Present Slope	Design Slope	Present Slope	Design Slope	Post Constr Slope	Present Slope
	(X:1)	(X:1)	(X:1)	(X:1)	(X:1)	(X:1)	(X:1)
Mean	8	10	10	8	10	11	14
Minimum		5		3		1	5
Maximum		20		17		40	38
Range		7		7		8	10

3.1.2 Hydrodynamics

During Hurricane Isabel and Tropical Storm Ernesto, the dominant winds were from northeast, southeast and south. These directions were modeled to determine storm surge and wave characteristics. The model simulation of storm tide distribution near the month of Potomac River and Patuxent River during hurricanes Isabel and Ernesto are shown in Figure 24. The model indicates that the storm surges at study sites are similar during both storms. At JPPM on the Patuxent River, the maximum observed water level was 5.7 feet (1.7 m) MLLW during Isabel and 4.7 feet (1.4 m) MLLW during Ernesto. The maximum water level elevation reported at Solomon's tide guage, also on the Patuxent, was about 4.5 feet (1.4 m) MLLW during both Isabel and Ernesto (Figure 10). In the St. Mary's River where St. Mary's City and Webster Field Annex are located, the model predicts a maximum surge of 5.7 feet (1.7 m) MLLW and 5.3 feet (1.6 m) MLLW during Isabel and Ernesto, respectively. The Lewisetta tide guage recorded maximum water elevation during Isabel (5.5 feet (1.7 m)MLLW) and Ernesto (5.8 feet (1.5 m) MLLW).

The estimated maximum waves are listed in Table 5 while the mean waves are shown in Table 6. The maximum wind many not generate maximum wave. This occurs at Webster and JPPM during Isabel and likely is due to the longer duration of the winds. During Isabel, the first phase of the storm had winds from the northeast and north. These winds would have generated relatively small waves (about 2 feet (0,6 m)) because of the limited fetch at St. Mary's and Webster. During the second phase of the storm, the southerly winds would not impact St. Mary's, but modeling indicates that a 6-7 feet (1.8 - 2.1 m) wave could have impacted the shore at Webster. During Ernesto, the northeast and north winds also generated relatively small at St. Mary's (1.4 feet (0.4 m)), but a 3 feet (0.9 m) wave impacted Webster. As the storm shifted to the southeast and south, the winds decreased leading to smaller wave heights, average 0.6 feet (0.2 m) but may have been a maximum of 1.5 feet (0.5 m). At JPPM, the significant winds were from the southeast/south and produced about a 4 feet (1.2 m) wave during Isabel but only a 0.5 feet (0.2 m) wave during Ernesto.

Table 5. Estimated wave characteristics corresponding to maximum wind speed and direction during Isabel and Ernesto.

Storm & Wind Direction	St. Mary's		Webster		Jefferson Patterson	
	Wave Height ft (m)	Period (Second)	Wave Height ft (m)	Period (Second)	Wave Height ft(m)	Period (Second)
Isabel (NE-N)	2.1(0.64)	3.4	1.9 (0.58)	3.2		
Isabel (SE-S)			5.9 (1.8)	6.1	3.6 (1.1)	4.5
Ernesto (NE-N)	1.4 (0.43)	2.7	3.0 (0.91)	4.1		
Ernesto (SE-S)			1.5 (0.46)	2.9	0.5 (0.15)	1.65

Table 6. Estimated wave characteristics corresponding to mean wind speed and direction during Isabel and Ernesto.

Storm & Wind Direction	St. Mary's		Webster		Jefferson Patterson	
	Wave Height ft(m)	Period (Second)	Wave Height ft(m)	Period (Second)	Wave Height ft(m)	Period (Second)
Isabel (NE-N)	1.0 (0.30)	2.4	0.9 (0.27)	2.2		
Isabel (SE-S)			7.1 (2.16)	6.6	4.3 (1.31)	4.9
Ernesto (NE-N)	0.9 (0.27)	2.2	1.2 (0.37)	2.6		
Ernesto (SE-S)			0.6 (0.18)	1.9	0.3 (0.09)	1.4

Although JPPM shoreline was overtopped by Isabel, only minor scarping occurred at the site. Isabel was the largest storm to impact the system since construction. The combination of stone and vegetated sand fill attenuated the impinging waves. At Webster, the plants were impacted, but the rest of the system remained intact (Figure 20).

3.2 Model Development

The sand fill encroachment model (Figure 25) depicts the various levels of protection that can be achieved by varying the slope and the upland limit of the fill (*i.e.*, level of protection). The level of protection is determined by the return frequency of storm events. In order to protect the shoreline during larger storms, a higher elevation of sand is needed to attenuate the wave before it impacts the bank. However, larger storms theoretically occur less frequently. Shore protection systems can be designed to have a level of protection for smaller, theoretically more frequent, events. Once the water levels of certain storm events are known at a site, the level of protection can be determined for a project. The elevation of the sand against the bank determines the level of protection.

In less energetic conditions, a narrower system on a 6:1 slope can be used. If the lower level of protection (+3 feet (0.9 m)) is used, the total encroachment would be 12 feet (3.7 m) from the bank to MTL. Encroachment increases with greater fill elevation and shallower slope. The upper limit of protection at +5 feet (1.5 m) would yield a 24 feet (8.3 m) encroachment. As wave energy increases, so too should the fill slope. At the minimum level of protection (+3 feet (0.9 m)) at a fill slope of 8:1, the encroachment would be 16 feet (4.9 m) whereas at the upper level of protection, it would be 32 feet (10 m). At 10:1, the encroachment ranges between 20 and 40 feet (6 and 12 m). Generally, the flatter the fill slope and the higher the level of protection, the more encroachment will occur. While more riverward encroachment, in theory, provides a greater level of storm protection, the amount of *S. alterniflora* does not increase greatly. This means that most of the marsh created would be high marsh. If a structure also is included in the design, the fill slope at MTL should hit the back of the sill. Depending on the width of the sill, encroachment increases by that amount.

4 DISCUSSION

Generally, regulatory agencies have accepted the habitat exchange of subaqueous bottom and non-vegetated tidal wetlands for fringe marsh in Chesapeake Bay (*i.e.* Maryland and Virginia). Most would agree that this methodology, if viable at a site, is preferable to a revetment or bulkhead which will protect the shoreline but provides little habitat value. By establishing design guidelines, encroachment onto existing habitats can be minimized.

Existing conditions, fetch, and elevation of protection desired are considerations in determining the method of shore protection appropriate at a location. Figure 26A depicts the encroachment and habitat types of three different methods. The most common shore-protection structure used in Chesapeake Bay today is the stone revetment which usually requires balanced bank cut and fill for construction. Therefore, the bayward encroachment may be dependent on bank height. A low bank may only require the stone to come up to or near the top of the bank whereas higher banks will require more landward grading and filling of the backshore. In Figure 26A, shore protection is afforded by the stone revetment with minimal encroachment bayward but with minimal habitat created.

With a high sill system using high marsh only, encroachment landward may reduced but bayward encroachment increases (Figure 26A). The high marsh is an extension of the riparian buffer, but the bank may still require grading for shore protection. The next option is the "standard" sill system with roughly equal amount of high and low marsh (Figure 26A and 26B). More bayward encroachment is associated with more habitat created. The extent of *S. patens* and *S. alterniflora* increases with a lower gradient (flatter) but with increased encroachment on state bottom. Generally a 50/50 split between S. *alterniflora* and *S. patens* is best from a habitat standpoint (Bosch *et al.*, 2006)

The created marsh often requires sand fill and lies on a gentle slope upon which are planted the marsh grasses. Most of the marshes have been constructed on a slopes between about 8:1 and 14:1, averaging 10:1 (Figure 26B). The slopes adjust and change within the context of the as-built profile depending on how the fill is retained. The amount of encroachment on state owned bottoms is a function of 1) existing gradient, 2) the sand fill level required plus, 3) the holding device which, for this discussion, is a stone sill.

The existing gradient is a function of local geomorphology. An erosion problem occurs when the protective natural marsh fringe is not wide enough to offer sustained buffer against waves. Along "typical" tidal creeks and rivers, stable upland banks reside behind a continuos, wide marsh fringe. The marsh width is a function of shore orientation, nearshore gradient, and fetch. The fetches vary from 0.5 to 2.0 miles (0.8 to 3.2 km) and protective fringes (those with stable upland banks) generally are 10 to 20 feet (3 to 6 m) wide from the marsh edge to the base of the bank. As the fringe narrowes through time to less than 5 feet (1.5 m) or less, the upland bank will often be impacted and erode and bank erosion will ensue. In this situation, mean high

water may be at or very close to the base of the bank. The lateral distance between MHW and MLW is a function of both the slope and the tide range.

The elevation of the upper limit of protection can vary. The simplest way to assign the critical elevation for protection is to remember that with greater fetch yields larger storm waves. In very fetch limited areas (<0.5 miles), this elevation might be only a foot (0.3 m) or so above MHW because the impinging waves are small and only rarely reach the base of the bank. With a larger fetch (> 2.0 miles (3 km)), an elevation of 2 feet (0.6 m) or more might be more prudent. The bank height is a factor in determining how high the protection should extend. In all the study sites, the banks were higher than the predicted 100 year storm tide elevation. Because it was not possible to grade the bank, extra fill was placed at the base of bank to raise the shore to the level of protection elevation. From the top of the sand fill, the sand is graded on a 8:1 to 10:1 slope to MTL at the back of the sill. The upper elevation of construction might be different along similar shore reaches because of land use considerations. Waterfront property with no improvements might need a lesser level of protection than improved property.

The sill height and consequently its width and front slope complete the encroachment scenario. Sills that are more than 2 feet (0.6 m) above MHW might more properly be considered breakwaters. Also, a long high, semi-continuous line of rock visible in the nearshore generally is not aesthetically acceptable. In very fetch-limited areas, a sill that just reaches MHW might work whereas on a more open shores, a 0.5 to 1.5 feet (1.2 to 0.5 m) elevation above MHW is more appropriate. The trade off is the height of the sill with the width of the encroachment.

5 CONCLUSIONS

The structural components of a sill system are the sand fill, the stone sill, and the marsh grass plantings. These are constructed according to a design based on existing site conditions, including nearshore water depth, and hydrodynamic factors or wave climate, including storm conditions. Cost also is an issue but is not considered here.

The long shoreline systems designed for St. Mary's, JJPM, and Webster used shore morphology to create, enhance, and maintain diverse coastal habitats comprised of marshes and beaches and secured by stone and vegetation. The design of each of the three study sites was based on a "standard" fill slope from the base of the eroding bank to about mid-tide level at the land side of the stone sills. In the case of St. Mary's (smaller fetch) the slope was 8:1 while at both JPPM and Webster the slope averaged 10:1 with certain site modifications for each. After experiencing different but direct effects of Hurricane Isabel and Tropical Storm Ernesto, the sills at each site performed as expected with minimal bank scarping and no bank failure. This suggests that this method of sill design should be a reasonable standard to begin the design process. To minimize encroachment, systems should be designed to the needed level of protection elevation and then be graded on an average slope to the back of the sill.

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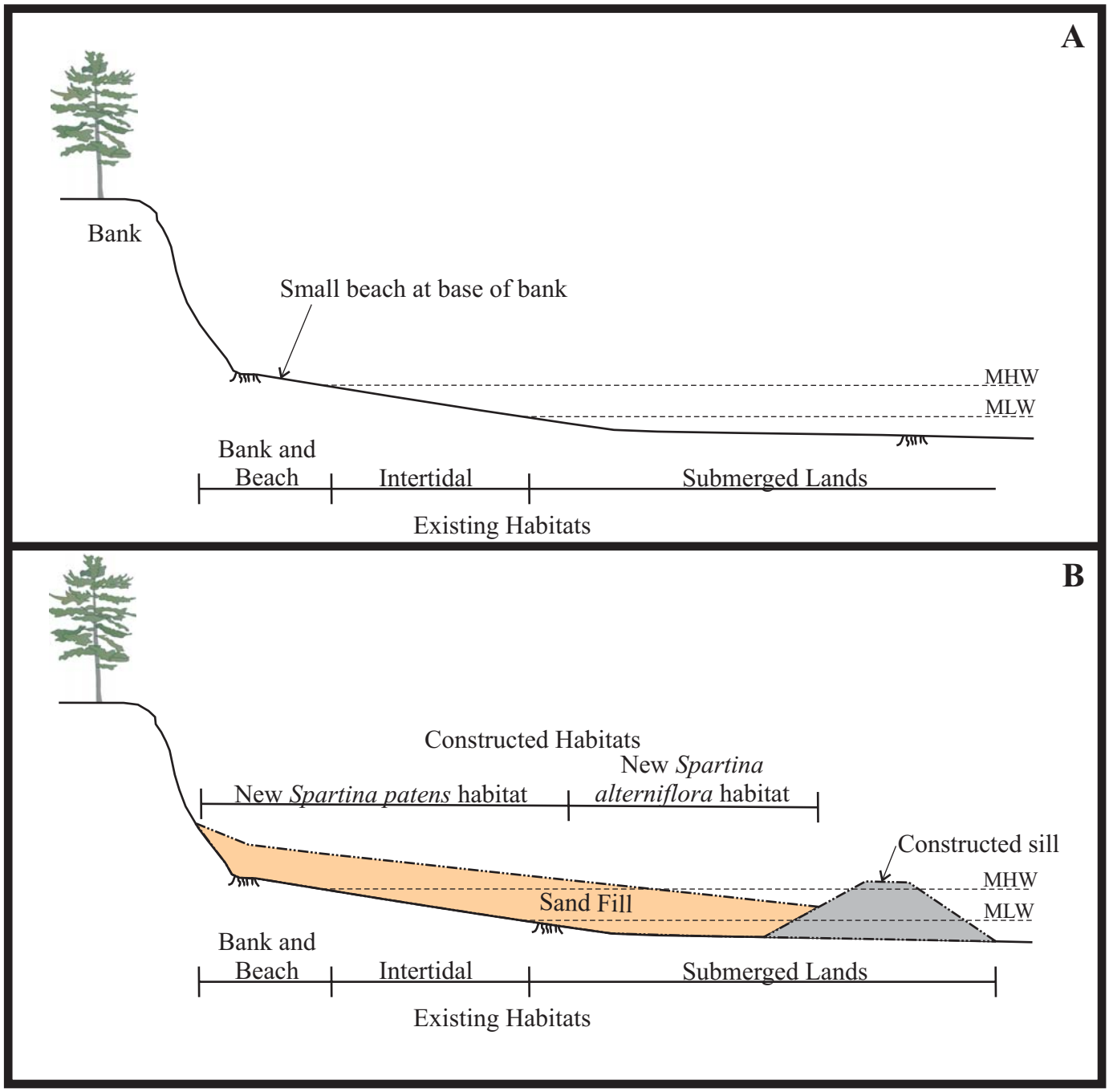


Figure 1. Sketches depicting the cross sections of a typical coastal setting before (A) and after (B) construction of a sill and sand fill project in a low to medium energy environment. The shaded areas show the extent of the encroachment of the project over existing habitats and into the regulated areas beneath MHW(Maryland) and MLW (Virginia).

Minor bank grading and temporary toe protection utilizing straw bales was used first then *Spartina alterniflora* was planted to establish a marsh fringe.

At this site, high water impinged upon the base of the bank. Therefore, only the intertidal species (*Spartina alterniflora*) was utilized. This photo shows the site one year after planting.

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

The established marsh fringe and vegetative upland slope are shown here after 24 years.

Figure 2. Example of a marsh planted on existing substrate through time along Tabbs Creek in Lancaster County, Virginia.

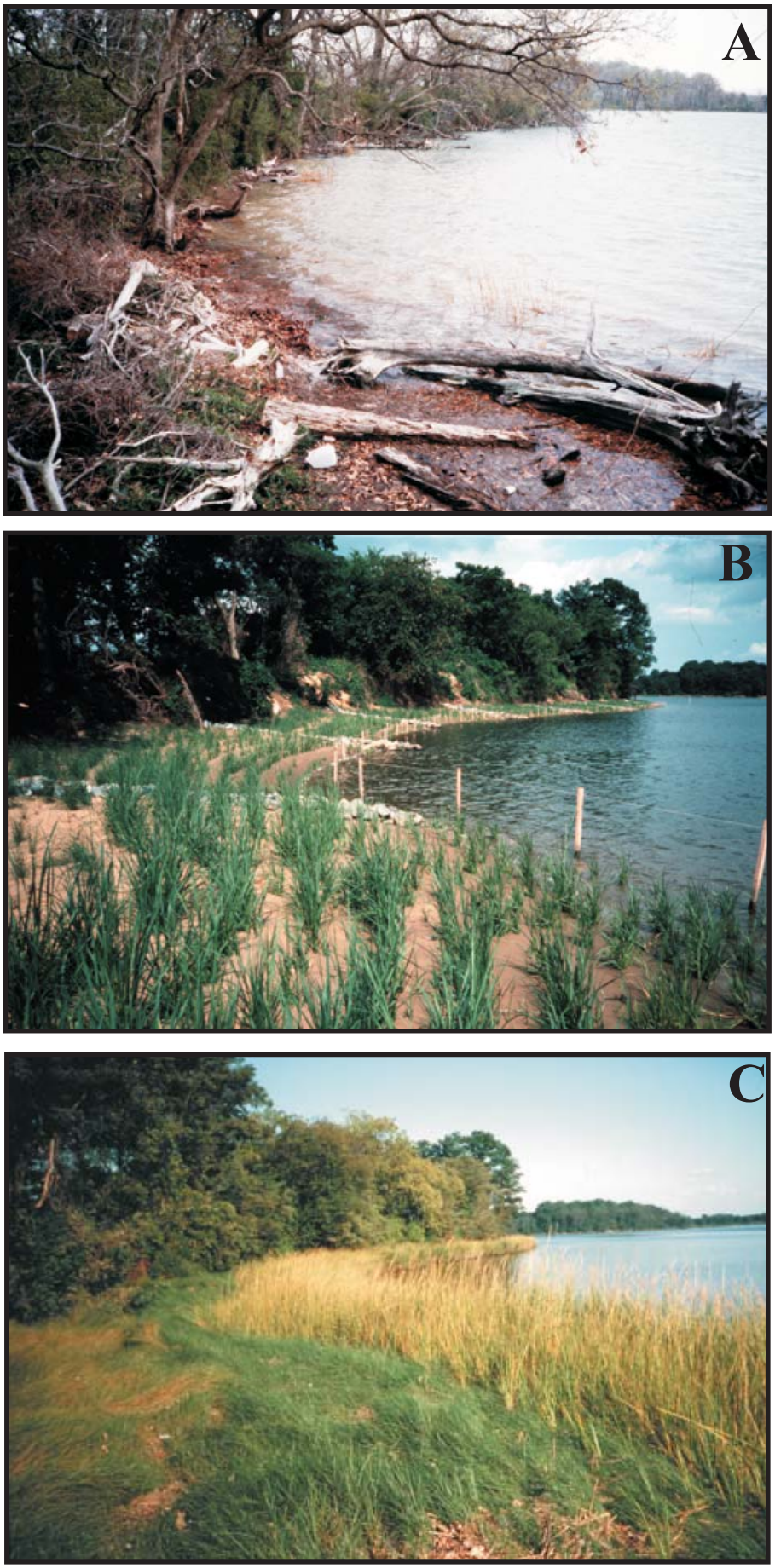


Figure 3. Photos showing a project consisting of short stone groins, sand fill, and marsh plantings at Wye Island, Kent County, Maryland A) before installation, B) three months after installation, and C) after four years.

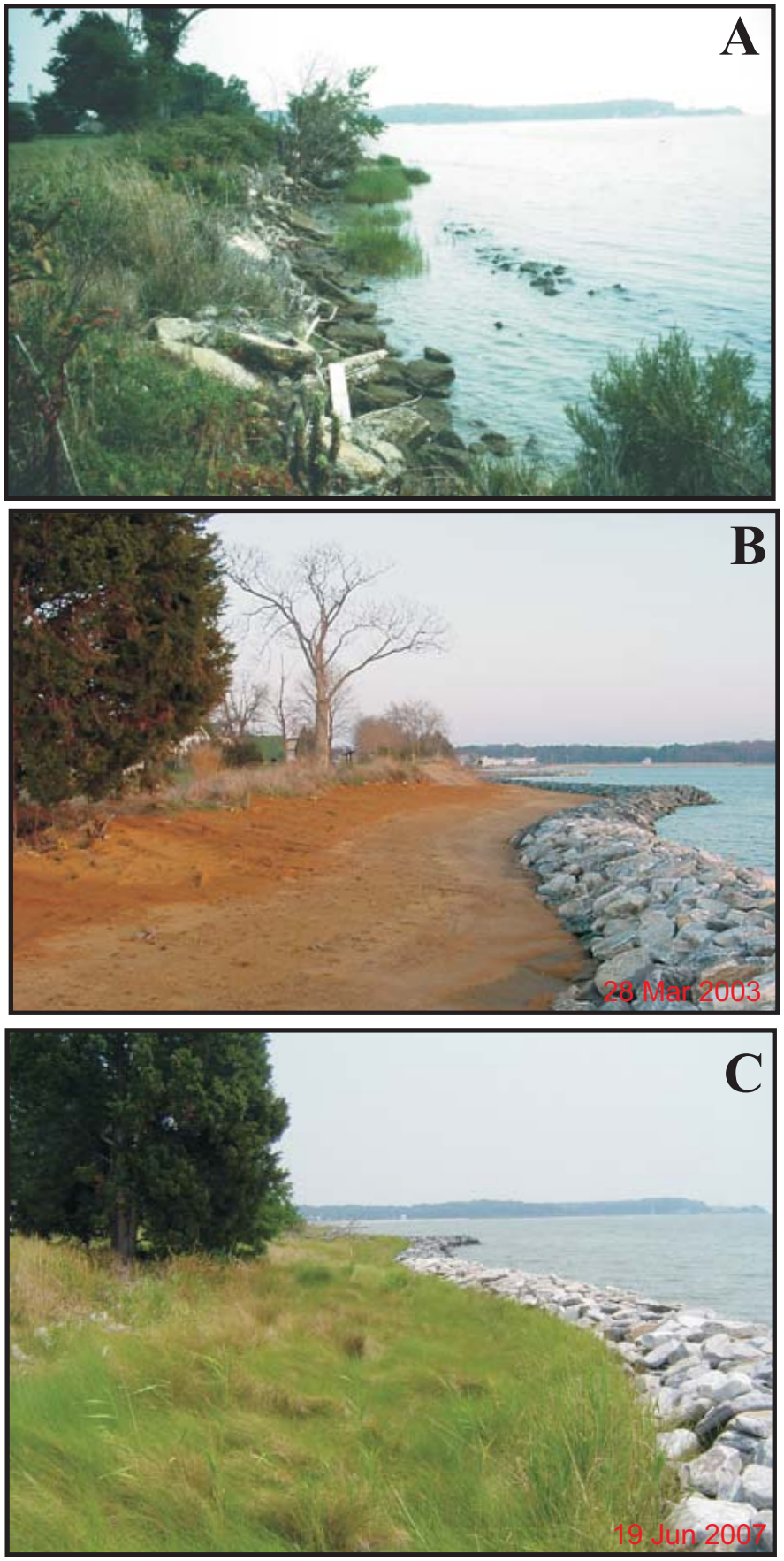


Figure 4. Sand fill with stone sills and marsh plantings at Webster Field Annex, St. Mary's County, Maryland A) before installation, B) after installation but before planting, and C) after four years.

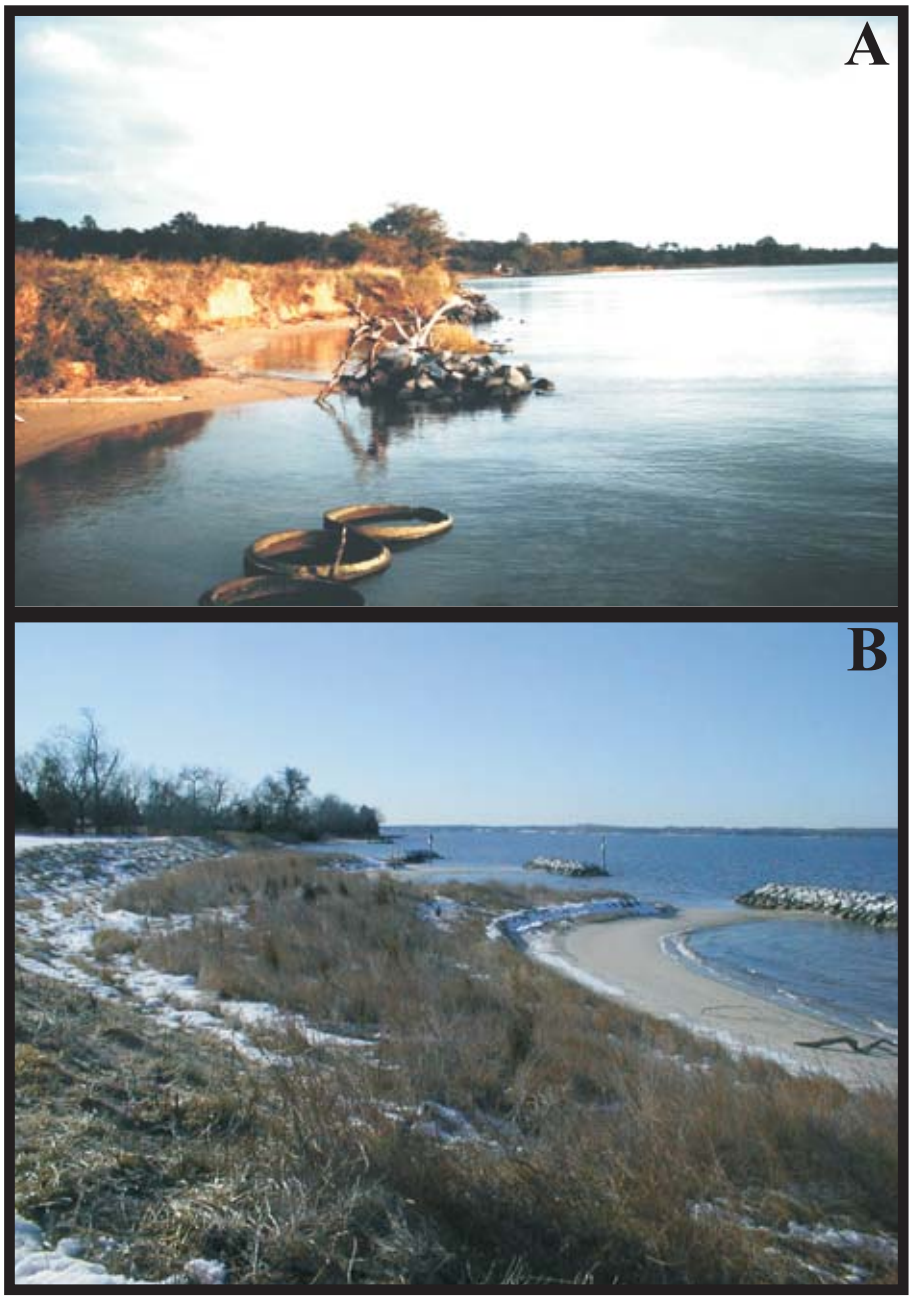


Figure 5. Jefferson Patterson Park and Museum A) before the upriver breakwater project (October 11, 1986) and B) in February 2003.

Figure 6. Example of A) a living shoreline that is being shaded by tree cover and dying off, and B) the typical homeowner's response to a perceived erosion.

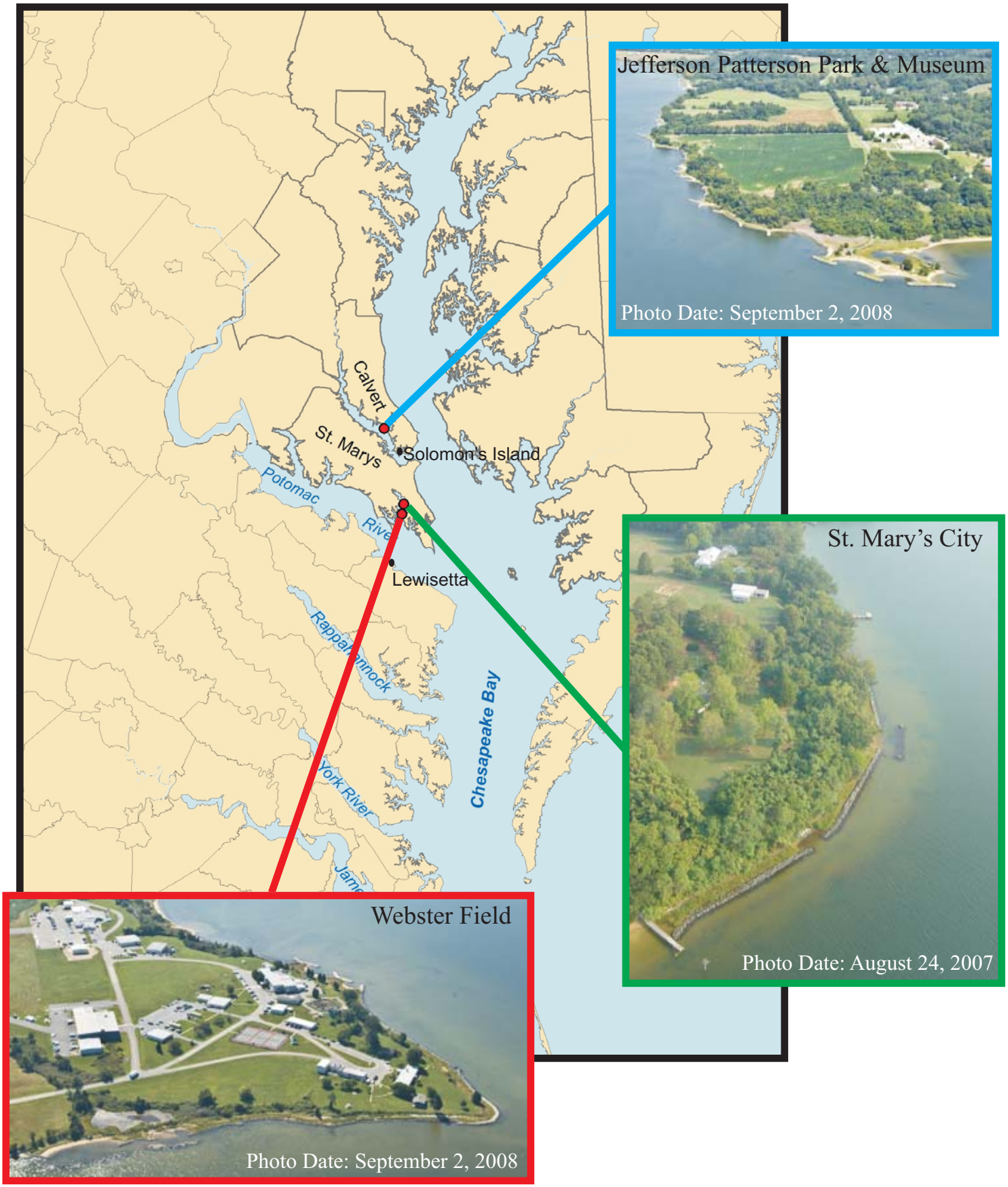


Figure 7. Map showing the locations within the Chesapeake Bay estuarine system of the three projects studied in this report. The insets are aerial photographs of each site. The location of the NOAA stations at Lewisetta, Virginia and Solomon's Island, Maryland also are shown.

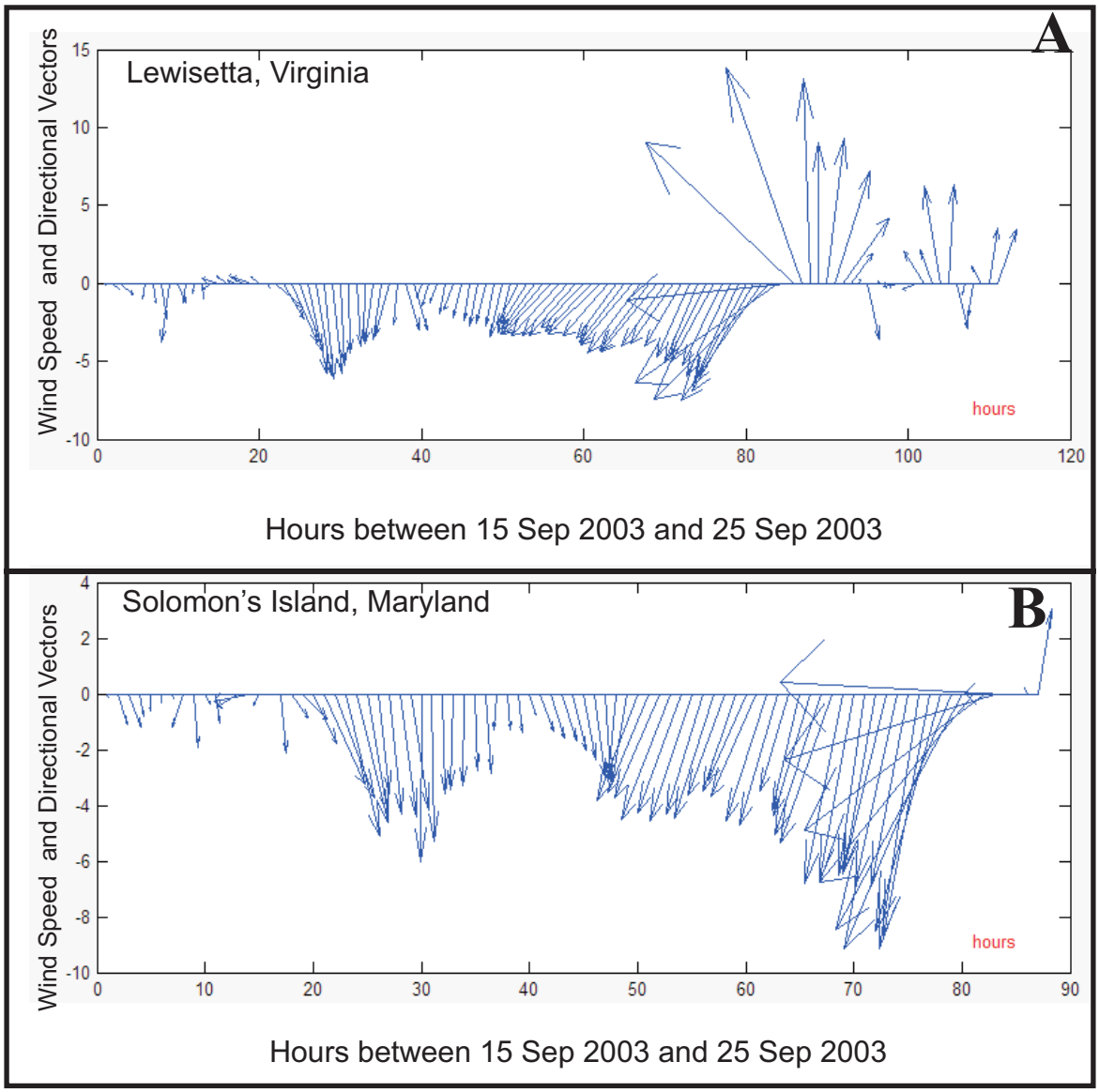
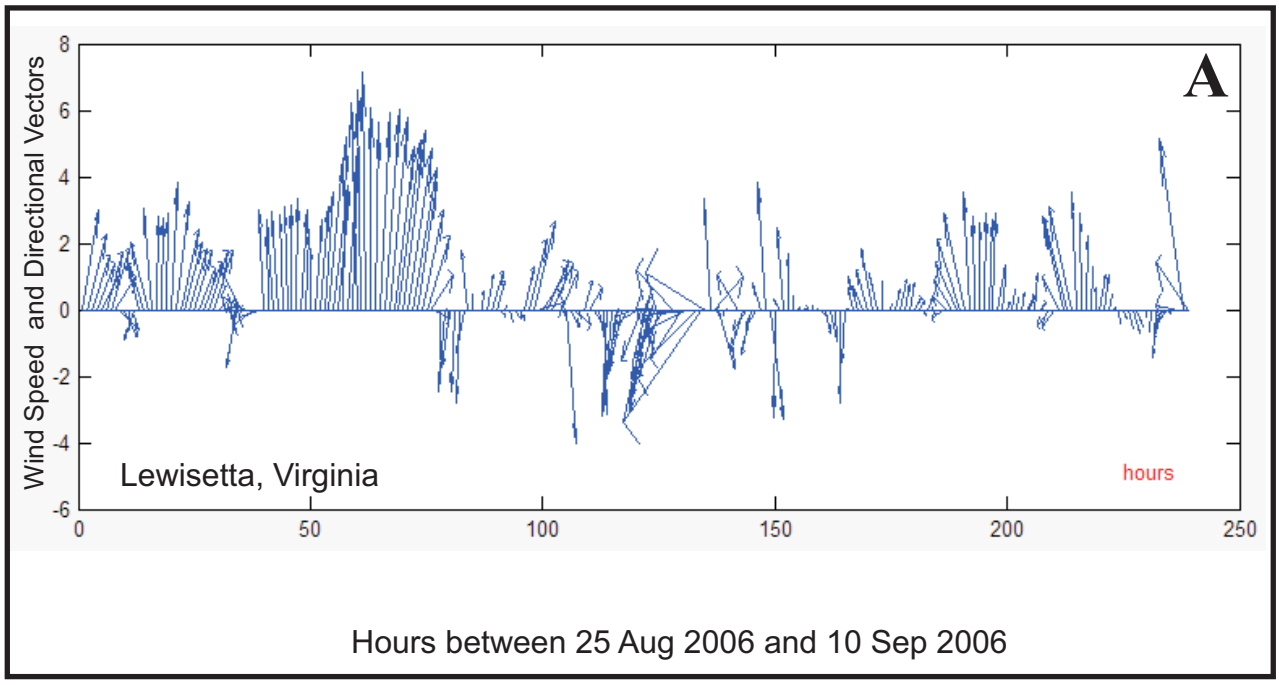


Figure 8. Plots of wind speeds and directions at the NOAA stations at A) Lewisetta, Virginia and B) Solomons's Island, Maryland during Hurrican Isabel. A complete data set may not exist at each site, but all hours available are shown.



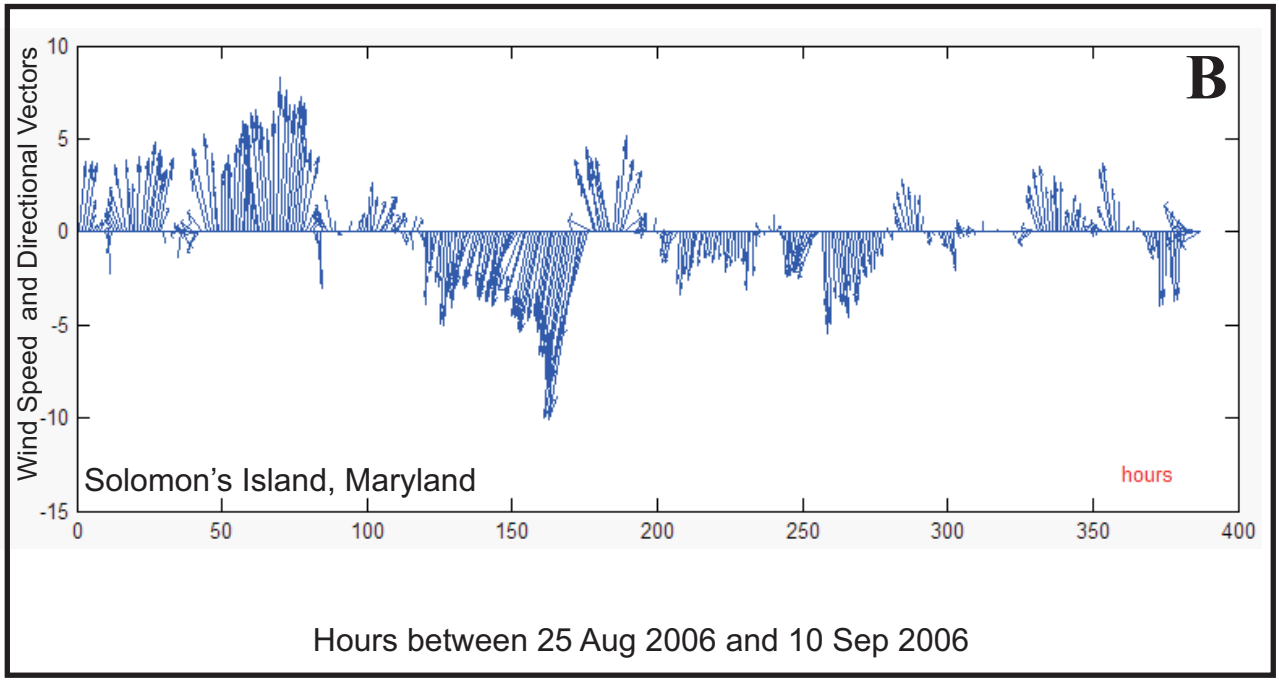


Figure 9. Plots of wind speeds and directions at the NOAA stations at A) Lewisetta, Virginia and B) Solomons's Island, Maryland during Tropical Storm Ernesto. A complete data set may not exist at each site, but all hours available are shown.

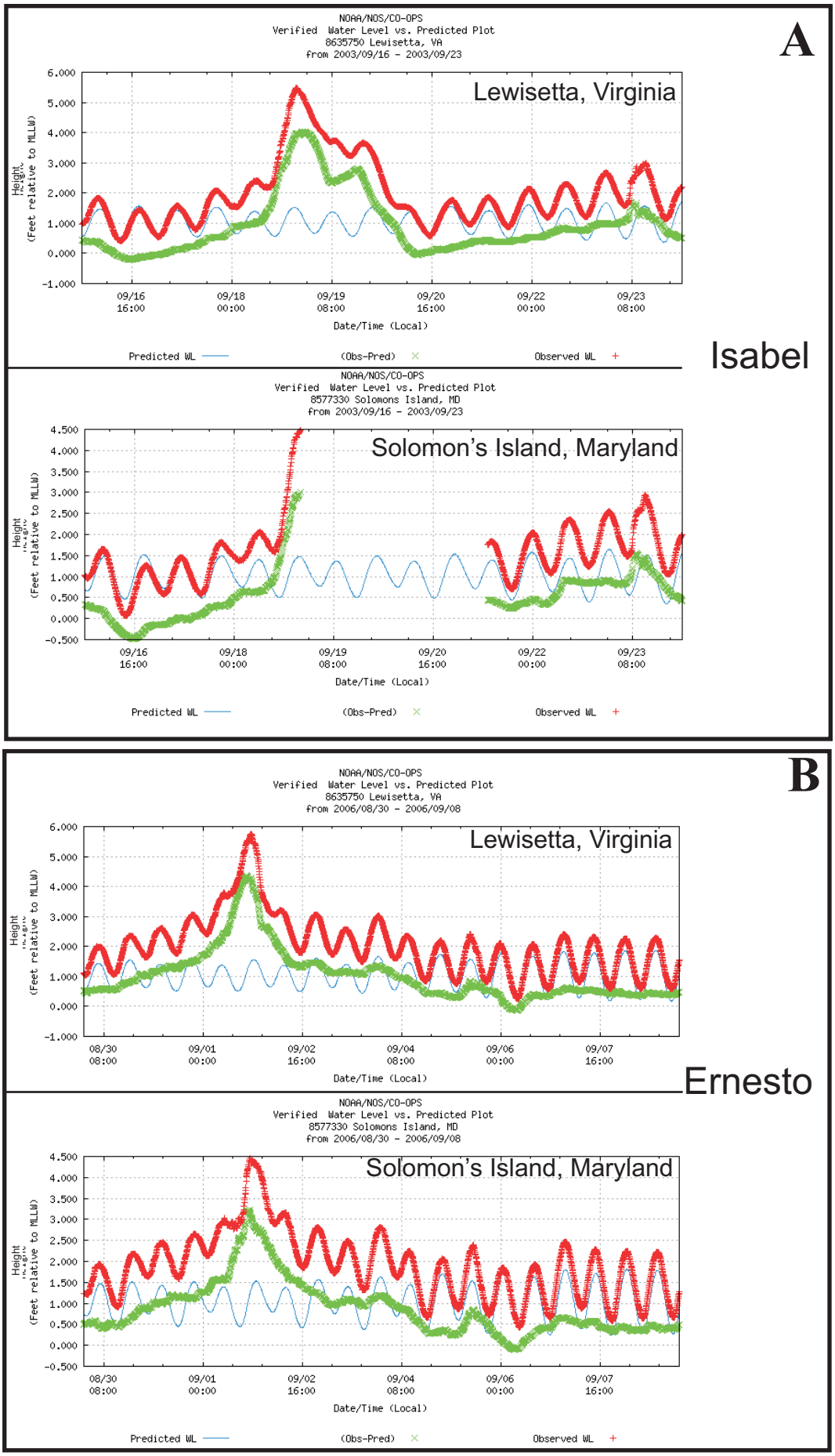


Figure 10. Water levels recorded during A) Huricane Isabel and B) Tropical Storm Ernesto on the NOAA tide gauges at Lewisetta, Virginia and Solomon's Island, Maryland. The gauge at Solomon's Island did not operate from late on day 3 through early day 6 of Hurricane Isabel. Vertical datum is MLLW.

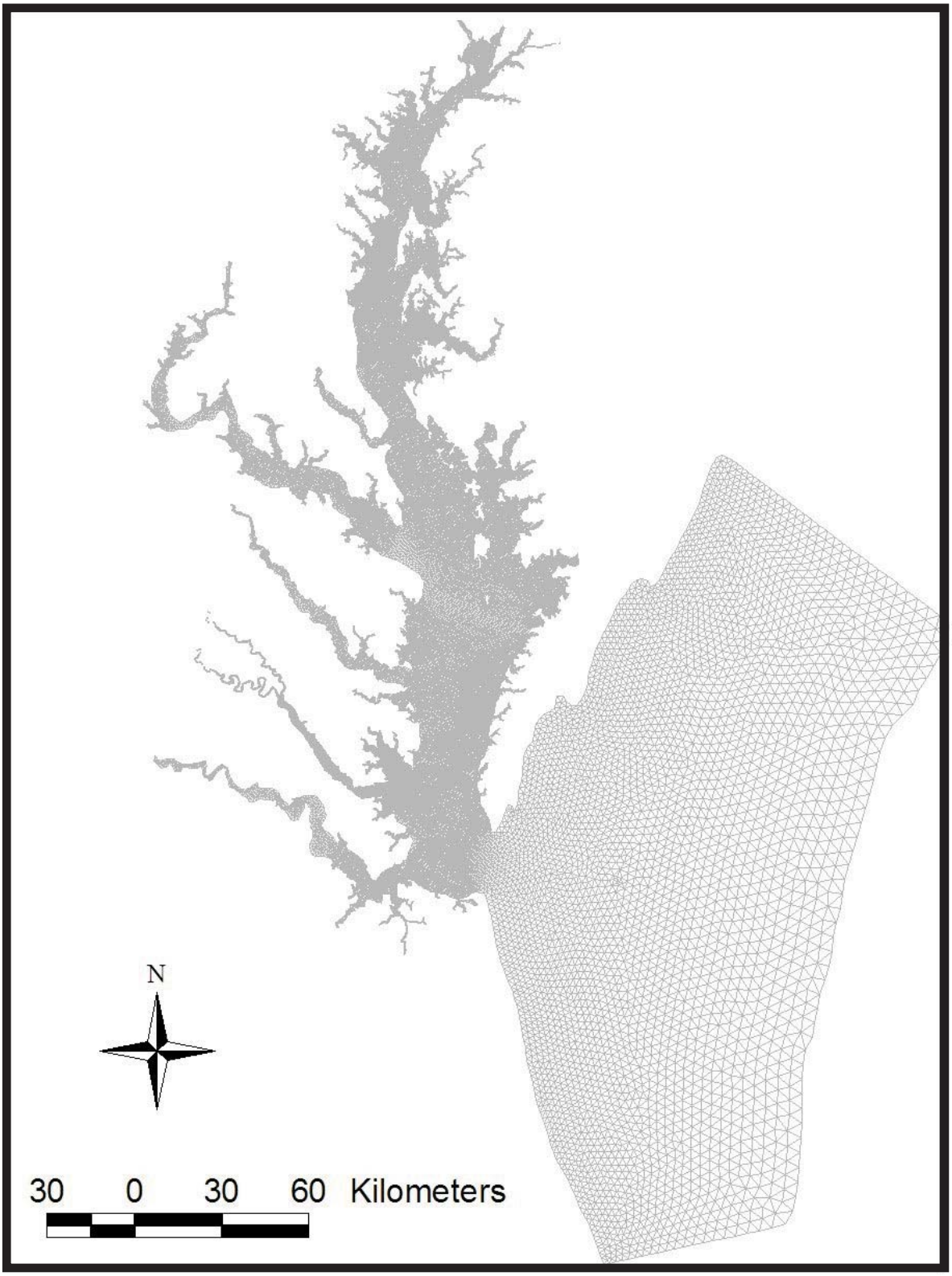


Figure 11. Model grid used for storm tide simulation.

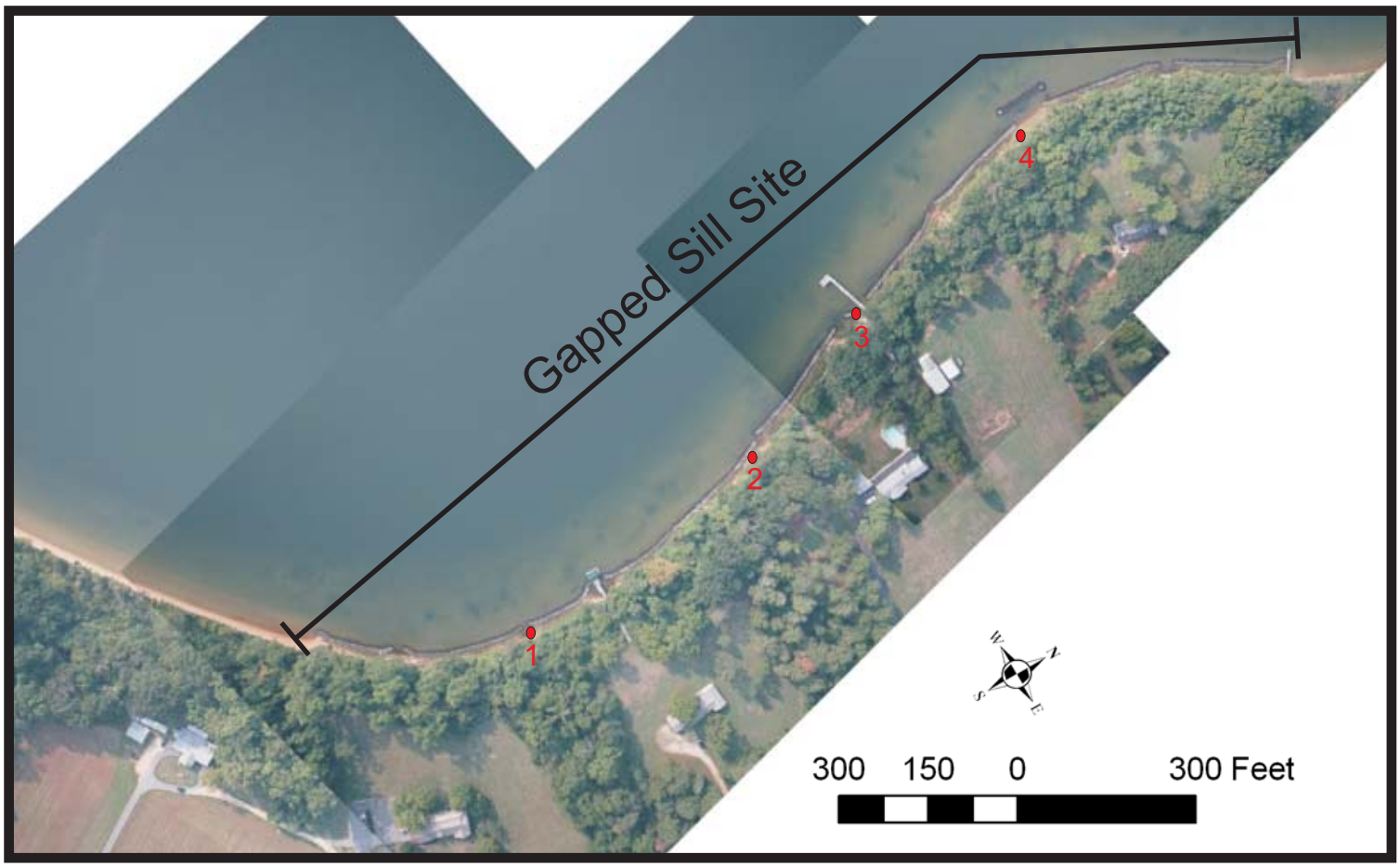


Figure 12. A photo mosaic of the St. Mary's City, Maryland shoreline on August 24, 2007 indicating the four sites of gapped fill projects and ground photographs of each site.

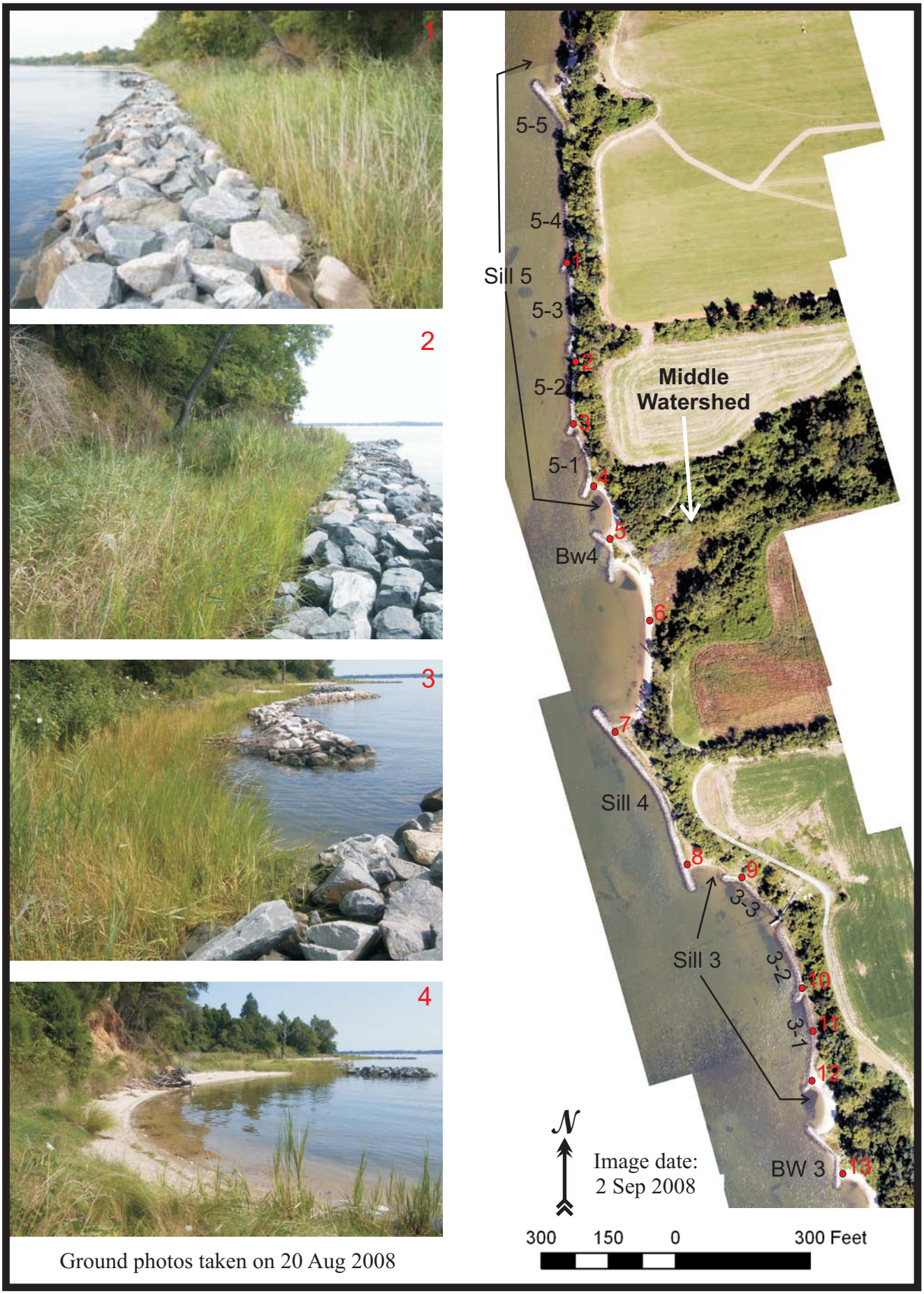


Figure 13. A photo mosaic of Jefferson Patterson Park & Museum shoreline on August 20, 2008 depicting the location of sills and breakwaters and indicating the locations of the ground photographs.

Figure 14. Ground photos taken along the Jefferson Patterson Park & Museum on 20 Aug 2008. Locations are shown on Figure 13.

Figure 15. Photographs of the banks a Jefferson Patterson Park & Museum showing A) the indurated, fossiliferous bed along a portion of the base of the bluff and B) the general setting.

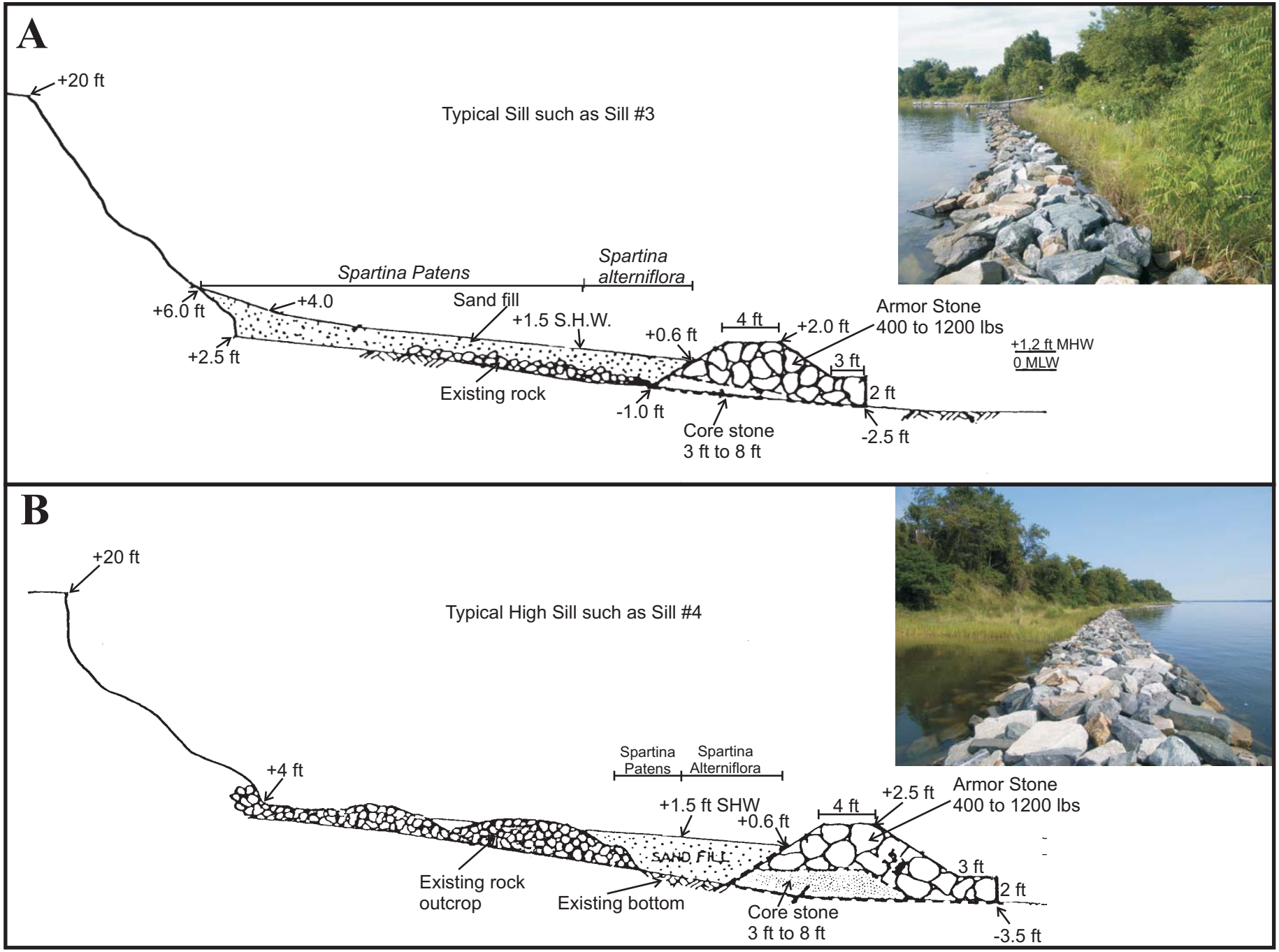


Figure 16. Design cross-sections of structures built at Jefferson Patterson Park & Museum in Phase 4 showing A) a typical sill such as Sill #3 (shown in the photo) and B) a typical high sill such as Sill #4 (shown in photo).

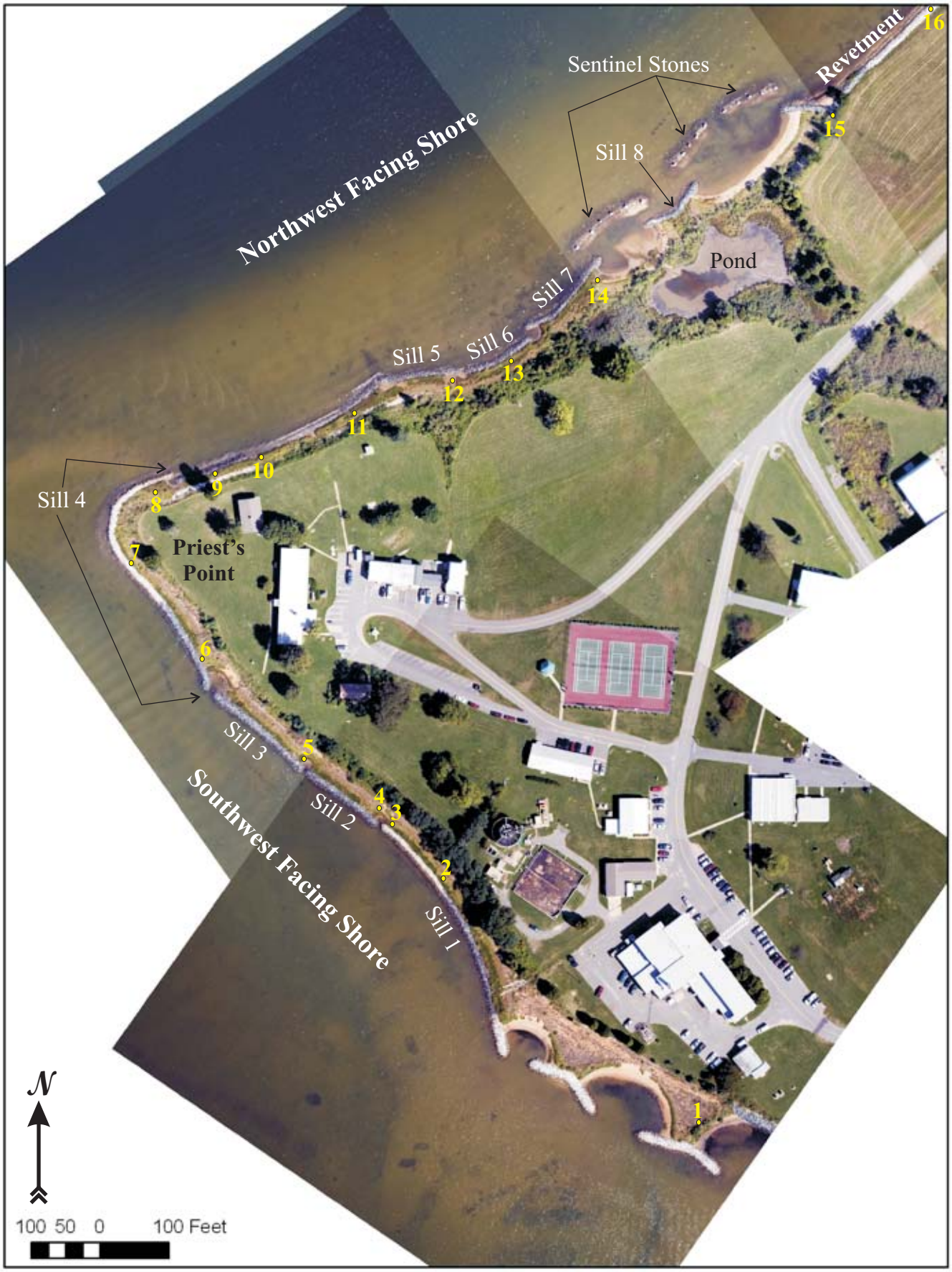


Figure 17. An aerial photo mosaic of th Webster Field Annex showing the structures and locations of the photographs in Figure 18.

Figure 18A. Ground photos 1-8 taken along the Webster Field Annex on 22 May 2008. See Figure 17 for photo locations.

Figure 18B. Ground photos 9-16 taken along the Webster Field Annex on 22 May 2008. See Figure 17 for photo locations.

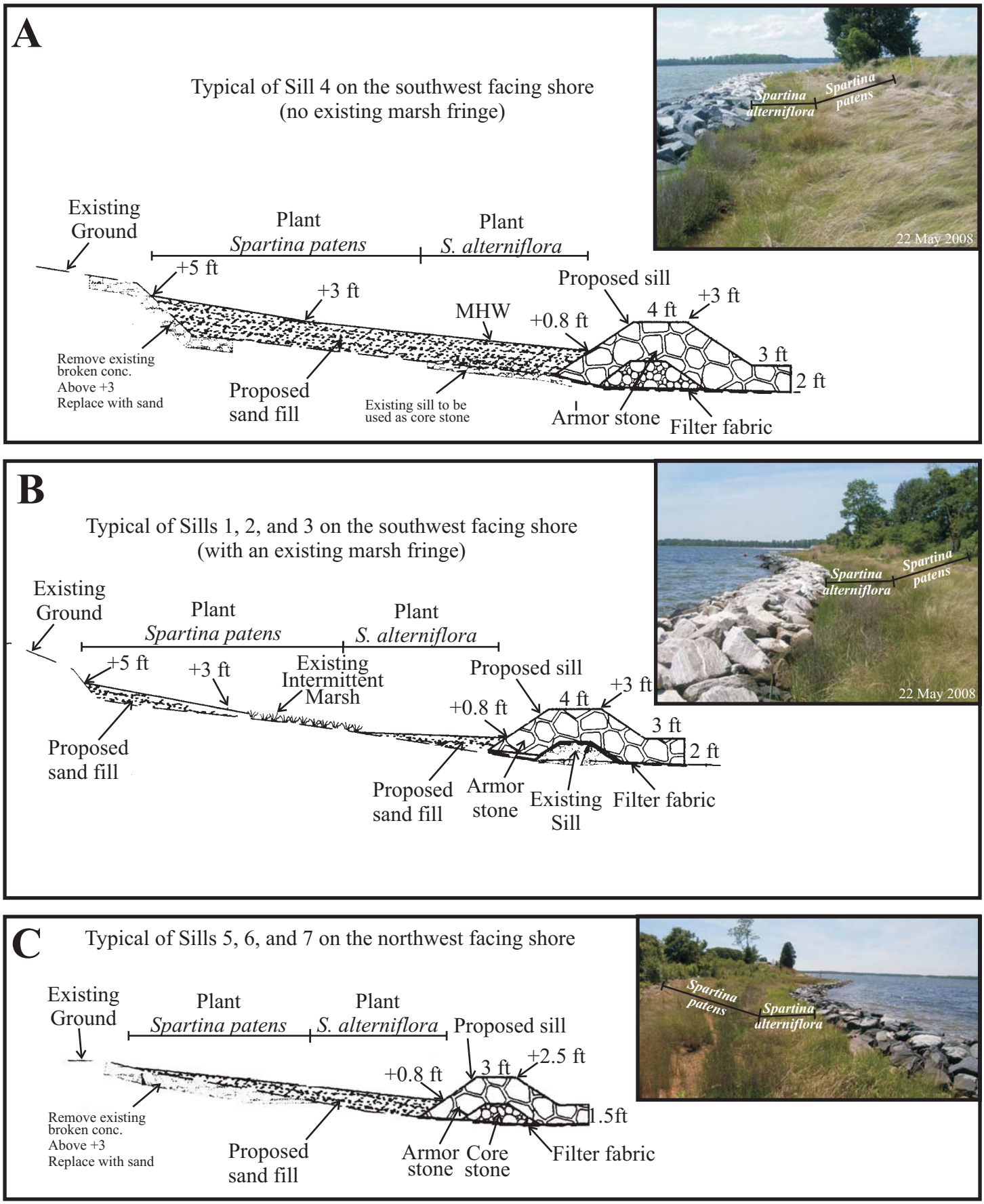


Figure 19. Cross sections of several of the shoreline protection projects at the Webseter Field Annex. A) shows typical conditions at Sill 4. B) shows typical conditions at Sills 1, 2, and 3. C. shows typical conditions at Sills 5, 6, and 7. See Figure 17 for locations of the sills.

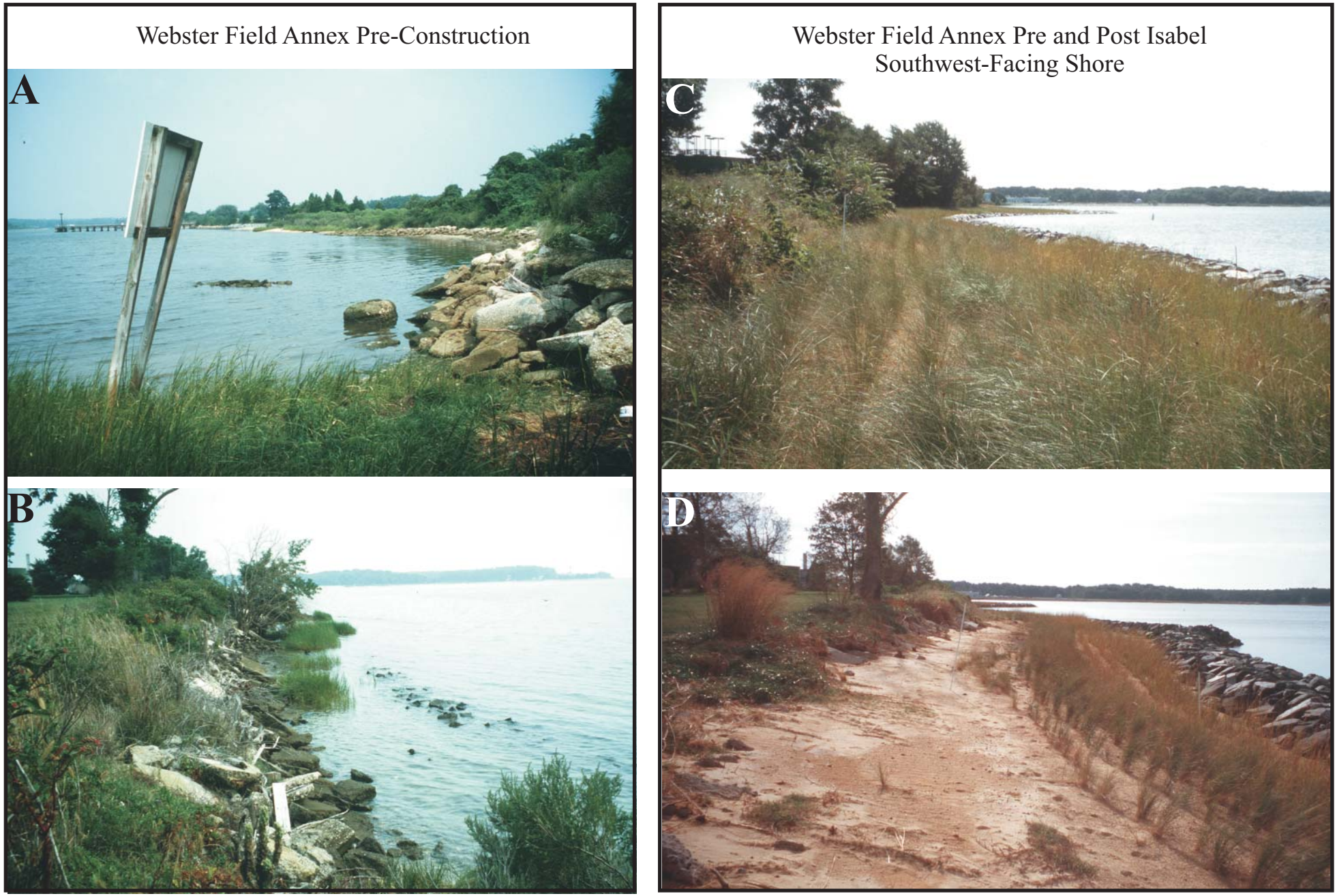


Figure 20. Photographs of the Webster Field Annex site. A and B are before construction. C is after construction, and D is after Hurricane Isabel.

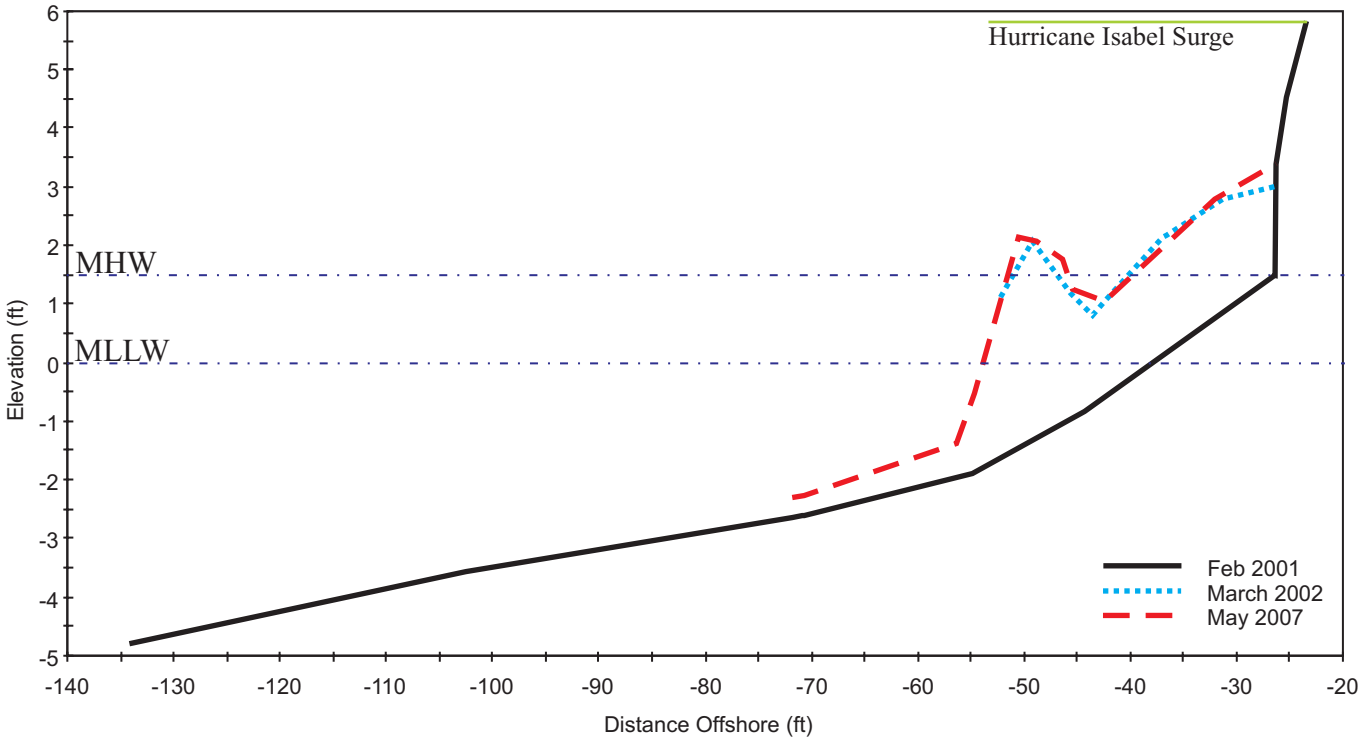


Figure 21. Example cross-sections at St. Mary's from profile data. The surge level is the result of hydrodynamic modeling.

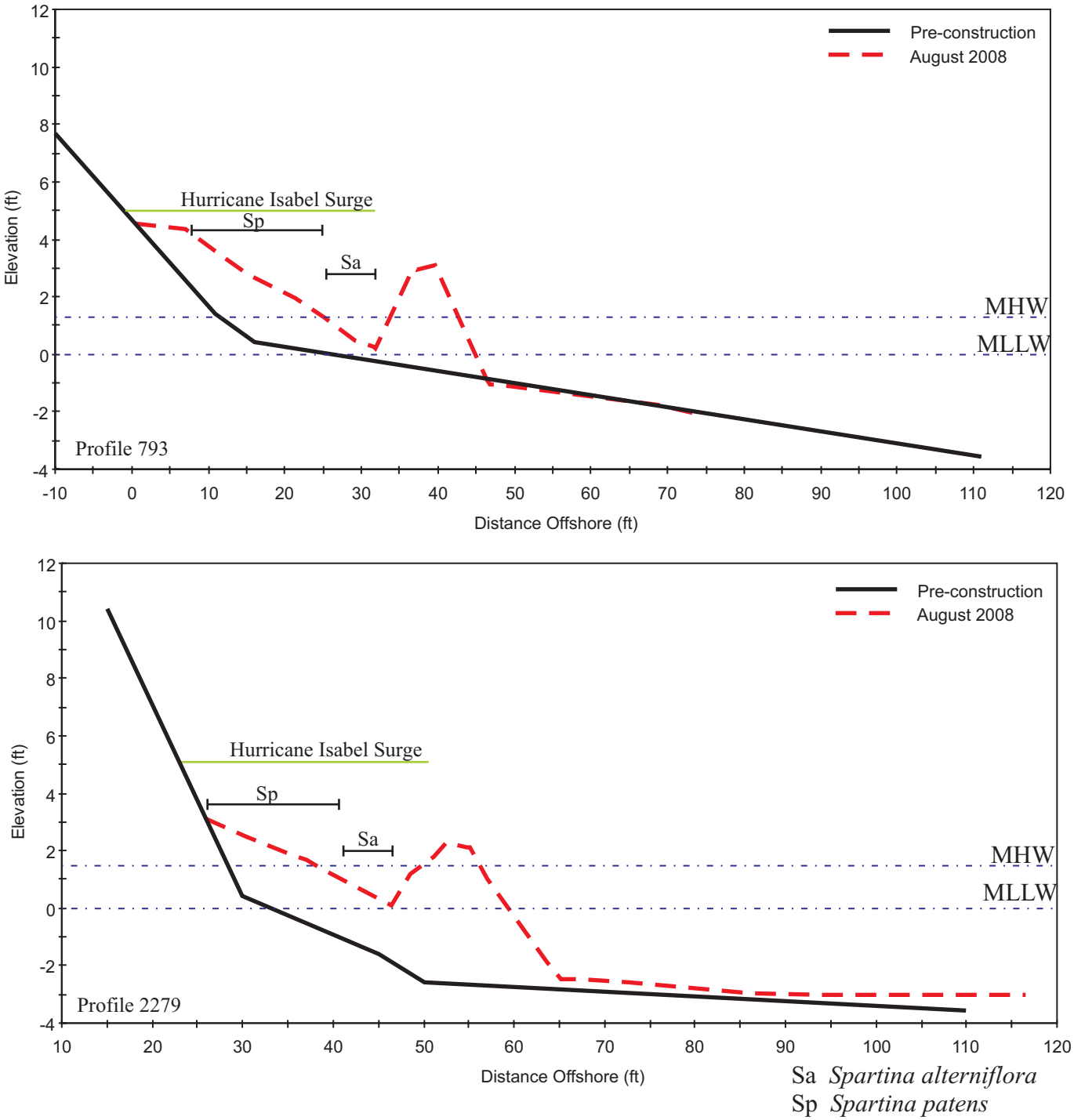
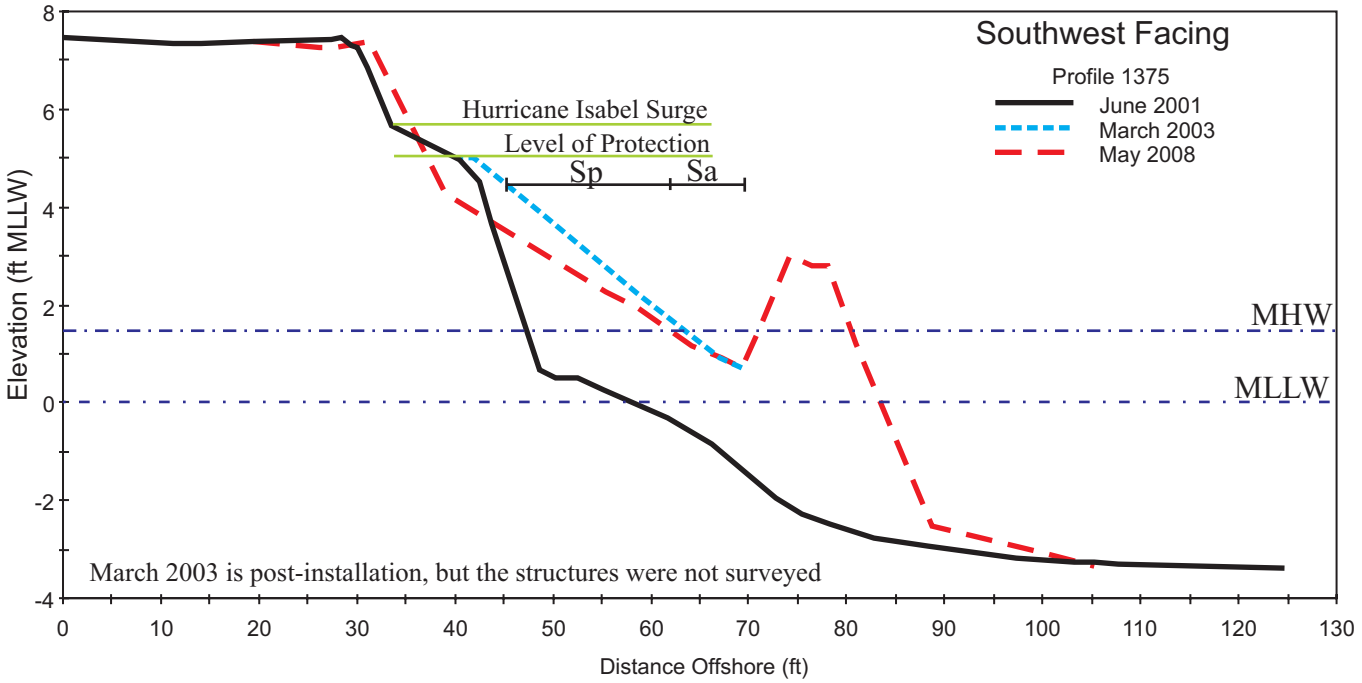


Figure 22. Two example cross-sections at Jefferson Patterson Park & Museum from profile data. The surge level is the result of hydrodynamic modeling. The widths of Spartina are averages from profile data and don't necessarily represent these profiles' vegetation.



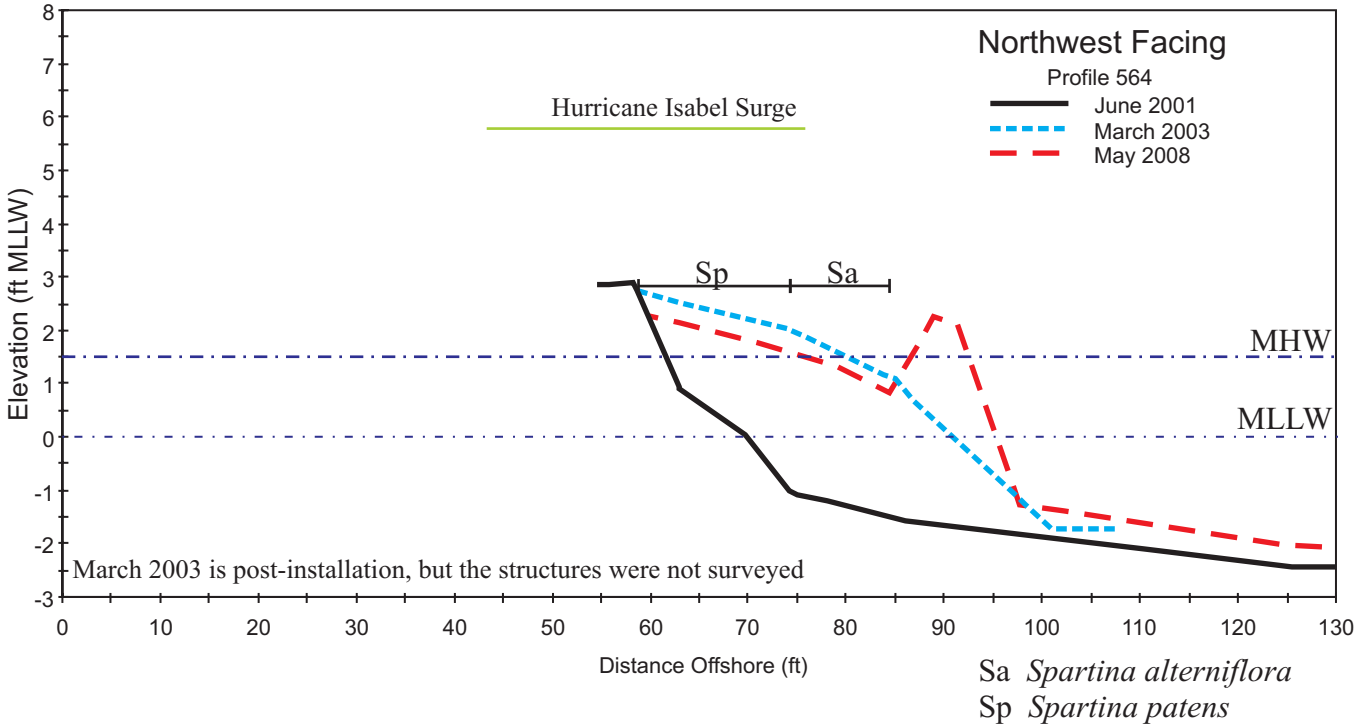


Figure 23. Two example cross-sections at Webster Field from profile data. The surge level is the result of hydrodynamic modeling. The widths of Spartina are averages from profile data and don't necessarily represent these profiles' vegetation.

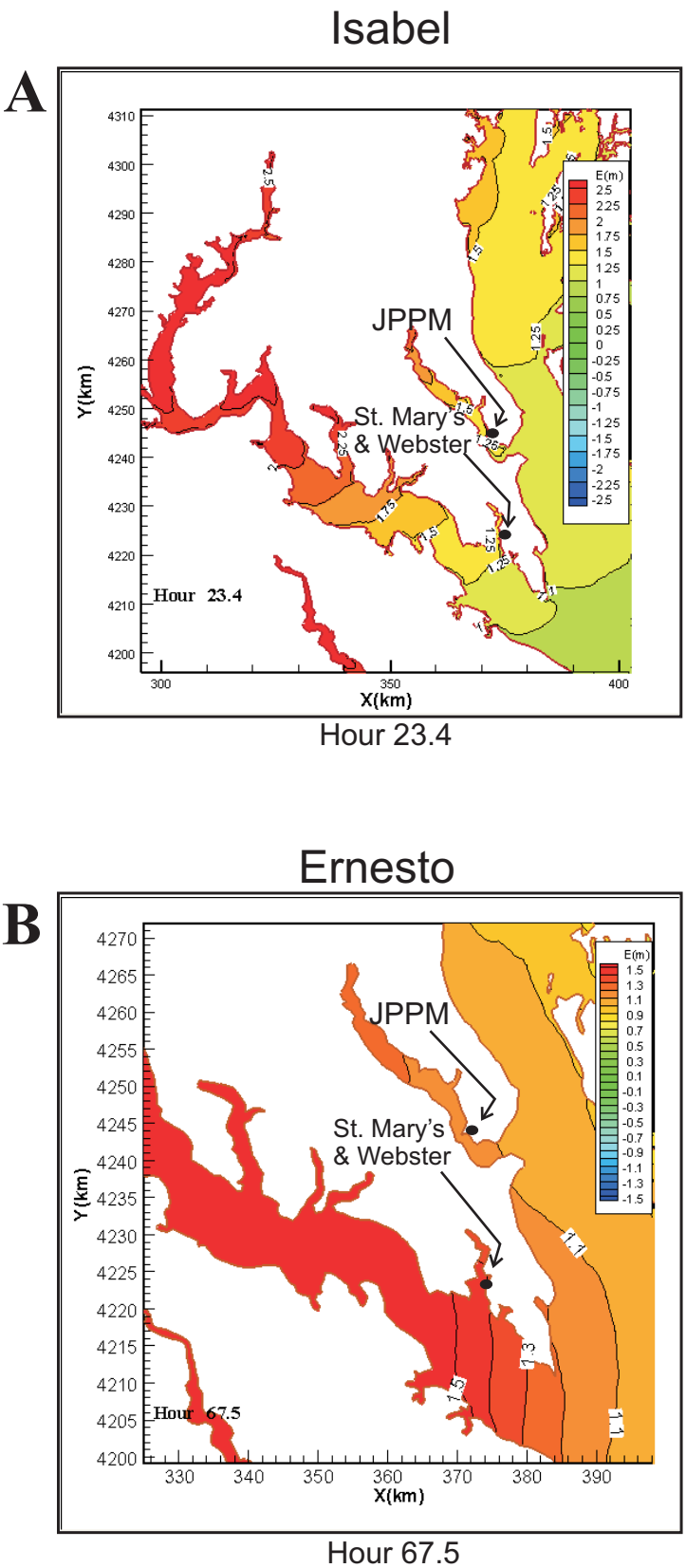


Figure 24. Model results showing the maximum elevation of the storm tide during A) Hurricane Isabel and B) Tropical Storm Ernesto. Site locations are approximate. Elevations are meters above mean tide level. At both locations, mean tide level is 0.2 m (0.7 ft) above mean lower low water.

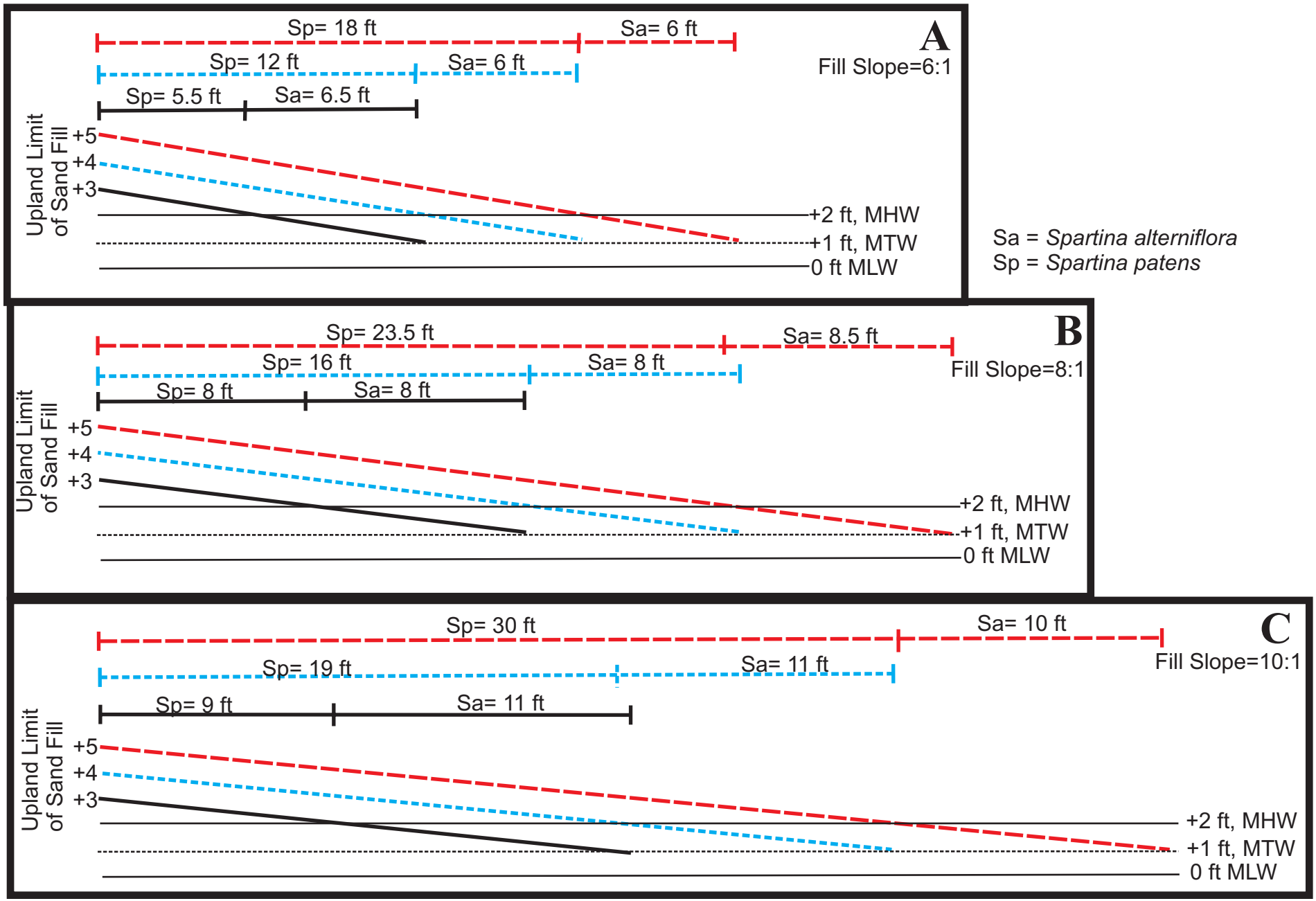


Figure 25. The sand fill model for A) a slope of 6:1, B) a slope of 8:1, and C) a slope of 10:1. The approximate width of the vegetated area (Sa is *S. alterniflora*, Sp is *S. patens*) on each slope is indicated. Sand fill model for various slopes. The total width of Sp and Sa is the total encroachment if no structure is included. Stone sill structure design is site specific.

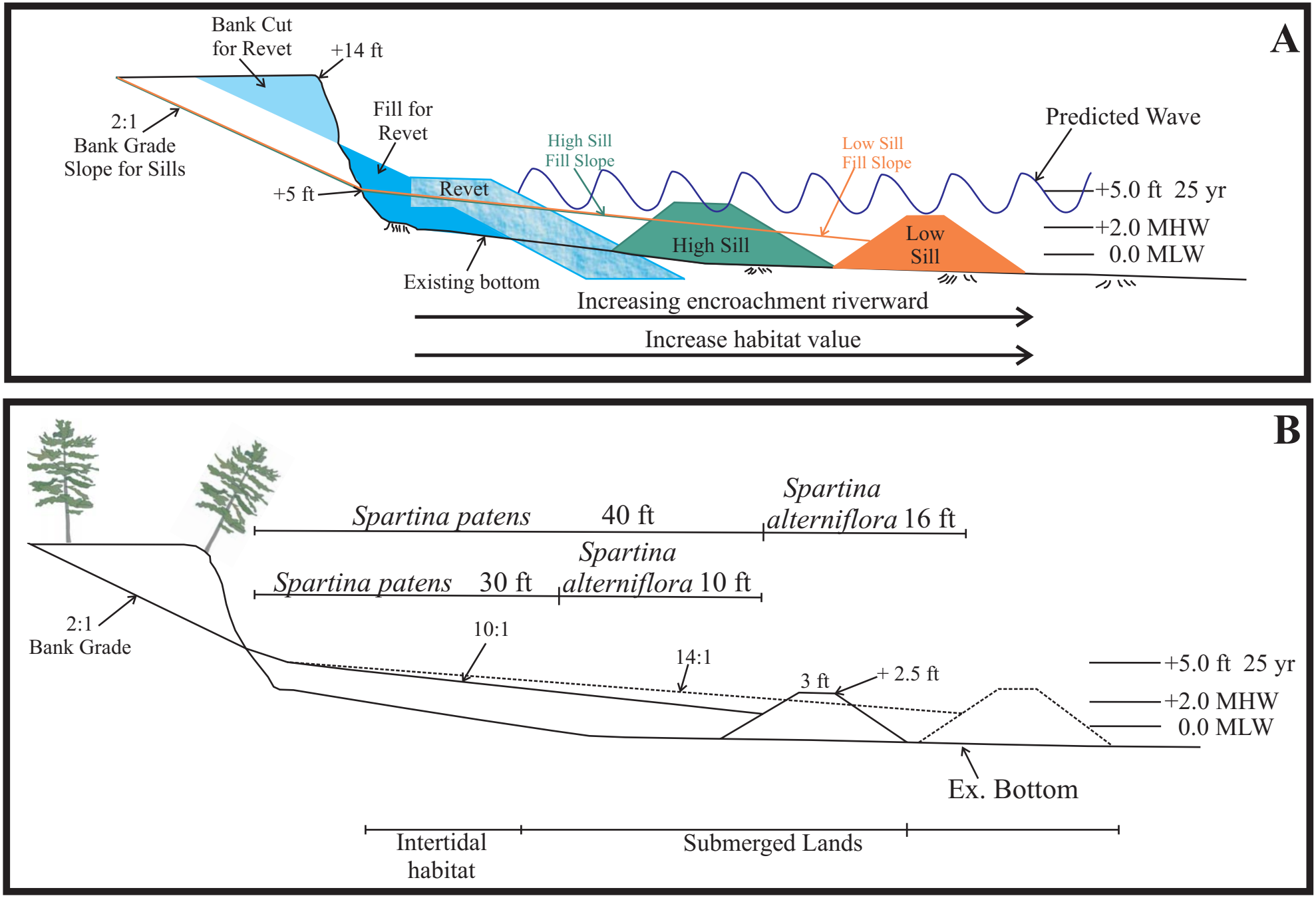


Figure 26. A) Shore protection options with encroachment, level of protection, and habitat value. B) Two sill options showing the amount of encroachment and the amount of habitat gained.

Appendix A

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Appendix B

Click to go to

Shore Survey Information

Appendix B
Survey data

All benchmarks were set with two-hour occupations and processed through the National Geodetic Survey's On-line Positioning User Service (OPUS) (http://www.ngs.noaa.gov/OPUS/). All the survey data were based on these benchmarks. In addition, 3-minute occupations were taken at secondary benchmarks in order to determine survey error.

Individual data points were processed in Trimble Terramodel.
Horizontal Datum: UTM, zone 18 N, NAD83, meters
Vertical Datum: collected in NAVD88, geoid03, meters. The vertical datum was converted to a local, tidal datum as described below.
For presentation purposes, the data was converted from meters to international feet.

St. Mary's City
April 10, 2007 and May 8-9, 2007
See Hardaway *et al.* (2007) for additional information on survey data results. No additional data is presented in this report. See website below for the report.
http://web.vims.edu/physical/research/shoreline/docs/St.MarysSill_Final.pdf

Webster Field
May 22-23, 2008
data converted to mean lower low water (MLLW) (1983-2001). NAVD88 =+0.25 m MLLW
Total length of shoreline surveyed: 950 m

Pre and post construction data was taken in June 2001 and March 2003, respectively. Hard copy data was available. The points were entered into the computer and converted to H: UTM, zone 18, NAD83, m and V: MLLW (1983-2001).

Jefferson Patterson Park & Museum
August 19-20, 2008
data converted to mean lower low water (MLLW) (1983-2001). NAVD88 =+0.24 m MLLW
Total length of shoreline surveyed: 850 m

Pre survey data was plotted from contours shown on the plans.

Lewisetta, VA

Station ID: 8635750

Lewisetta, VA: Data Inventory
Page Help

Datums

Click HERE for printable version

Data Units: Feet Meters Apply Change

```
Mar 31 2009 14:15        ELEVATIONS ON STATION DATUM
                       National Ocean Service (NOAA)

Station:  8635750                                        T.M.:        0 W
Name:     LEWISETTA, POTOMAC RIVER, VA                   Units:       Feet
Status:   Accepted                                       Epoch:  1983-2001

          Datum         Value  Description
          ---------  --------  -------------------------------------
          MHHW           6.27  Mean Higher-High Water
          MHW            6.13  Mean High Water
          DTL            5.52  Mean Diurnal Tide Level
          MTL            5.51  Mean Tide Level
          MSL            5.53  Mean Sea Level
          MLW            4.89  Mean Low Water
          MLLW           4.77  Mean Lower-Low Water
          GT             1.50  Great Diurnal Range
          MN             1.24  Mean Range of Tide
          DHQ            0.14  Mean Diurnal High Water Inequality
          DLQ            0.12  Mean Diurnal Low  Water Inequality
          HWI            6.17  Greenwich High Water Interval (in Hours)
          LWI            0.10  Greenwich Low  Water Interval (in Hours)
          NAVD           5.60  North American Vertical Datum
          Maximum        8.61  Highest Water Level on Station Datum
          Max Date   19980205  Date Of Highest Water Level
          Max Time      13:06  Time Of Highest Water Level
          Minimum        1.92  Lowest  Water Level on Station Datum
          Min Date   19750405  Date Of Lowest Water Level
          Min Time      03:36  Time Of Lowest Water Level

To refer Water Level Heights to a Tidal Datum, apply the desired Datum Value.

Click HERE for further station information including New Epoch products.


To refer Water Level Heights to either
   NGVD (National Geodetic Vertical Datum of 1929) or
   NAVD (North  American   Vertical Datum of 1988), apply the values located at:
   National Geodetic Survey
```

Station Home Page
Station Information
Tide / Water Level Data
Tide Predictions
Current Data
Meteorological Observations
Conductivity
PORTS
Operational Forecast System
Bench Mark Sheets
Datums
Harmonic Constituents
Sea Level Trends

Solomons Island, MD

Station ID: 8577330

Solomons Island, MD: Data Inventory

Page Help

Datums

Click HERE for printable version

Data Units: Feet Meters Apply Change

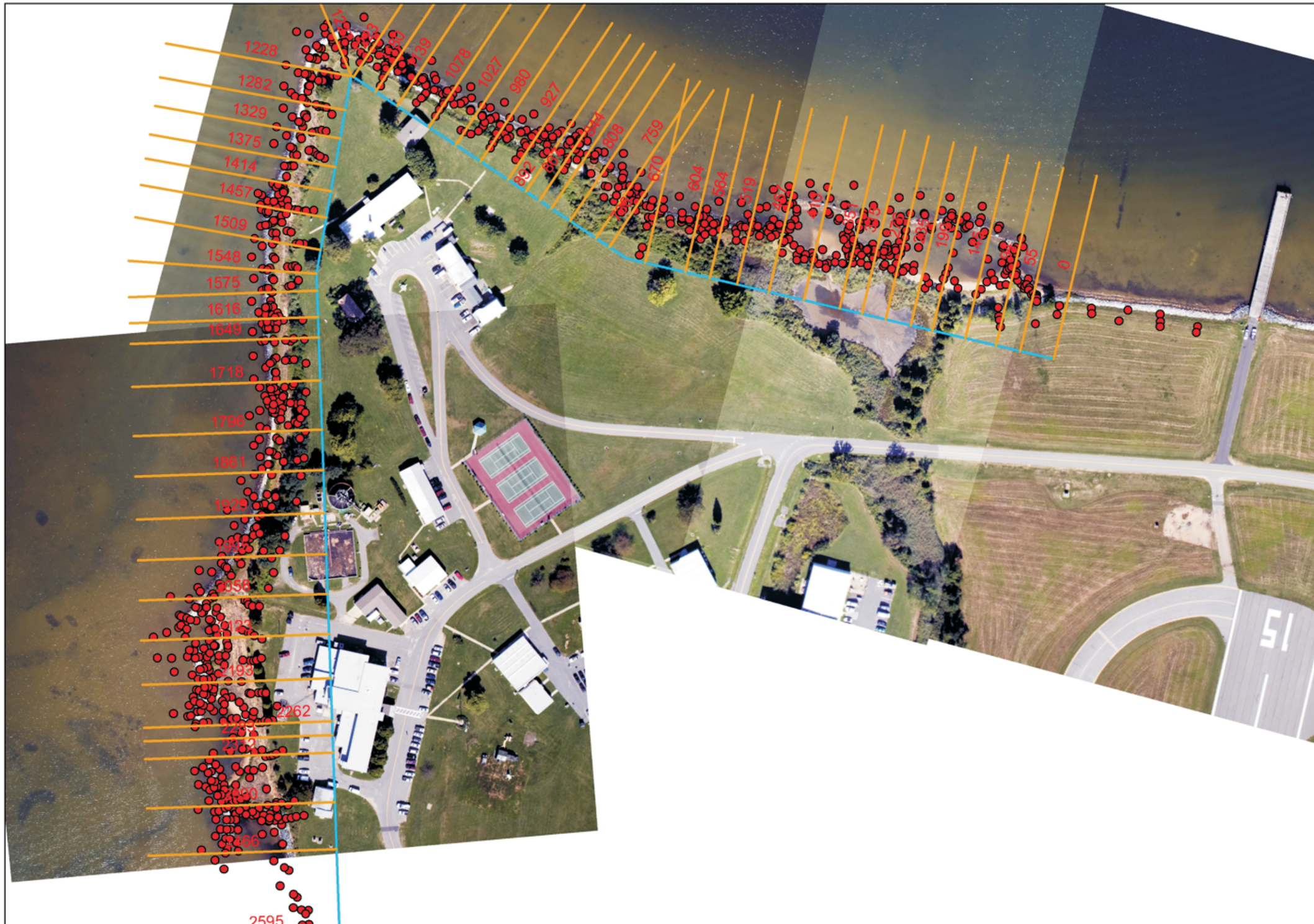
Mar 31 2009 15:09 **ELEVATIONS ON STATION DATUM**
National Ocean Service (NOAA)

Station:	**8577330**	**T.M.:**	**0 W**
Name:	**SOLOMONS ISLAND, PATUXENT RIVER, MD**	**Units:**	**Feet**
Status:	**Accepted**	**Epoch:**	**1983-2001**

Datum	Value	Description
MHHW	5.20	Mean Higher-High Water
MHW	5.05	Mean High Water
DTL	4.46	Mean Diurnal Tide Level
MTL	4.47	Mean Tide Level
MSL	4.48	Mean Sea Level
MLW	3.88	Mean Low Water
MLLW	3.72	Mean Lower-Low Water
GT	1.47	Great Diurnal Range
MN	1.17	Mean Range of Tide
DHQ	0.15	Mean Diurnal High Water Inequality
DLQ	0.16	Mean Diurnal Low Water Inequality
HWI	6.90	Greenwich High Water Interval (in Hours)
LWI	0.93	Greenwich Low Water Interval (in Hours)
NAVD	4.57	North American Vertical Datum
Maximum	8.00	Highest Water Level on Station Datum
Max Date	19550813	Date Of Highest Water Level
Max Time	03:48	Time Of Highest Water Level
Minimum	0.00	Lowest Water Level on Station Datum
Min Date	19621231	Date Of Lowest Water Level
Min Time	23:00	Time Of Lowest Water Level

To refer Water Level Heights to a Tidal Datum, apply the desired Datum Value.

Click HERE for further station information including New Epoch products.



Webster Field

St. Mary's County, MD

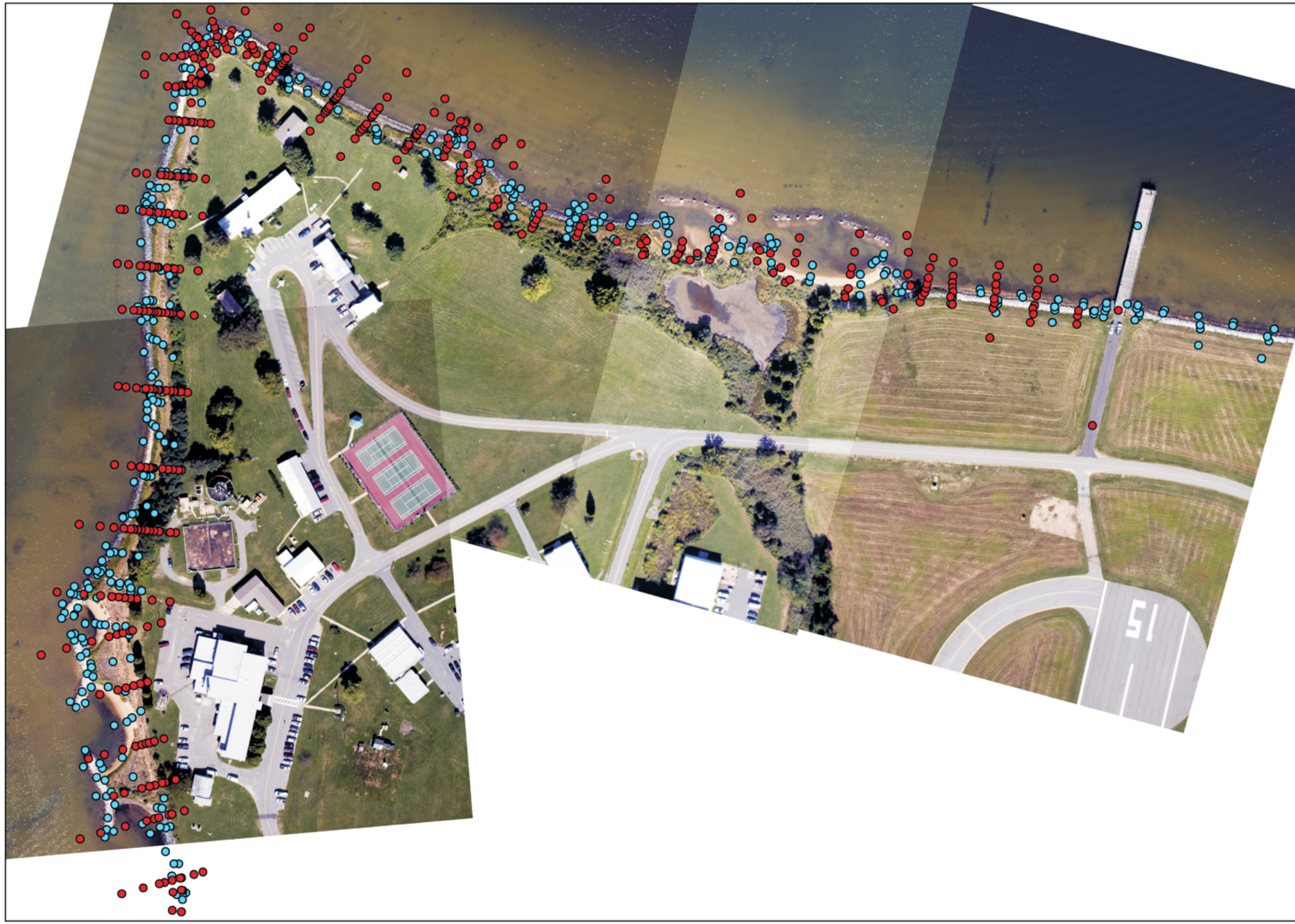
Legend

- Profiles
- Baseline
- Survey Points May 2008

Shoreline Studies Program
VIMS

150 75 0 Feet

Image Date: September 2, 2008



Webster Field

St. Mary's County, MD

Survey Points

- Survey Points_June 2001
- Survey Points_March 2003

Shoreline Studies Program
VIMS

150 75 0 Feet

Image Date: September 2, 2008

Webster Field

St. Mary's County, MD

Contours (International Feet)

- -3
- -2
- -1
- 0
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10

Shoreline Studies Program
VIMS

150 75 0 Feet

Survey Dates: May 22 - 23, 2008

Image Date: September 2, 2008

Webster Field

St. Mary's County, MD

Mean High Water (MHW)

MHW June 2001

MHW May 2008

Shoreline Studies Program

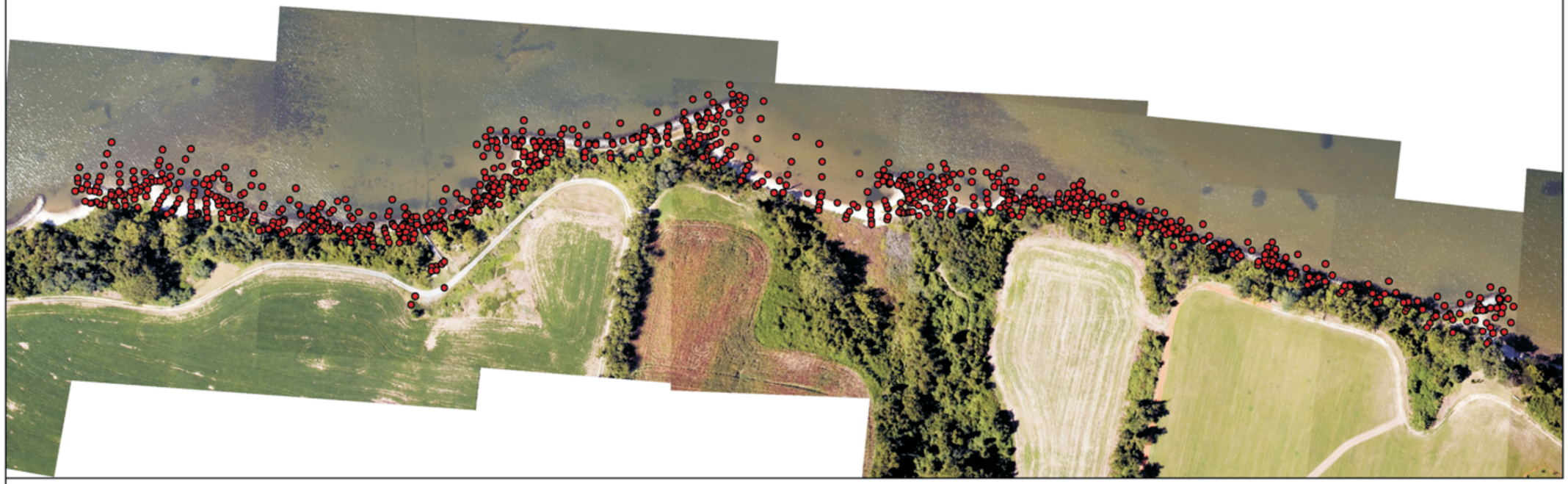
VIMS

150 75 0 Feet

Image Date: September 2, 2008

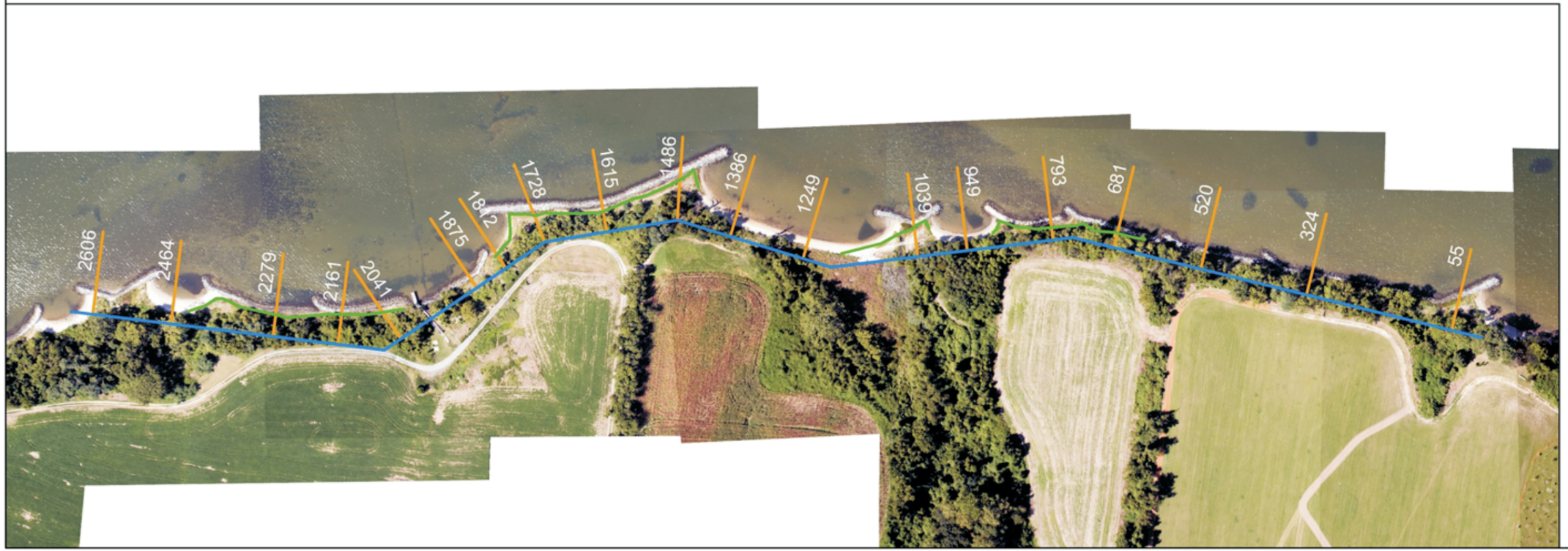
Jefferson Patterson Park & Museum

Calvert County, MD



Legend

- Data Point
- *Spartina alternifolia/ Spartina patens*
- Baseline
- Profiles



Shoreline Studies Program
VIMS

200 100 0 Feet

Survey Dates: August 19 -20, 2008

Image Date: September 2, 2008

Jefferson Patterson Park & Museum

Calvert County, MD

Contours (International Feet)

- -4
- -3
- -2
- -1
- 0
- 1
- 2
- 3
- 4
- 5
- 9

Shoreline Studies Program
VIMS

Survey Dates: August 19 - 20. 2008
Image Date: September 2, 2008