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Year 2 Summary Report

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November 2019

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Cover photo taken at Bavon Beach in October 2019

1 Introduction

1.1 Project Goals

The Coastal Zone Management program, through NOAA grants, has funded several projects that have reviewed design considerations and monitored living shoreline systems for effectiveness at both shore protection and habitat enhancement. These studies presented data regarding the construction and performance of three living shoreline projects that were built between 1999 and 2003 in Maryland (Hardaway *et al*., 2007 and 2009) and were in part the basis for the "Living Shoreline Design Guidelines for Shore Protection in Virginia's Estuarine Environments" and the contractor training classes (Hardaway *et al*., 2017). In addition, extensive research has been done on the design and performance of breakwater systems around Chesapeake Bay (Hardaway & Gunn, 1991; 2010; 2011). Breakwater and beach systems are appropriate for medium to high energy shorelines along Chesapeake Bay and its tributaries.

Monitoring effectiveness of nature-based resilience projects such as those that use living shoreline management strategies is essential to have a better understanding of their performance over time. Living shoreline strategies can efficiently control shoreline erosion while providing water quality benefits and maintaining natural habitat and coastal processes, and though these ecosystem-based management systems have been the preferred alternative for stabilizing tidal shorelines in the Commonwealth of Virginia since 2011, a recent analysis has shown that between 2011 and 2016 only 24% of the permits granted for shore protection were considered living shorelines (ASMFC, 2016). These types of systems may be relatively new to many landowners and some managers who may not be convinced about the long-term success of the systems for shore protection and their maintenance. Research has been performed on the effectiveness of created beaches and marsh habitats, but long-term studies of their efficacy for shore protection in Chesapeake Bay from a design and construction perspective are relatively few.

The present project seeks to build upon and expand monitoring efforts of sills and headland breakwater systems in Chesapeake Bay to determine effectiveness of shore protection and habitat creation and stability through time using a detailed site assessment and survey of five sites (Figure 1-1) including Aquia Landing, Bavon, Kingsmill, Virginia Institute of Marine Science (VIMS), and Yorktown. In addition, referencing the latest research results of migration and accretion of beaches and marshes in Chesapeake Bay, the project will seek to determine what elements make these successful over the short and longer terms.

A second goal of the present project was to determine the coastal habitat response of created wetlands and beaches at living shorelines in the face of sea-level rise. Using a detailed elevation survey of each site and the U.S. Army Corps of Engineers climate change adaptation sea-level rise scenarios, the whole system will be reviewed to study response to these changes in water level through time. Typically, shore protection structures are built in front of eroding banks that input sediment to Chesapeake Bay and provide limited subtidal habitat. Systems that are constructed in front of eroding upland banks have a ”backstop” up which these created intertidal habitats may not be able to migrate as sea level rises. This affects their long-term performance. The collected data will be used to project impacts of sea level rise through time on the structures, the upland banks, and created marshes and beaches to determine adaptive management strategies for these sites. These adaptive management strategies could be in the form of strategically adding rock and sand to the existing cross-section to address increased future water levels and to maintain the living shoreline benefits through time. Determining how resilient these systems will be in the face of climate change requires understanding how these systems functioned in the past.

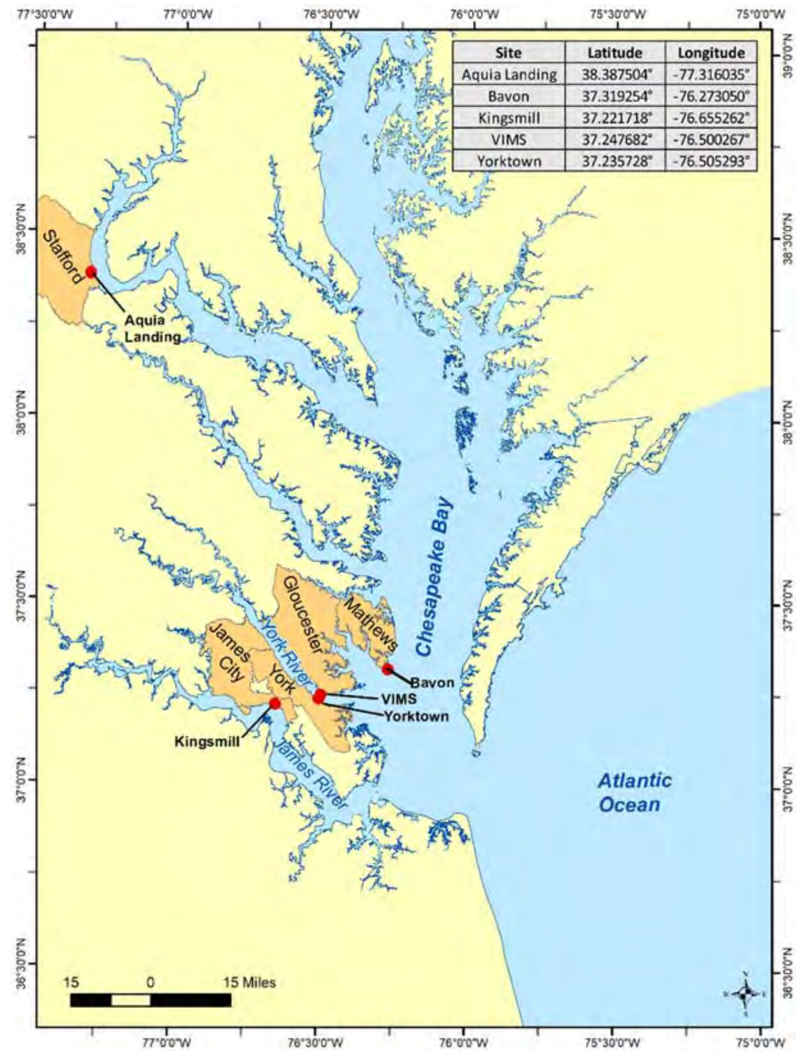


Figure 1-1. Location of breakwater sites assessed for this project.

1.2 Coastal Resiliency

Coastal resiliency is the ability to bounce back after hazardous events, such as hurricanes, coastal storms, and flooding, all of which are exacerbated by sea-level rise. Management practices in place today dictate how effective these strategies will be in the future. Understanding where and how shorelines are vulnerable to loss from coastal hazards, and adapting planning and development practices to compensate for these vulnerabilities will ultimately result in better shoreline management practices. Coastal salt marsh wetlands are particular vulnerable to even the smallest amount of sea level rise. Coastal wetlands are critical habitat for commercial and recreational fish and invertebrate species. Loss of these wetlands through sea level rise could pose a real threat to coastal economies and water quality if they are lost. Planning for sea level rise today can preserve inundated lands and allow coastal wetlands to migrate inland and maintain their essential functions for the community.

Coastal resiliency of shoreline protection measures is often couched in terms of habitat impacts, diversity and the change in habitat from before the measure was installed. Stone revetments are better than bulkheads, but living shorelines are better than revetments from a habitat perspective. However, measures to provide shoreline erosion control must be robust enough, designed for a certain level of protection, and now for a given scenario of sea level rise. The USACE has developed scenarios for this (Figure 1-2). In 2050, at the intermediate rate for SLR, sea level will be about 1.1 feet above present levels and at the high rate, sea level with 2.1 feet above present levels.

Because most of the sites selected for survey and assessment were constructed some time ago, they have been impacted in varying degrees by ongoing sea level rise. The amount of sea level rise since each sites installation from oldest to youngest are:

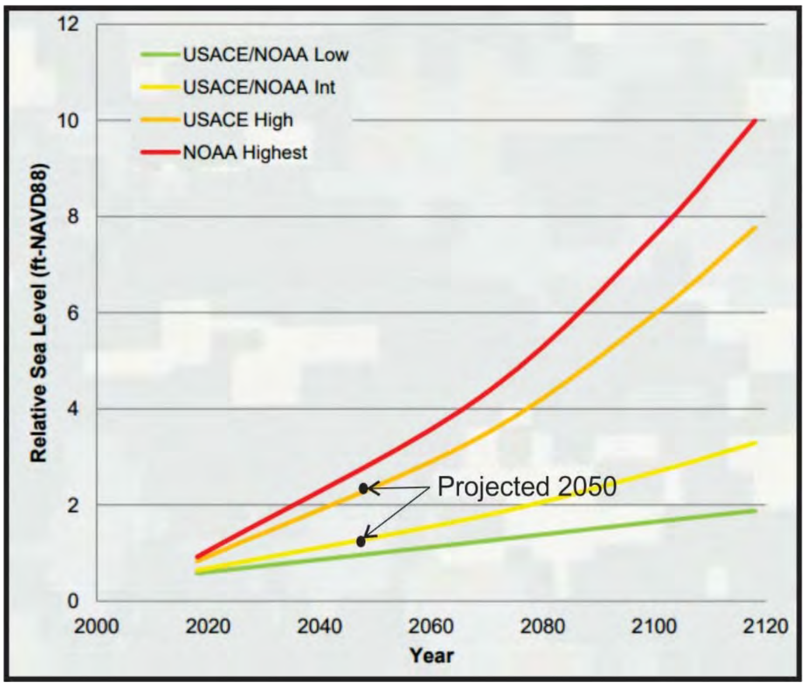


Figure 1-2. Sea-level rise predictions from the U.S. Army Corps of Engineers (2014).

1) Aquia Landing, installed in 1987, SLR = 0.33 ft. Reference: Washington DC
2) Yorktown, first phase installed in 1995, SLR =0.33 ft, Reference: Yorktown CGS
3) Kingsmill, installed in 1996, SLR = 0.3 ft, Reference: Sewells Point
4) VIMS, installed in 2010, SLR = 0.16 ft, Reference: Yorktown CGS
5) Bavon, installed in 2016, SLR = 0.05 ft, Reference: Yorktown CGS

Reference stations are NOAA tide gauge stations in Chesapeake Bay at Sewells Point, Yorktown Coast Guard Station, and Washington DC.

Few researchers have looked at the "long" term maturity of headland breakwater and sill systems and what that means to both habitat function and shore protection. Numerous recent studies have looked at relatively new projects, less than 10 years old, including Burke *et al.* (2005), Bilkovic and Mitchell (2013), and Bosch *et al.* (2006). Bilkovic and Mitchell (2017) stress the habitat component as essential along with shore protection. Accordingly, living shoreline designs should maintain or enhance sedimentation and accretion which promotes increased ecosystem function longevity with sea-level rise. Also necessary is that the projects have a robust maintenance program to address issues like invasive species and shading which is often not the case.

The SLR curves presented (Figure 1-2) impact implementation strategies that can 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.

Site recommendations for the selected project shorelines, all of which are breakwater systems with rock, sand, and plants, with or without bank grading, suggest that rather than adding rock and sand to the system initially to accommodate some level of SLR, a plan should provide for future adaptation. Therefore, the most cost effective adoption of this philosophy of coastal resiliency is to protect low banks where bank grading costs are less and more gradual bank grades, such as a 4:1 slope rather than the minimal 2:1 slope, are practical. More gradual bank grades will allow the wetland component to migrate laterally landward more effectively. For ungraded and graded high banks, the projects are in more of a "coastal squeeze" situation. Here, addressing the vertical growth component is the only option unless the existing breakwater system is moved farther offshore to gain a lateral gradient. This would be difficult to permit and costly. The question becomes, when is it best to add rock and sand to the breakwater system? Should it be done initially at present day cost or sometime in the future when needed?

According to the USACE (2014), increased water levels will produce an increase in depth-limit wave height. 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 with smaller wind wave climates.

Recent research on salt marsh complexes along the Gulf and East Coast indicate that they may in fact be able to keep up with SLR under the right circumstances (Kirwan et al 2016). According to Kirwan *et al.* (2016), their meta-analysis of marsh elevation change indicate that marshes are generally building at rates similar to or exceeding historical sea level rise, and the process-base models predict survival under a wide range of future sea level scenarios. They argue that marsh vulnerability tends to be overstated because assessment methods often fail to consider biophysical feedback processes known to accelerate soil building with sea level rise, and the potential for marshes to migrate landward. Whether the small marsh fringes created as part living shoreline projects can keep up vertically is uncertain but protecting the bay edge from eroding is essential to their long term stability. Landward migration will depend on upland bank height and grading potential.

1.3 High Water Events

Two basic types of increased water level impact the shoreline: 1) short term (storm surge) and long term (relative sea level rise). Hurricane Isabel was the most significant storm in terms of water level since 1933. Hurricane Isabel impacted Chesapeake Bay on September 18, 2003 with record high storm surge and winds. Virtually all Chesapeake Bay shorelines were impacted. Those shorelines with open fetch exposures to the north, northeast, east, southeast, and south were especially effected due to the rotation of Isabel's winds from north to south during her passage. Hundreds, if not thousands, of shore protection systems were damaged or destroyed. Many shorelines around the Bay which had no shore protection were moved 10 to 30 feet landward due to storm surge and waves. Shore reaches with properly designed and constructed headland breakwater systems incurred varying degrees of damage from none to several feet of cut at the adjacent base of the upland banks

The Chesapeake Bay Breakwater Database Project has 42 sites that have been monitored at some level by the Shoreline Studies Program over the years (Breakwater Database). Although more Bay breakwater systems exist, the sites in the database were chosen because they were designed with regard to their site setting, impinging wave climate, and desired level of protection, *i.e.* the 25 year or 50-year storm event. Many projects are older than 10 years, and all were impacted by Hurricane Isabel. After Hurricane Isabel, Hardaway *et al*. (2006), Aquia Landing, Kingsmill, Van Dyke, and Yorktown were selected for detailed analysis of Isabel's impacts since the four sites were surveyed immediately prior to the storm. This provided an opportunity to physically determine shore changes that may result due to a major storm event that equaled the 1933 Hurricane in storm surge level. The hurricane of 1933 is the unofficial 100-year event that the Federal Emergency Management Agency (FEMA) has, until this point, used for a reference datum in Chesapeake Bay.

These four sites were mapped using a real-time kinematic global positioning system before and after the storm. The data were analyzed for changes in sand levels on the beach and nearshore as well as for any upland or backshore impacts from the storm. To better understand these changes, low-level vertical aerial photography, taken before and after the storm, were georectified and the shorelines digitized. At all sites, the breakwaters performed well allowing little overall change to beach systems. Since these sites were designed for 25 and 50 year storms, all were "overtopped" with the combination of surge and wave runup. The beach/upland interface at the two high bank sites (Kingsmill and Van Dyke) incurred varying degrees of bank scarping, but no bank failure while the two low backshore sites (Aquia Landing and Yorktown) saw sand washed over into adjacent roadways. Beach planforms adjusted bayward under storm conditions but returned to pre-storm position.

Hurricane Isabel directly impacted three of the five breakwater sites assessed for this project, and the storm's impacts were a primary cause that spurred funding for shore protection systems around the Bay, particularly at VIMS and later at Bavon. The Bavon breakwaters also was tied to the endangered tiger beetle beach habitat restoration. Although Isabel was arguably the worst storm to hit southeast Virginia since 1933, numerous lesser but still significant storm events have occurred since. Some notables include:

Sept. 1, 2006: Hurricane Ernesto; +6.5 MLLW storm surge with mostly easterly winds sustained at 40 knots, gusting to 60 knots.

November 11-14, 2009: NorIda; Northeast storm setting in for several days with peak surge of +7 ft MLLW on the 12th and 6 consecutive +5ft high water events.

August 27, 2011: Hurricane Irene; Storm surge +6.2 MLLW with NE to NW winds 40 knots gusting to 55 knots.

2 Headland Breakwaters

The type of living shoreline rock structures/system installed along the higher energy shorelines of Chesapeake Bay typically are breakwater systems which are beach and dune centric. Stone breakwaters are "free standing" structures designed to reduce wave action by attenuation, refraction, and diffraction before it reaches the upland region. Headland breakwaters maintain stable pocket beaches between the structures and a sand tombolo that attaches the structure to the shore. Attached or headland breakwaters require beach fill in order to provide long-term shoreline erosion control (Figure 2-1) because they are constructed in areas that are subject to more energetic conditions. System design considerations are upland runoff, bank geology, shoreline morphology, sedimentation, and aesthetics. Because of the impact of the structures on longshore drift, the potential impacts to adjacent shorelines must also be considered and minimized.

Natural sandy beaches between rocky headlands have been called a variety of names in the literature, related to the curved shape of the bay found at many coasts around the world. Because of their geometry, they have been called spiral beaches, crenulate-shaped bays, log-spiral and parabolic-shaped shorelines, headland bay beaches and pocket beaches. Extensive research on crenulate bays resulted in relating the equilibrium beach planform to maximum bay indentation and incident wave angle. The bay can be divided into the tangential reach and the updrift structure-shadow reach also known as the logarithmic spiral (Figure 2-2). The logarithmic spiral reach is affected most by wave diffraction around the updrift headland/structure. The tangential reach, which is slightly convex seaward of straight, is affected mostly by wave refraction and generally aligns with the dominant or net direction of wave approach. Hsu *et al.* (1989a & b) and Silvester and Hsu (1993) determined that defining the headland bay curvature through the log spiral method was not precise and should be replaced with empirical relationships. These relationships revolve around a static equilibrium bay.

Stone for breakwater units comes from rock quarries located along the Fall Line of Virginia and Maryland. Rock types can be granite, metamorphosed limestone, or dolomite. A tombolo (sand behind the breakwater) is an essential element in headland breakwater systems although the degree of sand attachment between breakwater unit and the shore can vary (Figure 2-1). In Chesapeake Bay, the tombolo often must be created with beach nourishment since the natural supply of sand generally is limited. Coarse sand is appropriate for constructed beaches in Chesapeake Bay. The mean grain size (D_{50}) for naturally occurring beaches in Chesapeake Bay is 0.5 mm as sampled at mean high water (MHW) at 225 locations (Hardaway *et al.* 2001). Surveys of intertidal beach slope for the same sites yielded a 12% grade or about 10:1.

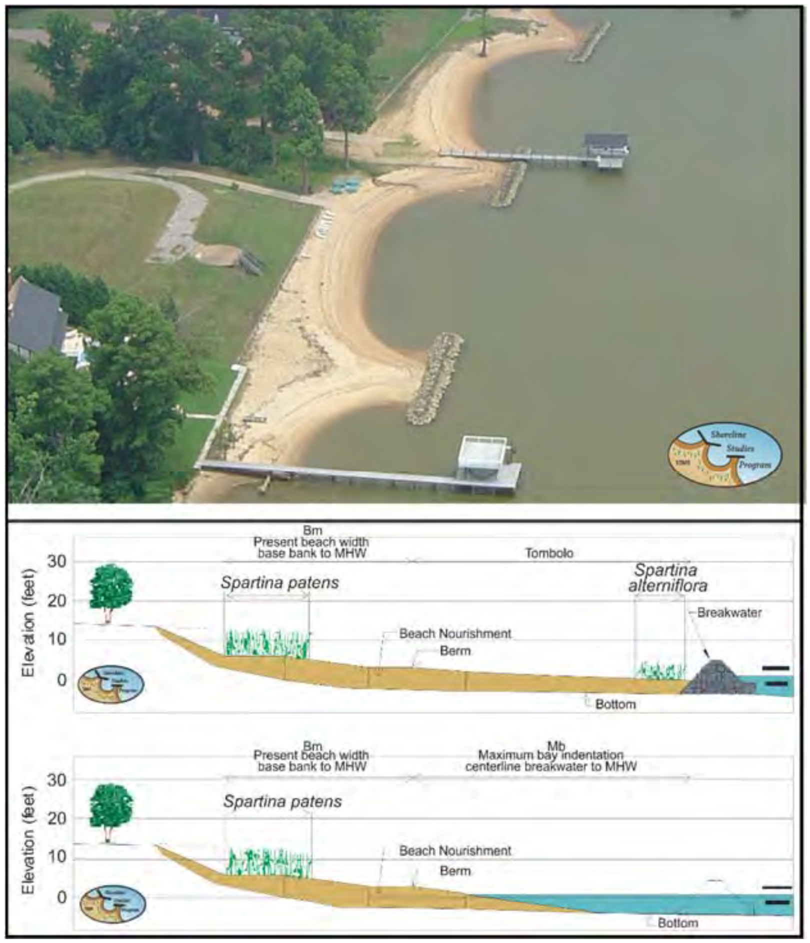


Figure 2-1. Top: First headland breakwater system built in 1985 at Drummond Field on James River. Bottom: Typical tombolo with breakwater and bay beach cross sections (after Hardaway and Byrne, 1999).

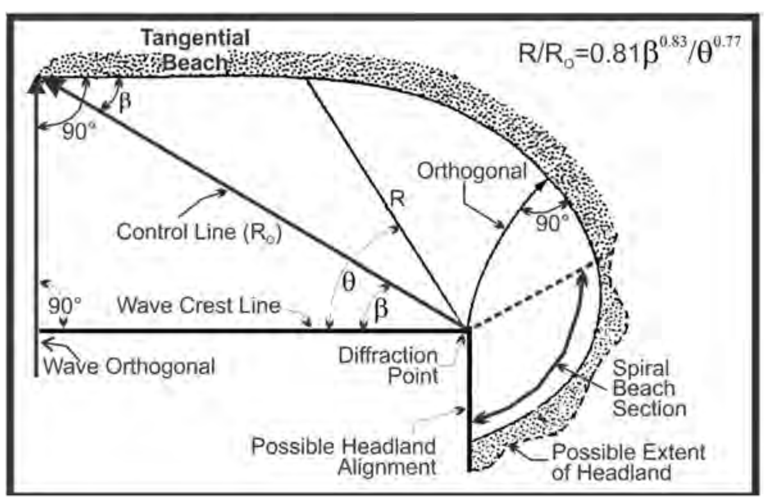


Figure 2-2. Parameters of the Static Equilibrium Bay (after Hsu et al., 1989) that are used to determine the shape of the embayments between headland breakwaters.

The dimensions of a breakwater system are dependent on the desired degree of protection and potential impacts on littoral processes. Hardaway and Gunn (2000) found that when breakwater length approaches double the design wave length, the structure can better hold a tombolo, particularly when the breakwater acts as a headland in multiple breakwater unit systems. The relationship between four specific headland breakwater system parameters were investigated by Hardaway *et al.* (1991) and Hardaway and Gunn (1991) for 35 breakwater embayments around Chesapeake Bay. Referring to Figure 2-3, these parameters include breakwater crest length, (LB), gap between breakwaters (GB), backshore beach width (Bm) and embayment indentation (Mb). The mid-bay backshore beach width and backshore elevation are important design parameters because they determine the size of the minimum protective beach zone in the headland breakwater system. This beach dimension often drives the bayward encroachment that is required for a particular shore protection design. Linear regression analyses were best for the relationship of Mb vs. GB with a correlation coefficient of 0.892. The ratio of these two parameters is about 1:1.65 and can be used as a general guide in siting the breakwater system for preliminary analysis. Then, the detailed bay shape can be determined. Stable relationships for Mb and GB are not valid for transitional bay/breakwater segments that interface the main headland breakwater system with adjacent shores. Numerous variations can occur depending on design goals and impinging wave climate. Hardaway and Gunn (2000) found that for 14 breakwater sites around the Bay, the Mb vs. Gb ratio varies in range and average for bimodal and unidirectional wind/wave settings. For unidirectional sites, the range of Mb:Gb can be 1:1.4 to 1:2.5 with an average of 1:1.8. Aquia Landing and Yorktown have average Mb:Gb ratios of 1:2.5 and 1:1.8, respectively. For bimodal sites, Mb:Gb ratios vary from 1:1.0 to 1:1.7 with an average of 1:1.6. Kingsmill has Mb:Gb ratios of 1:1.2.

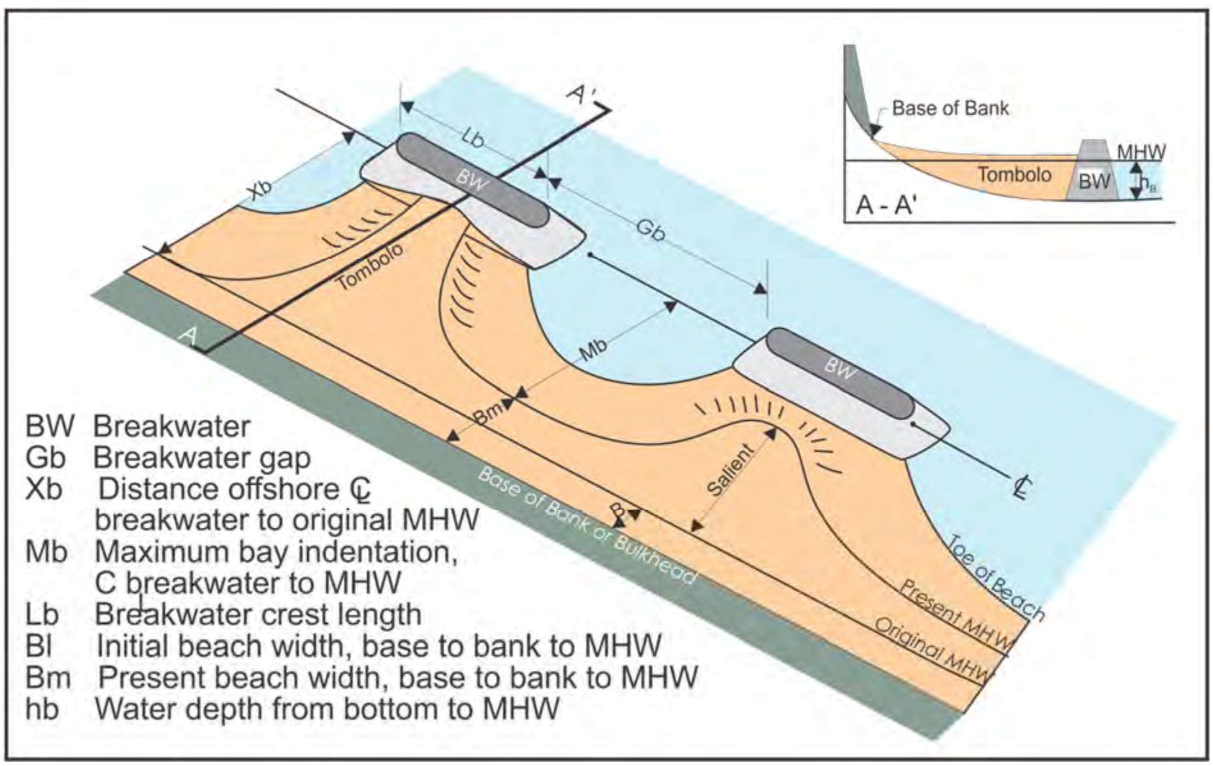


Figure 2-3. Breakwater design parameters (after Hardaway and Byrne, 1999).

3 Methods

In this second year, the research project examined medium to high energy shorelines (fetch 1-5 miles and > 5 miles respectively) along which breakwater systems have been built to create beach and dune habitat. By selecting sites that were recently installed as well as those that have been in place longer, both the short and longer-term shore protection effectiveness and changes in habitats were determined. A detailed site-specific assessment and survey was done to determine the condition of the upland bank and backshore barriers which will affect storm run-up and migration of the dune grasses and the width and elevations of the vegetation which will provide wave attenuation.

The site assessment includes type and condition of habitats including the marsh, dune, upland bank, riparian buffer, and in the nearshore. Where applicable, changes in submerged aquatic vegetation (SAV) will be determined from existing data available from the VIMS, SAV research group. SAV is important habitat for many shallow water species.

Using Real-Time Kinematic GPS and Robotic Total Station technology, five sites were surveyed for elevation and areal extent of habitat where possible. These sites were chosen for several reasons including site conditions, duration of the site, and existing data available. Several of these sites have as-built and some interim surveys that can be compared to the results of this project's surveys to determine existing conditions of the site and delineate habitats and how they have evolved. The sites include: VIMS (Figure 3-1); Yorktown Beach (Figure 3-2); Aquia Landing Beach (Figure 3-3); Kingsmill (Figure 3-4); and Bavon Beach (Figure 3-5).

Low-level vertical and oblique aerial images were acquired at all of these sites except Kingsmill to determine morphological changes over time. By selecting private and public properties, both high and low bank systems, the impact of sea-level rise was assessed using climate change adaptation sea-level rise scenarios. The site surveys were analyzed in GIS, and two sea level rise scenarios were assessed for a one and two-foot rise by 2050. The elevations of existing habitats and the shore planforms were assessed to determine the potential impacts as sea level rises and depicted on profile cross-sections.

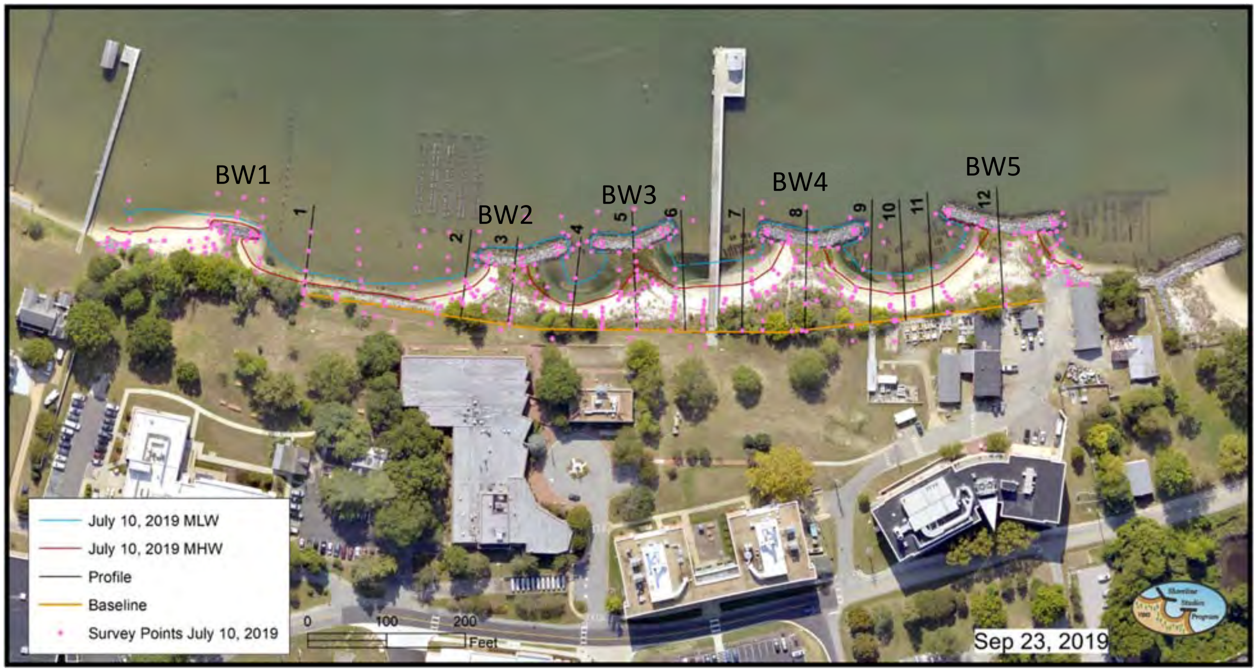


Figure 3-1. Data points collected at VIMS to determine elevation changes at the site since installation. Also shown are the measured mean high water and mean low water lines and the cross-sectional profiles exported for the project.

Figure 3-2. Data points collected at Yorktown to determine elevation changes at the site since installation. Also shown are the measured mean high water and mean low water lines and the cross-sectional profiles exported for the project.

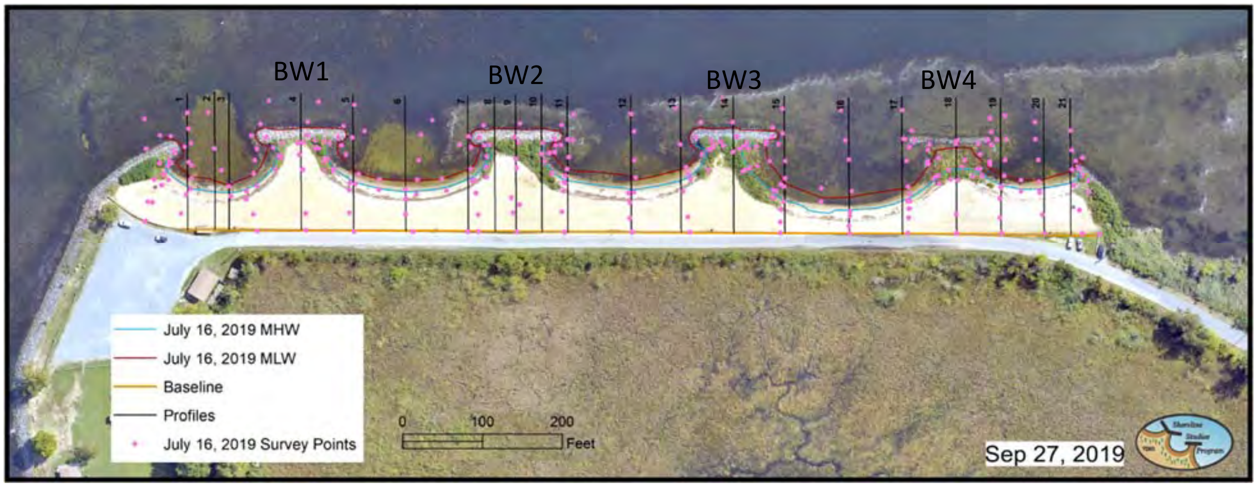


Figure 3-3. Data points collected to determine elevation changes at the site since installation. Also shown are the measured mean high water and mean low water lines and the cross-sectional profiles exported for the project.

Figure 3-4. Data points collected to determine elevation changes at the site since installation. Also shown are the measured mean high water lines and the cross-sectional profiles exported for the project.

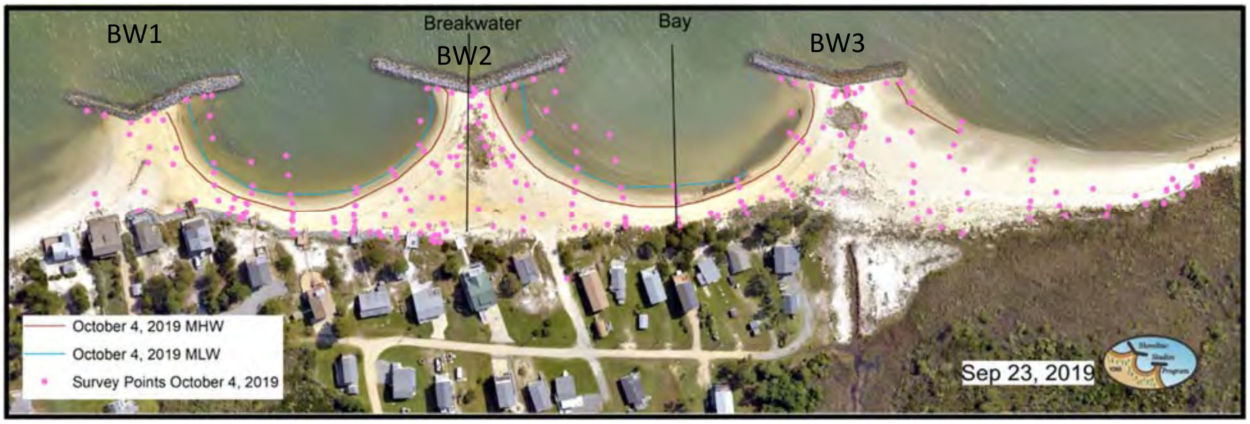


Figure 3-5. Data points collected at Bavon to determine elevation changes at the site since installation. Also shown are the measured mean high water and mean low water lines and the cross-sectional profiles exported for the project.

4 Site Background and Data

4.1 Virginia Institute of Marine Science, Gloucester County

The Virginia Institute of Marine Science is located at Gloucester Point, VA (Figure 4-1-1). VIMS was established in 1940 as the Virginia Fisheries Laboratory. The shoreline was an eroding high upland bank that was hardened with a concrete seawall in 1950 (Figure 4-1-2). As the Institute grew, the seawall was expanded alongshore (Figure 4-1-3). A narrow beach occurred along the shoreline but as the updrift shore was hardened, cutting off primary source of littoral sands, the beach narrowed (Figure 4-1-4). The April 1978 northeast storm event damaged the seawall and took away most what was left of the beach (Figure 4-1-5). A revetment was

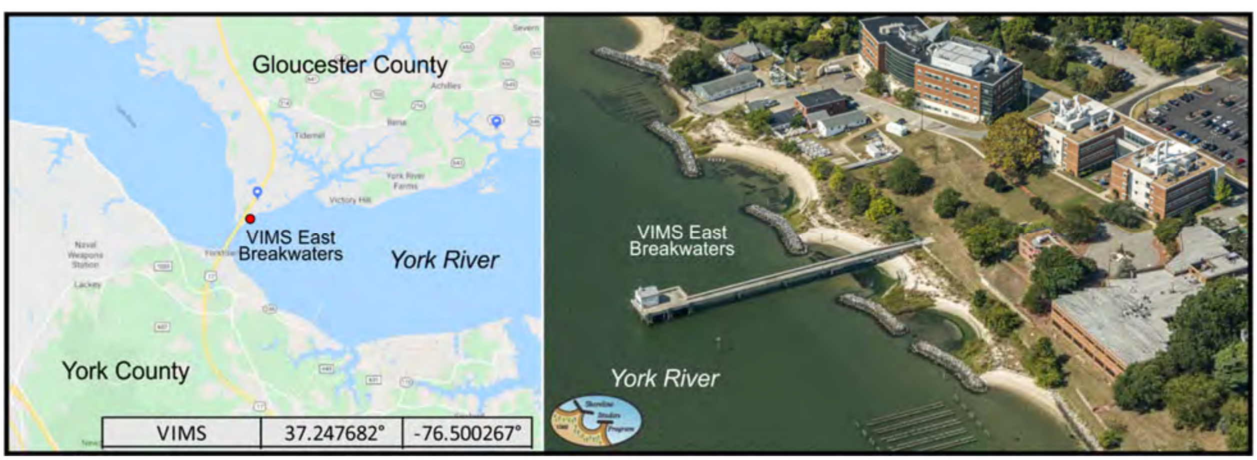


Figure 4-1-1. Left: Location of VIMS East breakwaters, and Right: Aerial image of breakwaters taken on 23 Sep 2019.

Figure 4-1-2. VIMS' first building and seawall at Gloucester Point in 1951.

Figure 4-1-3. By 1964, additional buildings had been constructed and the seawall was extended.

installed along the seawall in 1984 along with about 10,000 cubic yards (cy) of sand for a beach (Figure 4-1-6). By 2003, the nourished beach was significantly reduced by the time Hurricane Isabel hit, September 18, 2003 (Figure 4-1-7).

The VIMS shore protection system was conceptualized in 2002 and became a critical project after Isabel which resulted in significant impact to both VIMS East Coast and VIMS West Coast. After several iterations a conceptual plan was developed (Figure 4-1-8). The project was installed in 2010 and has since experienced several severe storms including Hurricane Irene on August 27, 2011.

Figure 4-1-4. Very little sand existed along the VIMS shoreline in 1970.

With time, the system has become more robust with the low marsh being replanted and expanding across the back and flanks of the breakwater tombolos (Figure 4-1-9). Though grasses were planted after breakwater installation, they had not taken hold behind the structures by 2013 (Figure 4-1-10). The breakwater 5 tombolo was relatively narrow. However, in 2019, all five structures are heavily vegetated, and sand is accreting along the updrift breakwater because sand movement along this section of shoreline is to the south. In addition, SAV has established itself in the embayments. It should be noted that the 2013 and 2019 MHW shorelines in the embayment between breakwater 4 and 5 are slightly landward of the 2003 post-Hurricane Isabel high water shoreline. Positioning of the structures and sand fill had to accommodate the established biological experiments located in the nearshore. As such, the gap between the structures was placed such that the minimal amount of fill would be placed near these experiments. This has not impacted the effectiveness of the system because the embayment is still wide enough that vegetation grows in the backshore to help hold the sand and should an extreme event occur, the embayment is backed by the seawall. The highest areas are along the backshore next to the seawall (Figure 4-1-11). Though the tombolo right adjacent to the pier is vegetated, it still does not have as much sand behind the structure as the other breakwaters.

Figure 4-1-5. Top: During the April 1978 northeast storm, waves directly impacted the seawall because VIMS had no sandy beach in front. Bottom: The storm damaged the seawall.

Figure 4-1-6. A revetment was installed and covered with beach fill along the shoreline to provide protection to the seawall.

Figure 4-1-7. In 2003, Hurricane Isabel greatly damaged many areas along the VIMS shoreline. Wave action overtopped the seawall and revetment cutting into the bank.

Figure 4-1-8. Shore protection plan designed for VIMS after Hurricane Isabel significantly impacted its shoreline.

Figure 4-1-9. VIMS shoreline in 2017.

Figure 4-1-10. Shoreline change between 2003 and 2019 at the VIMS breakwaters. The 2003 pre-installation date is shown for reference. The 2003 and 2013 shorelines are approximately mean high water based on the digitizer's best guess of the features shown. The 2019 shoreline is from the survey data.

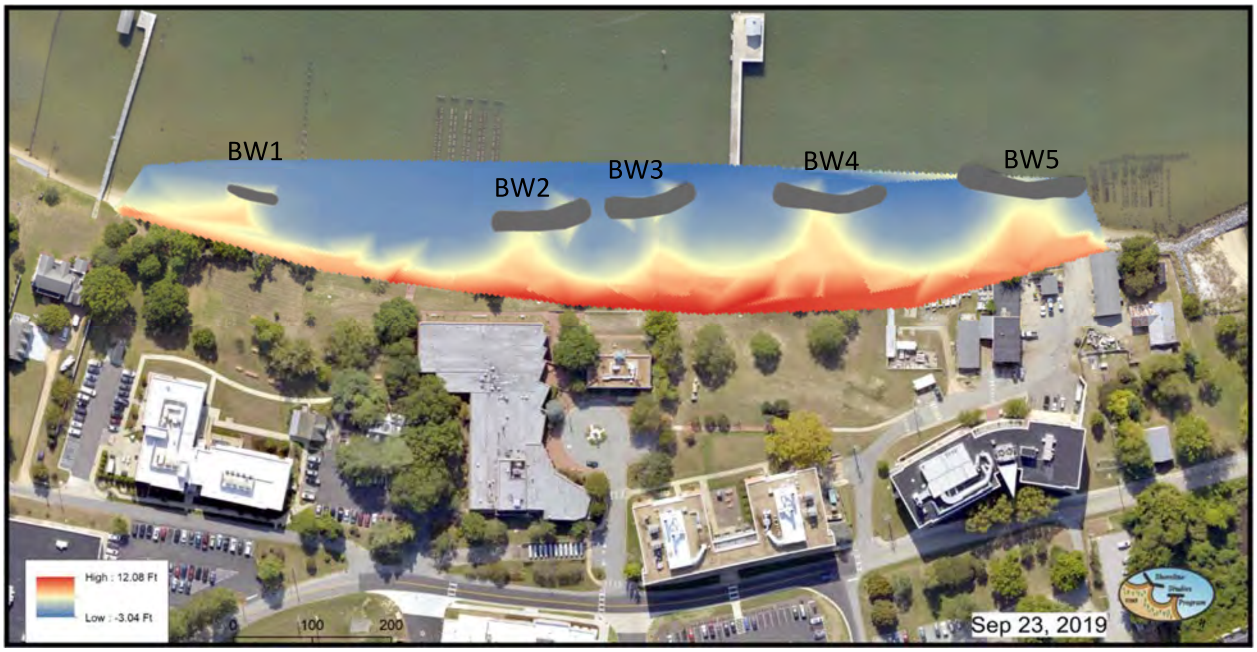


Figure 4-1-11. Digital elevation model of the collected survey points at VIMS.

4.2 Yorktown, York County

The Yorktown Public Beach is located on the south side of the York River in Yorktown, Virginia (Figure 4-2-1). It is approximately 1,200 feet in length. Historically, the beach was a product of erosion of nearby sandy upland banks and the littoral transport system. Over the years, the beaches along the waterfront began to narrow as the natural sediment supply was depleted by hardening of the updrift shorelines. Beaches were easily overwashed in storms, and they continued to erode. The nearshore closest to the Colman Memorial Bridge is very deep as the river narrows, and the channel under the bridge is naturally 90 ft deep. Downriver, the

Figure 4-2-1. Left: Location of Yorktown Beach breakwaters, and Right: Aerial image of breakwaters taken on 23 Sep 2019.

nearshore widens. Although the winter northwesters are strong, the long fetch to the east into the Bay and the shoreline morphology indicate an unidirectional wind/wave setting.

The history of the site, design guidelines, and performance of the Yorktown site over time has been documented in Milligan *et al.* (1996, 2005, & 2006), but a general summary is presented here. In 1978, York County installed a riprap revetment along its picnic area shore to the east end of Yorktown. This area had been filled in Colonial days to expand the warehousing facilities at the Port of Yorktown. After a damaging storm in November 1985, a small breakwater with beach nourishment was installed in order to maintain a storm water outfall. Subsequent renourishment occurred three years later, but the northeast storm in March 1993 severely eroded the shoreline (Figure 4-2-2).

Figure 4-2-2. Yorktown Beach shoreline on 4 March 1993 during a northeast storm.

In September 1994, York County installed Phase I of an offshore breakwater system which consisted of two shore-attached breakwaters. These breakwaters, 140 and 120 feet in length, were coupled with 7,500 cubic yards of beach fill and plantings of *Spartina alterniflora* and *Spartina patens* in the lee of the structure. The pre-existing breakwater was modified to interface the system on the downstream end and the 120-foot breakwater has a falling crest elevation to encourage wave refraction, and a winged breakwater was designed to achieve a reasonable interface with the adjacent shore and reduce potential wave force impacts during northeasters. In May 1996, approximately 600 cubic yards of sand was dredged from under the Coleman Bridge as part of the bridge widening project. This sand was subsequently used as beach fill on Yorktown Beach.

In the fall/winter of 1998-1999, Phase II of the Shore Erosion Control Plan was implemented along the shoreline. Two winged, headland breakwaters, 120 and 130 ft in length, were constructed downriver from the existing breakwaters. The small breakwater built in 1986 to stabilize the storm water outfall was removed in order to establish a better breakwater gap-to-bay indentation ratio for the new system. The storm water outfall pipe was relocated through one of the new breakwaters. In addition, approximately 10,000 cubic yards of sand was placed on the beach, and beach grasses were planted behind the structures.

Phase III of breakwater construction began in June 2000 (Figure 4-2-3). The completed project included three new breakwaters, beach fill along the Yorktown waterfront, and a revetment. Since then, the wharf where the old post office sat was removed. Two smaller breakwaters, 80 and 85 ft in length were positioned at the far west of the reach. A larger winged, headland breakwater, 150 ft in crest length, was installed as well, and beach grasses were planted behind it. The existing revetment on the upriver end of the site was repaired and a new section was added toward the west. Along with the breakwater construction, a new walkway adjacent to the Water Street was added. Since then, an additional two breakwaters have been built on the upriver end of the site, and in 2005, three more were constructed upriver and one more downriver.

Figure 4-2-3. Yorktown Beach shoreline on 13 Feb 2018.

The impacts of Hurricane Isabel were documented on Yorktown (Hardaway *et al.,* 2006). The beach was severely damaged because the low backshore and adjacent low bank allowed the storm surge to inundate the structures and the shoreline. However, the overall integrity of the system was maintained although some sand loss and local scour occurred. The system performed above expectations because the site was designed for a 50-year event. Since Hurricane Isabel, the Yorktown breakwater system has been impacted by Hurricane Irene, NorIda, Hurricane Ernesto and numerous lesser storm events and has remained very much intact. York County provides truck in sand annually and after storms, if needed, but these efforts are in the range of 500 cubic yards or so.

Today, the beach is wide and heavily used for recreation (Figure 4-2-4). The MHW shoreline is farther riverward than it was in 2004 and 2013 (Figure 4-2-5). This wide beach provides protection for infrastructure in the backshore because during high water events, the waves will break on the breakwaters or the beach before they cause damage. Highest elevations are located along the backshore and in the middle of the tombolos where the vegetation occurs (Figure 4-2-6).

Figure 4-2-4. A wide recreational beach exists at Yorktown Beach shoreline on 31 Jul 2019. Though the backshore is low, the beach provides protection to upland structures.

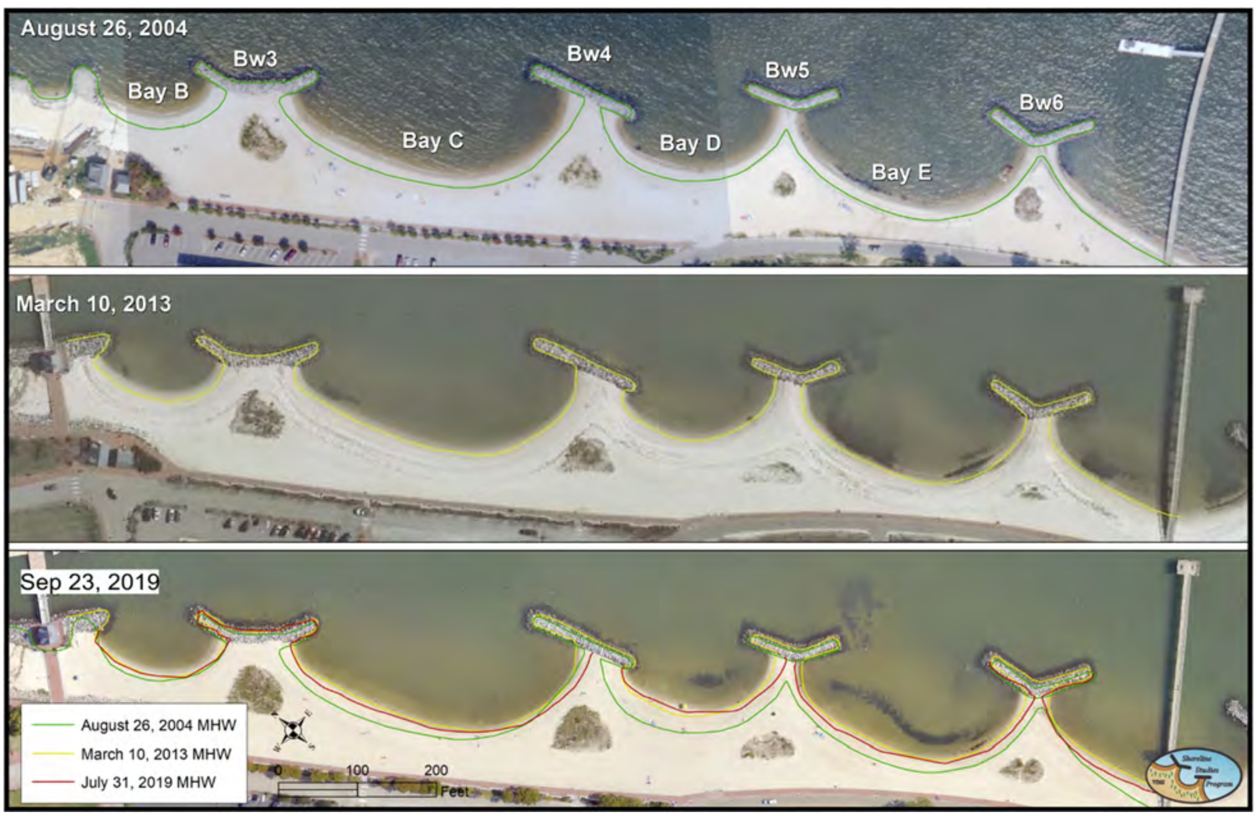


Figure 4-2-5. Shoreline change between 2004 and 2019 at the Yorktown breakwaters. The 2004 and 2013 shorelines are approximately mean high water based on the digitizer's best guess of the features shown on the aerial photo. The 2019 shoreline is from the survey data.

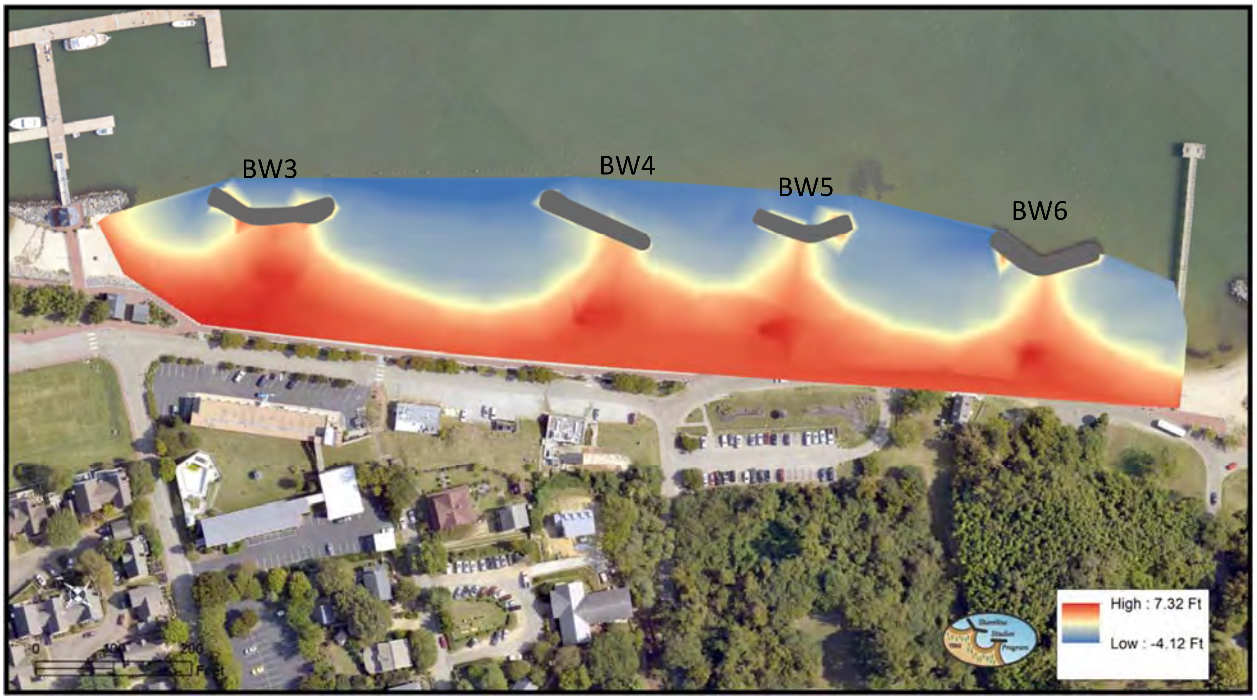


Figure 4-2-6. Digital elevation model of the collected survey points at Yorktown.

4.3 Aquia Landing, Stafford County

Aquia Landing is a county-owned public beach on the Potomac River in Stafford County, Virginia (Figure 4-3-1). Prior to the project installation, the county beach was severely deteriorated with failing groins and washovers across a very low upland shore zone (4-3-2). Long fetch exposures to the southeast of over 7 nautical miles (nm) and northeast of over 4 nm made the site vulnerable to storm damage. Dominant northwest wind-driven waves and northeasters create a generally unidirectional wave exposure coming down the Potomac River. A breakwater and beach fill project was installed in 1987; it covered 1,200 ft of shoreline and consisted of 700 ft of stone revetment, four 110 ft headland breakwaters with 20,000 cy of beach fill bounded on each end by spurs. The design utilized the shore morphology of the existing groin field to determine tangential beach orientation. The pocket beach configurations have been stable since installation. The overall purpose of the project was to provide shore protection, create a recreational beach, and reduce beach hazards from deteriorating groins.

The design and performance of the site was analyzed by Linden *et al.* (1991). They found that during the three years after the installation of the project, the overall volume of beach material within the monitoring area had not changed. The wide, flat, shallow nearshore has allowed submerged aquatic vegetation (SAV) to expand at the site in the last 10 years (VIMS SAV website). This has likely helped maintain a stable nearshore during storm events.

Figure 4-3-1. Left: Location of Yorktown Beach breakwaters, and Right: Aerial image of breakwaters taken on 23 Sep 2019.

Though the storm surge topped the system during Hurricane Isabel and sand washed over the jersey wall onto the road (Figure 4-3-3), no extreme changes in topography were measured indicating that overall, the breakwater system remained stable during the storm (Hardaway *et al.*, 2006). The beach along Aquia Landing has been relatively unchanged since Hurricane Isabel. The shore planform has remained relatively stable since Isabel except for the thinning of tombolo attachments which have not impacted the beach and backshore (Figure 4-3-4). A wide recreational beach occurs at the site. The tombolos are heavily vegetated and a great deal of SAV occurs in the nearshore. Some variation has occurred in the position of MHW over time (Figure 4-3-5), but it has been relatively minor. The position of the embayments post-Hurricane Isabel shoreline on October 30, 2003, were slightly shifted due to wind and wave action during the storm. The 2013 and 2019 high water shorelines are similar although the 2019 tends to be riverward of the 2013. The tombolo at breakwater 4 has lost its attachment over time as the structure itself sank. Though heavily vegetated, the breakwater 4 tombolo is lower than the others (4-3-6).

Figure 4-3-2. Aquia Landing shoreline on 11 March 1982 prior to the breakwater installation. Timber groins were becoming detached from the shoreline and were no longer effective shore protection.

Figure 4-3-3. Aquia Landing shoreline on 30 September 2003 post Hurricane Isabel. Though sand washed over the jersey wall, overall the system is intact.

Figure 4-3-4. A wide recreational beach exists at Aquia Landing shoreline on 16 Jul 2019.

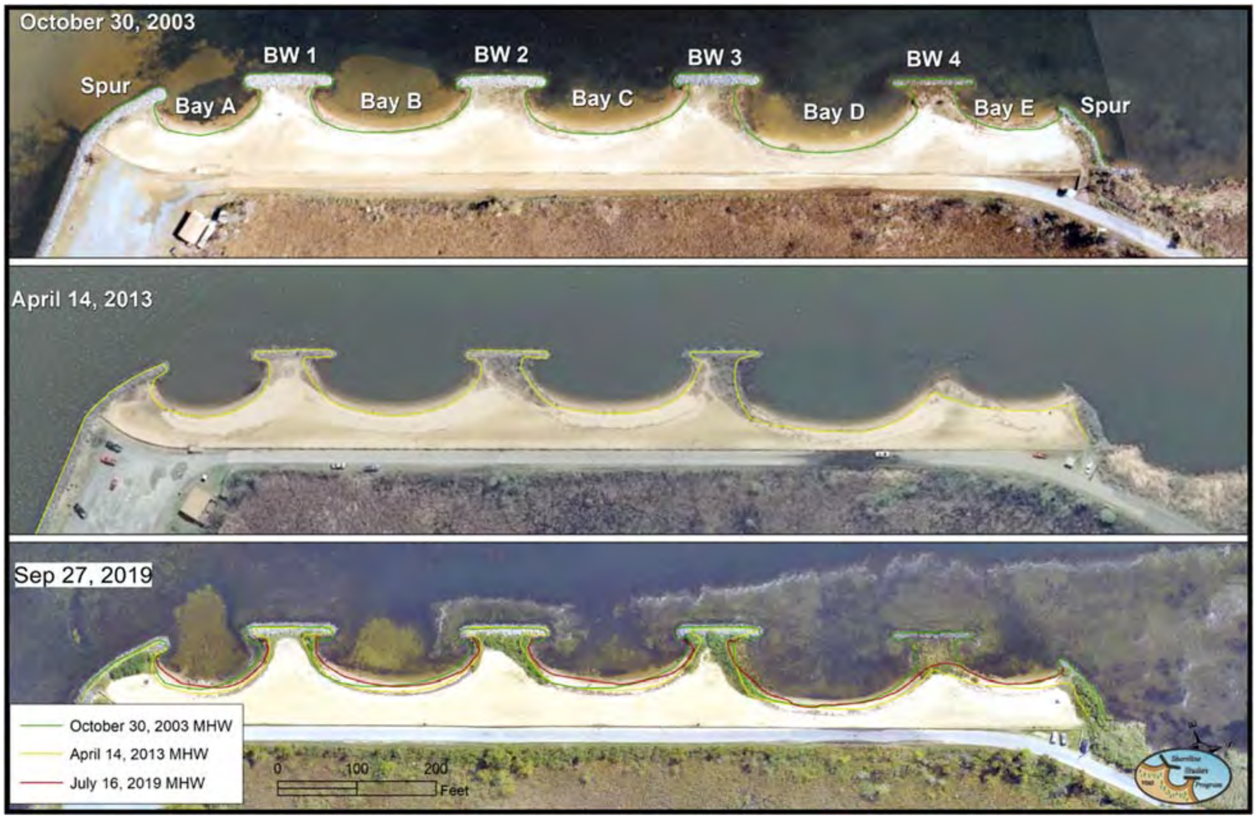


Figure 4-3-5. Shoreline change between 2003 and 2019 at the Yorktown breakwaters. The 2003 and 2013 shorelines are approximately mean high water based on the digitizer's best guess of the features shown on the aerial photo. The 2019 shoreline is from the survey data.

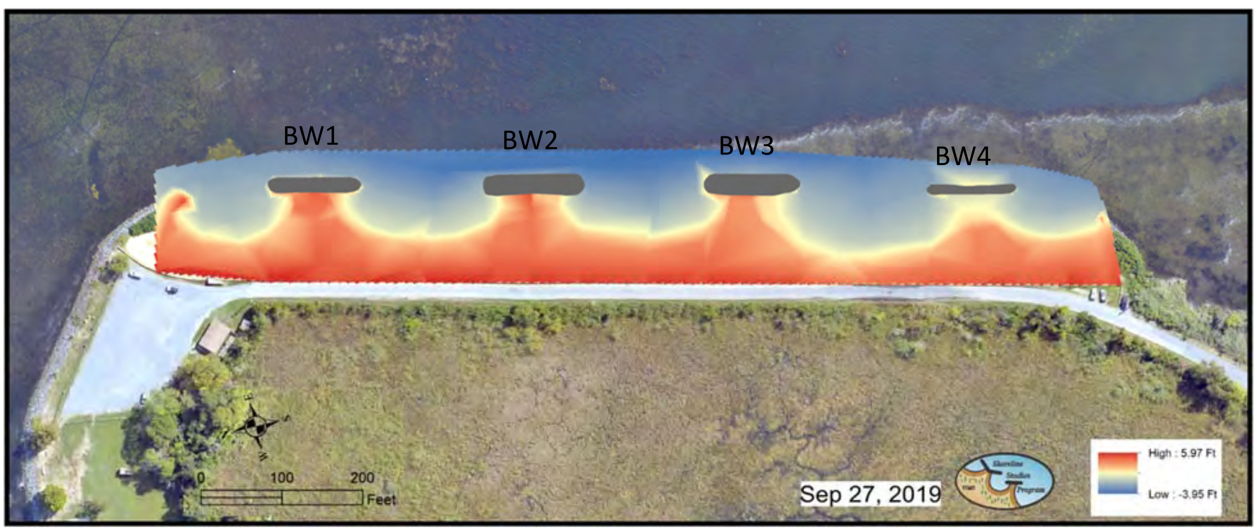


Figure 4-3-6. Digital elevation model of the collected survey points at Aquia Landing.

4.4 Kingsmill, James City County

Kingsmill is located on the north shore of the James River in James City County, Virginia (Figure 4-4-1). It is a privately owned site that had chronic bank erosion and has a long fetch exposure to the south of over 12 miles and the southwest of over 5 miles (Figure 4-4-2). Wind frequencies from these directions are about the same, and the site occurs in what is considered a bimodal wind/wave setting. The developer of the upscale residential community wanted shore erosion control with environmental edge so a 2,800 ft breakwater system was installed in 1996. It consisted of six headland breakwaters ranging in size from 115 ft to 210 ft, a 110 ft low breakwater and a 170 ft revetment for boundary interfacing structures, beach fill, and wetlands plantings, all of which were designed for a 50-yr storm event. The site's seventy-foot-high banks had little sand and posed potential upland drainage problems. The design routed upland drainage to an adjacent marsh, and low swales in the bank were used to allow storm water to diffuse through a vegetated beach fill. Beach fill was obtained from an upland borrow pit. The overall purpose of the project was to provide shore protection and habitat enhancement.

Though Hurricane Isabel was a significant event for this site and measurable bank erosion occurred, overall erosion of the upland bank was minimized by the heavily vegetated backshore (Hardaway *et al.*, 2006). The beach swiftly returned to its pre-storm conditions.

The shoreline is similar today with heavily vegetated tombolos and backshore and stable embayments (Figure 4-4-3). Post Hurricane Isabel, the tombolo attachment behind the breakwaters was lost (Figure 4-4-4). However, over time, sand accumulated behind the structures, particularly breakwaters 3 and 4, and became vegetated. Breakwaters 5 and 6 are still subaerially attached

Figure 4-4-1. Left: Location of Kingsmill breakwaters, and Right: Google Earth image of breakwaters taken in May 2018.

Figure 4-4-2. Kingsmill shoreline June 1996 prior to breakwater installation.

Figure 4-4-3. Stable embayment along the Kingsmill shoreline in 2019.

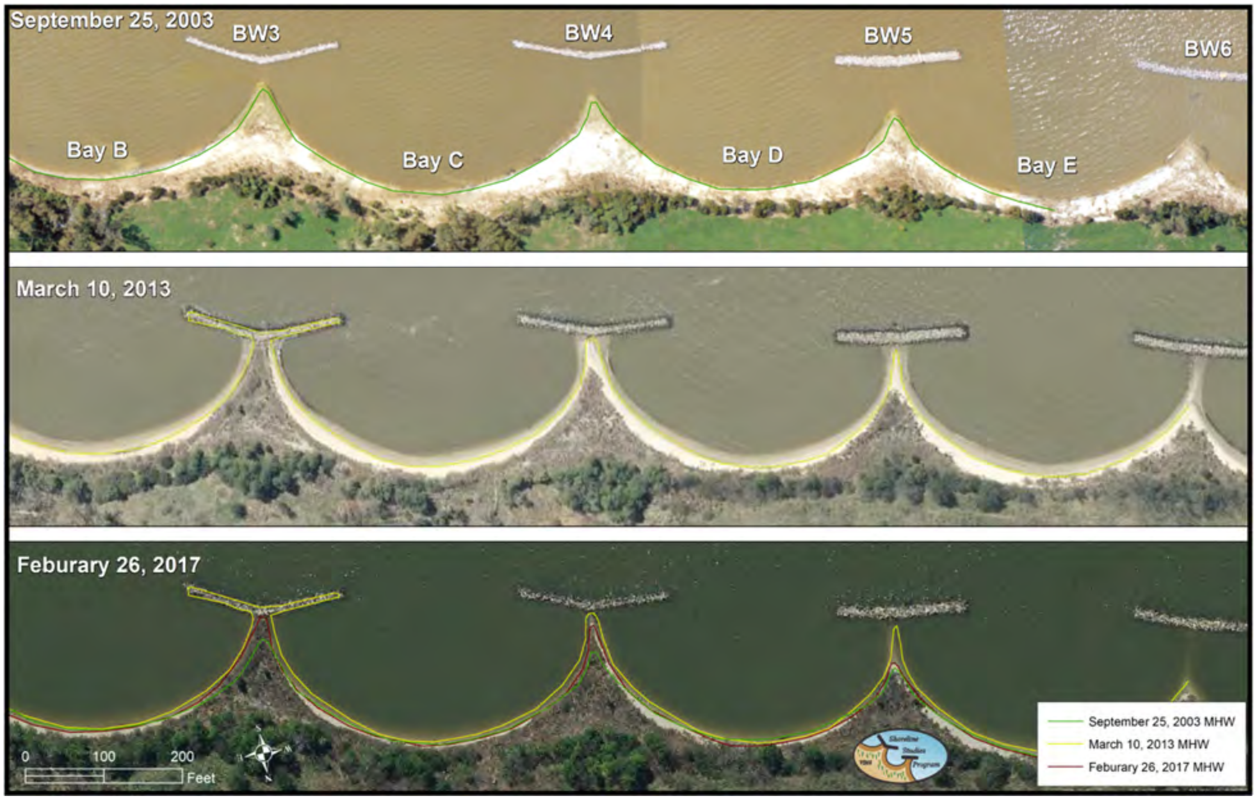


Figure 4-4-4. Shoreline change between 2003 and 2017 at the Yorktown breakwaters. The shorelines are approximately mean high water based on the digitizer's best guess of the features shown on the aerial photo.

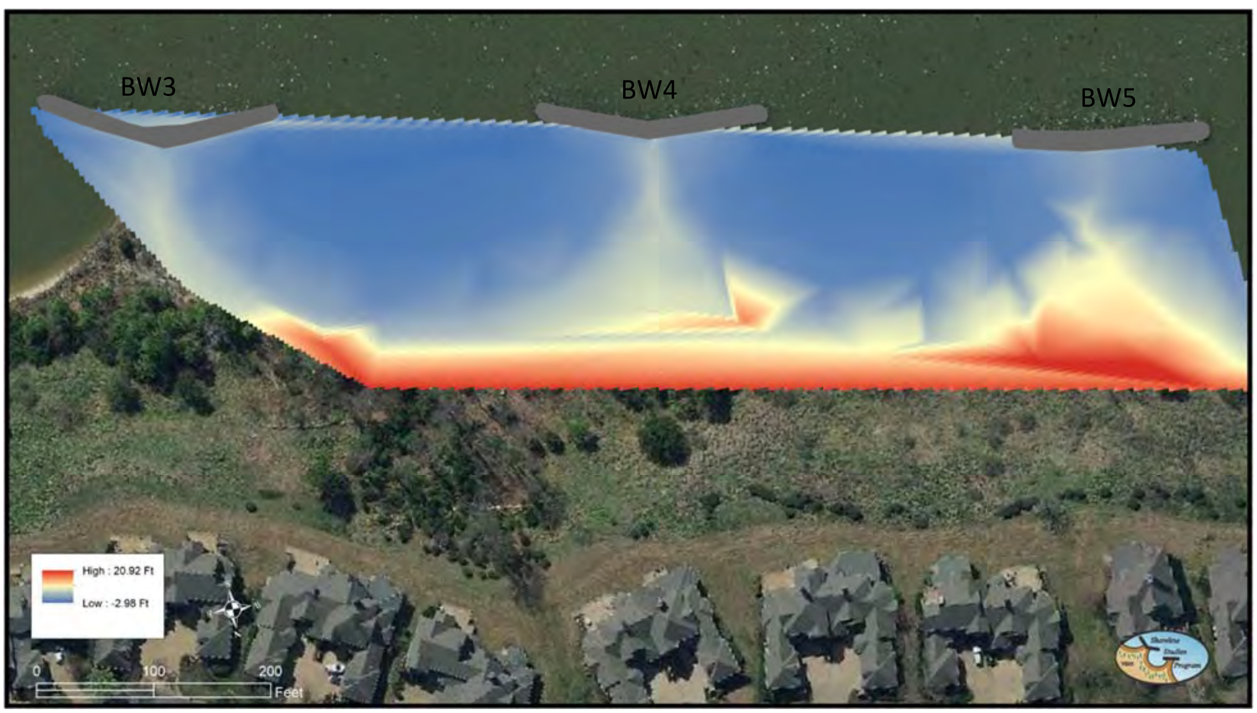


Figure 4-4-5. Digital elevation model of the collected survey points at Kingsmill.

4.5 Bavon Beach, Mathews County

Bavon Beach is located along the Chesapeake Bay in Mathews County, VA (Figure 4-5-1). Though the breakwater project was not installed until 2016, this site was monitored for many years as Chesapeake Bay Dune Site MA3 (Milligan *et al*., 2005; O'Brien *et al*., 2009; Milligan *et al*., 2013). The shoreline is an open Bay coast that has a low upland bank and residential properties sit immediately adjacent to the coast. Its morphology is of a Bay barrier system with dunes, beaches, and nearshore bar system (Figure 4-5-2). The shoreline position and stability is linked to the nearshore bar system that migrates along the shoreline depending on wind and wave events. South of the breakwaters is New Point Comfort which has had dramatic shifts in position. Once attached to the mainland, the lighthouse at New Point Comfort, constructed in 1805, has since been stranded on its own island in the Bay (Figure 4-5-1).

The Chesapeake Shores/Bavon Beach shore reach was significantly impacted by storms since monitoring began including those listed in Section 1.3 as well as Hurricane Sandy in October 2012 (Figure 4-5-3). The beach and dune system along the north half of the reach remained fairly well intact between 2001 and 2013 (Figure 4-5-3, top). The southern reach was particularly impacted as eroded beach sands were driven south with very little returning via northerly alongshore transport. As a result, several revetments were constructed along the subreach to protect houses exposed on the shoreline (Figure 4-5-4). Finally, in 2016, the breakwater system was constructed and consisted of 3 breakwaters with significant sand nourishment. Though the system has not weathered significant storms, overall, it has maintained its system integrity by maintaining tombolo attachment (Figure 4-5-5).

The southern section of the Bavon reach has been eroding rapidly. Between 2003 and 2013, the shoreline significantly retreated (Figure 4-5-6). Though high water advanced along most of this shoreline between 2013 and 2019 due to the construction of the breakwaters, its

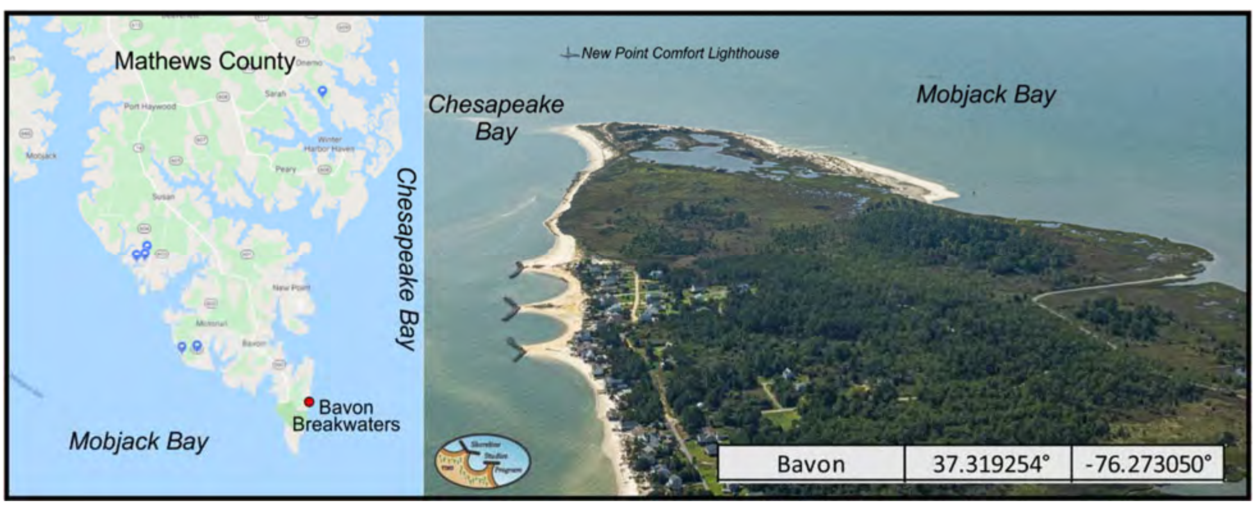


Figure 4-5-1. Left: Location of Yorktown Beach breakwaters, and Right: Aerial image of breakwaters taken on 23 Sep 2019.

position in the embayment between breakwater 2 and 3 is slightly landward of the 2013 shoreline. This is due to the erosion that occurred before 2016 when the breakwaters and fill were placed as well as to the placement of the structures. Their placement determines the bay shape based on the static equilibrium bay model. Sand may shift from side to side, but now the embayment is in dynamic equilibrium and should not retreat farther except possibly under a large storm event. Breakwaters 2 and 3 have the highest tombolo elevations (Figure 4-5-7) and vegetation is growing there. Breakwater 1 is still attached, but its attachment is lower and narrower.

Figure 4-5-2. A 2011 aerial photo of MA3 depicting morphologic features (from Milligan et al., 2013). The breakwaters shown are on the northern end of the system and are not the ones studied for this project. They occur at the southern end near where the exposed peat is shown in front of the houses.

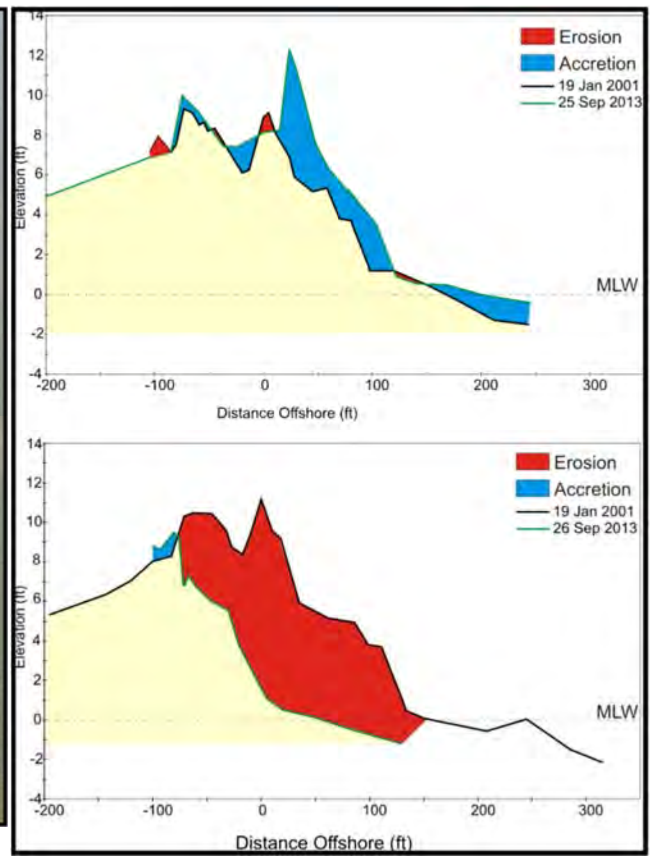


Figure 4-5-3. Depiction of the net change between 2001 and 2013 along the northern end (top) and southern end (bottom) of Ma3 (from Milligan et al., 2013). The southern end is where the breakwaters were constructed.

Figure 4-5-4. Top: Northern section of the Bavon reach during a high water event on 5 October 2015. The wide dunes protect the houses. Bottom: a revetment was constructed because the dunes had eroded along the southern section of the reach but no beach

Figure 4-5-5. The beach is wide and the tombolo attached and vegetated along Bavon's shoreline in 2019.

Figure 4-5-6. Shoreline change between 2003 and 2019 at the Yorktown breakwaters. The 2003 and 2013 shorelines are approximately mean high water based on the digitizer's best guess of the features shown on the aerial photo. The 2019 shoreline is from the survey data.

Figure 4-5-7. Digital elevation model of the collected survey points at Bavon.

5 Adaptive Management

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. Each project site will require its own plan for the future.

The intermediate position of sea level as described by the USACE of 1 or 2 feet by 2050 was modeled at the sites. VIMS, Yorktown and Aquia Landing have a backstop behind the system, whether it is a seawall, side walk with a granite curb/road and a raised backshore with jersey wall, respectively. At these sites, no landward migration of the beach is possible, and the system could eventually be squeezed out. The Kingsmill system transitions to a heavily vegetated base of bank and 2:1 bank slope up a 70-foot bank. The backshore has some room for landward migration of the system, but it is limited. Only Bavon Beach has a low, sandy backshore and dune along most of the shoreline for potential landward migration of the system. However, the land use is residential and migration of the beach will render the properties uninhabitable because of septic issues.

At sites that may experience the coastal squeeze scenario, the breakwaters may require an increase in elevation with additional rock and sand. Because sea level will be one to two feet higher, the beach barriers along Aquia Landing, Yorktown, and possibly VIMS will have to be raised as well. The VIMS seawall may be high enough to address the added volume of rock and sand that can be added to adapt to a rise in sea level (Figure 5-1). In addition, keeping the trees thinned to allow the beach system to be stabilized by marsh grasses is necessary to maintain the system. As noted in the earlier section, the bay at Profile 8 has moved landward slightly since pre-installation of the structures. This was due to placement of the structures and sand to minimize impacts to nearshore biologic experiments. However, the bay has reached a dynamic equilibrium and should maintain its shape.

At Yorktown, in addition to raising the backshore barrier, to address the 1 and 2 foot SLR by 2050, an increase in breakwater height is recommended (Figure 5-2). The new armor should be at least 2-3 feet higher to accommodate the required rock size which is 1 to 2-ton armor. Perhaps a more reasonable approach to raising breakwaters is to add rock blocks/rectangles along the crest. As an example, these would be on the order of 3x3x8 ft concrete structures that can weigh about 6 tons. Dimensions placement could vary. These would simply be placed along the top of each unit, and, although expensive to fabricate, it might be cheaper than adding and constructing additional armor layers. More sand will be required for the system as well. The shore planform can only adjust vertically with SLR unless the system is moved offshore. Moving the breakwaters offshore and adding much more sand might be cost prohibitive as the breakwater rock volume would increase and additional rock would be required. The high value of infrastructure behind Yorktown Beach as well as the economic value of beach usage make maintaining the beach important.

A similar approach could be used at Aquia Landing (Figure 5-3). It is important to note that as the height of each structure is raised, not only does the the front slope extend farther bayward but also each end extends making the structure longer. For this example, with a 2-foot increase, the Aquia Landing breakwaters will each increase by 9 to 10 feet on each end resulting in an 18 to 20 feet increase in breakwater length. The will be consequent decrease in Bay gap by the same which will also help further stabilize the newly elevated beach planform. The access road to Aquia Landing also will have to be raised to provide continued access.

The Kingsmill breakwater system has remained relatively stable with extensive vegetative growth across the backshore with numerous trees growing including cedar, pine, sweet gum, live oak and even cypress (Figure 5-4). These have the impact of shading out the low grasses that are providing an erosion resistant turf. The trees will eventually die due to rising sea level, except possibly the cypress and should at least be selectively thinned. The south facing shoreline will provide the necessary sunlight for a robust vegetative buffer. To address the 2050 sea level rise scenarios, an increase in rock elevation is recommended. Additional sand should also be brought in to increase beach and backshore width to help accommodate an evolving dune system.

At this stage, the Bavon Beach breakwater system is still evolving (Figure 5-5). Access to Bavon will be an issue in the future as sea level rises, because the road to the subdivision now frequently floods during spring tides. Unless the access issue is resolved any adaptive management options may not be available. Though not modeled, rock and sand could be added to adapt to SLR. As noted earlier, the bay profile shows erosion between 2011 and 2019 even though sand was place along the shoreline in 2016. The shoreline eroded significantly between 2011 and 2016. As shown in Figure 4-5-3, the southern section of the Bavon reach has had a great deal of beach and dune loss since monitoring of the site began in 2001. With the placement of the structures, the sand has evolved to a dynamic equilibrium and should maintain its shape.

With ongoing sea level rise all the shoreline projects will eventually be flooded and possibly abandoned. In which case, a breakwater, beach and dune system may become an offshore rock reef with submerged shoals along the shoreline. These may still offer some shore protection but will also become rock substrate for oysters and associated fish communities. The landward shoal areas should provide a benthos habitat possibly SAV pioneers from warmer water species.

Future funding will have its challenges. Bavon's shoreline is privately-owned by individual residents. Kingsmill is privately-owned by a large corporate entity. VIMS shoreline is owned by the Commonwealth of Virginia while Aquia Landing and Yorktown are locally-owned public beaches.

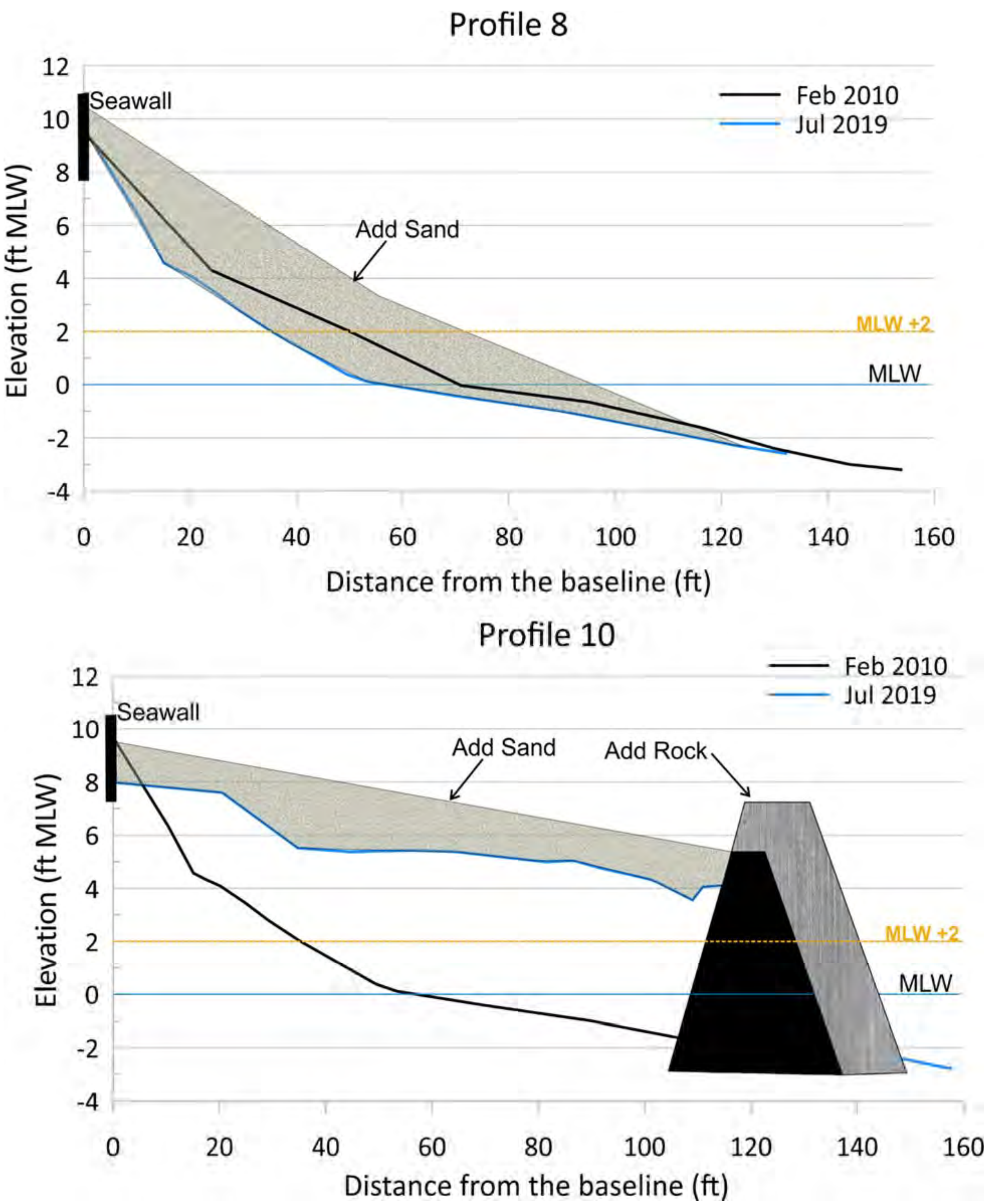
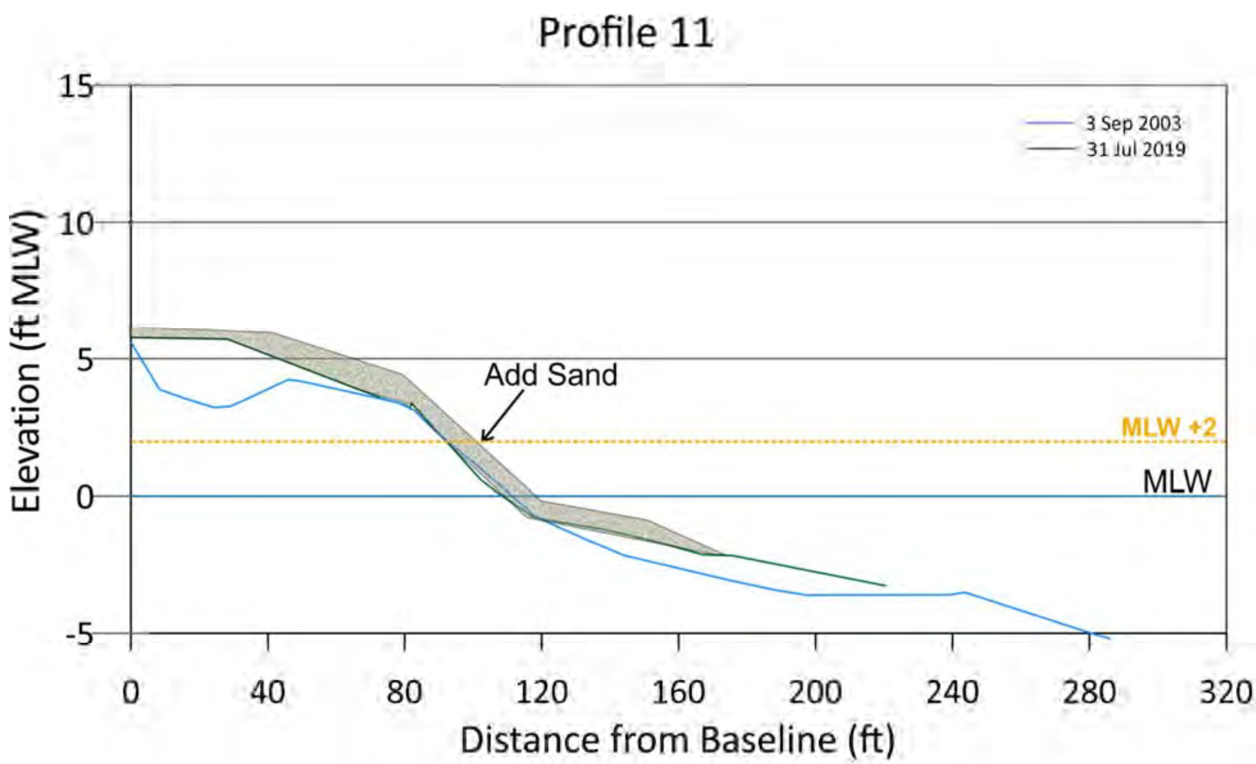


Figure 5-1. Selected cross-sectional profiles of survey data taken at VIMS in 2010, pre-project installation and 2019. The +2 ft MLW depicts the SLR scenario. Rock and sand can be added to the system to adapt to rising sea level to ensure resiliency of the overall system. The 2010 survey data provided by VHB, Inc.



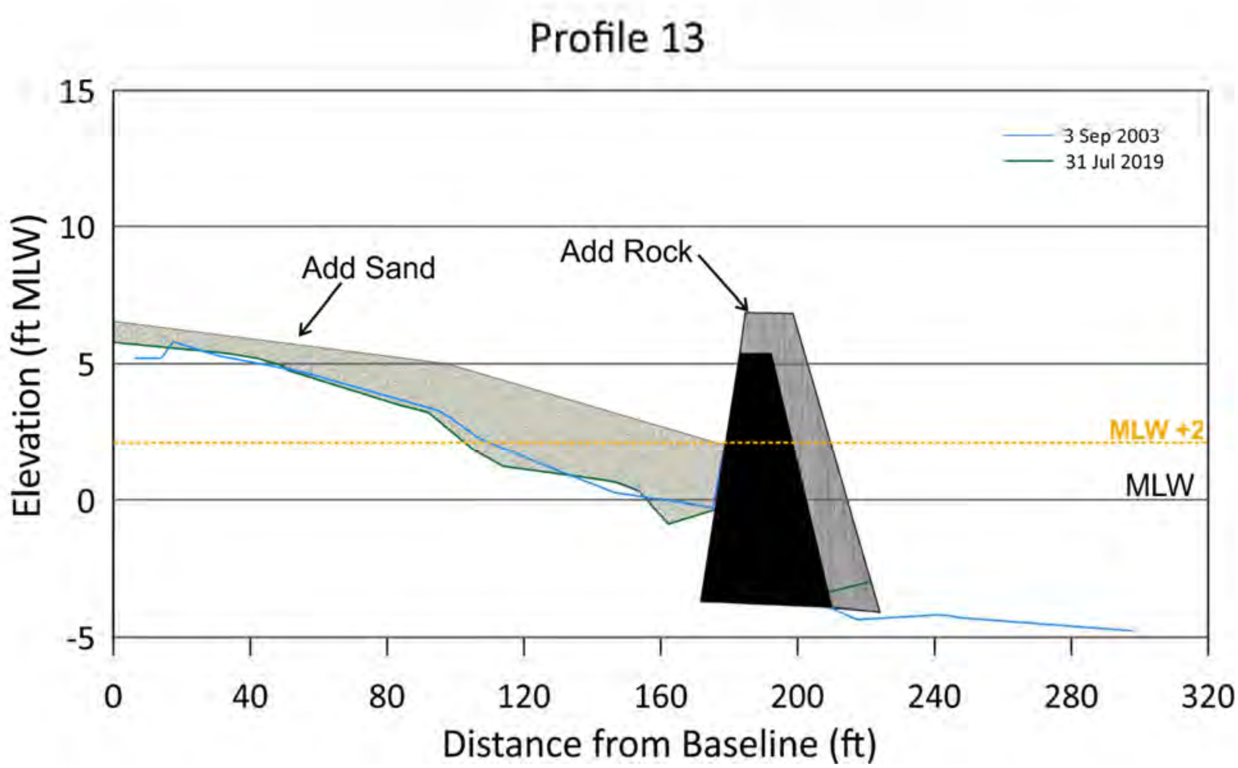


Figure 5-2. Selected cross-sectional profiles of survey data taken at Yorktown in 2003, Post Hurricane Isabel and 2019. The +2 ft MLW depicts the SLR scenario. Rock and sand can be added to the system to adapt to rising sea level to ensure resiliency of the overall system.

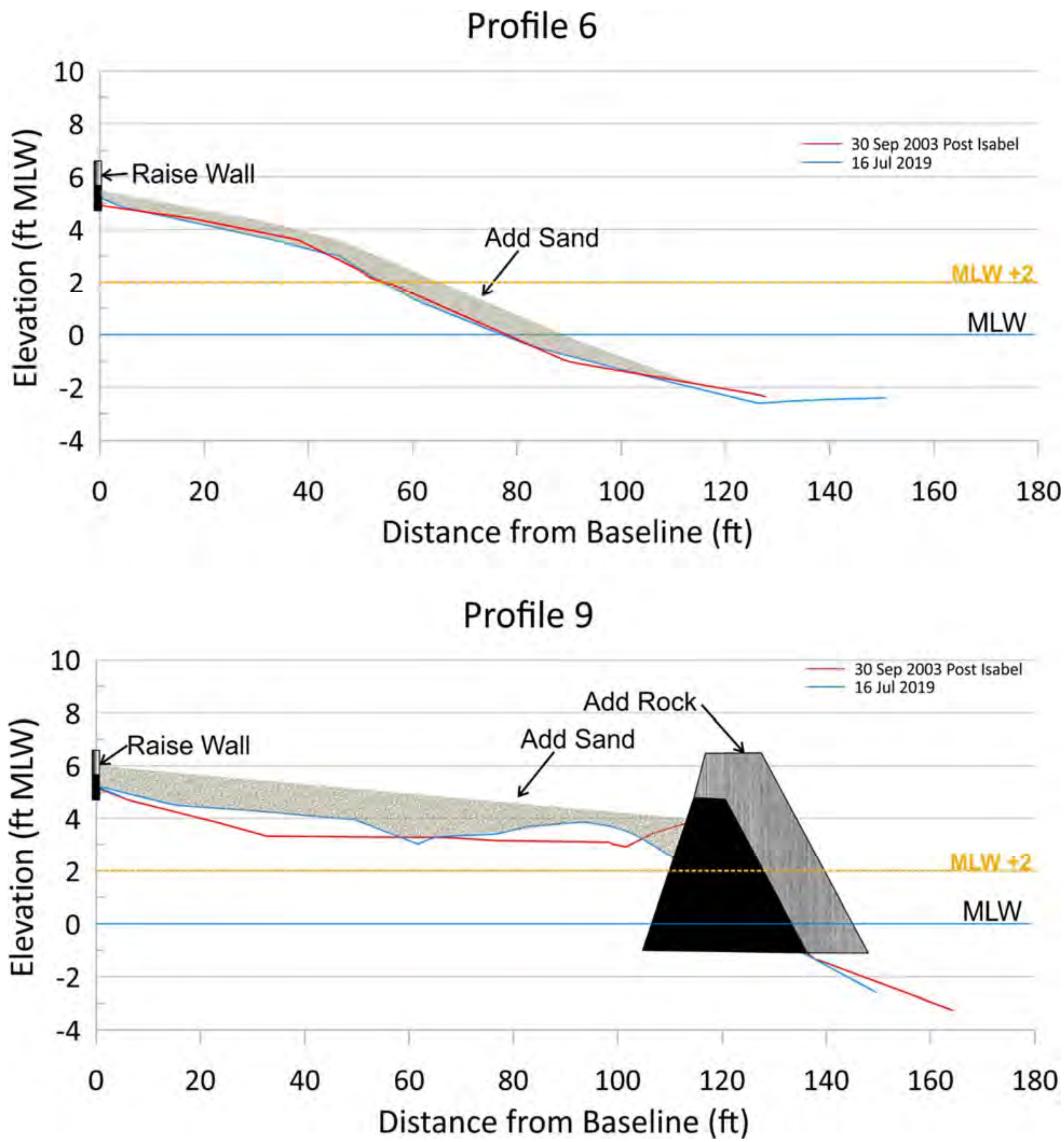


Figure 5-3. Selected cross-sectional profiles of survey data taken at Aquia Landing in 2003, Post Hurricane Isabel and 2019. The +2 ft MLW depicts the SLR scenario. Rock and sand can be added to the system to adapt to rising sea level to ensure resiliency of the overall system.

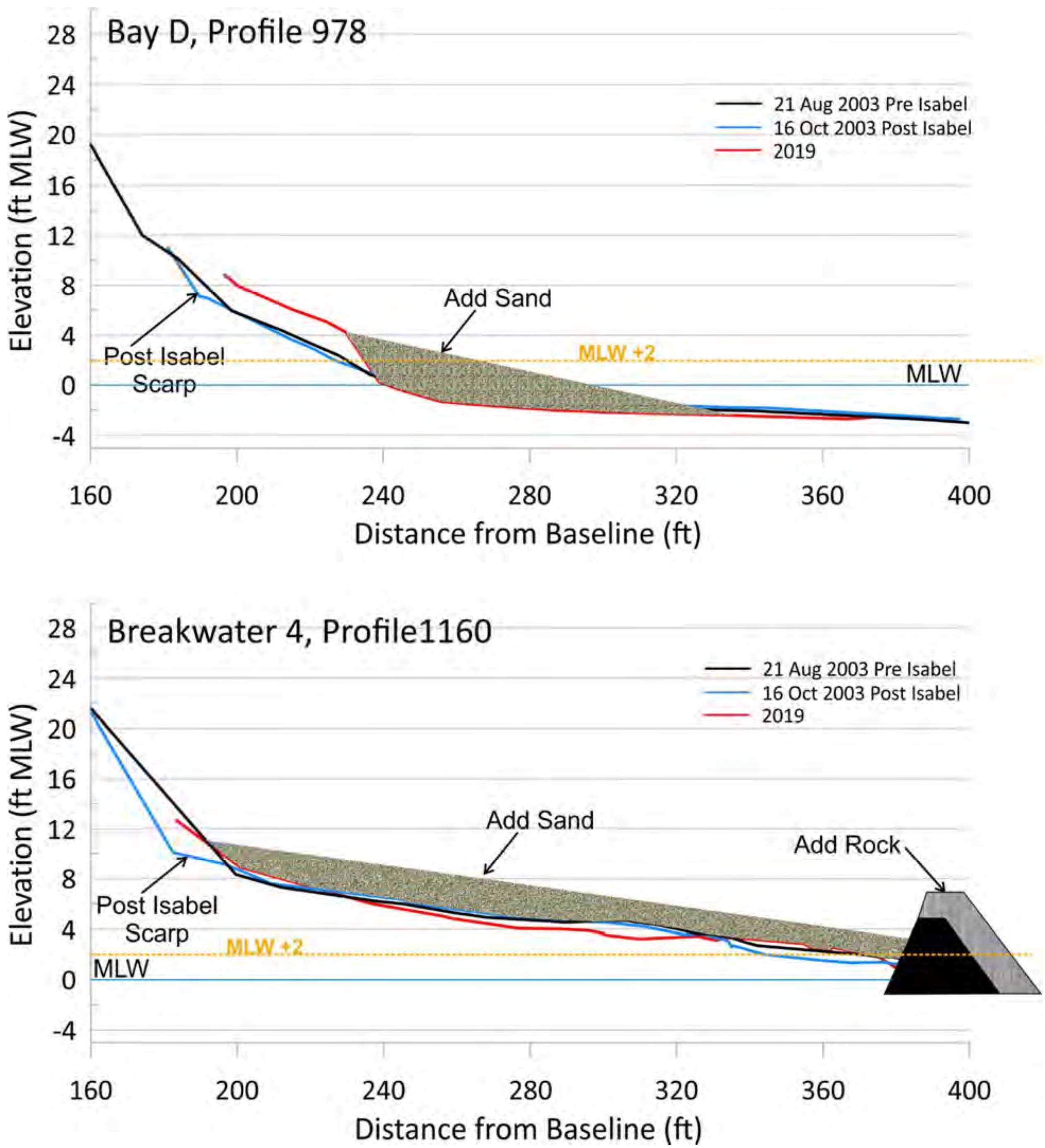


Figure 5-4. Selected cross-sectional profiles of survey data taken at Kingsmill in 2003, pre and post Hurricane Isabel and 2019. The +2 ft MLW depicts the SLR scenario. Rock and sand can be added to the system to adapt to rising sea level to ensure resiliency of the overall system.

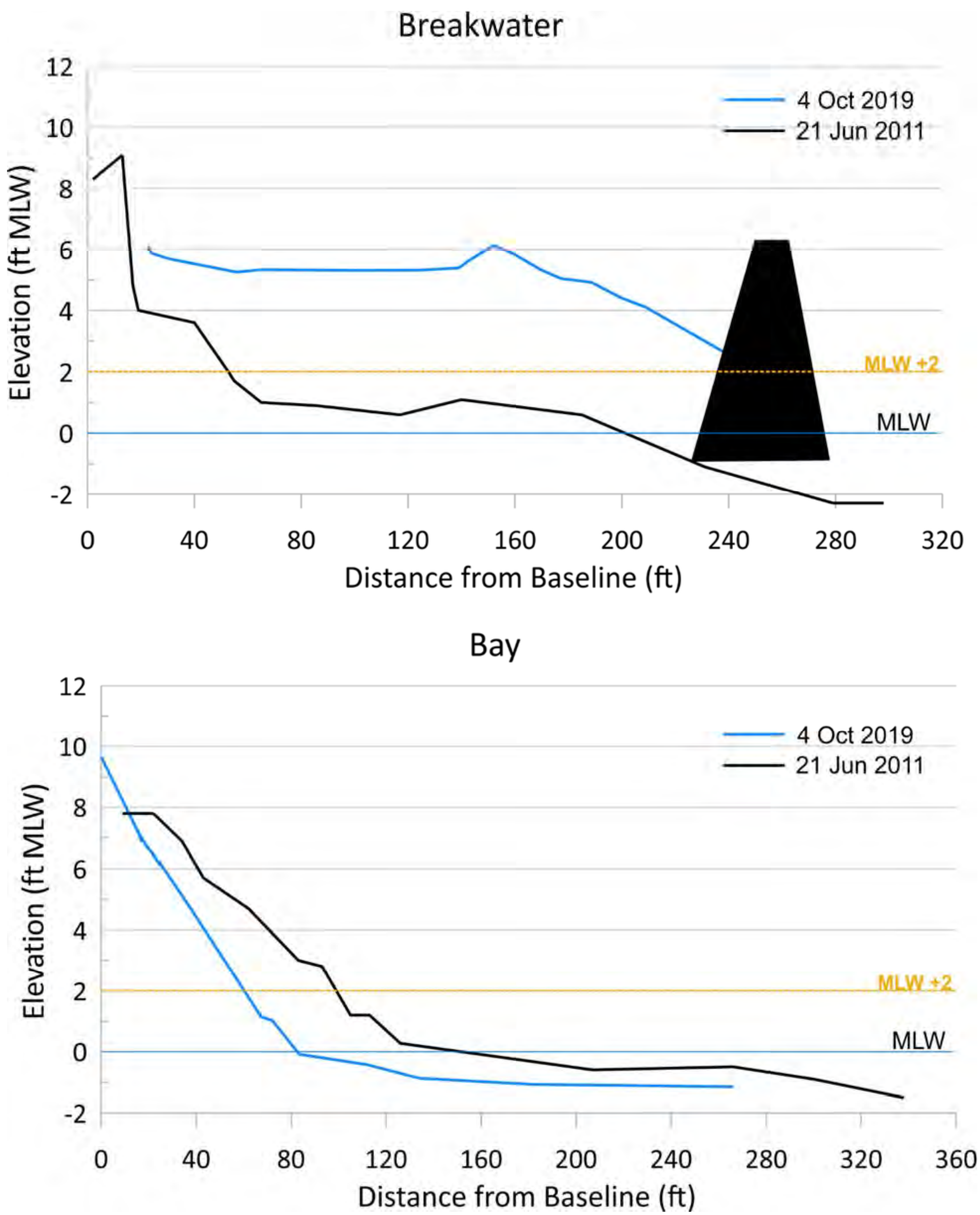


Figure 5-5. Selected cross-sectional profiles of survey data taken at Bavon in 2011 and 2019. The +2 ft MLW depicts the SLR scenario. 2011 survey data provided by VHB, Inc.

6 Summary

Many breakwater sites occur around Chesapeake Bay in a variety of settings, installed at different times over the past 30 years. The five sites in this report are just a sample in terms of site setting and age. The basic application of rock, sand and plants has taken on significant modifications in design and construction over the years, but the basics of creating a stable beach for shore protection remains. Fetch exposure drives design especially as it relates to shore protection, the primary reason for breakwater and beach system installations. Sites with larger fetches typically cannot sustain a marsh and require a beach for shore protection. These living shorelines can reduce sediment input as well as provide both subtidal, intertidal, and pore space habitats for diverse estuarine fauna and their predators.

With increasing sea level rise and the ongoing desire to provide shore protection with these types of system, it is important to look back on what has been done and how has it functioned. Has the system protected the shoreline and associated upland infrastructure and has it provided habitat diversity? At the five sites that were studied, the systems are functioning quite well for their intended purpose, shore protection with enhanced coastal habitats.

For adaptive management of these sites, increases in breakwater height are recommended to deal with the reality of sea level rise. At each site, shoreline erosion was occurring because of the lack of a stable natural marsh or beach feature to buffer the impinging wave climate. Due to their fetch exposures, just adding sand and planting that subgrade is not sustainable and will not be sustainable as sea level rises. Therefore, the increasing the rock structure height is required. Into the future, should the system be submerged, structures could provide wave attenuation and fish function habitat at some level. From these modeling results, recommendations and guidelines will be developed for managers, contractors, and homeowners to adapt existing and future living shoreline projects to sea level rise.

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