FINAL

ASSESSMENT AND

SHORELINE MANAGEMENT PLAN

FOR REACHING NPDES MUNICIPAL SEPARATE STORM

SEWER SYSTEM PERMIT (MS4) GOALS

FOR

CHARLES COUNTY, MARYLAND

September 2018

Prepared By:

SOUTHERN MARYLAND

RESOURCE CONSERVATION AND DEVELOPMENT

(RC&D)

Prepared For:

CHARLES COUNTY Maryland

PROJECT TEAM

Contractor

SOUTHERN MARYLAND RESOURCE CONSERVATION AND DEVELOPMENT BOARD, INC.

26737 Radio Station Way – Suite D

Leonardtown, MD 20650

240.577.6413

www.somdrcd.org

Subcontractor

COASTLINE DESIGN, P.C.

PO Box 157

Achilles, VA 23001

804.684.7277

scott@coastlinedesignpc.com

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Background and Purpose

Charles County, MD contains 180 miles of shoreline (Charles County Comprehensive Plan, 2016). Like many coastal areas in the Chesapeake Bay estuarine system, the County's shorelines experience varying levels of erosion and land subsidence. The County recognized the need for a comprehensive shoreline assessment and management plan, including both public and private properties, for the purpose of identifying and prioritizing shorelines in need of restoration. The assessment and plan will provide a basis for implementing the most effective shoreline restoration projects and meeting the Chesapeake Bay Total Maximum Daily Load (TMDL) goals for nitrogen, phosphorus and sediment.

The project team was assembled by Southern Maryland Resource Conservation and Development Board, Inc. (RC&D) for specific services under an agreement that included RC&D and Coastline Design, P.C. (Coastline). RC&D is the Cooperator under the Agreement and is the sole agent for the fiscal administration of any Cooperative Agreement with the County. RC&D contracted with Coastline to provide the site assessment, develop recommendations in the form of a draft report, and produce a final shoreline management plan report acceptable to the County.

To develop a comprehensive Shoreline Management Plan (Plan) for Charles County, Maryland (Figure 1-1), the shore zone around the tidal shorelines of the County were assessed along the Potomac River and its lateral creeks and rivers including the Wicomico River, Port Tobacco River, Nanjemoy Creek, Chicamuxen Creek, Mattawoman Creek, and the Patuxent River. Due to value added by restoration of private shorelines, the County recognized the need for an independent assessment and shoreline ranking for the purposes of unbiased project selection. This assessment identified eroding shore reaches that contribute significant sediment and nutrients into the tidal waters of the Chesapeake Bay and its tributaries and prioritized areas for restoration. The restoration site recommendations also consider where TMDL credits would be optimized.

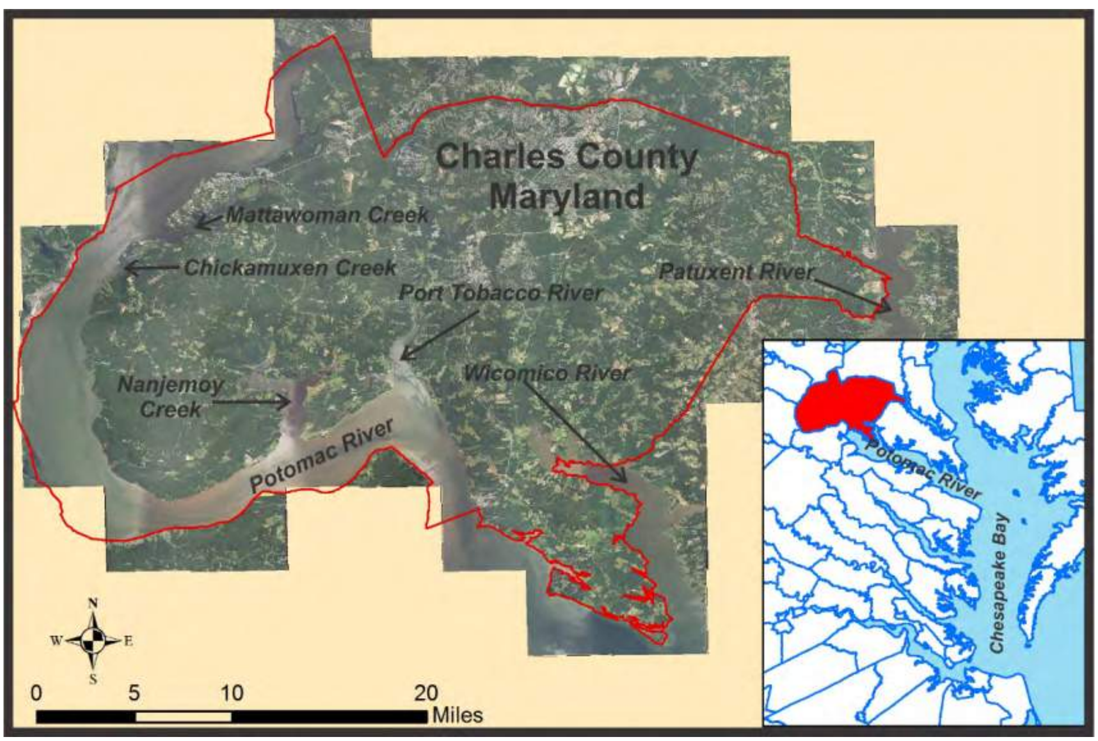


Figure 1.1. Location of rivers and creeks in Charles County, Maryland.

Generally, the County's shorelines on the open Potomac River are subject to wind-driven wave-forces that caused shoreline erosion ranging from low to severe. Shorelines along the lateral waterbodies are somewhat less exposed to wind wave action, except shore reaches near their mouth. Hydrodynamic forcing and its relationship to shoreline change were an important component of this study. This Plan put the natural process of shoreline erosion into perspective as to potential long-term impacts to upland banks, land loss, and the consequent input of sediments and nutrients into Chesapeake Bay. Priority was given to eroding shorelines with high erosion rates and those with potential infrastructure impacts. Eroding upland banks and shoreline morphology were addressed holistically in the context of the overall shoreline management plan.

This study yielded management strategy recommendations that addressed shoreline erosion on a reach basis. The impacts of "no action" at the shoreline also were considered. This plan employed the strategy of living shorelines as a best management practice for shore stabilization; living shorelines are shore protection strategies that are relatively non-intrusive to natural surroundings yet effective within the context of long-term shoreline erosion control. They consist of a combination of stone structures, particularly sills and/or breakwaters along with sand nourishment which create a stable substrate for establishing wetland vegetation. This living shoreline approach utilizes stable marshes and beaches for shore protection, are the preferred alternatives for shore protection, and can provide a platform for long-term coastal resiliency in the face of sea level rise.

1.2 Components of the Shoreline Management Plan

1.2.1 Existing Shoreline Conditions

Documentation of the existing conditions along the entire riparian zone were essential to management of the shore zone. Several features were described. The condition of the upland bank including both the base of bank (BOB) and the bank face (BF) were coded for stability. The BOB and BF are important factors in long-term shoreline management. Closest to the water, the beach, marsh, intertidal, and nearshore areas were assessed for type, material, and stability. Below low water, the nearshore water depths, bottom stability, and the presence of marine resources (i.e. submerged aquatic vegetation) were noted and compared to existing databases.

1.2.2 Shore Change, Geology, and Geomorphology

Understanding shoreline change within the study area was important in assessing specific shoreline reaches. Upland features were assessed in terms of coincidence with areas of shoreline erosion and flooding to determine priority of action and what shoreline strategies should be employed. Shoreline morphology and erosion patterns are evaluated in order to determine the long-term shore response to the hydrodynamic processes.

The geologic underpinnings relative to shore morphology also were assessed. The geology of an area may cause shorelines to erode unevenly. Adjacent shore types, such as uplands and marsh and even unprotected shore segments that border protected shores, result in the development of different morphologic expressions along the shore. The net effect is that beaches and shorelines tend to orient themselves into or parallel with the dominant direction of wave approach. Generally, beach and shoreline planforms tend to reflect the net impact of the impinging wave climate. Spits (an extended stretch of beach material that is joined to land at one end) usually indicate the net direction of sediment movement along the shoreline (littoral drift).

1.2.3 Wave Climatology and Water Levels

Shoreline change (erosion and accretion) is a function of upland geology, shore orientation and the impinging wave climate (Hardaway and Byrne, 1999). Wave climate refers to averaged wave conditions as they change throughout the year. It is a function of seasonal winds as well as extreme storms. Seasonal wind patterns vary. In the Chesapeake Bay region, from late fall to spring, the dominant winds are from the north and northwest. During the late spring through the fall, the dominant wind shifts to the south and southwest. Northeast storms occur from late fall to early spring (Hardaway and Byrne, 1999) while infrequent occurrence of hurricanes annually peaks in late August to mid-September.

The wave climate of a particular site depends not only on the wind but also the fetch, shore orientation, shore type, and nearshore bathymetry. Fetch is defined as the distance over open water that wind can generate waves and can be used as a simple measure of relative wave energy acting on shorelines (Hardaway and Byrne, 1999).

Increased water levels regardless of wind conditions pose a threat to coastal resources. For this reason, another component of the wave climate assessment was the determination of the frequency of storm surges and flooding. This assessment was based, in part, on long-term tidal data from the National Oceanic and Atmospheric Administration (NOAA), U.S. Army Corps of Engineers (Corps), and flood insurance studies conducted by Federal Emergency Management Agency (FEMA). These analyses were important when determining the potential impact of the local wave climate and storm surge on the shoreline. Consideration of these impacts was an important element in the design of a shoreline management strategy particularly the dimensions of structural options.

When developing the Plan to protect upland banks from erosion, sea-level rise was an important long-term consideration. Due to potential impacts of climate change, projected sea-level rise rates are higher than those measured over the recent past. However, the recommended shoreline strategies can be adjusted to account for sea-level rise for increased coastal resiliency. When the wave climate assessment agrees with the morphologic expression, then the impacts of proposed shoreline management strategies can be assessed with more confidence.

1.2.4 Total Maximum Daily Load (TMDL) Assessment

According to Drescher and Stack (2015), shoreline erosion is one of the greatest sources of sediment and turbidity to the Chesapeake Bay and its tributaries. Because there is no lag time associated with transport and delivery of sediment, the benefits of shoreline management and shore protection practices in reducing turbidity are immediate. Maryland Department of the Environment's (MDE) (2014) waste load allocation guidelines allow shoreline stabilization to be used as an alternative best management practice (BMP) for meeting the impervious surface restoration requirement under a jurisdiction's municipal separate storm sewer permit (MS4 permit). Shoreline stabilization projects that employ living shorelines, the preferred management strategy for water quality improvement, can provide pollutant reductions to meet the Bay TMDL and impervious surface restoration requirements under the stormwater permit.

Shoreline conditions that combine high erosion rates with agricultural riparian land use may be a high contributor of total suspended sediments (TSS) in combination with total nitrogen (TN) and total phosphorous (TP). The sediment load can be calculated by bank height and erosion rate along a given section of shoreline. A combination of historic shoreline erosion rates and bank heights were used to generate TMDL loading for shoreline reaches. Eroding marsh was not considered in the TMDL assessment. The TMDL assessment can be considered a tool for county shoreline management decisions.

1.2.5 Reach Recommendations and Prioritization

With the aforementioned analyses complete, shore reach assessment was performed. This assessment considered the County's goals, existing shoreline conditions and their potential for change, sea-level rise and the potential for increased coastal resiliency. The purpose of the assessment was to determine areas with urgent need for shoreline management, as well as make recommendations for long-term restoration. The degree of instability and potential for erosion were weighed against threatened infrastructure, land loss, and costs for shore/bank protection and structure relocation.
The recommended strategies included any of the following and are fully described in Section 4.2:

1. No action and/or move threatened infrastructure
2. Defensive approach (stone revetments)
3. Offensive Living Shoreline approach (stone sills with wetlands plantings, stone breakwaters and beach fill with wetlands planting)
4. Headland control (stone breakwaters strategically placed alongshore with wide gaps in between structures and sand fill)

One or a combination of the above strategies were appropriate for a given reach depending on the availability of funds and project goals. Combining and/or phasing shoreline management strategies through time also was addressed because it is usually the more prudent and cost-effective approach. All strategies integrate upland management into the plan. Bank grading was recommended in areas with lower banks so that impacts to the buffer were minimized and costs reduced.

All eroding shorelines received recommendations for shoreline management protection. However, those shoreline reaches that have high erosion rates and/or contribute significant quantities of sediments into the Chesapeake Bay estuarine system were ranked as high priority sites either at the Priority-1 (P-1), Priority-2 (P-2), or Priority-3 (P-3) level.

2 CHARLES COUNTY PHYSICAL AND ENVIRONMENTAL SETTING

2.1 Geology and Sea-Level Rise

The upland banks along Charles County geologically are mostly composed of upland and lowland sedimentary strata (Figure 2-1). The coastal uplands consist of Maryland Point Formation, Qm, (Upper Pleistocene, 1.8 million to 11,500 years ago) with intermittent Holocene, Qh, (11,500 years ago to present) tidal marsh sediments. The geomorphology of the Charles County coast, like most tidal Chesapeake Bay areas, is shaped by geologic history. During a protracted low stand in sea level during the Late Pliocene (3.6 to 1.8 million years ago), the present-day drainage channels of the Susquehanna and major estuaries, including the Potomac, were entrenched into the underlying strata. Sea level has risen and fallen numerous times, which resulted in deposition and erosion during the Pleistocene. The last low stand in sea level was about 15,000 years ago, and sea level has been rising ever since. The effect has been a rising ocean over a low coastal plain with the consequent flooding of the estuary's meandering river systems. The result is shoreline erosion along much of the Chesapeake Bay watershed.

Since the last low sea level 15,000 years ago, sea level has been rising at various rates. Over the past several thousand years, the rate has been about 1 foot per 100 years. However, analysis of tide gauge data taken in the middle section of the Potomac River indicates that, since 1970, sea level has risen at 4.9 mm/yr or 1.6 ft/100 years (NOAA, 2016).

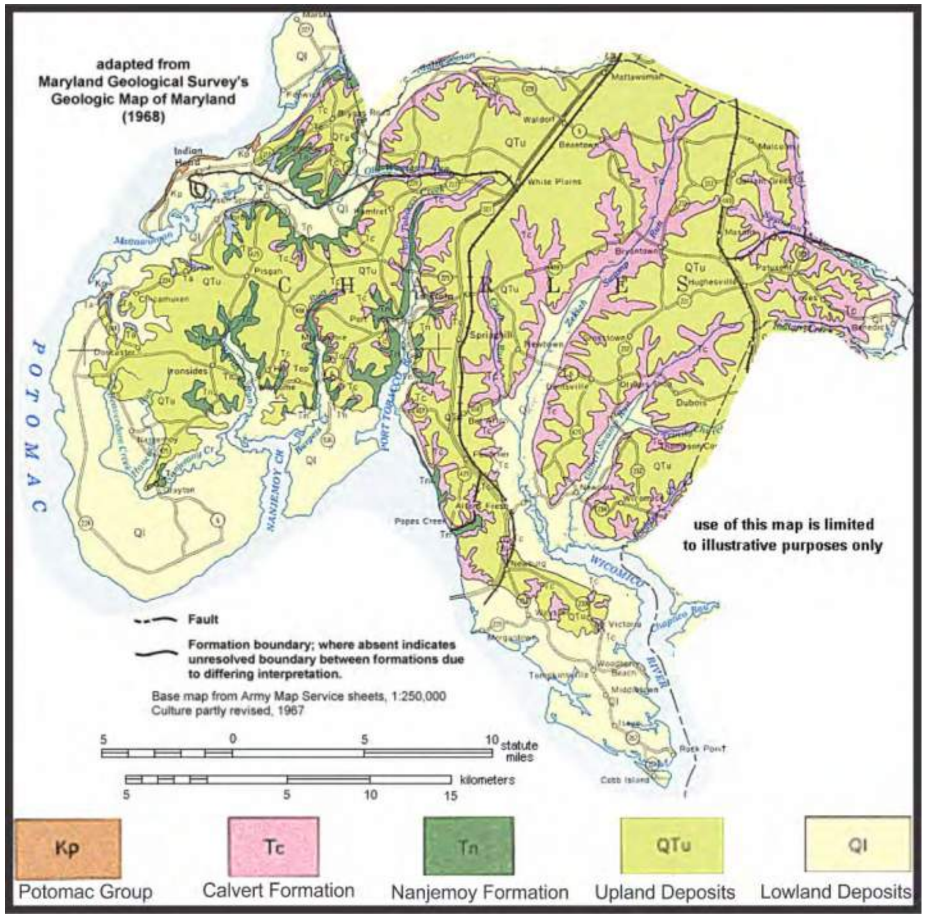


Figure 2-1. Geology of Charles County, Maryland (1968).

2.2 Geomorphology and Shore Types

For the purpose of this Plan, four shore types are considered along Charles County: beaches/spits, upland banks, marsh, and structurally-protected shorelines. The geomorphic evolution of estuarine shorelines is an interplay among these four features. Each type erodes differently, and the resulting planform helps describe the impinging wave climate and net direction of sediment transport. Fetch exposure and the direction that the shoreline faces (and therefore the main direction of wind approach) determine the wind/wave climate. Scarped and eroding shorelines indicate a higher impinging wave climate. The net movement of sediment transport is driven by the impinging wind/wave climate.

Beaches and upland banks tend to orient themselves in the direction of dominant wave approach. Where a “hard” point or erosion resistant feature (such as a structure, downed trees, etc.) occurs, sediment will accumulate on the updrift side, but the shore will erode on the downdrift side. Accumulation of sediment along shore against these features describes the net direction of sediment transport. These, along with the description of offsets in bank and marsh shores created by differential erosion of material type, provide an accurate picture of how the shoreline has evolved through time. Lack of these offset features also is important and may indicate a more balanced system of littoral movement.

For the upland banks, bank height is an important geomorphic description because it is very important in terms of shoreline management, recommended strategies, and cost. Six basic shore type descriptions based on bank height occur within the Chesapeake Bay (Figure 2-2). Low banks are those that are flooded during 100-year storms and where infrastructure is threatened if it is near the shoreline. High banks are above that flood level, and infrastructure is only threatened by shore erosion and land subsidence. In Charles County, many bank heights range from +15 ft to over 100 ft. Natural features such as beach and marshes, when present and

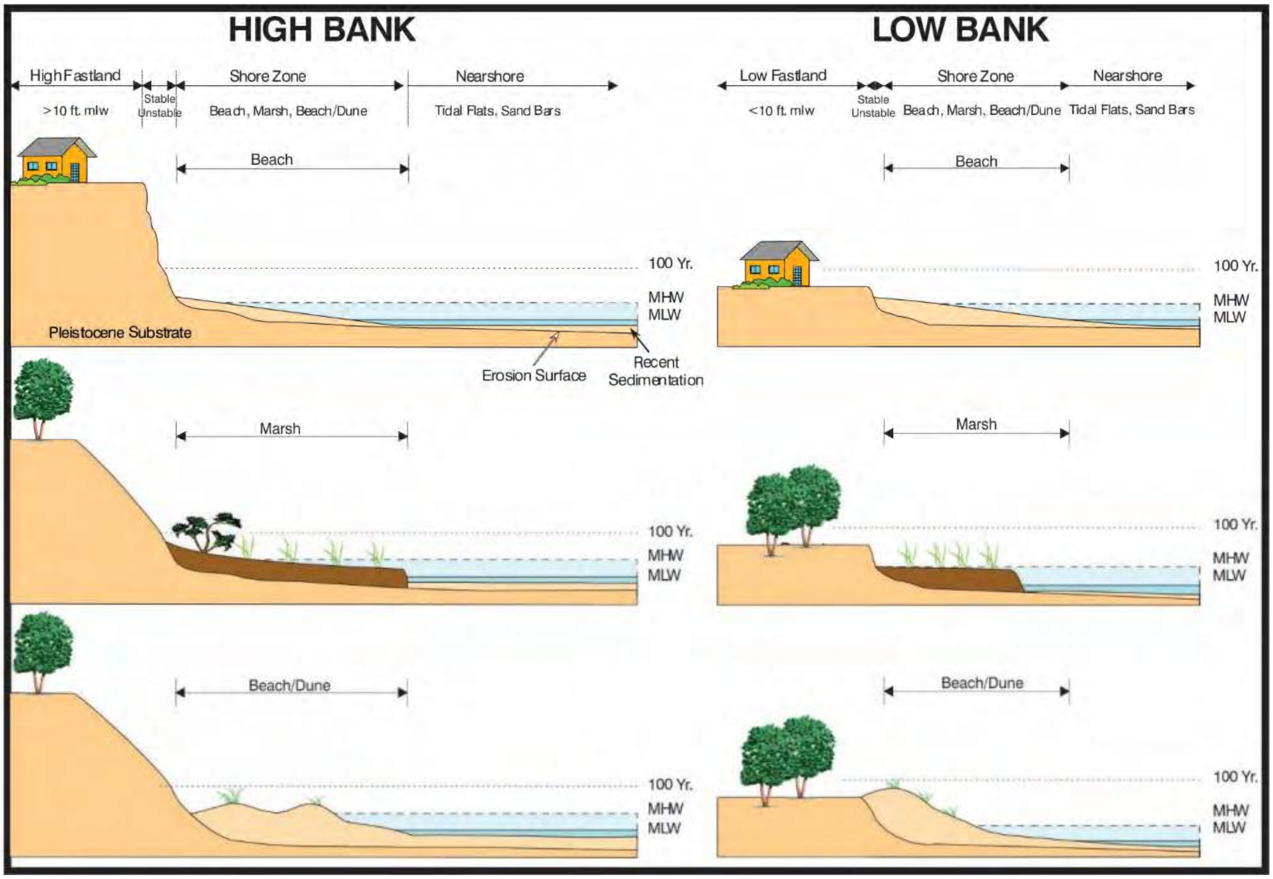


Figure 2-2. Storm water level impacts on high and low banks.

wide enough, protect the base of the bank from wave action. When these features erode, or have eroded away, erosion of the base of bank ensues.

Along the Charles County coast, the primary forces of geomorphic change are the undermining action of waves against the base of the banks (Figure 2-3). The bank face becomes too steep to support the load and fails by sloughing/slumping. For some time, the bank is stable where the sloughed material sits along the shore. However, the sloughed material is continually acted upon by the ongoing wave action and, with time, will erode back to the in-situ bank, and the process begins again. Other factors such as upland runoff, freeze/thaw, and groundwater can add to bank instability but are not major factors along Charles County's coast.

Figure 2-3. Sloughed/slumped material along a high bank. The material protects the base of bank until it erodes.

2.3 Shore Erosion

Erosion along estuarine shorelines are a function of two unrelated factors – wave climate and the site-specific character of the sediments. The different amount of energy required to suspend and re-suspend, hence erode, individual types of sediment determines the variations in erosion rates between sections of shore exposed to equal amounts of impinging energy. More energy, in terms of waves and currents, is required to re-suspend silts, clays, coarse sands, and larger-sized sediments than medium- and fine-grained sands. Thus, given equal exposure to waves and currents, shores consisting of medium and fine-grained sands will erode more rapidly than deposits of clays or silts.

Eroding upland banks supply sediments to the backshore, beach, and nearshore zones. The nature of the beach/backshore is a function of the adjacent bank geology. Sand, silts and clays are deposited differently as the bank erodes over time. The finer fraction (fine sands, silts, and clays) are readily carried away from the site. The coarser sands and gravels generally settle as beach and backshore deposits. Because much of the County's upland bank material contains clay, muddy fine sands to coarse sand, the beach/backshore often occurs as fine to medium sand and nearshore regions have a soft muddy fine sand layer over more stiff/dense clays and sand layers.

Historically, shoreline erosion in Chesapeake Bay has been controlled with defensive structures, wood bulkheads, rip rap, groins, or some combination. In Charles County, Berman et al. (2006) found that there were about 15.8 miles of bulkheads, 8.9 miles of riprap, and 29 groins some of which were used in combination with other shoreline hardening structures. Since that original inventory was completed, new structures have been built. Shoreline hardening can cut off a source of sediments to the littoral system impacting beach and spit formation downdrift.

2.4 Nearshore

Nearshore refers to the area close to the shore but still partly submerged. This area is where sand bars and shoals often form. A shoal is a shallow area in a waterway, often created by nearby sandbars or sandbanks. The nearshore region within the project area varies in extent and bathymetry. Bathymetry refers to the topography, or contours, of the bay bottom. The width and depth of the nearshore can have an impact on wave climate because wider nearshores better attenuate the impinging waves. Along the Potomac River shoreline, the nearshore "shelf" from the shoreline to about the -6 ft mean low water (MLW) isobath varies in width from 100 ft to a maximum of over 2000 feet.

Along the Potomac River, the nearshore bottom, which is important for structure stability, is relatively firm due to underlying medium stiff clays. The nearshore regions along the creek shores can vary from soft to hard. The nearshore region along the Charles County Shoreline were mostly firm but should be tested on sites where structures will be built.

2.5 Wind and Water Level Assessment

Wind data is used as a proxy for the wind/wave climate impacting individual shorelines. The closest long-term wind data set to Charles County is collected at Marine Corps Base Quantico, which is also on the Potomac River, and is used to describe the wind/wave climate along Charles County's shorelines. Hourly wind data from Quantico taken between 1973 and 2001 (Table 2-1) is categorized by cardinal and ordinal direction versus wind speed because the direction that the shoreline faces will determine which winds impact it. In addition, the wind/wave climate impacts erosional processes when water levels are elevated and wind speeds are about 20 mph or greater.

The analysis showed that the north direction has the highest overall percentage of frequency of occurrence (28%) and some of the highest winds. Because Charles County's shorelines generally face west, south, and east, these northerly winds do not directly affect Charles County shorelines. However, northwest winds, which have the second highest frequency (19%) and some of the highest winds, do impact the west-facing shorelines. The winds from the south, which impact south-facing shorelines, have the third highest frequency (18%) and some higher winds.

Basco and Shin (1993) described the wave climate through Chesapeake Bay and its tributaries. Their scenario analysis utilized winds of 35 miles per hour to predict waves patterns that could be expected to impact the coast about once every two years. The storm surge for this scenario is about 2.5 feet above mean high water (MHW). The resultant wave contours are plotted on Figure 2-4. The predicted wave height and period are the same along each contour line depicted on the map which is labeled with the wave height (in feet) on the top and the wave period (in seconds) on the bottom in parentheses. For example, wave heights and wave periods along contour closest to the shoreline along Reach II at Swan Point and Lower Cedar Point are 3.0 ft high with a period of 3.4 seconds. Farther north offshore Blossom Point, the predicted 2-year event can be expected to result in waves that are 2.5 ft high

Table 2-1. Summary wind data from hourly occurrences between 1973 and 2001 at Quantico.

# Occurrences									
Wind Speed									
mph	S	SW	W	NW	N	NE	E	SE	Total
0_5	12120	4194	6813	15305	35670	3282	3798	4725	76489
5_10	18480	6720	10506	13811	12522	7785	5461	6772	102844
10_20	4400	2175	2151	7434	6790	2984	1050	1287	63453
20_30	93	79	109	439	293	95	47	35	3620
30_40	3	3	7	9	15	3	3	2	45
40_60	2	0	1	2	1	0	1	1	8
Total	35098	13171	19587	37000	55291	14149	10360	12822	197478
Percentage									
	S	SW	W	NW	N	NE	E	SE	Total
0_5	6.1	2.1	3.5	7.8	18.1	1.7	1.9	2.4	31
5_10	9.4	3.4	5.3	7	6.3	3.9	2.8	3.4	41.7
10_20	2.2	1.1	1.1	3.8	3.4	1.5	0.5	0.7	25.7
20_30	0	0	0.1	0.2	0.1	0	0	0	1.5
30_40	0	0	0	0	0	0	0	0	0
40_60	0	0	0	0	0	0	0	0	0
Total	17.8	6.7	9.9	18.7	28	7.2	5.2	6.5	100

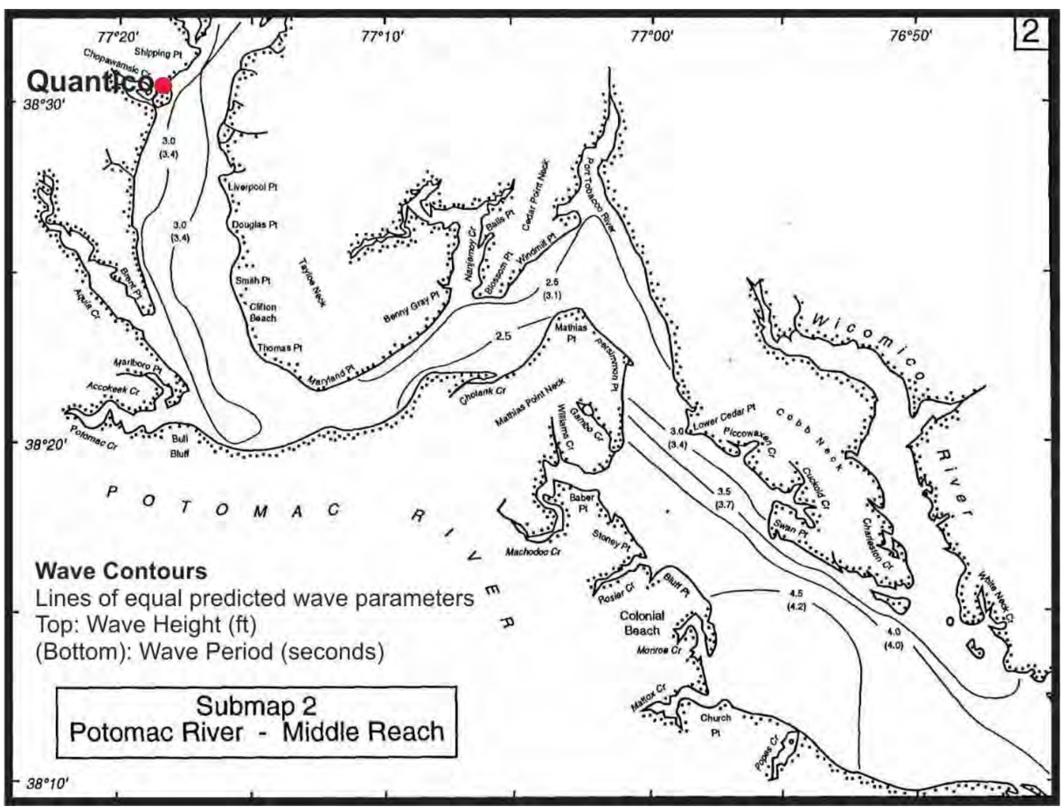


Figure 2-4. Wave modeling results along the Potomac River near Blossom Point from Basco and Shin (1993).

with a period of 3.1 seconds. These waves are predicted offshore and may shoal before they reach the shoreline at those heights.

Storms are a large part of the force of change along Potomac River shorelines. Two types of storms can impact the shore -- hurricanes and northeasters. During a hurricane, storm surges can exceed 6 feet along the Potomac River and high winds can generate a 4-foot breaking wave capable of transporting significant amounts of sediments. Northeasters have weaker wind fields and generally have surges less than 5 feet. However, these extratropical storms usually have longer durations and can span several tidal cycles significantly elevating water level during times of high tide. The frequency of various storm surge levels is shown in Table 2-2. Generally, storm surge levels increase farther up rivers and creeks because the waterbodies tend to become narrower upriver.

Table 2-2. Storm Surge Levels for Charles County (FEMA, 2015).

		Elevation (ft NAVD88)			
Waterbody	Location	10% Annual Chance; Recurrence interval is 10 years	2% Annual Chance; Recurrence interval is 50 years	1% Annual Chance; Recurrence interval is 100 years	0.2% Annual Chance; Recurrence interval is 500 years
Mattawoman Creek					
	480 ft downstream of Hawthorne Rd.	4.6	5.6	5.9	8.3
	Entire Mattawoman Creek shoreline within the Town of Indian Head	4.7-4.8	5.7-5.8	6.0-6.1	8.1-8.3
	Confluence with Potomac River	4.7	5.7	6.1	8.1
Patuxent River					
	Downstream side of State Rt. 231	3.8-3.9	4.7	5.0	7.3
Potomac River					
	Charles & Prince George County boundary	5.0	5.9	9.3*	8.9
	Confluence of Pomonkey Creek	4.9	5.8	8.8*	8.5
	Entire Potomac River shoreline within the Town of Indian Head	4.8	5.8	8.6-8.7*	8.4
	Confluence of Mattawoman Creek	4.7	5.7	6.1	8.1
	At U.S. Rt. 301	4.1	5.4	5.8	7.3
	At Swan Point	4.1	5.4	5.7	7.1-7.2
	At Cobb Island	3.9-4.0	5.2-5.3	5.6-5.7	6.6-6.8
Wicomico River					
	At Cooksey Point	4.4-4.5	5.6	6.1	9.5
	At Rock Point	4.0	5.2-5.3	5.6	6.9-7.0
*This value is from the 2008 USACE storm surge study.					

Tides and tidal currents can have an impact on wind/waves and sediment movement along the project shorelines. The mean tide ranges vary along Charles County. Table 2-3 shows the mean tide range (the difference between MHW and MLW). Similar to storm surge, tide ranges typically increase up rivers and creeks because the tide wave is squeezed by the narrower basins. Tidal currents off Maryland Point, about 6 miles upriver, are 1.8 knots for maximum ebb and 1.4 knots for maximum flood. Tidal currents were considered but are not a direct parameter in the wave climate analysis.

.

Table 2-3. Tide ranges in Charles County. Obtained from the Shoreline Studies Program Tide Range Google Earth tool.

Location	Average Mean Range (ft) MLW-MHW
Wicomico River to Port Tobacco River	1.6
Port Tobacco River to Mallows Bay	1.3
Mallows Bay to Indian Head	1.6
Indian Head to the Prince George County Line	2.1
Patuxent River	1.5

2.6 Environmental Setting

Locally in Charles County, marine flora resources of primary concern are submerged aquatic vegetation (SAV) because sea grasses offer habitat to various fish species. In 2017, SAV was mapped in the upper reaches of Nanjemoy Creek and several areas on the west-facing Potomac River shoreline (SAV, 2018). A small bed occurs in a shallow bay near Mallows Creek; Chickmuxen, Mattawoman, and Pomonkey Creeks have SAV; and north of Indian Head, SAV occurs along the Potomac River shoreline. No SAV was mapped along the Potomac River shoreline south of the shallow bay near Mallows Creek to the County boundary with St. Mary's. Additionally, no SAV was mapped in the main section of Nanjemoy Creek, Port Tobacco, Wicomico, or Patuxent Rivers. However, SAV fluctuates from year to year. Between 2011 and 2015, SAV beds were located along many of the county's shorelines (SAV, 2018). For this reason, a SAV determination should be made as part of the project design process.

Oyster bed leases are mostly found in the Wicomico River and in the adjacent Potomac River (Figure 2-5). The historic leases are show in off-white in the figure. These are the sites that have historically been fished. The yellow data indicate oyster plantings that took place in the 1980s and 1990s. The orange data, that does show up well on the figure depicts oyster plantings from 2000-present.

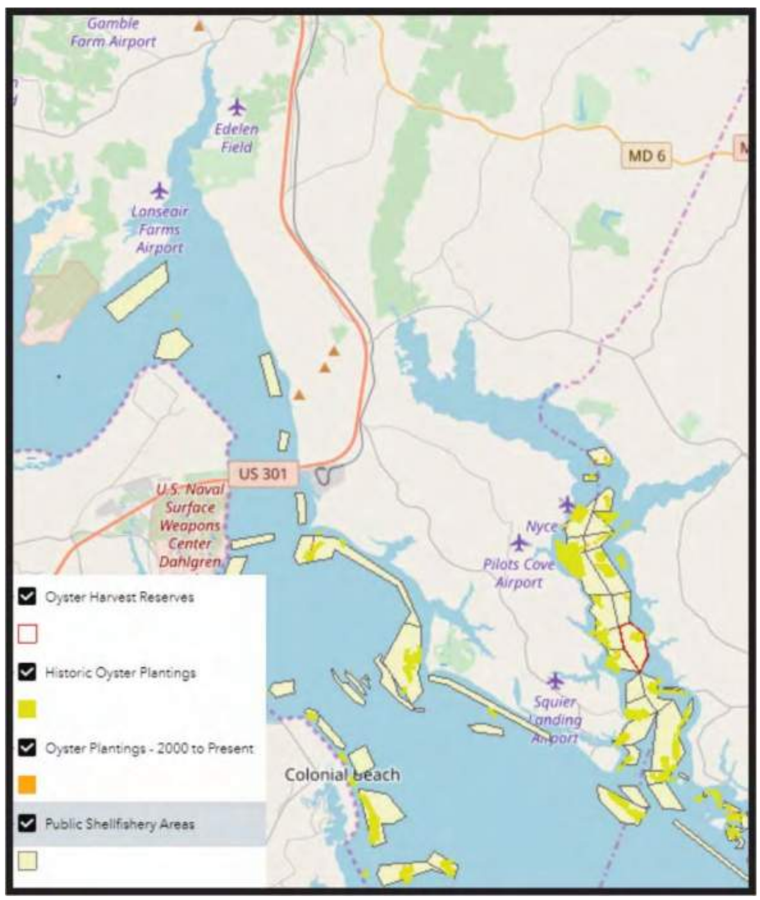


Figure 2-5. Oyster leases in the Charles County. From Maryland Coastal Atlas, https://gisapps.dnr.state.md.us/coastalatlas/WAB2/

The salinity varies around Charles County and varies over the course of the year. Higher river flows in the spring means fresher water farther south along the Potomac; in the fall, drier weather diminishes river flow, and salinities are higher farther up the river. Between 1985 and 2006, the Chesapeake Bay Program found that the mean surface salinity during the spring extended the tidal freshwater zone {0-0.5 parts per thousand (ppt)} to Aquia Creek (CBP, 2008). The rest of Charles County's Potomac River shoreline and its creeks and rivers were between 0.6-5.0 ppt. In the fall, the tidal freshwater zone only extended to Mattawoman Creek. From Mattawoman south to and including the Port Tobacco River, the salinity increased downriver from 0.6 to 7.5 ppt. The rest of the Charles County Potomac River and Wicomico River shorelines varied between 5.1 and 10 ppt. On the Patuxent River, the spring salinity was about 5-7.5 ppt, but in the fall, it was 10.1-12.5 ppt.

The National Wetland Inventory defines several different types of wetlands along Charles County's shoreline including Estuarine and Marine Wetland, Freshwater Emergent Wetland, and Freshwater Forested/Shrub Wetland (NWI, 2018). Estuarine and Marine Wetlands comprise most the wetlands in Charles County and occur along the upper reaches of the creeks and rivers and are estuarine, intertidal, emergent, persistent, as well as irregularly flooded. Dominate marsh grass species found include *Spartina alterniflora* (smooth cordgrass), *Spartina cynasuroides* (big cordgrass) and *Scirpus americanus* (American threesquare). Smaller areas of Freshwater Emergent and Freshwater Forested/Shrub occur which are emergent, persistent, scrub shrub, broad leaf deciduous, and seasonally flooded.

3 METHODS

3.1 Reach Boundaries, Geology/Geomorphology, and Shore Change

The Charles County's shorelines are described by reach and subreach based, in part, on fetch exposure, shore orientation, and geology (Figure 3-1). The County consists of seven reaches that were created through a combination of field observations, maps, charts, and aerial imagery:

- Reach I is along the Wicomico River from the County line to Cobb Point.
- Reach II extends from Cobb Point northward along the Potomac River up to the entrance to Aqua Land Marina.
- Reach III continues up the Potomac River and includes much of the Port Tobacco River.
- Reach IV, from just inside the mouth of the Port Tobacco River, continues out and up along the Potomac River, including Nanjemoy Creek and southwestward to Maryland Point.
- Reach V extends from Maryland Point up the Potomac to Mattawoman Creek.
- Reach VI goes from the mouth of Mattawoman Creek up the Potomac River coast to the County line along the north boundary of Piscataway Park, and
- Reach VII is on the Patuxent River.

Boat surveys were performed during the fall of 2017 to assess riparian upland, bank conditions, beach, intertidal and nearshore areas. Field notes were taken on base maps created from aerial imagery of Charles County taken in 2015 by the National Agricultural Imagery Program (NAIP) which collects 1-meter resolution imagery at the height of the growing season. In addition, global positioning system (GPS) referenced photos were taken. The field data were imported into Esri ArcGIS which is a geographic information system (GIS). The data for each management site are shown in Appendix A, B, and D.

The geomorphology of the study area was assessed using topographic maps and verified through field observations. A 2014 LIDAR survey of Charles County by the US Geological Survey (USGS) was used to obtain other information, particularly upland topography. In GIS, a cross-sectional profile of LIDAR data was created perpendicular to the shoreline at each shoreline management site to determine bank height. Bank height, as determined by LIDAR data, varied across a site; when this occurred, several cross-sections were drawn and the average elevation calculated. This was considered to representative of the site and was used in the ranking process. Bank height is depicted in Appendix D.

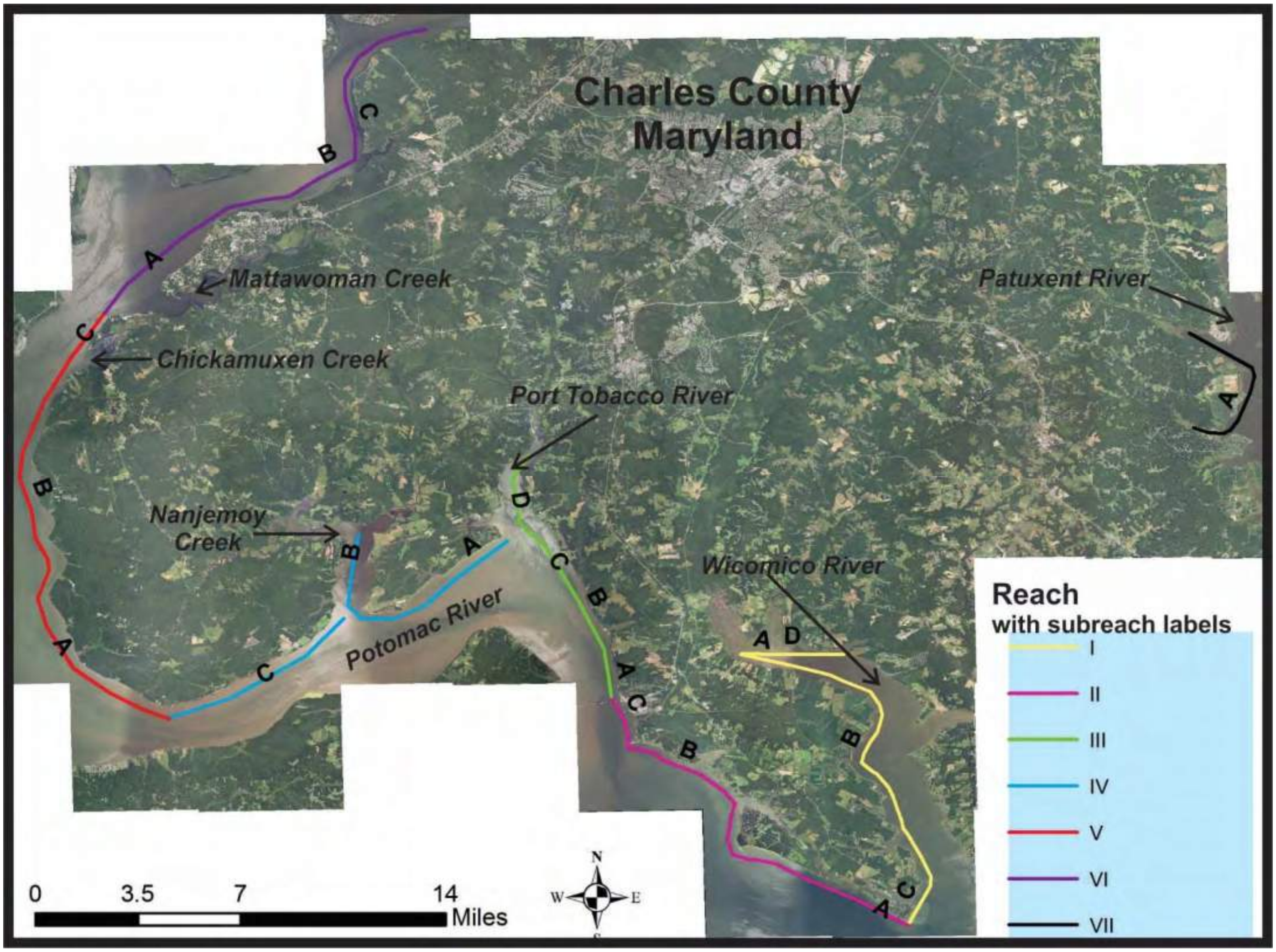


Figure 3-1. Location of reaches and subreaches within Charles County.

To determine shore change for Charles County, two shorelines were digitized for this project. The shorelines were digitized on the 1994 USGS digital ortho-quarter quadrangles and the 2015 NAIP images at scales that ranged from 1:2,000 to 1:5,000. Approximate high water was digitized as indicated by habitat - the edge of vegetation along marsh shorelines or by the wet/dry line on wide beaches and base of bank on narrow beaches. In many areas of the County, particularly those with high banks, tree cover obscured the shoreline. In these areas, the digitizer's experience was used to place the shoreline. These shorelines were analyzed in the Digital Shoreline Analysis System (DSAS) (Himmelstoss, 2009). DSAS was used to determine the end point rate (EPR) of change for County's shorelines between 1994 and 2015. The EPR described the net change between the two shorelines, whether erosion, accretion, or stability, for each site and are averaged in Appendix A. Shoreline change was mapped in Appendix D. Other existing shoreline datasets were considered but were determined to be too inaccurate in areas for use in the shoreline change analysis.

3.2 Riparian Upland, Banks and Nearshore Characteristics

The condition of the riparian upland, banks, and shore zone were qualitatively ascertained from alongshore boat observations and are shown in Appendix D. To simplify the field data for graphic display, a coding system was developed to display the condition of the base of the bank (BOB) and the bank slope or bank face (BK). The BOB and BK were characterized as 1) stable, 2) transitional or 3) erosive or undercut. Stable

BOBs were not undercut and often had a beach or vegetation along the base. Stable bank slopes were vegetated with relatively gentle slopes. The higher banks were sometimes complicated by stable slumps but had exposed and eroding upper bank faces. A transitional BOB was slightly undercut, possibly indicating a trend toward either more erosion or stability. Transitional bank slopes were partially vegetated banks with steeper slopes. Erosive BOBs often had vertical scarps at the boundary between the backshore and the BOB. Erosive bank slopes were steep, often vertically exposed, and had little or no stabilizing vegetation. Figure 3.2 shows an example of bank conditions with an erosive BOB and BK.

Nearshore depths were measured using a stadia rod and estimated time of tide along several cross-sections taken during the boat surveys. The nearshore also was frequently tested using probes to determine bottom conditions. This data was important to determine sizing of recommended structures and any factors that might influence stability of structures constructed in the nearshore.

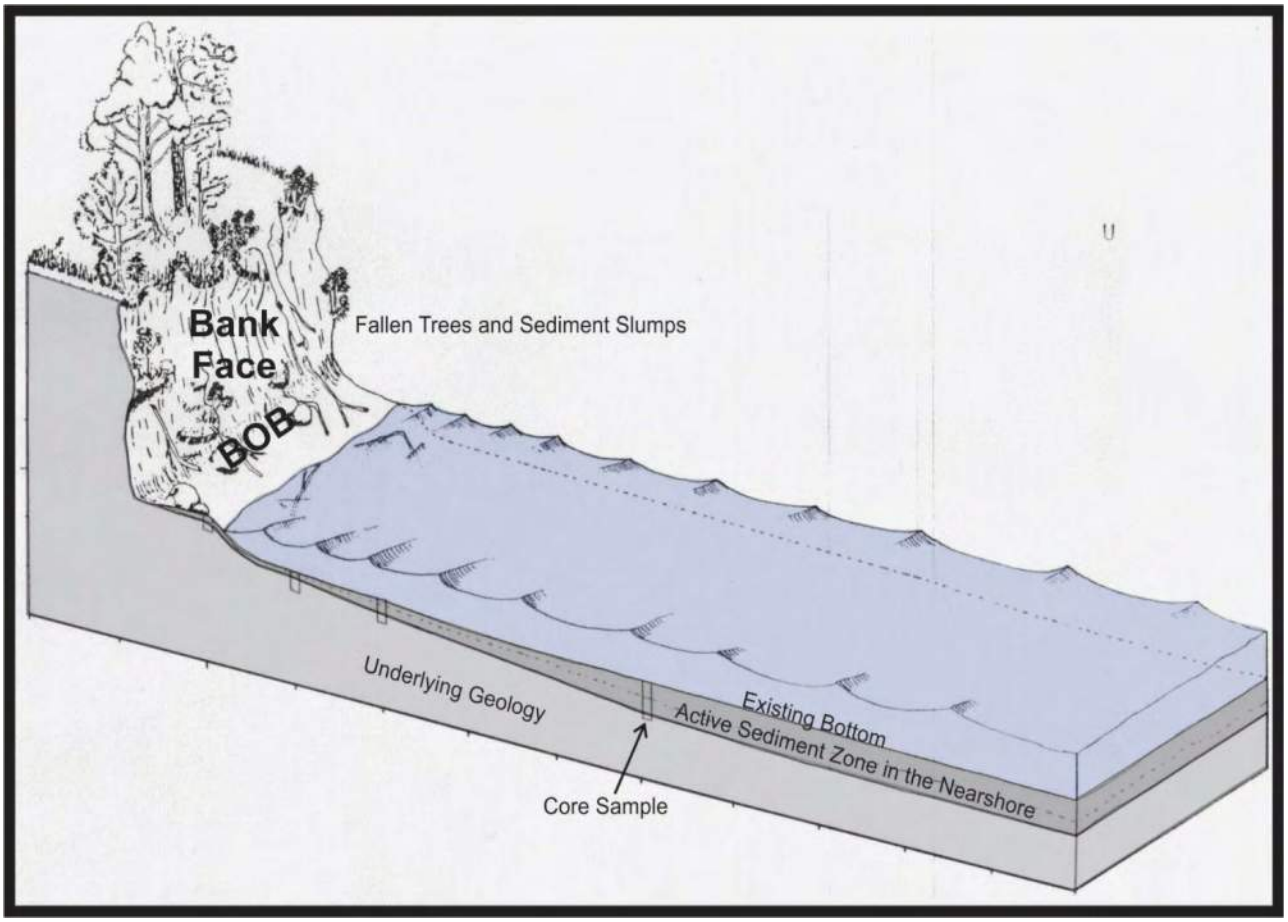


Figure 3.2 High Bank: erosive base of bank (BOB) and bank face (BK).

3.3 Wave Climate

To assess the wave climate along the Charles County coast, typical wave conditions were calculated using the US Army Corps of Engineers Coastal Engineer program, ACES. Longest and average fetch was calculated at five stations on the Potomac River and input to the program. Fetch is the distance over which wind can blow and generate waves. The longest fetch was the distance from the station to farthest shore regardless of angle. Average fetch used five arms radiating from the station to the distant shore at 45-degree increments on either side of the arm perpendicular to the shoreline. These five measurements were averaged to determine average fetch. Once fetch was calculated, the ACES model was used to predict wave heights and periods for specific wind and storm surge conditions. Wind/waves were calculated for the 25, 35, 45, and 55 mph winds with +3, +4, +5, and +6 ft surge levels above mean low water (MLW), respectively. See Appendix C for wave analysis of selected sites referenced in Section 12.

3.4 TMDL Credit Assessment

Shoreline conditions with both high erosion rates and agricultural riparian land use have potential to input large amounts of total suspended sediments (TSS), total nitrogen (TN), and total phosphorous (TP) to the Potomac River. Preventing or reducing these contributions could yield credit toward achieving TMDLs. Presently, three different methods can be used to determine the reductions or credits gained:

1. Calculating site specific credit based on field samples,
2. using MDE's (2014) standard efficiencies, and
3. applying the Environmental Protection Agency (EPA) protocols of Dresher and Stack (2015a) based on the type of shoreline management practice being installed.

More information on methods 2 and 3 can be found in Appendix E.

TSS Calculation

A combination of historic shoreline erosion rates and bank heights were used to generate TSS, TN and TP loading rates for sections of the shoreline. Bank heights were determined using Charles County LIDAR data. The calculation of lbs of sediments/ft/year was used to "normalize" the data (Appendix E). This calculation is only valid for the subaerial portion of the eroding banks. Eroding marsh was not be considered in the TMDL assessment.

To estimate sediment reduction rates using actual data, the volume of prevented erosion must be determined (Forand, 2015). Sediment loading rates were calculated using the following equation:

V=LEB where

V=volume of sediment eroded (ft^3),

L=length of shoreline segment (ft),

E=Shoreline erosion rate (ft/yr). (EPR as determined from the DSAS model)

B=Bank height

This equation yields a volume expressed in cubic feet per year. Cubic feet are converted to pounds using bulk density of 93.6lbs/ft^3 (Ibision, 1992), which is considered the default value bulk density. This volume is the TSS component. Refer to Appendix E for further TMDL discussion. The values for TSS, TN and TP were applied to all recommended sites in the plan Appendix E.

3.5 Prioritizing Shoreline Reaches

A table listing all recommended site projects is shown in Appendix A, and the sites were prioritized in Appendix B. The prioritization ranking structure consists of four categories to describe how each component affects the site ranking (Table 3-1). These are low, medium, high, and very high. Shoreline reaches that have high erosion rates were ranked as high priority at the P-1 level. Site ranking was based on four main criteria (Table 3-1) and, as they relate to prioritization of sites, are described below.

1) Erosion rate (active erosion) – The physical loss of land is most important both to the County and to the individual property owner. It results in acreage lost to the property owner and is a main factor in determining the volume of material eroded in TMDL calculations for the County. Therefore, the value

assigned to erosion rate was doubled in the ranking procedure to highlight its importance to both parties such that the highest erosion rates contribute the most to the ranking process.

2) Bank Height – The bank height dictates the amount of sediments contributing to Bay sedimentation, but more importantly, it determines the cost effectiveness of providing a "complete" shore protection project that achieves maximum coastal resiliency with bank grading. Since most of the recommendations given in the Plan were living shorelines that use sill systems with wetlands as part of the design, the ability of these wetlands to accommodate relative sea level rise was critical. Therefore, lower banks were prioritized as costs are lower and a gradual bank slope can be obtained. A 4:1 bank slope would allow for wetland landward migration in the face of sea-level rise. Banks that are not graded or are too high to accommodate a 4:1 slope restricts landward migration of the wetland, and ultimately, the wetland is subject to "coastal squeeze" where mainly vertical accretion by the wetland allows it to persist. Recent research has shown some Bay marshes are keeping up with sea level rise (Kirwan et al., 2016), but allowing the marsh to migrate landward could ensure its survival over time.
3) Buffer Width – Buffer width was chosen as a ranking criterion for several reasons. The width of trees along the shoreline can be a proxy for land use because agricultural and residential properties tend to have smaller or no buffer. The sites with smaller buffers had higher rankings than those of wooded tracts of land. Agricultural lands were considered the highest priority because of "legacy" applications of fertilizer and nutrient bound to sediments which are eroding. This relationship is not necessarily well known, but research conducted by Ibison et al. (1992) studied and categorized potential relationships. Furthermore, the width of the wooded buffer was considered a concurrent factor because a very narrow or no wooded buffer made the site potentially more accessible and easier to grade without mitigation for tree removal, and thus was given higher priority.
4) Project length – Longer projects tend to be more cost effective in terms of mobilization and demobilization and may give a better cost/foot value. Longer sites received a higher ranking.

For the ranking, the values for erosion rate, bank height, buffer width, and site length were added together. Erosion rate was assigned values of 2, 4, 6, and 8, while bank height, buffer width, and site length were assigned values of 1, 2, 3, and 4. The Priority Ranking, P-1, P-2, and P-3 designations discussed in the report are based on this primary analysis. No sites fell into the P-4 category; this is likely because the management sites were chosen because they were good candidates for shore protection projects due to active bank erosion. Those sites that were stable or too remote for practical application of shore management techniques generally did not receive a site designation. Therefore, no sites fell into the low category.

Though not included in the site ranking, additional criteria are important considerations to cost and constructability and are provided. These include:

- Acres lost per year – A function of erosion rate times the project length
- Access/Constructability – This criterion describes whether the site will have to be accessed by land or by barge. Land access was graded as a function of proximity to state roads, existing access, and width of wooded buffers. Agricultural lands often have access along adjacent woods for farm equipment and may need improvement or logging mats; however, logging mats can be expensive and increase the overall cost of a project. Barge access is dependent on water depth which is usually at least 3 feet MLW adjacent to the project. Project size/length can be a factor for barge access where a certain minimum of rock tonnage and/or sand volume is needed to be cost effective.
- Permitting challenges – Submerged aquatic vegetation (SAV) occurring in the project footprint will make permitting very difficult and alternate solutions would be required. If a recommended sill system impacts an SAV bed, a stone revetment would be an option, but a drawback to this is that no credit for created wetlands could be obtained.

- TMDL credits utilizing default values for TN, TP and TSS and Impervious Surface Credit (Appendix B and Appendix E). After the site ranking (per Table 3-1), sites were sorted by their priority level, Total rank, and then by TSS as calculated in Appendix E.

Table 3-1. Ranking criteria for eroding shorelines.

Ranking						
			Low	Medium	High	Very High
Erosion Rate	ft/yr	Criteria	<-1	>-1	>-2	>-3
		Ranking	2	4	6	8
Bank Height	ft	Criteria	>50	>20	20-10	<10
		Ranking	1	2	3	4
Buffer Width	ft	Criteria	>100	<100	<50	<5
		Ranking	1	2	3	4
Project Length	ft	Criteria	<500	500-1,000	1,000-2,000	>2,000
		Ranking	1	2	3	4
Total Rank			**5**	**6-10**	**11-15**	16-20
Priority Ranking			**P-4**	**P-3**	**P-2**	**P-1**

4 SHORELINE MANAGEMENT ELEMENTS

4.1 Objectives

The first step in developing a framework for shoreline management is establishing clear objectives and directing efforts towards those erosion control strategies which will meet those objectives. Charles County's Shoreline Management Plan aims to meet the following objectives:

- Prevent loss of land and protect upland improvement.
- Protect, maintain, enhance and/or create wetland habitat, both vegetated and non-vegetated.
- Enhance coastal resiliency
- Assess the potential for TMDL credits.
- Manage upland runoff and groundwater flow which may exacerbate bank erosion.
- For each proposed shoreline strategy, address potential secondary impacts within the reach which may include impacts to downdrift shores through a reduction in the sand supply or the encroachment of structures onto subaqueous land and wetlands.

Application of these objectives must be assessed in the context of a shoreline reach. While all objectives should be considered, each one will not carry equal weight. In fact, satisfaction of all objectives for any given reach is not likely as some may be mutually exclusive or not applicable.

Living shorelines are a best management practice that address erosion and enhance ecosystem services by providing long-term protection, restoration, or enhancement of vegetated shoreline habitats through strategic placement of plants, stone, sand fill and other structural or organic materials. Living shorelines are the overarching guide for the recommended protection strategies in the Plan because sills with low marsh are considered living shorelines. In higher energy areas where marshes are not feasible, breakwaters with sand fill and beach grass plantings can be used. However, not all erosion problems can be solved with a living shoreline design, and in some cases, a revetment is more practical. Living shoreline strategies provide the suitable gradient to address sea-level rise and enhance the coastal resiliency of the Charles County coast. The land use, active shore erosion, and shore zone geomorphology of each section of shoreline determined, in part, the detail of the shoreline management recommendations.

4.2 Protection Strategies and Coastal Structures

Four general types of shore protection strategies were considered in the discussion of each shore reach within the study area. These strategies consisted of several different types of structures including revetments, sills, breakwaters, spurs and groins, sand nourishment, and combinations of these structures that make up. They are discussed below.

4.2.1 No Action

Essentially, a no action strategy allows the natural processes of shoreline erosion and evolution to continue as they have for the past 15,000 years as part of the latest sea-level transgression. Anthropogenic impacts, such as infrastructure development, agricultural practices, and forest removal, have altered the natural processes. Threatened infrastructure, like roads and buildings, may force the implementation of shore protection strategies. Moving the buildings and roads will delay the problem, but it also might allow more room to initiate a lesser degree of bank work and a reduction in size and scope of shore structures.

No action can include low cost measures to address bank stability problems at the top of the bank by reducing the amount of storm water runoff and infiltration that reaches the bank slopes.

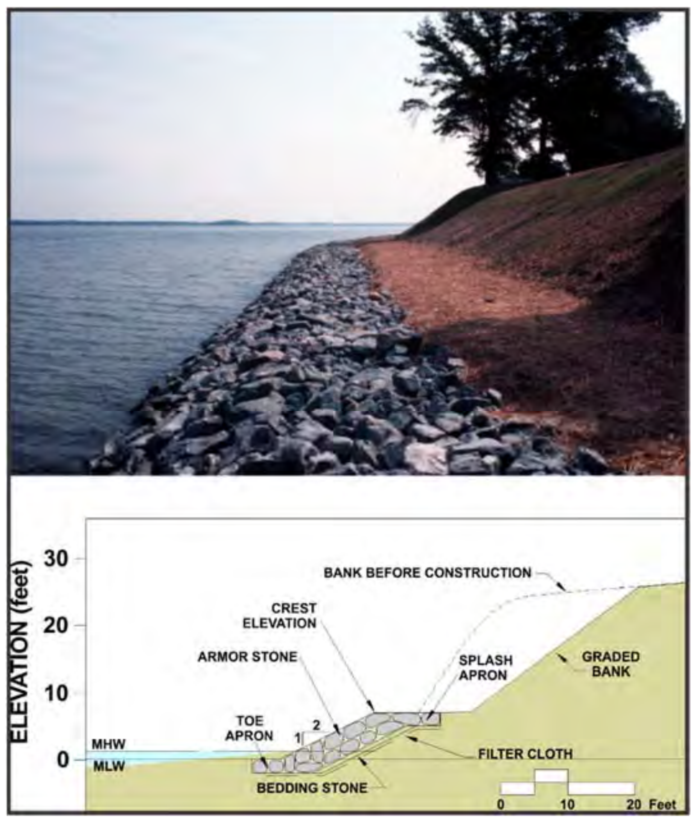


Figure 4-1. Stone revetment (top) and cross-section of elements necessary for proper stone revetment design (bottom). From Hardaway and Byrne (1999).

4.2.2 Defensive Approach

The Defensive Approach refers to the use of shore protection structures that commonly are placed along the base of an eroding bank as a "last line of defense" against the erosive forces of wave action, storm surge, and currents. For the purposes of this study, stone revetments are the strategy employed.

Revetments are shoreline armoring systems that protect the base of eroding banks and usually are built across a graded slope (Figure 4-1). The dimensions of the revetment are dependent on bank conditions and design parameters such as storm surge and wave height. These parameters also determine the size of the rock, also called riprap, required for long-term structural integrity. Generally, two layers of armor stone are laid over a bedding stone layer with filter cloth between the earth subgrade and bedding layer.

4.2.3 Offensive Approach

The Offensive Approach to shoreline protection refers to structures that are built in the region of sand transport to address impinging waves before they reach upland areas. These structures traditionally have been groins, but over the past decade, the use of breakwaters and sills have become important elements for shoreline protection. Spurs sometimes are installed on breakwaters and sills to move the wave diffraction point further offshore to assist in attaining local equilibrium of the shore planform. The use of offensive structures requires a thorough understanding of littoral processes acting within a given shore reach.

Breakwaters and sills are "free standing" structures designed to reduce wave action by attenuation, refraction, and diffraction before it reaches the upland region. A sill (Figure 4-2) has a lower crest, is usually closer to shore, and more continuous than larger breakwater units. Sills are installed with beach fill to create a substrate for establishing a marsh fringe.

Attached or headland breakwaters usually require beach fill to acquire long-term shoreline erosion control (Figure 4-3) because they are generally constructed in areas that are subject to more energetic conditions. Headland breakwaters can be used to accentuate existing shore features and are the primary component for Headland Control. The dimensions of a breakwater system are dependent on the desired degree of protection and potential impacts on littoral processes.

Figure 4-2. Webster Field Annex, Maryland sand fill with stone sills and marsh photos, Top: before installation, Middle: after installation but before planting, and Bottom: four years after installation. The typical cross-section from the project also is shown. From Hardaway et al. (2010).

Figure 4-3. Image from Google Earth showing a breakwater installation (top) and a typical breakwater cross-section (bottom).

A brill system is a combination of a sill and breakwater (Figure 4-4). It consists of relatively long sill structures with wide gaps like a breakwater system that can be used to create marsh in somewhat higher energy environments than a typical sill. This allows for both extensive marsh and beach habitats to exist along the same coast because it is closer to the shoreline than a breakwater system. Marsh is planted behind the structures while the embayments between the structures allow for wide beaches.

Spurs are like breakwaters and sills in that they are "free standing" structures. The distinction is that spurs are attached to the shoreline or another structure and extend at an angle (Figure 4-5). These differ from jetties in that jetties are typically perpendicular to the shoreline, although jetties can have a spur at the unattached end. The unattached end of the spur acts as a breakwater by diffracting, or spreading out, incoming waves. Spurs often are used as interfacing structures between other strategies and/or adjacent unprotected coasts.

4.2.4 Headland Control

Headland control is an innovative approach to shoreline erosion protection because it addresses long stretches of shoreline and can be phased over time. The basic premise is that by controlling existing points of land (i.e. headlands) or strategically creating new points of land, the shape of the adjacent embayments can be predicted (Hardaway and Byrne, 1999). A thorough understanding of the littoral processes operating within the reach is necessary to create a stable planform. Headland control can utilize elements of the three previous strategies.

Figure 4-4. Brill system soon after construction at Westmoreland State Park in Virginia. These large structures are more continuous than breakwaters, but they are farther offshore than a sill. Eventually, the backshore will begin to vegetate.

Headland control can be accomplished with the aforementioned structures and usually involves protecting a point or shore headland (Figure 4-6). This strategy partially protects long reaches of shoreline because littoral sands are encapsulated to create a beach, and impinging waves are redirected so that they have less impact alongshore. By providing a strategic hard point, adjacent shorelines can erode into equilibrium planforms. Predicted, stable shore planforms between proposed headland structures are provided for recommended shoreline strategies of each reach. These planforms are estimates based on general wave climatology and shoreline composition (*i.e*. marsh, upland).

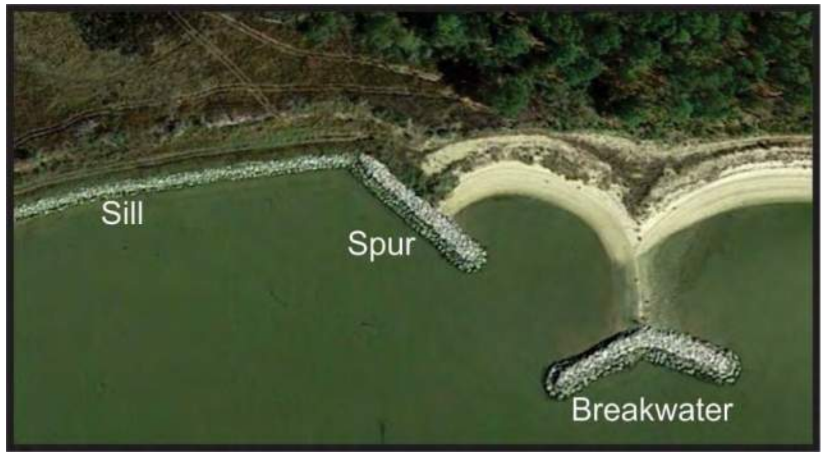


Figure 4-5. Structures at Swan Point include a breakwater, spur, and sill. The spur is attached to the mainland and protrudes at an angle. Google Earth Image.

Figure 4-6. Examples of headland breakwaters spaced widely apart to allow adjacent shoreline to erode toward a dynamic equilibrium. This is a cost-effective shoreline management strategy when infrastructure is not threatened by the upland erosion between the structures. From Hardaway and Byrne (1999).

4.3 Structure Design and Sea-Level Rise

The US Army Corps of Engineers has developed an adaptive management philosophy regarding future estimates of sea level rise (SLR) (USACE, 2014). Implementation strategies range from a conservative anticipatory approach, which constructs a resilient project at the beginning of the project life cycle, to a reactive approach, which consists of doing nothing until the impacts are experienced. Between the two extremes is an adaptive management strategy, which incorporates new assessments and actions throughout the project life based on thresholds and triggers. Most site recommendations for Charles County shorelines are sill systems with rock, sand and plants with or without bank grading. Rather than adding rock and sand to the sill system initially to accommodate some future higher level of sea level or provide a plan for future adaptation, this Plan utilizes the bank grading component in the initial design and construction of shore protection recommendations. Therefore, the most cost-effective route to achieving maximum coastal resiliency is to protect low banks where bank grading costs are less and using more gradual bank grades, such as a 4:1 slope rather than the minimal 2:1 slope, where practical. More gradual bank grades allow the wetland component to migrate landward more effectively (see Section 2.2). The question then becomes when is the addition of rock to the sill structure most timely? Or should it be done initially at present day cost?

According to the USACE (2014), increased water levels produce an increase in depth-limited wave heights. Because rubble-mound armor unit stability is proportional to the wave height cubed (H^3), a relatively moderate increase in water depth produces a much higher load on armor units. These statements pertain to much larger rock structures in more exposed wave energy settings. However, the basic premise is the same even at lesser wind wave climate.

On the Potomac River, the open shoreline reaches from Blossom Point to the Port Tobacco River and down to Cobb Island have fetch exposures of over 10 miles and can experience incoming storm waves of over 3.5 feet generated by a 40-mph wind. On the ocean, this would be considered minor; on the Potomac it is a design condition for the 25-year event.

Furthermore, impacts to project performance might include a higher wave height in the lee of a coastal structure and/or a greater inundation frequency and magnitude to the adjacent wetlands and banks. According to the Corps, a determination is made as to whether the expected impacts are driven by extreme events or by overall process changes. Examples of process-driven impact are increased salinity in an estuary or a gradual change in the overall mean or high tide range, both of which are pertinent to Chesapeake Bay shorelines.

Designing shore protection structures for specific return storm surge frequencies provides a metric by which the proposed system can expect to perform during that event. Factors to consider include costs, what's being protected, and durability. The shore protection system is usually designed for a storm condition, usually a 25-year event. A system does not necessarily fail at higher water levels and wave energies, but bank erosion may occur when the system is overtopped. The sediment from the non-graded bank will slump onto the fronting protective marsh, perhaps covering some. This process can create a more stable bank condition as it evolves to a more equilibrium slope. Typical eroding banks are at a 1:1 slope, but as they move toward a 1.3:1 slope, they become more stable.

In regard to durability, these systems composed of properly placed rock, sand, and plants have been very successful around the Chesapeake Bay watershed as demonstrated by projects that have been installed for 10, 20 and 30 years (Hardaway and Gunn, 2010). Looking to 2050 (34 years from now), with sea level rising at a rate of about +0.016 ft/yr (Colonial Beach), water levels will be about 0.5 ft higher somewhat submerging the sand and rock structures. Adaptive management considers if or when the system may need to be raised with additional rock and sand or require bank grading. This should be a consideration when the conceptual structures in this plan enter the design, permitting, and construction phase.

Three existing projects in Charles County were designed by Coastline Design, PC that include sills and breakwaters. These include Swan Point breakwaters, Horse Farm sill, and Indian Head sill system. The Swan Point breakwater system was installed in 2010 and consists of 12 breakwaters, two spurs and a sill extending along about 1 mile of coast (Figure 4-7). Horse Farm sill system was installed in 2002 and is about 650 feet long (Figure 4-8). Both the Swan Point breakwater and Horse Farm sills have long fetch exposure so the southwest and south across and down the Potomac River of 5 to 10 miles, respectively. The Indian Head sill system was installed in phases between 2008 and 2012 totals over 3.1 miles in length with numerous gaps in the sills and intermittent bank grading (Figure 4-9). The gaps in the structures, also sometimes called windows, allow the ingress and egress of marine fauna.

Figure 4-7. Swan Point breakwaters Top: post-construction, pre-planting, 27 March 2012; and Bottom: Four years post-construction, July 12, 2016.

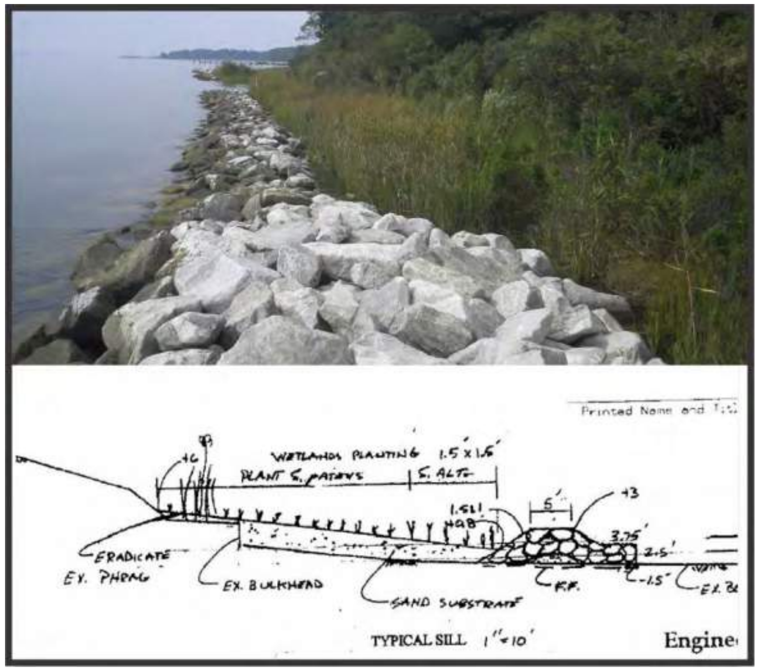


Figure 4-8. Swan Point Horse Farm Sill, Top: Photo taken on 3 October 2013, and Bottom: Typical cross-section.

4.4 Typical Structure Design

Five typical sill sections are recommended for the Charles County Shoreline Management Plan. The Type 1 sill is for very fetch limited shorelines (fetch less than 1 mile) and has a low rock crest at +2.5 ft MLW with clean sand that should go up the eroding bank face at least to +3 ft MLW at about a 10:1 grade (Figure 4-10). This relationship determines the position/distance of the sill from the BOB. The sand fill should intersect the back of the sill at no less than +1.0 ft MLW to establish the low marsh planting width. Previously, intersecting at mean tide level (MTL) was the “standard” but with increased sea level rise scenarios a higher intersection is warranted.

Figure 4-9. Indian Head Sill Top: Pre-construction in 2002, Bottom: 25 June 2012.

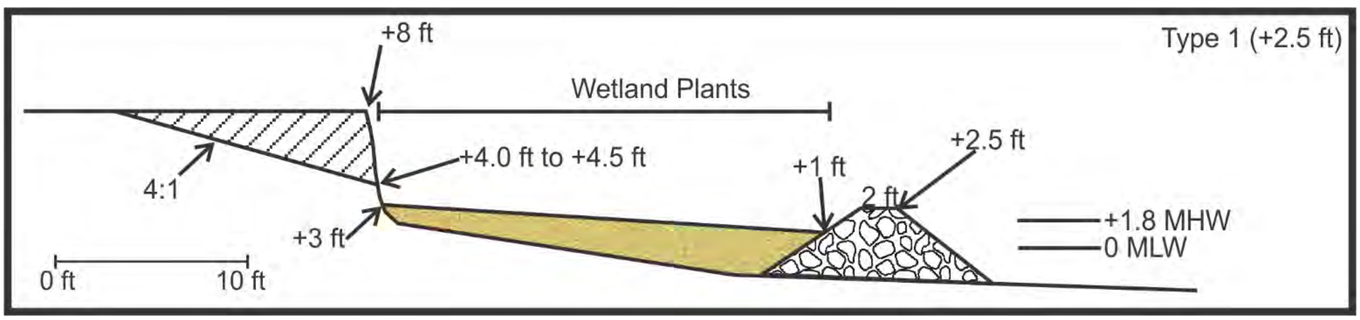


Figure 4-10. Type 1 typical sill cross-section.

The Type 2 sill is also for restricted fetch exposures between 1-2 miles (Figure 4-11). The sill height is +3.0 ft MLW with the sand fill intersecting the bank at +4 ft MLW or higher. Again, the sand fill should be on about a 10:1 grade. This can vary depending on site conditions, such as whether bank grading is part of the project design, and the need to increase the low marsh planting. The Type 3 cross-section illustrates two

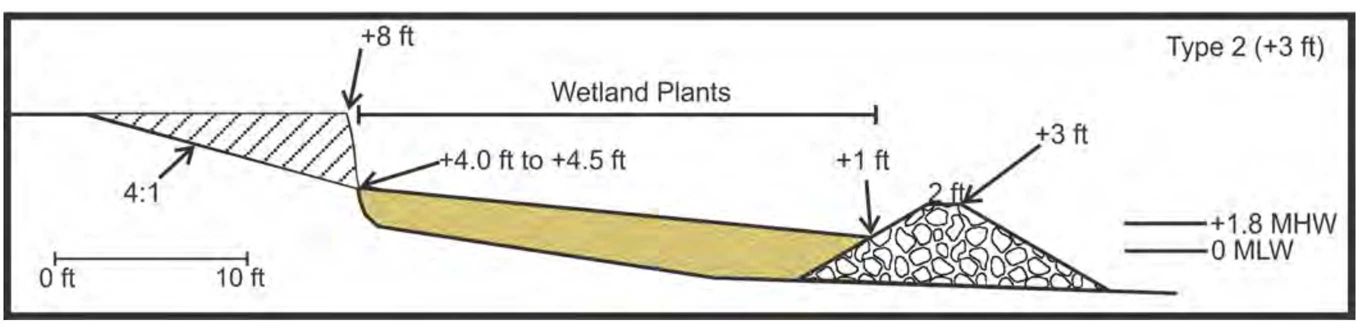


Figure 4-11. Type 2 typical sill cross-section.

different slopes of the placed sand where the lower sand goes from +1 to +2 on 15:1 grade, then has a steeper slope to the BOB/fill intersection at +4.5 or +5 MLW (Figure 4-12). This dual sand grading scenario provides approximately equal areas for the high and low marsh species. The Type 3 sill is higher at about +3.5 MLW because it is recommended in areas that have a fetch exposure greater than 2 miles, such as near the mouths of the lateral creeks and rivers.

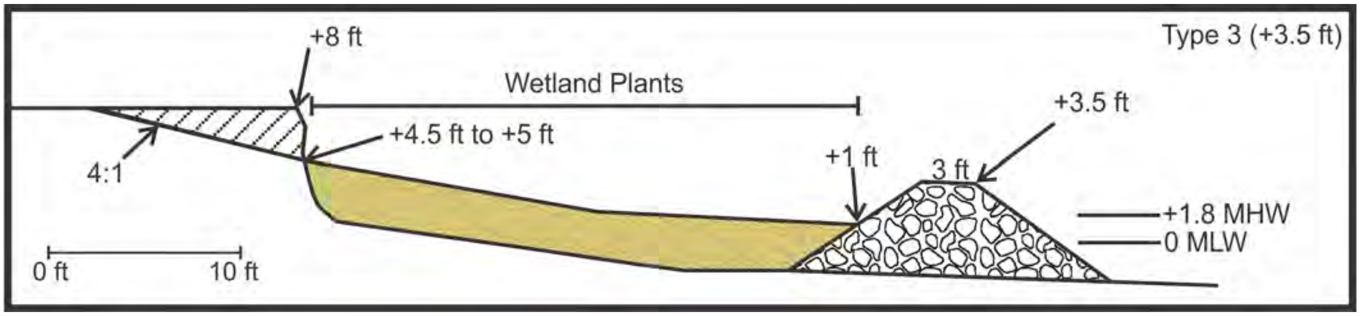


Figure 4-12. Type 3 typical sill cross-section.

On the open Potomac River shorelines, the Type 4 and Type 5 sill sections are recommended. The Type 4 is a minimum structure along the open river with a +3.5 ft crest elevation, 4 ft crest width, and sand intersecting the BOB at +4 to +5 ft (Figure 4-13). The 10-year water level is about +4.5 ft and the 25-year is +5 ft. These are target elevations meant to reflect a certain level of protection. Once again bank grading may add or reduce these target elevations. The Type 5 sill is an even more robust system with a +4 ft MLW crest elevation and sand fill intersecting BOB at + 5 to +6 ft MLW (Figure 4-14). The +6 ft elevation is the 50-year to 100-yr storm level. Both the Type 4 and Type 5 sills depict the 15:1 low marsh terrace up to +2 ft.

How much bank grading necessary at a site is very much dependent on site-specific conditions. The 4:1 slope (or greater) is best for long term coastal resiliency, but it is only practical on lower banks, less than 12-15 feet, because typically the bank material must be handled onsite. For lower banks, the material may be used as an upland berm or elsewhere on site, and because most of the P-1s and P-2s are on agricultural land this

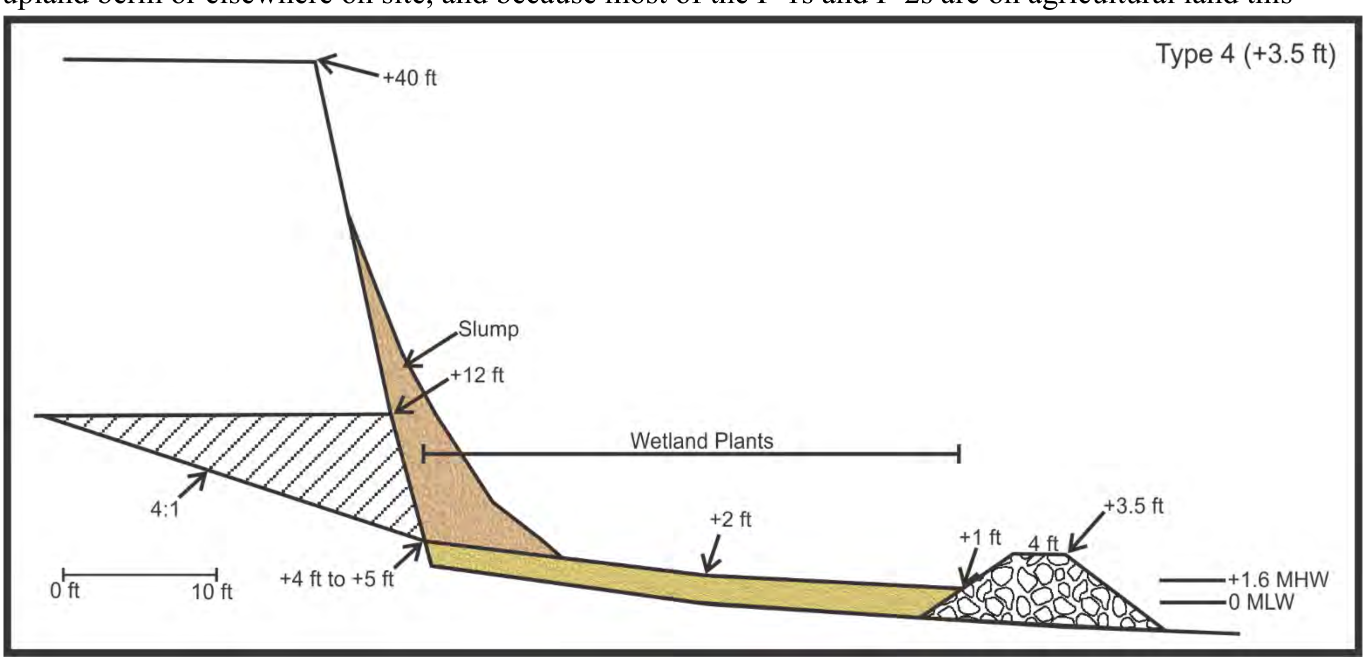


Figure 4-13. Type 4 typical sill cross-section.

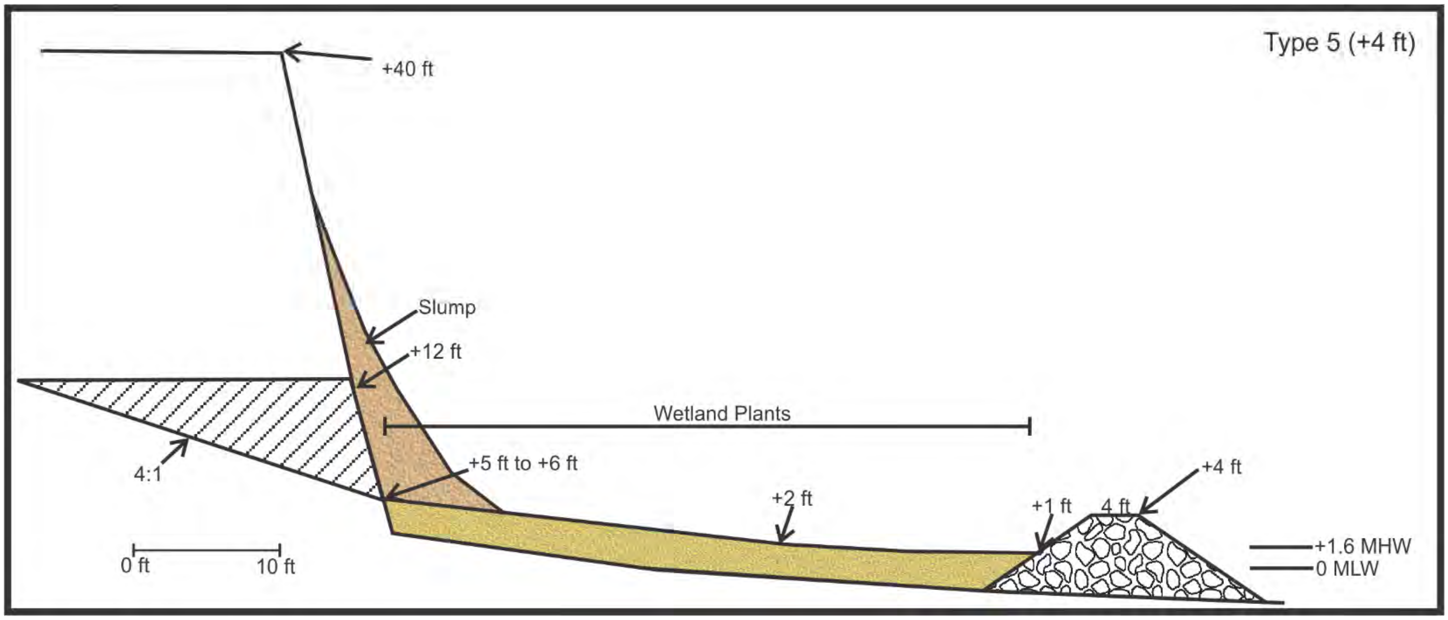


Figure 4-14. Type 5 typical sill cross-section.

opportunity is probably more practical. Not grading the bank is also an option which was used extensively on the Navy shoreline restoration project at Indian Head. This strategy allows natural sloughing to continue, and with a BOB stabilized by a structure, a state of dynamic equilibrium will be reached. However, both the top and face of the bank will continue to recede until equilibrium is reached which can impact infrastructure close to the shoreline. The final equilibrium grade will depend on bank height and composition (geology). These structures typically have more than 10 feet in front of the BOB to allow for sloughing bank material to accumulate, vegetate, and ultimately stabilize.

Another important design element is the nearshore water depth. The depth at the structure toe is depicted as -2 ft MLW on the Type 4 sill and -2.5 ft MLW on the Type 5 sill. As nearshore depths increase so does the amount of rock and sand required to accommodate the desired sill crest elevation and BOB sand fill intersection. Structures may have to be moved closer to the shore if funding does not allow for increased quantities. Alternatively, another structure type may be used, such as a revetment or high marsh; however, these structural solutions are not living shorelines. A few areas have revetments recommended as an alternative either due to nearshore SAV or nearshore depths >4 ft MLW, or both. These are noted in Appendix A.

5 CHARLES COUNTY, WICOMICO RIVER: REACH I

5.1 Physical Setting

Reach I extends along the shoreline of the Wicomico River from the County line down to Cobb Point at the confluence with the Potomac River, about 15 miles (Figure 5-1). Reach I can be roughly divided into 4 subreaches (I-A through I-D) running from north to south. Reach I-A is about 4.4 miles long and extends from Allens Fresh Run to Stoddard Point. Reach I-B extends about 3.3 miles from Stoddard Point down to Windmill Point. From Windmill Point to Cobb Point, about 4.7 miles, is Reach I-C. Reach I-D occurs on the north side of the Wicomico River extending from Allens Fresh downriver about 3 miles to the Charles County/St. Mary's County line.

Erosion rates of banks range from about -0.5 to -1.0 ft/yr along Reach I-A increasing to -0.8 to -2.8 ft/yr along Reach I-B and -0.2 to -2.5 ft/yr along Reach I-C. This is due to increasing fetch exposures from Allens Fresh to Cobb Point.

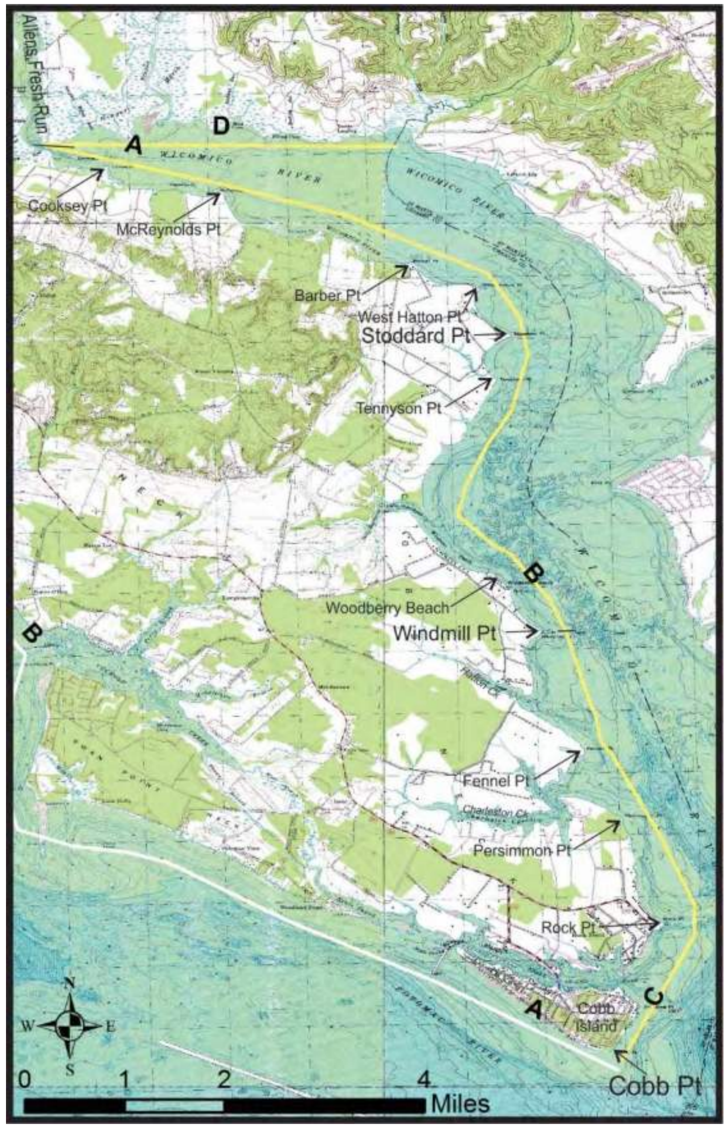


Figure 5-1. Reach 1 on the Wicomico River.

Reach I-A faces about east-northeast and is oriented about west-northwest to east-southeast, and the coast occurs as a series of headlands and embayments. Named points are the headlands and include from upriver to downriver: Cooksey Point, McReynolds Point, Barber Point, West Hatton Point, and finally Stoddard Point. These headland points appear to be ancient point bar features and the adjacent embayments are river meanders created during the last low stand in sea level when the channel was riverine. The banks are generally 5 to 10 feet in elevation and are composed of mostly clay material and actively eroding as evidenced by exposed BOB and bank face. This translates to the nearshore region where the bottom conditions are firm. A few remnant marsh fringes occur along the north-facing coast. The eroding banks are mostly wooded with adjacent agricultural land. The woodland varies from extensive parcels such as at site 2 (Figure 5-2) to little or none (Figure 5-3) at site 12. The bank decreases to about 3 feet high at Stoddard Point, a subtle sand spit feature.

Reach I-B turns southward downriver and occurs as a broad curvilinear embayment with defining headlands at Stoddard Point and Windmill Point with Tennyson Point and Woodberry Beach creating subtle headland features within the subreach. Several small tidal creeks issue into the Reach I-B embayment further segmenting the shorescape. Bank heights remain relatively low between 5 feet and 12 feet in elevation, with little or no marsh fringe. The banks are actively eroding with erosional BOB and bank. The geology underlying the banks and nearshore are predominately clay leading to firm bottom conditions in the nearshore. Wooded shorelines again vary in width from wide (>100ft) to no woodland. Site 23, assessed as a P-1 site, has one of

Figure 5-2. Reach 1-A – Eroding wooded upland bank, Site 2, Type 1 sill recommended.

the highest erosion rates in Reach I with no tree fringe along agricultural land (Figure 5-4). Intermittent residential properties occur along the Reach I-B coast, with the main ones located at Wicomico Beach and Woodberry Beach. These residential properties tend to be associated with defensive shoreline structures, such as bulkheads and revetments.

Figure 5-3. Reach 1-A – Eroding agricultural upland bank with no wooded buffer, Site 12, Type 2 sill.

Figure 5-4. Reach 1-B – Site 23, recommend a Type 3 sill; a designated P-1 site, eroding upland, farm field with no wood buffer.

The Reach I-C coast, beginning at Windmill Point extends southward to Cobb Point, is defined in part by headland points at Fennell Point, Persimmon Point, Rock Point, and Shipping Point. Hatton Creek drains into the embayment created by Windmill Point to Fennell Point, and Charleston Creek occurs between Fennell Point and Persimmon Point. Neale Sound drains into the embayment between Rock Point and Cobb Island. Upland bank heights remain low, between 5 ft. and 10 ft. Erosion rates for upland subreaches are between -0.8 and -2.5 ft/yr. The banks become sandier along Reach I-C, and the bottom is firm. The headland points are generally low sandy features, products of sediment derived from bank erosion updrift, upriver. The upland banks are actively eroding and have relatively narrow wood buffers fronting agricultural land and residential properties. The banks adjacent to Persimmon Point are widely wooded. The shoreline along Cobb Island is almost entirely residential and hardened with structures like bulkheads.

Reach I-D extends from Allens Fresh, on the north coast of the Wicomico River, downriver to the St. Mary's County line. The entire shoreline is a wide marsh resulting in stable upland banks that do not require any shore protection strategies.

The nearshore width is measured as the distance to the -6 ft MLW contour, which varies considerably along Reach I. Along Reach I-A, the -6 ft contour runs about 1,500 ft offshore the embayments and closes within several hundred feet off each headland point. The material in the very nearshore, within 50 feet of the eroding banks, is determined by the bank geology and is predominately clay and firm along the Reach I coast. No SAV beds occupied the nearshore region along Reach I in 2017 (VIMS, 2018).

5.2 Hydrodynamic Setting

The Wicomico River is about 0.5 miles wide at Cooksey Point, widening to 1.0 mile at Stoddard Point, Reach I-A. It widens to about 1.5 miles mid-way down Reach I-B and narrows to about 1.2 miles at Windmill Point. The River remains about 1.2 to 1.5 miles wide down to Cobb Point where it opens into the Potomac River. Reach I is mostly low wave energy coasts that get more exposed near the mouth of the Wicomico River and the Potomac River

Alongshore sediment transport along Reach I is generally downriver driven by the predominate northeasterly wind/wave climate. This is evidenced at the major points or headlands where the associated spits are trending asymmetrically downriver. However, at Rock Point, near the mouth of the Wicomico, the long spit feature is more symmetrical and is evidence of the southerly fetch exposure across the Potomac River.

Figure 5-5. Location of site recommendations 1-47 along the Reach I coast.

5.3 Shoreline Management Strategies and TMDL Assessment/Site selection

A total of 47 project sites are recommended along Reach I, totaling 6.4 miles (Figure 5-5) as listed in Appendix A. These are the options for Reach I:

No action – Expect ongoing erosion of shorelines that are currently eroding. Significant shoreline erosion often occurs during severe storm events.

Defensive – A great deal of shoreline is already hardened with defensive structures such as revetments along Reach I.

Offensive - Only a few existing living shorelines were noted, mostly in Neale Sound behind Cobb Island, but it is an appropriate strategy for future projects. The predominant shoreline protection strategy recommended for the eroding upland banks for Reach I is the rock sill system. Three types are recommended: Type 1 which is a small low sill with a crest height of +2.5 ft (Figure 4-8); Type 2 which is a low sill at +3 ft (Figure 4-9); and Type 3 which is a high sill with a +3.5 ft crest elevation (Figure 4-10). Type 3 is used primarily along P-1 designated sites for protection at the 25-year level of +5 ft MLW.

Headland control - Sill extensions or spurs are recommended as transition structures at headland points including West Hatton, Stoddard, Windmill, Persimmon, and Rock Points. By placing spurs off the end of the major points of land, this is a form of headland control. This will ensure the lee side of the point, which is mostly stable, will remain so.

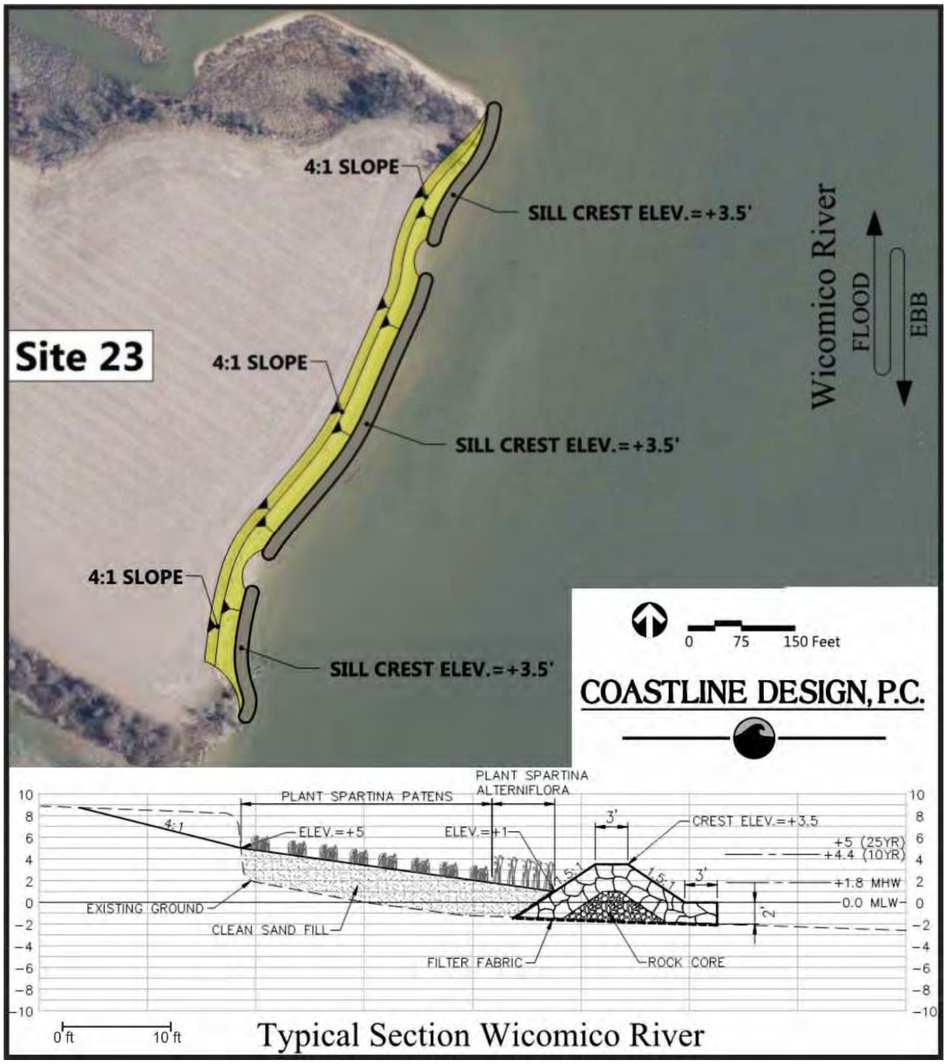


Figure 5-6. Site 23 conceptual plan and typical cross-section.

Only one site was designated a P-1(Appendix B) within Reach I. Figure 5-4 shows Site 23 which is agricultural land with a little to no wooded fringe and an erosion rate of -3.3 ft/yr. These conditions will result in less impact to a riparian buffer during construction access and bank grading, thereby requiring minimal mitigation. Consequently, this site has garnered a P-1 designation. Of the P-1s, site 23 has the highest ranking due, in part, to a relatively high erosion rate and unforested buffer. A conceptual plan was developed for this site (Figure 5-6).

From a cost effectiveness perspective, construction on multiple sites at a time should be considered. Reach I and Reach II sites are all accessed from Route 257, Newburg Road. Selecting two or more sites near each other should decrease construction costs if built at the same time. A two to four site package could begin the permit processes at the same time and could be constructed concurrently or sequentially after permit issuance. For instance, site 23 (P-1) and site 21 (P-2) could be constructed together.

6 CHARLES COUNTY, POTOMAC RIVER: REACH II

6.1 Physical Setting

Reach II begins at Cobb Point and extends up the Potomac River shoreline to Aqualand Marina, about 12 miles (Figure 6-1). Aqualand Marina roughly demarks the change in the underlying geology and the corresponding change in bank heights from about +10 feet MLW to upwards of +60 feet MLW and the boundary with Reach III. Reach II can be further divided into 3 subreaches. Reach II-A extends from Cobb Point to Swan Point about 5.3 miles. Reach II-B from Swan Point to Lower Cedar Point, about 5.4 miles.

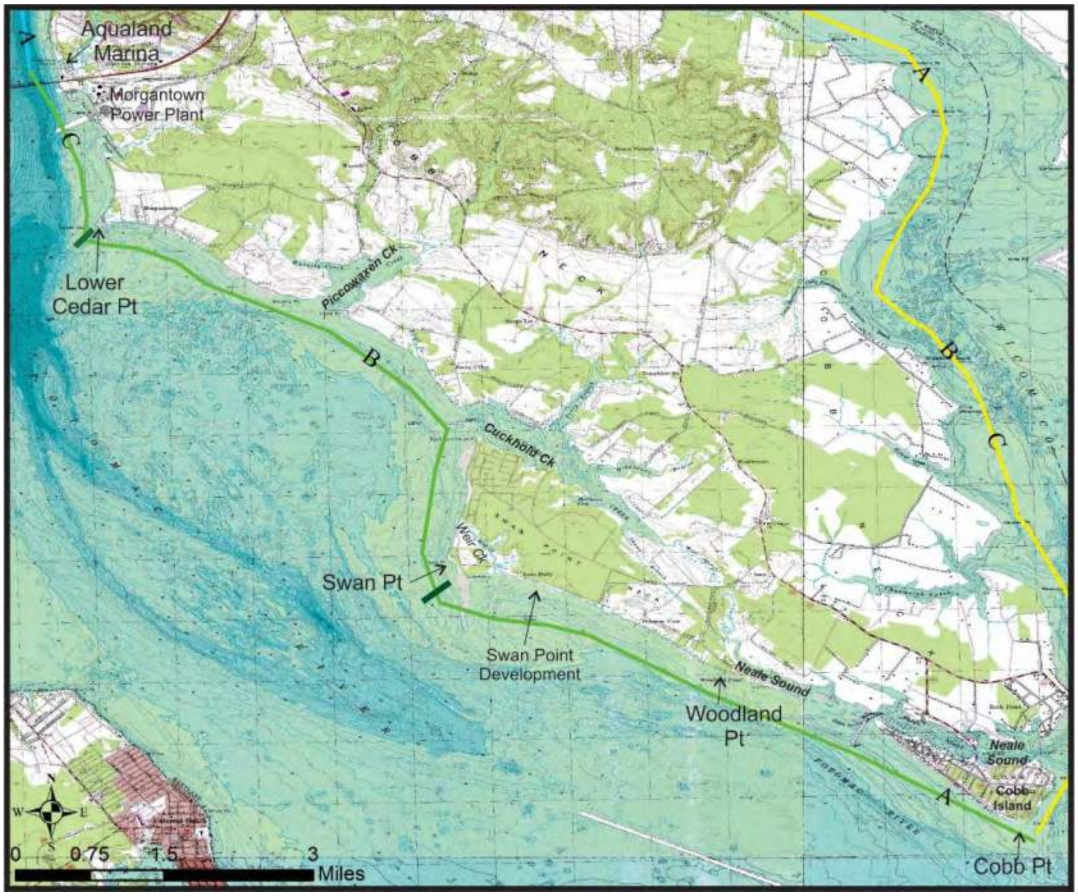


Figure 6-1. Reach II – Potomac River, Neale Sound, Cuckhold Creek and Piccowaxen Creek.

Finally, there are about 1.7 miles from Lower Cedar Point to Aqualand Marina. Two lateral creeks enter the Potomac River along this reach, Cuckhold Creek and Piccowaxen Creek.

The erosion rates of the upland banks vary from no erosion on the fetch limited lateral creeks and sounds, to several feet per year on the open Potomac River shorelines. Much of the shoreline has been hardened, and sand spits have accumulated at Swan Point and Lower Cedar Point, both extending downriver. They indicate the generally southerly net direction of sediment transport.

Most of the shoreline around Cobb Island is hardened. A long jetty extends from the mainland at the Neale Sound inlet channel north of Cobb Island. Low eroding, upland shorelines occur on either side of the jetty. The Woodland Point peninsula coast is mostly residential and hardened with bulkheads and riprap revetments (Figure 6-2). Farther north, an area of agricultural land at the old Horse Farm was protected by a sill system in 2002 that continues to function well (Figure 4-6). At Swan Point development, a breakwater system extends over 4,000 feet (Figure 4-5) and ends with 500 feet of low sill at the mouth of Weir Creek. A relatively stable beach resides between Weir Creek and the Swan Point spit, the boundary of Reach II-B.


Figure 6-2. Woodland Point residential coast mostly hardened with bulkheads.

Reach II-B begins at Swan Point and continues northward and upriver and has eroding banks from 5 to 10 feet high (Figure 6-3). Beyond that, the low marsh, and hardened residential coast continues to Cuckhold Creek. Cuckhold Creek is mostly residential with shore structures along the lower half and agricultural land and marsh along the upper half. From Cuckhold Creek, Reach II-B shoreline extends north and west up the Potomac River and is mostly residential and hardened up to Lower Cedar Point. The intervening Piccowaxen Creek has similar shoreline conditions. A few unprotected shore segments received sill recommendations along this section of shore. At site 55, a bulkhead is failing and could be replaced with a sill (Figure 6-4). The shoreline turns and extends almost due west about a half mile before Lower Cedar Point. A relatively wide, stable beach occurs along the south coast of the Lower Cedar Point spit, which has very low banks.

Figure 6-3. Swan Point eroding uplands, Site 54, Type 4 sill recommended.

Figure 6-4. Failing bulkhead, Site 55, recommend replace with Type 4 sill.

Reach II-C begins at Lower Cedar Point, turns northeastward and extends up the Potomac as a very low bank with two piers as part of a “park” complex. Fetch exposure shifts from southwest to west and northwest up the Potomac. The low bank coast rises to about +12 MLW north of Lower Cedar Point, and the shoreline becomes mostly erosional agricultural land (Figure 6-5). Beyond that is a small creek, then the Morgantown Power Plant complex which is hardened with rock and bulkhead up to and beyond the Harry W. Nice Memorial (Route 301) Bridge to the Aqualand Marina (Figure 6-6).

Figure 6-5. Eroding agricultural upland, Site 61, designated P-2 and recommend Type 5 sill.

Figure 6-6. Entrance to Aqualand Marina.

The nearshore width along Reach II-A, measured to the -6 ft MLW contour, varies from about 2,000 ft off the southwest side of Cobb Point, to only about 1,200 ft offshore at the Swan Point breakwaters. Both Cobb Point and Swan Point have extensive shoals forcing the -6 ft contour offshore 6,600 ft and 5,400 ft, respectively, which locally alters the impinging wave climate. Generally, the nearshore is firm. Along Reach II-B, upriver of Swan Point, the nearshore narrows to about 400 ft which might allow barge access for construction at site 54. Farther north, the nearshore widens to about 1,200 ft and continues steadily upriver to Piccowaxen Creek. No SAV beds have recently been mapped in the nearshore region.

6.2 Hydrodynamic Setting

Reach II-A extends generally southeast to northwest and is relatively straight with fetch exposures across the Potomac River to the south, southwest, and west of 6.8 mi, 6.2 mi and 6.3 miles, respectively. The Reach has a long oblique fetch to the southeast of about 13 miles. Reach II-B is a long, curvilinear embayment where the shoreline adjacent to Swan Point faces due west, the middle of the embayment between Cuckhold and Piccowaxen Creeks faces southwest, and the coast between Piccowaxen Creek to Lower Cedar Point faces due south. Fetches to the west, southwest, and south fir this reach are 5.7 mi, 4.5 mi and 5.2 miles, respectively. The Reach has a long fetch of 12.1 miles to the south-southeast from Lower Cedar Point. Reach II-C runs roughly north-south with fetch exposures to the southwest, west, and northwest of 4.1, 2.1, and 7.1, respectively. This is the narrowest part of the Potomac up to this point which is likely why the Route 301 bridge was located here. Alongshore sediment transport is generally downriver, and stable beaches occur on the downriver side of both Swan Point and Lower Cedar Point.

6.3 Shoreline Management Strategies and TMDL Assessment/Site Selection

Seventeen site recommendations were made along Reach II totaling 2.6 miles (Figure 6-7). These are the options for Reach II:

No Action – Expect continued erosion of project sites at rates similar to present rates.

Defensive – Some of the existing shoreline is hardened with rock revetments. No defensive structures are recommended along this reach.

Offensive -- The rock sill is recommended for the eroding upland sites along Reach II. Two types of sills are recommended along Reach II, the Type 4 sill (Figure 4-11) and the Type 5 sill (Figure 4-12)

Headland Control – a headland control opportunity occurs at site 53 where the Horse Farm spur holds one side of the embayment and the upriver section of shoreline is eroding (Figure 6-8). Eventually, if no other structures are placed along this stretch, the shoreline will form a long embayment.

One site was designated as P-1 sites in Reach II, site 54 (Appendix B). Due to its high erosion rate and long length, it ranked second highest of all the sites. A management strategy has previously been designed for this shoreline. Site 61 and 62 ranked as a P-2; it ranked as number 14 out of all 153 sites. Because the sites are agricultural with no wooded buffer, it is a good candidate for construction via possible barge access. A conceptual plan and cross section were developed (Figure 6-9). The total length for both sites is about 2,300 ft. Also, an old wharf existed at one time on the south side of nearby Lower Cedar Point because the deeper water comes close to the shore at this location. It could be possible to use this as an access point for a barge to bring rock ashore and transfer to trucks.

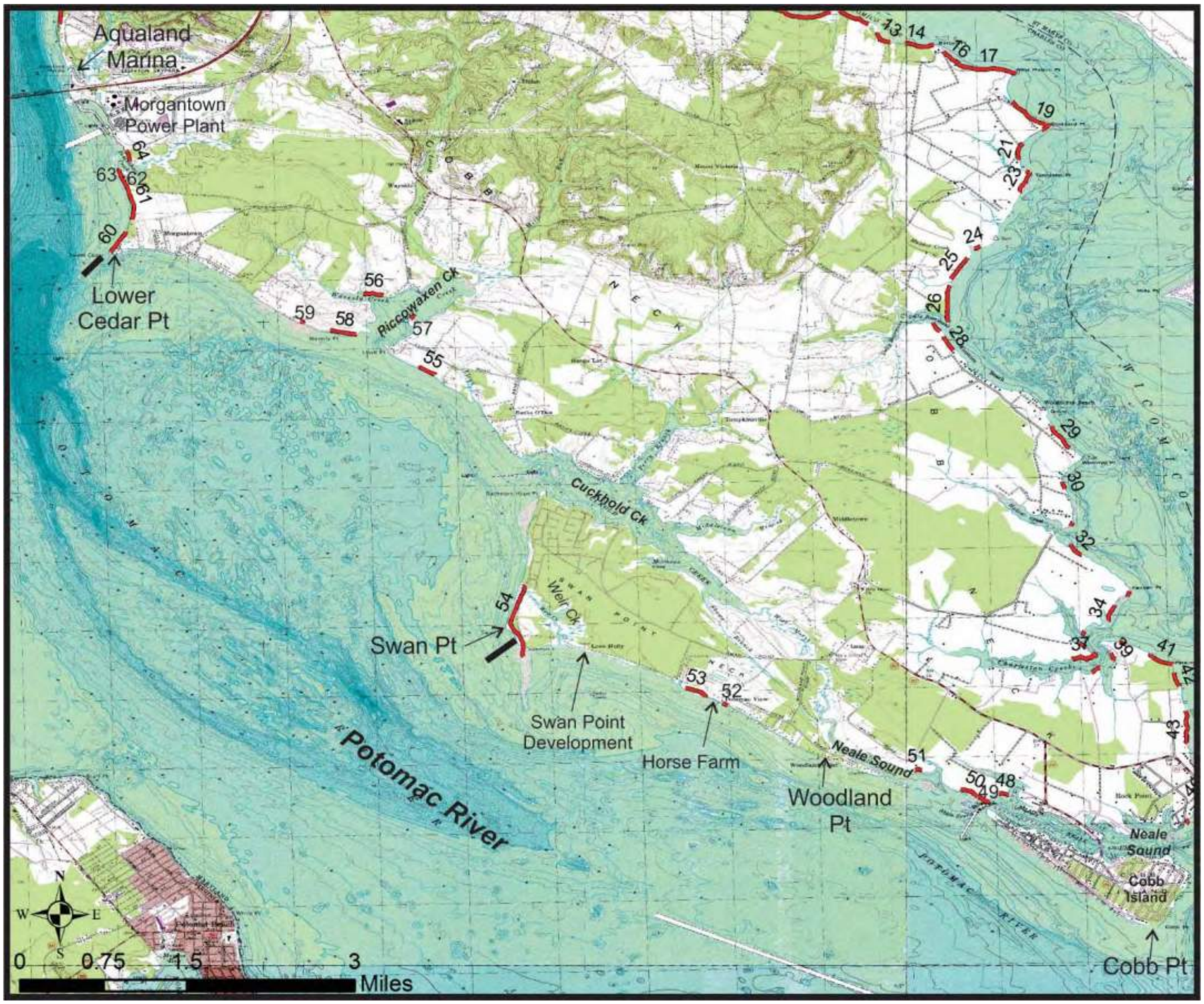


Figure 6-7. Reach II recommended site locations 48-64.

Figure 6-8. Horse Farm shore protection consists of two sills and a spur. The spur and the upriver bulkhead can be considered headlands that define an embayment along the shoreline which will erode to a dynamically stable planform over time.

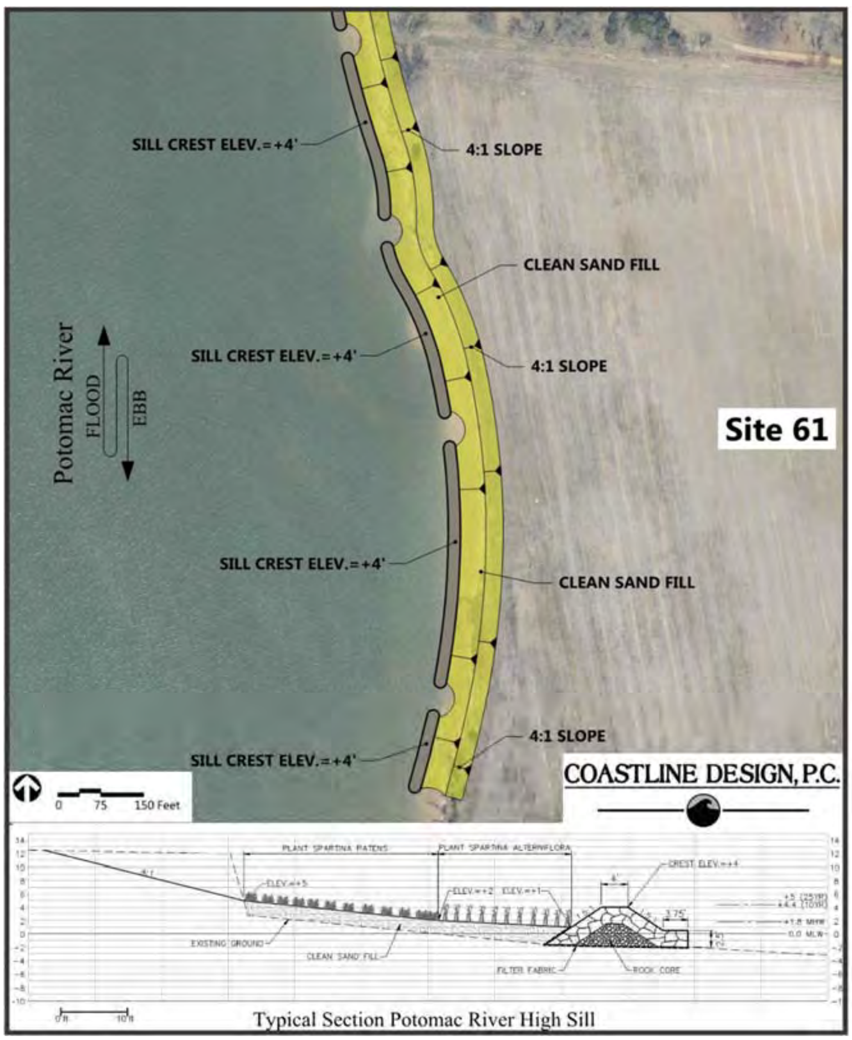


Figure 6-9. Site 61, designated as P-2 and having significantly eroding agriculture land with minimum wood buffer. Recommend Type 5 sill.

7 CHARLES COUNTY, POTOMAC AND PORT TOBACCO RIVERS: REACH III

7.1 Physical Setting

Reach III extends from Aqualand Marina roughly north-northwest and around the Port Tobacco River, about 9 miles (Figure 7-1). Reach III can be divided into 4 subreaches. Reach III-A is the upper end of Cobb Neck which extends from the Aqualand Marina up the Potomac River about 2.3 miles to Popes Creek. From Popes Creek, Reach III-B continues northward to a small, obliquely-trending unnamed watershed, about 1.8 miles. From there, Reach III-C extends upriver about 2.0 miles. The 3 miles of shoreline inside the Port Tobacco River is Reach III-D.

The historic erosion rates are rather modest due to the sloughing nature and erosion resistance of the high banks. These rates vary, but generally range from -0.8 ft/yr to -1.8 ft/yr.

The high banks are the defining features for Reach III with some areas rising to +80 feet MLW. Beginning Reach III-A, the residential community of Clifton on the Potomac occurs just north of Aqualand Marina and Campground, and the banks are mostly intermittently wooded and with no structures along the shoreline (Figure 7-2). These types of conditions continue to just south of Popes Creek where some patches of agricultural land can be found behind wooded buffers.

Popes Creeks has a small marina facility along the low bank coast where the watershed intersects the Potomac River (Figure 7-3). Reach III-B begins here along with the continuation of the high bank coast. Land use is mostly wooded and agricultural with wide wood buffers (>100 feet) and a few residential areas. The high banks have erosional BOBs with intermittent slumps of soil and trees that make the bank face transitional to erosional in nature (Figure 7-4). Some areas are actively eroding from top to bottom (Figure 7-5).

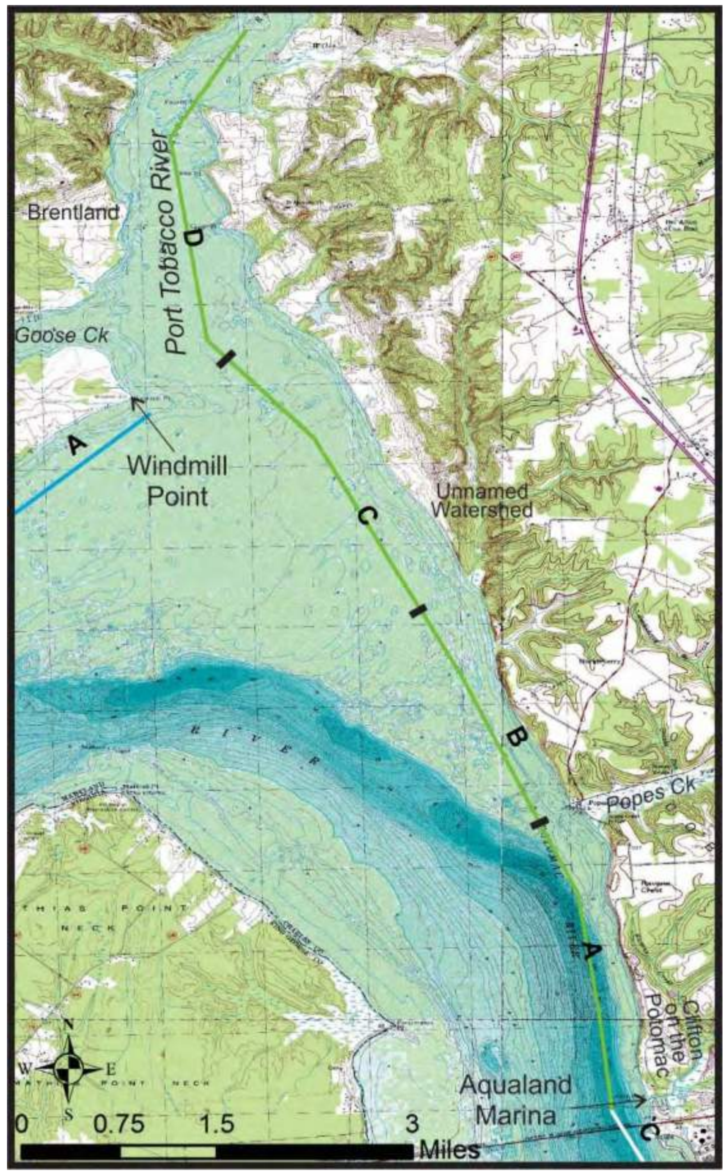


Figure 7-1. Reach III location – Potomac River, Pope's Creek and Port Tobacco River.

Figure 7-2. High eroding upland bluffs along Clifton, Site 66, recommend Type 5 sill.

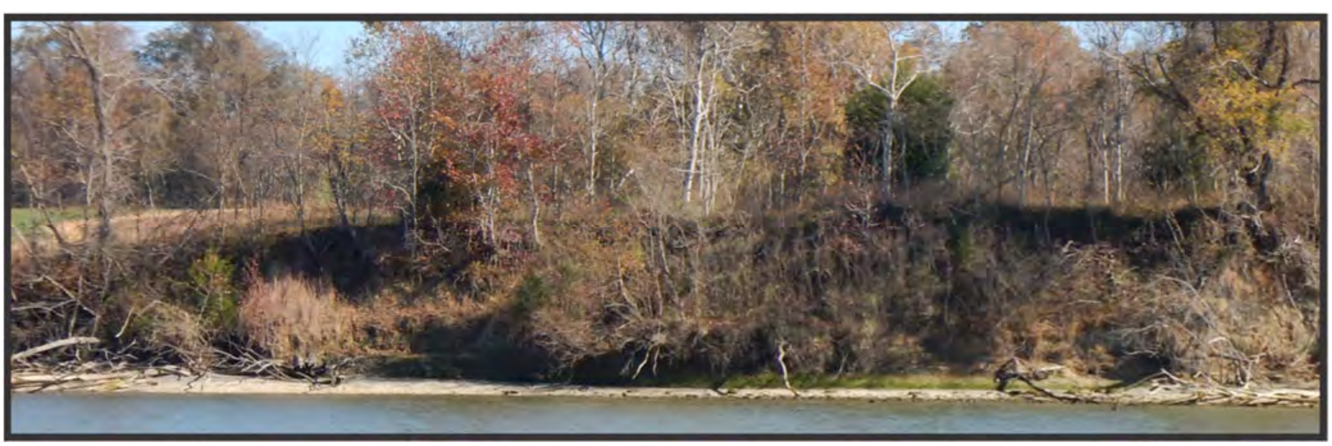
Figure 7-3. Popes Creek and marina along very low bank coast with narrow beach.

Figure 7-4. Eroding high upland bluffs with intermittent slumps. Site 73, recommend a Type 4 sill.

Reach III-C continues beyond a low, unnamed drainage inlet with slightly lower eroding banks, about +40 ft MLW, which eventually grade down to about + 20 ft MLW and stay at that elevation along most of the remaining reach length. These high banks are set back from the shoreline and form a terrace between the eroding shoreline banks and the upland scarp. The banks along Reach III-C range from about +10 to +20 ft MLW and are mostly erosional with areas of slumps and fallen trees (Figure 7-6 and 7-7). These are sites 81, designated a P-1, and 83, designated as a P-2. Also, a beach prism installation occurs on the south site of site 82 that is too low and has no sand terrace. Beach prisms are patented concrete units placed along the shoreline like a sill. These units are not providing protection to the adjacent eroding upland bank (Figure 7-8).

Figure 7-5. High upland bluffs with erosional BOB and bank face with residential land use. Site 76, recommend Type 5 sill.

Figure 7-6. Eroding low upland banks, Site 81, designated P-1, use Type 5 sill.



Reach III-D extends around the coast of the Port Tobacco River. The 20 ft to 30 ft banks continue up and along the east side of the river to the tidal marsh shoreline complex at Port Tobacco. The banks are generally unstable with low erosion rates and numerous fallen trees (Figure 7-9). The upland elevations increase to 80 ft along the west side of the Port Tobacco which grade down to lower banks of 20 ft along the River. The high banks turn sharply westward at Brentland transitioning to a low terrace with lower upland banks that continue around the coast of the Goose Creek watershed. Much of this terrace is agricultural land (Figure 7-10). Reach III-D continues along the backside of the Maryland state property to Windmill Point at the confluence of the Port Tobacco and the Potomac Rivers.

The nearshore region varies in width along Reach III. Along Reach III-A, the nearshore is about 450 feet offshore of Aqualand Marina to upriver to Popes Creek. Continuing up the Potomac into Reach III-B, the -6 ft MLW contour varies from 200 to 600 feet offshore which is relatively close. This trend continues through Reach III-C and into the Port Tobacco River. The -6 ft contour draws relatively close to the Port Tobacco coast varying from 200 feet to 500 feet offshore. A shoal occurs off Windmill Point that extends the -6 ft contour out about 3,000 feet offshore. No current (2017) SAV beds have been mapped along Reach III, but the composite data (2011-2015) shows beds in the Port Tobacco River.

Figure 7-8. Beach prisms along the shoreline are not effective at shore protection.

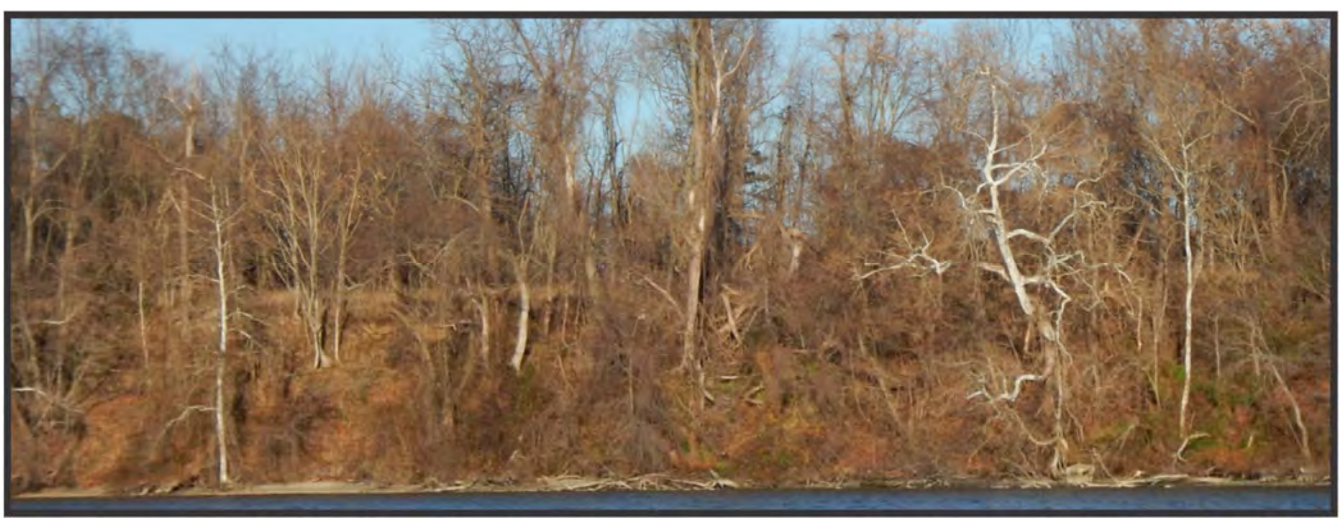


Figure 7-9. Reach III D, east side of Tobacco River, Erosional to transitional high upland banks.

Figure 7-10. West side of Tobacco River with very low eroding agricultural banks, Site 92, recommend Type 3 sill.

7.2 Hydrodynamic Setting

Except for Reach III-D along the Port Tobacco River, most of the Reach III coast is along the Potomac River and exposed to wind driven waves from a westerly direction. Reach III-A has fetches to the southwest, west, and northwest of 2.1, 1.9, and 5.3 miles, respectively. Reach III-B has fetches to the southwest, west, and northwest of 2.3, 4.8, and 3.3 miles, respectively. The fetch exposures for Reach III-C are 6.9, 2.0, and 2.2 miles for the southwest, west, and northwest directions, respectively. The Port Tobacco River has limited fetch exposures to the south along the shorelines near the mouth of the River and has a narrow fetch down the Potomac of over 14 miles.

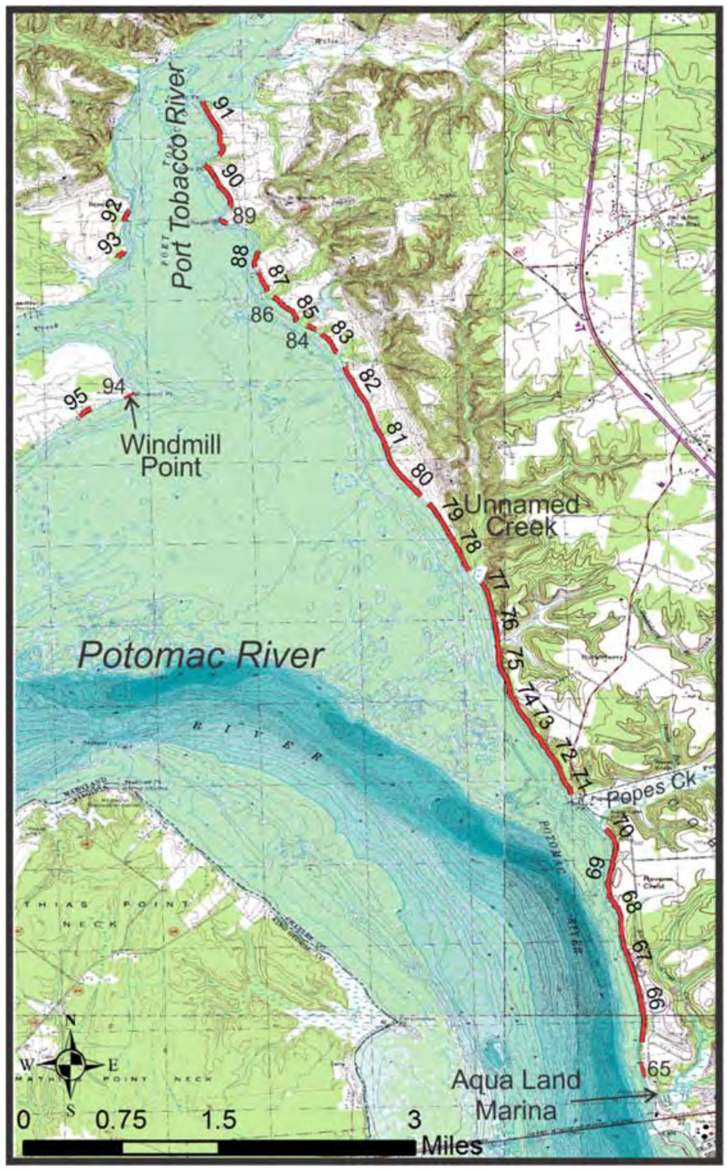


Figure 7-11. Reach III site recommendation locations.

7.3 Shoreline Management Strategies and TMDL Assessment/Site Selection

A total of 29 sites were given recommendations along 7 miles of shoreline for Reach III (Figure 7-11) as shown in Appendix A. These are the options for Reach III:

No action – Shoreline erosion will continue at unprotected shore segments.

Defensive- Hardened shorelines occur along Reach III and range from bulkheads to riprap revetments. No defensive recommendations were made along this Reach.

Offensive -The rock sill is the recommended strategy for the eroding uplands along Reach III. Four types are recommended: Type 2 which is a low sill at +3 ft (Figure 4-9); Type 3 which is a high sill with a +3.5 ft crest elevation (Figure 4-10); Type 4 which is a high sill with a +3.5 ft crest elevation but designed for a high bank (Figure 4-11); and Type 5 which is a high sill with a +4 ft crest elevation (Figure 4-12).

Headland Control – No geomorphic features occur along Reach III that would be suitable for the headland control option. However, leaving very wide gaps between sill structures and allowing the adjacent banks to erode toward equilibrium in that interim period can be cost effective if erosive conditions don't threaten life or property.

One site was designated a P-1 along Reach III, Site 81. Site 80 is ranked a P-2 and is adjacent to Site 81. Site 81 has a medium erosion rate with banks 12 to 15 feet high. Combined, sites 80 and 81 total 3,340 feet of shoreline with relatively narrow wooded buffer adjacent to agricultural land. Both have potential barge access, and Type 5 and 4 structure recommendations, respectively. The bank does not necessarily need to be graded, but as sea level rises, "coastal squeeze" may occur if it is not graded. The Type 5 sill is designed to accommodate those conditions. Or, the bank could be graded to a 2:1 "standard" after a modest 10-20 ft terrace at a 4:1 beginning at the top of sand fill. The main issue with bank grading is what to do with the material. Site 92 is ranked as a P-2, but it is very low-lying agricultural land with no trees. Site 92 has the potential for high coastal resiliency and has an access road to the site. At 500 ft. long, it is a shorter site and does not have another P-1 or P-2 site immediately adjacent.

8 CHARLES COUNTY, PORT TOBACCO RIVER TO MARYLAND POINT INCLUDING NANJEMOY CREEK: REACH IV

8.1 Physical Setting

Reach IV begins at Windmill Point and extends in a southwesterly direction, up the Potomac River. This reach includes Nanjemoy Creek to Maryland Point, about 14 miles (Figure 8-1). The reach can be divided into three subreaches beginning with Reach IV-A which extends from Windmill Point at the mouth of the Port Tobacco River upriver to Blossom Point, about 5.2 miles. Reach IV-B includes shorelines around Nanjemoy Creek to Benny Gray Point. Reach IV-C extends from Benny Gray Point to Maryland Point, about 5.9 miles.

The geology of Reach IV is mostly Upper Pleistocene fine sands, silts and clay. Bank heights vary slightly along Reach IV but generally are between +10 to +20 ft MLW. The historic shoreline change rates along Reach IV-A vary from +1ft/yr to -3 ft/yr. Areas of beach advance offer protection of the BOB against the impinging wave climate. Reach IV-B in Nanjemoy Creek has stable banks to slightly erosional at <-0.5 ft/yr. The Reach IV-C coast is stable to erosional averaging about -1ft/yr where it is not hardened.

The upland banks along Reach IV-A mostly back up to agricultural land with narrow wooded buffers and numerous fallen trees down (Figure 8-2). The first two miles of shoreline is state owned property, the Cedar Point Wildlife Management Area (WMA). This reach has low, eroding thinly wooded agricultural land warranting high rankings. Low drainages intersect the uplands with the associated marsh shoreline. The Blossom Point Research Lab occupies about four miles of shoreline from the WMA around Blossom Point and up into Nanjemoy Creek. A shoreline management plan was developed for this coast, but it has not been implemented yet (Hardaway et al., 2015).

Reach IV-B shoreline is the coast around Nanjemoy Creek. Extensive agricultural lands lie from Ball Point around to Gum Tree Cove with long segments protected by breakwaters and sills with little or no bank

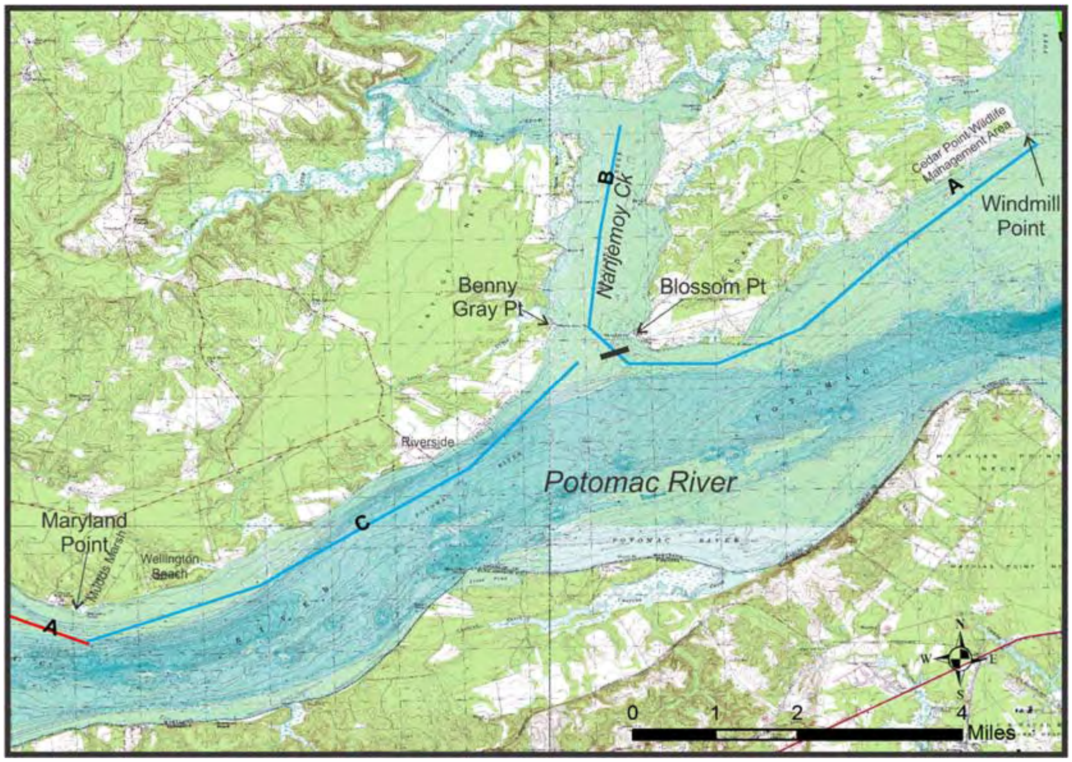


Figure 8-1. Reach IV location – Potomac River and Nanjemoy Creek.

grading (Figure 8-3). The remainder of the creek shoreline along the west shore has scattered residential dwellings between woodlands and creek drainages.

Reach IV-C continues along the Potomac River to Maryland Point. Several residential segments occur between agricultural land segments and unnamed tidal creeks. Wellington Beach is one of these residential segments that occurs between eroding wooded upland and an unnamed tidal creek. Much of the coast is hardened (Figure 8-4). At Maryland Point, a broad wetland, Mudds Marsh, occurs.

The -6 ft MLW contour occurs about 700 ft offshore at the beginning of Reach IV-A then turns riverward into a broad shoal region. Along this stretch, the -6 ft contour trends about 7,000 feet offshore. The nearshore narrows to about 3,000 feet again toward Blossom Point. The -6 ft contour comes within 200 feet of Blossom Point. Water depths in Nanjemoy Creek do not reach the –6 ft MLW contour. From Riverside, the -6 ft contour gradually trends offshore to about 2,400 feet off Welllington Beach before coming close again to about 700 feet off Maryland Point. The nearshore bottom is firm except for areas up in Nanjemoy Creek where soft muds have accumulated. Generally, no barge access opportunities exist.

No recent (2017) SAV beds along Reach IV. However, the composite SAV data (2011 to 2015) mapped SAV within Nanjemoy Creek and along Reach IV-C between Nanjemoy Creek and Maryland Point. Some sites where sills are recommended may need to switch to a revetment strategy for shore protection if the beds are found up to MLW during the design phase.

Figure 8-2. Eroding low agricultural upland bank, Site 96, ranked as a P-2, recommend Type 5 sill.

Figure 8-3. Along Nanjemoy Creek, a low upland bank protected by a gapped sill system exists, but the bank was not graded. This type of system is comparable to a Type 4 sill system.

Figure 8-4. Typical hardened shoreline along Reach IV-C.

8.2 Hydrodynamic Setting

Reach IV-A has fetch exposures to the east, south, and south-southwest of 3.5, 3.2, and 4.3, miles respectively. Nanjemoy Creek is about 1.0-mile-wide at its mouth then narrows to about 0.8 miles before it splits into an east and west branch. The long southerly fetch is about 5.7 miles down Nanjemoy Creek and across the Potomac River. Fetch exposures along Reach IV-C are to the east, south, and south-southwest are 5.0, 2.3, and 3.2 miles.

8.3 Shoreline Management Strategies and TMDL Assessment

A total of 20 sites were given recommendations along 3.3 miles of shoreline for Reach IV (Figure 8-5) as shown in Appendix A. These are the options for Reach IV:

No Action -- Unprotected shorelines will continue to erode at current rates. This will continue to yield eroded sediment as beach sands to adjacent shorelines, especially along the Cedar Point Wildlife Management Area coast.

Defensive – Shorelines are hardened along shoreline along Reach IV, especially up Nanjemoy Creek and along Reach IV-C. A living shoreline is recommended at site 111, but if SAV is found close to the shore, a revetment might have to be substituted.

Offensive - The rock sill is the recommended strategy for the eroding uplands along Reach IV. Four types are recommended: Type 2 which is a low sill at +3 ft (Figure 4-9); Type 3 which is a high sill with a +3.5 ft crest elevation (Figure 4-10); Type 4 which is a high sill with a +3.5 ft crest elevation but designed for a high bank (Figure 4-11); and Type 5 which is a high sill with a +4 ft crest elevation (Figure 4-12).

Headland Control – Several areas occur along Reach IV-A where headland control can be applied. The proposed sills will be long stable headlands as the adjacent lands continue to erode.

Two P-1 sites occur along Reach IV (Appendix B), sites 95 and 97 in Reach IV-A on the Cedar Point WMA agricultural land. They have relatively low banks (<10 ft) with grading possibilities and existing land access along Windmill Point Road. In fact, sites 94-98 occur along the Cedar Point WMA; this offers an opportunity to construct multiple sites very near to each other, within two miles, and with a single property owner. Sites 94 through 98 have areas of medium to high erosion and are ranked as P-2 sites.

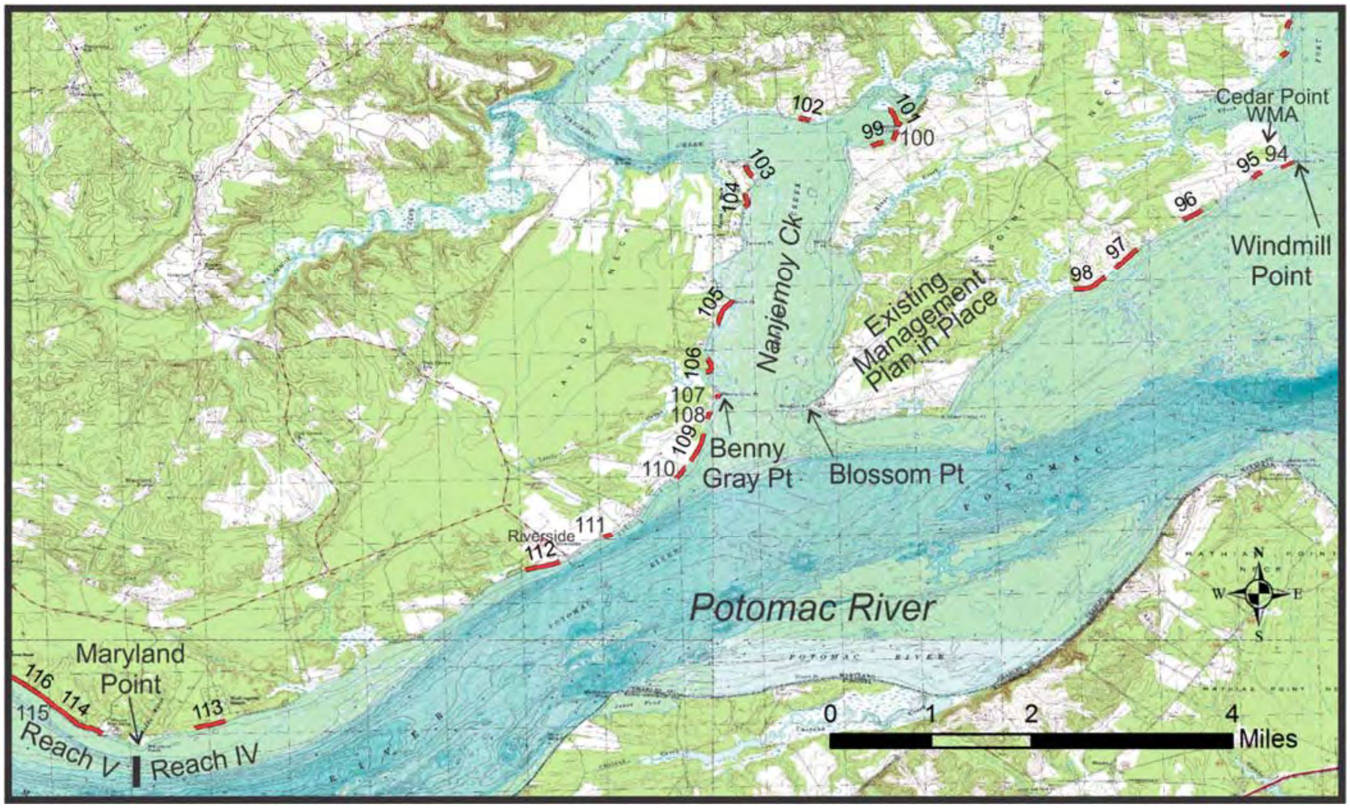


Figure 8-5. Reach IV site recommendation locations.

9 CHARLES COUNTY, MARYLAND POINT TO MATTAWOMAN CREEK: REACH V

9.1 Physical Setting

The Reach V coast extends from Maryland Point northward and upriver to Mattawoman Creek for about 16 miles (Figure 9-1) and is divided into 3 subreaches. Reach V-A extends from Maryland Point to Smith Point, 5.8 miles. Reach V-B extends from Smith Point about 4.7 miles to Sandy Point. Finally, Reach V-C continues north and upriver to the mouth of the Mattawoman Creek, about 5.6 miles. The Chicamuxen tidal creek coast is also included in V-C.

The historic erosion rates are between 0 and -2.5ft/yr and average about -1ft/yr. For the shorelines along the recommended sites erosion rates vary from -0.5 to -2.5 ft/yr.

Reach V-A occurs as a broad convex coast that undulates along the Potomac River. The headland at Thomas Point and the unnamed headland above it are defining features. Several upland drainages intersect the coast with associated marsh shores. The upland banks along Reach V-A range from +10 to +30 feet and range from very exposed to partially exposed features to trending stable. Actively eroding upland banks occur on residential property (Figure 9-2). Though a high sill is recommended at the Naval Research Lab Antennae Range, Site 118, it may require a revetment (Figure 9-3) because of the proximity of infrastructure. The shoreline is mostly unmanaged woods with some residential segments, but no agricultural lands. Some of the wooded areas were provided recommendations in anticipation of future residential development.

Figure 9-1. Reach V location – Potomac River and Chicamuxen Creek.

The eroding banks in Reach V-B are mostly broad, wooded uplands with no agricultural land and few residential properties. Therefore, there are no discernable reasons to provide recommendations for most of the coast except for residential properties or for taking advantage of geomorphic headlands. A no action strategy is largely recommended. Reach V-B is defined by four named headland points with well-defined intermediate bays. These are Douglas Point (Figure 9-4), Liverpool Point, and Sandy Point. The famous Mallows Bay lies between Liverpool and Sandy Points (Figure 9-5); it is where many unneeded ships were scuttled after WWI.

Reach V-C extends from Sandy Point northward, and the shoreline continues as eroding upland banks, increasing in elevation. These areas are heavily wooded. Banks slumps are common as large trees slide into the river (Figure 9-6). The Stump Neck coast is on Indian Head Naval Base which already has a Shoreline Management Plan developed for the base in 2002 by Coastline Design, PC. Much of the plan was implemented in several phases.

The nearshore region is deep off Maryland Point with the -6 ft MLW contour only about 700 feet offshore. The contour continues north close to shore up to Smith Point averaging about 400 to 600 feet and as close as 200 feet off Thomas Point and Smith Point, in Reach V-A. In Reach V-B, the -6 ft contour trends almost due north such that it is within 200 ft of each headland point. This trend continues along Reach V-C across Chicamuxen Creek.

Figure 9-2. Vertically exposed eroding upland bank on residential property along Reach VA, Site 115, recommend Type 5 sill.

Figure 9-3. Eroding upland banks at the Maryland Point Antenna Range, Site 118, recommend Type 5 sill or revetment for protection of valuable infrastructure.

Figure 9-4. Eroding headland at Douglas Point, Site 123, recommend a Type 4 sill.

Figure 9-5. Mallows Bay ship remains.

Figure 9-6. Slumps with trees along upland bank just upriver from Sandy Point.

No SAV beds, recent or historical, have been mapped along the reach V-A nearshore. Historical beds did occur in Reach V-B especially in Mallows Bay along with beds identified in 2017. Along Reach V-C, narrow beds occur in the narrow nearshore, along shore up to and including all of Chicamuxen Creek.

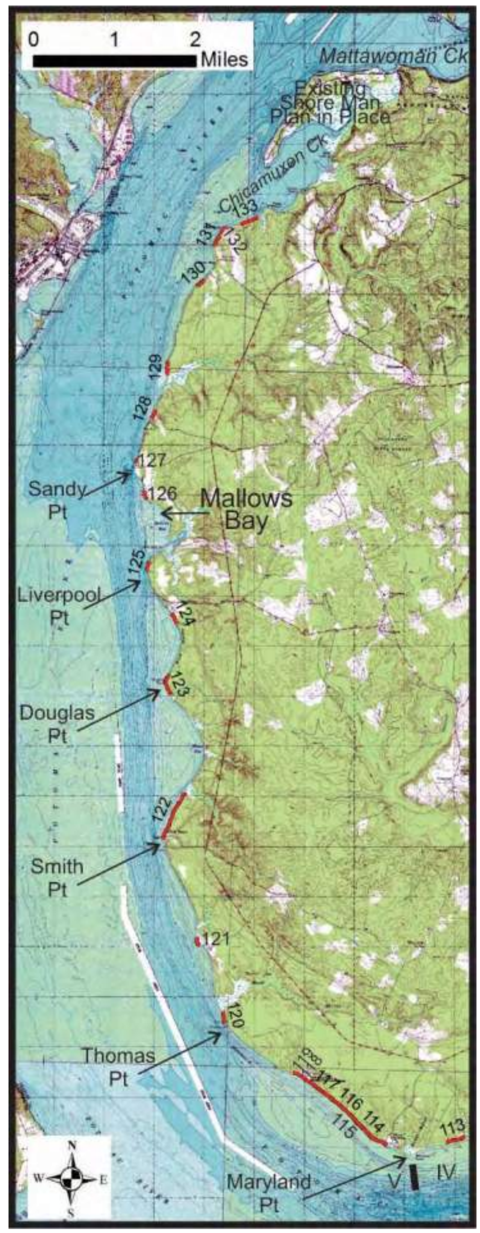


Figure 9-7. Reach V site recommendation locations.

9.2 Hydrodynamic Setting

Fetch exposures measured from Thomas Point in Reach V-A are 5.6, 3.7, 2.8, and 3.5 miles, respectively. The Reach V-B fetch exposures, measured from Douglas Point, are 3.0, 3.3, and 3.8 miles for the southwest, west and northwest directions. The river narrows from 3 miles to 2 miles off Sandy Point to 1 mile at the mouth of the Chicamuxen. Fetch exposures at the mouth of Chicamuxen Creek are 4.5, 1.6, 1.6, and 2.1 for the southwest, west, northwest, and north-northwest, respectively.

9.3 Shoreline Management Strategies and TMDL Assessment

A total of 20 sites were given recommendations along 4.1 miles of shoreline for Reach V (Figure 9-7) as shown in Appendix A. No sites are P-1. These are the options for Reach V:

No Action – This option is appropriate along most of Reach V because of the long stretches of actively eroding high banks that are heavily wooded with no nearby agricultural lands or existing residential properties.

Defensive - Site 118 in front of the military property where a much higher level of protection may be required.

Offensive – This is the preferred method of shore erosion control due to the wide wooded areas. Bank grading is proposed. The rock sill is the recommended strategy for the eroding uplands along Reach V. Two types are recommended: Type 4 which is a high sill with a +3.5 ft crest elevation but designed for a high bank (Figure 4-11); and Type 5 which is a high sill with a +4 ft crest elevation (Figure 4-12).

Headland Control – Protecting the major headland points by constructing breakwaters or revetments is a form of headland control as provided on Thomas Point, Smith Point, Douglas Point, and Liverpool Point.

10 CHARLES COUNTY, MATTAWOMAN CREEK TO COUNTY LINE: REACH VI

10.1 Physical Setting

Reach VI begins at the mouth of the Mattawoman Creek (Figure 10-1). The north shore of Mattawoman Creek and the Potomac shoreline of the Naval Support Facility at Indian Head are covered under a previous shoreline plan (Coastline Design PC, 2002). The southern part of Reach VI-A, which extends from Mattawoman Creek upriver to boundary of Indian Head, about 6.4 miles also is included in the previous shoreline plan. Reach VI-B continues up the Potomac River about 2.6 miles to Pomonkey Point. Reach VI-C extends from Pomonkey Point upriver about 5.4 miles to the Prince George's County line.

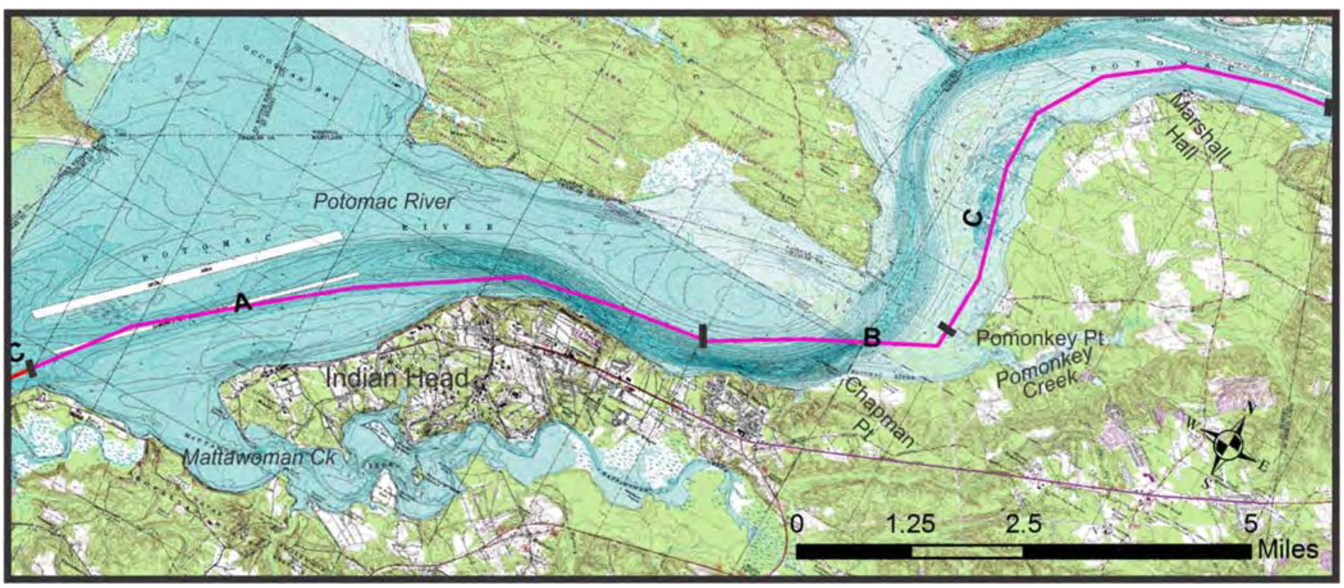


Figure 10-1. Reach VI location – Potomac River, Mattawoman Creek, and Pomonkey Creek.

Historical shoreline change rates along Reach VI vary from 0 to -2.0 ft/yr. Shoreline erosion at recommended sites varies from -0.2 to -2.0 ft/yr. These relatively modest rates are due to the slumping high banks and reduced fetch exposures.

Reach VI-A includes the coast of Indian Head up to upriver boundary of the Base where reach VI-B begins. Here the banks have erosional to transitional BOBs and bank face and vegetated slumps fronting residential properties with occasional bank grading and hardening (Figure 10-2 and 10-3). When the upland banks are cleared of trees and the grade is toward the river, active erosion from the top down can ensue (Figure 10-4). This reach has a deep nearshore, which can allow for transport of construction materials by barge. However, the deep nearshore restricts the width of the sill system such that only high marsh may exist, or a revetment may be needed. The uplands in Reach VI-B transition from residential to wide wooded banks. The high banks (+100 ft) decrease to 10-20 ft toward the north. The shoreline from Chapman Point north are alternating eroding banks (Figure 10-5) and intersecting low drainages or marshes (Figure 10-6).

Pomonkey Point marks the beginning of Reach VI-C which has low banks and residential coast that is mostly hardened for the next 4,000 feet (Figure 10-7). Reach VI-C continues almost due north as a very low upland with intermittent swamp forest shoreline. The shoreline turns again toward the northeast and land use becomes residential with properties that are intermittently hardened and erosional. Onward north, the shoreline becomes a low upland with occasional swamp forest to Marshal Hall with a boat landing. Upriver from Marshal Hall to the County line, the upland banks average about 20 feet and often have a low wooded backshore partially protecting the BOB. A few residential properties with unstable banks are present, for which site recommendations are included (Figure 10-8).

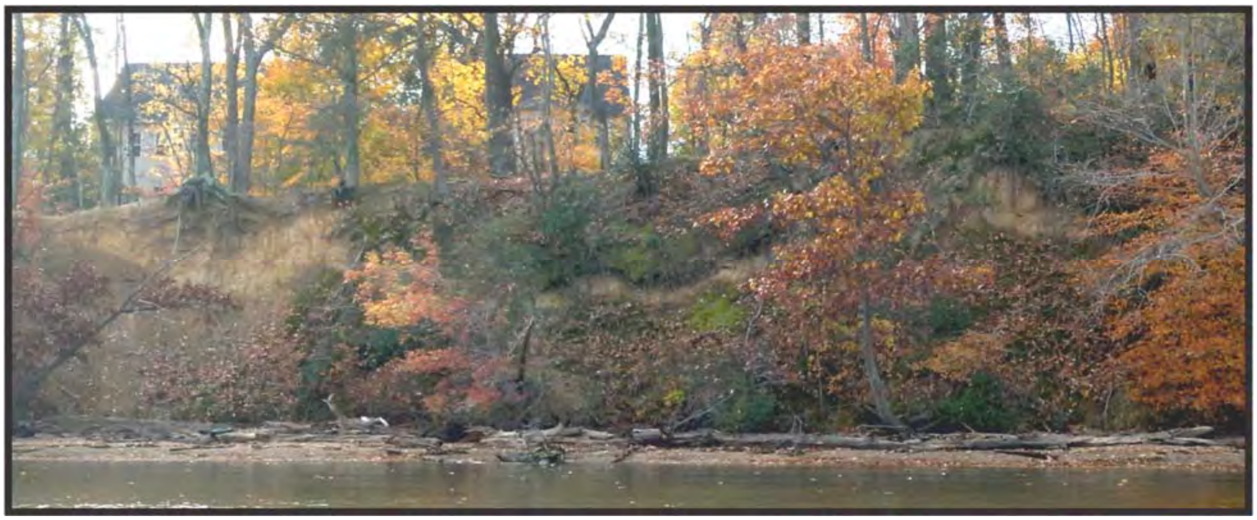


Figure 10-2. Slumping upland banks upriver of Indian Head.

Figure 10-3. Graded banks with a wide backshore can work along some segments of Reach VI-B.

Nearshore widths are very narrow along Reach VI-A and VI-B because of the nearby main channel of the Potomac River trending within 300 feet to 100 feet or less near Chapman Point. Here the main channel turns away from the Maryland coast and crosses to the Virginia side. Consequently, the nearshore widens to 2,100 feet off Pomonkey Point. It varies from 400 to 600 feet offshore along most of Reach VI-C before drawing within 100 feet at Marshall Hall and on to the County line. The historic and recent footprint of SAV hugs the narrow nearshore region from Indian Head to the County line.

10.2 Hydrodynamic Setting

Except for Mattawoman Creek, the Reach VI coast is exposed to wind-driven westerly waves across the Potomac River. Starting with Reach VI-A, fetch exposures along the main section of Indian Head are to the southwest, west, and northwest at 5.6, 3.0, and 4.1 miles, respectively. Reach VI-B has fetch exposures to the west, northwest, and north of 3.6, 1.5, and 4.5 miles, respectively. Reach VI-C has two fetch exposures due to the sharp turn the shoreline takes. The south segment has fetches of 1.5, 2.0, and 1.5 miles to the southwest, west, and northwest. The north segment has fetches to the west, northwest, north, and northeast of 1.1, 2.0, 1.0, and 2.5 miles.

Figure 10-4. Eroding high bank with upland runoff problems as evidenced by gullies running down the bank. Site 144, Type 5 sill, bank grading recommended. Nearshore is deep and may restrict options to shoreline defense, like a revetment.

Figure 10-5. Low eroding uplands north of Chapman Point.

Figure 10-6. Intersecting low drainages along the Reach VI-B coast.

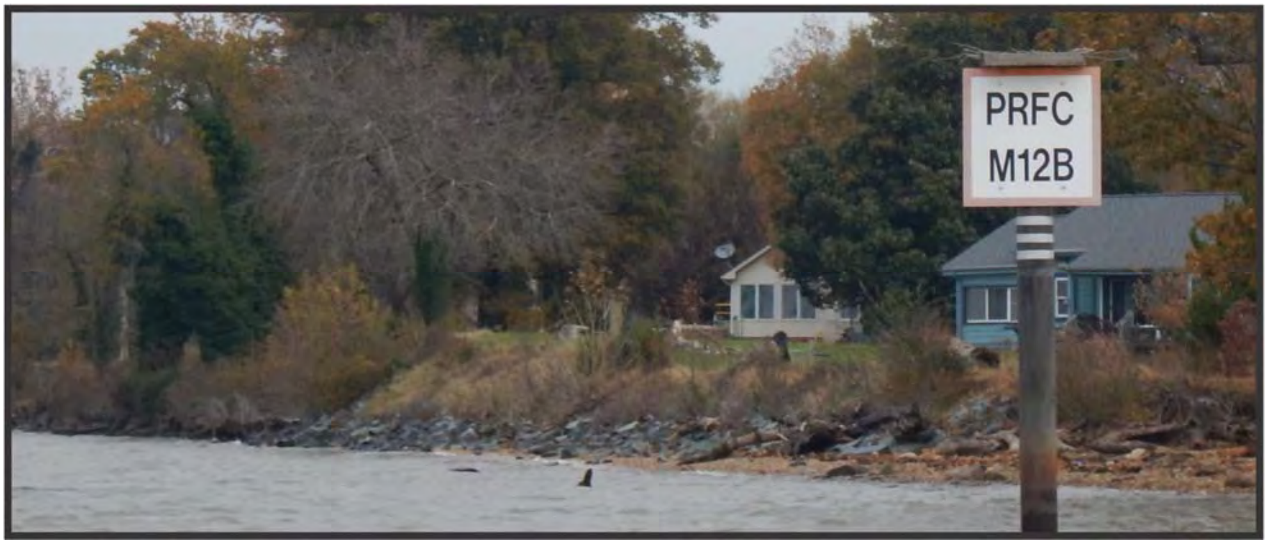


Figure 10-7. Low bank with hardened residential properties at and north of Pomonkey Point.

10.3 Shoreline Management Strategies and TMDL Assessment

A total of 17 sites were given recommendations along 2 miles of shoreline for Reach VI (Figure 10-9) as shown in Appendix A. Due to the lack of farmland, low banks, and low erosion rates, no P-1 or P-2 sites were identified. These are the options for Reach VI:

No Action - Expect a continuation of coastal processes that have been occurring to continue along the Reach VI shorelines. This is an acceptable approach along much of the Reach where the loss rates are on unmanaged wooded banks.

Defensive – Revetment might be the best for those sites where it's listed as an alternative due to the deep nearshore and possible SAV.

Offensive- Seventeen sites are recommended for shoreline protection/restoration along Reach VI, half of which are for a sill or revetment due to nearshore water depths. As aforementioned, the deep nearshore is good for barge access but not for offshore structures.

Headland Control – No obvious geomorphic opportunities exist other than protecting Chapman Point with a sill or revetment. The low swamp is acting as an eroding headland that helps control littoral processes on the shore segment adjacent to it. However, at this point a no action approach is recommended.

Figure 10-8. Eroding upland near the upriver boundary of Reach VI-C. It is the location of Site 157. Nearshore sill or revetment is recommended due to deep nearshore and historical presence of SAV.

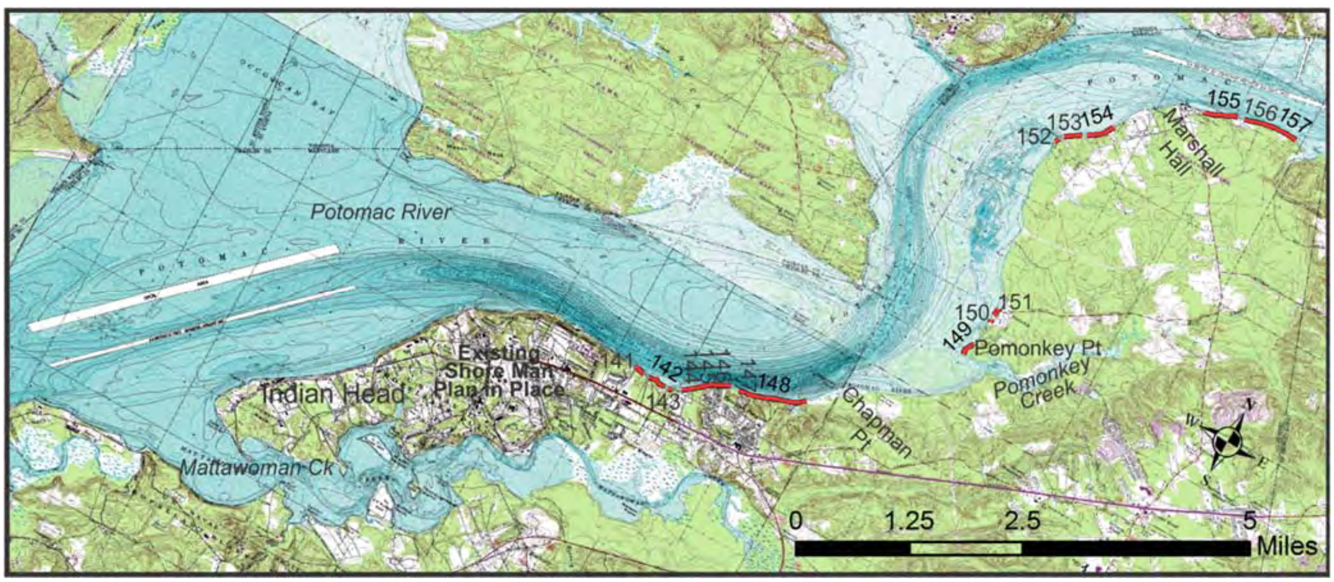


Figure 10-9. Reach VI site recommendation locations.

11 CHARLES COUNTY, BENEDICT, PATUXENT RIVER: REACH VII

11.1 Physical Setting

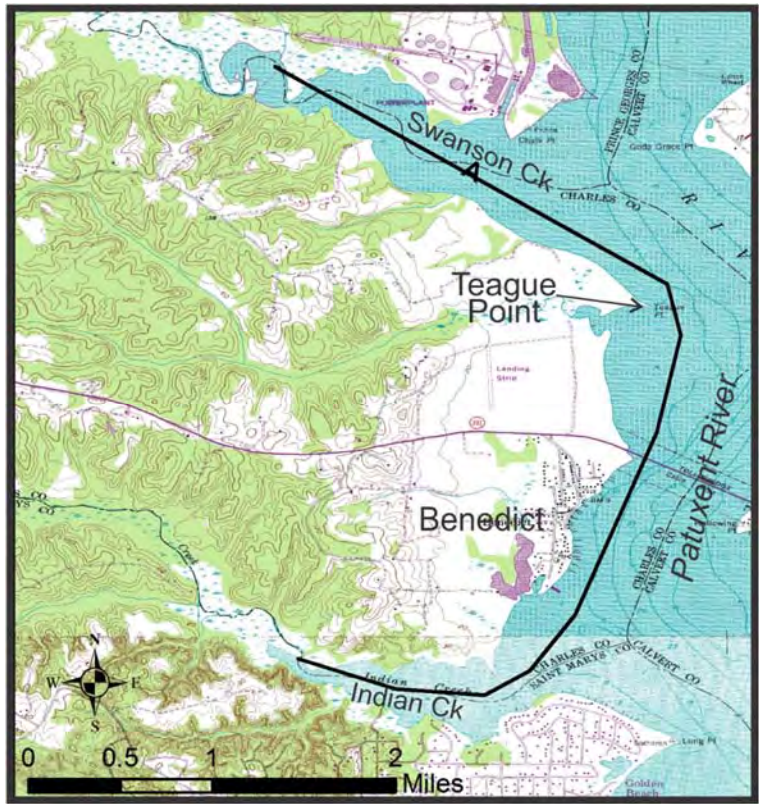


Figure 11-1. Reach VII location – Swanson Creek, Patuxent River and Indian Creek.

Reach VII occurs on the Patuxent River and extends from Swanson Creek to Indian Creek (Figure 11-1). The Town of Benedict's shoreline extends along the distal end of the neck formed by those two creeks. About 2.0 miles were assessed along Swanson Creek down to Teague Point. From Teague Point south along Benedict to Indian Creek is about 2.3 miles and then another mile up the north coast of Indian Creek totaling about 5.3 miles for the reach.

Recent erosion rates vary along Reach VII from very low erosion along much the coast to -3ft/yr adjacent to the Route 231 bridge.

Reach VII along Swanson Creek has a 20 ft bank that drops to a 10 ft bank from west to east toward Teague Point. Teague Point is a broad delta shaped tidal marsh with a narrow beach shoreline along its perimeter. From Teague Point down to the Rt. 231 bridge, the broad marsh continues, and the shoreline is eroding peat with small pockets of sand. South of the Route 231 bridge, the Benedict shore reach has numerous piers and intermittent shoreline hardening between a few small pocket beaches (Figure 11-2). Along the south end of the Benedict shoreline a sill project has been designed as part of a Charles County restoration project to address MS4 requirements through shoreline stabilization. Moving south, two small tidal creeks occur, and a section

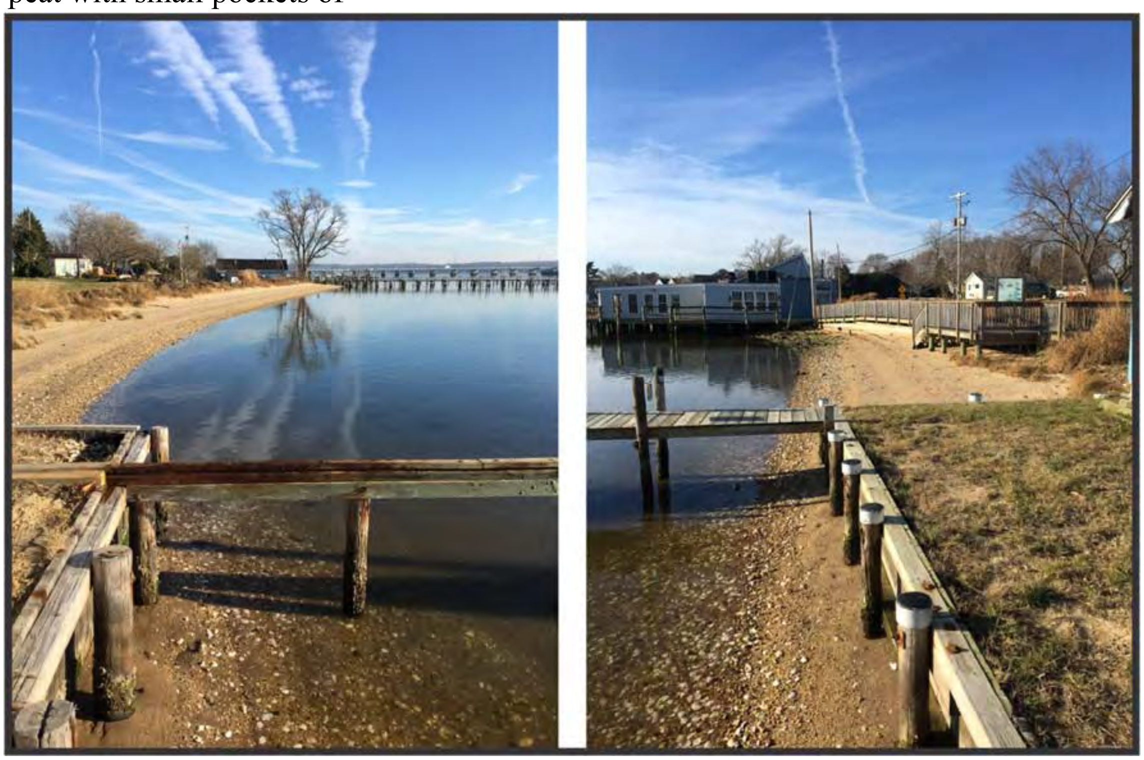


Figure 11-2. Town of Benedict shoreline that is mostly hardened which form some headlands with pocket beaches in between.

of low bank coast transitions to a marsh. A narrow sand beach defines the spit at the mouth of Indian Creek. The westward trending Indian Creek shoreline is a series of low wooded banks and pocket marshes.

Both Swanson Creek and Indian Creek are relatively shallow. The -6 ft MLW contour sits about 1,500 feet off the mouth of Indian Creek then trends north and draws very close to Benedict waterfront, within 150 feet. Upriver from the Benedict waterfront, the -6 ft contour heads back offshore to about 800 feet off Teague Point. There are no SAV or oyster beds around the Reach VII coast.

11.2 Hydrodynamic Setting

Benedict has fetch exposures to the northeast, east, and southeast of 2.1, 0.7, and 3.2 miles, respectively

11.3 Shoreline Management Strategies and TMDL Assessment

A total of three sites were given recommendations in Reach VII as shown in Appendix A and Figure 11-3. Due to the lack of farmland, low banks, and low erosion rates, no P-1 or P-2 sites were identified. These are the options for Reach VII:

No Action – Shoreline erosion will continue.

Defensive- Much of the town of Benedict has been protected with bulkheads.

Offensive - Three sites were given recommendations using sills, one on Swanson Creek and the other just south of Benedict. Both are low eroding upland banks with wooded buffers fronting agricultural land, but neither rank P-1 or P-2.

Headland Control – This has inadvertently been accomplished along the Benedict shoreline with the development of small pocket beaches between bulkhead segments of coast.

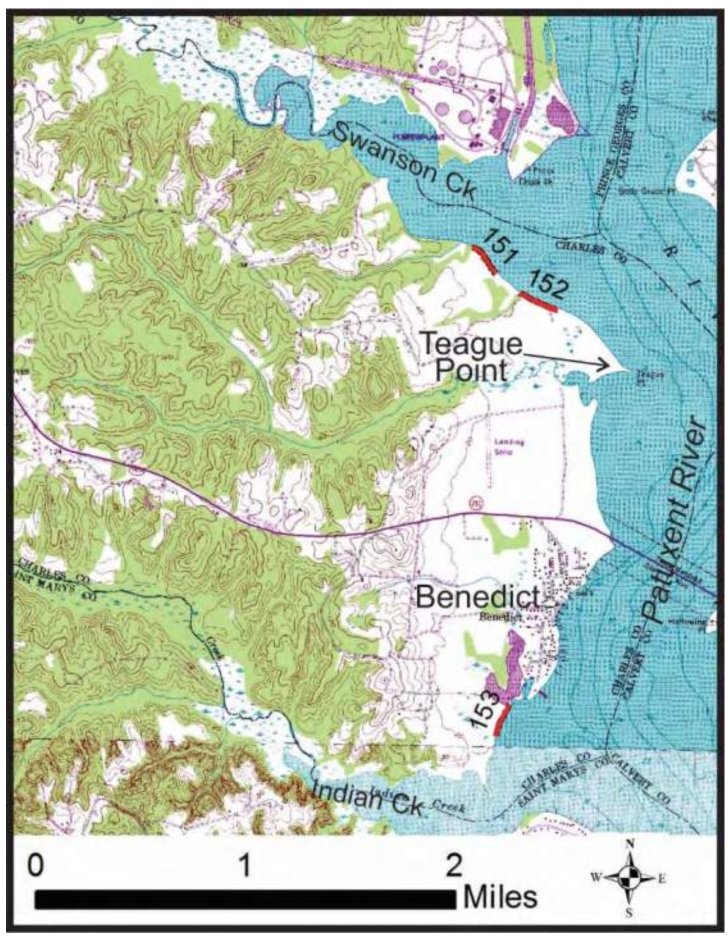


Figure 11-3. Reach VII site recommendation locations.

12 SUMMARY OF SHORELINE MANAGEMENT PLAN

12.1 Summary of Results

Approximately 110 miles of Charles County shoreline was surveyed by boat to assess the condition of the riparian upland, banks, beach, intertidal, and nearshore areas. Two shorelines (1994 and 2015) were digitized in ArcGIS and DSAS was used to calculate the rates of change for the entire County. The shoreline rates varied between very high erosion (<-10 ft/yr) and very high accretion (+10 ft/yr). However, 44% of the shoreline had very low erosion (0 to -1 ft/yr) and 28% had low erosion (-1 to -2 ft/yr). Medium erosion (-2 to -5 ft/yr encompassed 11% of the shoreline. Very low accretion (0 to +1 ft/yr) and low accretion (+1 to +2 ft/yr) made up 12% and 3%, respectively. Accretion results from structure construction as well as slumping along high banks. The wave climate results indicate that during large storms with high sustained winds, the southeast-facing Potomac River shoreline will experience the largest waves. Under smaller storms where the wind is only about 25 mph, waves will vary between 2 and 3 feet in the Potomac before they shoal as they move into the shore. It is evident that the longer average fetch exposures have the greatest potential wave heights during storm events. This data supports project design including sizing armor stone.

Shorelines backed by agricultural land or residential property near the coast were given priority over forested shoreline because of the increased TN and TP input potential to the water due to legacy nutrients in the eroding banks and due to the mitigation required for removal of trees. The banks were labeled stable, erosional, or trending toward stability or erosional, transitional. If the upland was erosional to transitional with a measurable erosion rate, usually less than -0.5 ft/yr, then some type of structural shoreline strategy was typically recommended. Recommended sites typically were upland banks, but some marsh sites were included. In long unmanaged coasts like those in Reach V, erosion was noted but the no action option was recommended because no infrastructure present exists to protect. Allowing banks to continue to erode along unmanaged coasts provides sand to the longshore sediment transport system. This sand helps maintain the beaches in front of upland banks and the finer sediments migrate to marshes so that they can accrete. Another option for long stretches of woodland with no infrastructure is to manage strategic points through headland control.

Because of the emphasis on living shorelines, sill systems were the primary site recommendation. Fetch exposure, wave climate, and site-specific conditions dictated the size of the structure and amount of sand and plants required. A total of 153 sites encompassing about 27 miles of shoreline received site recommendations. The site length varied from a few hundred feet to over 2,000 feet (Appendix A). A ranking of site criteria was used to develop a list of priority sites to carry forward for possible construction (Table 2-1 and Appendix B). Five sites were ranked as the highest priority, 67 were ranked P-2, and 81 were P-3s. The total rank sum number and the TSS were used to prioritize sites within the P-2 and P-3 categories.

12.2 Construction Strategies

As a cost effectiveness strategy for project construction, some P-1 and P-2 sites were recommended to be permitted and constructed concurrently where two or more sites were adjacent or in close proximity to one another. This might be two or more sites using the same access routes and/or two or more sites that can be built from barge.

Figure 12-1. Reach I, site recommendations 8 thru 28.

Reach I along the Wicomico River, has sites which are all relatively close to each other. All land access must come down Cobb Neck via Route 257, Newburg Road. Figure 12-1 shows sites 8 thru 28. Site 23 is a P-1. Grouping P-1s and P-2s during construction would be cost effective shoreline management planning in this case. Grouping two or more sites will require multiple landowner permissions and concurrent design and permitting of those selected sites so the permits for all sites are timely. Bidding for multiple projects also could be done simultaneously, which also saves time and money.

For example, sites 19, 21 and 23 could be grouped. The total cost is about $2.3 million garnering 150 acres of impervious surface restoration (IS) credit (Table 12-1). Site 23 is best suited for a coastal resiliency approach (i.e. bank grading) though it would be most cost effective to leave the existing wood buffers and perform no bank grading on the others. Land based construction access is usually through an existing wood buffer with some type of path, some tree removal involved, and one or two access points depending on project length. Any live tree removal will require mitigation.

In Reach II, sites 61and 62, make an obvious combination project location (Figure 12-2). They could be built from land with material brought in by both land and barge. An old wharf occurs on the side of Lower Cedar Point where rock could be brought in via a barge port and transferred the short distance to the sites by large site trucks (Figure 12-3). Sand would probably come in from land.

Reach III, sites 80, 81, and 82, are essentially adjacent to each other and tentatively buildable or at least accessed by barge (Figure 12-4). No bank grading would occur.

In Reach IV, sites 94, 95, 96, 97, and 98 are all located on Cedar Point Wildlife Management Area with one main access road that branches off to secondary accesses to the sites (Figure 12-5). All these sites appear to have either narrow wooded riparian buffers or grass buffers on the upland so bank grading could occur to enhance coastal resiliency. Construction still requires access through these buffers, so temporary impact to the grass buffers is preferred because they are more easily restored.

12.3 Conclusion

Figure 12-2. Reach II, example of combining Sites 61 and 62 for cost effective design permitting and construction.

The Charles County Shoreline Management Plan (for reaching NPDES Municipal Separate Storm Sewer System (MS-4 Goals) provides the necessary data for the County to assess shoreline protection strategies aimed at reaching those goals. It is also a management tool for the county and private waterfront property owners to guide shore erosion control using the Living Shoreline approach, the preferred method of shore protection in Maryland.

The ranking of eroding upland properties provides a basis to address sites that may have higher priority than others due to erosion and land use factors. Combining adjacent sites for construction will increase project length and, along with ease of access, may provide more cost effective shoreline protection installations.

The impervious surface (IS) credit of 0.04 acres/linear foot of shoreline protected is provided regardless of the type of shoreline protection strategy, in this case mostly sills. Credit for Total Suspended Sediments (TSS) and associated TN and TP loads is site specific.

The Plan elements can be reviewed and referred to over time by the County for adaptive shoreline management uses. The data provided in the Plan can be used to make calculations based on a modified ranking system, changes in TMDL credit variables, or variations in structure design. The data also can help determine cost-effective site combinations for construction, and shoreline management guidance for waterfront property owners in Charles County, Maryland.

Figure 12-3. Materials being brought to the site by barge.

Table 12-1. Example of Site Groupings for Cost Effective Design, Permitting, and Construction. Information provided below should only be used for example purposes, not for construction. Costs are estimated using the typical cross-sections shown in Section 4.4. As such, the cost, and IS acreage and TSS calculations may vary significantly from a final design of shore protection at each site.

	Site#	Rank	Approx. Total Cost	IS Acres	TSS	Cost per Acre	Cost per lb TSS
Reach I	19	3	$988,000	75.9	435,240		
	21	2	$442,000	33.4	184,566		
	23	1	$858,000	40.5	1,271,725		
	Total		**$2,288,000**	**150**	**1,891,531**	**$15,274**	**$1.21**
Reach II	61	2	$1,456,000	56.3	1,101,807		
	62	2	$728,000	30.8	1,112,909		
	Total		**$2,184,000**	**87.1**	**2,214,716**	**$25,075**	**$0.99**
Reach III	80	2	$2,288,000	74.7	2,787,199		
	81	1	$1,148,040	58.9	2,711,899		
	82	2	$2,457,000	100	2,875,236		
	Total		**$5,893,040**	**234**	**8,374,335**	**$25,227**	**$0.70**
Reach IV	95	1	$624,000	21	571,245.4		
	96	2	$1,248,000	37.2	1,084,533.6		
	97	1	$1,872,000	55.3	1,724,313.8		
	98	2	$1,872,000	61.9	2,638,800.0		
	Total		**$5,616,000**	**175**	**6,018,893**	**$32,018**	**$0.93**

Figure 12-4. Reach III. Combining Sites 80, 81, and 82 for cost effective design, permitting and construction.

Figure 12-5. Reach IV. Combining Sites 95, 96, 97, and 98 for cost effective design, permitting and construction.

13 REFERENCES

Basco, D.R. & C.S. Shin, 1993. Design Wave Information for Chesapeake Bay and Major Tributaries in Virginia. Coastal Engineering Program, Civil and Environmental Engineering Department, Old Dominion University, Norfolk, Virginia. Report No. 93-1.

Berman, M.R., Berquist, H., Killeen, S., Nunez, K., Rudnicky, T., Schatt, D.E., Weiss, D. & K. Reay, 2006. Charles County, Maryland - Shoreline Situation Report. Comprehensive Coastal Inventory Program, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA

Charles County Comprehensive Plan, 2016. Charles County Comprehensive Plan. Retrieved from https://www.charlescountymd.gov/pgm/planning/comprehensive-plan-2016

CBP, 2008. Chesapeake Bay Mean Surface Salinity. Maps retrieved from www.chesapeakebay.net

Coastline Design PC, 2002. Indian Head Naval Propellant Plan: Shoreline Management Plan. Prepared for U.S. Navy.

Coastline Design, PC. 2004. Swan Point Development Shoreline Management Plan. Prepared for Brookfield Homes.

Drescher, S. & B. Stack 2015. Recommendations of the Expert Panel to Define Removal Rates for Shoreline Management Projects. Prepared by Center for Watershed Protection for EPA Chesapeake Bay Program Office, Urban Stormwater Work Group.

Drescher, S. & B. Stack 2015a, revised 6.01.17. Recommendations of the Expert Panel to Define Removal Rates for Shoreline Management Projects. Prepared by Center for Watershed Protection for EPA Chesapeake Bay Program Office, Urban Stormwater Work Group.

FEMA, 2015. Flood Insurance Study, Charles County, Maryland and Unincorporated Areas. Federal Emergency Management Agency, Flood Insurance Study Number 24017CV000B. Retrieved from https://msc.fema.gov/portal/home

Hardaway. C.S., J.R.Gunn & R.N. Reynolds, 1993. Breakwater Design in Chesapeake Bay: Dealing with the End Effects. Coastal Engineering Considerations in Coastal Zone Management. Proceedings, 8th Symposium on Coastal and Ocean Management, ASCE, July 19-23, New Orleans, LA. Pages 27-41.

Hardaway, C.S. & R.J. Byrne, 1999. Shoreline Management in Chesapeake Bay. Special Report in Applied Marine Science and Ocean Engineering No 356, Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, VA.

Hardaway, Jr., C.S., D. A. Milligan, & C. A. Wilcox, 2016. U.S. Army Garrison Adelphi Laboratory Center Blossom Point Research Facility Shoreline Management Plan for Potomac River and Nanjemoy Creek. Shoreline Studies Program, Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, VA.

Ibison, N.A., C.W. Frye, J.E. Frye, C.L. Hill, & N.H. Burger, 1992. Eroding Bank Nutrient Verification Study for the Lower Chesapeake Bay. Department of Conservation and Recreation, Division of Soil and Water Conservation, Shoreline Studies Program, Gloucester Point, VA.

Kirwan, M.L., S. Temmerman, E.E. Skeehan, G.R. Guntenspergen, & S. Fagherazzi, 2016. Overestimation of marsh vulnerability to sea level rise. Nature Climate Change. Feburary 24, 2016, DOI 10.1038/NClimate 2909.

MDE, 2014. Accounting for Stormwater Wasteload Allocations and Imperivous Acres Treated, Guidance for National Pollutant Discharge Elimination System Stormwater Permits. Maryland Department of the Environment, 1800 Washington Boulevard, Baltimore MD. Retrieved from http://www.mde.state.md.us/programs/Water/TMDL/DataCenter/Pages/TMDLStormwaterImplementation.aspx

NWI, 2018. National Wetlands Inventory. Fish & Wildlife Service online mapper. Retrieved July 2018 from https://www.fws.gov/wetlands/data/Mapper.html

SAV, 2018. Submerged Aquatic Vegetation Viewer. Submerged Aquatic Vegetation Program, Virginia Institute of Marine Science, William & Mary online viewer. Retrieved from http://web.vims.edu/bio/sav/maps.html

U.S. Army Corps of Engineers, 2014. Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation. Technical Letter No. 1100-2-1. Department of the Army, U.S. Army Corps of Engineers, Washington DC. 2-314-1000

Appendix A

Charts of Sites, Characteristics, & Recommendations

Site Number	Site designation	Condition of Bank Face	Description of the condition of the bank face (stable, transitional, erosional) based on the project field visit.
Waterbody	Body of water on which the site occurs	Condition of Base of Bank	Description of the condition of the bank face (stable, transitional, erosional, undercut) based on the project field visit.
Reach	Reach designation; based on morphology of the shoreline	Shore Man Recommendation	Structure type recommended for the site. A description is available in section 4.4 of the report
Site Length	GIS measured length of suggested site; in feet	Recommended Structure Type	Numbered, representative cross-section of the recommended structure as shown in Figures 4-10 through 4-13 in section 4.4 of the report
Shore Change	Rate of shore change between digitized shorelines 1994 and 2015; in feet per year	Probable Construction Accessibility	Probable way to access the site during construction (land, barge via water). Accessibility should be confirmed in the project design phase.
Bank Height	Representative bank height based on typical cross-sections of LIDAR data; in feet		
Buffer Width	Approximate, representative width of wooded buffer along the site; in feet		
Mean Tide Range	Mean tide range based on NOAA data as represented by the Google Earth tool available at Virginia Institute of Marine Science		
Landscape	Representative land use		

Sites can be located on the location maps within this report, in the ArcGIS data delivered to the County or using the Google Earth kml file.

Site Number	Waterbody	Reach	Site Length (ft)	Shore Change (ft/yr)	Bank Height (ft)	Buffer Width (ft)	Mean Tide Range (ft)	Landscape
1	Wicomico River	I-A	256.4	-1.0	9.8	160	1.8	Wood/ag
2	Wicomico River	I-A	1726.5	-1.0	9.3	1800	1.8	Wooded
3	Wicomico River	I-A	1203.0	-0.6	9.4	45	1.8	Wooded
4	Wicomico River	I-A	224.4	-0.5	2.6	42	1.8	Wooded
5	Wicomico River	I-A	62.8	-0.8	2.3	0	1.8	Low marsh
6	Wicomico River	I-A	468.4	-0.6	4.9	80	1.8	Wooded
7	Wicomico River	I-A	855.7	-0.5	5.2	80	1.8	Wooded
8	Wicomico River	I-A	1207.4	-0.8	8.2	2800	1.8	Wooded
9	Wicomico River	I-A	406.9	-1.4	9.8	0	1.8	Wooded
10	Wicomico River	I-A	1401.3	-0.8	7.9	7000	1.8	Wooded
11	Wicomico River	I-A	578.9	-1.0	9.8	971	1.8	Wooded
12	Wicomico River	I-A	731.9	-0.8	9.0	0	1.8	Wooded
13	Wicomico River	I-A	737.1	-0.6	8.2	190	1.8	Wooded
14	Wicomico River	I-A	643.1	-0.1	11.5	992	1.8	Wooded
15	Wicomico River	I-A	469.0	-0.3	11.5	0	1.8	Residential
16	Wicomico River	I-A	925.9	-0.3	11.1	86	1.8	Wooded
17	Wicomico River	I-A	2022.2	-0.4	21.9	46	1.8	Wooded
18	Wicomico River	I-A	142.6	-0.5	1.6	0	1.8	Spit
19	Wicomico River	I-A	1896.8	-0.3	15.3	50	1.8	Wooded
20	Wicomico River	I-A	185.8	-0.3	8.2	0	1.8	Residential
21	Wicomico River	I-B	834.8	-0.4	13.1	0	1.8	Wooded
22	Wicomico River	I-B	162.9	-0.1	9.8	64	1.8	Wooded
23	Wicomico River	I-B	1013.2	-3.3	8.2	0	1.8	No wood
24	Wicomico River	I-B	267.1	-1.7	9.0	0	1.8	low wood
25	Wicomico River	I-B	1182.1	-1.4	13.9	99	1.8	Wooded
26	Wicomico River	I-B	1733.3	-2.6	9.4	306	1.8	Wooded
27	Wicomico River	I-B	511.2	-0.8	8.5	68	1.8	Wooded
28	Wicomico River	I-B	785.8	-1.9	13.1	47	1.8	Wooded
29	Wicomico River	I-B	1266.2	-0.7	13.5	54	1.8	Wood ed
30	Wicomico River	I-C	368.1	-0.9	16.4	166	1.8	Wooded
31	Wicomico River	I-C	169.9	-2.0	4.1	0	1.8	marsh
32	Wicomico River	I-C	683.3	-1.7	13.1	40	1.8	Wooded

Information for sites 1-32 continued on next page.

Site Number	Condition of Bank Face	Condition of Base of Bank	Shore Management Recommendation	Recommend Structure Type	Probable Construction Accessibility
1	Transitional	Erosional	Small Low Sill	1	Land
2	Erosional	Erosional	Small Low Sill	1	Land
3	Broken Concrete	Broken Concrete	Small Low Sill	1	Land
4	Erosional	Erosional	Small Low Sill	1	Land
5	No Discernable Bank	Erosional	Spur = 150'-200'	2	Land
6	Transitional	Erosional	Small Low Sill	1	Land
7	Transitional	Erosional	Small Low Sill	1	Land
8	Erosional	Erosional	Small Low Sill	1	Land
9	Erosional	Erosional	Small Low Sill	1	Land
10	Erosional	Erosional	Small Low Sill	1	Land
11	Erosional	Erosional	Small Low Sill	1	Land
12	Erosional	Erosional	Low Sill	2	Land
13	Transitional	Erosional	Small Low Sill	1	Land
14	Transitional	Erosional	Small Low Sill	1	Land
15	Broken Concrete		Low Sill	2	Land
16	Erosional-Transitional	Erosional-Undercut	Small Low Sill	1	Land
17	Erosional-Transitional	Erosional	Low Sill	2	Land
18	No Discernable Bank		Spur	2	Land
19	Erosional-Transitional	Erosional-Undercut	Small Low Sill	1	Land
20	Erosional	Erosional	Small Low Sill	1	Land
21	Stable-Erosional	Erosional-Transitional	Small Low Sill	1	Land
22	Erosional	Erosional	Small Low Sill	1	Land
23	Erosional	Erosional	High sill	3	Land
24	Erosional	No Discernable Bank	Small low sill tie in	1	Land
25	Erosional-Transitional	Erosional-Undercut	Small low sill	1	Land
26	Erosional	Erosional	Small low sill w/spur	1	Land
27	Erosional-Transitional	Erosional-Undercut	Small low sill	1	Land
28	Erosional	Erosional	Small low sill	1	Land
29	Erosional-Transitional	Erosional	small low sill	1	Land
30	Erosional-Transitional	Erosional-Undercut	small low sill	1	Land
31	Erosional	Erosional	Small low sill	1	Land
32	Erosional	Erosional	Low Sill	2	Land

Site Number	Waterbody	Reach	Site Length (ft)	Shore Change (ft/yr)	Bank Height (ft)	Buffer Width (ft)	Mean Tide Range (ft)	Landscape
33	Wicomico River	I-C	276.4	-2.3	2.5	0	1.8	marsh
34	Wicomico River	I-C	799.0	-1.1	13.1	2000	1.8	Wooded
35	Wicomico River	I-C	219.8	-1.0	7.4	2500	1.8	Wooded
36	Wicomico River	I-C	329.0	-0.7	6.6	0	1.8	Wood/res
37	Wicomico River	I-C	1213.4	-0.2	7.0	194	1.8	Wooded
38	Wicomico River	I-C	417.3	-0.3	7.4	18	1.8	Residential
39	Wicomico River	I-C	382.8	-0.2	9.0	46	1.8	Residential
40	Wicomico River	I-C	276.0	-1.7	6.6	46	1.8	Residential
41	Wicomico River	I-C	1019.1	-1.6	13.1	1500	1.8	Wooded
42	Wicomico River	I-C	680.9	-1.2	13.9	237	1.8	Wooded
43	Wicomico River	I-C	1568.4	-0.9	11.9	0	1.8	Residential
44	Wicomico River	I-C	349.1	-2.3	2.6	328	1.8	Wooded
45	Wicomico River	I-C	247.2	-0.3	4.1	437	1.8	Shrub/grass
46	Wicomico River	I-C	413.6	-1.5	3.0	0	1.8	Wooded
47	Wicomico River	I-C	227.9	-1.8	13.1	81	1.8	Wood/res
48	Neale Sound	II-A	369.5	-0.6	5.7	451	1.8	Wooded
49	Neale Sound	II-A	542.2	-1.9	13.9	800	1.8	Wooded
50	Neale Sound	II-A	781.4	-1.8	4.9	800	1.8	Wooded
51	Neale Sound	II-A	311.0	-2.1	4.9	0	1.8	Residential
52	Potomac River	II-A	236.9	0.2	11.5	0	1.6	Ag
53	Potomac River	II-A	940.2	-1.1	5.6	211	1.6	Wood/ag
54	Potomac River	II-B	3560.2	-4.5	9.8	1000	1.6	Wooded
55	Potomac River	II-B	651.9	-0.1	16.4	54	1.6	Ag
56	Piccowaxen	II-B	805.5	-0.6	9.0	60	1.5	wooo/ag
57	Piccowaxen	II-B	222.5	-0.6	2.3	0	1.5	Residential
58	Potomac River	II-B	1016.5	-2.4	6.6	800	1.5	Wooded/marsh
59	Potomac River	II-B	193.7	-2.2	18.0	0	1.5	Wooded
60	Potomac River	II-C	1120.7	-0.7	3.8	0	1.5	shrub/grass
61	Potomac River	II-C	1407.0	-1.2	13.9	0	1.5	Ag
62	Potomac River	II-C	771.1	-1.9	16.4	0	1.5	Ag/res
63	Potomac River	II-C	362.7	-2.9	3.3	64	1.5	Wooded
64	Potomac River	II-C	548.1	-1.5	14.8	100	1.5	Wooded
65	Potomac River	III-A	332.0	-1.0	13.8	276	1.5	Wooded
66	Potomac River	III-A	2393.0	-0.4	53.3	274	1.5	Wood/res
67	Potomac River	III-A	2435.3	-1.2	106.6	1160	1.5	Wooded
68	Potomac River	III-A	1404.9	-0.9	82.0	170	1.5	Wood/res

Information for sites 33-68 continued on next page.

Site Number	Condition of Bank Face	Condition of Base of Bank	Shore Management Recommendation	Recommend Structure Type	Probable Construction Accessibility
33	Erosional	No Discernable Bank	Small low sill	1	Land
34	Erosional-Transitional	Erosional-Undercut	small low sill	1	Land
35	Erosional	Erosional	small low sill	1	Land
36	Erosional-Transitional	Erosional-Undercut	small low sill	1	Land
37	Erosional	Erosional	small low sill	1	Land
38	Erosional-Transitional	Erosional-Undercut	small low sill	1	Land
39	Erosional-Transitional	Erosional-Undercut	small low sill	1	Land
40	Erosional	Erosional	small low sill	1	Land
41	Erosional	Erosional	Low Sill	2	Land
42	Erosional	Erosional	Low Sill	2	Land
43	Erosional	Erosional	Lo w Sill/brill	2	Land
44	Erosional-Transitional	No Discernable Bank	small low sill	1	Land
45	Low Headland		Headland BW/high sill	3	Land
46	Erosional	Erosional	Low Sill	2	Land
47	Erosional	Erosional	High/low sill	2	Land
48	Erosional	Erosional	small low sill	1	Land/Barge
49	Erosional	Erosional	Low Sill	2	Land/Barge
50	Erosional	Erosional	Low Sill	2	Land/Barge
51	Erosional	Erosional	Low Sill	2	Land
52	Erosional-Transitional	Erosional-Transitional	low Sill +3.5	4	Land
53	Erosional	Erosional	bws	5	Land
54	Erosional	Erosional	sills/revetment	4	Barge
55	Transitional	Transitional	Low Sill +3.5 w/spurs	4	Land
56	Erosional	Erosional	small low sill	1	Land
57	Erosional	Erosional	low sill +3	2	Land
58	Erosional	Erosional	Low sill +3 to +3.5	4	Land
59	Erosional	Erosional	low sill +3.5	5	Land
60	Erosional	Erosional	small low sill +3.0/+4	4	Land/Barge
61	Erosional	Erosional	High sill	5	Land/Barge
62	Erosional	Erosional	High sill	5	Land
63	Erosional	No Discernable Bank	small low sill +3	6	Land
64	Erosional	Erosional	low sill +3.5	4	Land
65	Erosional	Erosional	low sill +3.5 river	4	Land
66	Erosional	Erosional	high sill +4	5	Barge
67	Erosional	Erosional	high sill +4	5	Barge
68	Erosional-Transitional	Erosional	low sill +3.5	4	Barge

Site Number	Waterbody	Reach	Site Length (ft)	Shore Change (ft/yr)	Bank Height (ft)	Buffer Width (ft)	Mean Tide Range (ft)	Landscape
69	Potomac River	III-A	1395.8	-1.6	98.4	152	1.5	wood/ag
70	Potomac River	III-A	1324.2	-1.8	98.4	118	1.5	wooded
71	Potomac River	III-B	713.4	-0.9	82.0	0	1.5	Residential
72	Potomac River	III-B	1823.9	-1.7	93.5	600	1.5	wooded
73	Potomac River	III-B	1206.8	-2.4	57.4	614	1.5	Wooded
74	Potomac River	III-B	1828.4	-2.0	106.6	81	1.5	Wooded
75	Potomac River	III-B	898.7	-1.1	65.6	440	1.5	Wooded
76	Potomac River	III-B	2197.8	-2.4	80.4	32	1.5	Wood/res
77	Potomac River	III-B	618.0	-1.5	49.2	3000	1.5	Wooded
78	Potomac River	III-C	1536.2	-1.6	65.6	3000	1.5	Wooded
79	Potomac River	III-C	1491.8	-0.8	27.9	2700	1.5	wooded
80	Potomac River	III-C	1867.5	-1.6	19.7	0	1.5	Ag
81	Potomac River	III-C	1471.8	-2.0	19.7	0	1.5	Wooded,res, ag
82	Potomac River	III-C	2500.1	-1.1	23.0	47	1.5	Wood
83	Potomac River	III-C	941.1	-2.7	23.0	36	1.5	Wood/ag
84	Potomac River	III-C	339.1	-1.9	19.7	104	1.5	Wood/ag
85	Potomac River	III-C	980.3	-1.9	13.1	37	1.5	Wood/ag
86	Potomac River	III-C	331.6	-2.2	16.4	0	1.5	Residential
87	Port Tobacco River	III-D	865.8	-1.1	16.4	11	1.5	R/ag
88	Port Tobacco River	III-D	697.8	-0.6	19.7	35	1.5	Residential
89	Port Tobacco River	III-D	335.4	-0.8	19.7	880	1.5	Wooded
90	Port Tobacco River	III-D	1966.5	-1.0	36.1	316	1.5	Wooded
91	Port Tobacco River	III-D	2357.1	-1.3	27.9	500	1.5	Wooded
92	Port Tobacco River	III-D	494.2	-1.0	8.2	0	1.5	Ag
93	Port Tobacco River	III-D	334.6	-1.0	3.3	0	1.5	Wooded
94	Potomac River	IV-A	465.7	-3.7	3.1	535	1.4	Wooded
95	Potomac River	IV-A	525.5	-2.4	9.8	0	1.4	Ag
96	Potomac River	IV-A	929.4	-1.9	13.1	0	1.4	ag
97	Potomac River	IV-A	1383.0	-2.0	13.1	0	1.4	ag
98	Potomac River	IV-A	1548.3	-1.9	19.7	0	1.4	ag
99	Nanjemoy Creek	IV-B	563.7	-1.0	6.6	249	1.2	Wood/ag
100	Nanjemoy Creek	IV-B	553.1	-0.3	6.6	133	1.2	Wood/ag
101	Nanjemoy Creek	IV-B	1050.0	-0.7	6.6	552	1.2	Wood
102	Nanjemoy Creek	IV-B	513.2	-1.0	8.2	0	1.2	ag

Information for sites 69-102 continued on next page.

Site Number	Condition of Bank Face	Condition of Base of Bank	Shore Management Recommendation	Recommend Structure Type	Probable Construction Accessibility
69	Transitional-Stable	Transitional-Undercut	Low siil +3.5	4	Barge
70	Erosional	Erosional	low sill +3.5	4	Barge
71	Erosional	Erosional	low sill +3.5	4	Barge
72	Erosional	Erosional	high sill +4	5	Barge
73	Erosional-Transitional	Erosional	low sill +3.5	4	Barge
74	Erosional-Transitional	Erosional	low sill =3.5	4	Barge
75	Erosional	Erosional	hihg sill +4	5	Barge
76	Erosional	Erosional	High/low sill	5	Barge
77	Erosional	Erosional	low sill +3.5	4	Barge
78	Erosional	Erosional	low sill +3.5	4	Barge
79	Erosional	Erosional	low sill +3.5	4	Land/Barge
80	Erosional	Erosional	high sill +4	5	Land/Barge
81	Erosional	Erosional	low sill +3.5	4	Land/Barge
82	Erosional	Erosional	high sill +4 with low sill components +3.5	5	Land/Barge
83	Erosional-Transitional	Erosional	low sill +4 P1	5	Land
84	Erosional-Transitional	Erosional	low sill +4 P1	5	Land
85	Erosional	Erosional	low sill +4 P1	5	Land
86	Erosional	Erosional	low sill +3.5	4	Land
87	Erosional-Transitional	Erosional	low sill +3.5	3	Land
88	Erosional	Erosional	low sill +3	2	Land
89	Erosional	Erosional	low sill +3	2	Land
90	Stable-Transitional	Erosional-Undercut	low sill +3	2	Land
91	Stable-Erosional	Erosional-Undercut	low sill +3	2	Land
92	Erosional	Erosional	low sill +3.5 as twp headlands	3	Land
93	Erosional-Transitional	Erosional-Undercut	low sill +3	2	Land
94	Erosional	Erosional	low sill +3 w/spur	3	Land
95	Erosional	Erosional	low sill +4 P2? With spurs	5	Land
96	Erosional	Erosional	low sill +4 P1	5	Land
97	Erosional	Erosional	low sill/brill +4 P1	5	Land
98	Erosional	Erosional	low sill/bill +4 P1	5	Land
99	Erosional	Erosional	low sill +3	2	Land
100	Erosional	Erosional	low sill +3	2	Land
101	Erosional	Erosional	low sill +3	2	Land
102	Erosional	Erosional	low sill +3.5	2	Land

Site Number	Waterbody	Reach	Site Length (ft)	Shore Change (ft/yr)	Bank Height (ft)	Buffer Width (ft)	Mean Tide Range (ft)	Landscape
103	Nanjemoy Creek	IV-B	720.3	-2.3	6.6	58	1.2	Wood/res
104	Nanjemoy Creek	IV-B	812.2	-0.9	3.3	71	1.2	Wood
105	Nanjemoy Creek	IV-B	1432.6	-0.7	18.0	48	1.2	Wood/ag
106	Potomac River	IV-C	930.8	-2.2	19.7	1330	1.2	Wooded
107	Potomac River	IV-C	308.5	-1.5	19.7	392	1.2	Wooded
108	Potomac River	IV-C	394.4	-0.7	18.0	136	1.2	Wooded
109	Potomac River	IV-C	1561.5	-1.0	18.0	29	1.3	Wood/ag
110	Potomac River	IV-C	653.7	-1.0	19.7	0	1.3	Wooded
111	Potomac River	IV-C	398.9	-0.8	19.7	0	1.2	Wooded
112	Potomac River	IV-C	1494.9	-0.8	18.9	35	1.2	Ag/wood
113	Potomac River	IV-C	1350.6	-1.7	16.4	1588	1.1	Wooded
114	Potomac River	V-A	2605.1	-2.0	24.6	1000	1.1	Wooded
115	Potomac River	V-A	311.9	-2.3	26.2	0	1.1	Residential
116	Potomac River	V-A	1920.2	-1.5	24.6	1000	1.1	Wooded
117	Potomac River	V-A	1920.1	-0.7	24.6	1700	1.1	Wooded
118	Potomac River	V-A	780.6	-0.4	26.2	45	1.1	Antennae Farm
119	Potomac River	V-A	347.6	-0.7	19.7	167	1.1	Wooded
120	Potomac River	V-A	795.0	-1.4	18.0	1400	1.1	Wooded
121	Potomac River	V-A	616.9	-1.4	14.8	3300	1.1	Wooded
122	Potomac River	V-B	3472.8	-1.5	27.1	2700	1.1	Wooded
123	Potomac River	V-B	1559.4	-0.9	24.6	4600	1.3	Wooded
124	Potomac River	V-B	749.3	-0.5	26.3	292	1.3	Wooded
125	Potomac River	V-B	690.9	-1.1	32.8	2500	1.3	Wooded
126	Potomac River	V-B	575.1	-1.2	32.2	4800	1.5	Wooded
127	Potomac River	V-C	311.0	-1.2	41.0	5145	1.5	Wooded
128	Potomac River	V-C	643.1	-1.1	32.8	108	1.5	Residential
129	Potomac River	V-C	956.1	-1.4	19.7	1780	1.5	Wooded
130	Potomac River	V-C	692.9	-1.7	26.9	86	1.5	Wooded
131	Potomac River	V-C	829.3	-1.2	31.2	67	1.5	Residential

Information for sites 103-131 continued on next page.

Site Number	Condition of Bank Face	Condition of Base of Bank	Shore Management Recommendation	Recommend Structure Type	Probable Construction Accessibility
103	Erosional	Erosional-Undercut	low sill +3/revet SAV	4	Land
104	Erosional	Erosional-Undercut	low sill +3/revet SAV	4	Land
105	Erosional-Transitional	Erosional-Undercut	low sill +3.5/revet SAV	4	Land
106	Erosional	Erosional	low sill +3.5 river	4	Land
107	Erosional	Erosional	low sill +3.5	4	Land
108	Erosional-Transitional	Erosional-Undercut	low sill +3	3	Land
109	Erosional-Transitional	Erosional-Undercut	Brill/low sill +3.5	4	Land
110	Stable-Transitional	Stable-Undercut	Brill/spurs/low sill +3.5	4	Land
111	Erosional	Erosional	low sill +3.5/revet	4	Land
112	Stable-Erosional	Stable-Erosional	Brill +3.5	4	Land
113	Erosional	Erosional	low sill +3.5 SAV	4	Land/Barge
114	Erosional	Erosional	low sill +3.5	4	Land/Barge
115	Erosional	Erosional	High Sill +4.0 residentail	5	Land/Barge
116	Erosional-Transitional	Erosional	low sill +3.5	4	Land/Barge
117	Erosional-Transitional	Erosional-Transitional	low sill +3.5	4	Barge
118	Erosional-Transitional	Erosional-Transitional	High Sill/Revet	5	Land/Barge
119	Erosional-Transitional	Erosional-Transitional	low sill +3.5	4	Barge
120	Erosional-Transitional	Erosional-Transitional	low hill +3.5	4	Barge
121	Erosional	Erosional-Transitional	low sill+3.5	4	Barge
122	Erosional	Erosional	low sill +3.5	4	Barge
123	Erosional	Erosional	low sill +3.5	4	Barge
124	Erosional	Erosional	low sill +3.5	4	Barge
125	Erosional	Erosional	low sill +3.5	4	Barge
126	Erosional-Transitional	Erosional-Undercut	low sill +3.5	4	Barge
127	Erosional-Transitional	Erosional-Undercut	low sill +3.5 with spur	4	Barge
128	Erosional-Transitional	Erosional-Undercut	low sill +3.5	4	Land/Barge
129	Erosional	Erosional	low sill +3.5	4	Barge
130	Erosional	Erosional	low sill +3.5	4	Land/Barge
131	Erosional-Transitional	Erosional-Undercut	low sill +3.5	4	Land/Barge

Site Number	Waterbody	Reach	Site Length (ft)	Shore Change (ft/yr)	Bank Height (ft)	Buffer Width (ft)	Mean Tide Range (ft)	Landscape
132	Potomac River	V-C	785.7	-1.2	21.3	48	1.5	Open, Power Lines
133	Potomac River	V-C	1260.7	-1.4	27.9	40	1.5	Residential
134	Potomac River	VI-A	514.2	-1.5	26.2	71	1.8	Wooded/res
135	Potomac River	VI-A	875.3	-1.6	19.7	63	1.8	Wooded/res
136	Potomac River	VI-B	233.7	-1.2	19.7	15	1.8	Wooded/res
137	Potomac River	VI-B	701.6	-0.8	32.8	0	1.8	Res
138	Potomac River	VI-B	817.7	-0.8	32.8	345	1.8	Wooded/res
139	Potomac River	VI-B	1011.6	-1.0	23.0	170	1.8	Wooded/res
140	Potomac River	VI-B	424.9	-0.9	65.6	84	1.8	Wooded/res
141	Potomac River	VI-B	2931.7	-0.8	98.4	1200	1.8	Wooded/res
142	Potomac River	VI-C	843.6	-1.4	8.2	0	1.8	Residential
143	Potomac River	VI-C	181.8	-1.6	6.6	0	1.8	Residential
144	Potomac River	VI-C	461.0	-1.8	9.8	0	2.0	Residential
145	Potomac River	VI-C	272.5	-1.6	3.9	130	2.0	Res/wood
146	Potomac River	VI-C	928.3	-0.6	6.1	0	2.0	Res/wood
147	Potomac River	VI-C	1517.4	-0.6	21.3	55	2.0	Res/wood
148	Potomac River	VI-C	1698.5	-0.2	16.4	450	2.0	Wooded
149	Potomac River	VI-C	1507.3	0.1	27.9	352	2.0	Wooded
150	Potomac River	VI-C	1103.2	0.2	23.0	59	2.0	Res/wood
151	Patuxent River	VII	926.0	-0.4	9.8	125	1.5	Ag
152	Patuxent River	VII	1058.3	-0.1	11.5	119	1.5	Ag
153	Patuxent River	VII	899.5	-0.8	8.2	140	1.5	Ag

Information for sites 132-153 continued on next page.

Site Number	Condition of Bank Face	Condition of Base of Bank	Shore Management Recommendation	Recommend Structure Type	Probable Construction Accessibility
132	Erosional	Erosional	High Sill +4	5	Land/Barge
133	Erosional	Erosional	low sill +3.5	4	Land
134	Stable-Transitional	Undercut	low sill +3.5	4	Land/Barge
135	Stable-Transitional	Undercut	low sill +3.5	4	Land/Barge
136	Stable-Transitional	Stable-Undercut	low sill +3.5	4	Land/Barge
137	Erosional	Erosional	low sill +3.5	5	Land/Barge
138	Stable-Transitional	Stable-Undercut	low sill +3.5	4	Land/Barge
139	Stable-Transitional	Undercut	low sill +3.5	4	Land/Barge
140	Stable-Transitional	Undercut	low sill +3.5	4	Barge
141	Stable-Transitional-Erosiona	Erosional-Undercut	Near sill/revetment due to SAV	4	Barge
142	Failed bulkheads/rever		Revetments	4	Land
143	Erosional	Erosional	Near sill/revetment due to SAV	4	Land
144	Erosional	Undercut	Near sill/revetment due to SAV	4	Land
145	Erosional	Erosional	Near sill/revetment due to SAV	4	Land/Barge
146	Failed bulkheads/rever		Near sill/revetment due to SAV	4	Land/Barge
147	Stable-Transitional-Erosiona	Undercut	Near sill/revetment due to SAV	4	Barge
148	Erosional-Transitional	Erosional	Near sill/revetment due to SAV	4	Land/Barge
149	Erosional-Transitional	Erosional-Undercut	Near sill/revetment due to SAV	4	Land/Barge
150	Erosional-Transitional	Erosional	Near sill/revetment due to SAV	4	Land
151	Erosional-Transitional	Erosional-Undercut	low sill +3.5	3	Land
152	Erosional-Transitional	Erosional-Undercut	low sill +3.5	3	Land
153	Erosional	Erosional	low sill +3	2	Land

Appendix B

Ranking tables

Ranking Table: the sites are ordered by Total Rank, Priority number, and TSS from highest priority to lowest priority. Priority 1 sites are highlighted.

Site Number	Site designation	Rank ER	Numeric rank based on erosion rate as described in section 3.5 and Table 3-1.
Reach	Reach designation; based on morphology of the shoreline	Rank BH	Numeric rank based on bank height as described in section 3.5 and Table 3-1.
Structure Type	Numbered, representative cross-section of the recommended structure as shown in Figures 4-10 through 4-13 in section 4.4 of the report	Rank BW	Numeric rank based on buffer width as described in section 3.5 and Table 3-1.
Shore Change	Rate of shore change between digitized shorelines 1994 and 2015; in feet per year	Rank Length	Numeric rank based on site length as described in section 3.5 and Table 3-1.
Bank Height	Representative bank height based on typical cross-sections of LIDAR data; in feet	Total Rank	Sum of the four individual numeric rankings
Buffer Width	Approximate, representative width of wooded buffer along the site; in feet	Priority Number	Assigned priority number based on Total Rank as described in section 3.5 and Table 3-1.
Site Length	GIS measured length of suggested site; in feet	Protocol 1 TSS/site length	Volume (height*erosion rate*site length) * 93.6 (lbs / cf; bulk density) * 0.5 (Sand reduction factor in Maryland) divided by site length; in pounds per foot per year; Drescher and Stack, 2015a

Sites can be located on the location maps within this report, in the ArcGIS data delivered to the County or using the Google Earth kml file.

Site Number	Reach	Structure Type	Shore Change (ft/yr)	Bank Height (ft)	Buffer Width (ft)	Site Length (ft)	Rank ER	Rank BH	Rank BW	Rank Length	Total Rank	Priority Number	Protocol 1 - TSS/site length (lbs/ft/yr)
23	I-B	3	-3.3	8.2	0	1013.2	8	4	4	3	19	1	1,255
54	II-B	4	-4.5	9.8	1000	3560.2	8	4	1	4	17	1	2,055
81	III-C	4	-2.0	19.7	0	1471.8	6	3	4	3	16	1	1,835
97	IV-A	5	-2.0	13.1	0	1383.0	6	3	4	3	16	1	1,245
95	IV-A	5	-2.4	9.8	0	525.5	6	4	4	2	16	1	1,082
51	II-A	2	-2.1	4.9	0	311.0	6	4	4	1	15	2	475
33	I-C	1	-2.3	2.5	0	276.4	6	4	4	1	15	2	254
76	III-B	5	-2.4	80.4	32	2197.8	6	1	3	4	14	2	8,831
59	II-B	5	-2.2	18.0	0	193.7	6	3	4	1	14	2	1,836
98	IV-A	5	-1.9	19.7	0	1548.3	4	3	4	3	14	2	1,697
86	III-C	4	-2.2	16.4	0	331.6	6	3	4	1	14	2	1,681
80	III-C	5	-1.6	19.7	0	1867.5	4	3	4	3	14	2	1,486
26	I-B	1	-2.6	9.4	306	1733.3	6	4	1	3	14	2	1,139
61	II-C	5	-1.2	13.9	0	1407.0	4	3	4	3	14	2	911
58	II-B	4	-2.4	6.6	800	1016.5	6	4	1	3	14	2	736
103	IV-B	4	-2.3	6.6	58	720.3	6	4	2	2	14	2	712
142	VI-C	4	-1.4	8.2	0	843.6	4	4	4	2	14	2	526
94	IV-A	3	-3.7	3.1	535	465.7	8	4	1	1	14	2	519
83	III-C	5	-2.7	23.0	36	941.1	6	2	3	2	13	2	2,904
115	V-A	5	-2.3	26.2	0	311.9	6	2	4	1	13	2	2,857
114	V-A	4	-2.0	24.6	1000	2605.1	6	2	1	4	13	2	2,326
62	II-C	5	-1.9	16.4	0	771.1	4	3	4	2	13	2	1,443
96	IV-A	5	-1.9	13.1	0	929.4	4	3	4	2	13	2	1,165
82	III-C	5	-1.1	23.0	47	2500.1	4	2	3	4	13	2	1,147
109	IV-C	4	-1.0	18.0	29	1561.5	4	3	3	3	13	2	851
144	VI-C	4	-1.8	9.8	0	461.0	4	4	4	1	13	2	803
24	I-B	1	-1.7	9.0	0	267.1	4	4	4	1	13	2	729
9	I-A	1	-1.4	9.8	0	406.9	4	4	4	1	13	2	642
143	VI-C	4	-1.6	6.6	0	181.8	4	4	4	1	13	2	496
63	II-C	6	-2.9	3.3	64	362.7	6	4	2	1	13	2	431
92	III-D	3	-1.0	8.2	0	494.2	4	4	4	1	13	2	399
31	I-C	1	-2.0	4.1	0	169.9	4	4	4	1	13	2	378
46	I-C	2	-1.5	3.0	0	413.6	4	4	4	1	13	2	197
93	III-D	2	-1.0	3.3	0	334.6	4	4	4	1	13	2	154
60	II-C	4	-0.7	3.8	0	1120.7	2	4	4	3	13	2	116
74	III-B	4	-2.0	106.6	81	1828.4	6	1	2	3	12	2	10,028
106	IV-C	4	-2.2	19.7	1330	930.8	6	3	1	2	12	2	2,000
133	V-C	4	-1.4	27.9	40	1260.7	4	2	3	3	12	2	1,860
85	III-C	5	-1.9	13.1	37	980.3	4	3	3	2	12	2	1,165
28	I-B	1	-1.9	13.1	47	785.8	4	3	3	2	12	2	1,159
32	I-C	2	-1.7	13.1	40	683.3	4	3	3	2	12	2	1,030
25	I-B	1	-1.4	13.9	99	1182.1	4	3	2	3	12	2	917
87	III-D	3	-1.1	16.4	11	865.8	4	3	3	2	12	2	837
40	I-C	1	-1.7	6.6	46	276.0	4	4	3	1	12	2	511
43	I-C	2	-0.9	11.9	0	1568.4	2	3	4	3	12	2	485
102	IV-B	2	-1.0	8.2	0	513.2	2	4	4	2	12	2	368
12	I-A	2	-0.8	9.0	0	731.9	2	4	4	2	12	2	320
44	I-C	1	-2.3	2.6	328	349.1	6	4	1	1	12	2	285
3	I-A	1	-0.6	9.4	45	1203.0	2	4	3	3	12	2	273
146	VI-C	4	-0.6	6.1	0	928.3	2	4	4	2	12	2	166
73	III-B	4	-2.4	57.4	614	1206.8	6	1	1	3	11	2	6,367
122	V-B	4	-1.5	27.1	2700	3472.8	4	2	1	4	11	2	1,921
91	III-D	2	-1.3	27.9	500	2357.1	4	2	1	4	11	2	1,665
135	VI-A	4	-1.6	19.7	63	875.3	4	3	2	2	11	2	1,495
113	IV-C	4	-1.7	16.4	1588	1350.6	4	3	1	3	11	2	1,274
132	V-C	5	-1.2	21.3	48	785.7	4	2	3	2	11	2	1,206
136	VI-B	4	-1.2	19.7	15	233.7	4	3	3	1	11	2	1,064

Site Number	Reach	Structure Type	Shore Change (ft/yr)	Bank Height (ft)	Buffer Width (ft)	Site Length (ft)	Rank ER	Rank BH	Rank BW	Rank Length	Total Rank	Priority Number	Protocol 1 - TSS/site length (lbs/ft/yr)
41	I-C	2	-1.6	13.1	1500	1019.1	4	3	1	3	11	2	1,005
110	IV-C	4	-1.0	19.7	0	653.7	2	3	4	2	11	2	899
112	IV-C	4	-0.8	18.9	35	1494.9	2	3	3	3	11	2	686
105	IV-B	4	-0.7	18.0	48	1432.6	2	3	3	3	11	2	607
11	I-A	1	-1.0	9.8	971	578.9	4	4	1	2	11	2	477
17	I-A	2	-0.4	21.9	46	2022.2	2	2	3	4	11	2	429
50	II-A	2	-1.8	4.9	800	781.4	4	4	1	2	11	2	410
99	IV-B	2	-1.0	6.6	249	563.7	4	4	1	2	11	2	310
53	II-A	5	-1.1	5.6	211	940.2	4	4	1	2	11	2	288
21	I-B	1	-0.4	13.1	0	834.8	2	3	4	2	11	2	221
36	I-C	1	-0.7	6.6	0	329.0	2	4	4	1	11	2	201
20	I-A	1	-0.3	8.2	0	185.8	2	4	4	1	11	2	123
5	I-A	2	-0.8	2.3	0	62.8	2	4	4	1	11	2	81
57	II-B	2	-0.6	2.3	0	222.5	2	4	4	1	11	2	59
18	I-A	2	-0.5	1.6	0	142.6	2	4	4	1	11	2	37
67	III-A	5	-1.2	106.6	1160	2435.3	4	1	1	4	10	3	6,086
130	V-C	4	-1.7	26.9	86	692.9	4	2	2	2	10	3	2,095
134	VI-A	4	-1.5	26.2	71	514.2	4	2	2	2	10	3	1,827
116	V-A	4	-1.5	24.6	1000	1920.2	4	2	1	3	10	3	1,704
131	V-C	4	-1.2	31.2	67	829.3	4	2	2	2	10	3	1,703
129	V-C	4	-1.4	19.7	1780	956.1	4	3	1	2	10	3	1,284
137	VI-B	5	-0.8	32.8	0	701.6	2	2	4	2	10	3	1,228
120	V-A	4	-1.4	18.0	1400	795.0	4	3	1	2	10	3	1,205
49	II-A	2	-1.9	13.9	800	542.2	4	3	1	2	10	3	1,203
47	I-C	2	-1.8	13.1	81	227.9	4	3	2	1	10	3	1,073
64	II-C	4	-1.5	14.8	100	548.1	4	3	1	2	10	3	1,032
121	V-A	4	-1.4	14.8	3300	616.9	4	3	1	2	10	3	991
42	I-C	2	-1.2	13.9	237	680.9	4	3	1	2	10	3	794
111	IV-C	4	-0.8	19.7	0	398.9	2	3	4	1	10	3	715
34	I-C	1	-1.1	13.1	2000	799.0	4	3	1	2	10	3	644
88	III-D	2	-0.6	19.7	35	697.8	2	3	3	2	10	3	523
29	I-B	1	-0.7	13.5	54	1266.2	2	3	2	3	10	3	436
2	I-A	1	-1.0	9.3	1800	1726.5	2	4	1	3	10	3	418
27	I-B	1	-0.8	8.5	68	511.2	2	4	2	2	10	3	310
10	I-A	1	-0.8	7.9	7000	1401.3	2	4	1	3	10	3	307
8	I-A	1	-0.8	8.2	2800	1207.4	2	4	1	3	10	3	292
145	VI-C	4	-1.6	3.9	130	272.5	4	4	1	1	10	3	285
56	II-B	1	-0.6	9.0	60	805.5	2	4	2	2	10	3	257
19	I-A	1	-0.3	15.3	50	1896.8	2	3	2	3	10	3	229
101	IV-B	2	-0.7	6.6	552	1050.0	2	4	1	3	10	3	225
15	I-A	2	-0.3	11.5	0	469.0	2	3	4	1	10	3	139
104	IV-B	4	-0.9	3.3	71	812.2	2	4	2	2	10	3	135
7	I-A	1	-0.5	5.2	80	855.7	2	4	2	2	10	3	114
38	I-C	1	-0.3	7.4	18	417.3	2	4	3	1	10	3	113
39	I-C	1	-0.2	9.0	46	382.8	2	4	3	1	10	3	97
37	I-C	1	-0.2	7.0	194	1213.4	2	4	1	3	10	3	74
4	I-A	1	-0.5	2.6	42	224.4	2	4	3	1	10	3	58
52	II-A	4	0.2	11.5	0	236.9	2	3	4	1	10	3	5
70	III-A	4	-1.8	98.4	118	1324.2	4	1	1	3	9	3	8,105
69	III-A	4	-1.6	98.4	152	1395.8	4	1	1	3	9	3	7,506
72	III-B	5	-1.7	93.5	600	1823.9	4	1	1	3	9	3	7,264
78	III-C	4	-1.6	65.6	3000	1536.2	4	1	1	3	9	3	5,004
71	III-B	4	-0.9	82.0	0	713.4	2	1	4	2	9	3	3,492
77	III-B	4	-1.5	49.2	3000	618.0	4	2	1	2	9	3	3,431
126	V-B	4	-1.2	32.2	4800	575.1	4	2	1	2	9	3	1,848
128	V-C	4	-1.1	32.8	108	643.1	4	2	1	2	9	3	1,719
84	III-C	5	-1.9	19.7	104	339.1	4	3	1	1	9	3	1,715
125	V-B	4	-1.1	32.8	2500	690.9	4	2	1	2	9	3	1,689

Site Number	Reach	Structure Type	Shore Change (ft/yr)	Bank Height (ft)	Buffer Width (ft)	Site Length (ft)	Rank ER	Rank BH	Rank BW	Rank Length	Total Rank	Priority Number	Protocol 1 - TSS/site length (lbs/ft/yr)
107	IV-C	4	-1.5	19.7	392	308.5	4	3	1	1	9	3	1,385
65	III-A	4	-1.0	13.8	276	332.0	4	3	1	1	9	3	665
147	VI-C	4	-0.6	21.3	55	1517.4	2	2	2	3	9	3	608
118	V-A	5	-0.4	26.2	45	780.6	2	2	3	2	9	3	478
153	VII	2	-0.8	8.2	140	899.5	2	4	1	2	9	3	292
13	I-A	1	-0.6	8.2	190	737.1	2	4	1	2	9	3	226
151	VII	3	-0.4	9.8	125	926.0	2	4	1	2	9	3	202
16	I-A	1	-0.3	11.1	86	925.9	2	3	2	2	9	3	170
6	I-A	1	-0.6	4.9	80	468.4	2	4	2	1	9	3	126
148	VI-C	4	-0.2	16.4	450	1698.5	2	3	1	3	9	3	115
100	IV-B	2	-0.3	6.6	133	553.1	2	4	1	2	9	3	79
152	VII	3	-0.1	11.5	119	1058.3	2	3	1	3	9	3	59
22	I-B	1	-0.1	9.8	64	162.9	2	4	2	1	9	3	46
55	II-B	4	-0.1	16.4	54	651.9	2	3	2	2	9	3	38
150	VI-C	4	0.2	23.0	59	1103.2	2	2	2	3	9	3	11
141	VI-B	4	-0.8	98.4	1200	2931.7	2	1	1	4	8	3	3,500
75	III-B	5	-1.1	65.6	440	898.7	4	1	1	2	8	3	3,408
127	V-C	4	-1.2	41.0	5145	311.0	4	2	1	1	8	3	2,322
90	III-D	2	-1.0	36.1	316	1966.5	2	2	1	3	8	3	1,617
123	V-B	4	-0.9	24.6	4600	1559.4	2	2	1	3	8	3	1,071
139	VI-B	4	-1.0	23.0	170	1011.6	2	2	1	3	8	3	1,061
66	III-A	5	-0.4	53.3	274	2393.0	2	1	1	4	8	3	1,048
79	III-C	4	-0.8	27.9	2700	1491.8	2	2	1	3	8	3	1,028
117	V-A	4	-0.7	24.6	1700	1920.1	2	2	1	3	8	3	852
1	I-A	1	-1.0	9.8	160	256.4	2	4	1	1	8	3	445
35	I-C	1	-1.0	7.4	2500	219.8	2	4	1	1	8	3	335
48	II-A	1	-0.6	5.7	451	369.5	2	4	1	1	8	3	157
14	I-A	1	-0.1	11.5	992	643.1	2	3	1	2	8	3	69
45	I-C	3	-0.3	4.1	437	247.2	2	4	1	1	8	3	63
149	VI-C	4	0.1	27.9	352	1507.3	2	2	1	3	8	3	13
68	III-A	4	-0.9	82.0	170	1404.9	2	1	1	3	7	3	3,569
138	VI-B	4	-0.8	32.8	345	817.7	2	2	1	2	7	3	1,213
89	III-D	2	-0.8	19.7	880	335.4	2	3	1	1	7	3	743
30	I-C	1	-0.9	16.4	166	368.1	2	3	1	1	7	3	668
124	V-B	4	-0.5	26.3	292	749.3	2	2	1	2	7	3	662
119	V-A	4	-0.7	19.7	167	347.6	2	3	1	1	7	3	660
108	IV-C	3	-0.7	18.0	136	394.4	2	3	1	1	7	3	556
140	VI-B	4	-0.9	65.6	84	424.9	2	1	2	1	6	3	2,855

Appendix C

Wave data calculation results

Wave heights and periods for a suite of wind and surge conditions were calculated using ACES (Automated Coastal Engineering System) software in the Coastal Engineering Design and Analysis System (CEDAS). This data was used to estimate rock size for recommended structures.

Appendix C. ACES wind wave analysis of selected sites on Potomac River. Refer to sites in Section 12.

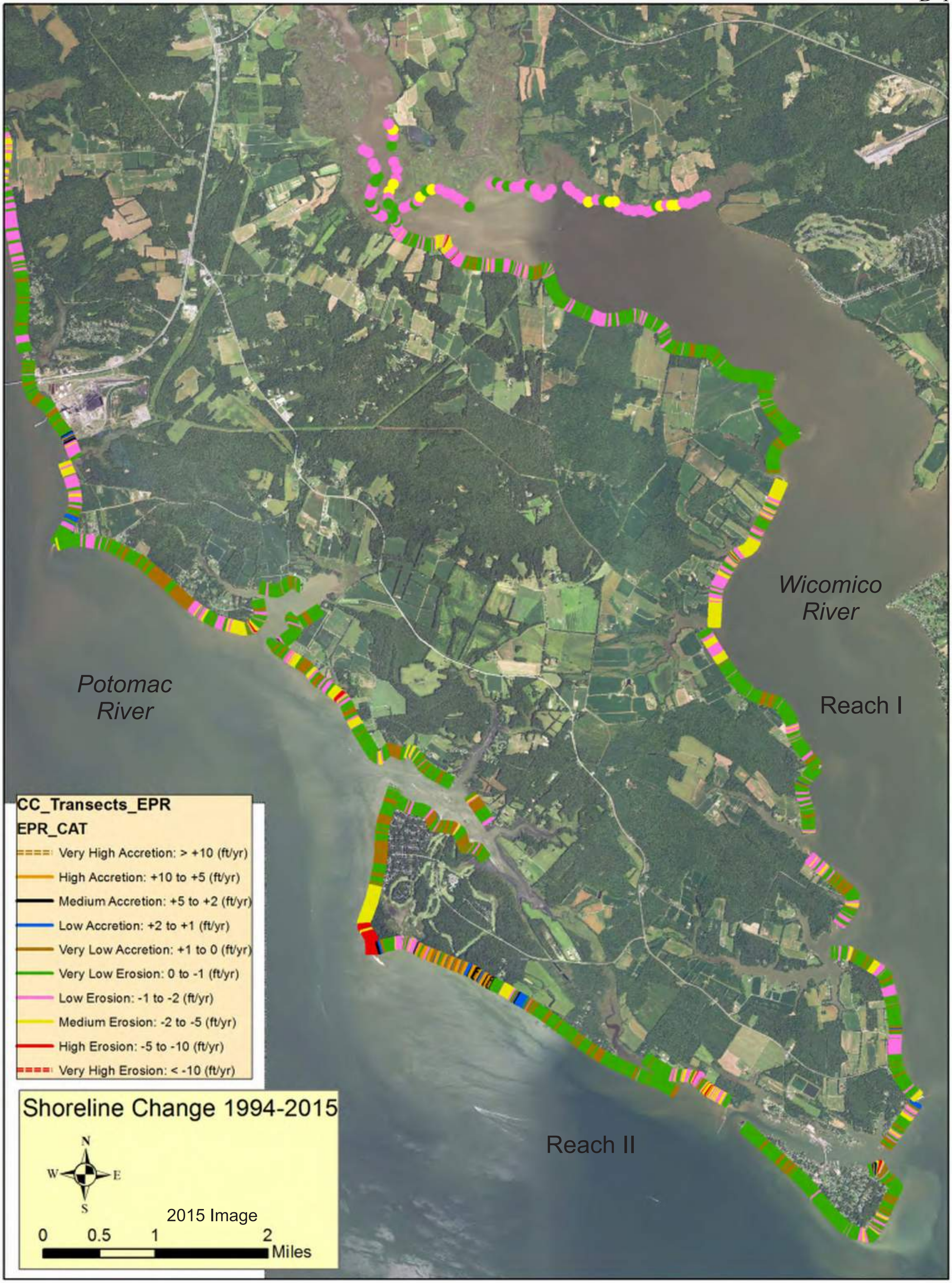
Sites 61-62			Sites 80-82			Sites 95-98		
Avg Fetch (miles)	4.3		Avg Fetch (miles)	5.9		Avg Fetch (miles)	5.8	
Direction	Northwest		Direction	Southwest		Direction	Southeast	
	Wave Height (ft)	Wave Period (s)		Wave Height (ft)	Wave Period (s)		Wave Height (ft)	Wave Period (s)
25 mph 3ft surge	1.9	2.6	25 mph 3ft surge	2.6	3.15	25 mph 3ft surge	2.9	3.3
35 mph 4ft surge	2.7	3.12	35 mph 4ft surge	3,3	3.7	35 mph 4ft surge	3.8	3.9
45 mph 5ft surge	3.5	3.5	45 mph 5ft surge	4.2	4.1	45 mph 5ft surge	4.6	4.5
50 mph 6ft surge	4.3	3.8	50 mph 6ft surge	4.9	4.5	50 mph 6ft surge	5.6	4.9

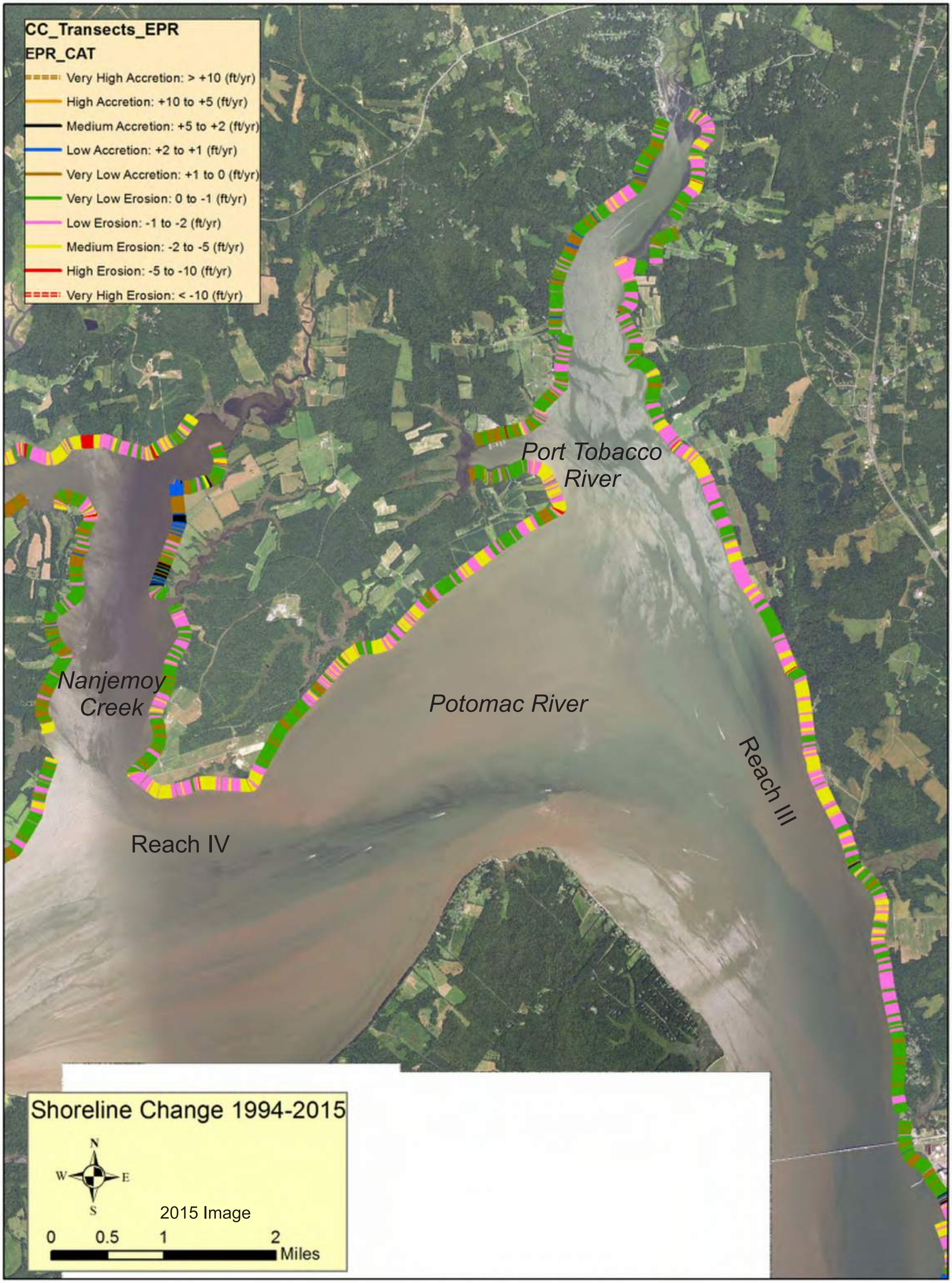
Appendix D

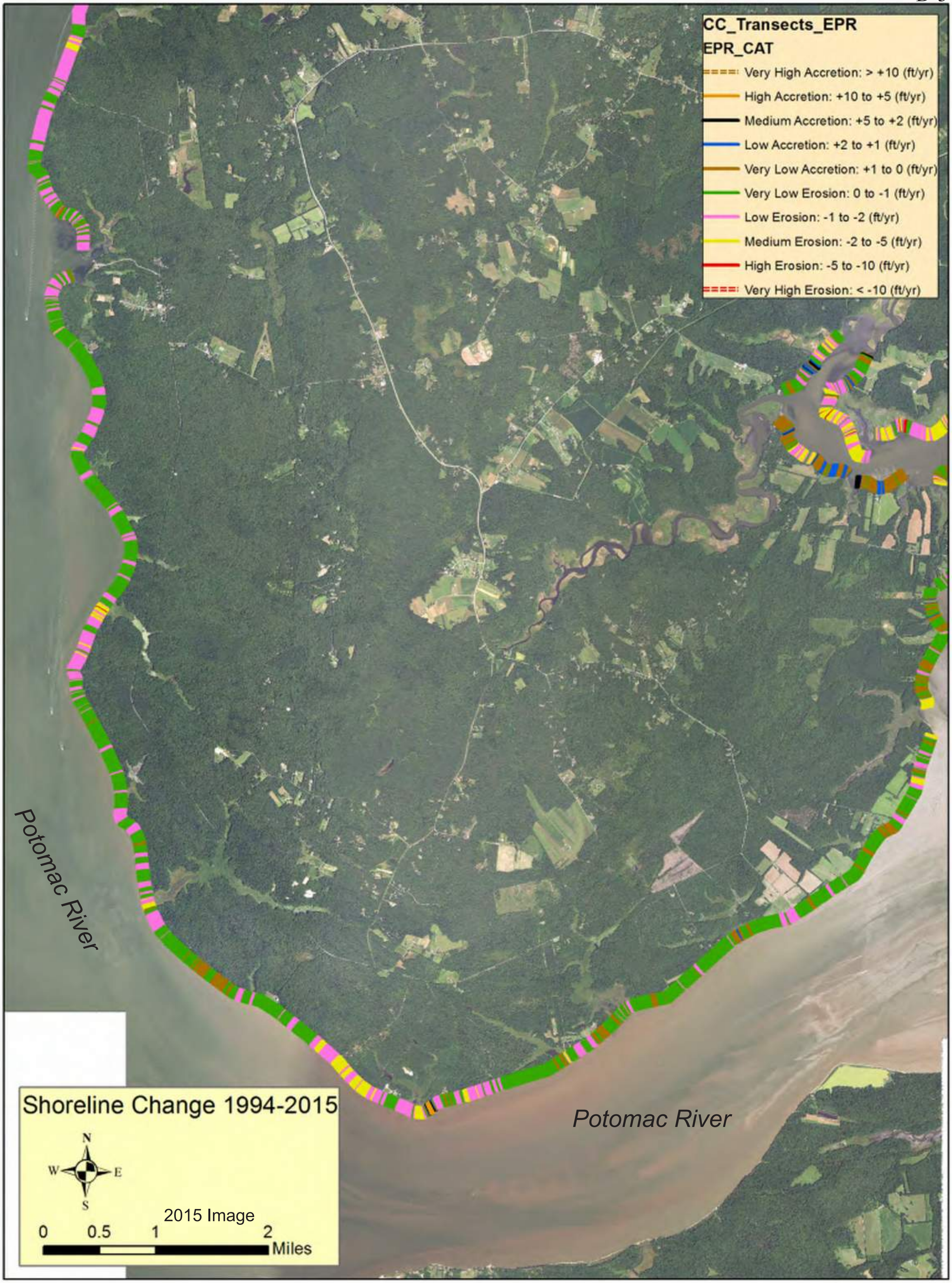
GIS data maps

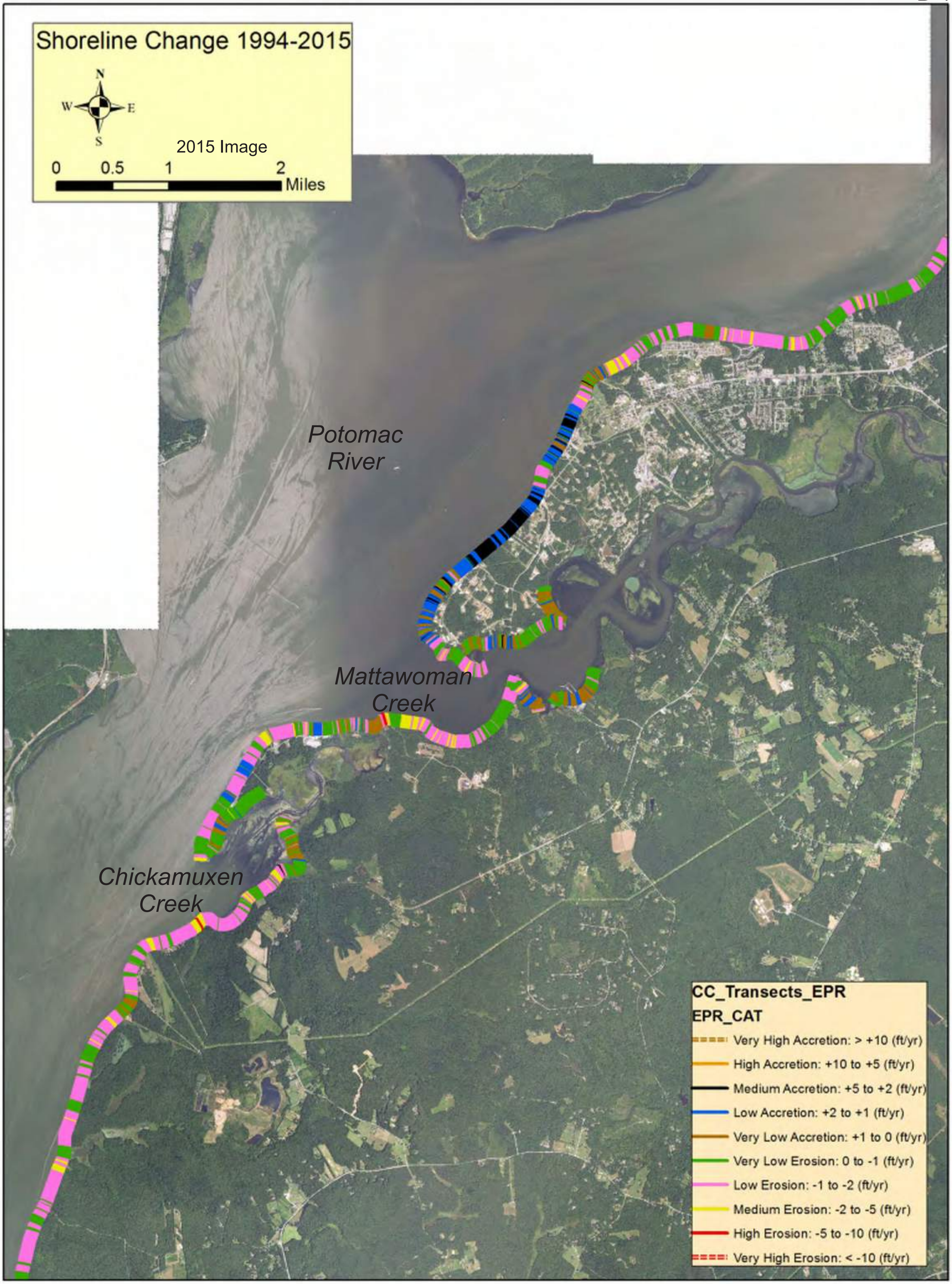
Shoreline Change	Change between the 1994 and 2015 digitized shorelines calculated by the Digital Shoreline Analysis System (DSAS) on the 2015 photo; categorized by ft/yr
SAV Composite	Outline of all Submerged Aquatic Vegetation (SAV) beds mapped between 2011 and 2015 on the 1994 USGS DOQQ Image; from VIMS SAV Program mapper
SAV 2016	Outline and density of Submerged Aquatic Vegetation (SAV) beds mapped in 2016 on the 2015 photo; from VIMS SAV Program mapper
Bank Face Conditions	Condition of the bank face as determined during the site visits shown on the 2015 photo Existing structures are plotted in black.
Base of Bank Conditions	Condition of the base of bank as determined during the site visits shown on the 2015 photo. Existing structures are plotted in black.
Shoreline Structures	Shoreline structures mapped by VIMS in 2006 and shown on the 2015 photo; Because this file is dated, structures built since then were mapped during the field visit. They are shown in black along the shoreline.
Bank Height	The 2014 USGS LIDAR data was categorized to the bank height ranking structure and plotted.

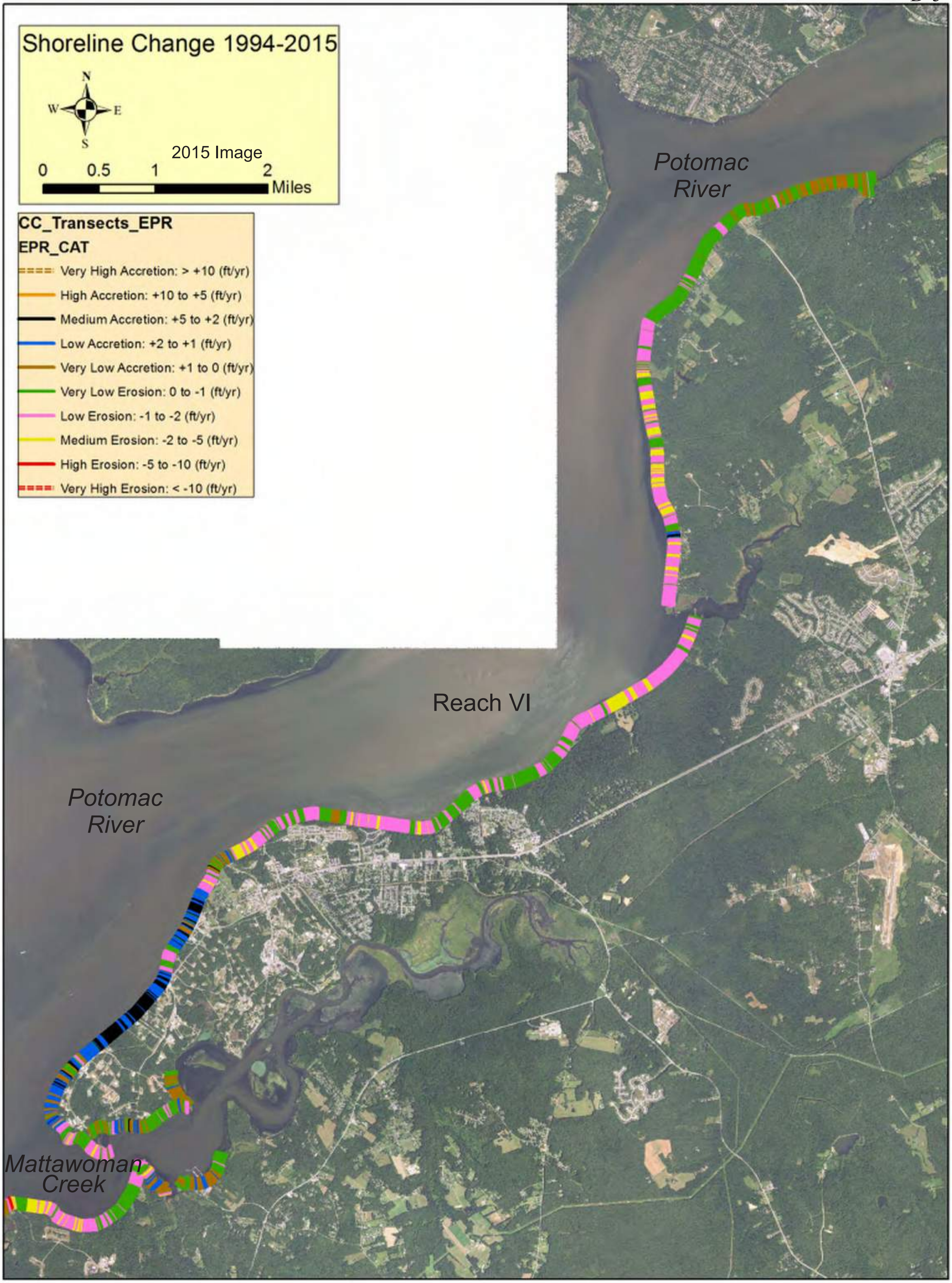
The shoreline recommendation sites are plotted for reference on maps on which they do not overlay the data.

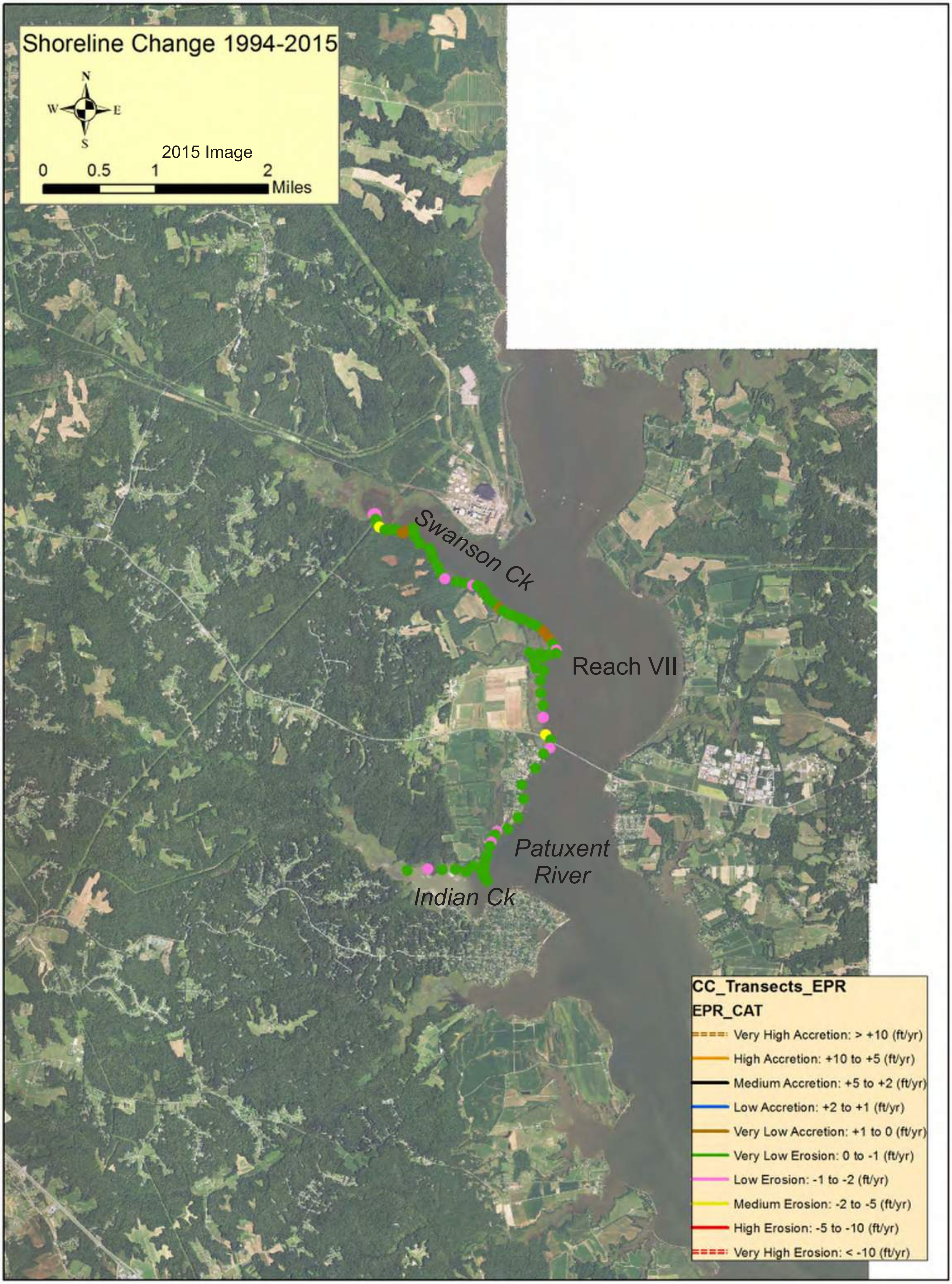

Wicomico River
Potomac River
Reach I
Reach II
CC_Transects_EPR
EPR_CAT
Very High Accretion: > +10 (ft/yr)
High Accretion: +10 to +5 (ft/yr)
Medium Accretion: +5 to +2 (ft/yr)
Low Accretion: +2 to +1 (ft/yr)
Very Low Accretion: +1 to 0 (ft/yr)
Very Low Erosion: 0 to -1 (ft/yr)
Low Erosion: -1 to -2 (ft/yr)
Medium Erosion: -2 to -5 (ft/yr)
High Erosion: -5 to -10 (ft/yr)
Very High Erosion: < -10 (ft/yr)
Shoreline Change 1994-2015
N
W
E
S
2015 Image
0
0.5
1
2
Miles


CC_Transects_EPR
EPR_CAT
Very High Accretion: > +10 (ft/yr)
High Accretion: +10 to +5 (ft/yr)
Medium Accretion: +5 to +2 (ft/yr)
Low Accretion: +2 to +1 (ft/yr)
Very Low Accretion: +1 to 0 (ft/yr)
Very Low Erosion: 0 to -1 (ft/yr)
Low Erosion: -1 to -2 (ft/yr)
Medium Erosion: -2 to -5 (ft/yr)
High Erosion: -5 to -10 (ft/yr)
Very High Erosion: < -10 (ft/yr)
Port Tobacco River
Nanjemoy Creek
Potomac River
Reach III
Reach IV
Shoreline Change 1994-2015
N
W
E
S
2015 Image
0
0.5
1
2
Miles

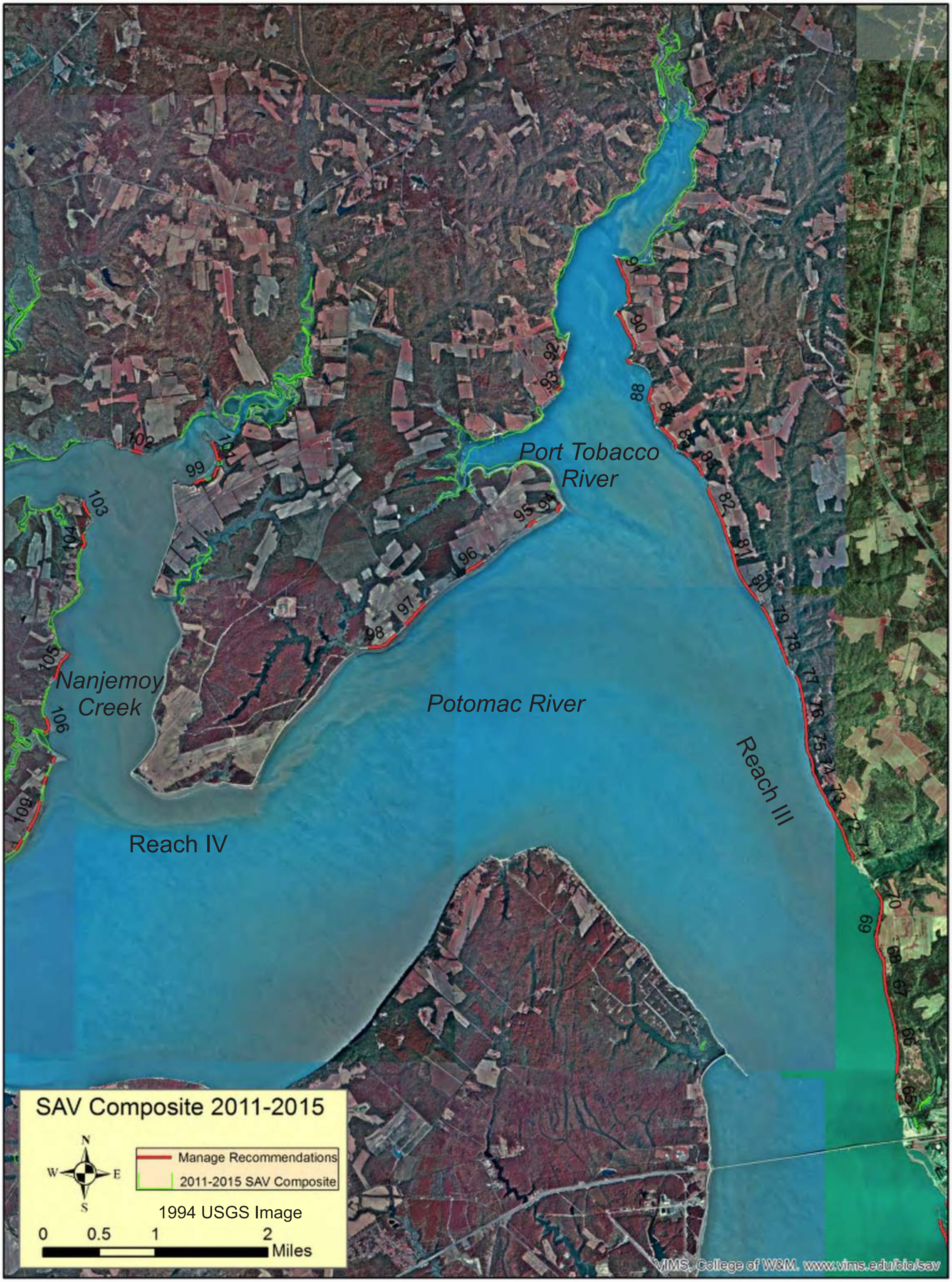

CC_Transects_EPR
EPR_CAT
Very High Accretion: > +10 (ft/yr)
High Accretion: +10 to +5 (ft/yr)
Medium Accretion: +5 to +2 (ft/yr)
Low Accretion: +2 to +1 (ft/yr)
Very Low Accretion: +1 to 0 (ft/yr)
Very Low Erosion: 0 to -1 (ft/yr)
Low Erosion: -1 to -2 (ft/yr)
Medium Erosion: -2 to -5 (ft/yr)
High Erosion: -5 to -10 (ft/yr)
Very High Erosion: < -10 (ft/yr)
Potomac River
Potomac River
Shoreline Change 1994-2015
N
W
E
S
2015 Image
0
0.5
1
2
Miles


Shoreline Change 1994-2015
N
W
E
S
2015 Image
0
0.5
1
2
Miles
Potomac
River
Mattawoman
Creek
Chickamuxen
Creek
CC_Transects_EPR
EPR_CAT
Very High Accretion: > +10 (ft/yr)
High Accretion: +10 to +5 (ft/yr)
Medium Accretion: +5 to +2 (ft/yr)
Low Accretion: +2 to +1 (ft/yr)
Very Low Accretion: +1 to 0 (ft/yr)
Very Low Erosion: 0 to -1 (ft/yr)
Low Erosion: -1 to -2 (ft/yr)
Medium Erosion: -2 to -5 (ft/yr)
High Erosion: -5 to -10 (ft/yr)
Very High Erosion: < -10 (ft/yr)

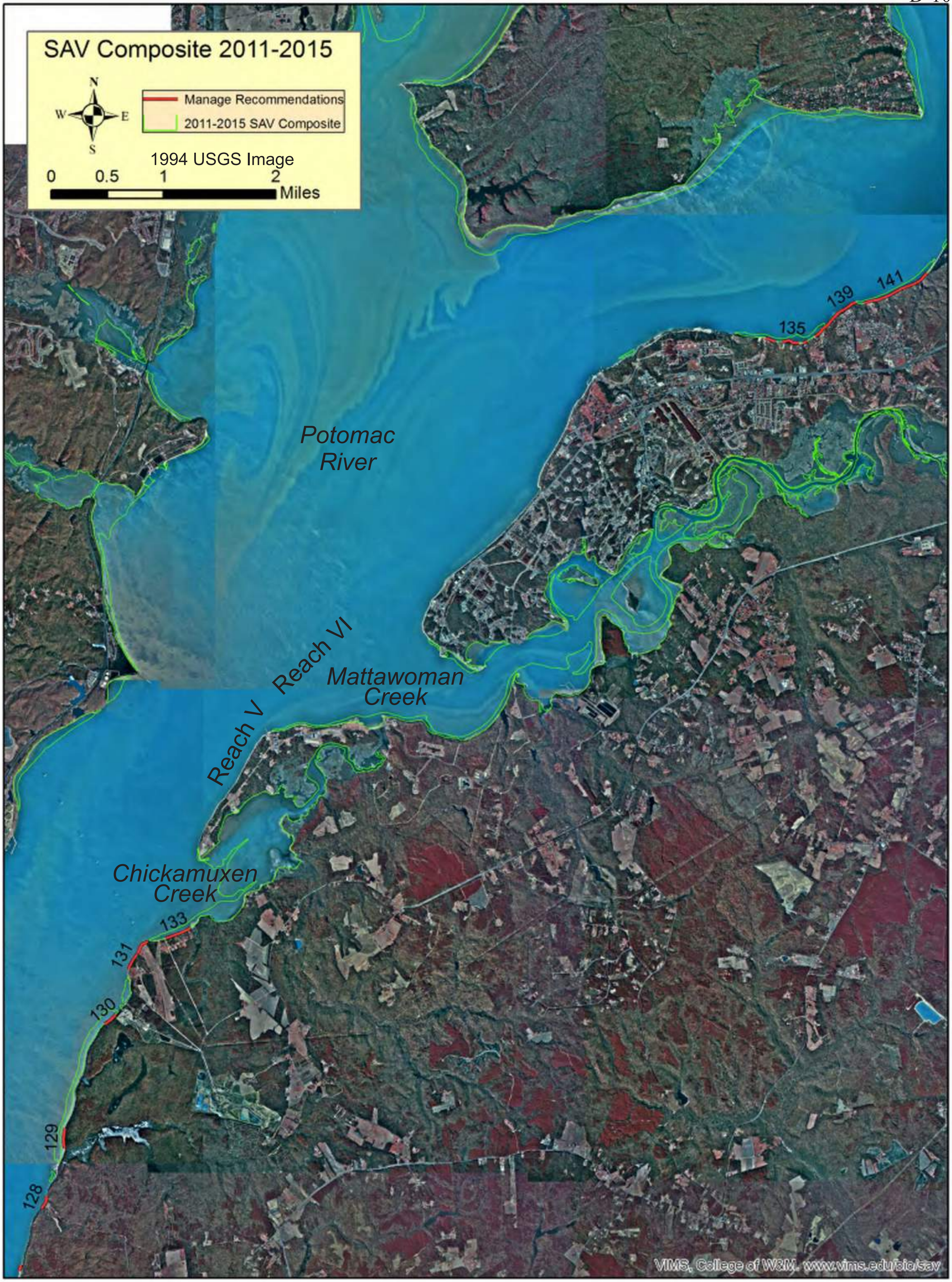

Shoreline Change 1994-2015
N
W
E
S
2015 Image
0 0.5 1 2
Miles
CC_Transects_EPR
EPR_CAT
Very High Accretion: > +10 (ft/yr)
High Accretion: +10 to +5 (ft/yr)
Medium Accretion: +5 to +2 (ft/yr)
Low Accretion: +2 to +1 (ft/yr)
Very Low Accretion: +1 to 0 (ft/yr)
Very Low Erosion: 0 to -1 (ft/yr)
Low Erosion: -1 to -2 (ft/yr)
Medium Erosion: -2 to -5 (ft/yr)
High Erosion: -5 to -10 (ft/yr)
Very High Erosion: < -10 (ft/yr)
Potomac River
Reach VI
Potomac River
Mattawoman Creek


Shoreline Change 1994-2015
N
W
E
S
2015 Image
0
0.5
1
2
Miles
Swanson Ck
Reach VII
Patuxent
River
Indian Ck
CC_Transects_EPR
EPR_CAT
Very High Accretion: > +10 (ft/yr)
High Accretion: +10 to +5 (ft/yr)
Medium Accretion: +5 to +2 (ft/yr)
Low Accretion: +2 to +1 (ft/yr)
Very Low Accretion: +1 to 0 (ft/yr)
Very Low Erosion: 0 to -1 (ft/yr)
Low Erosion: -1 to -2 (ft/yr)
Medium Erosion: -2 to -5 (ft/yr)
High Erosion: -5 to -10 (ft/yr)
Very High Erosion: < -10 (ft/yr)

Potomac River
Wicomico River
Reach I
Reach II
SAV Composite 2011-2015
Manage Recommendations
2011-2015 SAV Composite
1994 USGS Image
0 0.5 1 2 Miles
VIMS, College of W&M. www.vims.edu/bio/sav

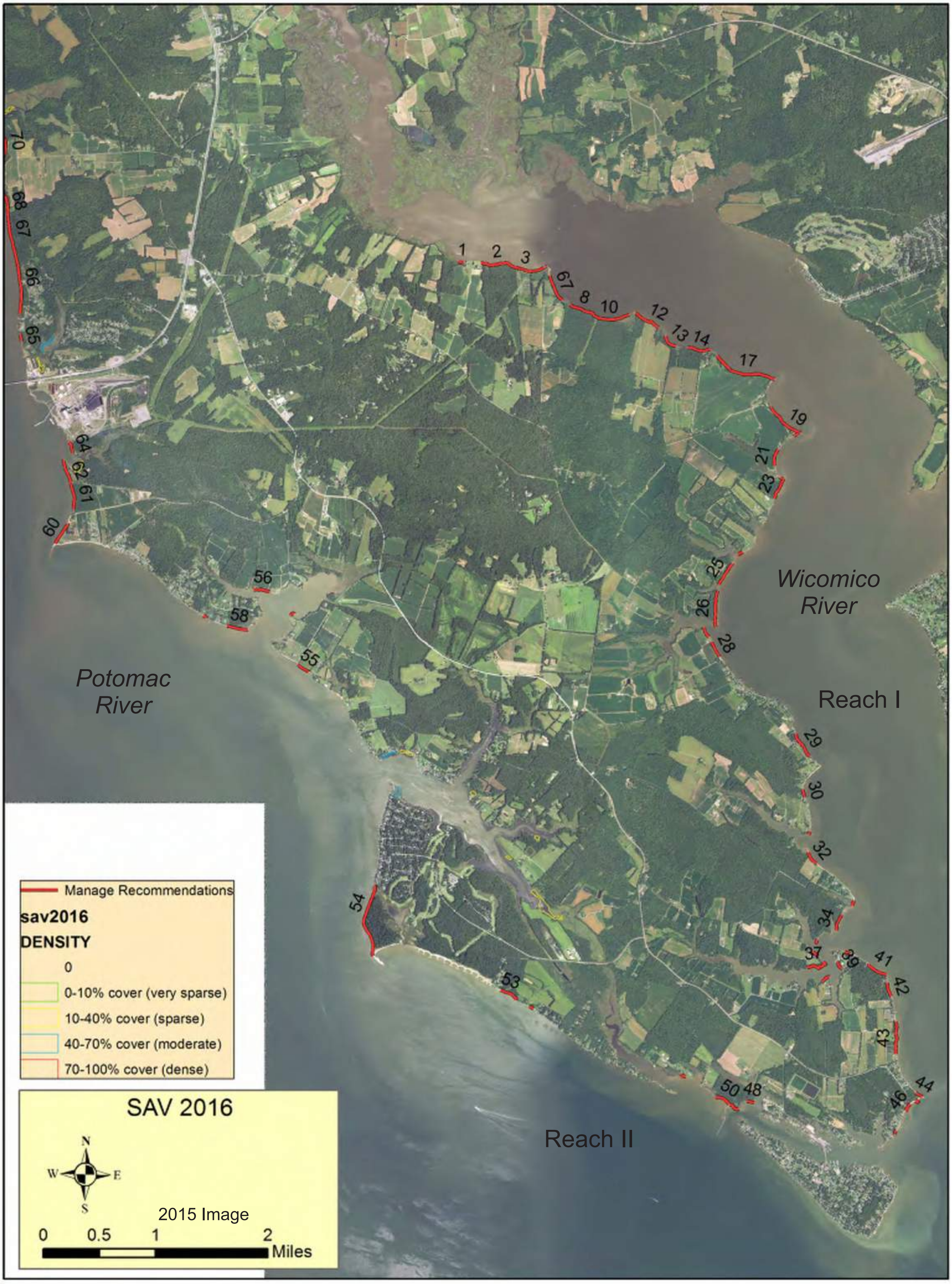

Port Tobacco
River
Nanjemoy
Creek
Potomac River
Reach III
Reach IV
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
85
87
88
90
91
92
93
94
95
96
97
98
99
101
102
103
104
105
106
108
SAV Composite 2011-2015
N
W
E
S
Manage Recommendations
2011-2015 SAV Composite
1994 USGS Image
0
0.5
1
2
Miles
VIMS, College of W&M. www.vims.edu/bio/sav

128
126
125
124
123
122
121
120
118
117
116
114
113
112
109
106
105
Potomac River
Reach V
Reach IV
Potomac River
SAV Composite 2011-2015
N
W
E
S
Manage Recommendations
2011-2015 SAV Composite
1994 USGS Image
0 0.5 1 2
Miles
VIMS, College of W&M. www.vims.edu/bio/sav

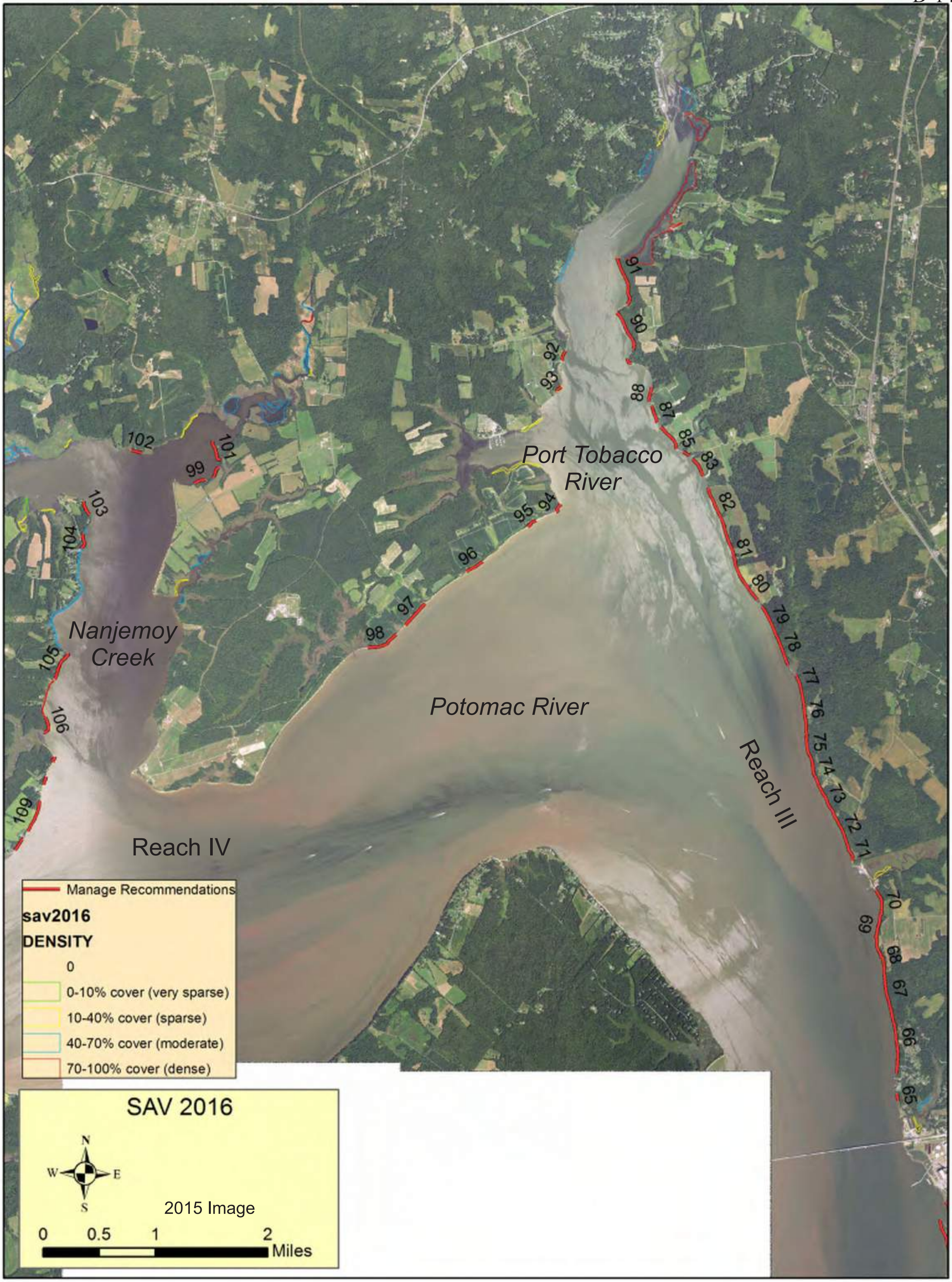

SAV Composite 2011-2015
N
S
W
E
Manage Recommendations
2011-2015 SAV Composite
1994 USGS Image
0
0.5
1
2
Miles
Potomac
River
Reach VI
Reach V
Mattawoman
Creek
Chickamuxen
Creek
135
139
141
133
131
130
129
128
VIMS, College of W&M. www.vims.edu/bio/sav


SAV Composite 2011-2015
N
S
E
W
Manage Recommendations
2011-2015 SAV Composite
1994 USGS Image
0
0.5
1
2
Miles
Potomac River
148
149
147
144
142
Reach VI
139
141
135
Potomac River
Mattawoman Creek
VIMS, College of W&M. www.vims.edu/bio/sav

Swanson Ck
151
152
Reach VII
No SAV
153
Indian Ck
Patuxent
River
SAV Composite 2011-2015
N
W
E
S
Manage Recommendations
2011-2015 SAV Composite
1994 USGS Image
0
0.5
1
2
Miles
VIMS, College of W&M. www.vims.edu/bio/sav



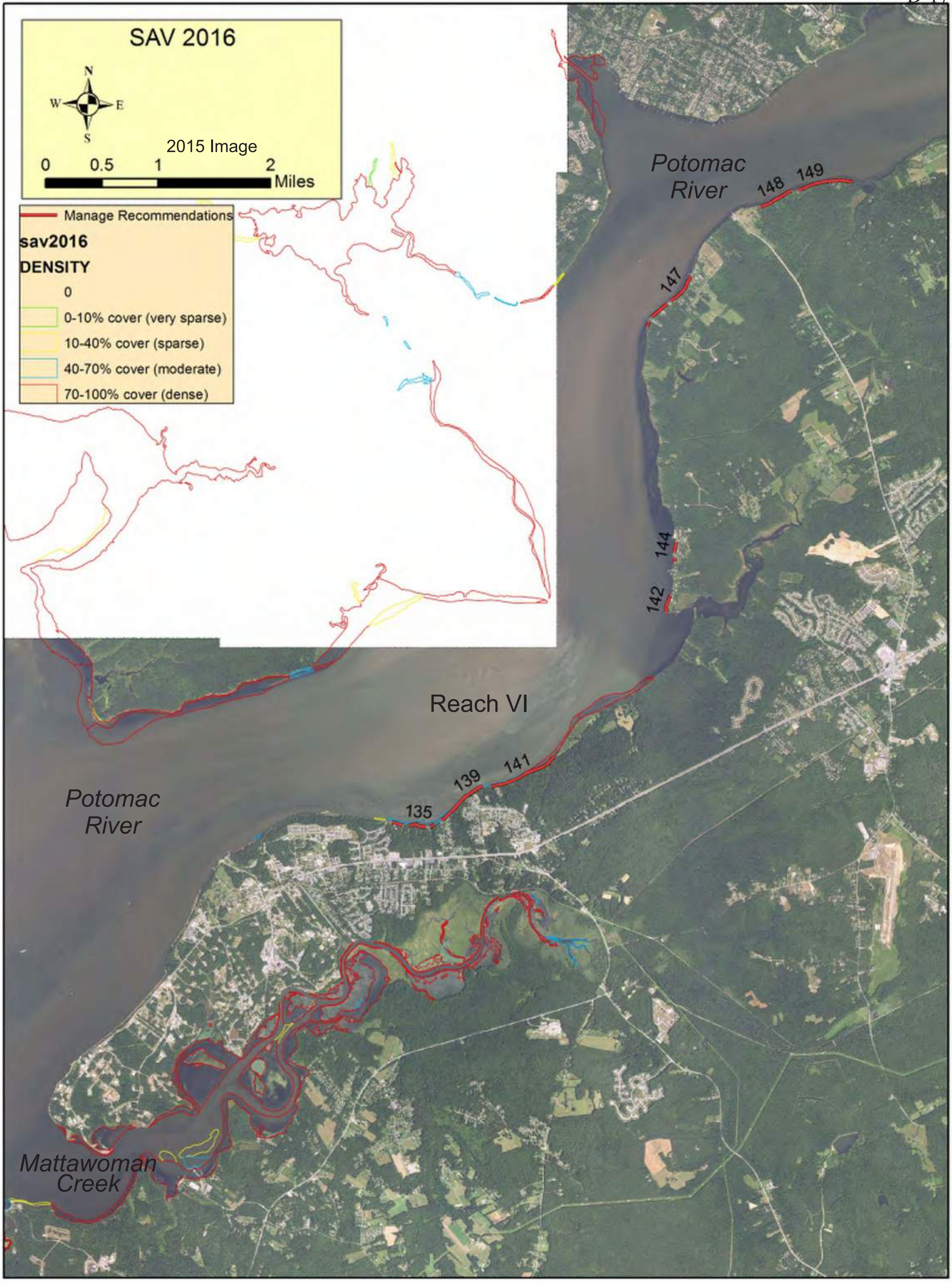
Wicomico River
Potomac River
Reach I
Reach II
1
2
3
67
8
10
12
13
14
17
19
21
23
25
26
28
29
30
32
34
37
39
41
42
43
44
46
48
50
53
54
55
56
58
60
61
62
64
65
66
67
68
70
Manage Recommendations
sav2016
DENSITY
0
0-10% cover (very sparse)
10-40% cover (sparse)
40-70% cover (moderate)
70-100% cover (dense)
SAV 2016
N
W
E
S
2015 Image
0
0.5
1
2
Miles



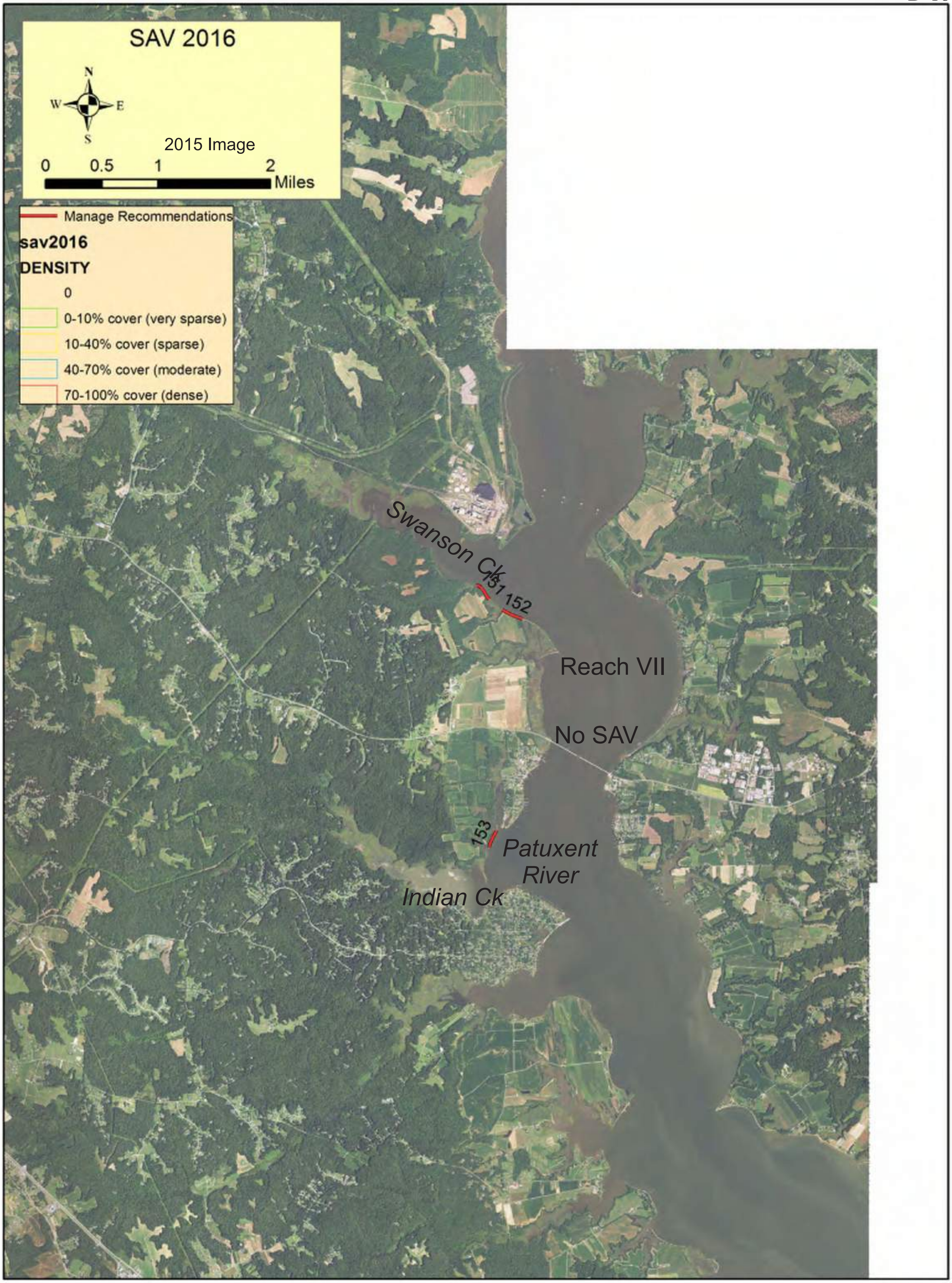
Port Tobacco River
Nanjemoy Creek
Potomac River
Reach III
Reach IV
91
90
92
93
88
87
85
83
82
81
80
79
78
77
76
75
74
73
72
71
70
69
68
67
66
65
94
95
96
97
98
99
101
102
103
104
105
106
109
Manage Recommendations
sav2016
DENSITY
0
0-10% cover (very sparse)
10-40% cover (sparse)
40-70% cover (moderate)
70-100% cover (dense)
SAV 2016
N
W
E
S
2015 Image
0
0.5
1
2
Miles


128
126
125
124
123
122
121
120
118
117
116
114
113
112
109
106
105
Potomac River
Reach V
Reach IV
Potomac River
SAV 2016
N
W
E
S
2015 Image
0
0.5
1
2
Miles
Manage Recommendations
sav2016
DENSITY
0
0-10% cover (very sparse)
10-40% cover (sparse)
40-70% cover (moderate)
70-100% cover (dense)

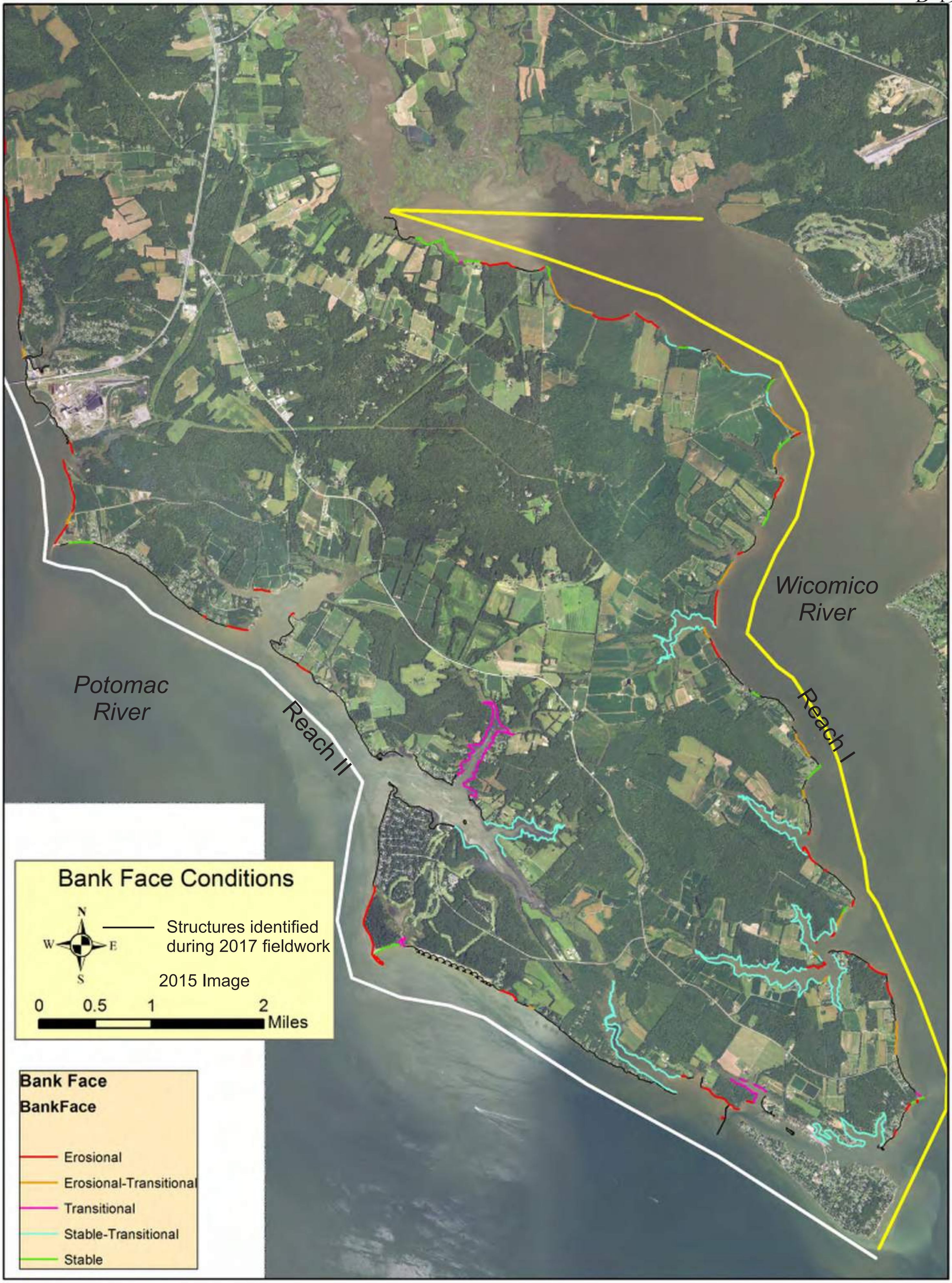

SAV 2016
N
W
E
S
2015 Image
0 0.5 1 2
Miles
Manage Recommendations
sav2016
DENSITY
0
0-10% cover (very sparse)
10-40% cover (sparse)
40-70% cover (moderate)
70-100% cover (dense)
Potomac River
Reach VI
Reach V
Mattawoman Creek
Chickamuxen Creek
135
139
141
133
131
130
129
128

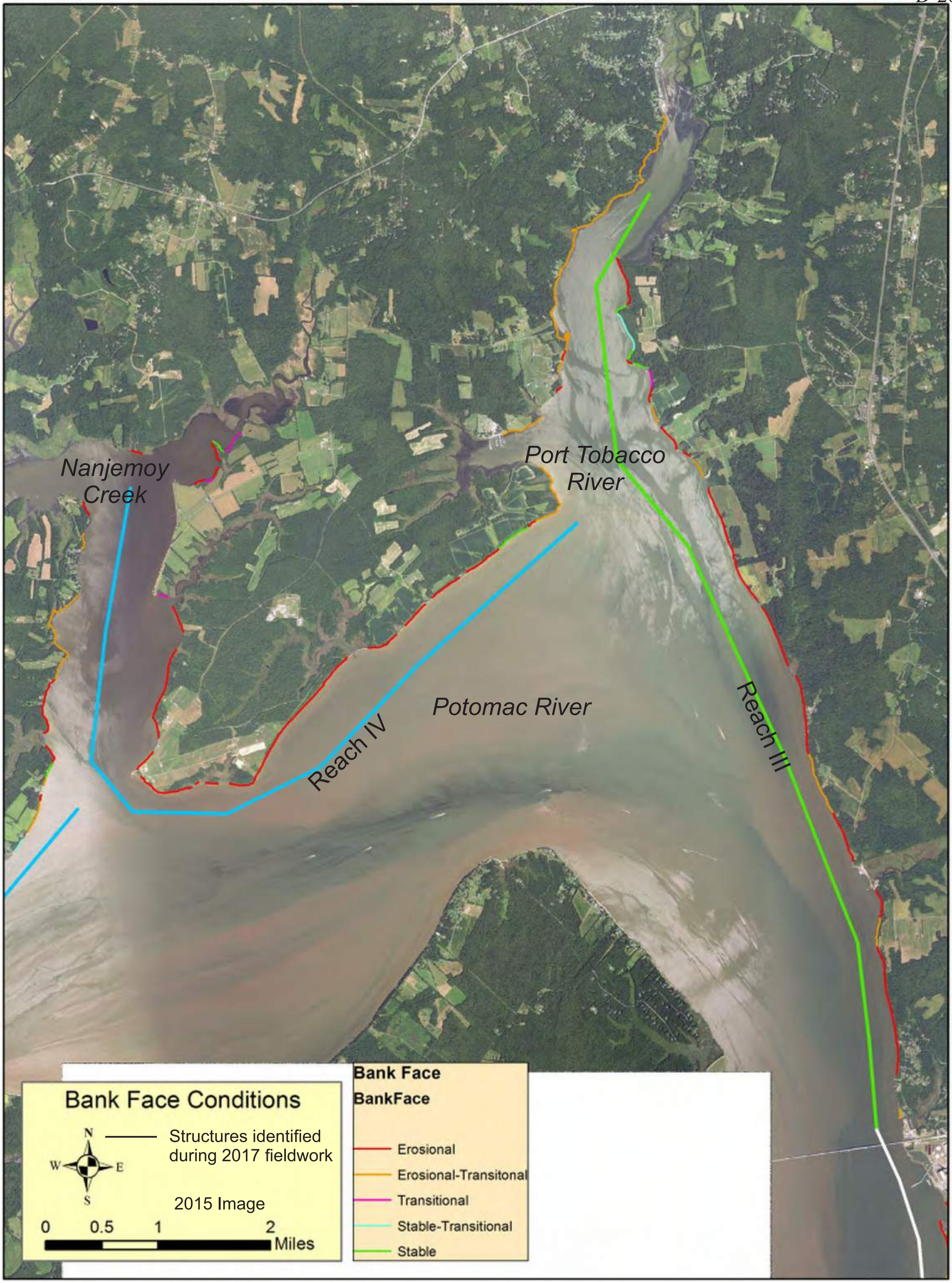


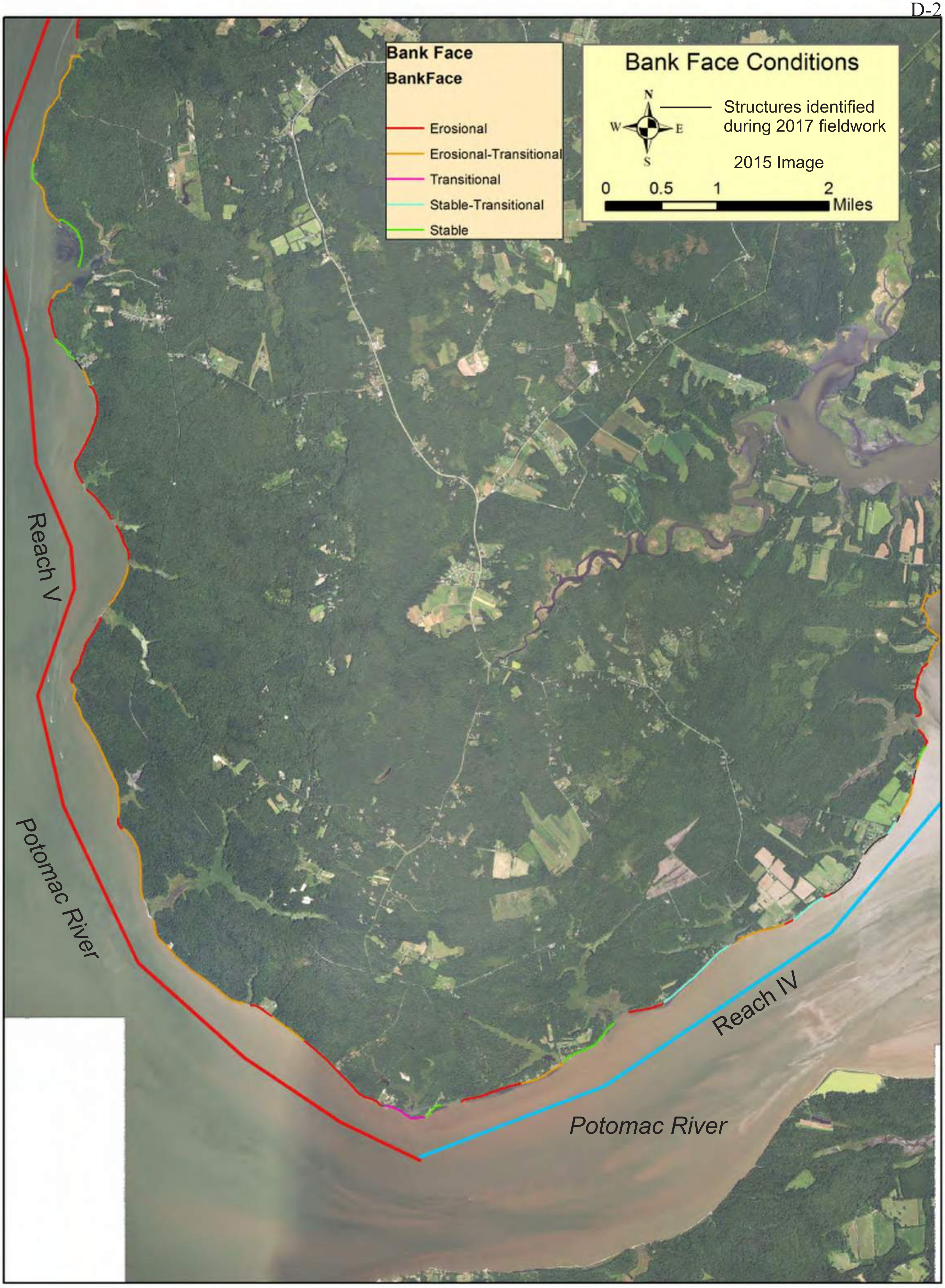
SAV 2016
N
W
E
S
2015 Image
0 0.5 1 2 Miles
Manage Recommendations
sav2016
DENSITY
0
0-10% cover (very sparse)
10-40% cover (sparse)
40-70% cover (moderate)
70-100% cover (dense)
Potomac River
148
149
147
144
142
Reach VI
141
139
135
Potomac River
Mattawoman Creek

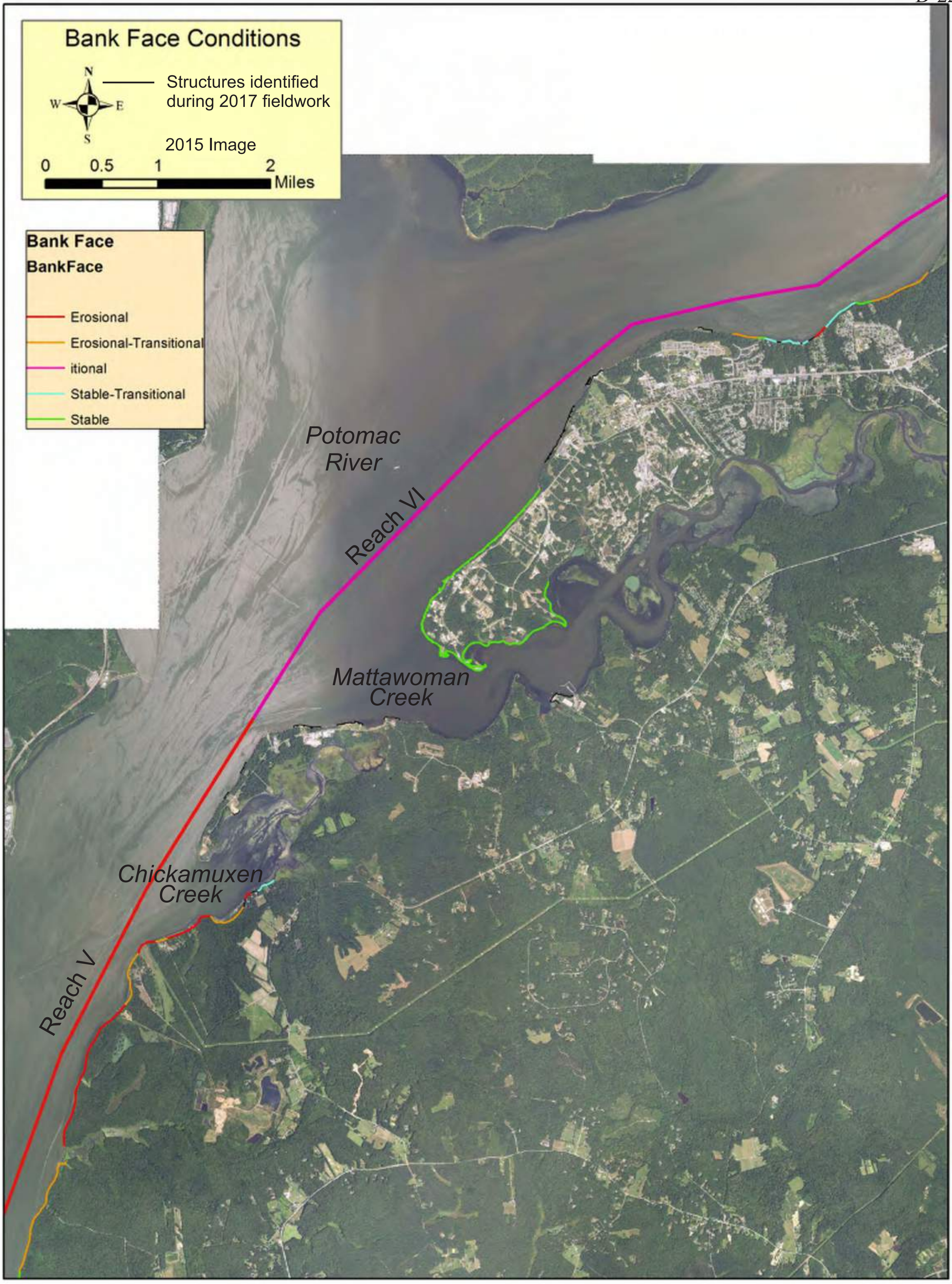


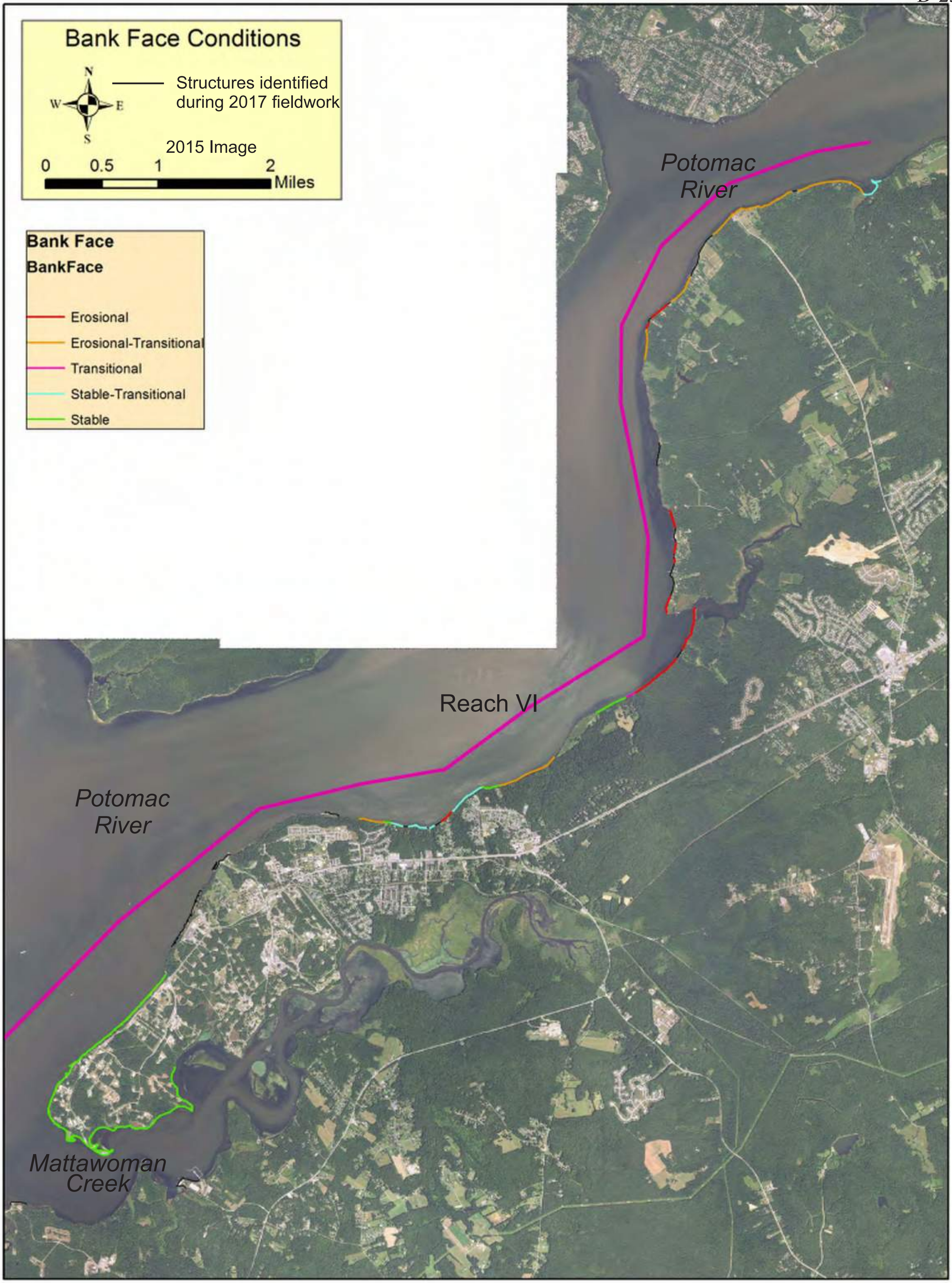
SAV 2016
N
W
E
S
2015 Image
0
0.5
1
2
Miles
Manage Recommendations
sav2016
DENSITY
0
0-10% cover (very sparse)
10-40% cover (sparse)
40-70% cover (moderate)
70-100% cover (dense)
Swanson Ck
151
152
Reach VII
No SAV
153
Patuxent
River
Indian Ck

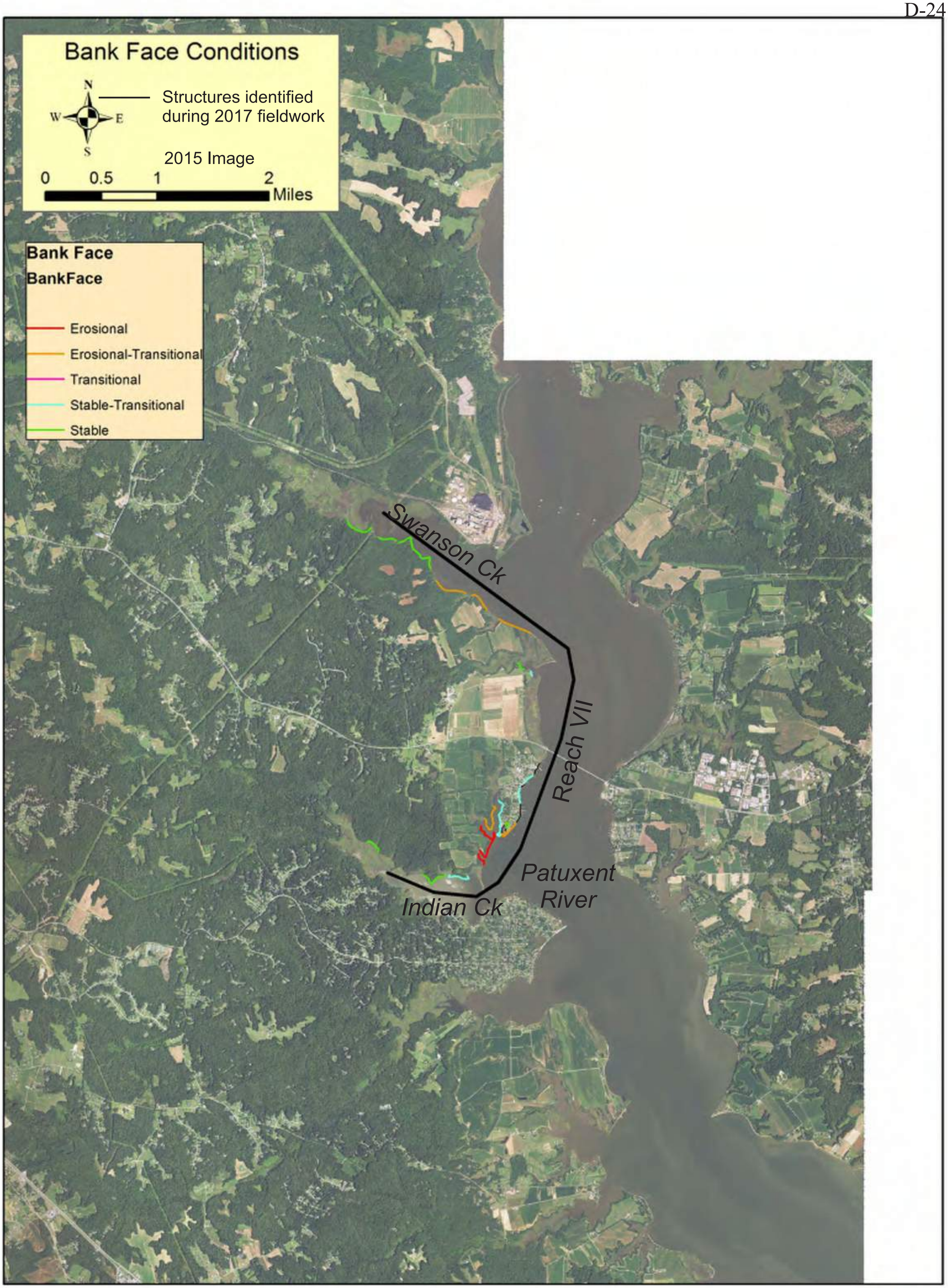

Wicomico
River
Potomac
River
Reach II
Reach I
Bank Face Conditions
N
W
E
S
Structures identified
during 2017 fieldwork
2015 Image
0
0.5
1
2
Miles
Bank Face
BankFace
Erosional
Erosional-Transitional
Transitional
Stable-Transitional
Stable

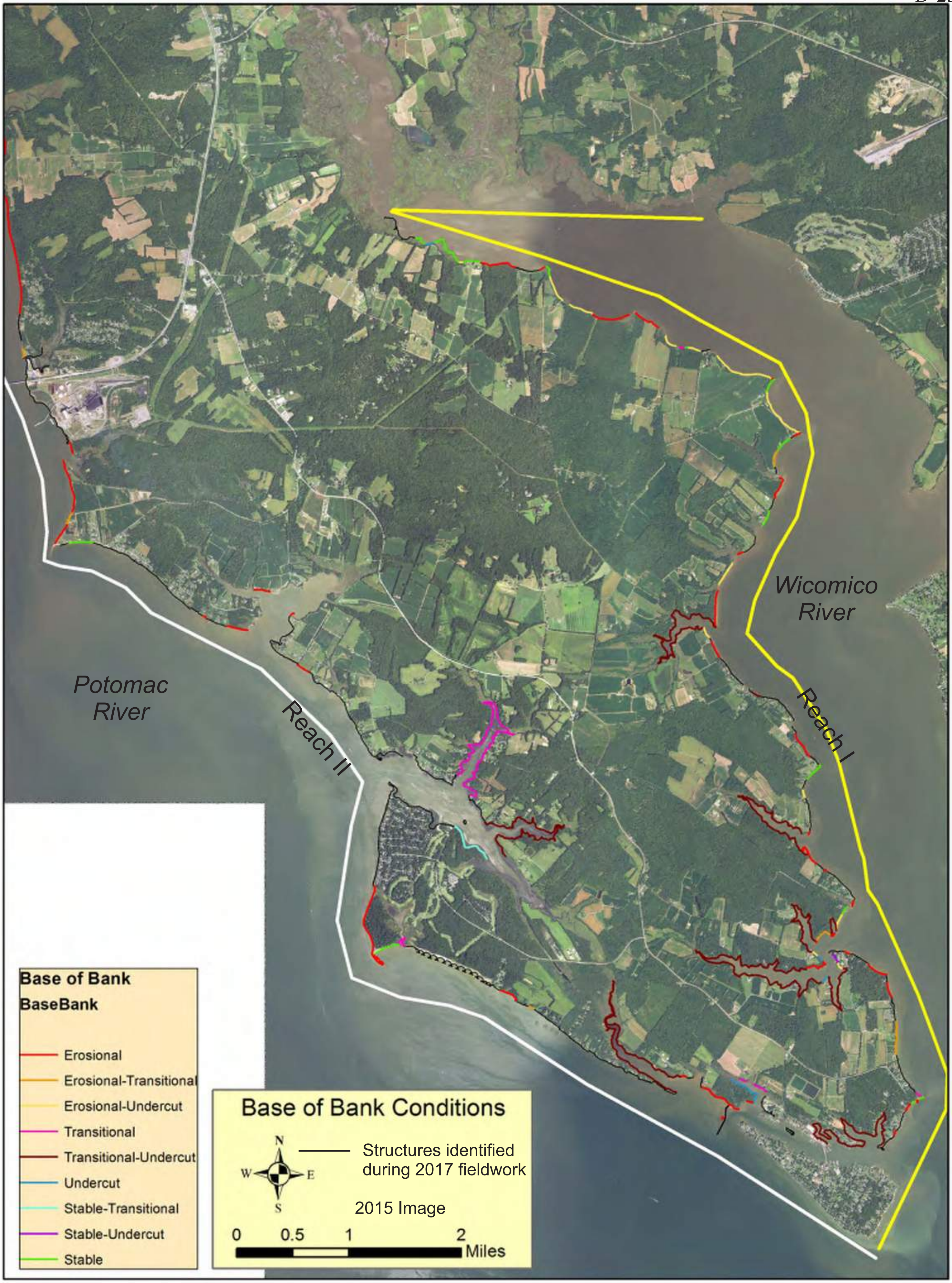

Nanjemoy Creek
Port Tobacco River
Potomac River
Reach IV
Reach III
Bank Face Conditions
Structures identified during 2017 fieldwork
2015 Image
0 0.5 1 2 Miles
N
S
E
W
Bank Face
BankFace
Erosional
Erosional-Transitonal
Transitional
Stable-Transitional
Stable

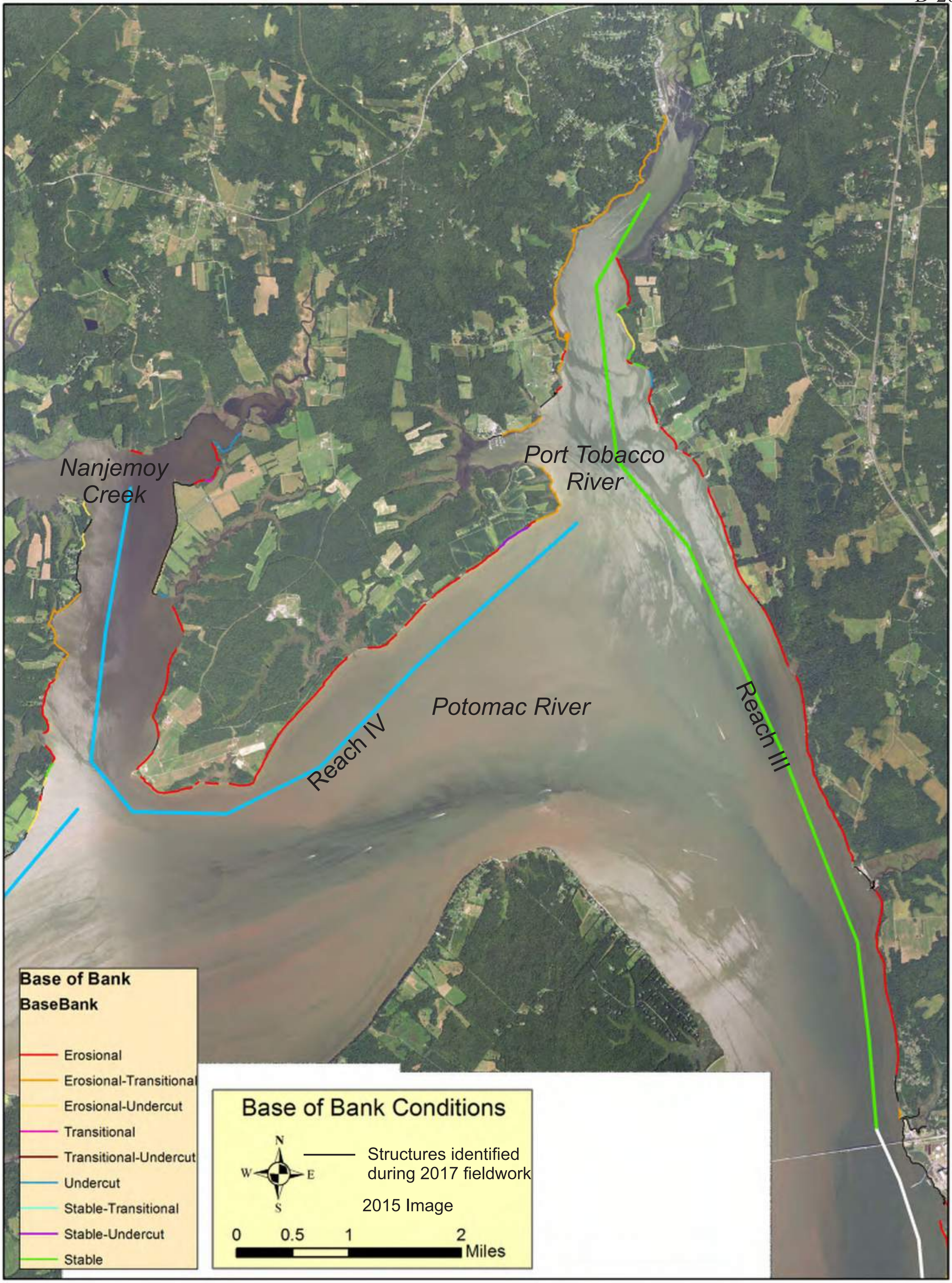

Bank Face
BankFace
Erosional
Erosional-Transitional
Transitional
Stable-Transitional
Stable
Bank Face Conditions
N
W
E
S
Structures identified during 2017 fieldwork
2015 Image
0
0.5
1
2
Miles
Reach V
Potomac River
Reach IV
Potomac River

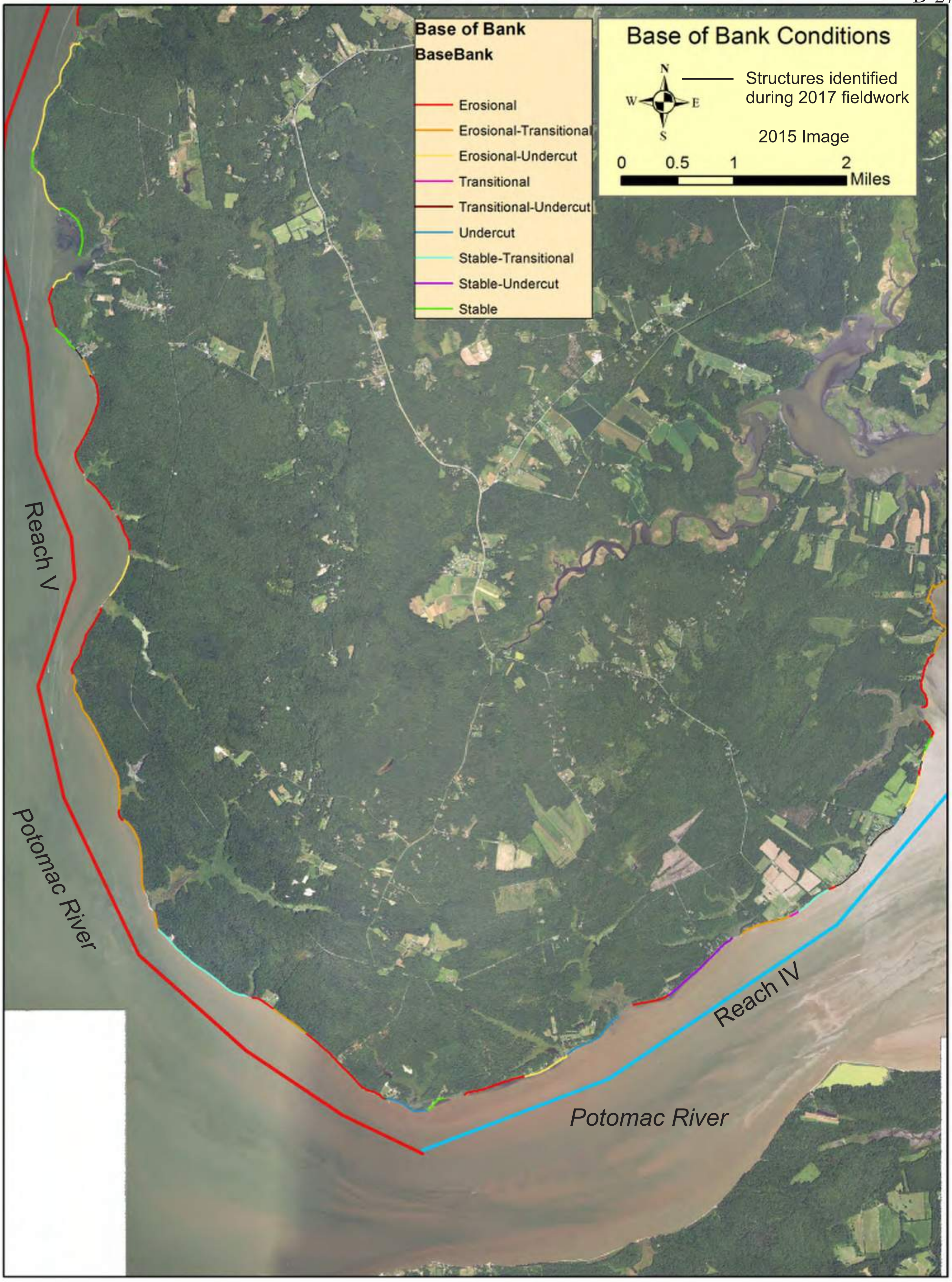

Bank Face Conditions
N
W
E
S
Structures identified during 2017 fieldwork
2015 Image
0 0.5 1 2
Miles
Bank Face
BankFace
Erosional
Erosional-Transitional
itional
Stable-Transitional
Stable
Potomac River
Reach VI
Mattawoman Creek
Chickamuxen Creek
Reach V

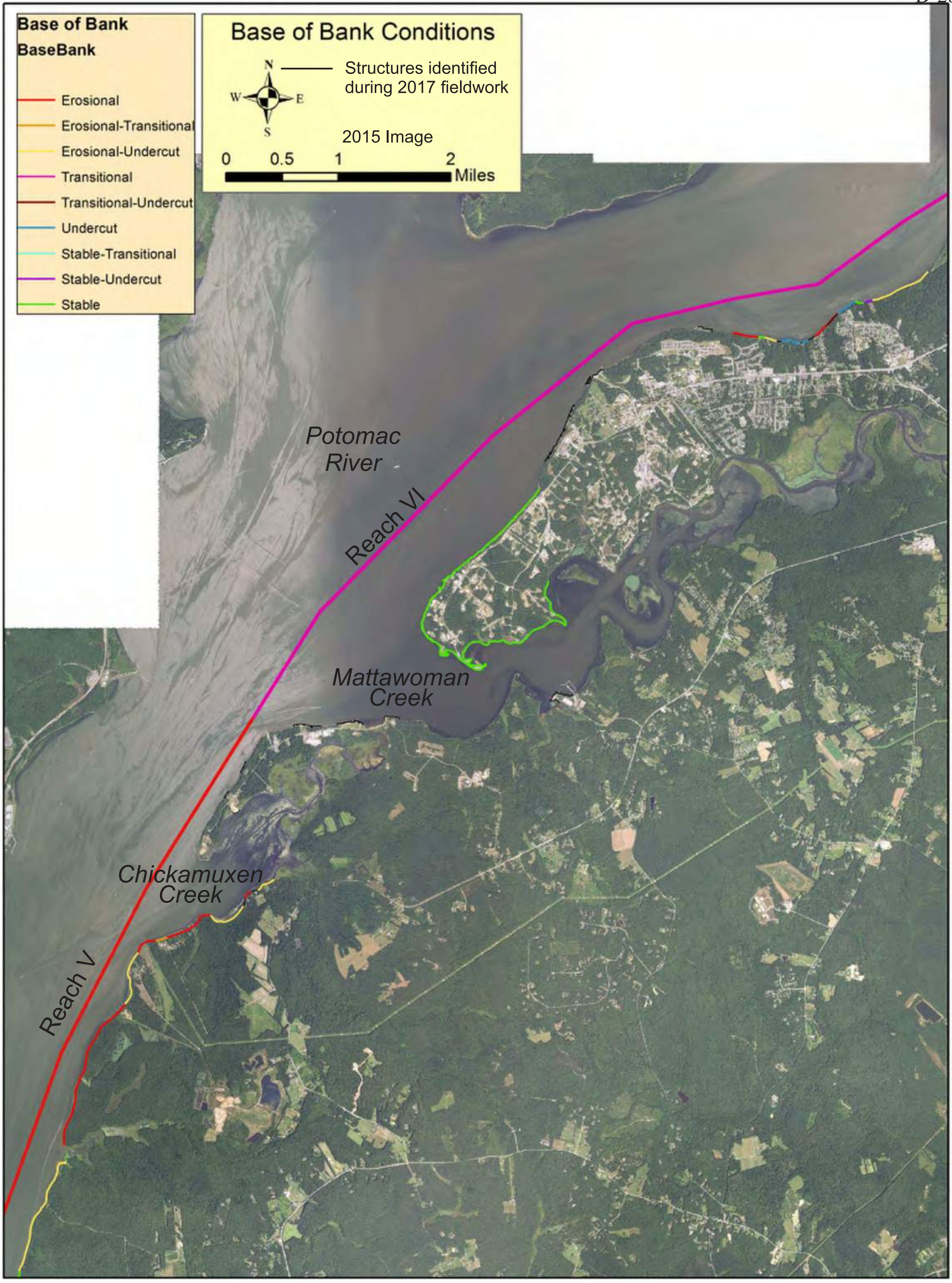

Bank Face Conditions
N
W
E
S
Structures identified during 2017 fieldwork
2015 Image
0 0.5 1 2 Miles
Bank Face
BankFace
Erosional
Erosional-Transitional
Transitional
Stable-Transitional
Stable
Potomac River
Reach VI
Potomac River
Mattawoman Creek

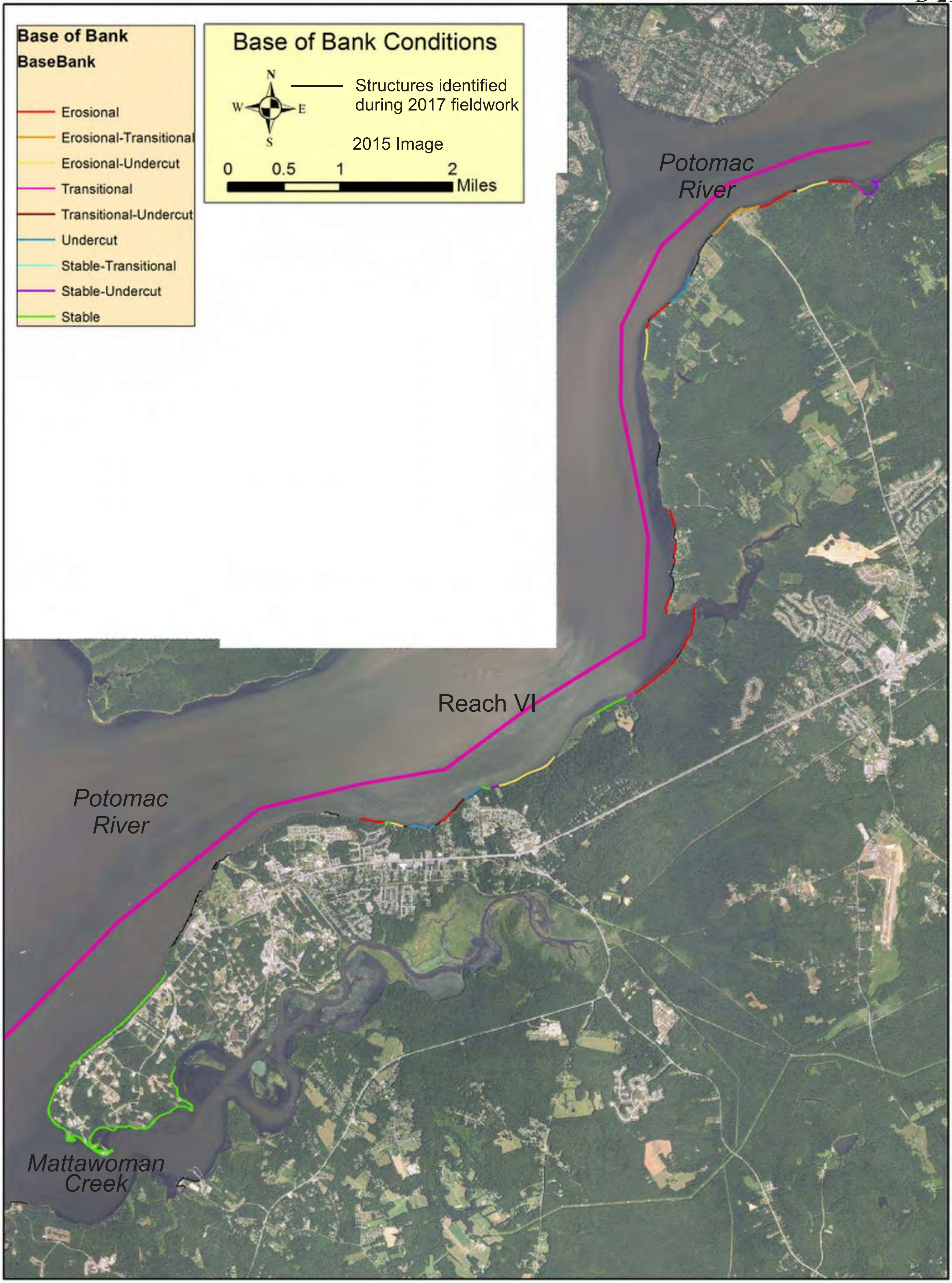

Bank Face Conditions
N
W
E
S
Structures identified during 2017 fieldwork
2015 Image
0 0.5 1 2
Miles
Bank Face
BankFace
Erosional
Erosional-Transitional
Transitional
Stable-Transitional
Stable
Swanson Ck
Reach VII
Patuxent River
Indian Ck


Wicomico
River
Potomac
River
Reach II
Reach I
Base of Bank
BaseBank
Erosional
Erosional-Transitional
Erosional-Undercut
Transitional
Transitional-Undercut
Undercut
Stable-Transitional
Stable-Undercut
Stable
Base of Bank Conditions
N
W
E
S
Structures identified
during 2017 fieldwork
2015 Image
0
0.5
1
2
Miles


Nanjemoy Creek
Port Tobacco River
Potomac River
Reach IV
Reach III
Base of Bank
BaseBank
Erosional
Erosional-Transitional
Erosional-Undercut
Transitional
Transitional-Undercut
Undercut
Stable-Transitional
Stable-Undercut
Stable
Base of Bank Conditions
N
W
E
S
Structures identified during 2017 fieldwork
2015 Image
0
0.5
1
2
Miles

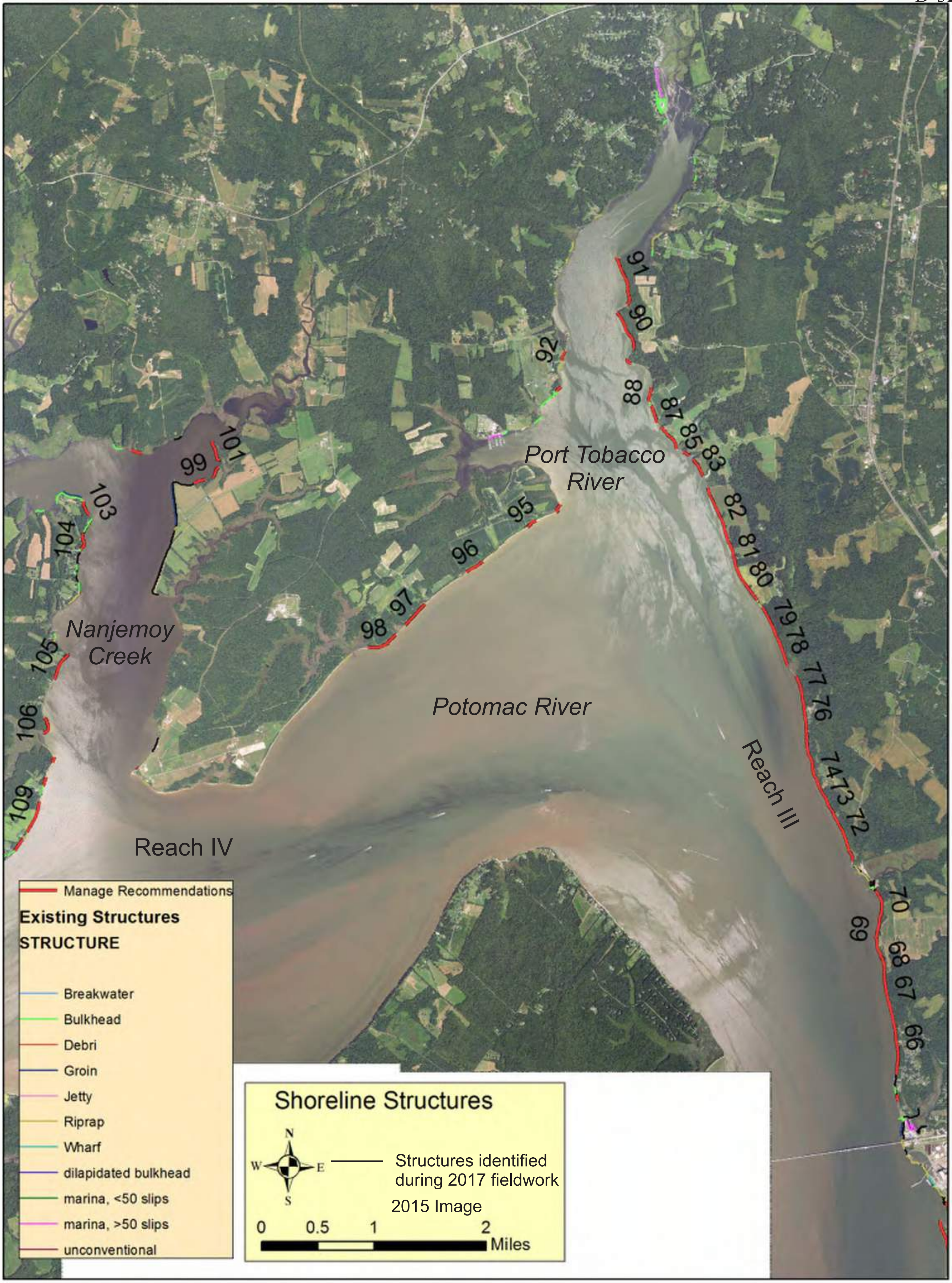

Base of Bank
BaseBank
Erosional
Erosional-Transitional
Erosional-Undercut
Transitional
Transitional-Undercut
Undercut
Stable-Transitional
Stable-Undercut
Stable
Base of Bank Conditions
N
W
E
S
Structures identified during 2017 fieldwork
2015 Image
0
0.5
1
2
Miles
Reach V
Potomac River
Reach IV
Potomac River


Base of Bank
BaseBank
Erosional
Erosional-Transitional
Erosional-Undercut
Transitional
Transitional-Undercut
Undercut
Stable-Transitional
Stable-Undercut
Stable
Base of Bank Conditions
N
W
E
S
Structures identified during 2017 fieldwork
2015 Image
0
0.5
1
2
Miles
Potomac River
Reach VI
Mattawoman Creek
Chickamuxen Creek
Reach V

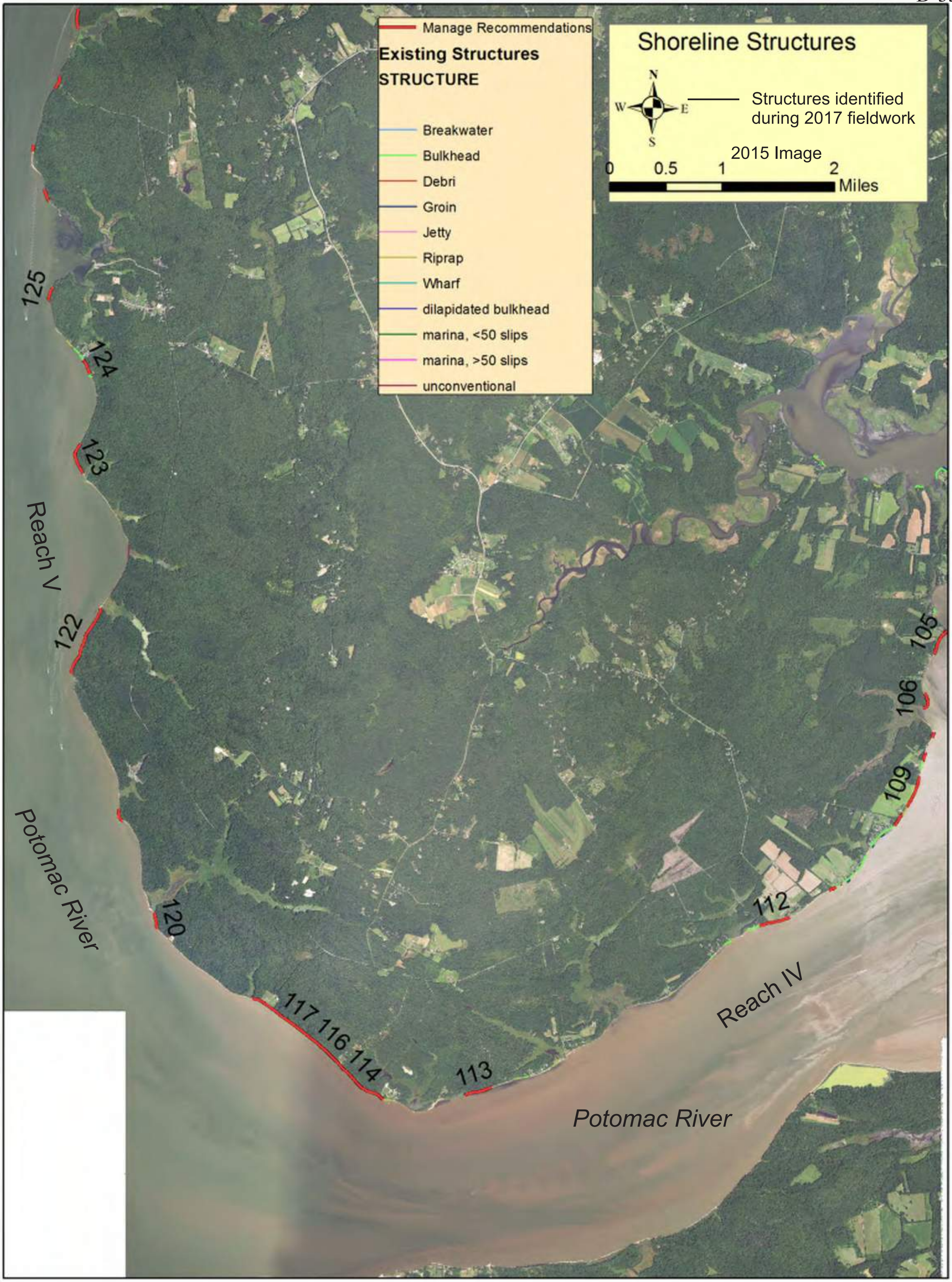

Base of Bank
BaseBank
Erosional
Erosional-Transitional
Erosional-Undercut
Transitional
Transitional-Undercut
Undercut
Stable-Transitional
Stable-Undercut
Stable
Base of Bank Conditions
N
W
E
S
Structures identified during 2017 fieldwork
2015 Image
0
0.5
1
2
Miles
Potomac River
Reach VI
Potomac River
Mattawoman Creek


Base of Bank
BaseBank
Erosional
Erosional-Transitional
Erosional-Undercut
Transitional
Transitional-Undercut
Undercut
Stable-Transitional
Stable-Undercut
Stable
Base of Bank Conditions
N
W
E
S
Structures identified during 2017 fieldwork
2015 Image
0
0.5
1
2
Miles
Swanson Ck
Reach VII
Patuxent River
Indian Ck

Shoreline Structures
Structures identified during 2017 fieldwork
2015 Image
0 0.5 1 2 Miles
N
S
E
W
Manage Recommendations
Existing Structures 2006
STRUCTURE
Breakwater
Bulkhead
Debri
Groin
Jetty
Riprap
Wharf
dilapidated bulkhead
marina, <50 slips
marina, >50 slips
unconventional
Potomac River
Wicomico River
Reach I
Reach II
1
2
3
7
8
10
12
14
17
19
23
25
26
28
29
32
34
37
41
42
43
50
53
54
55
56
58
60
61
64
66
67
68

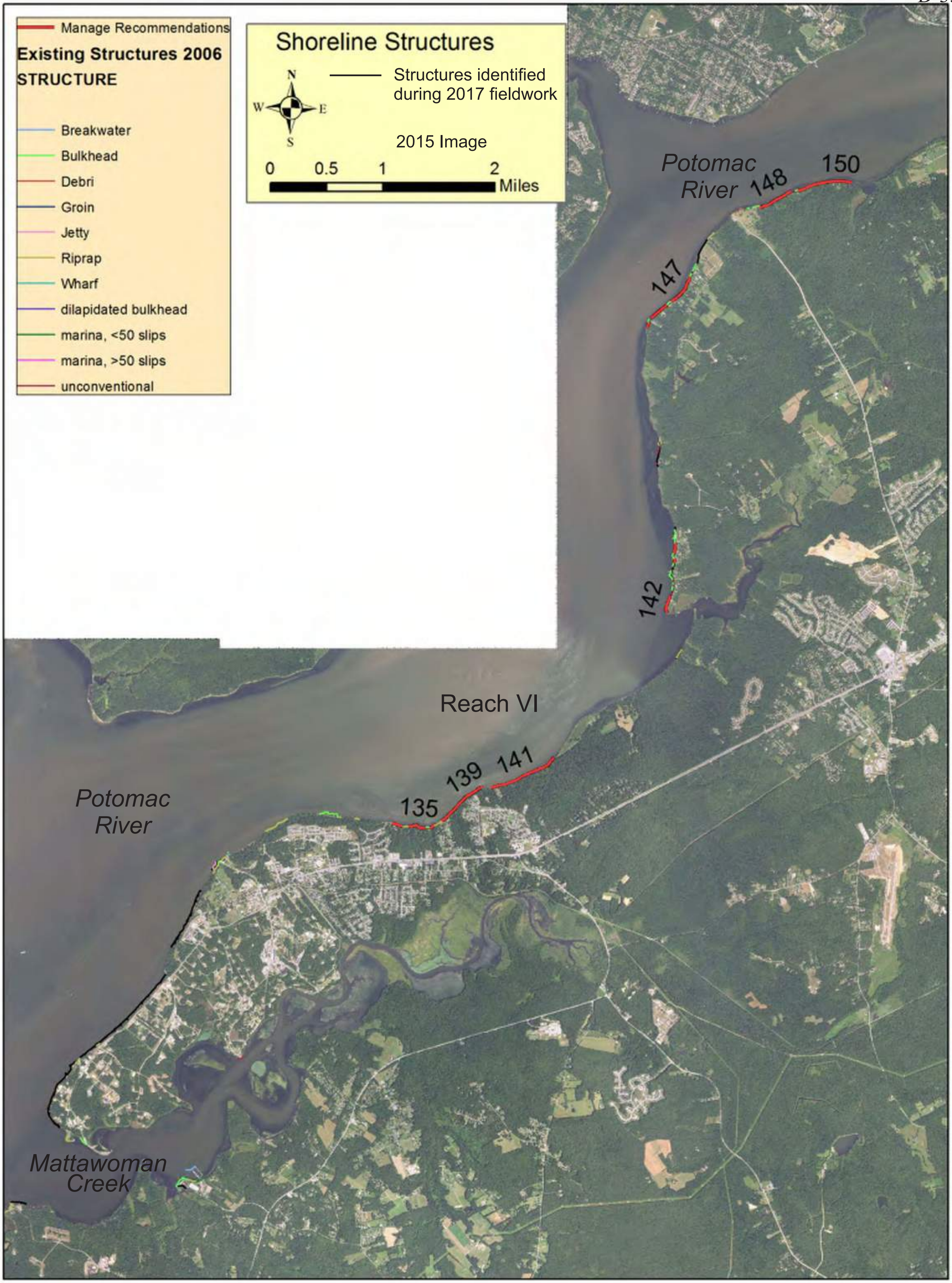


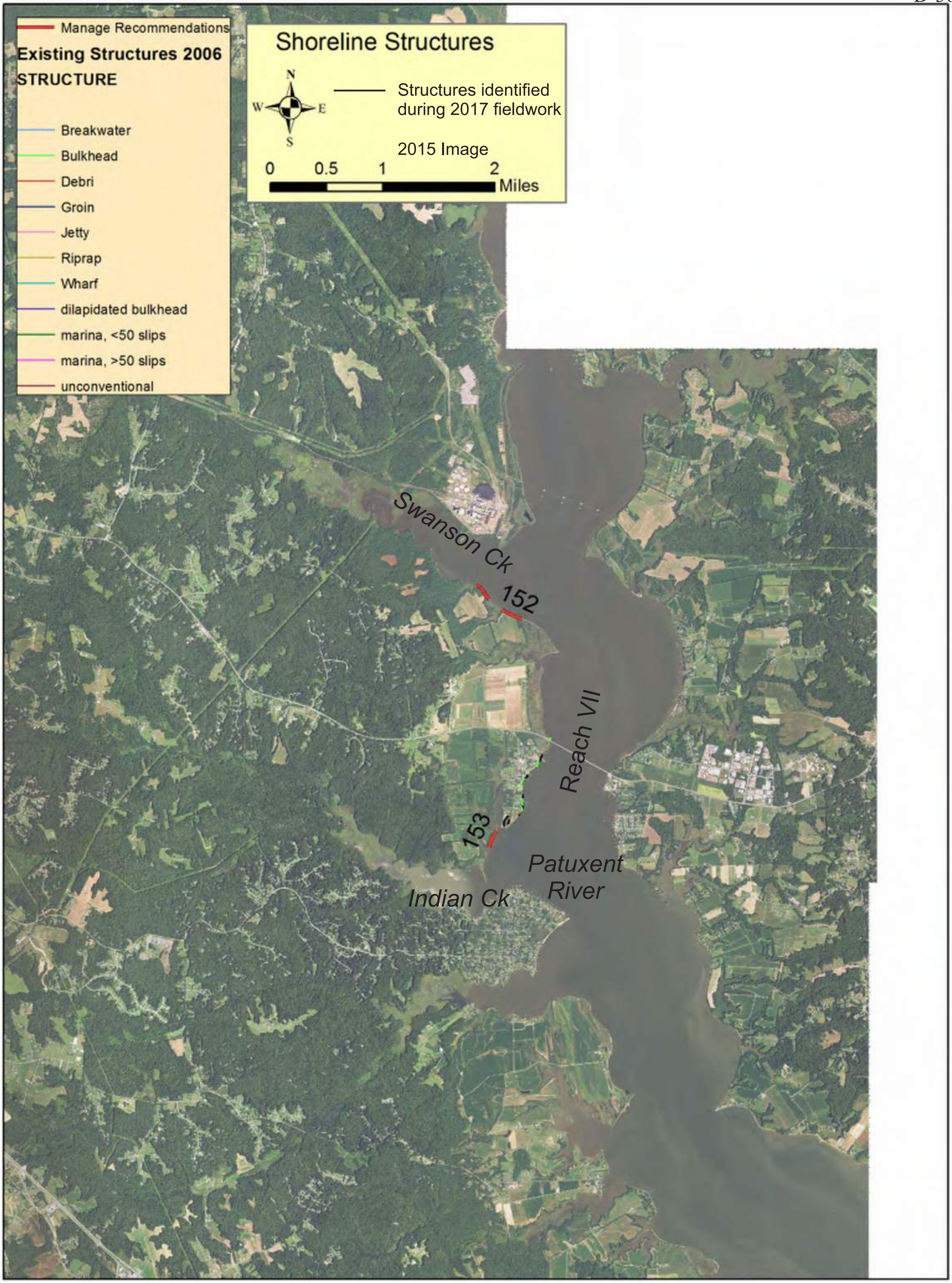
Port Tobacco River
Nanjemoy Creek
Potomac River
Reach III
Reach IV
91
90
92
88
87
85
83
82
81
80
79
78
77
76
74
73
72
70
69
68
67
66
101
99
103
104
95
96
97
98
105
106
109
Manage Recommendations
Existing Structures
STRUCTURE
Breakwater
Bulkhead
Debri
Groin
Jetty
Riprap
Wharf
dilapidated bulkhead
marina, <50 slips
marina, >50 slips
unconventional
Shoreline Structures
N
W
E
S
Structures identified during 2017 fieldwork
2015 Image
0
0.5
1
2
Miles

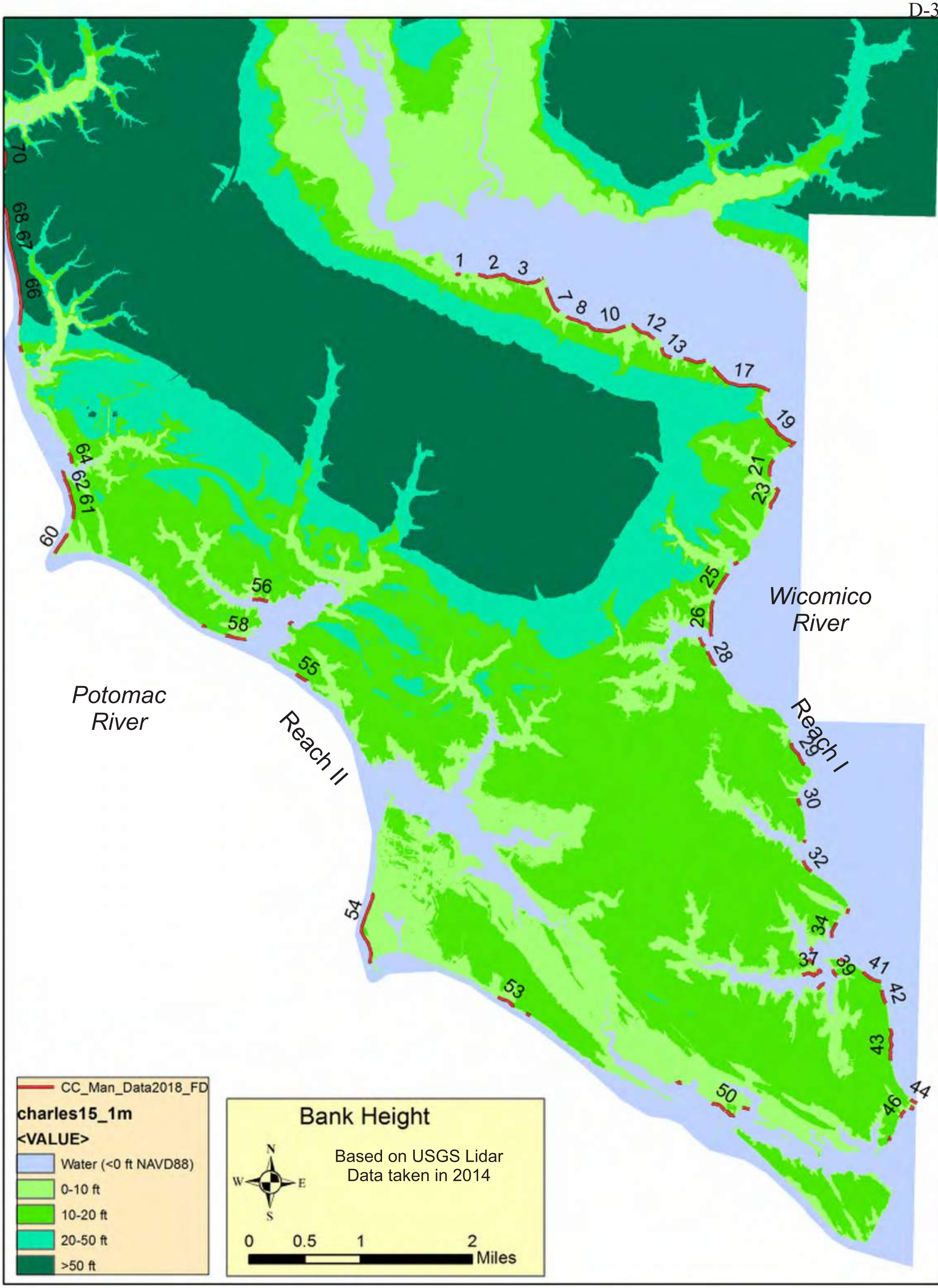


Manage Recommendations
Existing Structures
STRUCTURE
Breakwater
Bulkhead
Debri
Groin
Jetty
Riprap
Wharf
dilapidated bulkhead
marina, <50 slips
marina, >50 slips
unconventional
Shoreline Structures
N
W
E
S
Structures identified during 2017 fieldwork
2015 Image
0
0.5
1
2
Miles
125
124
123
Reach V
122
Potomac River
120
117 116 114
113
112
Reach IV
Potomac River
109
106
105

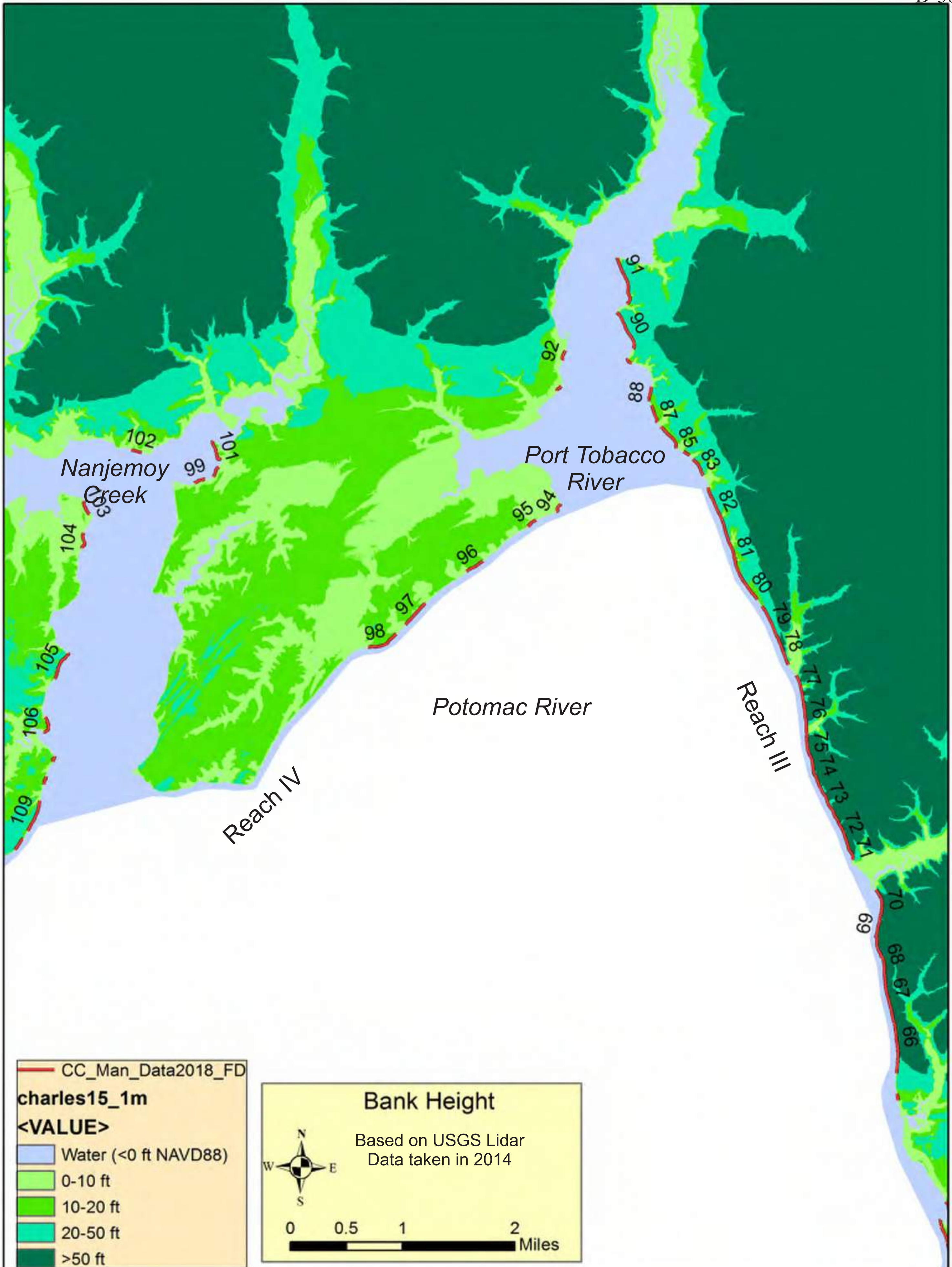

Manage Recommendations
Existing Structures 2006
STRUCTURE
Breakwater
Bulkhead
Debri
Groin
Jetty
Riprap
Wharf
dilapidated bulkhead
marina, <50 slips
marina, >50 slips
unconventional
Shoreline Structures
N
S
E
W
Structures identified during 2017 fieldwork
2015 Image
0 0.5 1 2 Miles
Potomac River
Reach VI
Mattawoman Creek
Chickamuxen Creek
Reach V
129
130
131
133
135
139
141


Manage Recommendations
Existing Structures 2006
STRUCTURE
Breakwater
Bulkhead
Debri
Groin
Jetty
Riprap
Wharf
dilapidated bulkhead
marina, <50 slips
marina, >50 slips
unconventional
Shoreline Structures
N
S
E
W
Structures identified during 2017 fieldwork
2015 Image
0 0.5 1 2 Miles
Potomac River
150
148
147
142
Reach VI
141
139
135
Potomac River
Mattawoman Creek

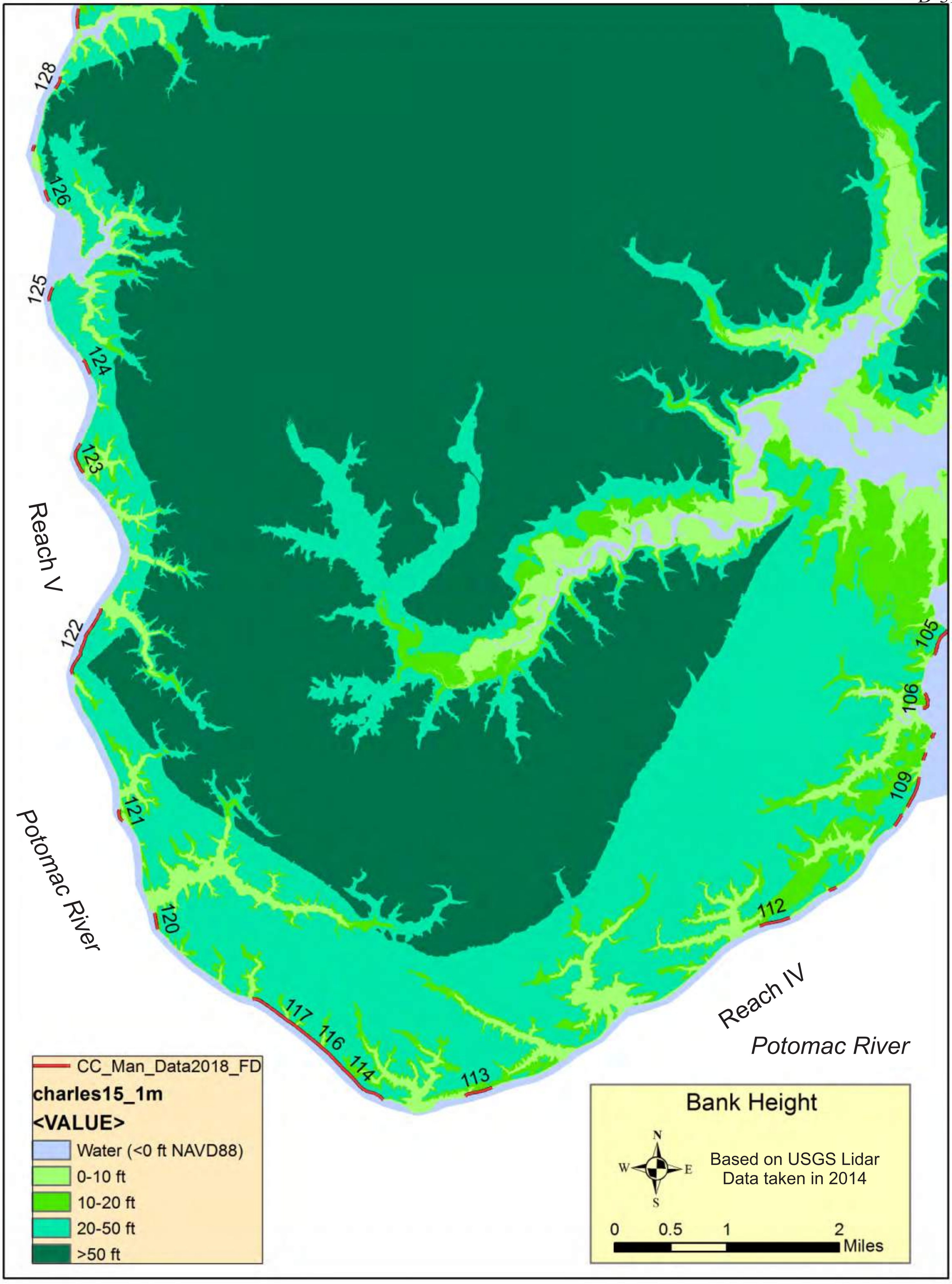

Manage Recommendations
Existing Structures 2006
STRUCTURE
Breakwater
Bulkhead
Debri
Groin
Jetty
Riprap
Wharf
dilapidated bulkhead
marina, <50 slips
marina, >50 slips
unconventional
Shoreline Structures
N
W
E
S
Structures identified during 2017 fieldwork
2015 Image
0
0.5
1
2
Miles
Swanson Ck
152
Reach VII
153
Patuxent River
Indian Ck

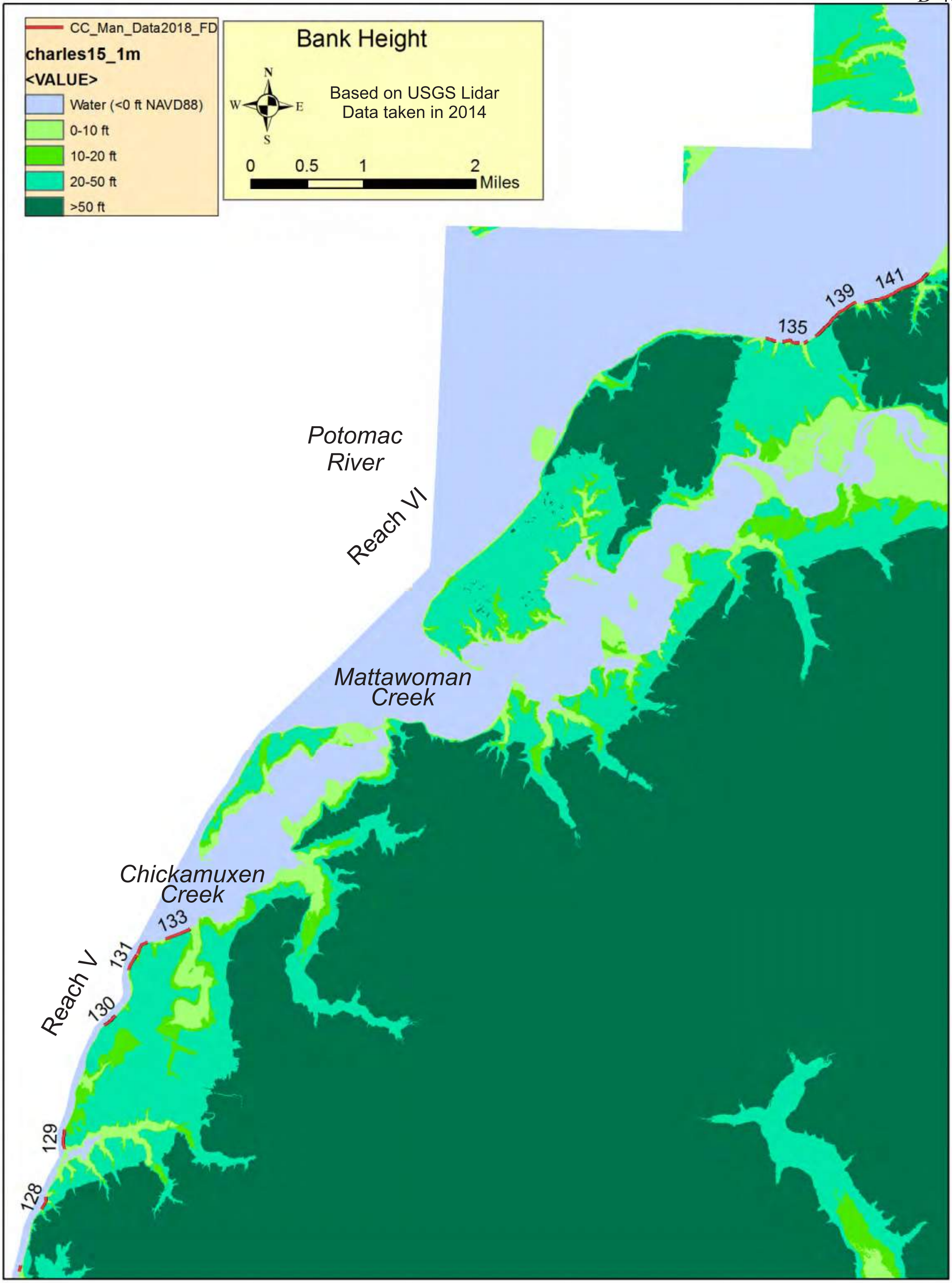


1
2
3
7
8
10
12
13
17
19
21
23
25
26
28
29
30
32
34
37
39
41
42
43
44
46
50
53
54
55
56
58
60
61
62
64
66
67
68
70
Wicomico River
Potomac River
Reach II
Reach I
CC_Man_Data2018_FD
charles15_1m
<VALUE>
Water (<0 ft NAVD88)
0-10 ft
10-20 ft
20-50 ft
>50 ft
Bank Height
Based on USGS Lidar Data taken in 2014
N
W
E
S
0 0.5 1 2 Miles

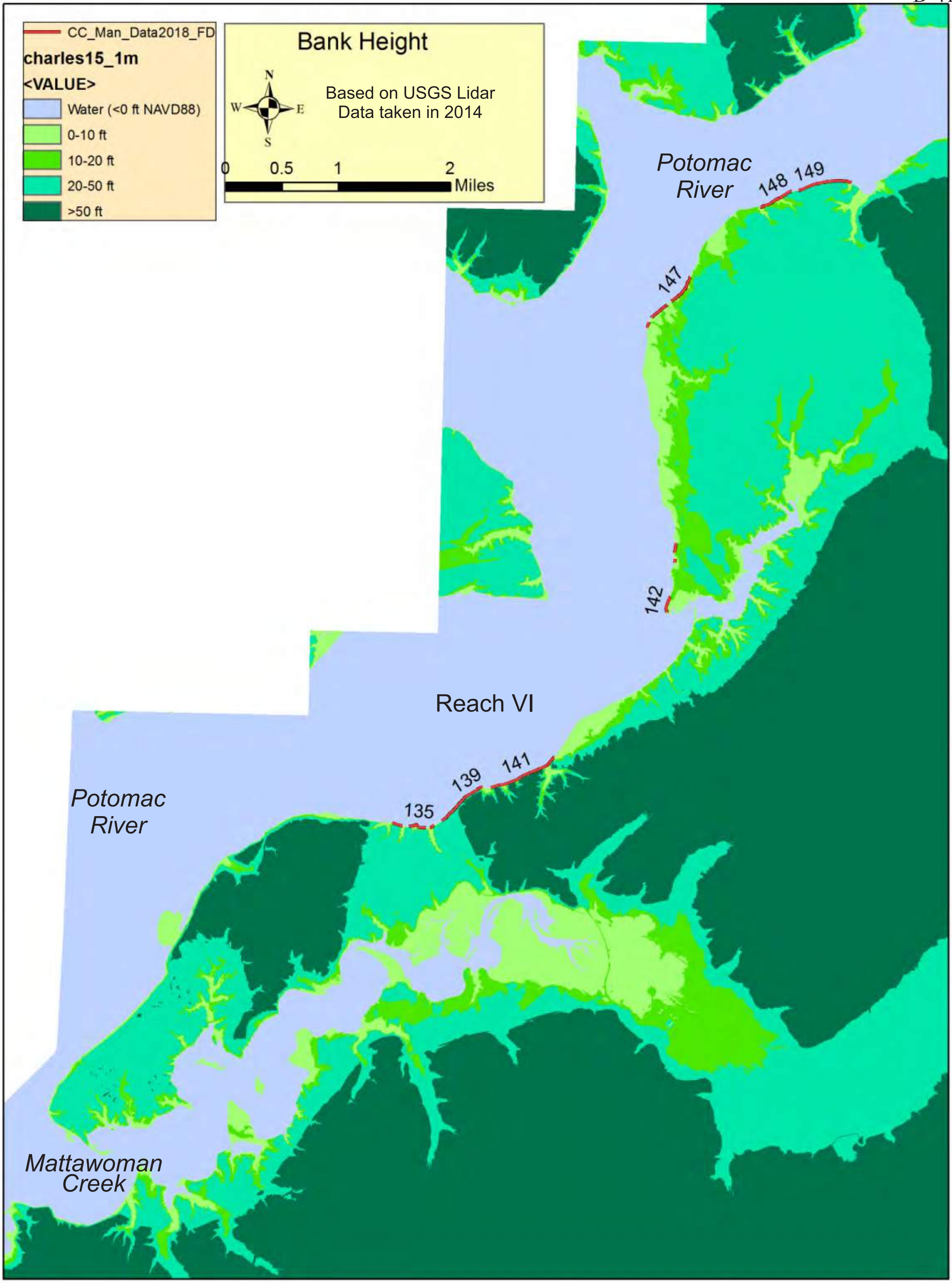


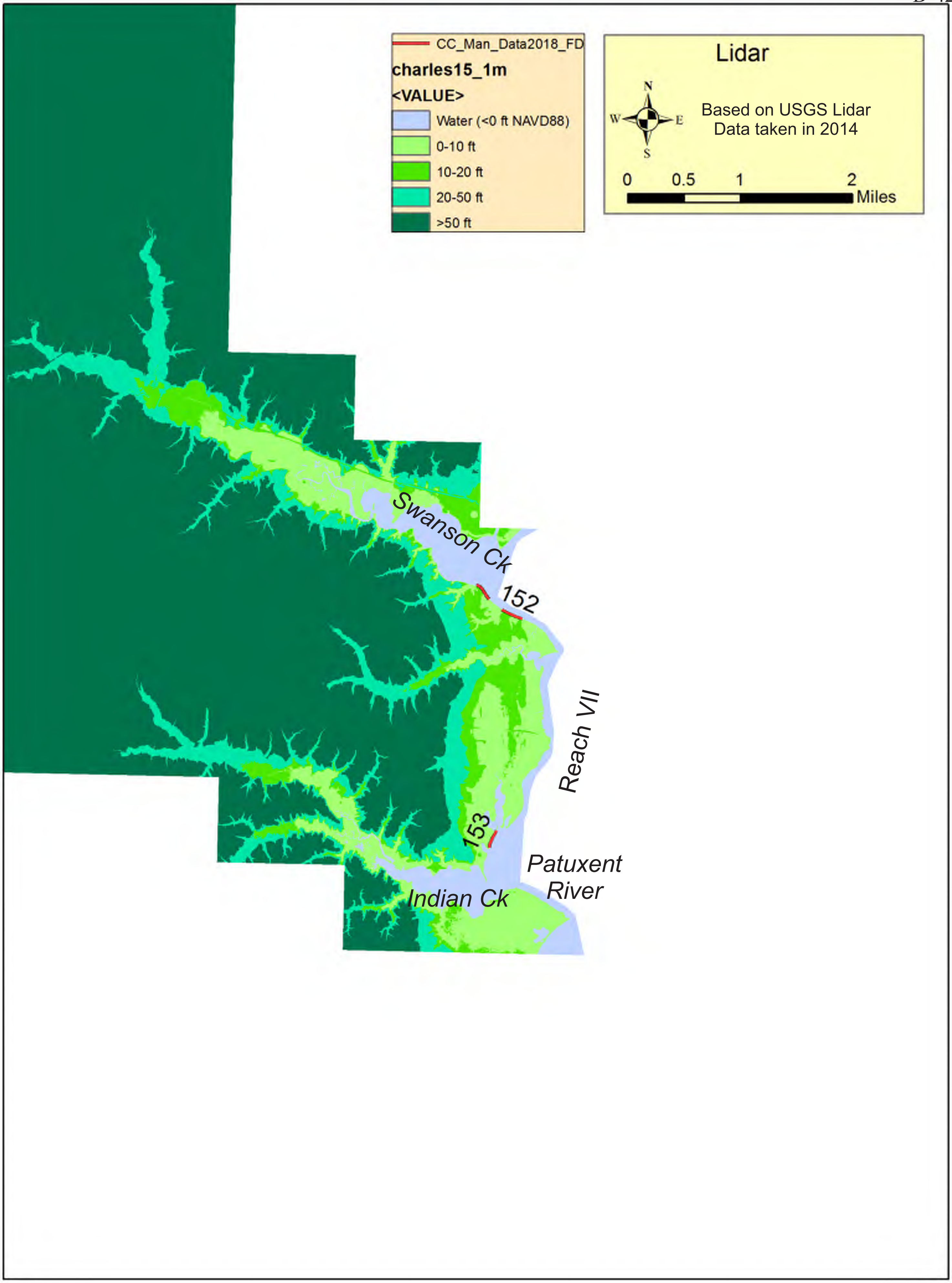
Nanjemoy Creek
Port Tobacco River
Potomac River
Reach IV
Reach III
102
101
99
103
104
105
106
109
92
91
90
88
87
85
83
82
81
80
79
78
77
76
75
74
73
72
71
70
69
68
67
66
95
94
96
97
98
CC_Man_Data2018_FD
charles15_1m
<VALUE>
Water (<0 ft NAVD88)
0-10 ft
10-20 ft
20-50 ft
>50 ft
Bank Height
Based on USGS Lidar Data taken in 2014
N
S
E
W
0
0.5
1
2
Miles


128
126
125
124
123
Reach V
122
121
Potomac River
120
117
116
114
113
112
109
106
105
Reach IV
Potomac River
CC_Man_Data2018_FD
charles15_1m
<VALUE>
Water (<0 ft NAVD88)
0-10 ft
10-20 ft
20-50 ft
>50 ft
Bank Height
N
W
E
S
Based on USGS Lidar Data taken in 2014
0
0.5
1
2
Miles



CC_Man_Data2018_FD
charles15_1m
<VALUE>
Water (<0 ft NAVD88)
0-10 ft
10-20 ft
20-50 ft
>50 ft
Bank Height
N
W
E
S
Based on USGS Lidar Data taken in 2014
0 0.5 1 2 Miles
Potomac River
Reach VI
Mattawoman Creek
Chickamuxen Creek
Reach V
128
129
130
131
133
135
139
141


CC_Man_Data2018_FD
charles15_1m
<VALUE>
Water (<0 ft NAVD88)
0-10 ft
10-20 ft
20-50 ft
>50 ft
Bank Height
N
W
E
S
Based on USGS Lidar Data taken in 2014
0
0.5
1
2
Miles
Potomac River
148
149
147
142
Reach VI
141
139
135
Potomac River
Mattawoman Creek


CC_Man_Data2018_FD
charles15_1m
<VALUE>
Water (<0 ft NAVD88)
0-10 ft
10-20 ft
20-50 ft
>50 ft
Lidar
N
W
E
S
Based on USGS Lidar Data taken in 2014
0
0.5
1
2
Miles
Swanson Ck
152
Reach VII
153
Patuxent River
Indian Ck

Appendix E

TMDL Information

TMDL Table: the sites are ordered by site number

Site Number	Site designation
Volume	Site length (ft)*Bank Height (ft)*Rate of Change (ft/yr)
Area Planted	Width of planting (ft) based on structure type*site length (ft)/43,560 (sq.ft/acre)
Impervious Surface Acre Equivalent	Site length * 0.04; based on Table 3.E in MDE (2014)
Protocol 1 – TSS	Volume (height*erosion rate*site length) * 93.6 (lbs / cf; bulk density) * 0.5 (Sand reduction factor in Maryland); in pound per year; Drescher and Stack, 2015a
Protocol 1 – TSS/site length	Volume (height*erosion rate*site length) * 93.6 (lbs / cf; bulk density) * 0.5 (Sand reduction factor in Maryland) divided by site length; in pounds per foot per year; Drescher and Stack, 2015a
Protocol 1 - TN	Total nitrogen calculated for Protocol 1; (Protocol 1 TSS) * 0.00029 (lbs TN / lbs TSS); Drescher and Stack, 2015a
Protocol 1 - TP	Total phosphorus calculated for Protocol 1; (Protocol 1 TSS) * 0.000205 (lbs TP / lbs TSS); Drescher and Stack, 2015a
Protocol 2 - TN	Plantings (acre) * (85 lbs TN / ac); See Appendix E for more information.
Protocol 3 – TSS	Plantings (acre) * (6,959 lbs TSS / ac)
Protocol 3 - TP	Plantings (acre) * (5.289 lbs TP / ac)
Protocol 4 - TN	Plantings (acre) * (6.83 lbs TN / ac)
Protocol 4 - TP	Plantings (acre) * (0.3 lbs TP / ac)
Total TSS (lbs / yr)	Sum of TSS Protocols (Protocol 1 – TSS+ Protocol 3 – TSS)
Total TN (lbs / yr)	Sum of TN Protocols (Protocol 1 – TN + Protocol 2 – TN + Protocol 4 – TN)
Total TP (lbs / yr)	Sum of TP Protocols (Protocol 1 – TP + Protocol 3 – TP + Protocol 4 – TP)

To provide information on the possible TMDL credits for shore protection structures constructed along Charles County's shoreline, the following TMDL calculations were made on all of the recommended sites. The results are shown in the following listing of TMDL data.

Maryland Department of the Environment 2014 established a default value for impervious surface acre equivalent for shoreline management as 0.04 times the site length (Table E-1).

Dresher and Stack 2015 revised provided guidance for shoreline management using 4 Protocols (Table E-2). Protocols 2, 3 and 4 require the width of re-vegetation of marsh as part of accreditation for TN and TP removal. For the Charles County Shoreline Management Plan, this width is determined by the structure type recommended at the site. Planted marsh widths per structure type are: Type 1= 23.6 ft, Type 2 = 27.1 ft, Type 3= 28.6 ft, Type 4= 34.7 ft, and Type 5 = 44.4 ft. The planted marsh width is multiplied times the site length and converted to acres. The TMDL credits for the EPA Protocols 1 thru 4 (Drescher and Stack, 2015) are described below:

Protocol 1 – Prevented Sediment

- Total Suspended Sediments (TSS). The actual volume per of foot of eroded bank sediment and the associated grain and nutrients can be determined for a site by sampling and analyzing the bank's sediments (see section below on bank sediments).
- Total Nitrogen (TN). 0.00025 lbs TN per lbs of TSS
- Total Phosphorus (TP). 0.000205 lbs TP per lbs of TSS

Protocol 2 - Denitrification

- TN - acres of planted vegetation (marsh fringe), measured TN removal for denitrification at 85 lbs TN/acres/yr.

Protocol 3 – Sedimentation

- TSS. Measured at 6,959 lbs TSS/acre/yr
- TP. 0.3 lbs TP/acre/yr.

Protocol 4 -Marsh Redfield Ratio

This protocol provides one-time nutrient reduction credit for shoreline management practices that include vegetation, marsh fringe.

- TN. 0.83 TN/acre/yr
- TP. 0.3 lbs TP/acre/yr.

Sediment Sampling

In order to verify the nature of the eroding sediments and acquire site specific data, bank sampling must be performed. Bank sampling protocol is provided in Drescher and Stack's (2015) Appendix K. For the Charles County project, one site was sampled to assess a site specific bank sediments and compared to default values.

According to Protocol 1, the TSS calculation is site specific and unique to each site. To test bank the sampling technique against the latest default value for TN, two bank samples were taken from the boat at Site 23. This site has an eight-foot bank, and one sample was taken in the soil horizon and one in the middle of the bank. The one-foot-thick soil horizon represents 13% of the eroding bank, and the rest of the bank was similar material represented by the one sample. The sediment samples were analyzed for TN and grain size. The results, when mean weighted, showed the TN load for the site was 0.00034 lbs TN/lbs of TSS. Referring to the listing of data in this Appendix, Site 23, Protocol 1 for TN gives 369 lbs/yr using the default value 0.00029 lbs TN/lb of TSS. Using the above results from the field samples the TN load is 343 lbs/yr, a bit lower. Therefore, there may be advantage (or disadvantage) sampling the P-1 and P-2 sites to gain further insight or credit. The sampled sediments for Site 23 were about 50/50 sand and fines so that fits well with default TSS credit at this site.

Table E-1. Alternative Urban BMPs. From MDE (2014).

	Notes	Efficiency Per Acre			Impervious Acre Equivalent
		TN	TP	TSS	
Mechanical Street Sweeping	High density urban areas where sweeping occurs 2x/month	4%	4%	10%	0.07
Regen/Vacuum Street Sweeping	High density urban areas where sweeping occurs 2x/month	5%	6%	25%	0.13
Reforestation on Pervious Urban	Survival rate of 100 trees/acre or greater; at least 50% of trees have two inch diameter or greater (4.5 ft. above ground)	66%	77%	57%	0.38
Impervious Urban to Pervious	Remove pavement and provide vegetative cover for 95% of area	13%	72%	84%	0.75
Impervious Urban to Forest	Survival rate of 100 trees/acre or greater; at least 50% of trees have two inch diameter or greater (4.5 ft. above ground)	71%	94%	93%	1.00
Regenerative Step Pool Storm Conveyance (SPSC)[1]	Located in dry or ephemeral channels; nutrient removal and impervious area credit is based on runoff depth treated	57%	66%	70%	1.00
		Lbs Reduced / Ton			Impervious Acre Equivalent
		TN	TP	TSS	
Catch Basin Cleaning	High density urban areas; storm drains are routinely maintained	3.5	1.4	420	0.40
Storm Drain Vacuuming	High density urban areas; storm drains are routinely maintained	3.5	1.4	420	0.40
Mechanical Street Sweeping	High density urban areas where sweeping occurs 2x/month	3.5	1.4	420	0.40
Regen/Vacuum Street Sweeping	High density urban areas where sweeping occurs 2x/month	3.5	1.4	420	0.40
		Lbs Reduced / Linear Ft			Impervious Acre Equivalent
		TN	TP	TSS	
Stream Restoration: load reductions for interim rate[2]	Schueler and Stack (2014) specify qualifying conditions and protocols to calculate individual load reductions per project	0.075	0.068	15/45	0.01
Outfall Stabilization	Stabilization or repair of localized areas of erosion below a storm drain outfall; max credit is 2 acres per project	n/a	n/a	n/a	0.01
Shoreline Management [3]	Revised protocols are pending CBP approval	0.075	0.068	137	0.04
		Lbs Reduced / Unit			Impervious Acre Equivalent
		TN	TP	TSS	
Septic Pumping	Pumping system is maintained and verified for annual credit	0[4]	0	0	0.03
Septic Denitrification	Permanent credit for installing enhanced septic denitrification	0[4]	0	0	0.26
Septic Connections to WWTP	Permanent credit for septic system connected to a WWTP	0[4]	0	0	0.39

1. Efficiencies and impervious acre equivalents shown are based on treating 1 inch of rainfall. When less than 1 inch of rainfall is treated, then refer to Table 2 for impervious acre equivalent and Table 6 for nutrient and sediment removal efficiencies.
2. Load reductions are based on current proposal under consideration by CBP. TSS is based on coastal plain and non-coastal plain applications. (Refer to Appendix E, Stream Restoration).
3. Load reductions are based on current proposal under consideration by CBP based on Drescher and Stack (2014). (Refer to Appendix E, Shoreline Management).
4. Actual load reductions shall be reported through local health department. Septic system credits only apply to impervious acre requirements.

Table E-2. Summary of shoreline management pollutant load reduction for individual projects. From Dresher and Stack (2015).

Protocol	Submitted Unit	Total Nitrogen (lbs per unit)	Total Phosphorus (lbs per unit)	Total Suspended Sediment (lbs per unit)
Protocol 1 - Prevented Sediment	Linear Feet	Project-Specific*	Project-Specific*	Project-Specific
Protocol 2 – Denitrification	Acres of re-vegetation	85	NA	NA
Protocol 3 - Sedimentation	Acres of re-vegetation	NA	5.289	6,959
Protocol 4 – Marsh Redfield Ratio	Acres of re-vegetation	6.83	0.3	NA
Non-conforming/Existing Practices	Linear Feet	0.04756/0.01218 *	0.03362/0.00861 *	164 /42 **

*The WTWG recommended no reductions for TN and TP until the Modeling Workgroup has an opportunity to evaluate the availability of TN and TP in shoreline sediments. The WTWG will be asked to approve reductions following this analysis (p. 2-3). This analysis indicated that an average of 0.00029 lbs TN/ lb of TSS and 0.000205 lbs TP/ lb of TSS. These values can be used directly by jurisdictions for their calculations in Protocol 1, and were adapted for non-conforming/existing practices by multiplying by the default TSS reduction for non-conforming projects by the average nutrient concentrations in sediment. The first number applies to MD, DE and DC and the second number applies to VA.

Site Number	Volume (ft^3 / yr)	Area Planted (acres)	Impervious Surface Acre Equivalent	Protocol 1 - TSS (lbs / yr)	Protocol 1 - TSS/site length (lbs/ft/yr)	Protocol 1 - TN (lbs / yr)	Protocol 1 - TP (lbs / yr)	Protocol 2 - TN (lbs / yr)
1	2,437.3	0.14	10.3	114,067.4	444.9	33	23	12
2	15,407.3	0.94	69.1	721,061.0	417.6	209	148	80
3	7,011.1	0.65	48.1	328,118.7	272.8	95	67	55
4	280.1	0.12	9.0	13,106.4	58.4	4	3	10
5	109.1	0.04	2.5	5,108.1	81.3	1	1	3
6	1,262.1	0.25	18.7	59,064.8	126.1	17	12	22
7	2,091.3	0.46	34.2	97,874.3	114.4	28	20	39
8	7,524.5	0.65	48.3	352,147.4	291.7	102	72	56
9	5,582.7	0.22	16.3	261,268.9	642.1	76	54	19
10	9,188.3	0.76	56.1	430,013.6	306.9	125	88	65
11	5,900.1	0.31	23.2	276,127.0	477.0	80	57	27
12	5,005.5	0.46	29.3	234,258.0	320.1	68	48	39
13	3,566.1	0.40	29.5	166,893.0	226.4	48	34	34
14	952.9	0.35	25.7	44,596.9	69.4	13	9	30
15	1,389.8	0.29	18.8	65,043.6	138.7	19	13	25
16	3,361.0	0.50	37.0	157,295.6	169.9	46	32	43
17	18,514.3	1.26	80.9	866,471.5	428.5	251	178	107
18	111.7	0.09	5.7	5,228.5	36.7	2	1	8
19	9,286.7	1.03	75.9	434,619.1	229.1	126	89	87
20	487.5	0.10	7.4	22,816.8	122.8	7	5	9
21	3,936.4	0.45	33.4	184,225.6	220.7	53	38	38
22	159.5	0.09	6.5	7,466.7	45.9	2	2	7
23	27,165.3	0.67	40.5	1,271,334.3	1,254.9	369	261	57
24	4,158.7	0.14	10.7	194,629.4	728.7	56	40	12
25	23,166.0	0.64	47.3	1,084,169.6	917.2	314	222	54
26	42,198.9	0.94	69.3	1,974,909.5	1,139.4	573	405	80
27	3,389.3	0.28	20.4	158,617.2	310.3	46	33	24
28	19,453.1	0.43	31.4	910,407.2	1,158.7	264	187	36
29	11,793.7	0.69	50.6	551,946.2	435.9	160	113	58
30	5,250.6	0.20	14.7	245,729.2	667.7	71	50	17
31	1,372.3	0.09	6.8	64,222.8	378.0	19	13	8
32	15,038.1	0.43	27.3	703,781.5	1,030.0	204	144	36
33	1,499.2	0.15	11.1	70,162.3	253.8	20	14	13
34	10,990.2	0.43	32.0	514,343.5	643.7	149	105	37
35	1,571.7	0.12	8.8	73,557.1	334.8	21	15	10
36	1,411.0	0.18	13.2	66,033.9	200.8	19	14	15
37	1,925.5	0.66	48.5	90,113.7	74.3	26	18	56
38	1,005.3	0.23	16.7	47,046.9	112.7	14	10	19
39	792.4	0.21	15.3	37,084.1	96.9	11	8	18
40	3,012.8	0.15	11.0	141,000.4	511.1	41	29	13
41	21,894.3	0.63	40.8	1,024,655.3	1,005.5	297	210	54
42	11,546.7	0.42	27.2	540,385.7	793.6	157	111	36
43	16,237.6	0.98	62.7	759,921.8	484.5	220	156	83

Site information continues on next page.

Site Number	Protocol 3 - TSS (lbs / yr)	Protocol 3 - TP (lbs / yr)	Protocol 4 - TN (lbs / yr)	Protocol 4 - TP (lbs / yr)	Total TSS (lbs/yr)	Total TN (lbs/yr)	TP (lbs/yr)
1	967	0.7	0.9	0.0	115,034.1	45.8	24.2
2	6,509	4.9	6.4	0.3	727,570.3	295.0	153.0
3	4,536	3.4	4.5	0.2	332,654.4	155.0	70.9
4	846	0.6	0.8	0.0	13,952.4	15.0	3.4
5	272	0.2	0.3	0.0	5,379.9	5.1	1.3
6	1,766	1.3	1.7	0.1	60,830.4	40.4	13.5
7	3,226	2.5	3.2	0.1	101,100.5	71.0	22.7
8	4,552	3.5	4.5	0.2	356,699.6	162.2	75.8
9	1,534	1.2	1.5	0.1	262,803.0	96.0	54.8
10	5,283	4.0	5.2	0.2	435,296.8	194.4	92.4
11	2,183	1.7	2.1	0.1	278,309.6	108.9	58.4
12	3,168	2.4	3.1	0.1	237,426.2	109.7	50.6
13	2,779	2.1	2.7	0.1	169,672.1	85.1	36.4
14	2,424	1.8	2.4	0.1	47,021.2	44.9	11.1
15	2,030	1.5	2.0	0.1	67,073.6	45.7	15.0
16	3,491	2.7	3.4	0.2	160,786.5	91.7	35.0
17	8,754	6.7	8.6	0.4	875,226.0	366.8	184.7
18	617	0.5	0.6	0.0	5,845.4	9.7	1.6
19	7,151	5.4	7.0	0.3	441,770.5	220.4	94.8
20	701	0.5	0.7	0.0	23,517.3	15.9	5.2
21	3,147	2.4	3.1	0.1	187,372.7	95.0	40.3
22	614	0.5	0.6	0.0	8,080.5	10.3	2.0
23	4,629	3.5	4.5	0.2	1,275,963.2	429.8	264.3
24	1,007	0.8	1.0	0.0	195,636.4	69.7	40.7
25	4,456	3.4	4.4	0.2	1,088,626.1	373.2	225.8
26	6,535	5.0	6.4	0.3	1,981,444.5	659.0	410.1
27	1,927	1.5	1.9	0.1	160,544.5	71.4	34.1
28	2,962	2.3	2.9	0.1	913,369.5	303.1	189.0
29	4,774	3.6	4.7	0.2	556,719.7	223.1	117.0
30	1,387	1.1	1.4	0.1	247,116.7	89.6	51.5
31	641	0.5	0.6	0.0	64,863.4	27.1	13.7
32	2,958	2.2	2.9	0.1	706,739.8	243.1	146.7
33	1,042	0.8	1.0	0.0	71,204.4	34.1	15.2
34	3,012	2.3	3.0	0.1	517,355.9	188.9	107.9
35	828	0.6	0.8	0.0	74,385.5	32.3	15.7
36	1,240	0.9	1.2	0.1	67,273.9	35.5	14.5
37	4,574	3.5	4.5	0.2	94,688.2	86.5	22.1
38	1,573	1.2	1.5	0.1	48,620.2	34.4	10.9
39	1,443	1.1	1.4	0.1	38,527.4	29.8	8.8
40	1,040	0.8	1.0	0.0	142,040.6	54.6	29.7
41	4,412	3.4	4.3	0.2	1,029,067.4	355.4	213.6
42	2,948	2.2	2.9	0.1	543,333.6	195.6	113.1
43	6,790	5.2	6.7	0.3	766,712.0	310.0	161.2

Site Number	Volume (ft^3 / yr)	Area Planted (acres)	Impervious Surface Acre Equivalent	Protocol 1 - TSS (lbs / yr)	Protocol 1 - TSS/site length (lbs/ft/yr)	Protocol 1 - TN (lbs / yr)	Protocol 1 - TP (lbs / yr)	Protocol 2 - TN (lbs / yr)
44	2,123.9	0.19	14.0	99,399.7	284.7	29	20	16
45	334.5	0.16	9.9	15,652.8	63.3	5	3	14
46	1,738.8	0.26	16.5	81,374.3	196.8	24	17	22
47	5,224.6	0.14	9.1	244,511.6	1,072.9	71	50	12
48	1,242.3	0.20	14.8	58,139.3	157.4	17	12	17
49	13,940.1	0.34	21.7	652,396.8	1,203.5	189	134	29
50	6,852.8	0.49	31.3	320,710.2	410.5	93	66	41
51	3,153.5	0.19	12.4	147,581.9	474.7	43	30	16
52	27.0	0.19	9.5	1,263.4	5.3	0	0	16
53	5,791.6	0.96	37.6	271,048.4	288.3	79	56	81
54	156,307.0	2.84	142.4	7,315,168.6	2,054.7	2,121	1,500	241
55	534.6	0.52	26.1	25,017.3	38.4	7	5	44
56	4,421.6	0.44	32.2	206,933.0	256.9	60	42	37
57	278.9	0.14	8.9	13,052.0	58.7	4	3	12
58	15,989.5	0.81	40.7	748,310.7	736.2	217	153	69
59	7,600.8	0.20	7.7	355,716.9	1,836.4	103	73	17
60	2,778.0	0.89	44.8	130,008.9	116.0	38	27	76
61	27,380.2	1.43	56.3	1,281,394.3	910.7	372	263	122
62	23,771.5	0.79	30.8	1,112,504.9	1,442.9	323	228	67
63	3,341.7	0.37	14.5	156,392.6	431.3	45	32	31
64	12,083.4	0.44	21.9	565,503.1	1,031.9	164	116	37
65	4,717.6	0.26	13.3	220,784.9	665.2	64	45	22
66	53,569.7	2.44	95.7	2,507,061.9	1,047.7	727	514	207
67	316,715.6	2.48	97.4	14,822,291.7	6,086.4	4,298	3,039	211
68	107,130.0	1.12	56.2	5,013,686.2	3,569.0	1,454	1,028	95
69	223,875.2	1.11	55.8	10,477,357.2	7,506.3	3,038	2,148	95
70	229,312.9	1.05	53.0	10,731,845.3	8,105.0	3,112	2,200	90
71	53,226.4	0.57	28.5	2,490,997.7	3,492.2	722	511	48
72	283,072.0	1.86	73.0	13,247,769.5	7,263.8	3,842	2,716	158
73	164,170.7	0.96	48.3	7,683,186.8	6,366.6	2,228	1,575	82
74	391,764.0	1.46	73.1	18,334,553.1	10,027.6	5,317	3,759	124
75	65,432.5	0.92	35.9	3,062,239.0	3,407.8	888	628	78
76	414,717.0	2.24	87.9	19,408,754.6	8,831.4	5,629	3,979	190
77	45,304.3	0.49	24.7	2,120,243.3	3,430.8	615	435	42
78	164,252.1	1.22	61.4	7,686,998.3	5,004.2	2,229	1,576	104
79	32,762.9	1.19	59.7	1,533,304.3	1,027.8	445	314	101
80	59,296.9	1.90	74.7	2,775,093.0	1,486.0	805	569	162
81	57,694.6	1.17	58.9	2,700,105.4	1,834.6	783	554	100
82	61,260.0	2.55	100.0	2,866,965.7	1,146.7	831	588	217
83	58,403.7	0.96	37.6	2,733,294.3	2,904.4	793	560	82
84	12,428.7	0.35	13.6	581,662.8	1,715.3	169	119	29
85	24,399.7	1.00	39.2	1,141,904.4	1,164.9	331	234	85
86	11,909.7	0.26	13.3	557,376.1	1,680.9	162	114	22

Site information continues on next page.

Site Number	Protocol 3 - TSS (lbs / yr)	Protocol 3 - TP (lbs / yr)	Protocol 4 - TN (lbs / yr)	Protocol 4 - TP (lbs / yr)	Total TSS (lbs/yr)	Total TN (lbs/yr)	TP (lbs/yr)
44	1,316	1.0	1.3	0.1	100,715.9	46.2	21.4
45	1,129	0.9	1.1	0.0	16,782.3	19.4	4.1
46	1,790	1.4	1.8	0.1	83,164.5	47.2	18.1
47	987	0.7	1.0	0.0	245,498.3	83.9	50.9
48	1,393	1.1	1.4	0.1	59,532.0	35.2	13.0
49	2,347	1.8	2.3	0.1	654,743.7	220.2	135.6
50	3,383	2.6	3.3	0.1	324,092.8	137.6	68.5
51	1,346	1.0	1.3	0.1	148,927.9	60.6	31.3
52	1,313	1.0	1.3	0.1	2,576.1	17.7	1.3
53	6,669	5.1	6.5	0.3	277,717.4	166.6	60.9
54	19,736	15.0	19.4	0.9	7,334,904.7	2,381.8	1,515.5
55	3,614	2.7	3.5	0.2	28,631.2	54.9	8.0
56	3,037	2.3	3.0	0.1	209,969.6	100.1	44.9
57	963	0.7	0.9	0.0	14,014.9	16.5	3.4
58	5,635	4.3	5.5	0.2	753,945.7	291.4	157.9
59	1,374	1.0	1.3	0.1	357,090.8	121.3	74.0
60	6,212	4.7	6.1	0.3	136,221.0	119.7	31.6
61	9,980	7.6	9.8	0.4	1,291,374.4	503.3	270.7
62	5,469	4.2	5.4	0.2	1,117,973.7	394.8	232.5
63	2,572	2.0	2.5	0.1	158,964.6	79.3	34.1
64	3,038	2.3	3.0	0.1	568,541.0	204.1	118.4
65	1,840	1.4	1.8	0.1	222,624.8	88.3	46.7
66	16,974	12.9	16.7	0.7	2,524,035.9	951.0	527.6
67	17,274	13.1	17.0	0.7	14,839,565.8	4,526.4	3,052.4
68	7,788	5.9	7.6	0.3	5,021,473.8	1,556.7	1,034.1
69	7,738	5.9	7.6	0.3	10,485,094.9	3,140.5	2,154.1
70	7,340	5.6	7.2	0.3	10,739,185.6	3,209.1	2,205.9
71	3,954	3.0	3.9	0.2	2,494,951.9	774.6	513.8
72	12,937	9.8	12.7	0.6	13,260,706.1	4,012.6	2,726.2
73	6,690	5.1	6.6	0.3	7,689,876.8	2,316.4	1,580.4
74	10,136	7.7	9.9	0.4	18,344,688.9	5,450.8	3,766.7
75	6,374	4.8	6.3	0.3	3,068,613.0	972.2	632.9
76	15,589	11.8	15.3	0.7	19,424,343.3	5,834.2	3,991.3
77	3,426	2.6	3.4	0.1	2,123,669.2	660.1	437.4
78	8,515	6.5	8.4	0.4	7,695,513.8	2,341.6	1,582.7
79	8,270	6.3	8.1	0.4	1,541,574.1	553.8	321.0
80	13,247	10.1	13.0	0.6	2,788,339.6	979.6	579.5
81	8,159	6.2	8.0	0.4	2,708,264.4	890.7	560.1
82	17,734	13.5	17.4	0.8	2,884,699.4	1,065.4	602.0
83	6,675	5.1	6.6	0.3	2,739,969.7	880.7	565.7
84	2,405	1.8	2.4	0.1	584,068.1	200.4	121.2
85	6,953	5.3	6.8	0.3	1,148,857.9	422.9	239.7
86	1,838	1.4	1.8	0.1	559,214.3	185.9	115.7

Site Number	Volume (ft^3 / yr)	Area Planted (acres)	Impervious Surface Acre Equivalent	Protocol 1 - TSS (lbs / yr)	Protocol 1 - TSS/site length (lbs/ft/yr)	Protocol 1 - TN (lbs / yr)	Protocol 1 - TP (lbs / yr)	Protocol 2 - TN (lbs / yr)
87	15,475.3	0.57	34.6	724,241.8	836.6	210	148	48
88	7,795.8	0.43	27.9	364,844.5	522.8	106	75	37
89	5,323.2	0.21	13.4	249,126.8	743.0	72	51	18
90	67,958.8	1.22	78.7	3,180,471.1	1,617.4	922	652	104
91	83,871.5	1.47	94.3	3,925,185.6	1,665.3	1,138	805	125
92	4,214.5	0.32	19.8	197,240.4	399.1	57	40	28
93	1,102.8	0.21	13.4	51,613.0	154.3	15	11	18
94	5,168.2	0.31	18.6	241,869.9	519.5	70	50	26
95	12,151.5	0.54	21.0	568,687.9	1,082.4	165	117	46
96	23,130.3	0.95	37.2	1,082,497.0	1,164.9	314	222	81
97	36,778.1	1.41	55.3	1,721,216.0	1,244.6	499	353	120
98	56,137.7	1.58	61.9	2,627,245.9	1,697.0	762	539	134
99	3,736.7	0.35	22.5	174,876.1	310.3	51	36	30
100	934.6	0.34	22.1	43,737.9	79.1	13	9	29
101	5,050.0	0.65	42.0	236,340.9	225.1	69	48	56
102	4,039.9	0.32	20.5	189,067.8	368.4	55	39	27
103	10,955.8	0.57	28.8	512,729.7	711.8	149	105	49
104	2,338.8	0.65	32.5	109,458.1	134.8	32	22	55
105	18,566.5	1.14	57.3	868,912.0	606.5	252	178	97
106	39,771.2	0.74	37.2	1,861,293.2	1,999.7	540	382	63
107	9,130.4	0.25	12.3	427,301.1	1,385.1	124	88	21
108	4,684.3	0.26	15.8	219,224.5	556.0	64	45	22
109	28,386.3	1.24	62.5	1,328,476.6	850.8	385	272	106
110	12,554.3	0.52	26.1	587,543.5	898.9	170	120	44
111	6,096.9	0.32	16.0	285,332.8	715.5	83	58	27
112	21,921.2	1.19	59.8	1,025,912.8	686.3	298	210	101
113	36,768.7	1.08	54.0	1,720,776.8	1,274.1	499	353	91
114	129,447.7	2.08	104.2	6,058,150.5	2,325.6	1,757	1,242	176
115	19,040.2	0.32	12.5	891,083.6	2,857.0	258	183	27
116	69,907.0	1.53	76.8	3,271,647.6	1,703.9	949	671	130
117	34,951.7	1.53	76.8	1,635,738.6	851.9	474	335	130
118	7,975.1	0.80	31.2	373,237.0	478.2	108	77	68
119	4,903.9	0.28	13.9	229,503.5	660.4	67	47	24
120	20,463.3	0.63	31.8	957,682.4	1,204.6	278	196	54
121	13,056.4	0.49	24.7	611,040.6	990.7	177	125	42
122	142,519.6	2.77	138.9	6,669,917.7	1,920.7	1,934	1,367	235
123	35,673.7	1.24	62.4	1,669,527.5	1,070.7	484	342	106
124	10,601.1	0.60	30.0	496,131.3	662.1	144	102	51
125	24,924.1	0.55	27.6	1,166,446.2	1,688.5	338	239	47
126	22,702.7	0.46	23.0	1,062,487.5	1,847.8	308	218	39
127	15,423.7	0.25	12.4	721,831.5	2,321.7	209	148	21
128	23,624.9	0.51	25.7	1,105,646.3	1,719.2	321	227	44
129	26,235.4	0.76	38.2	1,227,816.0	1,284.2	356	252	65

Site information continues on next page.

Site Number	Protocol 3 - TSS (lbs / yr)	Protocol 3 - TP (lbs / yr)	Protocol 4 - TN (lbs / yr)	Protocol 4 - TP (lbs / yr)	Total TSS (lbs/yr)	Total TN (lbs/yr)	TP (lbs/yr)
87	3,955	3.0	3.9	0.2	728,197.3	262.2	151.6
88	3,021	2.3	3.0	0.1	367,865.5	145.7	77.2
89	1,452	1.1	1.4	0.1	250,578.5	91.4	52.2
90	8,513	6.5	8.4	0.4	3,188,984.4	1,034.7	658.8
91	10,204	7.8	10.0	0.4	3,935,390.0	1,273.0	812.9
92	2,258	1.7	2.2	0.1	199,498.4	87.0	42.2
93	1,449	1.1	1.4	0.1	53,061.6	34.1	11.7
94	2,127	1.6	2.1	0.1	243,997.2	98.2	51.3
95	3,727	2.8	3.7	0.2	572,414.7	214.1	119.6
96	6,592	5.0	6.5	0.3	1,089,088.7	400.9	227.2
97	9,810	7.5	9.6	0.4	1,731,025.9	628.6	360.7
98	10,982	8.3	10.8	0.5	2,638,227.5	906.8	547.4
99	2,440	1.9	2.4	0.1	177,316.1	82.9	37.8
100	2,394	1.8	2.3	0.1	46,132.0	44.3	10.9
101	4,545	3.5	4.5	0.2	240,886.3	128.5	52.1
102	2,222	1.7	2.2	0.1	191,289.7	84.1	40.5
103	3,993	3.0	3.9	0.2	516,722.7	201.4	108.3
104	4,502	3.4	4.4	0.2	113,960.0	91.1	26.1
105	7,942	6.0	7.8	0.3	876,853.7	356.8	184.5
106	5,160	3.9	5.1	0.2	1,866,453.2	607.9	385.7
107	1,710	1.3	1.7	0.1	429,011.3	146.5	89.0
108	1,802	1.4	1.8	0.1	221,026.1	87.3	46.4
109	8,656	6.6	8.5	0.4	1,337,132.3	499.5	279.3
110	3,623	2.8	3.6	0.2	591,166.8	218.2	123.4
111	2,211	1.7	2.2	0.1	287,543.6	111.9	60.3
112	8,287	6.3	8.1	0.4	1,034,199.9	406.9	217.0
113	7,487	5.7	7.3	0.3	1,728,263.9	597.8	358.8
114	14,441	11.0	14.2	0.6	6,072,591.5	1,947.4	1,253.5
115	2,212	1.7	2.2	0.1	893,295.9	287.6	184.4
116	10,644	8.1	10.4	0.5	3,282,291.8	1,089.2	679.2
117	10,644	8.1	10.4	0.5	1,646,382.3	614.8	343.9
118	5,536	4.2	5.4	0.2	378,773.2	181.3	81.0
119	1,926	1.5	1.9	0.1	231,429.8	92.0	48.6
120	4,407	3.3	4.3	0.2	962,089.6	335.9	199.9
121	3,419	2.6	3.4	0.1	614,459.8	222.3	128.0
122	19,251	14.6	18.9	0.8	6,689,168.8	2,188.3	1,382.8
123	8,644	6.6	8.5	0.4	1,678,171.6	598.2	349.2
124	4,154	3.2	4.1	0.2	500,285.1	198.7	105.0
125	3,829	2.9	3.8	0.2	1,170,275.7	388.8	242.2
126	3,188	2.4	3.1	0.1	1,065,675.1	350.2	220.4
127	1,723	1.3	1.7	0.1	723,554.9	232.1	149.4
128	3,565	2.7	3.5	0.2	1,109,211.4	367.7	229.5
129	5,300	4.0	5.2	0.2	1,233,116.2	426.0	256.0

Site Number	Volume (ft^3 / yr)	Area Planted (acres)	Impervious Surface Acre Equivalent	Protocol 1 - TSS (lbs / yr)	Protocol 1 - TSS/site length (lbs/ft/yr)	Protocol 1 - TN (lbs / yr)	Protocol 1 - TP (lbs / yr)	Protocol 2 - TN (lbs / yr)
130	31,011.4	0.55	27.7	1,451,335.0	2,094.6	421	298	47
131	30,172.1	0.66	33.2	1,412,054.3	1,702.9	409	289	56
132	20,249.8	0.80	31.4	947,692.8	1,206.2	275	194	68
133	50,117.9	1.00	50.4	2,345,516.2	1,860.5	680	481	85
134	20,073.3	0.41	20.6	939,432.3	1,827.0	272	193	35
135	27,964.1	0.70	35.0	1,308,719.1	1,495.2	380	268	59
136	5,311.1	0.19	9.3	248,560.9	1,064.0	72	51	16
137	18,410.0	0.72	28.1	861,587.3	1,228.0	250	177	61
138	21,188.2	0.65	32.7	991,609.7	1,212.7	288	203	55
139	22,934.0	0.81	40.5	1,073,310.4	1,061.0	311	220	68
140	25,916.2	0.34	17.0	1,212,878.1	2,855.2	352	249	29
141	219,236.8	2.34	117.3	10,260,281.0	3,499.9	2,975	2,103	199
142	9,477.0	0.67	33.7	443,523.7	525.8	129	91	57
143	1,926.2	0.14	7.3	90,144.8	495.8	26	18	12
144	7,904.4	0.37	18.4	369,927.6	802.6	107	76	31
145	1,657.9	0.22	10.9	77,589.3	284.7	23	16	18
146	3,286.2	0.74	37.1	153,793.3	165.7	45	32	63
147	19,715.6	1.21	60.7	922,689.1	608.1	268	189	103
148	4,178.1	1.35	67.9	195,533.4	115.1	57	40	115
149	419.0	1.20	60.3	19,610.6	13.0	6	4	102
150	252.6	0.88	44.1	11,823.2	10.7	3	2	75
151	3,992.5	0.61	37.0	186,848.1	201.8	54	38	52
152	1,327.0	0.69	42.3	62,102.8	58.7	18	13	59
153	5,605.1	0.56	36.0	262,316.8	291.7	76	54	48

Site Number	Protocol 3 - TSS (lbs / yr)	Protocol 3 - TP (lbs / yr)	Protocol 4 - TN (lbs / yr)	Protocol 4 - TP (lbs / yr)	Total TSS (lbs/yr)	Total TN (lbs/yr)	TP (lbs/yr)
130	3,841	2.9	3.8	0.2	1,455,176.2	471.6	300.6
131	4,597	3.5	4.5	0.2	1,416,651.0	470.2	293.2
132	5,573	4.2	5.5	0.2	953,265.9	348.4	198.8
133	6,989	5.3	6.9	0.3	2,352,505.0	772.4	486.4
134	2,850	2.2	2.8	0.1	942,282.8	310.1	194.9
135	4,852	3.7	4.8	0.2	1,313,571.4	443.6	272.2
136	1,295	1.0	1.3	0.1	249,855.8	89.2	52.0
137	4,977	3.8	4.9	0.2	866,563.8	315.5	180.6
138	4,533	3.4	4.4	0.2	996,142.7	347.4	206.9
139	5,608	4.3	5.5	0.2	1,078,918.3	385.3	224.5
140	2,355	1.8	2.3	0.1	1,215,233.0	382.8	250.5
141	16,251	12.4	16.0	0.7	10,276,532.5	3,189.9	2,116.4
142	4,677	3.6	4.6	0.2	448,200.3	190.3	94.7
143	1,008	0.8	1.0	0.0	91,152.6	39.4	19.3
144	2,555	1.9	2.5	0.1	372,482.6	141.0	77.9
145	1,511	1.1	1.5	0.1	79,099.9	42.4	17.1
146	5,146	3.9	5.1	0.2	158,939.4	112.5	35.7
147	8,412	6.4	8.3	0.4	931,100.9	378.6	195.9
148	9,415	7.2	9.2	0.4	204,948.6	180.9	47.6
149	8,356	6.4	8.2	0.4	27,966.4	115.9	10.7
150	6,116	4.6	6.0	0.3	17,938.9	84.1	7.3
151	4,230	3.2	4.2	0.2	191,078.6	110.0	41.7
152	4,835	3.7	4.7	0.2	66,937.8	81.8	16.6
153	3,894	3.0	3.8	0.2	266,210.7	127.5	56.9