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Marine Corps Base, Quantico Shoreline Protection Plan

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1 Introduction

1.1 Shore Setting

Marine Corps Base, Quantico (MCB, Quantico or Base) is located on the Potomac River in Virginia about 35 miles south of Washington, D.C. and 20 miles north of Fredricksburg, Virginia (Figure 1-1). The Base covers nearly 100 square miles in Prince William, Stafford, and Fauquier Counties. It has almost five miles of shoreline along the Potomac River and a little more than two miles on Quantico Creek. In addition, Chopawamsic Creek is included within the base (Figure 1-2).

1.2 Statement of the Problem and Goals

MCB, Quantico is a major U.S. Marine Corps training base for both amphibious warfare and air-support tactics. A great deal of infrastructure is directly adjacent to the shoreline. As such, shore change likely has been an issue since the Base's inception in 1917 as evidenced by the many fill projects and erosion control structures that have been placed along the shoreline.

Many areas of Quantico's shoreline already have protection, particularly the areas that have infrastructure. However, those structures, mostly revetments of broken concrete and concrete and stone walls, are old and deteriorating. Broken concrete revetments are not standard engineered structures, and many structures could use rehabilitation. Other areas of the Base have exposed high banks that are actively eroding and threatening upland infrastructure.

One goal of this management plan is to provide more habitat-friendly management strategies which utilize the creation of marshes and beaches for shore protection rather than hardening the coast. Many of these strategies have been implemented around the Bay. These approaches include creating a marsh fringe by direct planting of the existing substrate, adding sand, and adding sand with stone sills. On more open coasts, breakwaters and beach fills can be built to achieve a stable sandy habitat of beaches 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 a water quality buffer. 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.

2 Shore Management Strategies

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 wetland habitats, 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.
- 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 Quantico are listed below.

1) <u>Stone sills</u>: The stone sill has been used extensively in Chesapeake Bay (Figure 2-1). 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 wetland 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.

2) <u>Breakwater System</u>: Although single breakwaters can be used, two or more are recommended to address several hundred feet of coast (Figure 2-2). 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.

3) <u>Revetments</u>: Many bulkheads and revetments exist along the Quantico coast, some of which are in need of repair or extensions (Figure 2-3). Stone revetments may be the preferred method for shore erosion control along high banks or where vital infrastructure is located close to the shoreline. It is usually the preferred strategy when hardening of the shoreline is required

4) <u>Spurs:</u> A spur is a structure that is connected either to the land or another structure (Figure 2-4). Spurs can be used to 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; on the seaward side, wave 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 replanted 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.

The location of submerged aquatic vegetation (SAV) must also be considered in the placement of structures in the nearshore. At Quantico, the nearshore is heavily covered in SAV (Figure 2-5) which complicates obtaining permits for structures in the nearshore. Various species cover the nearshore at 70%-100% density. These species are *Ceratophyllum demersum* (coontail), *Heteranthera dubia* (water stargrass), *Hydrilla verticillata* (hydrilla), *Myriophyllum spicatum* (Eurasian watermilfoil), *Najas guadalupensis* (southern naiad), *Najas minor*, and *Vallisneria americana* (wild celery) (SAV, 2007). More information on SAV types can be found at http://web.vims.edu/bio/sav/species_classification.html.

3 Methods

3.1 Photo Rectification and Shore Change

In order to understand the suite of processes that work to alter a shoreline, knowledge of the history of shoreline change is essential. Often analysis of aerial photographs provides the historical data. Images of Quantico from 1937, 1996, 1999, 2002, and 2009 were used in the analysis. The 1937 photos were rectified by VIMS using the procedure below. The 1996 and 1999 images were provided in GIS format by Quantico. One photo tile in the 1999 image series was missing. The 2002 and 2009 imagery were orthorectified by the Virginia Base Mapping Program (VBMP).

The 1937 images were scanned as tiffs 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 mosaicked together using the ERDAS Imagine mosaic tool to produce a one-meter resolution mosaic also in .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.

Once the 1937 aerial photos were orthorectified and mosaicked, the shoreline was digitized in ArcMap with the mosaic in the background. This procedure also occurred for the 1996, 1999, 2002, and 2009 mosaics. The toe of the narrow beaches, which can indicate the position of low water, was delineated as the shoreline. In 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. The photos and shorelines are displayed using a set of four plates created along the shoreline (Figure 3-1). The images and the shorelines are shown in Appendix A.

Horizontal positional accuracy is based upon orthorectification of scanned aerial photography using USGS DOQQs. Vertical control is the USGS 100 ft (30 m) 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 2009 Virginia Base Mapping Program's orthophotography were developed in accordance with the National Standard for Spatial Data Accuracy (NSSDA). Horizontal root mean square error (RMSE) for the 1937 mosaic was held to less than 20 ft (6 m).

Using methodology reported in Morton *et al.* (2004) and National Spatial Data Infrastructure (1998), estimates of error in orthorectification, control source, DEM and digitizing were combined to provide an estimate of total maximum shoreline position error. The data set that was orthorectified (1937) has an estimated total maximum shoreline position error of 20.0 ft (6.1 m), while the total shoreline error for the 1994, 2002, and 2009 datasets are estimated at 18.3 ft (5.6 m) for USGS and 10.2 ft (3.1 m) for VBMP. The maximum annualized error for the shoreline data is +0.4 ft/yr (+0.2 m/yr).

The Digital Shoreline Analysis System (DSAS) was used to determine the rate of change for Quantico's shoreline (Himmelstoss, 2009). All DSAS input data must be managed within a personal geodatabase, which includes all the baselines for Quantico and the digitized shorelines for 1937, 1996, 1999, 2002, and 2009. Baselines were created about 200 feet or less, depending on features and space, seaward of the 1937 shoreline and encompassed most of the Base's main shorelines but generally did not include Chopawamsic Creek. DSAS generated transects perpendicular to the baseline about 33 ft apart. For Quantico, this method represented about 6.4 miles of shoreline along 998 transects.

The End Point Rate (EPR) is calculated by determining the distance between the oldest (1937) and most recent shoreline (2009) in the data and dividing it by the number of years between them. This method provides an accurate net rate of change over the long term and is relatively easy to apply to most shorelines since it only requires two dates. This method does not use the intervening shorelines so it may not account for changes in accretion or erosion rates that may occur through time. The EPR rate is shown on the Plates in Appendix A, except for Plate 2, Chopawamsic Creek. Average EPR rates were calculated along each site segment.

3.2 Wave Climate

Two local grids were created from bathymetry obtained from the NOAA ENC Database, one to model waves coming from the south and another grid to model waves coming from the northeast (Figure 3-2). In order to determine input waves, the US Army Corps of Engineers ACES (http://chl.erdc.usace.army.mil/aces) program was used to simulate waves that could occur from each direction exposure to the outside of the grid. The ACES application provides quick and simple estimates for wave growth over open-water and restricted fetches in deep and shallow water. The average fetch was calculated to the grid edge so that wave height and period could be calculated by ACES for selected water depths and wind speeds.

These wave data were input to STWAVE (STeady State spectral WAVE) in order to model the maximum wave parameters at the project site. STWAVE is a half-plane model for nearshore wind-wave growth and propagation. It simulates depth-induced wave refraction and shoaling, current-induced refraction and shoaling, depth- and steepness-induced wave breaking, diffraction, parametric wave growth because of wind input, and wave-wave interaction and white capping that redistribute and dissipate energy in a growing wave field.

For both the south and northeast wind wave scenarios, four cases were run. The cases represent conditions that may occur during a 10-yr, 25-yr, 50-yr, and 100-yr storms (Table 3-1). The 10-yr and 50-yr storm surge elevations were reported at Chopawamsic Creek (FEMA, 1995) and referenced to the National Geodetic Vertical Datum 1929 (NGVD29). The elevations were converted to MLLW (1983-2001 by adding 0.44 ft to NGVD29 elevation as calculated from the National Geodetic Survey's (NGS) benchmarks for Colonial Beach, Virginia and Washington, DC. The 25-yr storm surge elevations were not calculated in the FEMA (1995) report but were interpolated from the 10-yr and 50-yr storm surge levels for this analysis. While FEMA (1995) reported a 100-yr storm surge of 8.1 ft MLLW, this analysis used a storm surge of 8.6 ft MLLW which was the reported stillwater level during Hurricane Isabel (September 2003) at Aquia Landing just south of Quantico (Hardaway *et al.*, 2005).

These cases were chosen to represent the wind wave climate for design purposes. The input wave conditions enter the grid at its seaward edge (as indicated by the arrow on Figure 3-2) and are transformed across the bathymetry of the grid to the shore. Output stations were created along the shoreline for each individual grid. The stations were placed at approximately 0 ±0.5 ft MLW. The wave height, period and direction were exported at each station for each wave condition.

Table 3-1. Wind wave conditions input to the STWAVE hydrodynamic model.

Grid Direction	Return Interval Year	Return Interval Frequency	Wind Speed (mph)	Surge (ft MLLW)	Input Wave Height (ft)	Input Wave Period (s)
South	10	10%	35	5.2	2.91	3.32
South	25	4%	45	6.1	3.86	3.81
South	50	2%	55	7.1	4.84	4.26
South	100	1%	69	8.6	5.9	4.7
Northeast	10	10%	35	5.2	2.79	3.21
Northeast	25	4%	45	6.1	3.76	3.7
Northeast	50	2%	55	7.1	4.78	4.14
Northeast	100	1%	69	8.6	5.87	4.56

3.3 Existing Conditions Survey and Shore Management Strategy Development

The existing conditions were determined by Shoreline Studies Program personnel in a small, shallow draft vessel, navigating at slow speeds parallel to the shoreline on 5 November 2009. Strategies were coded into handheld global positioning system (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 Geographic Information System (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 existing structures, the condition of the bank face and toe, marsh width, landscape type, and GPS-referenced photos.

The shoreline was broken into 74 site segments (called both Site and Segment in the report and on graphics) that generally have the same conditions (Appendix B). The dominant code is listed in the GIS attribute table (Appendix C). However, the shoreline can include more than one type of shoreline. For the base of bank and bank face, shore segments were coded as erosional, transitional, or stable. Some segments had more than one base of bank or bank face status and were given the conditional codes of erosional and transitional or stable and transitional. For example, an area that is coded as erosional and transitional may have sections of bank that are stable.

Much of the base of bank along Quantico's main shoreline has been protected by structures (Appendix B). These structures vary considerably along the shoreline in materials and effectiveness. Some sections of the shore noted as having a protected base of bank (structure present) may have areas of erosion at the base. Overall the existing shoreline structure is protecting the base of bank, but in a few areas along the segment, it may not be.

The primary erosion control strategies are based on an analysis of 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.

The decision to apply a primary shore stabilization approach is based on the condition of the upland bank at the time of the survey. Stable banks do not receive a recommendation since they either are already protected with a structure or have a sufficiently wide marsh fringe. If the shore protection is failing or inadequate then a recommendation was made.

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.

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 generally are of types listed in Chapter 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.

Generally, the recommendations can be phased in. As such, each segment of shore was coded with a priority (Appendix C). Low priority has a stable bank, no threatened infrastructure, or the existing structure is adequate. Medium priority has an erosional to transitional bank or an existing failed structure. High priority shorelines have erosional to transitional bank with threatened upland infrastructure.

Two distinct GIS data sets were created. The first data set contains the shore segments with existing conditions. The second data set has the recommendations which can span several shore segments. As such, the information from several shore segments were visually "averaged" to best represent the existing conditions for the recommended strategy. This is particularly true of the priority. Shore segments may have varying priority. When a recommendation crosses several segments, other factors and data collected were used to determine the appropriate priority for the structure.

For ease of discussion, the Quantico shoreline has been divided into five reaches for ease of discussion (Figure 3-3). Reach 1 is located along the Potomac River south of Chopawamsic Creek while Reach 2 is inside Chopawamsic Creek. Reach 3 includes the Base's shoreline north of Chopawamsic Creek to the Town of Quantico. Reach 4 extends northward from the Town around the headland into Quantico Creek. It ends where the bridge spans Quantico Creek. Reach 5 includes the Quantico Creek shoreline from the bridge to the end of the Base.

4 Physical Setting

4.1 Geology and Shoreline Change

Along Quantico's shoreline, the banks consist of the Patapsco Formation (Figure 4-1). The Patapsco Formation of the Potomac Group, which crops out in eastern Virginia and Maryland, contains sediment deposited in a large fluvial system, including stream channels, levees, crevasse splays, and meander cutoffs (Doyle and Hickey, 1976 ; Upchurch *et al.*, 1994, Royer *et al.*, 2010). This formation is extremely uneven and consists of variable materials, clays, sands, gravels, and conglomerates. A section of the Patapsco Formation just south of Quantico at Widewater, Virginia showed the bank to be sandy clay exposed to the water and extending up 5-10 feet. Above that, coarse sand extended up about 15-20 feet (Clark and Miller, 1912)

Much of the shoreline south of Chopawamsic Creek shows very low accretion (Appendix A-3). This likely is the result of slumping of the bank material in some areas, but also, sections of this shoreline had sediment and/or structures placed along the shoreline over time. Much of the shoreline north of Chopawamsic Creek (Appendix A-9) shows very low erosion likely due to the influence of structures placed along the shoreline. Several areas show high levels erosion while others show significant fill. Past the bridge crossing Quantico Creek, much of the shoreline is natural. Generally, along this shore, the headlands have higher erosion rates, sometimes more than -5 ft/yr erode while other shorelines had very little change (Appendix A-12).

4.2 Wave Climate

The wave climate at Quantico was modeled to determine the maximum conditions possible during storms. Tables 4-1 and 4-2 list the output wave heights, periods and direction for each station along the shoreline as shown in Figure 3-2. From the south, waves approach the shore at an angle. Station S5 is protected by Chopawamsic Island and has very little impact from southerly waves (Table 4-1). Stations S1 and S2 are the farthest north and also have lower southerly wave energy impacting the shore. From the northeast during the larger storm events modeled (Table 4-2), the southernmost section of shoreline would be the most impacted by larger storm waves likely due to its orientation and longer fetch.

Table 4-1. Wave conditions resulting from STWAVE modeling of the southerly wind/wave climate.

	10-yr			25-yr			50-yr			100-yr		
Station Number	Height (ft)	Period (s)	Direction (Deg TN)	Height (ft)	Period (s)	Direction (Deg TN)	Height (ft)	Period (s)	Direction (Deg TN)	Height (ft)	Period (s)	Direction (Deg TN)
S1	1.3	3.7	319	1.8	4.3	323	2.1	4.3	323	2.8	5.6	324
S2	1.9	3.7	329	2.5	4.3	335	2.9	4.3	336	3.6	5.6	337
S3	2.3	3.6	335	3.1	4.3	339	3.7	4.3	338	4.3	4.3	339
S4	2.2	3.6	327	3.1	4.3	332	3.9	4.3	331	4.5	4.3	333
S5	1.8	3.6	340	2.6	3.6	342	3.9	4.3	341	0.9	4.3	342
S6	2.1	3.6	330	2.9	3.6	331	3.9	4.3	328	4.5	4.3	331
S7	2.0	3.4	331	2.9	3.6	333	3.5	4.3	331	4.6	4.3	333
S8	1.7	3.4	315	2.5	3.6	320	3.2	4.3	318	4.1	4.3	322
S9	1.5	3.4	316	2.2	3.6	322	3.9	4.3	320	3.6	4.3	322
S10	2.0	3.4	329	2.8	3.6	332	4.0	4.3	330	4.5	4.3	332
S11	2.2	3.4	336	3.0	3.6	337	4.0	4.3	334	4.6	4.3	336
S12	2.3	3.4	336	3.0	3.6	337	2.9	4.3	335	4.6	4.3	337
S13	1.5	3.4	318	2.0	3.6	322	2.9	4.3	320	3.3	4.3	324

Table 4-2. Wave conditions resulting from STWAVE modeling of the northeasterly wind/wave climate.

	10-yr			25-yr			50-yr			100-yr		
Station Number	Height (ft)	Period (s)	Direction (Deg TN)	Height (ft)	Period (s)	Direction (Deg TN)	Height (ft)	Period (s)	Direction (Deg TN)	Height (ft)	Period (s)	Direction (Deg TN)
NE1	1.1	3.3	230	1.4	3.8	231	1.9	4.3	233.3	2.4	4.8	234
NE2	1.9	3.3	243	2.3	3.8	245	3.1	4.3	246.0	3.8	4.8	246
NE3	1.5	3.3	260	1.8	3.8	261	2.5	4.3	261.0	3.1	4.8	260
NE4	1.5	3.3	264	2.0	3.8	264	2.7	4.3	264.0	3.4	4.8	263
NE5	1.4	3.3	270	1.8	3.8	270	2.4	4.3	269.0	3.0	4.8	268
NE6	0.4	3.4	275	0.5	3.8	275	0.7	4.3	275.0	1.0	4.8	274
NE7	1.8	3.4	250	2.3	3.8	250	3.1	4.3	252.0	3.9	4.8	251
NE8	1.5	3.4	251	1.9	3.8	251	2.5	4.3	253.0	3.1	4.8	253
NE9	1.3	3.4	285	1.7	3.8	282	2.3	4.3	280.0	3.0	4.8	276
NE10	1.0	3.4	270	1.3	3.8	270	1.8	4.3	269.0	2.3	4.8	268
NE11	1.6	3.4	250	2.0	3.8	251	2.7	4.3	250.0	3.5	4.8	250
NE12	1.7	3.4	255	2.2	3.8	255	3.0	4.3	254.0	3.8	4.8	253
NE13	2.1	3.4	248	2.7	3.8	248	3.7	4.3	247.0	4.7	4.8	247
NE14	2.0	3.4	265	2.6	3.8	263	3.5	4.3	261.0	4.4	4.8	259
NE15	2.1	3.4	253	2.7	3.8	253	3.6	4.3	251.0	4.6	4.8	250
NE16	2.1	3.4	247	2.7	3.8	247	3.6	4.3	247.0	4.5	4.8	247
NE17	2.1	3.4	248	2.6	3.8	248	3.4	4.3	248.0	4.4	4.8	248

4.3 Tide and Storm Surge

The mean tide range at Quantico is 1.40 ft and the spring range is 1.54 ft (NOAA, 2010). FEMA (1995) predicted storm surges for the Quantico shorelines are listed in Table 2. The 100-year event is predicted to have an 8.1 ft MLLW surge. This does not include waves.

Table 4-3. Storm surge elevations at the confluence of Chopawamsic Creek and the Potomac River (FEMA, 1995).

Storm Event	Frequency	Elevation ft NGVD29	Elevation ft NAVD88*	Elevation ft MLLW*'
10-yr	10%	4.8	4.0	5.2
25 yr^	4%	4.7	4.9	6.1
50-yr	2%	6.7	5.9	7.1
100-yr	1%	7.7	6.9	8.1
500-yr	0.2%	10.6	9.8	11.0

^Interpolated *Converted using NOAA datums 'MLLW (1983-2001)

4.4 Sea-Level Rise

Sea level is rising around Chesapeake Bay. This is due to a combination of both the higher global sea levels as well as land subsidence. Downriver from Quantico at Colonial Beach, sea-level rise has been measured at 0.19 in/yr or 1.6 ft/century. Upriver of Quantico at Washington, D.C., the rate of sea-level rise is slightly less, 0.12 in/yr or 1.0 ft/century.

5 Reach 1: Potomac River South of Chopawamsic Creek

5.1 Shore Conditions

5.1.1 Reach Boundaries and Shore Change

Beginning at the mouth of Tank Creek, the base's southern boundary, Reach 1 extends northward, upriver, for about 1.4 miles to Chopawamsic Creek (Figure 5-1 and Figure 5-2). The reach is divided into two subreaches, 1A and 1B, and consists of 24 shore segments based on shore type. Reach1A is mostly wooded, un-managed upland while Reach 1B is a developed upland coast with base infrastructure, roads and buildings near the shore. Reach 1A is about 0.9 miles in length and includes shore Segments 1 to13. Reach 1B includes shore Segments 14 to 24 and is about 0.4 miles in length.

Historic shore change along Reach 1 is slightly variable ranging from -0.39 to 1.36. Some of the shore advance appears to be more a function of slight beach accretion often caught by fallen trees. In this case, the measure of MLW over time often does not reflect the condition or change in upland bank conditions. In the case of Reach 1A, the upland bank has obvious erosion as evidenced by vertically exposed bank face along much of the coast. The top of upland banks, especially when heavily wooded, are difficult to delineate in older aerial imagery. Reach 1B is heavily influenced by the upland development of the MCB, Quantico where riverward filling was common and positive shore changes are calculated.

5.1.2 Upland and Shore Characteristics

Reach1A shoreline starts at Tank Creek as a low bank headland in Segment 1 (Figure 5-3A). The upland banks rise up and are between 10 feet and 30 feet MLW along the length of the Reach. The base of bank and bank face area intermittently undercut and eroding with no coastal protection structures present (Figure 5-3B, Figure 5-3C). A relatively wide beach face exists along the Reach, but the backshore width is less the 10 feet along most of the reach (Appendix B-1). Numerous fallen trees occur along the shore (Figure 5-3D). Indurated bank rock that is moderately resistant to erosion and weathering is exposed along Segments 4, 5, 6, and 7 of the Reach (Figure 5-3E). The railroad line comes very close to the eroding bank at Segments 4 and 5 making these critical areas of concern (Appendix B-1).

Reach 1B begins where the base upland infrastructure begins (Segment 14) and extends to the mouth of Chopawamsic Creek (Segment 24) (Appendix B-1). The bank reaches heights of up to 20 feet MLW, but also has sections with only a minimal bank. Reach 1B begins where the upland has been developed with various base infrastructure including buildings, concrete pads and parking lots (Figure 5-3F, Figure 5-3G). The shoreline has been protected for the most part with stone revetment, old concrete walls and old stone walls (Figure 5-3H), but the bank generally still erosional. These structures also have reduced the intertidal beach width and backshore along most of the reach. At the mouth of Chopawamsic Creek (Segment 24), the bank is about +20 ft MLW and erosional even though the base has been protected by rock and rubble (Figure 5-3I)

5.1.3 Nearshore Characteristics

The nearshore width along Reach 1, from MLW to the -6 ft contour, varies from about 1,600 feet off Tank Creek to about 600 ft off Segment 9 and continues so to the entrance of Chopawamsic Creek. The landward limit of SAV averages about 25 feet from MLW and consists of various species including coontail, water stargrass, hydrilla, Eurasian watermilfoil, southern naid, and wild celery.

5.2 Design Considerations and Recommendations

The No Action alternative along Reach 1 would allow erosion of upland banks of Quantico's property to continue to intermittently erode. Several areas of Reach 1 should be considered for further action. These include shore Segments 2 through 7, due to the proximity of the railroad tracks to the shoreline. The top of the eroding bank is less than 10 ft from the railway ballast stone foundation. Because the railroad tracks curve, this is the only area where the tracks are threatened.

The inner limit of SAV is relatively close to the shore at Segments 1 through 7 and makes a large sill or breakwater system problematic from a permitting perspective so in general, a revetment is recommended. The design consideration for Segment 5, where the railroad bed is most threatened, is to provide shore protection for the 100-year storm as defined in Figure 5-4A. The revetment would continue up and down river. Downriver, the revetment could drop as the bank got lower and the railroad turns westward (Figure 5-4B). The upriver extension should be built to a "safe" distance from the railroad then drop down where the option could be to transition to a sill (Figure 5-4C). Here, three sill segments across existing small beach headlands and/or revetments are proposed along Segments 8 and 9. A continuous sill would then begin at Segment 10 (Figure 5-1). The proposed sills have to stay close to shore to avoid SAV, but this is possible because the backshore widens upriver and the back face is less erosive making the situation less critical. This would provide shore protection to something less than the 100-year storm, more in line with the 25-year event.

The sill continues to Segment 11 where no structure is proposed for about 400 feet because an upland drainage crosses the shore (Figure 5-1). The backshore is wide while the banks are low and not erosive. Also, the nearshore bottom might be soft and may not adequately support a structure. The sill begins again on Segment 12 and continues upriver where it is intermittently gapped at a small embayment along the coast (Figure 5-1).

Reach 1B begins at the boundary of Segment 13 and Segment 14 where upland and shoreline development begins (Figure 5-2). The groin-type existing structure at the boundary between Segments 14 and 15 has created a headland/geomorphic opportunity. The existing beach can be enhanced with spurs and a breakwater with a beach fill along this section of shore. These structures also will provide added scour protection to the low upland that is now protected by a revetment and low wall (Figure 5-2).

Along shore Segment 16 the bank rises to about + 15 feet MLW and continues across Segment 17. The bank face is intermittently transitional to exposed and eroding along the top which is within a few feet of adjacent parking lots on Segment 16. The base of bank is erosional to transitional. If not for the proximity of the parking lots to the top of the bank, a sill would be appropriate and recommended for Segment 17. However, to insure bank protection on Segment 16 a revetment is the preferred strategy (Figure 5-5A).

The upland bank drops down to + 8 MLW beginning at Segment 18 where a sloping concrete wall occurs. Although in fair condition, the wall is old and signs of deterioration are evident along its base. "Do Nothing" is an option, but a low sill would soften the hard edge and provide scour protection the base. At Segment 19 the bank drops to about +5 ft MLW and the shore is protected with low stone and concrete walls which are old and could benefit from armoring the face with rock or a low sill system (Figure 5-5B).

The upland bank rises to about + 10 along Segment 20 where the base of bank is undercut and erosive. A sill is proposed (Figure 5-5C). In Segment 21, a low stone wall protects a stable upland bank face. Again the wall is old but still in fair conditions. "Do Nothing" is an option or the sill could be extended. Along shore Segment 22, a crib wall appears to be in good condition and is protecting the bank. Along shore Segment 23, the base of bank is transitional with a transitional to stable, but steep, top of bank. However, about midway alongshore, the upland bank, now about + 20 feet MLW, has a parking lot near the top of the bank. Here a sill or revetment is proposed (Figure 5-5D). A revetment might require excavating the bank slump, and a more detailed geotechnical analysis is recommended.

Segment 24 is on the headland point at the confluence of Chopawamsic Creek and the Potomac River. Broken concrete along the base of the bank offers minimal shore protection. The bank face is steep and heavily vegetated. A sill or revetment should be installed to hold this point and protect the nearby parking lot at the top. However, as this area begins to come into view of the runway and aircraft operations, a revetment might be preferable to the sill with the marsh habitat component. This also is the end of Reach 1 and the beginning of Reach 2.

6 Reach 2: Chopawamsic Creek

6.1 Shore Conditions

6.1.1 Reach Boundaries and Shore Change

Reach 2 includes 6.4 miles of Chopawamsic Creek, but most of the shoreline management recommendations occur along the long narrow entrance channel that extends about 1,800 feet from the Potomac River and averages about 125 feet wide (Figure 6-1). The remaining shoreline around Chopawamsic Creek was visited but not assessed in detail because it is all wooded or marsh coast with no threatened infrastructure, and erosion rates are very low. Base personnel placed those shorelines as low priority. The Reach is divided into three subreaches. Reach 2A extends along the south side of the entrance channel and Reach 2C along the north. Reach 2A includes Segments 24 to 28 and Reach 2C has Segments 29 to part of 32. Reach 2B is the remaining shoreline around Chopawamsic Creek, about 5.8 miles.

The channel into Chopawamsic has been in its present configuration at least since the 1930s and has shown little change over time at the scale of the shore change analysis. While historic shoreline change is minimal, bank erosion threatens the upland infrastructure along the length of Reach 2A. Erosion continues along the low bank inside Chopawamsic Creek beyond the boat ramp. The northern side of the channel, Reach 2C, has been hardened from the entrance to just past the railroad and Base road overpass bridges where the low bank continues to erode.

The shoreline inside the creek, Reach 2B, has obvious erosional sections of shore, but they were not calculated for this report. However, the historic and recent shorelines were digitized and are shown in Appendix A, Plate 2. Rates of change can be approximated by scaling change and dividing by the number of years between the shores.

6.1.2 Upland and Shore zone Characteristics

The bank height along Reach 2A is about +20 ft MLW. The base of bank is either undercut or erosional along Segments 24 and 25 with a transitional to stable bank face (Figure 6-2A). One problem is that occasional slumping occurs and threatens the parking lot. Efforts to fix this are seen in Segment 26 with a rock toe and concrete bank face (Figure 6-2B). Shore Segment 27 is fairly stable to the bridge where the abutments act as a tall bulkhead along the shore (Figure 6-2C). Beyond the bridges, the low bank is mostly undercut and erosional, Segment 28 (Figure 6-2D).

The Reach 2B coast along the interior of Chopawamsic Creek has mostly high wooded banks on the south shore that are intermittently undercut (Figure 6-2E and Figure 6-2F) and eroding on the headlands with stable bank faces. Wide marsh complexes and narrow marsh fringes also occur. The north coast is lower in elevation with broad marsh complexes along much of its shore (Figure 6-2G).

Reach 2C begins on the north side of the entrance channel in Chopawamsic Creek as a low bank on Segments 29 and 30 (Figure 6-2H). Riverward of the bridge, the bank becomes higher and the shoreline bridge abutment is bolstered by gabions (Figure 6-2I). For the remainder of Reach2C, Segment 31 has been armored with stone (Figure 6-2J) and part of Segment 32 has scattered broken concrete alongshore and intermittently eroding upland banks (Figure 6-2K).

6.1.3 Nearshore characteristics

The narrow entrance channel into Chopawamsic Creek (Reach 2A and 2C) is straight and about 125 feet wide at MHW. It averages about 3 to 5 feet deep in the center. No SAV occurs along the bottom. The channel widens quickly into Chopawamsic Creek which is a wide but very shallow water body. Historical imagery in 1937 of Chopawamsic Creek (Appendix A-4) shows a series of interior channels that appear to be through tidal marsh and abundant SAV. Today, the channels are less defined, and SAV is still abundant.

6.2 Design Considerations and Recommendations

For Reach 2A, the "Do Nothing" option requires careful monitoring of the high upland bank face for signs of continued slumping and bank undercutting. A proactive approach would involve a more detailed survey of the upland bank and a geotechnical investigation to better understand the short and long-term stability of the bank face. Long-term stabilization could be done with a free standing revetment and bank grading (Figure 6-3A). Inside the creek, if left alone, the low bank would continue its slow erosion process. Alternatively, a low revetment could be installed (Figure 6-3B) that transitions to a sill past the boat ramp (Figure 6-3C).

The Reach 2B coast has been determined by Navy personnel to be logistically too difficult to address the several small erosive headlands that exist. Access to the site by land would require clearing woods and it's too shallow to get in by water even if one could get under and through the bridge.

For Reach 2C the low banks on the north shore would continue to erode at a slow rate if nothing is done. Alternatively, the lower banks could use a low sill (Figure 6-3C) and the higher banks with a revetment (Figure 6-3B). The riverward section of Reach 2C, Segment 31, has been protected with riprap both new (Figure 6-2J) and old (Figure 6-2I). At the beginning of Segment 32, old broken concrete is deteriorating and does not offer proper shore protection (Figure 6-2K) as evidenced by continued bank erosion. "Rearmoring" the bank with stone would provide for long term-shore protection (Figure 6-3D).

7 Reach 3: North of Chopawamsic Creek to the Marina

7.1 Shore Conditions

7.1.1 Reach Boundaries and Shore Change

Reach 3 extends from the mouth of Chopawamsic Creek upriver for about 2.5 miles to the Base marina. It is subdivided into four shore segments. Reach 3A extends to north end of runway 02 and includes Segments 32, 33 (Figure 6-1), 34, 35 and 36 (Figure 7-1) and is about 1.1 miles long. This long stretch of shoreline is adjacent to aircraft operations. Reach 3B extends upriver for about 2,300 feet and includes Segments 37 and 38 (Figure 7-1). Reach 3C is relatively short at 1,400 ft and includes Segments 39, 40, 41, 42, 43 and 44 (Figure 7-2). The next reach, 3D includes shore Segments 45, 46, 47, and 48 (Figure 7-2) and is about 3,400 feet in length and ends at the Base marina.

The 1937 aerial imagery shows the base in early stages of development. The outline of Runway 02 can be seen (Appendix A-1). Since then, historic shore change has been a function of shoreline hardening along Segments 32 and 33. Significant erosion has occurred in Segments 34, 35 and 36 (Appendix A-9). Conversely significant accretion occurred in Segments 37 and 38 (Appendix A-9) likely as a result of placement of material along the shore. Shore retreat dominates the rest of Reach 3C and 3D, which has mostly hardened, except for the shore advance near the marina, Segments 46 and 47, where filling has occurred (Appendix A-9).

The shoreline turns into an embayment between shore Segments 33 and 44 and is partially protected from the impinging wind/wave climate by Chopawamsic Island. This section of shore will be called “Chopawamsic Bay” for purposes of discussion in this report.

7.1.2 Upland and Shore Zone Characteristics

The Reach 3 shoreline has mostly been hardened or otherwise modified over time by filling. Reach 3A has been protected by various materials mostly broken concrete and rock. The bank height is fairly constant at about +10 ft MLW along most of Segment 32. A runway intersects the shore about half way along Segment 32 (Figure 7-3A). The broken concrete used along the upland bank is randomly-placed and occasionally intermixed with rock (Figure 7-3B) but functioning as shore protection nevertheless. However, it is not an engineered structure and there are many voids and inconsistencies.

At the boundary between Segment 32 and 33, the upland bank is characterized with mostly rock along the base, broken concrete along top with a grassy swath in between (Figure 7-3C). An LCAC landing ramp is the approximate boundary between Segments 33 and 34 and consists of a series of parallel concrete beans on grade (Figure 7-3D). The bank elevation drops to about +5 ft MLW to the end of Reach 3A, Segments 34, 35 and 36 where a broken concrete and unprotected erosional low banks (Figures 7-3E and 7-3F).

Reach 3B includes Segment 37, a low unprotected marshy shoreline that is eroding (Figure 7-3G) and Segment 38 which has been armored with a stone revetment (Figure 7-3H). Reach 3C is a low eroding marshy shoreline (Figure 7-3I) with a small stone wall (Figure 7-3J) on Segments 39 and 40. Segment 41 is very low with scattered pieces of broken concrete (Figure 7-3K). The bank rises to more than 10 feet on Segment 42 with a small beach and relatively wide backshore (Figure 7-3L). More broken concrete occurs along the base of the upland banks in Segments 43 and 44. The bank face is relatively stable with vegetation but steep with leaning trees, evidence of slow bank creep (Figure 7-3M).

Reach 3D begins with a concrete/stone wall on Segment 45 (Figure 7-3O) which continues for about 2,400 feet. The wall is in fair to good condition (Figure 7-3P) along most of its length. There is a Base landmark, the Wisdom Tree, which is perched on the bank (Figure 7-3N). Numerous weep holes help relieve hydrostatic pressure from upland runoff and groundwater. The wall ends and Segment 46 where a very low bank (Figure 7-3Q) and small embayment begins. Broken concrete along the shore continues across Segment 47 (Figure 7-3R) to the marina. The marina shore is protected by a bulkhead, and the docks are protected from wave action by a concrete wall (Figure 7-3S) on the south and large dock on the north, Segment 48 (Figure 7-3T). The marina marks the end of Reach 3.

7.1.3 Nearshore Characteristics

The -6 foot contour is relatively close to shore along Segment 32 averaging about 300 feet from MLW. The nearshore shelf gets wider in Chopawamsic Bay in the shelter of Chopawamsic Island where it averages more than 1,000 ft offshore. The -6 contour draws within 300 feet by the end of Reach 3D. SAV remains very close to shore along the entirety of Reach 3.

7.2 Design Considerations and Recommendations

The no-action alternative for Reach 3A would not result in short-term problems for the existing shore protection. While the existing materials have been functioning to protect the bank, long-term local failures in the broken concrete layers will lead to bank slumping. This can be addressed by adding more broken concrete or stone. The use of a Living Shoreline approach is not feasible because the created wetlands may pose a BASH issue by attracting waterfowl.

The long-term option for Segment 32 and 33 would be to rework the existing broken concrete and add armor stone as discussed in previous section (Figure 6-3D). This would provide predictable protection for the exposed airfield coast that would be designed to withstand a 100-year storm.

As the shoreline turns into “Chopawamsic Bay,” the bank becomes lower and there is much less broken concrete. Continued slow erosion of the upland can be expected. A coarse cobble beach could be created to protect the low eroding upland bank rather than hardening the shore with a stone revetment. This is proposed for Segments 34, 35 and 36 (Figure 7-4A).

Reach 3B includes shore Segments 37and 38, both of which are the result of infilling. Segment 37 is a low marshy shoreline with a very soft bottom. A “Do Nothing” approach is recommended. Segment 38 has been recently protected by a stone revetment (Figure 7-3U).

A “Do Nothing” approach would not result in any significant shoreline retreat along Reach 3C because of the intermittent presence of broken concrete. However, this shore provides the opportunity to build “Living Shoreline” marsh sills. This is recommended for Segments 40 and 41 which have a low bank (Figure 7-4B) and Segments 42, 43 and 44 which have high banks (Figure 7-4C).

Most of Reach 3D is protected by a concrete wall that appears to be in good condition. In this case a “Do Nothing” approach may be warranted. However, a more detailed analysis should be performed to ensure the long-term integrity of the wall. Problems such as scour along the base can be addressed by using stone along the front face. Large trees along the adjacent bank face might pose a bank stability problem if uprooted and dislodged during large storms. This might be a problem with the large oak on the riverbank by the Wisdom Tree. If it were to be blown down then the large root system would pull out a large portion of the bank, which could in turn threaten the bank by the Wisdom Tree.

A spur and some sand fill along the upriver end of Reach 3D will help maintain the small embayment on Segment 46. The remaining coast, Segment 47, could be left alone as broken concrete occurs along the shore or it could be armored for long-term integrity (Figure 7-4D).

8 Reach 4: North of the Marina to Quantico Creek

8.1 Shore Conditions

8.1.1 Reach Boundaries and Shore Change

Reach 4 extends from the marina upriver for about 1 mile around Shipping Point and into the mouth of Quantico Creek (Figure 8-1 and Figure 7-2). It includes shore Segments 49 through 56 (Appendix B-2). Segment 49 is the park in the Town of Quantico and is labeled Reach 4A. Reach 4B extends from the Town park north around Shipping Point and includes shore Segments 50 through 54. The Reach 4C coast continues alongshore to the Railroad Avenue bridge that crosses Quantico Creek.

Historic shore change shows shore advance from filling adjacent to the marina wall in Reach 4A and as well as in the tidal creek channel. Little net change along the beginning of Reach 4B, Segment 50, is due to shore hardening. Shore advance due to beach accretion occurs toward the north half of Segment 50. Moderate shore retreat occurs in Segments 51, 52 and 53 along the Potomac River to Shipping Point. Historic shore retreat occurs along the Quantico Creek shore along Segments 54 and 55 to the boat ramp except for an area of filling just east of the ramp. A cut and fill sequence occurs around the next point along Segment 56 where marsh accretion occurs.

8.1.2 Upland and Shore Zone Characteristics

A small tidal creek at the upriver boundary of the Town’s park can be seen in 1937 imagery (Appendix A-7). However subsequent images show that the creek was dammed resulting in accretion of the shore. The bank is low with a narrow beach with grassy backshore (Figure 8-2A). A low stone wall (Figure 8-2B) transitions to a small beach and then broken concrete which is protecting the fill at the old creek channel (Figure 8-2C). The north end of the wall has failed allowing some bank scarping (Figure 8-2D).

A concrete wall starts at Reach 4B, Segment 50, which is similar to the type and style seen in Reach 3D (Figure 8-2E). The upland bank along this shore is heavily vegetated and stable. No backshore/beach exists along the first half of Segment 50, but farther north, the sandy backshore increases in width to about 30 feet at the Segment 50/51 boundary where the concrete wall ends. Segment 51 is a low bank and is where there once was a series of wharfs as seen in 1937 imagery (Appendix A-7)and whose remains are seen in Figure 8-2F. These likely are the remnants of Quantico Shipyards which was established in the early 1900s. Some scattered broken concrete is concentrated alongshore and intermittent bank scarping occurs. The piles of concrete have created small headland features.

This trend continues around to Segment 52 (Figure 8-2G) as the bank rises to about +15 feet MLW. The concrete wall begins again at Segment 53 (Figure 8-2H). The upland bank is heavily vegetated and stable, and no beach exists. The wall continues to and around the next point of land and ends where an old bulkhead begins (Figure 8-2I).

Reach 4C begins with Segment 54 which is short and has an old wood bulkhead with horizontal "sheets". The upland bank is stable and there is no beach (Figure 8-2J). Segment 55 has a low undercut upland bank that has a gradual to steep bank face and vegetated. A few scattered rocks and pieces of broken concrete occur along the shoreline, but no structurally-sound shore protection structures occur (Figure 8-2K). A narrow beach face is exposed at low water to the small boat ramp (Figure 8-2L). The ramp marks the end of Segment 55 and the beginning of Segment 56, which is a very low, slightly undercut bank with an intermittent marsh fringe that continues around into the mouth of Quantico Creek.

8.1.3 Nearshore Characteristics

The - 6 ft contour, except for Segment 49, is within 100 feet of the shoreline around the Reach 4 coast. SAV beds remain close to shore.

8.2 Design Considerations and Recommendations

Reach 4A, the waterfront park for the Town of Quantico, currently has a stable beach area but the old stone wall is failing with some consequent bank scarping. For a park, the failing wall and broken concrete at the north end seem a bit unsightly. To enhance the beach and provide some a living shoreline component, the recommended shore strategy would be the addition of sand, a small sill along the wall, and a spur at the north and south end. The spur would transition into a sill and spur on the north headland.

The concrete wall along Reach 4B, Segment 50, is in good shape so a "Do Nothing" approach is recommended. The north boundary of Segment 50 with Segment 51 and including Segments 52 and 53, the existing broken concrete headlands offer a geomorphic opportunity to utilized headland breakwaters and beach fill to create stable pocket beaches for shore protection (Figure 8-3A).

Around Shipping Point where the banks are undercut, Segment 55, a sill system would provide shoreline and base of bank protection (Figure 8-3B). Further along beyond the boat ramp, Segment 56, the upper intertidal zone could benefit is the intertidal marsh was planted along its eroding marsh edge (Figure 8-3C). A very low sill could be added for long-term integrity.

9 Reach 5: Quantico Creek

Reach 5 includes the shoreline of Quantico Creek inland of the railroad bridge, approximately 1.8 miles (Appendix B-2). This reach contains Segments 57 through 74. Much of this shoreline has had very little shoreline change, either very low erosion or very low accretion (Appendix A-12). Several sections of shoreline, particularly near the points of land at Segments 60 and 72, have had medium and high erosion. A section of shoreline, just west of the railroad bridge, Segment 57, shows long-term accretion. It is likely this is the result of infill since 1937 (Appendix A-10), but the historical images are not conclusive. However, *Phragmites Australis* is growing in the marsh indicating fill material. The bank along this Reach varies between erosional and stable (Figure 9-1 and 9-2) mainly due to the undulating topography that has some sections of banks vertically-exposed along the shoreline while others have a gradual slope from the water to the top of bank.

This shoreline is low and marshy adjacent to the railroad bridge at Segment 57(Figure 9-3A). The bank rises farther up Quantico Creek at Segment 58 where the bank face is relatively stable, but the base of the bank has minor scarping (Figure 9-3B). One section of bank at the boundary between Segments 58 and 59, has been cleared and tiered from the top of the bank near the building and parking lot to the water line (Figure 9-3C). However, minor base of bank scarping continues. Segment 59 has a section of vertically-exposed, eroding bank (Figure 9-3D). Segment 60 is a point of low, eroding marsh (Figure 9-3E). This pattern of vertically-exposed, eroding banks and gradual slope banks continues up Quantico Creek (Figure 9-3F) except where a marsh drainage enters the Creek between Segments 68 and 69 (Figure 9-3G).

The nearshore is very shallow in Quantico Creek. There is no -6 ft contour within the Creek. In addition, SAV is very dense close to the shore (Figures 9-3H and 9-3I).

Even though some sections of the shoreline have vertically-exposed banks and are eroding, no structures have been recommended for this Reach. Most of this Reach is wooded with no infrastructure. As such, no access to the shoreline is readily available. In addition, the density of the SAV in the Creek will make it difficult to access by water and construct a structure. Just north of the railroad bridge at Segment 58, infrastructure is located close to the top of bank. A sill (Figure 7-4B or 7-4C) could be installed along the eroding bank.

10 Summary and Cost of Structures

The Quantico Shoreline Protection Plan was developed at the request of MCB, Quantico to provide a document for making decisions along the Base shoreline regarding the nature of shore change and how it impacts upland infrastructure. The location and functionality of existing structures as well as physical parameters of the shore zone were used to make shore management recommendations. Overall, 34 structures were recommended along 16,844 feet of shoreline (Table 10-1). Eight individual breakwater units were recommended as were revetments, sills, and spurs. Two sections of existing revetment was recommended for rehabilitation. A cobble beach was recommended along 2,100 feet of shoreline. In addition, 1,200 ft of beaches will be constructed in conjunction with the breakwaters ad spurs.

An estimated cost of the installation cost of the rock, sand and plants was calculated and summarized by Reach and by priority (Table 10-1). Costs are conceptual estimates based on recommended structure cross-sections. It does not include any additional work necessary such as obtaining site access, project cleanup, permit preparation, *etc*. A recent survey and updated design is needed to determine actual costs. Amount of cut/fill from the bank was difficult to determine and is an estimate only. Since the recommendations can be built in phases, a structure priority also is noted. Low priority recommendations have a stable bank, no threatened infrastructure, or the existing structure is adequate. Medium priority recommendations have an erosional to transitional bank or an existing failed structure. High priority shorelines have erosional to transitional bank with threatened upland infrastructure. Tables 10-2 through 10-5 show the materials and estimated costs of individual recommended structures for each reach. It should be noted that the individual shoreline sites were given a priority (as shown in Appendix C), and when the recommended structure crossed several sites, the priority listed in the following tables are based on a visual "average". For instance, the recommended Cobble Beach 3A-1 includes Sites 34, 35, and 36. Sites 34 and 35 have medium priorities because the airstrip is not in close proximity to the shoreline. However, Site 36 is given a high priority because a section of the airstrip is close to the shoreline. When creating a priority ranking for the recommended structures, the individual site priorities were taken into account as was other data. In the case of Cobble Beach 3A-1, because the section of shore in question is behind Chopawamsic Island, it was determined that in the context of the overall shoreline management plan, this structure would have a medium priority rather than high. Other structures may have similar situations.

Table 10-1. Summary of recommended structures for Quantico's shoreline with estimated costs by Reach and by priority. Costs are conceptual estimates based on recommended structure cross-sections.

Type	Total Num.	Total Length (ft)	Total Cost by Reach		Total Cost by Priority	
Breakwater	8	845	Reach 1, Revet Option 1	$2,790,020	High Priority	$1,699,500
Revetment	7	4,224	Reach 1, Sill Option 2	$2,710,080	Medium Priority	
Revetment Rehab	2	3,960	Reach 2	$776,420	With Option 1	$4,842,240
Revetment or Sill	1	370	Reach 3	$2,550,940	With Option 2	$4,762,300
Cobble Beach	1	2,112	Reach 4	$519,320	Low Priority	$94,960
Sill	13	5,227	**Total with Option 1**	**$6,636,700**		
Spur	2	106	**Total with Option 2**	**$6,556,760**		
Total	**34**	**16,844**				

Table 10-2. Material and cost estimate summary for Reach 1. Costs are conceptual estimates based on recommended structure cross-sections. A recent survey and updated design is needed to determine actual costs.

Structure Type	Reach	Number	Priority	Length (ft)	Rocks (tons/ft)	Sand (cy/ft)	Plants (plants/ft)	Bank Grade* Cut/Fill (cy/ft)	Rock ($)	Sand ($)	Plants ($)	Bank Grade ($)	Structure Total ($)
Revetment	1A	1	H	1850	6			5	$888,000			$92,500	$980,500
Revetment (Option1)	*1A*	*2*	*M*	*550*	*6*			*5*	*$264,000*			*$27,500*	*$291,500*
Sill (Option 2)	*1A*	*1*	*M*	*200*	*4.5*	*2.8*	*22*		*$72,000*	*$22,400*	*$8,800*		*$103,200*
Sill (Option 2)	*1A*	*2*	*M*	*80*	*4.5*	*2.8*	*22*		*$28,800*	*$8,960*	*$3,520*		*$41,280*
Sill (Option 2)	*1A*	*3*	*M*	*130*	*4.5*	*2.8*	*22*		*$46,800*	*$14,560*	*$5,720*		*$67,080*
Sill	1A	4	M	530	4.5	2.8	22		$190,800	$59,360	$23,320		$273,480
Sill	1A	5	M	300	4.5	2.8	22		$108,000	$33,600	$13,200		$154,800
Sill	1A	6	M	470	4.5	2.8	22		$169,200	$52,640	$20,680		$242,520
Beach	1B	1	L	100	4.5	3	10		$36,000	$12,000	$2,000		$50,000
Breakwater	1B	1	M	90	5	3	10		$36,000	$10,800	$1,800		$48,600
Sill	1B	1	H	750	4	2	18		$240,000	$60,000	$27,000		$327,000
Sill	1B	2	M	400	4	2	18		$128,000	$32,000	$14,400		$174,400
Sill	1B	3	M	270	4	2	18		$86,400	$21,600	$9,720		$117,720
Revetment	1B	1	H	350	4			5	$112,000			$17,500	$129,500
												Total with Revetment 1A-2	**$2,790,020**
												Total with Sills 1A-1, 2, and 3	**$2,710,080**

Table 10-3. Material and cost estimate summary for Reach 2. Costs are conceptual estimates based on recommended structure cross-sections. A recent survey and updated design is needed to determine actual costs.

Structure Type	Reach	Number	Priority	Length (ft)	Rocks (tons/ft)	Sand (cy/ft)	Plants (plants/ft)	Bank Grade (cy/ft)	Rock ($)	Sand ($)	Plants ($)	Bank Grade ($)	Structure Total
Revetment	2A	1	H	400	4			3	$128,000			$12,000	$140,000
Revetment	2A	2	H	350	4			3	$112,000			$10,500	$122,500
Revetment	2A	3	M	500	2.5				$100,000				$100,000
Sill	2A	1	L	120	1.5	1	8		$14,400	$4,800	$1,920		$21,120
Sill	2C	1	M	200	1.5	1	8		$24,000	$8,000	$3,200		$35,200
Revetment	2C	1	M	380	2.5				$76,000				$76,000
Revetment	2C	2	M	440	8				$281,600				$281,600
												Total	**$776,420**

Table 10-4. Material and cost estimate summary for Reach 3. Costs are conceptual estimates based on recommended structure cross-sections. A recent survey and updated design is needed to determine actual costs.

Structure Type	Reach	Number	Priority	Length (ft)	Rocks (tons/ft)	Sand (cy/ft)	Plants (plants/ft)	Bank Grade (cy/ft)	Rock ($)	Sand ($)	Plants ($)	Bank Grade ($)	Structure Total
Revetment	3A	1	M	2800	8				$1,792,000				$1,792,000
Cobble Beach	3A	1	M	2100	2.5				$420,000				$420,000
Sill	3C	1	M	850	2.5	1.6	11		$170,000	$54,400	$18,700		$243,100
Spur	3D	1	L	60	2.5	1.6			$12,000	$3,840			$15,840
Beach	3D	1	L	100		2				$8,000			$8,000
Revetment	3D	1	M	300	3				$72,000				$72,000
												Total	**$2,550,940**

Table 10-5. Material and cost estimate summary for Reach 4. Costs are conceptual estimates based on recommended structure cross-sections. A recent survey and updated design is needed to determine actual costs.

Structure Type	Reach	Number	Priority	Length (ft)	Rocks (tons/ft)	Sand (cy/ft)	Plants (plants/ft)	Bank Grade (cy/ft)	Rock ($)	Sand ($)	Plants ($)	Bank Grade ($)	Structure Total
Spur	4A	1	M	50	2.5	1.6	8		$10,000	$3,200	$800		$14,000
Breakwater	4A	1	M	130	2.5	1.6	8		$26,000	$8,320	$2,080		$36,400
Breakwater	4A	2	M	110	2.5	1.6	8		$22,000	$7,040	$1,760		$30,800
Breakwater	4A	3	M	110	2.5	1.6	8		$22,000	$7,040	$1,760		$30,800
Breakwater	4B	1	M	110	3.5	3	18		$30,800	$13,200	$3,960		$47,960
Beach	4B	1	M	110		2	12			$8,800	$2,640		$11,440
Breakwater	4B	2	M	70	3.5	3	18		$19,600	$8,400	$2,520		$30,520
Beach	4B	2	M	60		2	12			$4,800	$1,440		$6,240
Breakwater	4B	3	M	85	3.5	3	18		$23,800	$10,200	$3,060		$37,060
Beach	4B	3	M	130		2	12			$10,400	$3,120		$13,520
Breakwater	4B	4	M	120	3.5	2	12		$33,600	$9,600	$2,880		$46,080
Sill	4C	1	M	750	2.5	1.5	13		$150,000	$45,000	$19,500		$214,500
												Total	**$519,320**

Table 10-6. Summary of cost estimate by reach. Costs are conceptual estimates based on recommended structure cross-sections. A recent survey and updated design is needed to determine actual costs.

Reach 1, Revetment Option1	$2,790,020
Reach 1, Sill Option2	$2,710,080
Reach 2	$776,420
Reach 3	$2,550,940
Reach 4	$519,320
Total with Reach 1 Revet	**$6,636,700**
Total with Reach 1 Sill	**$6,556,760**

11 References

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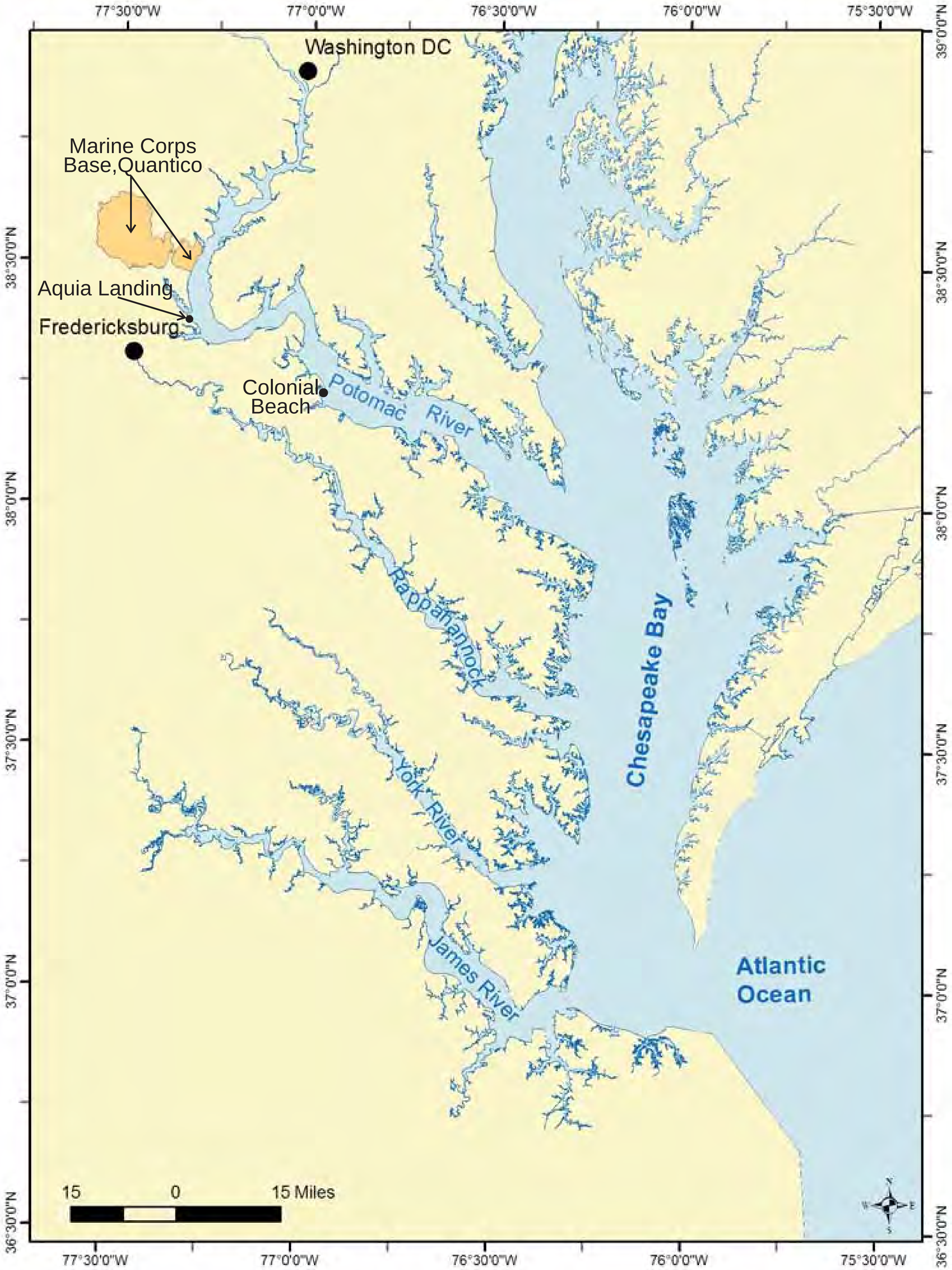


Figure 1-1. Location of Marine Corps Base, Quantico within the Chesapeake Bay estuarine system.

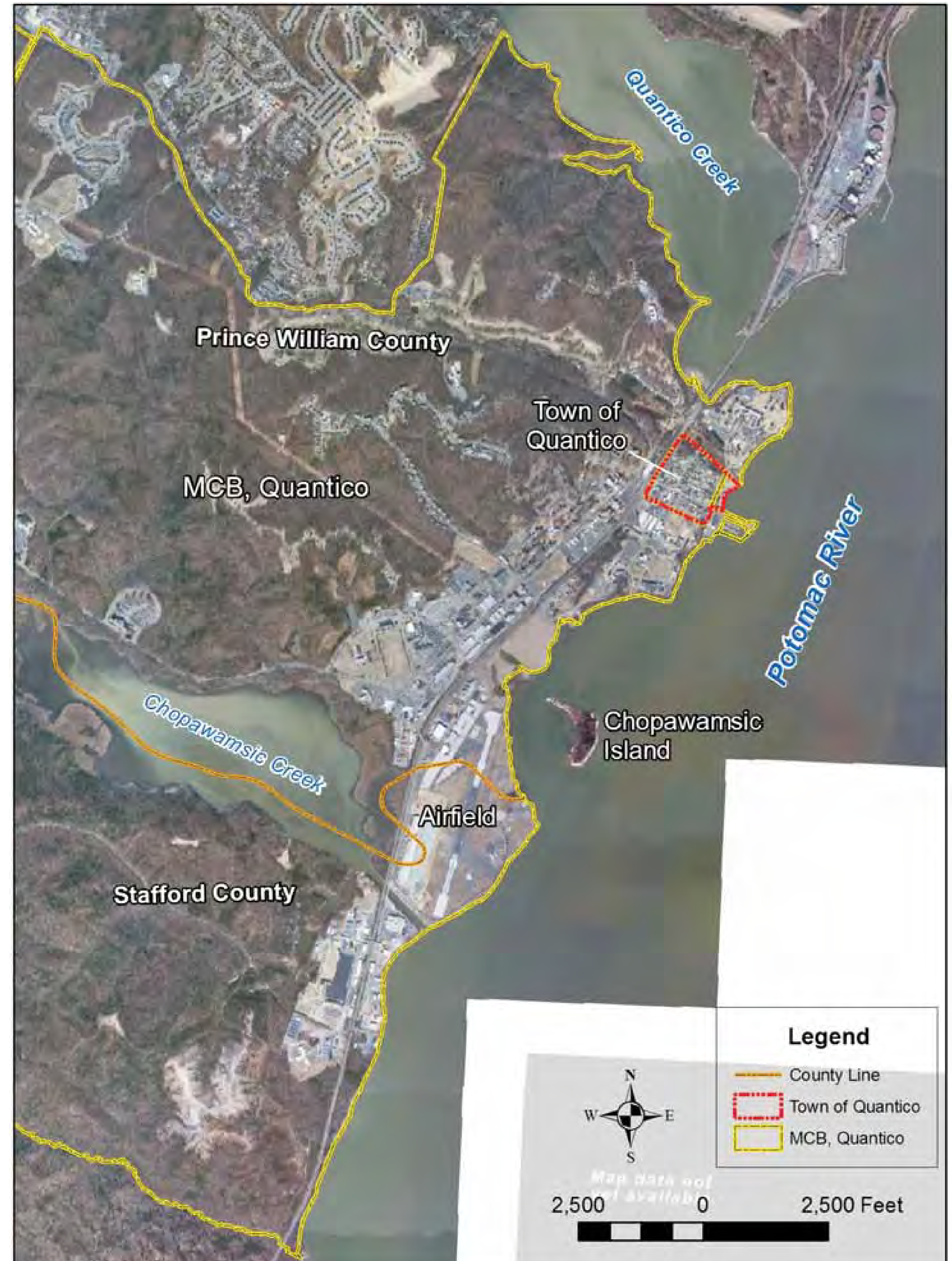


Figure 1-2. Boundaries of MCB, Quantico and the Town of Quantico.

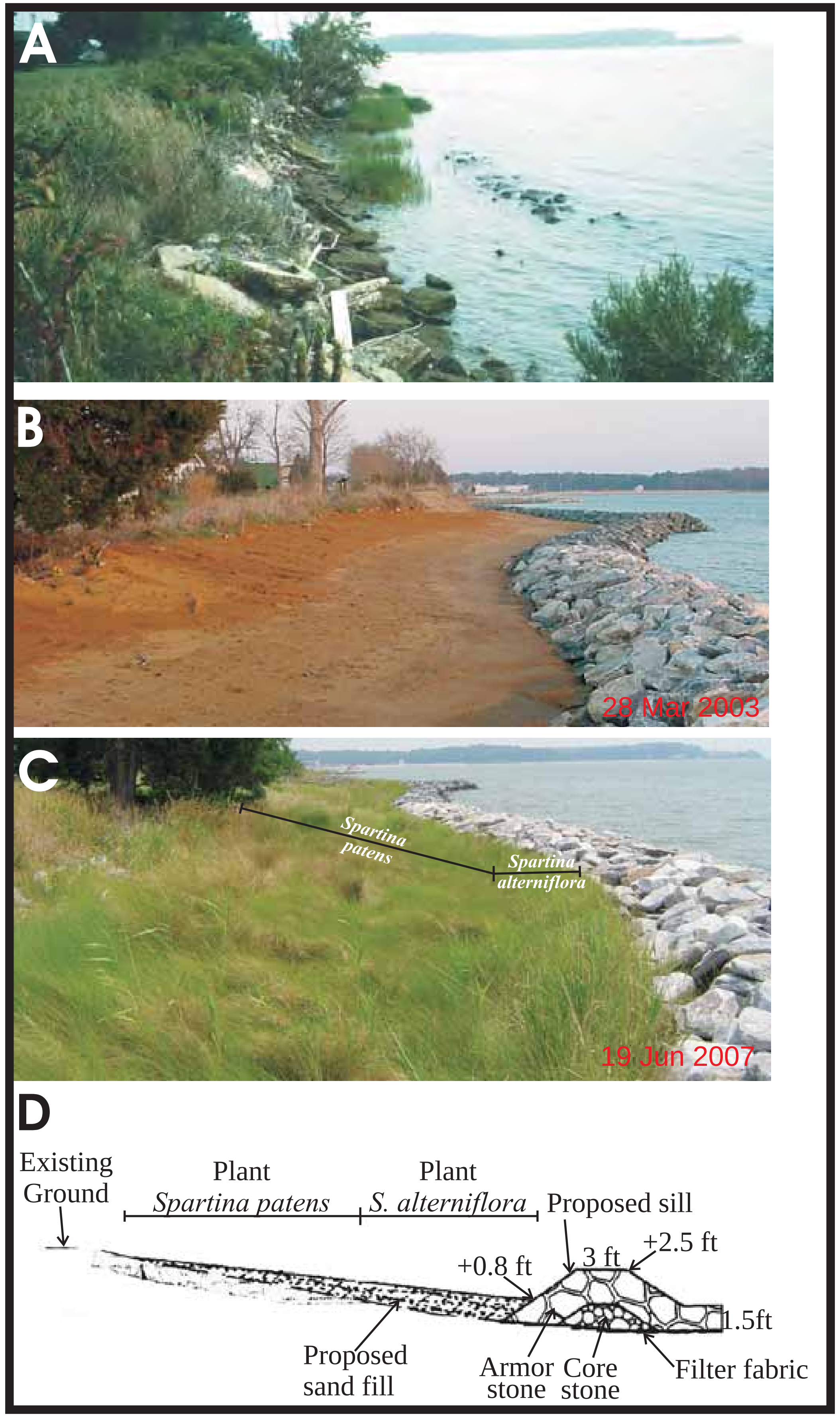


Figure 2-1. Sand fill with stone sills and marsh plantings at Webster Field Annex, St. Mary's County, Maryland A) before installation, B) after installation but before planting, C) after four years, and D) the cross-section used for construction.

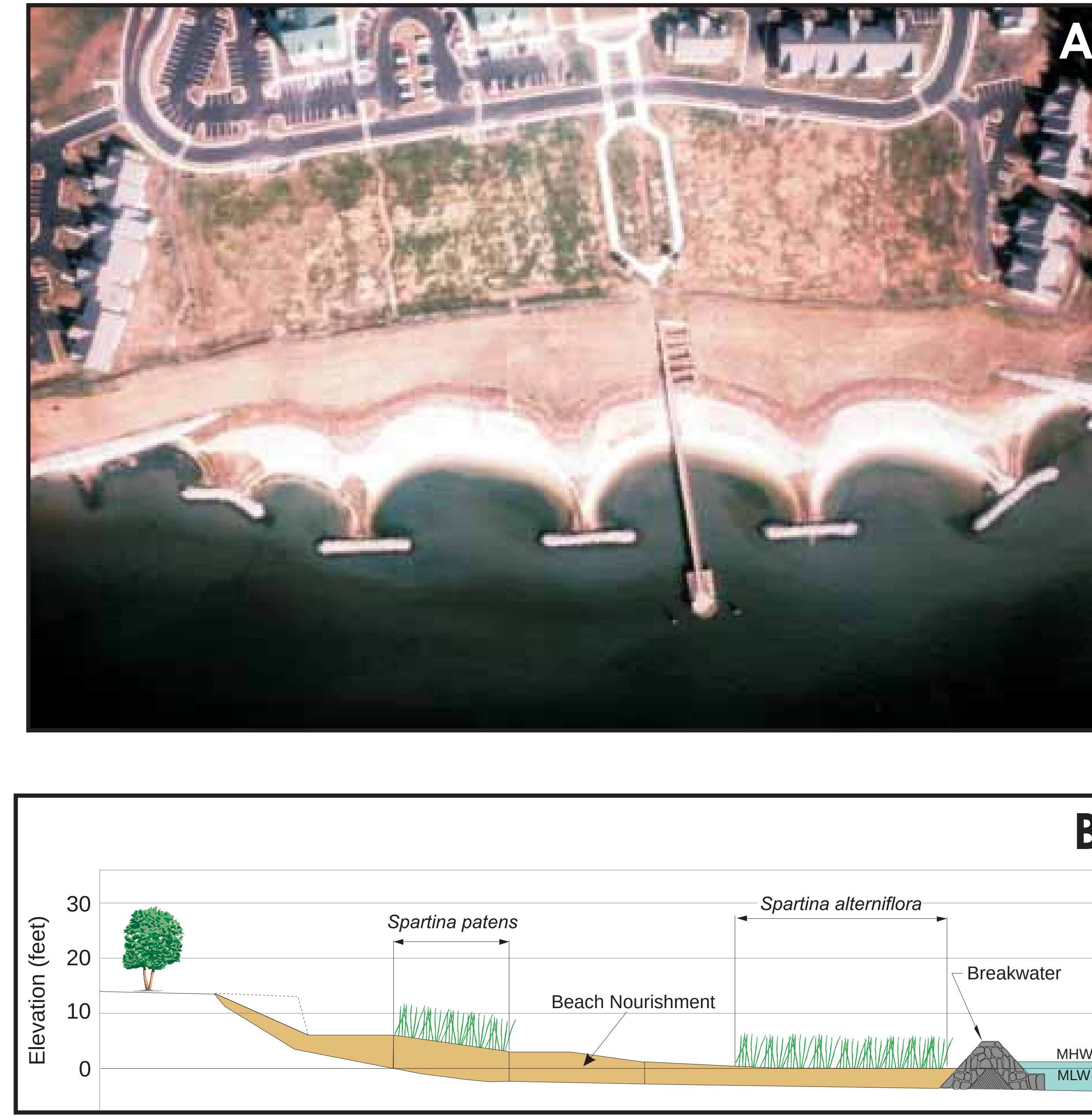


Figure 2-2. Breakwater system on Patuxent River in Calvert County, Maryland and a typical breakwater cross-section.

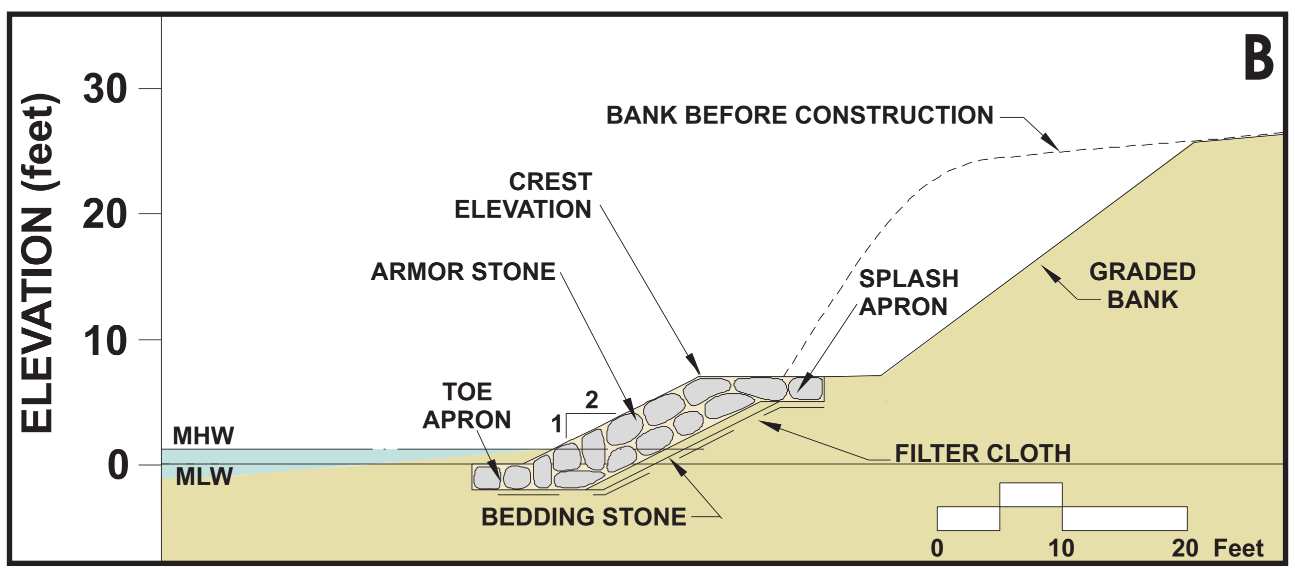


Figure 2-3. A) Stone revetment shortly after construction on the Potomac River, Virginia, and B) cross-section of the elements necessary for proper stone revetment design (Hardaway and Byrne, 1999).

Figure 2-4. Shore-attached and structure-attached spurs used as part of a shore protection system at Point Lookout, Maryland. Photo date 12 Jan 2006.

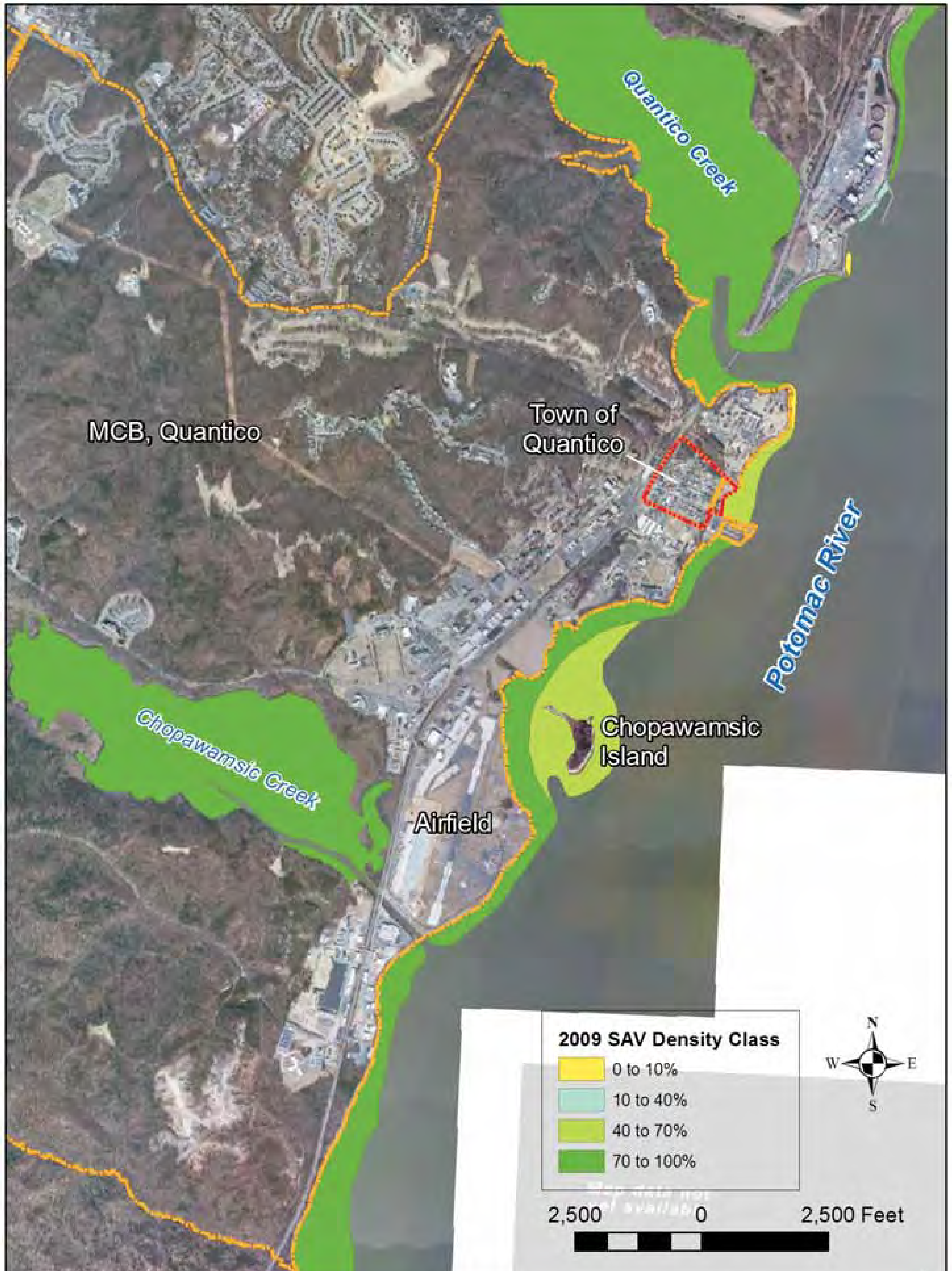


Figure 2-5. Location and density of submerged aquatic vegetation at MCB, Quantico as mapped by the Virginia Institute of Marine Science in 2009 (http://web.vims.edu/bio/sav/maps.html).

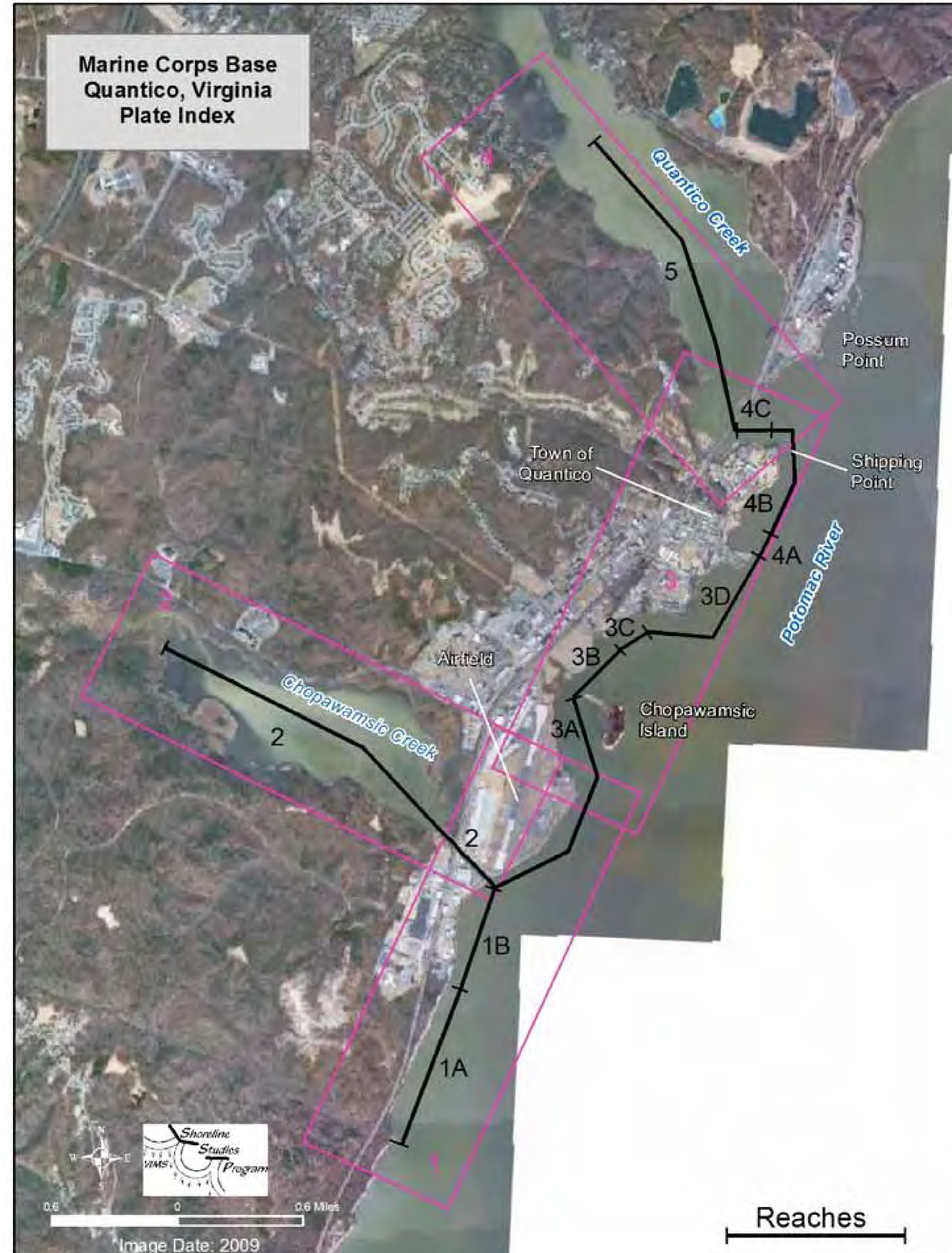


Figure 3-1. Index of plates used to display historical and recent aerial imagery and the rates of shoreline change.

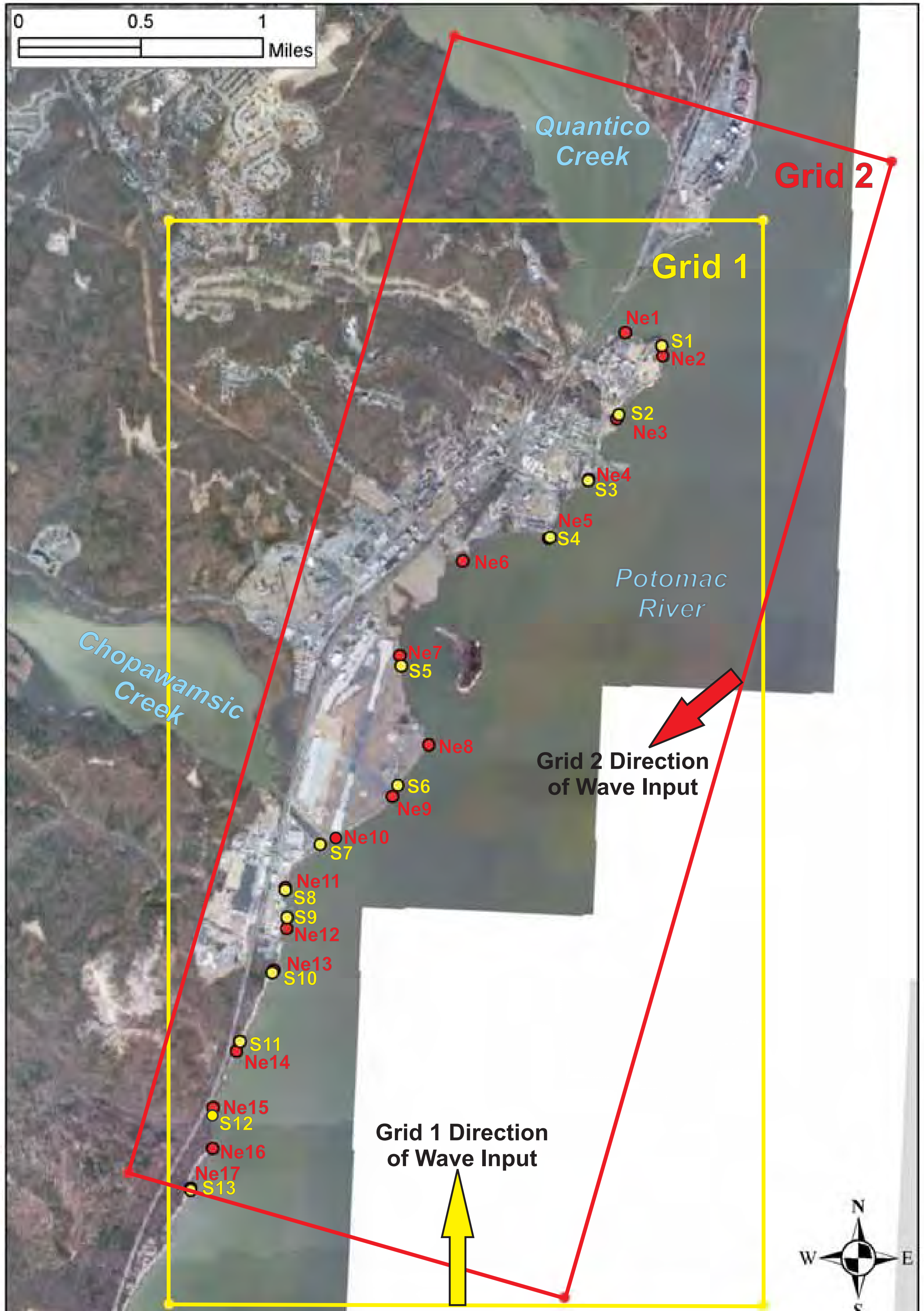


Figure 3-2. Location of STWAVE grids and data output stations.

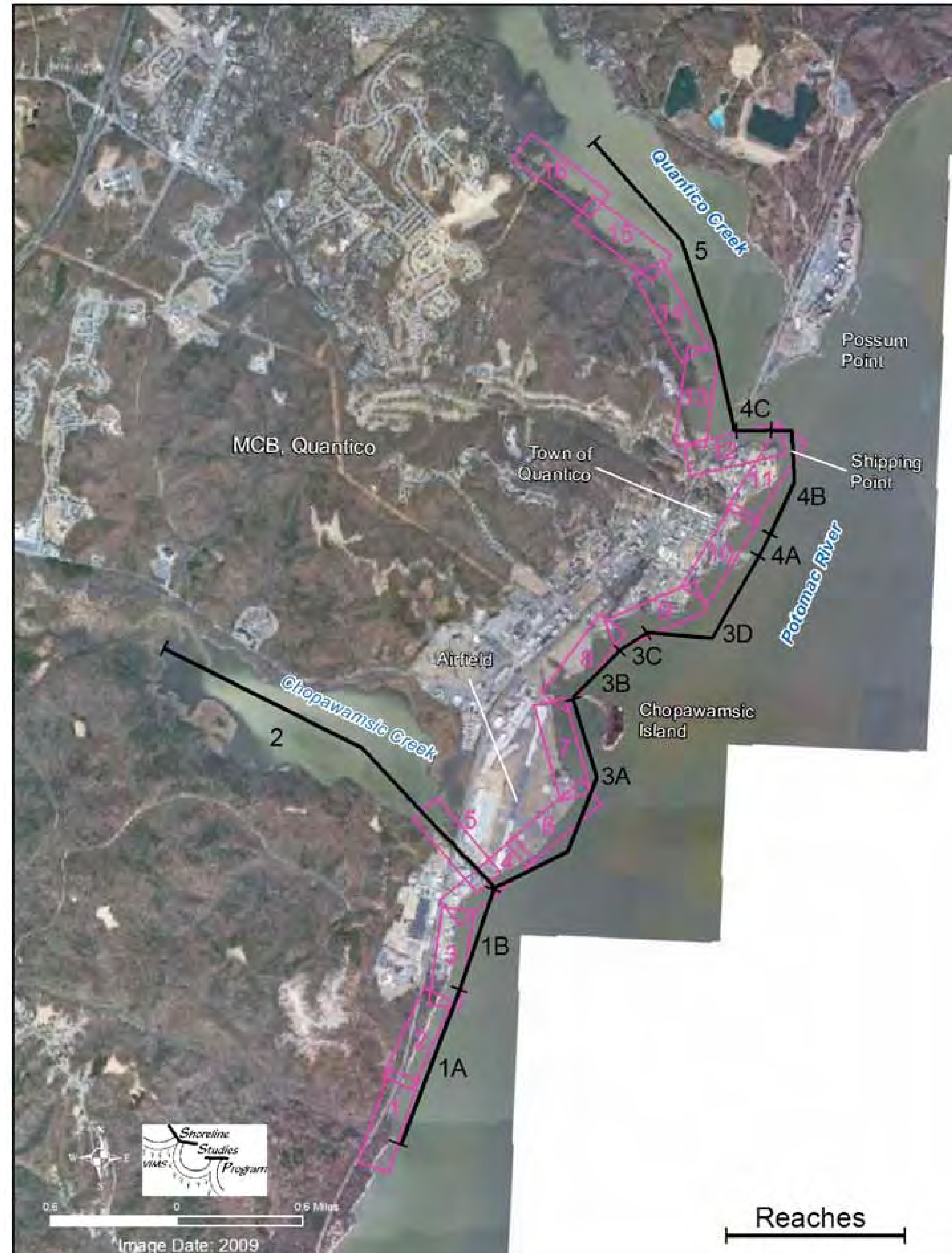


Figure 3-3. Index of plates used to display shore management recommendations and the shore reaches used in the discussion of the reaches.

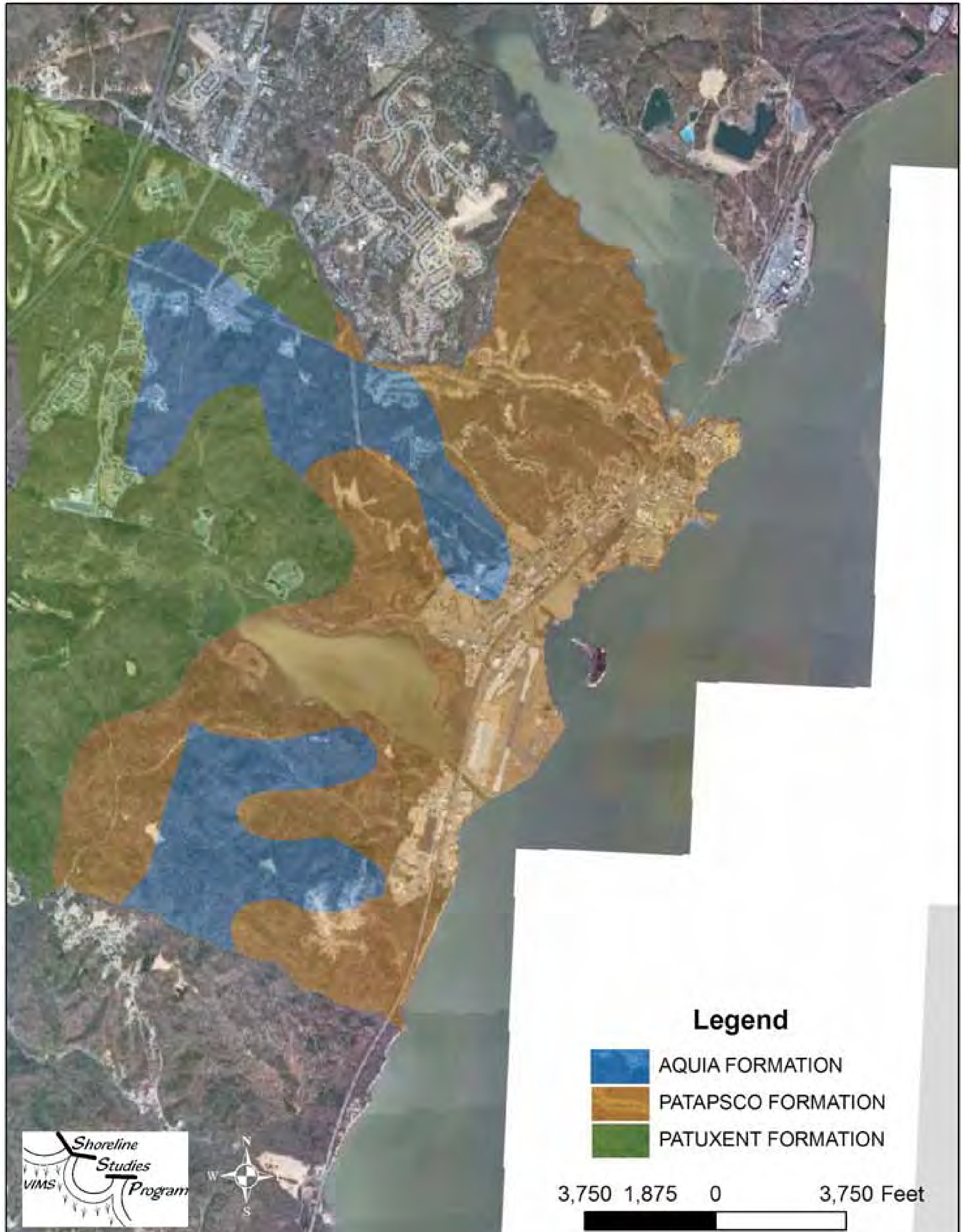


Figure 4-1. Geologic strata map of Marine Corps Base, Quantico. GIS data provided by Quantico.

Figure 5-1. Bank conditions recommended shore management structures for Plates 1 and 2. Segment number (shown in white) is for location reference only. The recommendation name matches, in color, its representative alongshore line. Photo base VGIN 2009.

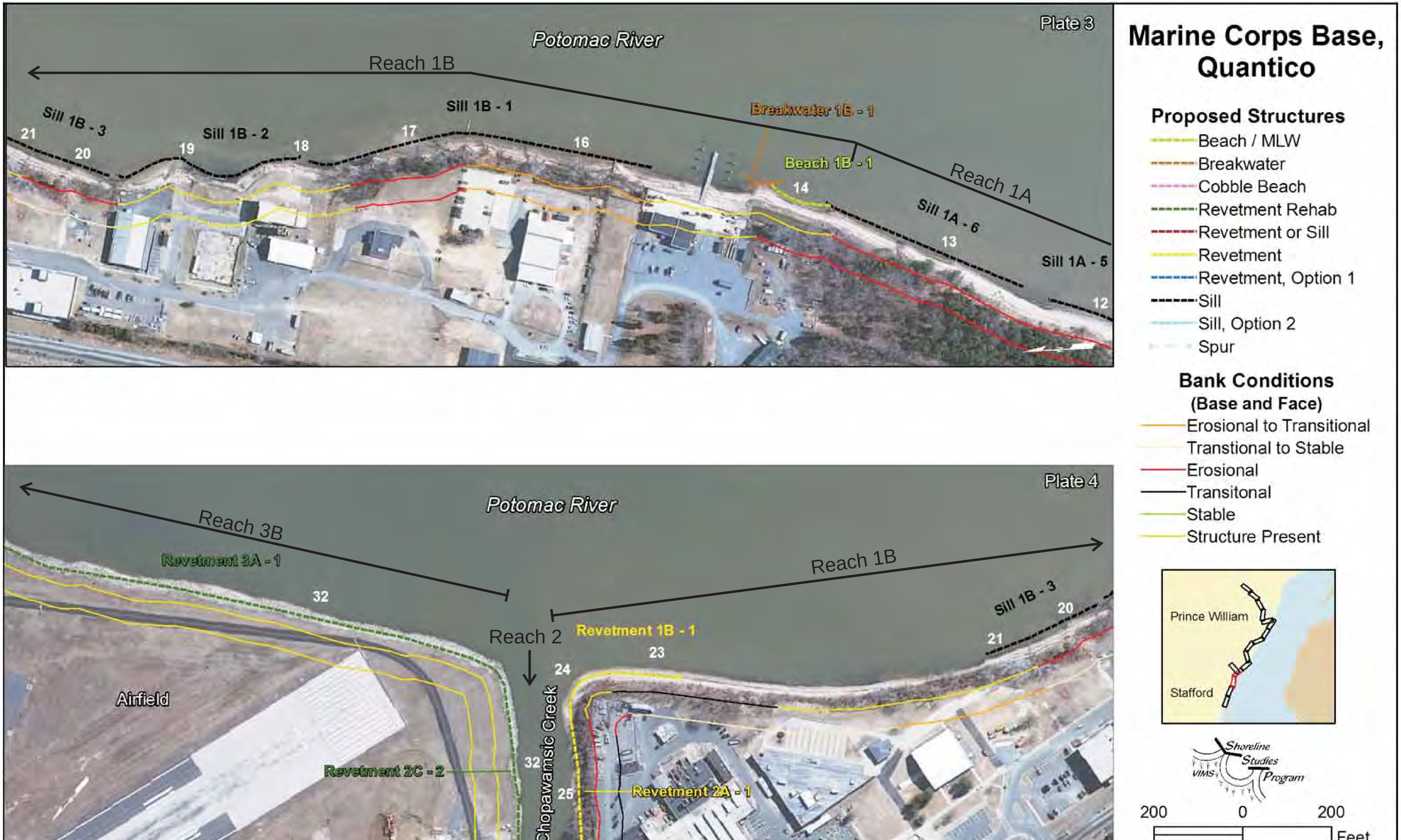


Figure 5-2. Bank conditions and recommended shore management structures for Plates 3 and 4. Segment number (shown in white) is for location reference only. The recommendation name matches, in color, its representative alongshore line. Photo base VGIN 2009.

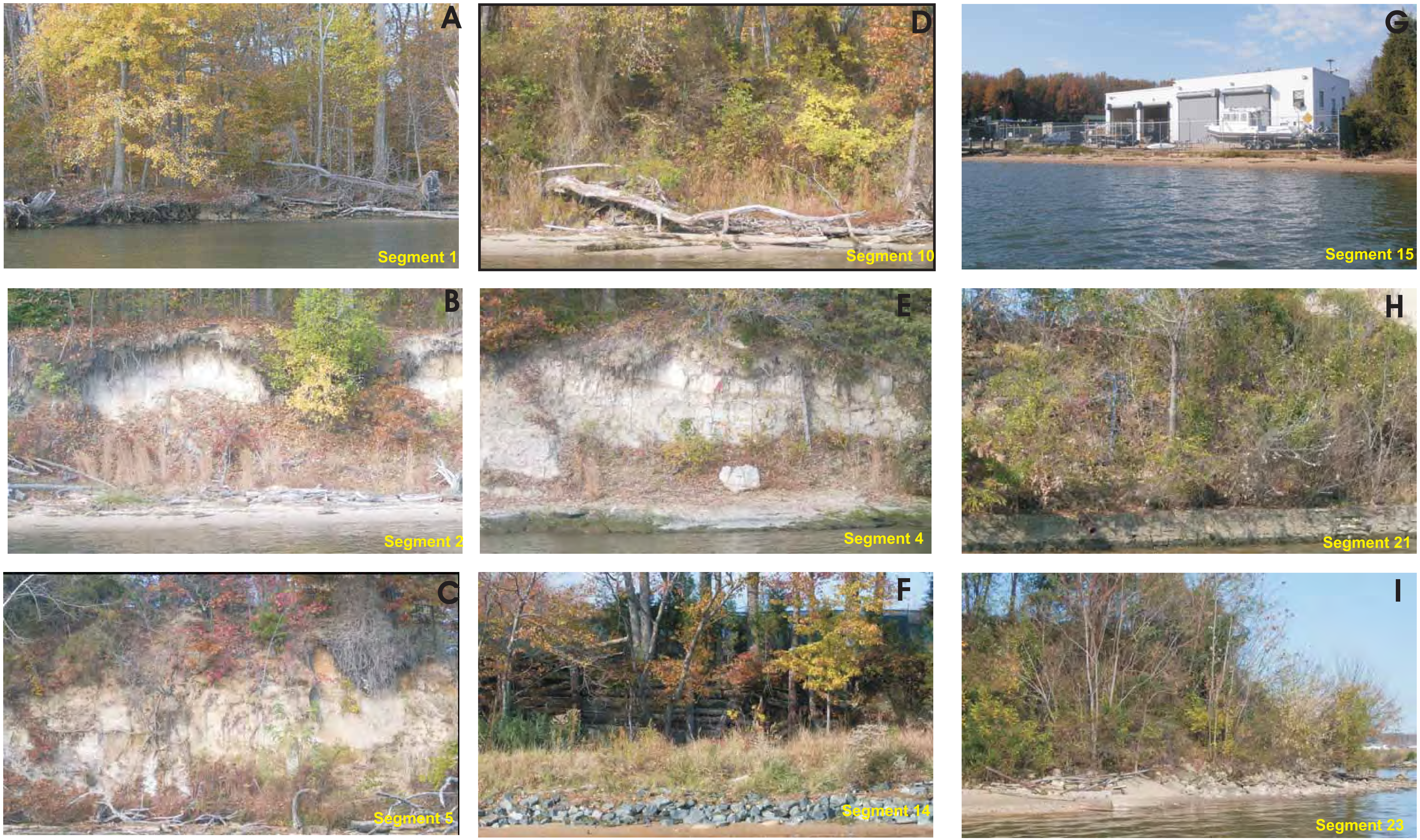


Figure 5-3. Photos taken along Quantico's shoreline in Reach 1. Photos taken on 5 Nov 2009 by VIMS personnel.

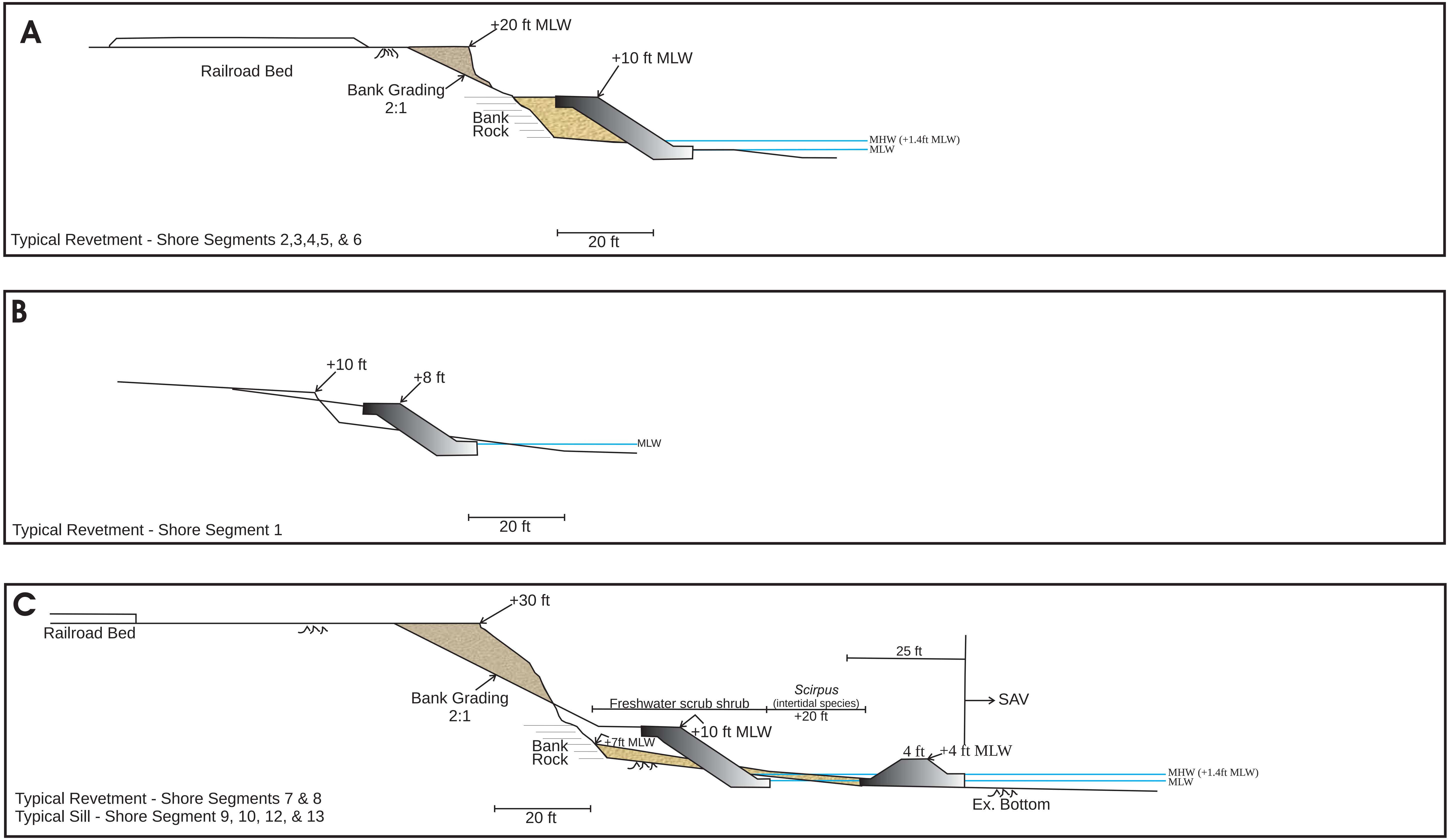


Figure 5-4. Shore management strategy cross-sections for Reach 1A.

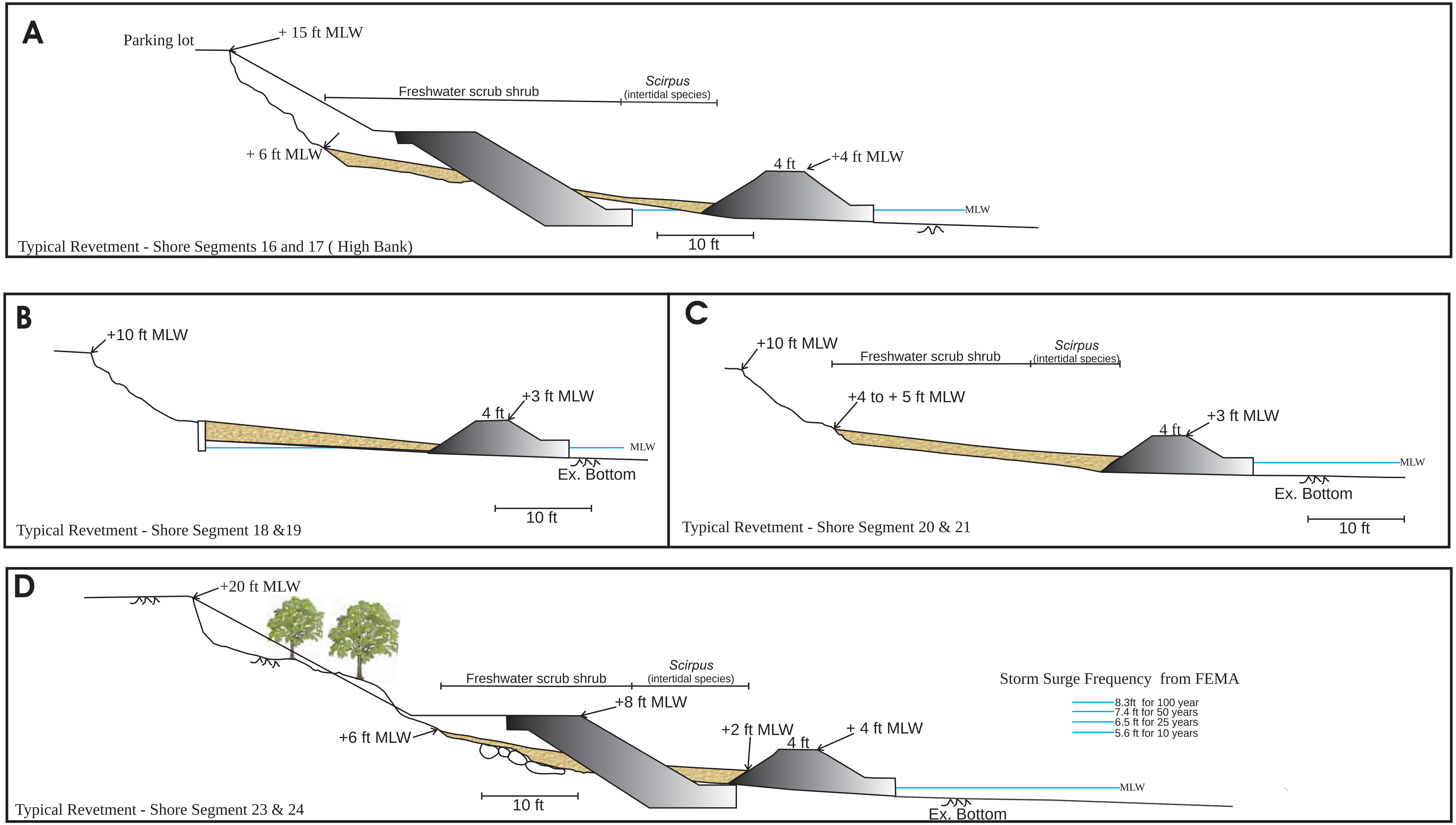


Figure 5-5. Shore management strategy cross-sections for Reach 1B.

Figure 6-1. Bank conditions and recommended shore management structures for Plates 5 and 6. Segment number (shown in white) is for location reference only. The recommendation name matches, in color, its representative alongshore line. Photo base VGIN 2009.

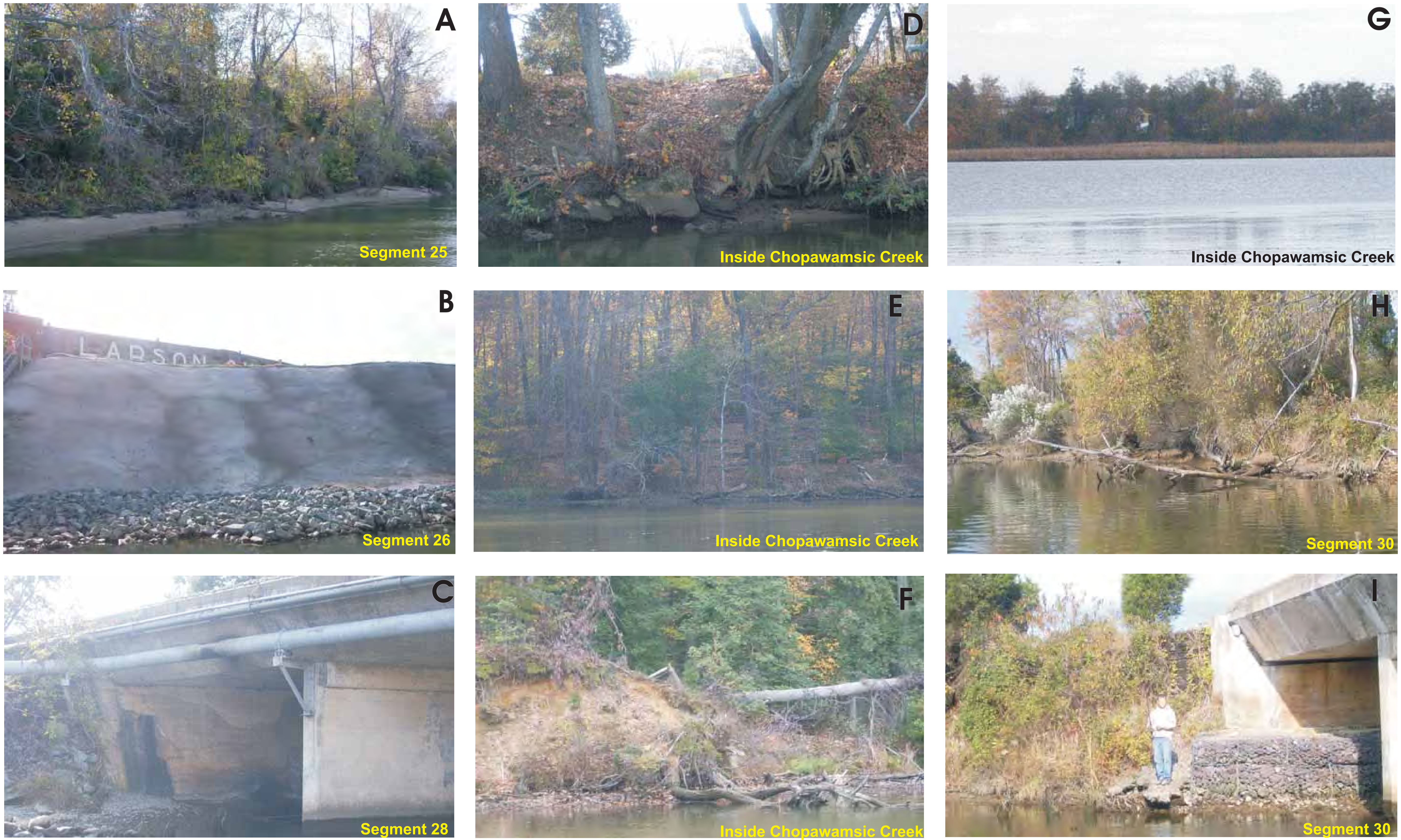


Figure 6-2. Photos taken along Quantico's shoreline in Reach 2. Photos taken on 5 Nov 2009 by VIMS personnel.

Figure 6-2 (cont.). Photos taken along Quantico's shoreline in Reach 2. Photos taken on 5 Nov 2009 by VIMS personnel.

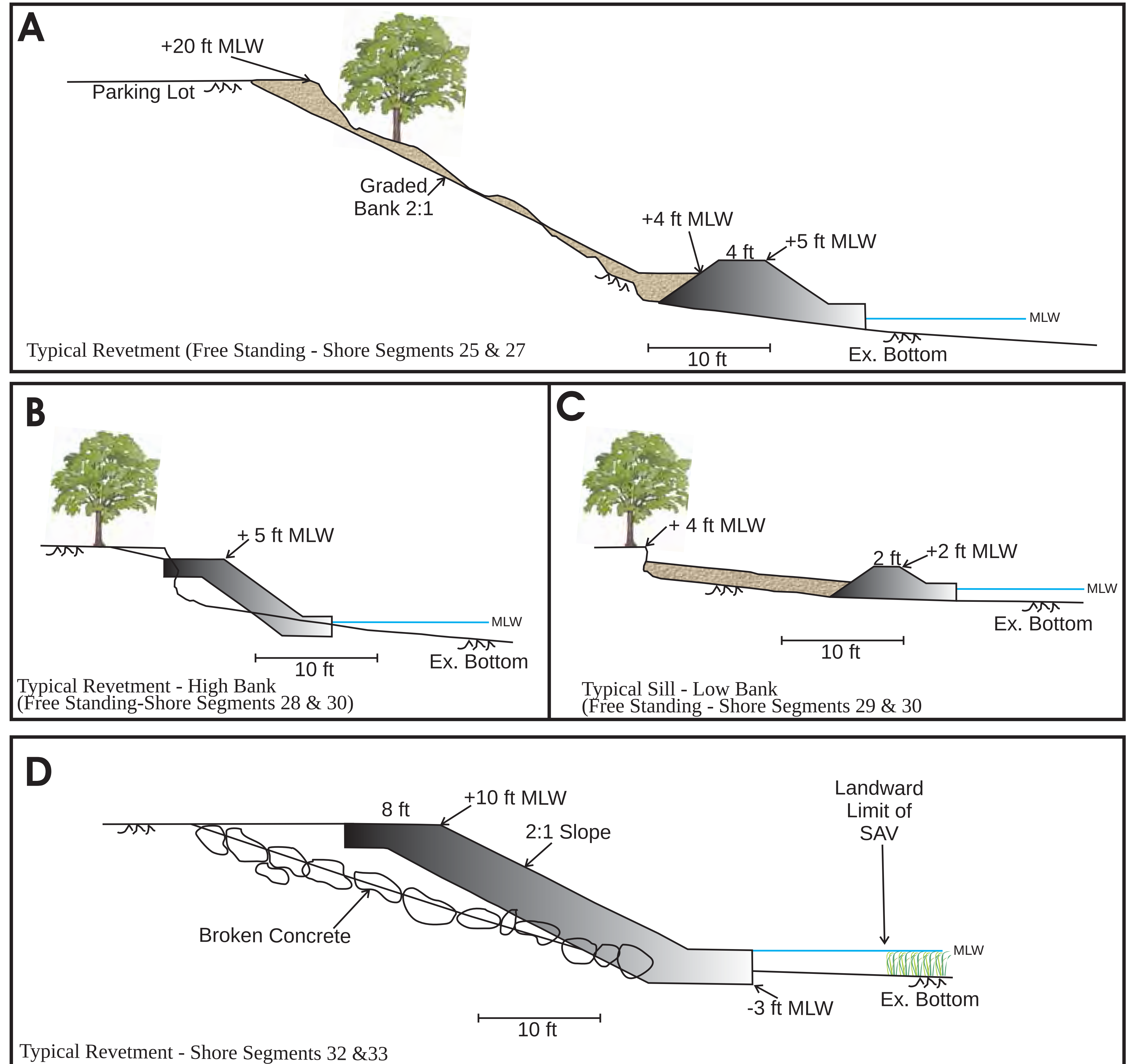


Figure 6-3. Cross-sections of typical structures for Reach 2.

Figure 7-1. Bank conditions and recommended shore management structures for Plates 7 and 8. Segment number (shown in white) is for location reference only. The recommendation name matches, in color, its representative alongshore line. Photo base VGIN 2009.

Figure 7-2. Bank conditions and recommended shore management structures for Plates 9 and 10. Segment number (shown in white) is for location reference only. The recommendation name matches, in color, its representative alongshore line. Photo base VGIN 2009.

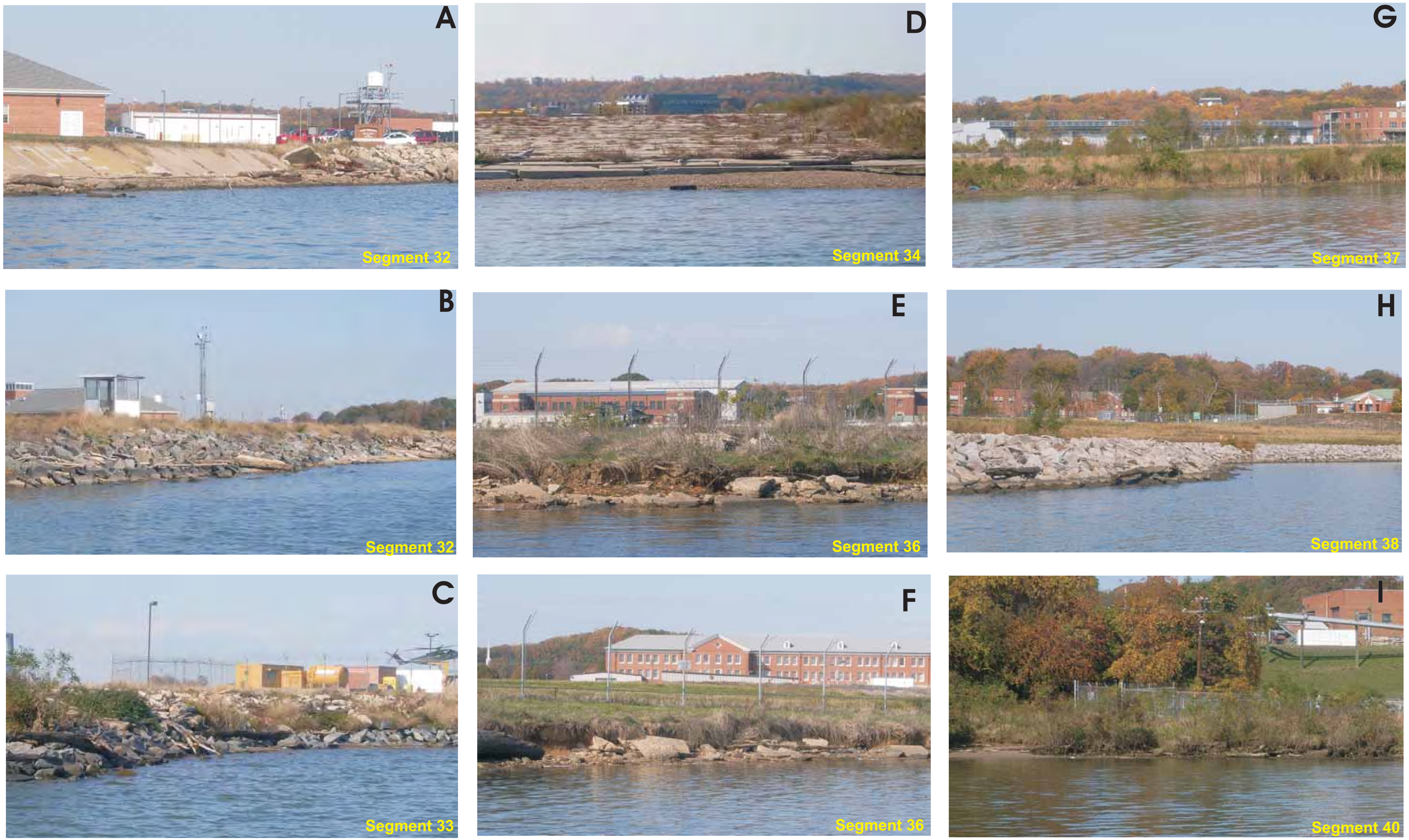


Figure 7-3. Photos taken along Quantico's shoreline in Reach 3. Photos taken on 5 Nov 2009 by VIMS personnel.

Figure 7-3 (cont). Photos taken along Quantico's shoreline in Reach 3. Photos taken on 5 Nov 2009 by VIMS personnel.

Figure 7-3 (cont). Photos taken along Quantico's shoreline in Reach 3. Photos taken on 5 Nov 2009 by VIMS personnel.

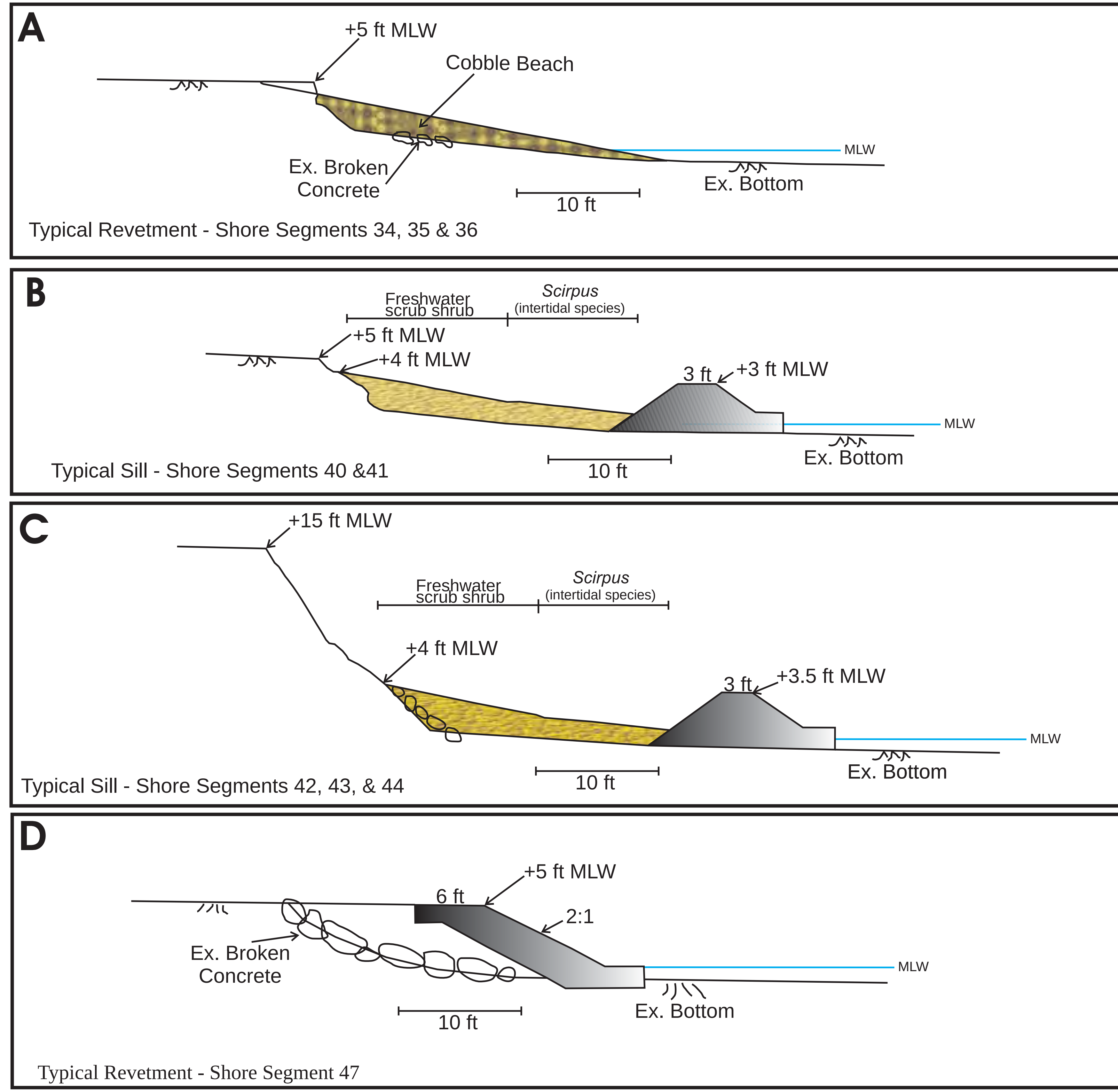


Figure 7-4. Typical cross-sections for recommended structures in Reach 3.

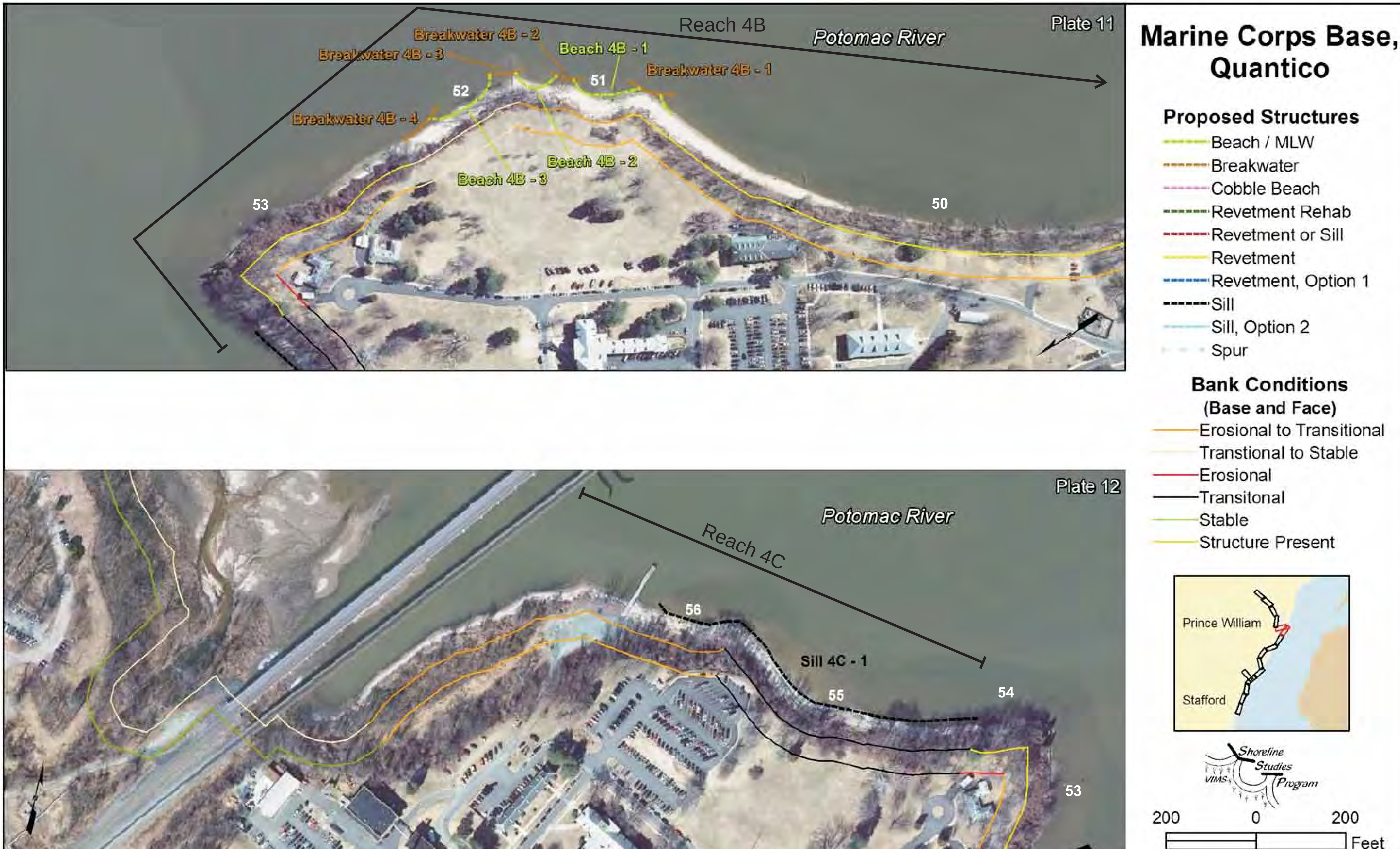


Figure 8-1. Bank conditions and recommended shore management structures for Plates 11 and 12. Segment number (shown in white) is for location reference only. The recommendation name matches, in color, its representative alongshore line. Photo base VGIN 2009.

Figure 8-2. Photos taken along Quantico's shoreline in Reach 1. Photos taken on 5 Nov 2009 by VIMS personnel.

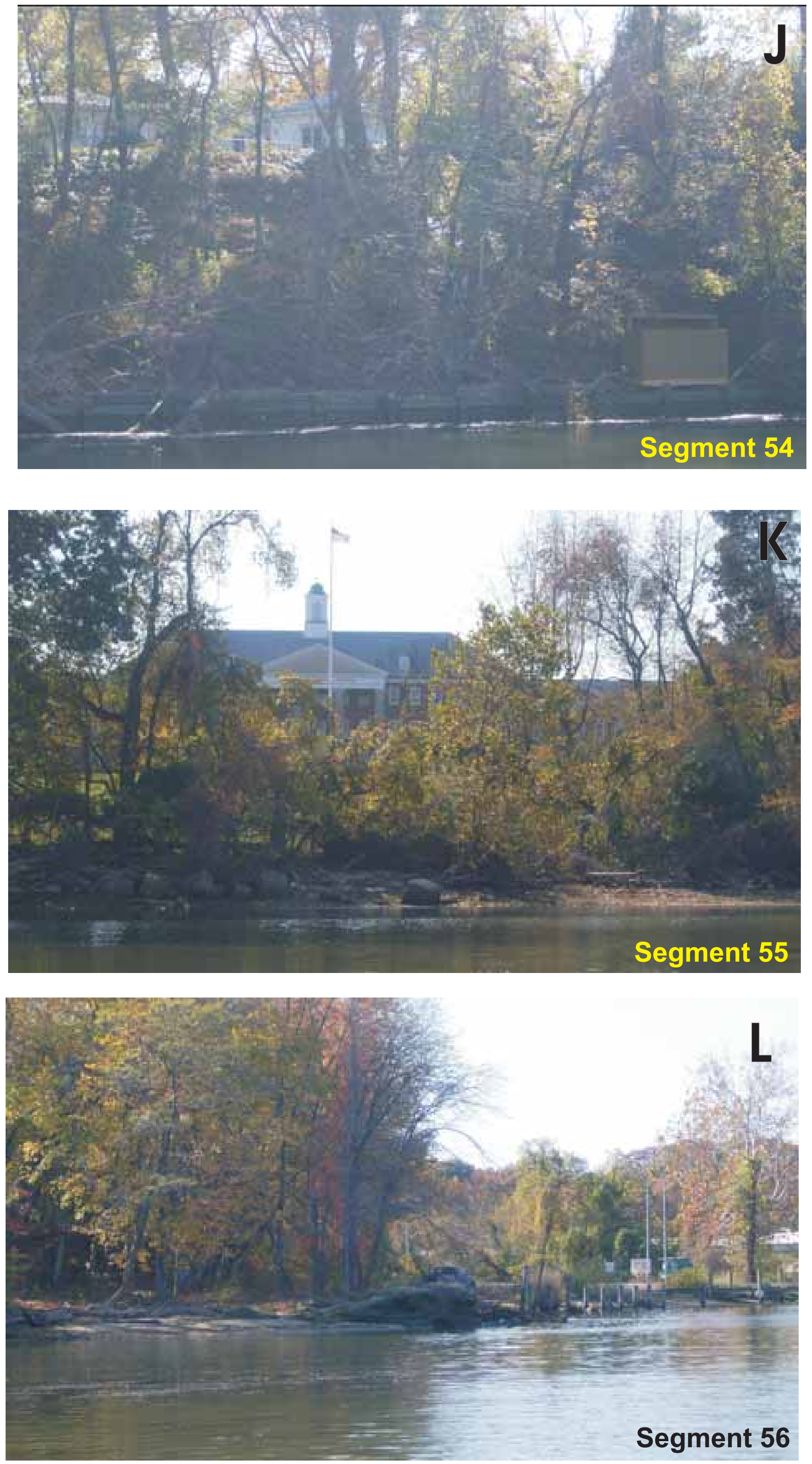


Figure 8-2 (cont). Photos taken along Quantico's shoreline in Reach 1. Photos taken on 5 Nov 2009 by VIMS personnel.

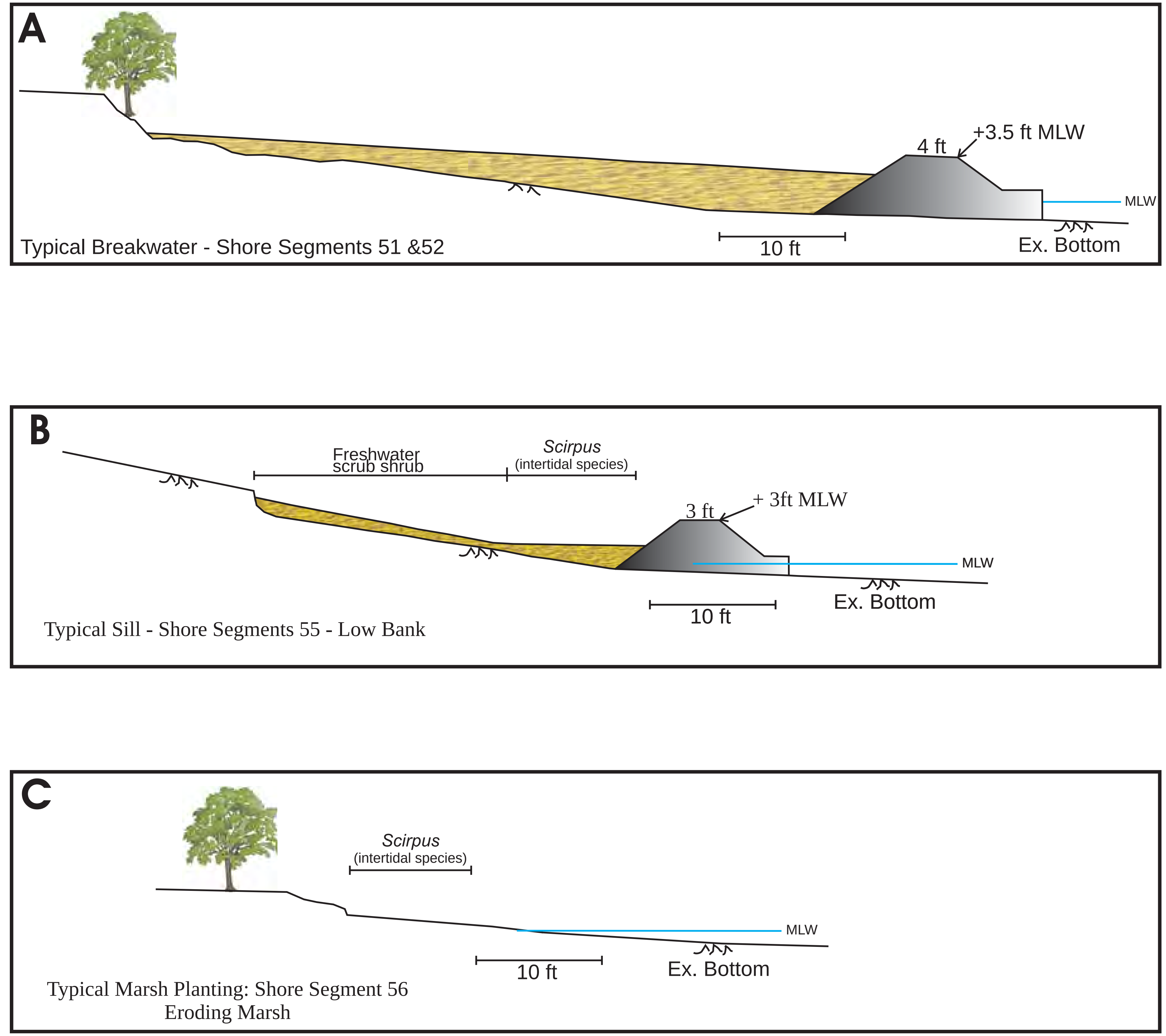


Figure 8-3. Typical cross-sections for management strategies recommended in Reach 4.

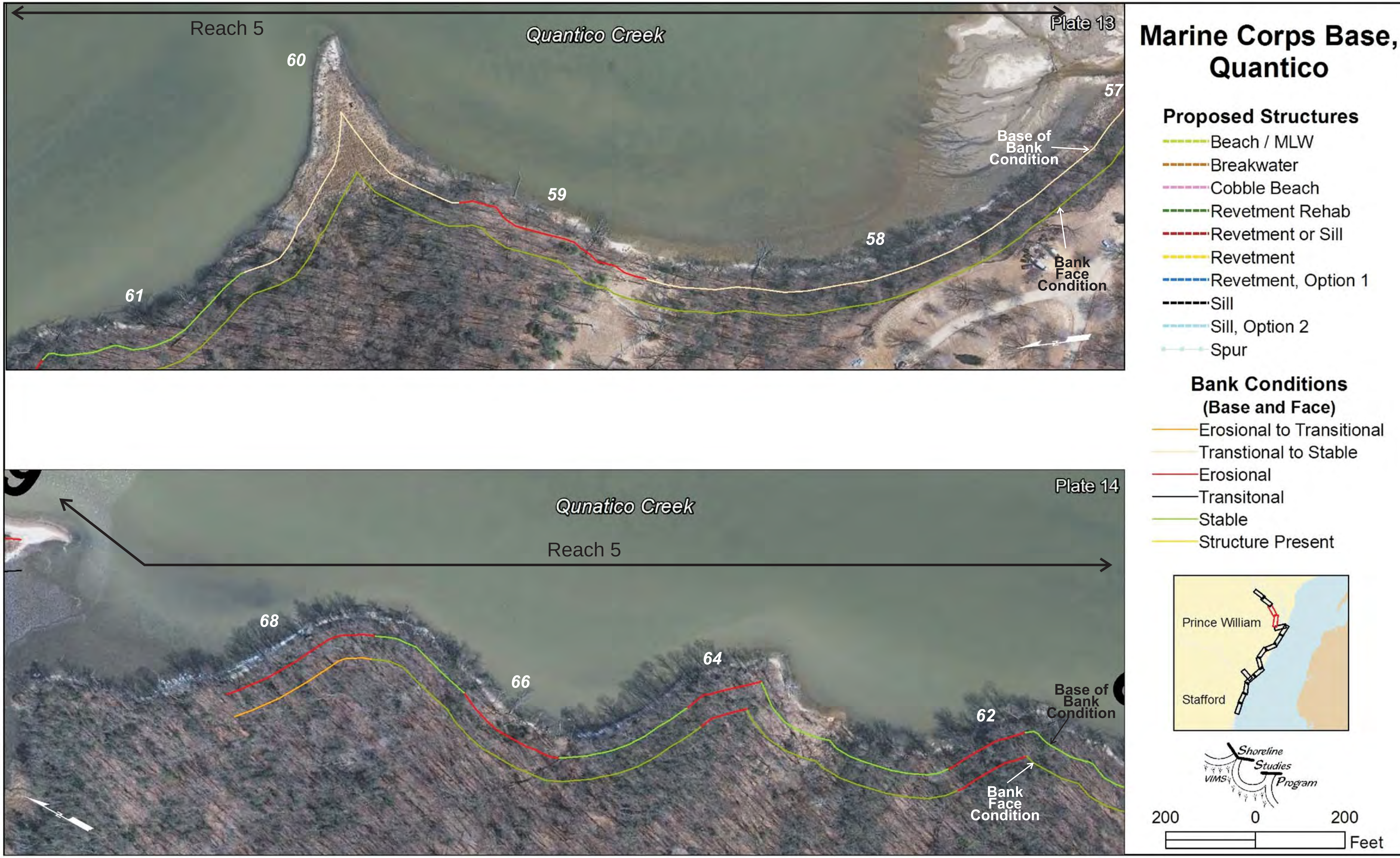


Figure 9-1. Bank conditions for Plates 13 and 14. Segment number (shown in white) is for location reference only. No shoreline management structures have been proposed for this Reach. Photo base VGIN 2009.

Figure 9-2. Bank conditions for Plates 15 and 16. Segment number (shown in white) is for location reference only. No shoreline management structures have been proposed for this Reach. Photo base VGIN 2009.

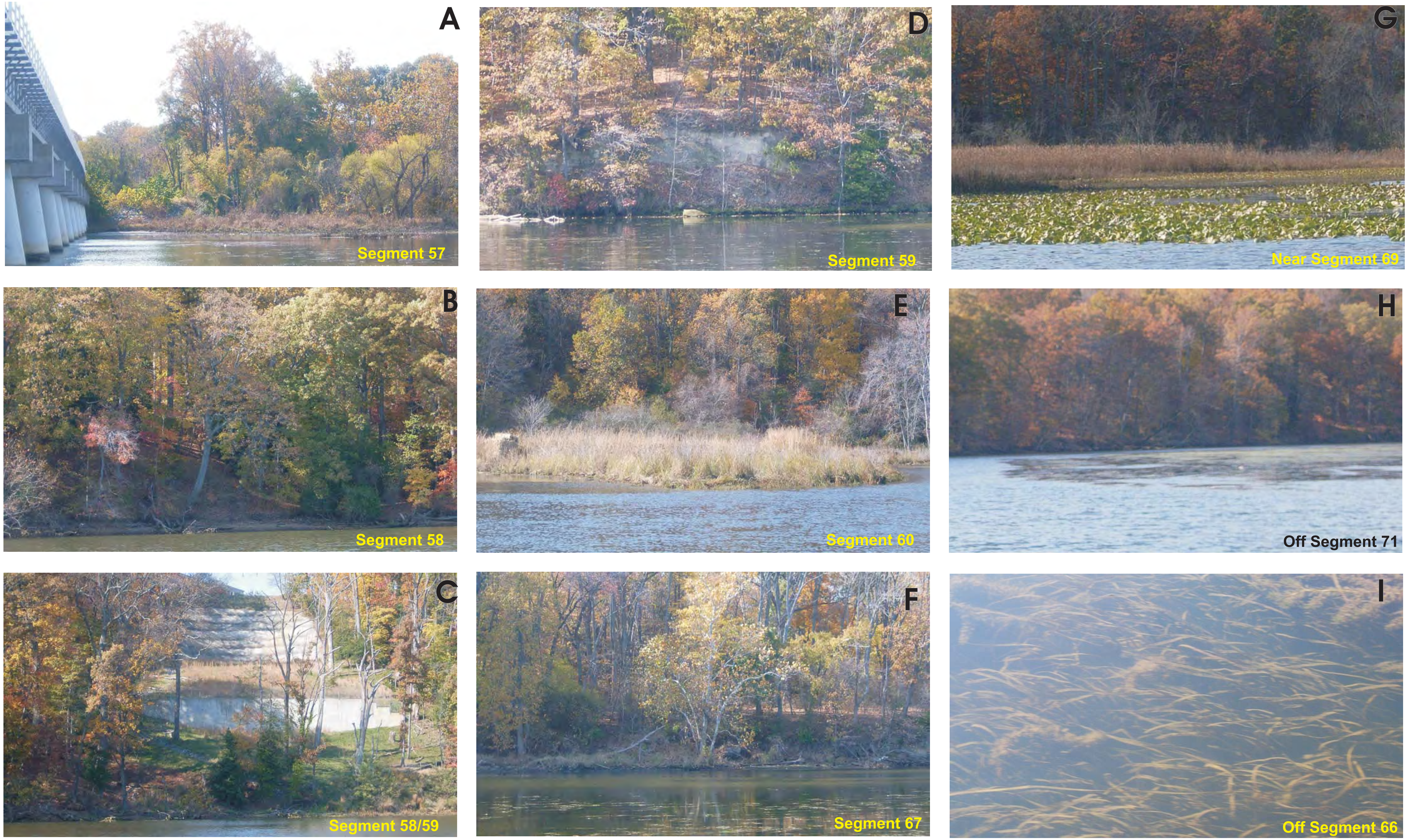


Figure 9-3. Photos taken along Quantico's shoreline in Reach 5. Photos taken on 5 Nov 2009 by VIMS personnel.

Appendix A

Historic and Recent Aerial Imagery, Digitized Shorelines, and End Point (1937-2009) Rate of Shoreline Change

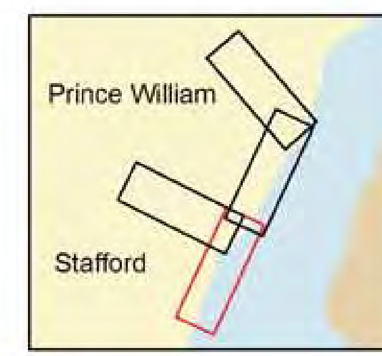
Marine Corps Base, Quantico

Plate 1

Legend

1937 Shoreline

1996 Shoreline

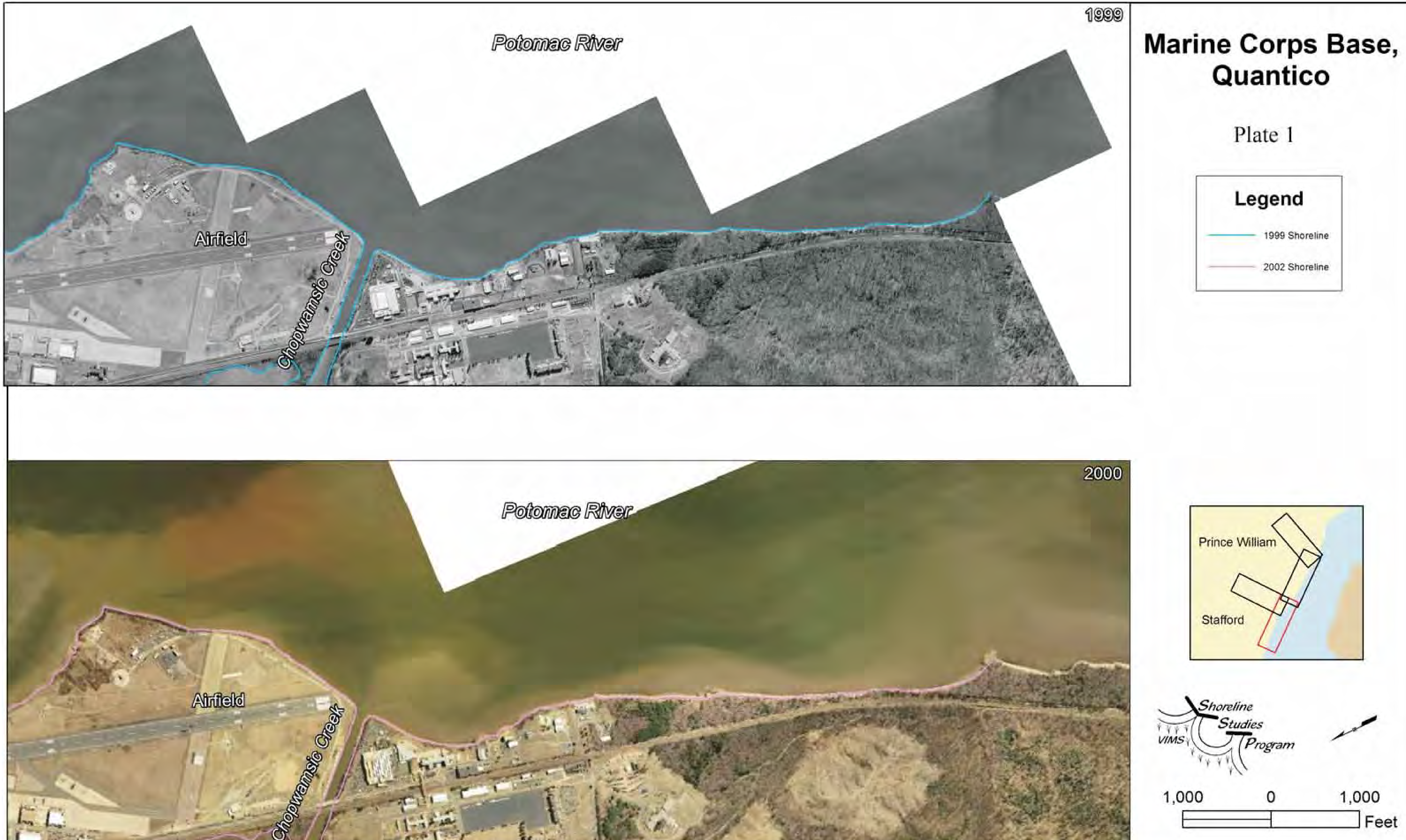


Shoreline Studies Program

VIMS

1,000 0 1,000

Feet


Marine Corps Base, Quantico
Plate 1
Legend
1999 Shoreline
2002 Shoreline
1999
Potomac River
Airfield
Chopwamsic Creek
2000
Potomac River
Airfield
Chopwamsic Creek
Prince William
Stafford
Shoreline Studies Program
VIMS
1,000
0
1,000
Feet


2009
Potomac River
Airfield
Chopwamsic Creek
End Point Rate
Potomac River
Airfield
Chopwamsic Creek
Marine Corps Base, Quantico
Plate 1
1937 Shoreline
2002 Shoreline
1996 Shoreline
2009 Shoreline
1999 Shoreline
Shoreline Rates of Change
High Accretion: > +5 (ft/yr)
Medium Accretion: +5 to +2 (ft/yr)
Low Accretion: +2 to +1 (ft/yr)
Very Low Accretion: +1 to >0 (ft/yr)
No Change: 0 (ft/yr)
Very Low Erosion: <0 to -1 (ft/yr)
Low Erosion: -1 to -2 (ft/yr)
Medium Erosion: -2 to -5 (ft/yr)
High Erosion: < -5 (ft/yr)
Prince William
Stafford
Shoreline Studies Program
VIMS
1,000
0
1,000
Feet

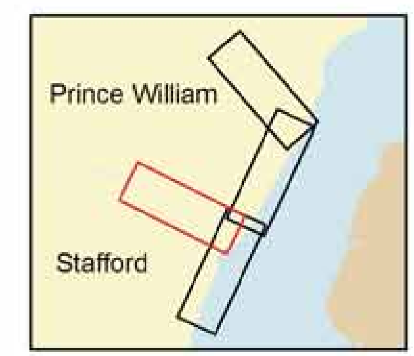
Marine Corps Base, Quantico

Plate 2

Legend

1937 Shoreline

1996 Shoreline



Shoreline Studies Program VIMS

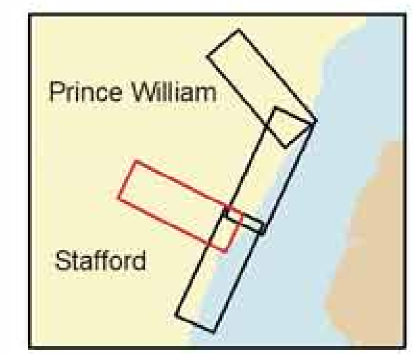
1,000 0 1,000 Feet

Marine Corps Base, Quantico

Plate 2

Legend

- 1999 Shoreline
- 2002 Shoreline



Shoreline Studies Program
VIMS

1,000 0 1,000 Feet

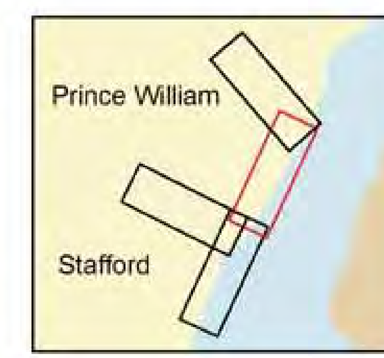

Marine Corps Base, Quantico
Plate 2
1937 Shoreline
2002 Shoreline
1996 Shoreline
2009 Shoreline
1999 Shoreline
Shoreline Rates of Change
High Accretion: > +5 (ft/yr)
Medium Accretion: +5 to +2 (ft/yr)
Low Accretion: +2 to +1 (ft/yr)
Very Low Accretion: +1 to >0 (ft/yr)
No Change: 0 (ft/yr)
Very Low Erosion: <0 to -1 (ft/yr)
Low Erosion: -1 to -2 (ft/yr)
Medium Erosion: -2 to -5 (ft/yr)
High Erosion: < -5 (ft/yr)
2009
Chopawamsic Creek
Airfield
End Point Rate
Chopawamsic Creek
Airfield
End Point Rate Not Calculated for Creek
Prince William
Stafford
Shoreline Studies Program
VIMS
1,000
0
1,000
Feet

Marine Corps Base, Quantico

Plate 3

Legend

- 1937 Shoreline
- 1996 Shoreline



Shoreline Studies Program VIMS

1,000 0 1,000 Feet

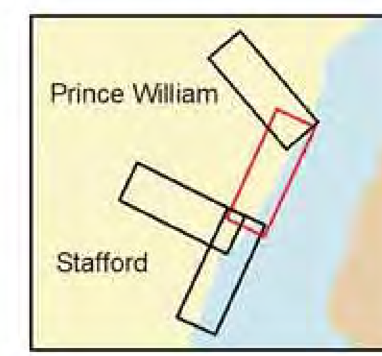
Marine Corps Base, Quantico

Plate 3

Legend

1999 Shoreline

2002 Shoreline



Shoreline Studies Program

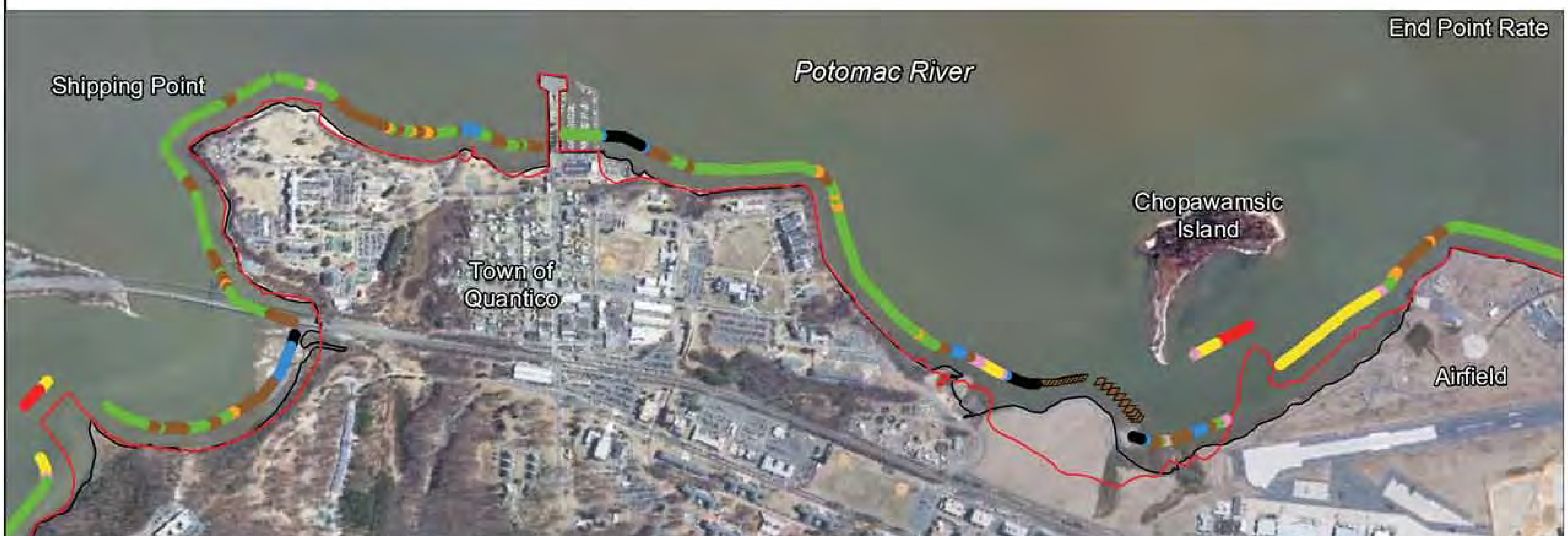
VIMS

1,000 0 1,000

Feet

Marine Corps Base, Quantico

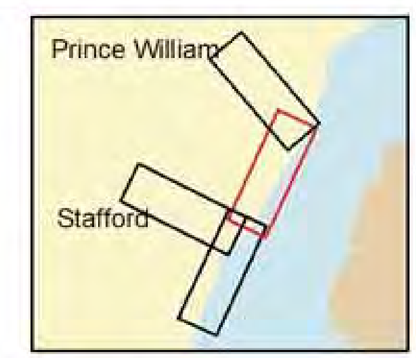
Plate 3



1937 Shoreline
2002 Shoreline
1996 Shoreline
2009 Shoreline
1999 Shoreline

Shoreline Rates of Change

- High Accretion: > +5 (ft/yr)
- Medium Accretion: +5 to +2 (ft/yr)
- Low Accretion: +2 to +1 (ft/yr)
- Very Low Accretion: +1 to >0 (ft/yr)
- No Change: 0 (ft/yr)
- Very Low Erosion: <0 to -1 (ft/yr)
- Low Erosion: -1 to -2 (ft/yr)
- Medium Erosion: -2 to -5 (ft/yr)
- High Erosion: < -5 (ft/yr)

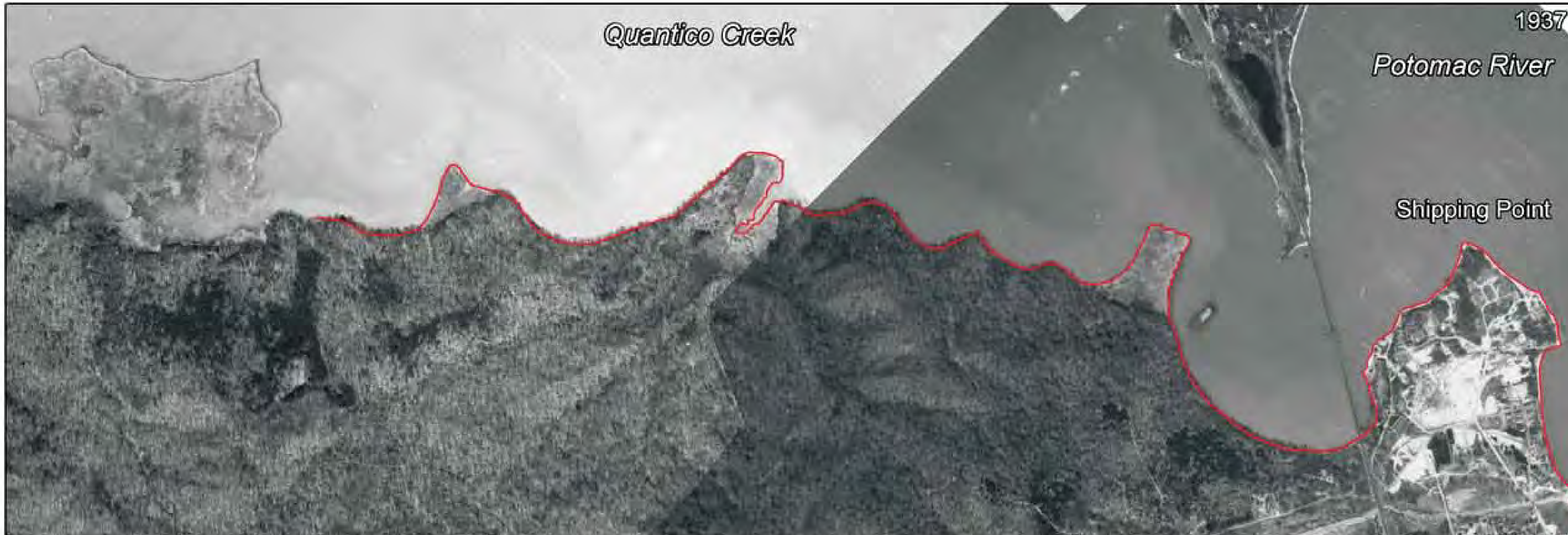


VIMS Shoreline Studies Program

1,000 0 1,000 Feet

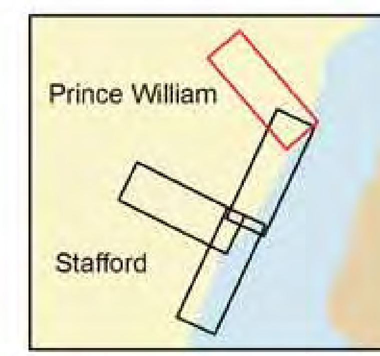
Marine Corps Base, Quantico

Plate 4



Legend

- 1937 Shoreline
- 1996 Shoreline



VIMS Shoreline Studies Program

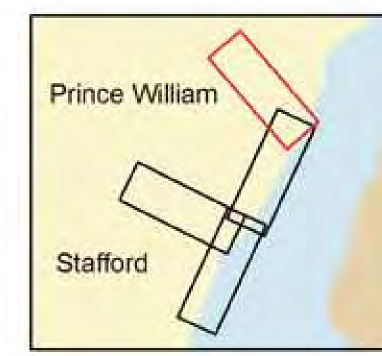
1,000 0 1,000 Feet

Marine Corps Base, Quantico

Plate 4

Legend

- 1999 Shoreline
- 2002 Shoreline



Shoreline Studies Program
VIMS

1,000 0 1,000
Feet

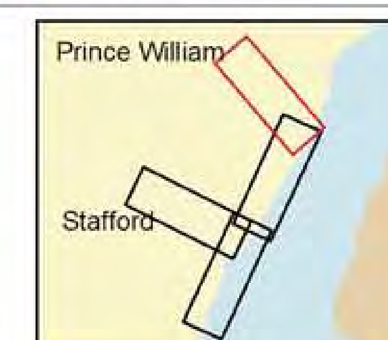
Marine Corps Base, Quantico

Plate 4

1937 Shoreline
2002 Shoreline
1996 Shoreline
2009 Shoreline
1999 Shoreline

Shoreline Rates of Change

High Accretion: > +5 (ft/yr)
Medium Accretion: +5 to +2 (ft/yr)
Low Accretion: +2 to +1 (ft/yr)
Very Low Accretion: +1 to >0 (ft/yr)
No Change: 0 (ft/yr)
Very Low Erosion: <0 to -1 (ft/yr)
Low Erosion: -1 to -2 (ft/yr)
Medium Erosion: -2 to -5 (ft/yr)
High Erosion: < -5 (ft/yr)

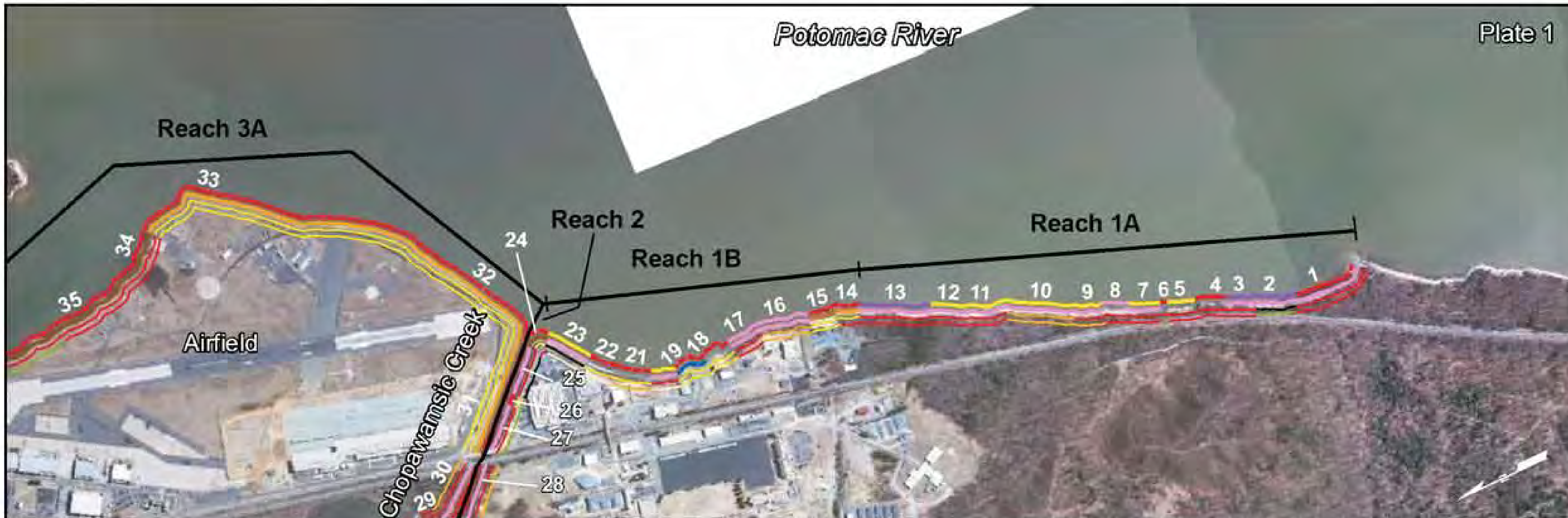


Shoreline Studies Program
VIMS

1,000 0 1,000
Feet

Appendix B

Base of Bank and Bank Face Conditions, Existing Structures, and Backshore Width by Reach and Segment Number



Marine Corps Base, Quantico

Bank Conditions (Base and Face)

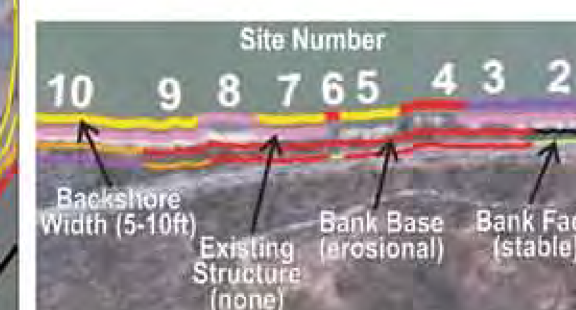
- Erosional to Transitional
- Transtional to Stable
- Erosional
- Transitonal
- Stable
- Structure Present

Existing Structures

- Bank Rocks
- Beach
- Breakwater
- Broken Concrete
- Bulkhead
- Concrete Wall
- Crib Wall
- In Situ Natural Bank Rocks
- Marsh
- None
- Old Mill
- RipRap
- Stone Wall

BackShore Width

- 0
- <5ft
- 10 to 15ft
- NA
- 5 to 10ft
- 5 to 15ft



1,000 0 1,000 Feet


Plate 3
Reach 4A
Reach 3D
Potomac River
Reach 4B
Reach 4C
Reach 5
Town of Quantico
Reach 3C
Reach 3B
Chopawamsic Island
Reach 3A
Airfield
Plate 4
Quantico Creek
Potomac River
Reach 5
Reach 4C
Reach 4B
Marine Corps Base, Quantico
Bank Conditions (Base and Face)
Erosional to Transitional
Transtional to Stable
Erosional
Transitonal
Stable
Structure Present
Existing Structures
Bank Rocks
Beach
Breakwater
Broken Concrete
Bulkhead
Concrete Wall
Crib Wall
In Situ Natural Bank Rocks
Marsh
None
Old Mill
RipRap
Stone Wall
Backshore Width
0
<5ft
10 to 15ft
NA
5 to 10ft
5 to 15ft
Site Number
Backshore Width (5-10ft)
Existing Structure (none)
Bank Base (erosional)
Bank Face (stable)
1,000
0
1,000
Feet
Shoreline Studies Program
VIMS

Appendix C

Table of Existing Data by Segment Number

Segmt Number	Reach	Priority^	Site Length (ft)	Average EPR* (ft)	Base of Bank	Bank Face	Back Shore Width (ft)	Existing Structures	Comments	Landscape	Distance to 6ft Contour (ft)
1	1A	L	635	-0.4	Erosional	Erosional	NA	None		Wooded	1,409
2	1A	**H**	352	1.4	Transitonal	Stable	10 to 15ft	None	Railroad tracks near eroding banks	Wooded	1,411
3	1A	**H**	266	0.7	Erosional	Erosional	10 to 15ft	None	Railroad tracks near eroding banks	Wooded	1,328
4	1A	**H**	244	0.3	Erosional	Erosional	0	In Situ Natural Bank Rocks	Railroad tracks near eroding banks	Wooded	1,237
5	1A	**H**	235	0.7	Erosional	Erosional	5 to 10ft	In Situ Natural Bank Rocks	Railroad tracks near eroding banks	Wooded	1,144
6	1A	**H**	63	0.9	Erosional	Stable	0	In Situ Natural Bank Rocks	Railroad tracks near eroding banks	Wooded	1,113
7	1A	**H**	274	0.5	Erosional	Erosional	5 to 10ft	None	Railroad tracks near eroding banks	Wooded	1,010
8	1A	M	205	0.3	Erosional	Erosional	<5ft	In Situ Natural Bank Rocks		Wooded	936
9	1A	M	263	0.0	Erosional	Erosional to Transitional	5 to 10ft	None		Wooded	854
10	1A	M	576	0.1	Erosional to Transitional	Erosional and Transitional	5 to 10ft	None		Wooded	647
11	1A	M	321	-0.7	Erosional	Erosional	5 to 10ft	None	Low bank drainage	Wooded	647
12	1A	M	329	-0.1	Erosional	Erosional	5 to 10ft	None		Wooded	665
13	1A	M	608	0.2	Erosional	Erosional	10 to 15ft	None	Vegetated	Wooded	623
14	1B	L	187	0.7	Structure Present	Erosional	NA	RipRap	Base Infrastructure	Pond	623
15	1B	M	257	0.3	Structure Present	Structure Present	NA	Bulkhead		Parking Lot	632
16	1B	**H**	429	0.0	Erosional to Transitional	Erosional and Transitional	<5ft	None		Wooded Bank / Parking	717
17	1B	M	289	-0.2	Erosional	Erosional	<5ft	None		Wooded Bank / Grass	857
18	1B	M	289	0.6	Structure Present	Structure Present	NA	Concrete Wall	Old concrete wall	Grass	953
19	1B	M	290	0.3	Structure Present	Structure Present	NA	Stone Wall	Old stone wall	Parking Lot	940
20	1B	M	205	0.6	Erosional	Transtional to Stable	5 to 10ft	None		Wooded Bank / Grass	984
21	1B	L	323	0.5	Structure Present	Erosional and Transitional	NA	Concrete Wall	Old low concrete wall	Wooded Bank / Grass	927
22	1B	L	255	0.4	Structure Present	Transtional and Stable	NA	Crib Wall		Wooded Bank / Grass	858
23	1B	**M / H**	383	0.4	Transitonal	Transtional to Stable	5 to 10ft	None	Steep bank face	Wooded Bank / Grass	677
24	1B	**H**	200	0.3	Structure Present	Erosional	NA	Broken Concrete		Wooded Bank / Parking	666
25	2	**H**	420	0.3	Erosional	Transitonal	0	None		Wooded Bank / Parking	None
26	2	L	97	0.3	Structure Present	Stable	NA	Bank Rocks		Wooded Bank / Parking	None
27	2	**H**	395	0.0	Erosional	Stable	NA	None		Wooded Bank / Parking	None
28	2	M	480	0.0	Erosional	Erosional to Transitional	NA	None	Grade bank	Wooded Bank / Grass	None
29	2	M	320	0.0	Erosional	Erosional	NA	None		Wooded	None
30	2	M	499	0.0	Erosional	Erosional to Transitional	NA	None		Wooded	None
31	2	L (SA)	657	0.0	Structure Present	Structure Present	NA	RipRap	New riprap	Side Walks / Grass	None
32	3A	M	3,204	0.2	Structure Present	Structure Present	NA	RipRap	Old riprap	Grass / Airfield	99
33	3A	M	869	0.0	Structure Present	Structure Present	NA	RipRap		Grass / Airfield	185
34	3A	M	584	-1.6	Erosional	Erosional	NA	Broken Concrete	Intermittant	Grass / Airfield	558
35	3A	M	645	-2.8	Erosional	Erosional	NA	Broken Concrete	Old broken concrete	Grass / Airfield	1,081
36	3A	**H**	1,056	-3.5	Erosional	Stable	NA	Broken Concrete		Grass / Airfield	1,578
37	3B	L	892	0.8	Erosional and Transitional	Stable	NA	Marsh		Marsh / Grass	2,303
38	3B	L (SA)	1,461	5.9	Structure Present	Structure Present	NA	RipRap	New riprap	Grass	1,887
39	3C	L	136	-2.6	Structure Present	Stable	NA	Stone Wall	Old stone wall	Marsh	1,894
40	3C	M	438	-0.4	Erosional	Erosional	NA	None		Wooded Bank / Grass	1,653
41	3C	M	283	0.9	Structure Present	Erosional and Transitional	NA	Broken Concrete		Wooded Bank / Road	1,576
42	3C	M	180	-0.2	Transitonal	Stable	10 to 15ft	Beach	Narrow beach	Wooded	1,510
43	3C	M	346	-0.1	Structure Present	Erosional	NA	Broken Concrete		Wooded	1,304
44	3C	M	259	-0.1	Erosional to Transitional	Transtional to Stable	<5ft	None		Wooded	1,150
45	3D	L (SA)	2,421	-0.1	Structure Present	Erosional and Transitional	NA	Concrete Wall		Wooded Bank / Grass / Parking Lot	299
46	3D	L	172	0.6	Stable	Stable	NA	None		Grass	410
47	3D	M	286	2.5	Structure Present	Structure Present	NA	Broken Concrete		Wooded / Parking Lot	356
48	3D	L (SA)	2,040	0.0	Structure Present	Structure Present	NA	Bulkhead		Marina / Bulkhead	57

^L-Low Priority, L(SA)= Low Priority/Structure Adequate, M=Medium Priority, H=High Priority

*End Point Rate was calculated between 1937 and 2009

Segmt Number	Reach	Priority^	Site Length (ft)	Average EPR* (ft)	Base of Bank	Bank Face	Back Shore Width (ft)	Existing Structures	Comments	Landscape	Distance to 6ft Contour (ft)
49	4A	M	879	0.4	Stable	Stable	5 to 10ft	Old Mill	In Town of Quantico; Concrete/Stone wall failure in places	Grass	371
50	4B	M	1,291	0.0	Structure Present	Erosional and Transitional	NA	Concrete Wall	Beach in front in some sections	Wooded Bank / Grass	58
51	4B	M	245	-0.7	Erosional to Transitional	Erosional to Transitional	NA	None	Scattered broken concrete	Grass	49
52	4B	M	282	-0.3	Transtional to Stable	Transtional to Stable	<5ft	None		Wooded Bank / Grass	51
53	4B	L (SA)	543	-0.2	Structure Present	Erosional and Transitional	NA	Concrete Wall		Wooded Bank / Grass	2
54	4B	M	168	-0.1	Structure Present	Erosional	NA	Crib Wall	Wooden crib wall that is decaying	Wooded Bank / Grass	3
55	4C	M	612	-0.3	Transitonal	Transitonal	5 to 10ft	Broken Concrete	Down trees and broken concrete	Wooded Bank / Parking	80
56	4C	M	972	0.0	Erosional to Transitional	Erosional to Transitional	<5ft	Broken Concrete	Intermittant broken concrete and low bank face	Marsh / Wooded	79
57	5	L	1,624	1.4	Transtional and Stable	Stable	NA	Marsh		Marsh	None
58	5	L	940	0.2	Transtional to Stable	Stable	<5ft	None		Wooded	None
59	5	L	485	-0.1	Erosional	Stable	<5ft	None	A couple of spots of bank rock	Wooded	None
60	5	L	994	-3.0	Transtional and Stable	Stable	NA	Marsh		Wooded	None
61	5	L	550	-0.4	Stable	Stable	NA	None		Wooded	None
62	5	L	197	-0.2	Erosional	Erosional	NA	None		Wooded	None
63	5	L	483	0.0	Stable	Stable	NA	None		Wooded	None
64	5	L	219	-0.2	Erosional	Erosional	NA	None		Wooded	None
65	5	L	277	0.0	Stable	Stable	NA	None		Wooded	None
66	5	L	227	-0.1	Erosional	Stable	NA	None		Wooded	None
67	5	L	276	0.1	Stable	Stable	NA	None		Wooded	None
68	5	L	390	0.1	Erosional	Erosional to Transitional	NA	None		Wooded	None
69	5	L	350	-0.2	Erosional	Transitonal	NA	None		Wooded	None
70	5	L	762	-0.3	Erosional	Erosional to Transitional	NA	None		Wooded	None
71	5	L	1,416	-0.3	Erosional to Transitional	Transtional to Stable	NA	None		Wooded	None
72	5	L	377	-0.6	Transtional to Stable	Stable	5 to 10ft	None		Wooded	None
73	5	L	324	-2.5	Transtional and Stable	Stable	NA	Marsh		Wooded	None
74	5	L	892	-1.1	Erosional	Transtional to Stable	NA	None		Wooded	None

^L-Low Priority, L(SA)= Low Priority/Structure Adequate, M=Medium Priority, H=High Priority

*End Point Rate was calculated between 1937 and 2009