



Inventory of Coastal Engineering Projects in Colonial National Historical Park

Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2013/690



ON THE COVER

Revetment at Bellfield Straights along the York River, Yorktown, Virginia.
Photograph by: NPS staff

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Abstract

A reconnaissance-level investigation, analysis and inventory of coastal engineering projects in eight coastal national parks were completed by Oregon State University with funding provided by the National Park Service Geologic Resources Division. The coastal national parks inventoried in this study include:

1. Cape Hatteras National Seashore
2. Colonial National Historical Park
3. Fort Matanzas National Monument
4. Fort Raleigh National Historic Site
5. Gateway National Recreation Area
6. Golden Gate National Recreation Area
7. Olympic National Park
8. San Francisco Maritime National Historical Park

This report includes information on coastal engineering projects identified in, or immediately adjacent to, Colonial National Historic Park (COLO). The report serves as a supplement to a Geographic Information Systems (GIS) database (the GIS data are available online at <http://irma.nps.gov>).

One hundred and fifty-three coastal engineering projects were identified in, or immediately adjacent to, COLO. This total includes 134 coastal structures, 11 fill projects, and 8 beach nourishment projects. Within the park, coastal structures extend for 15,070 m (49,450 ft), stabilizing 39% of the shoreline. Beach nourishment projects placed a minimum of 30,000 m³ (39,000 yd³) of sediment from 1985 to 2009, while fill projects impacted roughly 0.48 km² (118 ac) of subaerial and submerged land from 1931 to 1955.

COLO has a highly manipulated system of coastal engineering structures that were designed to stabilize the shoreline and protect cultural resources. These attempts have been generally successful in meeting their objective, but have also likely altered the natural sediment transport processes in the region.

Acknowledgments

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We would like to thank Dorothy Geyer for her help and support throughout the project. Dorothy led us on a tour of coastal structures at COLO and helped locate many informative park documents. Dave Frederick provided help with imagery and background information. Jodi Eshleman accompanied us during the field visit, shared data and references, and helped us define our methods.

Wes Ripley, the Facility Manager at the Jamestown-Scotland ferry, provided information related to the Jamestown-Scotland ferry pier. Michael Shuflat from the Jamestown-Yorktown Foundation helped with background information for structures at the Jamestown Settlement. Scott Hardaway and Donna Milligan at the Virginia Institute of Marine Science generously shared references and historic shoreline data.

Introduction

The Coastal Engineering Inventory (CEI) project aims to inventory, catalog and map coastal engineering projects in and adjacent to coastal units of the National Park Service (NPS). The primary projects that were inventoried include coastal structures, dredge and fill projects, and beach nourishment and dune construction projects. In this phase of the inventory coastal engineering projects were identified in eight coastal national parks. Prior to this study another report (Coburn et al. 2010) documented coastal engineering projects in ten additional coastal national parks. The report and GIS data are available online at <http://irma.nps.gov>.

In this phase of the NPS CEI project, a qualitative impacts analysis was also performed to help better understand the extent of human-altered coastal areas within each respective park. This section describes the impacts of coastal engineering projects and their influence on natural sediment transport processes. In addition to highlighting major engineering projects that are impacting local and regional sediment transport, we have also included related information pertaining to current park management concerns as expressed during the site visit.

Coastal engineering projects are usually motivated by a desire to protect the backshore environment from erosion or alter the coastal zone for a particular purpose (i.e. maintain a navigation channel, develop roadways, or restore wetlands). In order to fulfill project objectives, a suite of engineering solutions are available that are typically categorized into hard and soft engineering projects. Coastal engineering solutions often combine both hard and soft engineering approaches, such as when beaches are nourished following breakwater construction.

Hard engineering solutions include the construction of seawalls, revetments, breakwaters, sills, and bulkheads to protect the backshore from coastal erosion and sometimes flooding (see the Glossary in Appendix A for definitions). Jetties and groins are also classified as hard engineering projects and are used to alter the sediment transport regime by trapping sediment. Impacts from hard structures are highly site dependent, but may include the loss of sediment supplied to downdrift areas, localized scour in front of and at the downdrift end of structures, visual impacts, placement losses, reduction in beach access, and the alteration or reduction of habitat.

Soft engineering solutions include non-structural means of stabilizing the backshore or changing coastal environments through beach nourishment, dune construction, dredging, or filling. These methods add or redistribute sediment within the system and are used to widen sediment-starved beaches, maintain navigable waterways, protect coastal infrastructure, and restore wetlands. As with hard solutions, impacts vary significantly by project and location. Soft engineering projects may impact hydrodynamic and sediment transport processes, beach morphology, aquatic ecosystems, and/or beach habitats.

The overall goal of this project is to develop a greater understanding of the coastal engineering modifications in the National Park System. Along coastlines expected to be impacted by climate change, structurally modified shorelines will likely respond differently than natural coastlines, which may have a more dynamic response to coastal erosion and sea level rise. An inventory of coastal engineering modifications will provide information to allow resource managers to make better decisions about how to preserve NPS resources, establish baselines, develop desired future conditions, and balance the protection of historic resources and infrastructure with the

preservation of natural systems. All of these actions will improve the ability of the NPS to manage coastal park units in accordance with NPS policies. The main NPS policies relevant to coastal engineering projects are summarized below (see *NPS Management Policies 2006* for more detail).

Maintenance of Natural Processes

Generally, NPS policy requires that natural coastal processes in parks, such as erosion, shoreline migration, deposition, overwash, and inlet formation, be allowed to continue without interference (*NPS Management Policies* § 4.8.1.1 2006). The NPS may intervene in these processes only in limited circumstances, such as when there is no other feasible way to protect natural resources, park facilities, or historic properties (*NPS Management Policies* § 4.8.1 2006).

Restoration of Natural Processes

In parks where pre-existing or new activities or structures have altered and/or are currently altering coastal dynamics, ecosystems, tidal regimes, and sediment transport rates, the NPS policy is to investigate, in consultation with appropriate state and federal agencies, alternatives for mitigating the effects of such projects and for restoring natural conditions (*NPS Management Policies* § 4.8.1.1 2006). NPS restoration actions in human-disturbed areas seek to return the area to the natural conditions and processes characteristic of the ecological zone in which the damaged resources are situated, as called for by park management plans (*NPS Management Policies* § 4.1.5 and § 4.4.2.4 2006). An example would be the restoration of shoreline processes.

Park landscapes disturbed by natural events, such as hurricanes, are allowed to recover naturally unless manipulation is necessary to 1) mitigate for excessive disturbance caused by past human effects, 2) preserve cultural and historic resources as appropriate based on park planning documents, or 3) protect park developments or the safety of people. (*NPS Management Policies* § 4.1.5 and § 4.4.2.4 2006).

Construction of Facilities

Generally, the NPS must avoid the construction of buildings, roads, and other development that will cause unacceptable impacts on park resources and values (*NPS Management Policies* § 9.1 2006). Development will not compete with or dominate park features or interfere with natural processes (*NPS Management Policies* § 9.1.1.2 2006). In shoreline areas, this means that new developments will not be placed in areas subject to wave erosion or active shoreline processes unless 1) the development is required by law; or 2) the development is essential to meet the park's purposes, as defined by its establishing act or proclamation, and

- no practicable alternative locations are available;
- the development will be reasonably assured of surviving during its planned life span without the need for shoreline control measures; and
- steps will be taken to minimize safety hazards and harm to property and natural resources (*NPS Management Policies* § 4.8.1.1 2006).

Replacement of Facilities

Park development that is damaged or destroyed by a hazardous or catastrophic natural event will be thoroughly evaluated for relocation or replacement by new construction at a different location. If a decision is made to relocate or replace a severely damaged or destroyed facility, it will be

placed, if practicable, in an area that is believed to be free from natural hazards (NPS *Management Policies* § 9.1.1.5 and § 4.1.5 2006).

Cooperative Conservation

Under NPS policy, park superintendents are required to monitor state government programs for managing state-owned submerged lands and resources within NPS units. When there is potential for such programs to adversely impact park resources or values, superintendents will make their concerns known to appropriate state government officials and encourage compatible land uses that avoid or mitigate potential adverse impacts. When federal acquisition of state-owned submerged lands and resources within NPS units is not feasible, NPS will seek to enter into cooperative agreements with state governments to ensure the adequate protection of park resources and values (NPS *Management Policies* §3.4 2006).

In addition, the NPS has the authority under 36 C.F.R. §1.2(a)(3) to apply general NPS regulations, such as special use permit requirements, on or in waters that are subject to the jurisdiction of the United States, or in areas within their ordinary reach up to the mean or ordinary high water line, even if the submerged lands are non-federally-owned and regardless of whether the park has exclusive, concurrent, or proprietary jurisdiction. Waters subject to the jurisdiction of the United States refers to three types of waters: (1) navigable (as defined in 33 C.F.R. § 2.36(a)), (2) non-navigable but located on lands for which the U.S. has acquired title or control and has accepted or retained exclusive or concurrent jurisdiction, and (3) waters made subject to U.S. jurisdiction by certain international agreements and statutes (33 C.F.R. § 2.38).

Methods

Coastal engineering terminology was adapted from the NPS Coastal Engineering Inventory pilot project (Coburn et al. 2010) and through discussion with the NPS Geologic Resources Division. The NPS selected eight coastal national parks in which coastal engineering projects were identified, inventoried and mapped. Projects in the inventory include coastal structures, dredging, filling, beach nourishment, and dune construction.

A digital park boundary shapefile for all of the inventoried parks was downloaded from the NPS Integrated Resources Management Applications Portal (<https://irma.nps.gov>). Georeferenced digital orthophoto imagery was obtained from each park and added to ArcMap 10.0 to create a basemap.

A visual inspection of the orthophoto imagery was completed and locations of all discernible coastal structures were digitized using ArcMap. A site visit to the park, along with staff correspondence, was used to complement and confirm initial findings based on examination of the imagery and to identify other coastal engineering projects. A comprehensive online and hardcopy literature search was undertaken to obtain attribute data for each project (year of construction, material, year of maintenance, cost, lead construction agency, and volume). Unless otherwise specified, costs presented in the report are in project-year dollars.

A coastal engineering project was considered distinct if there was any discernible, physical separation between it and an adjacent engineering project. A series of bulkheads constructed by individual interests, for example, would be classified as one structure as long as no identifiable gaps were observed between them. Some projects, such as dredge projects that place dredge spoil on the beach, serve multiple purposes (i.e., dredging and beach nourishment). In these cases, the primary reason for the project was ascertained and the project was classified accordingly. Projects that occurred repeatedly in one place (e.g. inlet dredging) were counted as one project.

Overview statistics were calculated to summarize the coastal engineering projects within each park. The percentage of shoreline armored by coastal structures was found by totaling the length of bulkheads, breakwaters, groins, revetments, seawalls, and sills and dividing it by the total length of shoreline. Structure length and shoreline length were determined using ArcMap. The structure length used in calculating the percentage of shoreline armored for individual structures was merely the length of the structure. For groin fields (defined here as three or more groins) the length was set as the length of the groin field along the shoreline, while for jetties the width of the mouth of the inlet was used.

An ArcGIS 10.0 file geodatabase for each park was compiled using ArcMap. Each geodatabase includes a park boundary feature class and identified coastal engineering projects separated into three feature classes: 1) coastal structures 2) dredge and fill projects and 3) beach nourishment and dune construction projects. The GIS projects also contain an ArcMap document for data viewing (.mxd), data layer files (.lyr), FGDC-compliant metadata (.xml and .txt), FAQ metadata (.html), a table attribute file (.pdf), and a README file (.pdf). Location information for dredge, fill, beach nourishment, and dune construction projects was often non-existent or vague. Therefore, not all of these projects are included in the GIS data, and those that are included have only approximate locations.

Results

One hundred and fifty-three coastal engineering projects were identified in, or immediately adjacent to, COLO. This total includes 134 coastal structures (Table 1), 11 fill projects, and 8 beach nourishment projects (See Appendices B, C, and D for detailed data). Seventy-nine of the coastal structures are located in or adjacent to the Jamestown unit, while 55 structures are in or adjacent to the Yorktown unit (Table 1 and Figure 1).

Table 1. Coastal structures located in and adjacent to COLO.

¹ Structure	Total	Total Length (m)	Jamestown Unit Total	Jamestown Unit Total Length (m)	Yorktown Unit Total	Yorktown Unit Total Length (m)
Breakwater	53	2,385	34	1,770	19	615
Bulkhead	8	930	8	930	0	0
Pier	16	5,070	3	590	13	4,480
Revetment	41	11,325	21	3,920	20	7,405
Seawall	2	595	1	530	1	65
Sill	14	1,250	12	905	2	345
TOTAL	134	21,555	79	8,645	55	12,910

¹ See the glossary in Appendix A for coastal structure definitions.

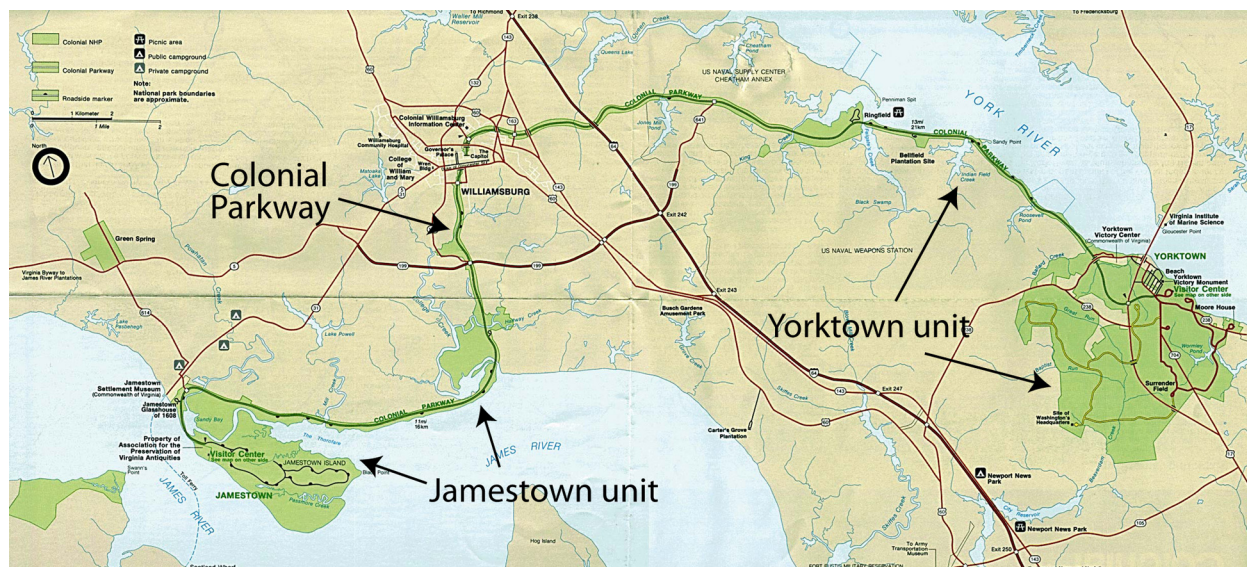


Figure 1. Map of Colonial National Historic Park showing the two major park units, Jamestown and Yorktown, connected by the Colonial Parkway (NPS map modified from UT 2012).

Thirty-nine percent of the roughly 39 km (24 mi) of shoreline within COLO is armored by coastal structures (excludes all structures adjacent to the park) (Figure 2). Approximately 28% of the 27 km (17 mi) of shoreline in the Jamestown unit, which includes Jamestown Island and the northern James River shoreline, is armored by coastal structures (Figure 3). Jamestown Island itself has roughly 13 km (8 mi) of shoreline and is 37% armored.

The Yorktown unit has the greatest percentage of armored shoreline in the park, with 66% of its 11.5 km (7 mi) shoreline armored (Figure 3). In addition, beach nourishment projects placed a minimum of 30,000 m³ (39,000 yd³) of sediment on park beaches from 1985 to 2009 (minimum because not all projects were documented) and fill projects impacted roughly 0.48 km² (118 ac) of subaerial and submerged land within the park between 1931 and 1955.

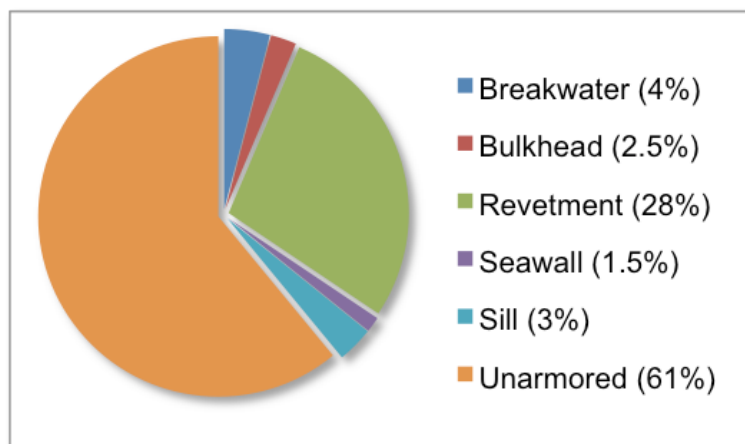


Figure 2. Percent of shoreline armored (by structure type) and unarmored in COLO (excludes overlapping structures and all structures adjacent to the park).

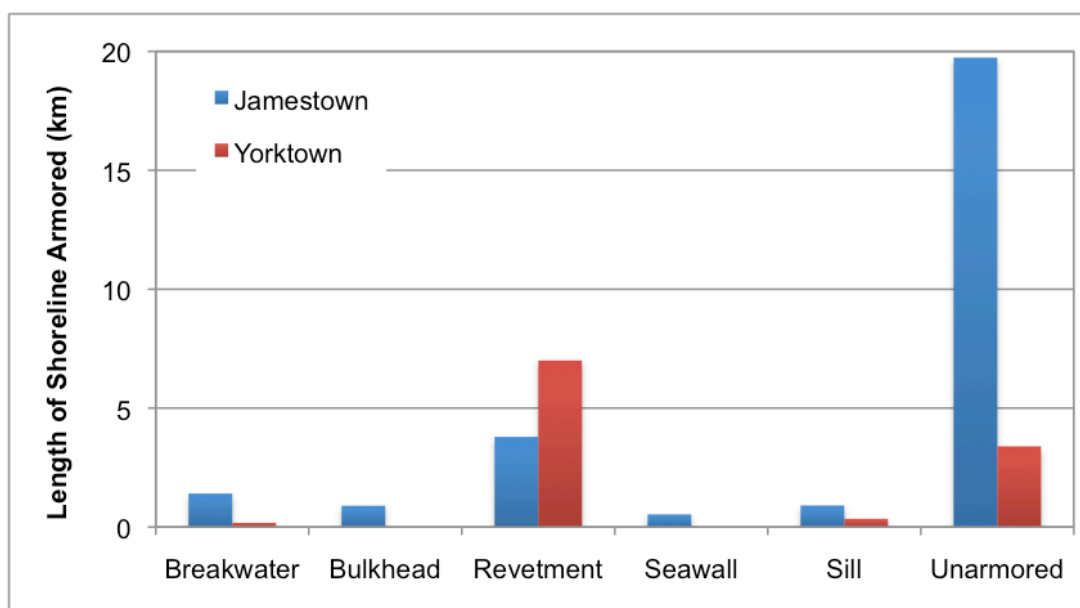


Figure 3. Length of shoreline armored (by structure type) and unarmored in the two units of COLO (excludes overlapping structures and all structures adjacent to the park).

Background

Colonial National Monument (now a national historical park) was established on June 3, 1930 for the preservation of the park's historic structures and remains (NPS 1993). The park, located

in southeastern Virginia, covers 35 km² (8,677 ac) between the James and York rivers (Figure 1). Colonial National Historical Park is comprised of two major units, Jamestown and Yorktown.

Jamestown Island (Figure 4) is the site of the first permanent English settlement in North American, while Yorktown (Figure 5) was the location of the last major battle of the American Revolution. The park also includes the 37-kilometer (23 mi) long Colonial Parkway that connects these two sites (Figure 1).

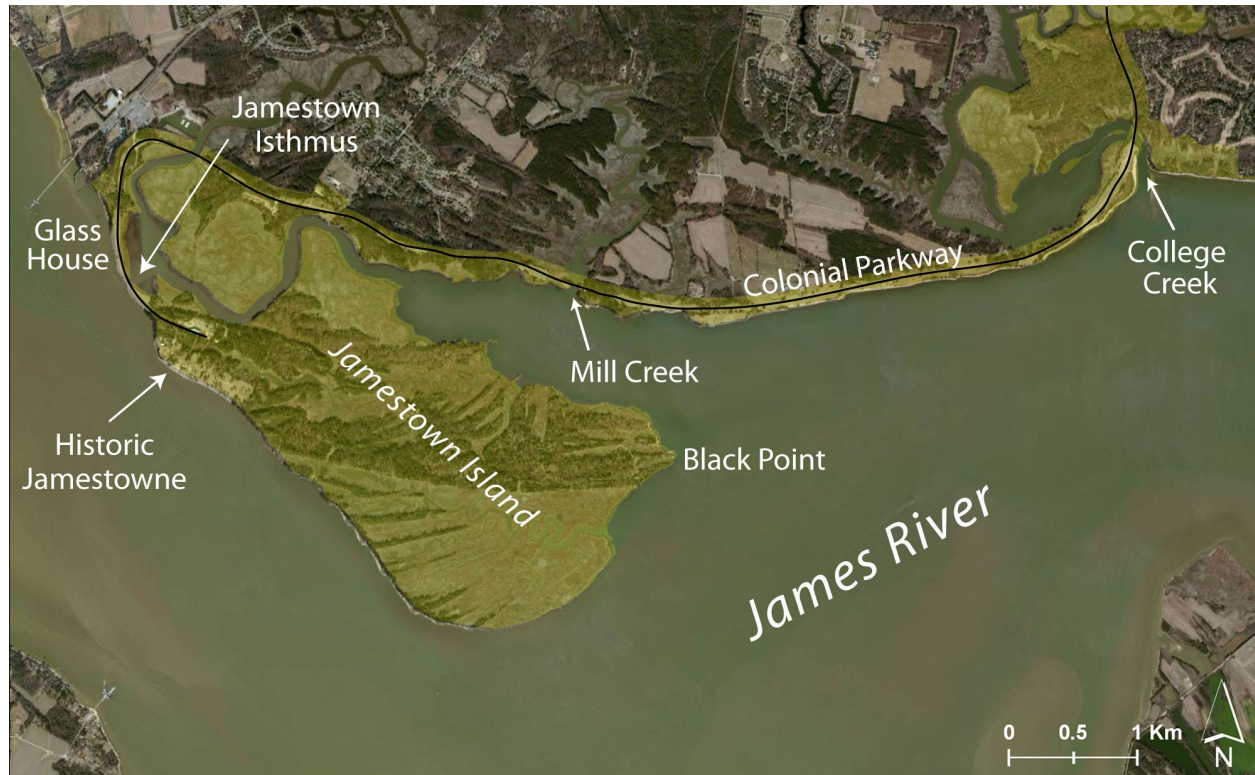


Figure 4. Map of the Jamestown unit, including Jamestown Island and the northern James River shoreline from Jamestown Island to College Creek. Yellow shading shows the park boundary (image from ESRI Bing Maps basemap layer 2012).

The Colonial Parkway was built between 1930 and 1957 and is listed in the National Register of Historic Places. The National Park Service owns and maintains the Parkway, including a minimum 152-meter (500 ft) wide right-of-way outside the Jamestown and Yorktown areas. Preservation Virginia owns the land around Historic Jamestowne (Figure 4) and jointly administers the site with COLO.

Given the legislation establishing COLO, the parks' primary responsibility is to preserve cultural resources. This legislation, as it relates to coastal processes, has permitted the installation of engineering structures along sections of the park to stabilize the shoreline adjacent to historic sites and the Colonial Parkway.

Setting

The modern landscape of the Chesapeake Bay region is a product of the last great Ice Age. Some 15,000 to 20,000 years ago sea level was between 46 to 91 m (150 to 300 ft) lower than its

present location as a large volume of water was held within glaciers. During this time the Susquehanna River and its tributaries (James, York, Potomac and Rappahannock) carved out the coastal plain. As the glaciers melted sea level rose, flooding the river valleys and creating the shallow estuary features of the Chesapeake Bay (Ward et al. 1989). The natural riverine environment continues to evolve in response to natural and human influences (Thornberry-Ehrlich 2005). The natural processes of sedimentation and erosion have produced a dynamic coastal landscape that varies throughout COLO and includes marshes, tall upland banks, low upland banks, small pocket beaches, and sandy segments. Shoreline type and composition greatly affect local vulnerability to shoreline change and flooding throughout COLO.

The lower James and York rivers are microtidal river-estuaries (i.e., tidal ranges are less than 2 m [6.6 ft]) and are large tributaries of the Chesapeake Bay (NPS 2011). In the park area, the water levels of the James and York rivers fluctuate an average of <1 m (<2.5 ft) due to tides (Thornberry-Ehrlich 2005). From 1950 to 2003 the mean sea level trend at the Gloucester Point gauge, located across the York River from the park, was an increase of 3.81 mm/yr (0.15 in/yr) (NPS 2011). This rate of rise is considerably larger than the 20th century global average of 1.7 mm/yr (0.07 in/yr) (Church and White 2006).



Figure 5. Map of the Yorktown unit, stretching along the York River from Felgates Creek to the U.S. Coast Guard Training Center. Yellow shading shows the park boundary (image from ESRI Bing Maps basemap layer 2012).

The dominant force driving sediment transport and shaping the shoreline within the park is wave energy. Wave energy is variable depending on the fetch distance, nearshore bathymetry and

shoreline orientation. Within the Chesapeake Bay, wind patterns shift seasonally from the North and Northwest during late fall to Southwest in spring and for the remainder of the year (Hardaway and Byrne 1999). The local wave climate is limited due to fetch lengths generally less than 9 km (5 mi) (Hardaway et al. 2006).

The two major storm types that occur in the park, nor'easters and tropical storms, account for the highest magnitude sediment transport and shoreline change events. On average the region is impacted by one or two tropical storms and three to five nor'easters of varying intensity per year (Ward et al. 1989). Storm surge, the rise in water level associated with low pressure weather systems, allows wave energy to be applied at higher elevations along the shoreline and can increase erosion (NPS 2011). Storm surge during Hurricane Isabel in 2003 was estimated at 2.6 m (8.6 ft) and wave heights reached 3.8 m (12.5 ft) (NPS 2011). In some places revetments were breached and a scarp was carved that reached 0.9–1.8 m (3–6 ft) from the Colonial Parkway (Thornberry-Ehrlich 2005).

River and tidal currents play a secondary role in sediment transport and landform modification. Currents within this system can approach 1 m/s (3 ft/s) with average velocities on the order of 6 cm/s (2.4 in/s) (Friedrichs 2009). Given the relatively low river inflow rates for the York (71 m³/s [2,507 ft³/s]) and James Rivers (150 m³/s [5,297 ft³/s]), and the generally weak circulation patterns, currents are believed to only dominate sediment resuspension and transport processes in the lower depths of the water column and not contribute greatly to alongshore gross sediment transport, which is dominated by wave energy (Friedrichs 2009).

Historic shoreline change rates vary throughout the park. Between 1937 and 2009 the shoreline change rate in the Jamestown unit varied from -1.2 to 7.0 m/yr (-4.0 to 23.1 ft/yr), with an overall average rate of 0.1 m/yr (0.4 ft/yr) (Milligan et al. 2010). However, these rates include episodes of shoreline filling and the installation of shoreline protection structures that significantly affect the rate of change. Shoreline change rates for the York River park shoreline from 1937 to 2002 range between -1.3 to 0.5 m/yr (-4.2 to 1.5 ft/yr), with an overall average rate of -0.12 m/yr (-0.4 ft/yr) (Hardaway et al. 2006).

The dominant source of sediment in the region comes from shoreline erosion (eroding marshes, beaches and bluffs) (USGS 2003). Much of the York and James River shorelines, both inside and outside of the park, have been protected by shoreline erosion control structures for decades, limiting the sediment supply. Shoreline armoring may accelerate erosion in unarmored, down drift sections of shoreline.

Coastal Structures

Jamestown Unit Shoreline

The Jamestown unit of the park includes Jamestown Island and the northern James River shoreline from Jamestown Island to College Creek (Figure 4). In this area, 79 coastal structures have been installed over time to protect uplands and cultural resources (Figure 6).

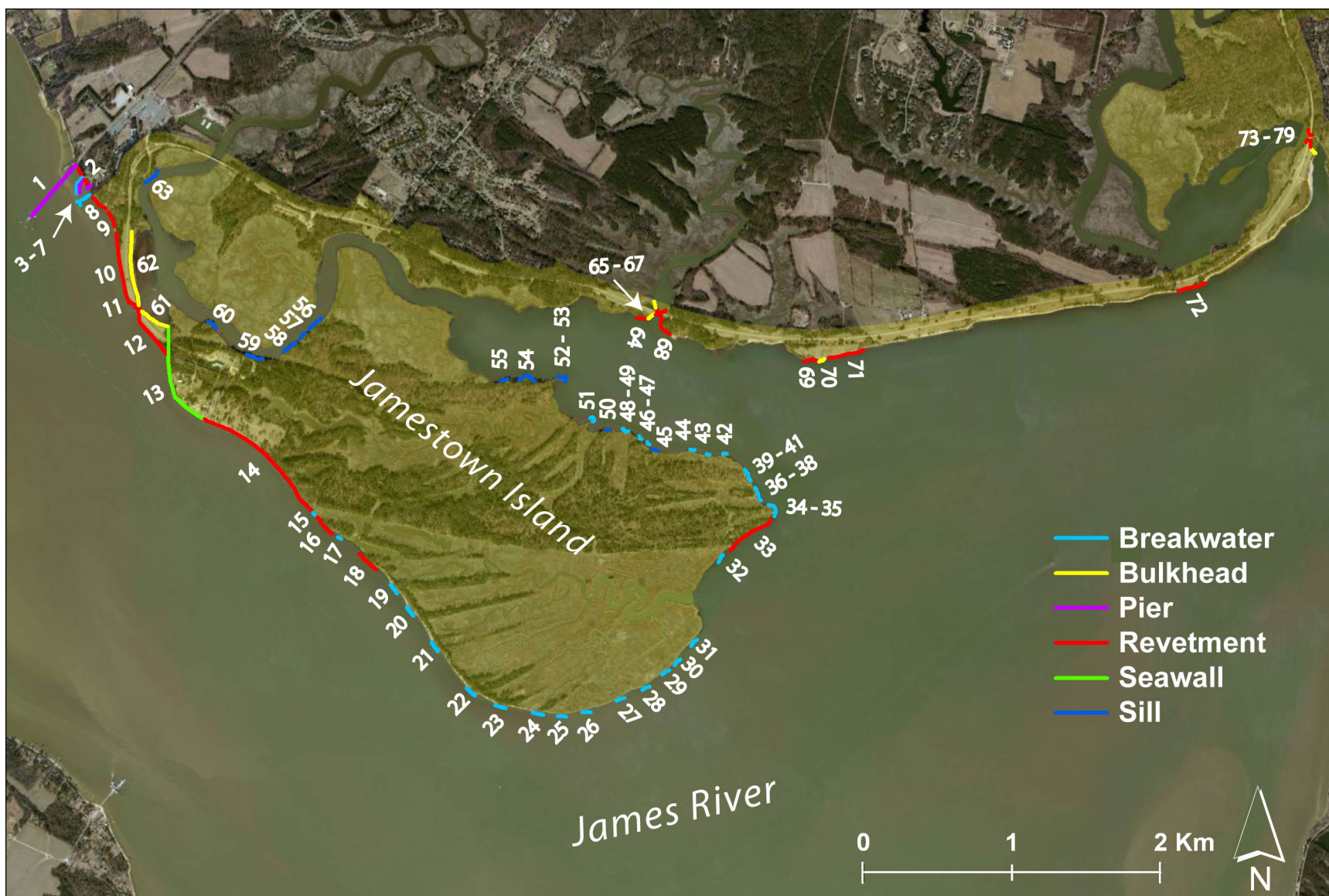


Figure 6. Map of coastal structures in the Jamestown unit. Yellow shading shows the park boundary (image from ESRI Bing Maps basemap layer 2012).

Jamestown Island Shoreline

The shoreline of Jamestown Island consists of eroding marsh and uplands and has been armored with many coastal structures. These structures encompass 32 breakwaters, 11 sills, 5 revetments, a bulkhead, and a seawall that together provide nearly 5 km (3 mi) of protection to cultural sites and infrastructure on the island (#12–61 Figures 6).

At Historic Jamestowne the shoreline has eroded more than 120 m (400 ft) since the first landing in 1607 (Johnson et al. 2001). A sloped 730-meter (2,395 ft) long concrete seawall (structure #13 Figures 6 & 7), built by the U.S. Army Corps of Engineers (USACE) from 1900 to 1905 and rehabilitated in 1969 and 1982, protects the Jamestown site (USACE 2002, John Milner Associates et al. 2006). The Historic Jamestowne property and seawall are owned and maintained by Preservation Virginia. Immediately downstream (southeast) from the seawall is a 970-meter (3,180 ft) long revetment (#14 Figure 6) originally built by the NPS in 1935–1936 (John Milner Associates et al. 2006).



Figure 7. A concrete seawall protects Historic Jamestowne along the James River (#13 Figure 6). View is to the southeast.

A timber bulkhead spans the entire eastern side of the Jamestown Isthmus (#61 & 62 Figure 6). It is unknown exactly when the bulkhead was built, but it likely coincided with the creation of the isthmus in 1955 (see the Fill section). Timber bulkheads were also built on the James River side of the isthmus in 1955 (HAER 1995a), but have since been covered by revetments (#10–12 Figure 6).

The northwestern side of the isthmus is protected by a 529-meter (1,736 ft) long revetment, originally built in 1956 and reinforced in 1996 (#10 Figure 6) (John Milner Associates et al. 2006). Around the same time, a revetment was also installed in front of the Glasshouse to stabilize the shoreline (#9 Figure 6). An additional 390-meter (1,280 ft) long revetment protects the southwestern side of the isthmus (#12 Figure 6) and was built prior to 1978 (Dorothy Geyer, email, 5/3/12). Rock gabions were placed around the northern end of the Isthmus Bridge in 1996 at a cost of \$175,283 (#11 Figure 6) (NPS 1996).

In 2002 a combination of breakwaters, sills, and spurs off existing revetments was built along the Jamestown Island shoreline to manage shoreline erosion and protect cultural resources (#15, 17, 19–32, 34–60, and 63 Figure 6) (USACE 2002). In total, 32 breakwaters, 11 sills (Figure 8), and 6 revetment spurs were built. Many of the structures were designed to allow for headland control. The concept of headland control involves armoring an existing headland or protecting a stretch of shoreline with a breakwater (or multiple, spaced breakwaters like Jamestown Island) and allowing adjacent shorelines to erode into crenulate bays. Small beach nourishment projects also occurred concurrently behind the structures during construction (see Beach Nourishment section).



Figure 8. Rock sills near Black Point, Jamestown Island (#35–37 Figure 6). View is to the northwest.

Immediately upriver from the Glasshouse, outside of the park, are the Jamestown-Scotland ferry pier and Jamestown Settlement museum. The modern concrete ferry pier (#1 Figure 6) was built in the 1950s and updated in 1991 by Tidewater Construction Company. A wooden pier completed in 1925 existed previously and was used to transport people to Jamestown Island (Wes Ripley, Facility Manager Jamestown-Scotland Ferry, email, 12/20/11).

The Jamestown Settlement property is located between the ferry pier and the park and has two breakwaters, two piers, and two sections of revetment (#2–7 Figure 6). The first structure installed was a small timber pier in 1992 by Crofton Diving Corporation as a temporary location for the museum's ships before construction of the main pier. Tidewater Construction Company built the southern rock breakwater, main timber pier, earth and rock breakwater, and both rock revetments in 1994 at a cost of roughly \$1,500,000 (Michael Shuflat, Jamestown-Yorktown Foundation, email, 2/8/12). These structures were built to provide safe mooring for the museum's three replica ships.

Northern James River Shoreline

The northern James River shoreline has sections of revetments and bulkheads (#64–79 Figure 6). Nearly all of these structures are associated with construction of the Colonial Parkway in 1955. Timber bulkheads were installed on both sides of Mill Creek and College Creek in 1947–1948 to

stabilize fill placed in preparation for bridge construction. Remains from these bulkheads can be seen on the west side of Mill Creek and southwest side of College Creek (#65, 67, 73 Figures 6). More recently, in 2011, a steel sheet pile bulkhead was built on both sides of College Creek (#75 & 77 Figure 6).

Revetments around the bridge supports are also present on both sides of Mill and College creeks, but their installation dates are unknown. Historic aerial images show that the Mill Creek revetment predates the late 1980s. Three rock revetments and one timber bulkhead are also present along the shoreline between Mill Creek and College Creek, but no background information could be found on these structures (#69–72 Figure 6).

Yorktown Unit Shoreline

The Yorktown unit of the park includes roughly 8 km (5 mi) of the southern York River shoreline from Felgates Creek to the U.S. Coast Guard Training Center (Figure 5). Fifty-five coastal structures exist in and adjacent to this unit, stabilizing 67% of the shoreline (Figure 9).

Felgates Creek to Yorktown

The Parkway runs in very close proximity to the York River for approximately 6.5 km (4 mi) from Felgates Creek to Yorktown (Figure 5). Erosion along the shoreline from Felgates Creek to Indian Field Creek, known as Bellfield Straight, has been an issue since 1933 (NPS 2011). This stretch of shoreline is armored with a 2.4-kilometer (7,900 ft) long revetment built in the late 1930s (#83 Figures 9 & 10) (NPS 2011). Recent storms have separated the revetment from the bank and stormwater-induced gullies have formed adjacent to the Parkway. An Environmental Assessment, currently in draft form, calls for rehabilitation of the Bellfield Straight revetment in addition to rehabilitation or installation of rock revetments, rock spurs, continuous and gap sills, pocket beaches, and shore-attached breakwaters along the York River shoreline (NPS 2011).



Figure 9. Map of coastal structures in the Yorktown unit. Yellow shading shows the park boundary. The yellow box is enlarged in Figure 12 (image from ESRI Bing Maps basemap layer 2012).



Figure 10. Revetment at Bellfield Straight along the York River (#83 Figure 9). View is to the west.

Downriver from Indian Field Creek there is a revetment and two sills (#85–86 Figure 9). No information could be found on the revetment, but historic park maps show that the sills existed in 1962 (Dorothy Geyer, email, 5/3/12).

Continuing along the shoreline, there are five small breakwaters, called the NPS breakwaters (#87–91 Figure 9 and Figure 11). These breakwaters were constructed in 1985 of broken concrete to control shoreline erosion (NPS 2011). However, the low elevation of these breakwaters (0.6 to 0.9 m MLLW [2 to 3 ft]) provides little protection during storms (NPS 2011).



Figure 11. NPS broken concrete breakwaters along the York River (#87–91 Figure 9). View is to the southeast.

Downriver from the breakwaters there is a revetment (#92 Figure 9) and the 2,020-meter (6,630 ft) long, concrete Yorktown Naval Weapons Station pier (#94 Figure 9). The original pier was built in 1919 of timber, and rebuilt in 1962 with concrete (Piggott 2008). Historic park drawings show that the revetment was built prior to 1962 (Dorothy Geyer, email, 5/3/12).

Combined erosion from Hurricane Isabel in 2003, Tropical Storm Ernesto in 2006, and a nor'easter in 2009 prompted emergency construction of two short revetments to protect the Parkway (#93 & 97 Figure 9) (NPS 2011). At kilometer 5, just downriver from the NPS breakwaters, the top of the bank had eroded within 1.8 m (6 ft) of the Parkway (NPS 2011).

Yorktown

Until the mid-1970s a wide beach existed at Yorktown (Milligan et al. 1996). Over time the beaches along the waterfront eroded as sediment supply decreased due to the hardening of updrift shorelines (Milligan et al. 1996). In response to shoreline erosion, a stone revetment was built along the picnic area in 1978 (#121 Figure 9) (Hardaway et al. 2005). After a severe storm in November 1985, a new revetment, offshore breakwater, and beach fill were installed in early 1986 (Milligan et al. 1996). The small breakwater protected a storm drain and was eventually removed in 1999.

Continued erosion of Yorktown Beach led to the development of a breakwater system. Twelve breakwaters and a revetment were installed in four phases from 1994 to 2005 (Figures 12 & 13). In phase one, two breakwaters (#115 & 116 Figure 12) were installed in September 1994 (Milligan et al. 1996). In the fall/winter of 1998–1999 phase two was implemented and two additional breakwaters (#117 & 118 Figure 12 and Figure 13) were built on the southern end of the beach (VHB 1998). Phase three began in June 2000 and included three new breakwaters (#110, 112, and 113 Figure 12) and a revetment (#109 & 114 Figure 12) (Hardaway et al. 2005).

In 2005, three additional breakwaters were added to the northern reach (#99 & 101, 102, & 104 Figure 12) and one at the very southern end (#120 Figure 12) (VHB 2004). The two floating docks were also built in 2005 (#108 & 111 Figure 12). Lastly, a small rock breakwater was built on the northern end close to the shore in 2006 or 2007 (#100 Figure 12) (VHB 2006). All of the breakwaters were accompanied by small beach nourishment projects.



Figure 12. Map of coastal structures in Yorktown. Yellow shading shows the park boundary (image from ESRI Bing Maps basemap layer 2012).



Figure 13. Rock breakwaters at Yorktown Beach along the York River (#116–118 Figure 12). Coleman Bridge in the background carries U.S. Highway 17. View is to the northwest.

Downriver from the picnic area there are three naturally occurring headlands, known as Point of Rocks (Figure 5). These headlands were hardened with revetment in the early 1960s and reinforced in 1979 (#122 & 123 Figure 9) (Hardaway et al. 1992). Spiral-shaped pocket beaches exist behind the headlands and have reached a dynamic equilibrium over the past 50 years

(Hardaway et al. 2006). Continuing downstream, private property is intermingled with NPS property to the park boundary at the U.S. Coast Guard Training Center. Most of this section has been treated with a rock revetment (#124 & 131 Figure 9). Historic drawings show that a revetment was built along some of this section in the late 1930s (NPS 1937) and repaired circa 1979 (USDT 1979). Adjacent to the southern end of the park is the U.S. Coast Guard pier, which extends 630 m (2,070 ft) offshore (full pier length is 1,530 m [5,020 ft]) (#134 Figure 9). Historic nautical charts show the pier was built prior to 1943 and was extended by 1967 (NOAA 2012).

Beach Nourishment

In 2002, a total of approximately 17,600 m³ (23,000 yd³) of sand was placed behind various breakwaters and sills along the Jamestown Island shoreline to create stable substrates for establishing wetland vegetation (Hardaway et al. 1992). Beach nourishment has occurred along the Yorktown shoreline, primarily in conjunction with breakwater construction, since at least 1986.

On November 4–5, 1985 a severe storm eroded a large amount of sand from Yorktown Beach and destroyed the backshore sidewalk. In response, a revetment and breakwater were installed and beach nourishment was applied in early 1986 (Milligan et al. 1996). Continued erosion threatened the revetment over time and a small beach nourishment project occurred in 1989, but the sediment was quickly lost (Milligan et al. 1996).

In September 1994, 5,730 m³ (7,500 yd³) of beach fill was placed behind two newly installed breakwaters on central Yorktown Beach (Milligan et al. 1996). Roughly 460 m³ (600 yd³) of sand was dredged from under the Coleman Bridge in May 1996 and placed on central Yorktown Beach (Milligan et al. 1996). An additional 7,650 m³ (10,000 yd³) of sand was applied to the beach in fall/winter of 1998–1999 when two additional breakwaters were constructed towards the southern end of the beach (Hardaway et al. 2005). After Hurricane Isabel in 2003, 765 m³ (1,000 yd³) was placed on Yorktown Beach in the winter of 2003 to fill scour holes (Hardaway et al. 2005). An additional unknown volume of fill was placed at various locations along the Yorktown shore when eight breakwaters were installed from 2000 to 2007.

Fill Projects

Prior to the late 18th century Jamestown Island was connected to the mainland by a narrow isthmus. Over time the isthmus was breached and the island became separated. The isthmus was rebuilt from March to November 1955 with sediment dredged from the James River (HAER 1995a). When complete, the fill spanned nearly 915 m (3,000 ft) and was constructed to an elevation of 2.4 m (8 ft) with an embankment crest width of 12 m (40 ft) (HAER 1995a) (Figure 14).

The mouths of College Creek (512,750 m³ [670,648 yd³]) and Mill Creek (266,700 m³ [348,833 yd³]), and five other locations between College and Mill Creeks (total of 443,840 m³ [580,519 yd³]) (proposed volumes from NPS 1941) were filled with sediment dredged from the James River in 1955 for parkway construction (HAER 1995b) (Figure 14).

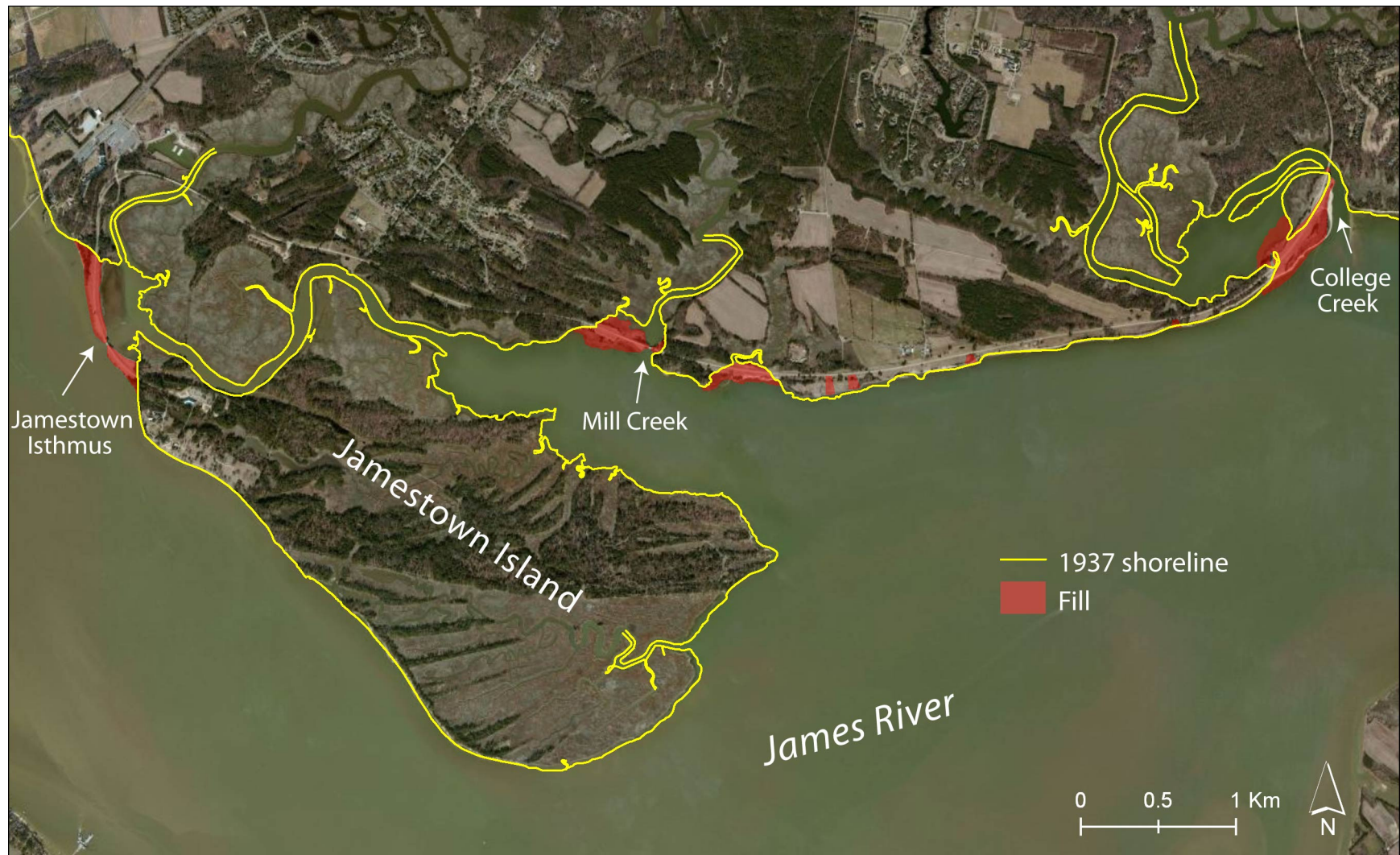


Figure 14. The 1937 Jamestown shoreline overlain on a recent aerial photograph. Comparison of the historic shoreline with the image shows where fill was placed at the Jamestown Isthmus and the mouths of Mill Creek and College Creek. Other fill locations along the northern James River shoreline are very approximate and are from NPS (1941) (1937 shoreline from S. Hardaway, image ESRI Bing Maps basemap layer 2012).

Along the York River, the mouths of Felgates Creek and Indian Field Creek were filled in August 1931 for construction of the Colonial Parkway at a cost of \$197,300 (HAER 1988). The creek mouths were filled with sand and gravel removed from the bottom of the York River (NPS 2011). Fill length was 365 m (1,200 ft) and 1,340 m (4,400 ft) at Felgates Creek and Indian Field Creek, respectively, and included a 30-meter (100 ft) wide embankment that was 3 m (11 ft) above sea level (HAER 1995b). During construction the mouth of Indian Field Creek was rerouted to the north (the mouth had previously faced east adjacent to a historic spit) (Figure 15) (USACE 1931).

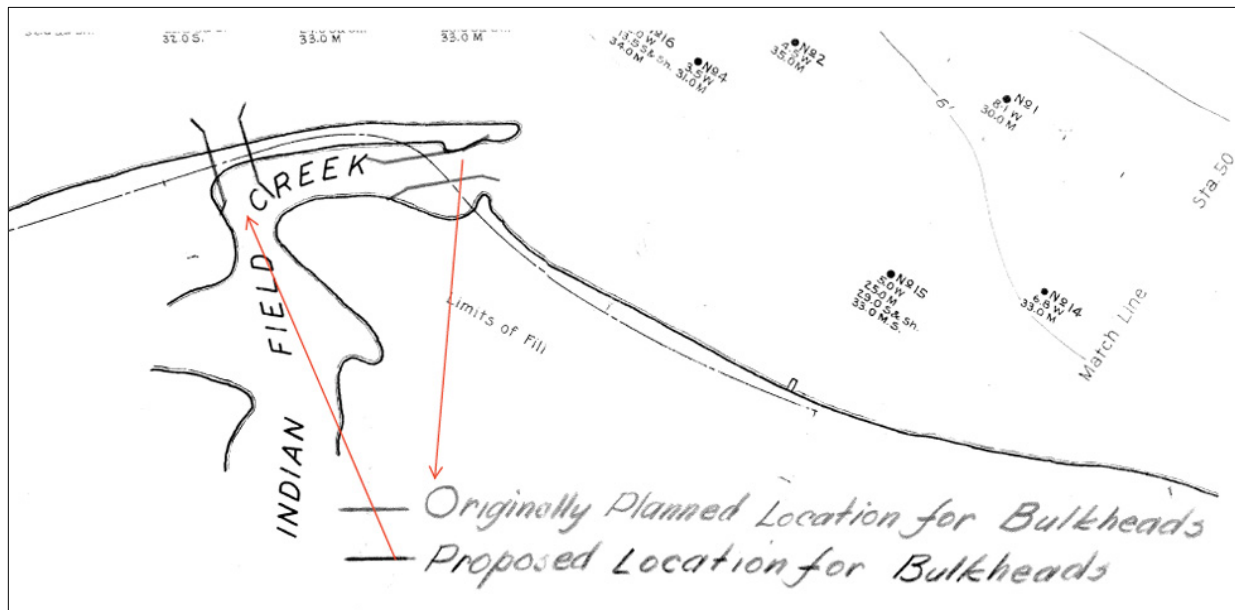


Figure 15. United States Corps of Engineers plan drawing showing the rerouting of the mouth of Indian Field Creek in the 1930s (USACE 1931).

Impacts

In response to ongoing coastal erosion, a wide range of coastal engineering structures have been constructed in COLO in an effort to preserve cultural sites and the Colonial Parkway, mitigate damages, and limit further erosion of the river banks (NPS 2011). A few notable structures that significantly affect natural sediment processes are discussed below in detail. Coastal engineering structures may have other local or long-term impacts that are not addressed here.

Jamestown Seawall

The Jamestown seawall (#13 Figures 6, 7 & 16) was designed and built by the USACE from 1900–1905 (USACE 2002). This 730-meter (2,395 ft) long concrete structure protects the original settlement site and has eliminated bank erosion since its installation. The seawall in conjunction with adjacent hard structures (most notably revetment #14 Figure 6) effectively holds the Historic Jamestowne shoreline in place.

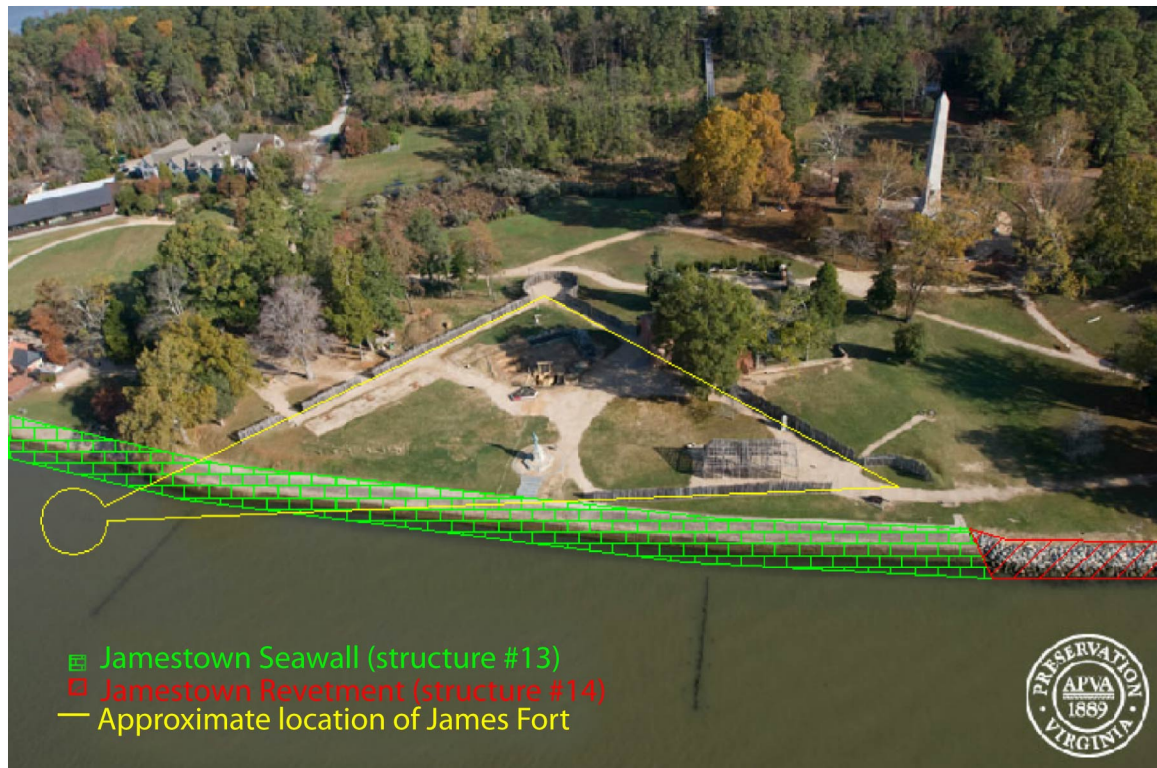


Figure 16. Aerial image of the Jamestown seawall. View is to the northeast (modified from PV 2012).

Historically, this area was actively eroding. In the three hundred years from the first settlement to the construction of the seawall the shoreline receded nearly 120 m (400 ft), suggesting an average shoreline change rate of about -0.4 m/yr (-1.3 ft/yr) (Johnson et al. 2001). It is therefore estimated that the Jamestown seawall has potentially preserved more than 30 m (100 ft) of shoreline from eroding over the last century. However, the result of this armoring has also deprived Jamestown Island and the surrounding areas of a sediment source. This has likely contributed to the need for additional coastal stabilization in downstream locations.

Jamestown Island Breakwaters

Much of Jamestown Island is armored with coastal structures. In 2002 a large shoreline management project was completed that involved construction of 32 breakwaters, 11 sills, and extensions off 3 existing revetments (#15–32, 34–60 Figure 6). The impetus for this project was long-term shoreline retreat on Jamestown Island, which averaged -0.2 m/yr (-0.7 ft/yr) from 1937–1994 (Milligan et al. 2010).

In general, breakwaters are designed such that some wave energy is dissipated over the structure, while the remaining wave energy is diffracted around the structure. The diffracted waves then break at angles to the coast, driving longshore currents and sediment transport towards the center of the structure (Hsu and Silvester 1990). Depending on the conditions, the accretion may form into a bulge (salient) or connect the structure to the shoreline (tombolo).

In 2011 the breakwaters on Jamestown Island had accretion formations at various stages of development (Figure 17). Breakwaters #23, 24 and 37 (Figure 17) had attached formations, while breakwaters #25 and 26 had only minor accretion bulges. In both cases, the system will ideally reach a dynamic equilibrium and the natural flow of sediment will be able to bypass the structure. As a regional approach to sediment management, the Jamestown Island breakwater system was designed to armor existing headlands and fortify the shoreline at intervals such that equilibrium beaches may form to stabilize the backshore (Hardaway et al. 1999).



Figure 17. Aerial imagery of Jamestown Island breakwaters (images from ESRI Bing Maps basemap layer 2012).

Additional impacts include possible limited leeward (bay) circulation during periods of low wave energy or within sheltered areas (namely along the protected north side of Jamestown Island). This can adversely affect local biota through potential pollutant build up and shifting preferential habitat for vegetation and local biodiversity (French 2001). However, these structures may also preserve local marshes and intertidal habitat for wildlife (Hardaway et al. 1999).

As the island is dominated by low-lying marshes, this area is particularly susceptible to shoreline retreat and inundation with increased sea level. Future impacts of these structures may include localized flow alterations and a lack of sediment supply to surrounding areas.

Yorktown Breakwaters

The Yorktown breakwater field is a system of fourteen breakwaters (#99–102, 104, 107, 110, 112, 113, 115–118, and 120 Figure 12) installed along the Yorktown shoreline between 1994–2005 that affect the local sediment transport and landscape. These structures, unlike those found along Jamestown Island, were designed and built to maintain a sandy beach for recreation as well as stabilize the eroding shoreline (Milligan et al. 1996). As is typical with these installations, beach nourishment was also employed to further stabilize the backshore upon their initial construction.

Along this stretch of river the sand and gravel shoreline is backed by high bluffs, which have historically supplied the material for Yorktown's beaches (Milligan et al. 1996). Over time, upstream hardening has limited the local sediment supply, exacerbating erosion. The construction of the breakwater system at Yorktown is the latest attempt, following revetments and individual breakwaters, to stabilize the city's shoreline.

Beyond limiting sediment to the system, the breakwaters also impact local hydrodynamics. Sand has been impounded leeward of the structures creating tombolos (Figure 12), amplifying circulation patterns between structures. During periods of intense wave action this system of structures can be potentially hazardous to recreational users as strong rip currents may develop (Silvester and Hsu 1993).

Jamestown Isthmus Fill

Jamestown Island was historically connected to the mainland by a natural, narrow isthmus. The land bridge gradually eroded until it became fully separated in the late 18th century (Figure 18) (John Milner Associates et al. 2006). Upon the demise of the isthmus, Sandy Bay began to encroach upon the marshlands of Back River due to wave action, while a confluence developed between Back River and Powhatan Creek (Johnson et al. 2001). These actions occurred until the isthmus was artificially re-developed in 1955 (Figure 19) for the 350th anniversary of the Jamestown settlement. The incorporation of this substantial amount of fill altered tidal currents and terrestrial river flow from the Back River and Powhatan Creek into the James River.



Figure 18. Historic aerial image of the Jamestown Island area (exact date unknown, but it does predate construction of the artificial isthmus in 1955). Jamestown Island is in the middle of the image with the James River in the distance. View is to the southeast (from Cotter and Hudson 2005).

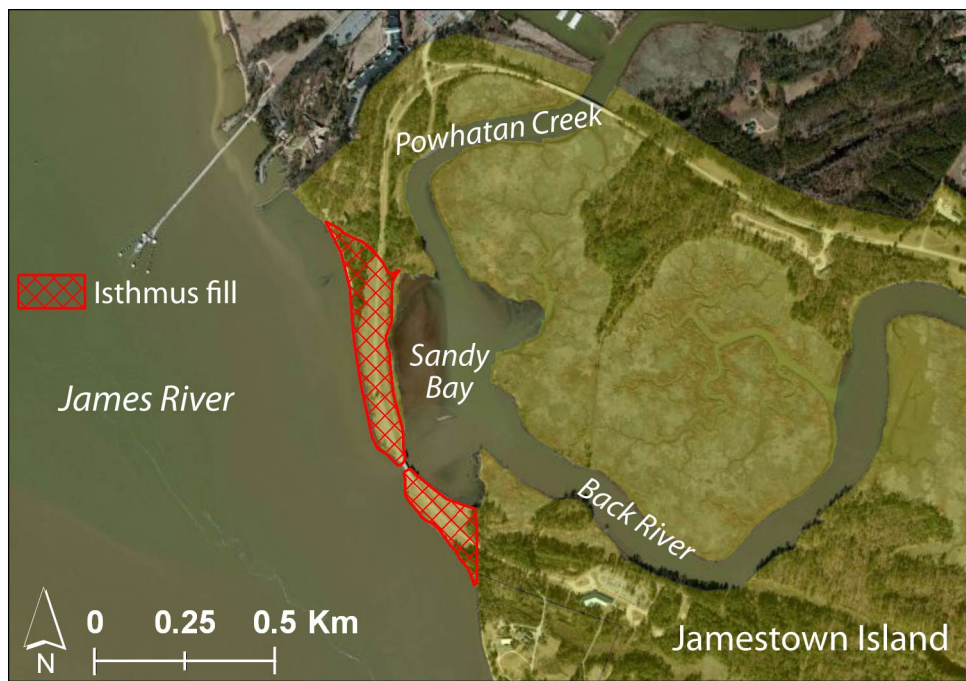


Figure 19. Aerial image of the Jamestown Island isthmus area. Yellow shading shows park boundary (image ESRI Bing Maps basemap layer 2012).

Since its construction, the isthmus has protected the Back River marshes and split the flow of Powhatan Creek into the Back and James rivers. If natural processes had continued unimpeded it is likely that both shorelines along with the Back River marsh system would have experienced further retreat. The change in flow patterns now affords less sediment into Sandy Bay and allows for littoral transport along the shoreline. The current isthmus consists of local sediments mined from the James River and contrasts with the surrounding Jamestown Island marshlands and pine-oak forests (HAER 1995a, Johnson et al. 2001).

Discussion and Recommendation for Further Study

COLO's shoreline has been highly manipulated by a system of coastal engineering structures, with an emphasis on breakwaters and revetments. These structures were designed to stabilize the shoreline to protect cultural resources, and have been mostly successful in meeting their objective. However, the coastal engineering structures have also likely altered the natural sediment transport processes in the region.

Armoring within the park, as well as in adjacent areas, has limited the local sediment supply to the region's beaches. The stabilization strategies employed in the park are common along the Chesapeake Bay system where 85% of the shoreline is privately owned (Chesapeake Bay Program 2012) and largely engineered. Given the overall erosive nature of the system, coupled with a lack of available sediment supply, unarmored regions are particularly vulnerable to wave action and erosion processes.

Much of the park's backshore environment (in particular the marshes and low upland banks of Jamestown Island) is at an elevation of less than 1 m (3.2 ft) above sea level (Figure 20) (Saunders et al. 2010). These low-lying lands are susceptible to increased erosion and flooding in light of the Intergovernmental Panel on Climate Change's sea level rise projections of 0.18 to 0.59 m (0.59 to 1.9 ft) by 2100 (IPCC 2007). Hurricane Isabel in 2003 clearly illustrated the park's vulnerability to inundation when storm surge breached revetments as high as 2 m (6 ft) along the York River and flooded the Visitor Center and Glasshouse remains on Jamestown Island (Thornberry-Ehrlich 2005, Saunders et al. 2010).

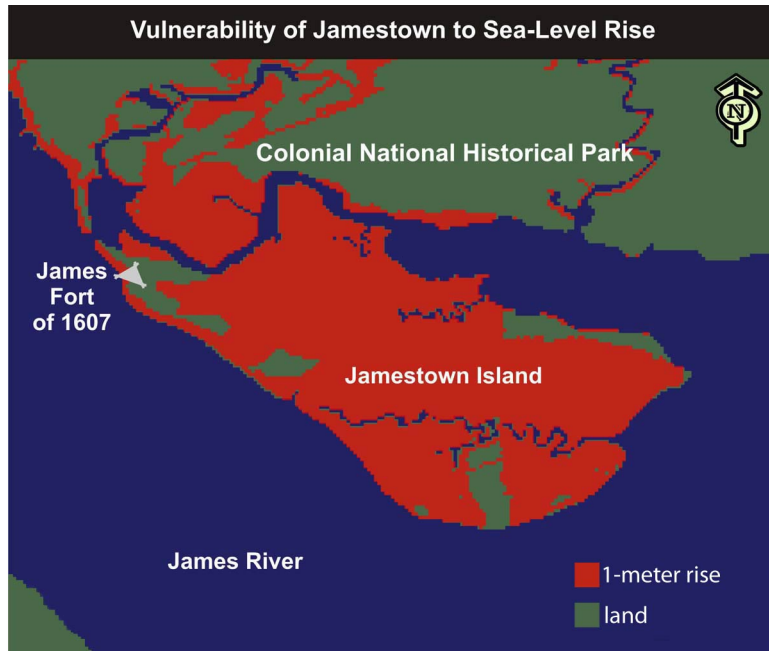


Figure 20. Vulnerability of Jamestown Island to sea level rise. Red shading represents areas that would be inundated with a 1-meter (3.2 ft) rise in sea level (adapted from Saunders et al. 2010).

In general, sediment transport patterns within the park are not fully understood. A number of locations continue to exhibit localized zones of erosion that cause concern for park management, namely Bellfield Straight along the York River. Future research should focus on developing a quantitative system-wide sediment budget. This information should include data related to sediment sources and sinks and could aid park officials in making informed, long-term management decisions regarding flooding and erosion hazards in light of anticipated climate change.

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Appendix A. Glossary

Accretion: The accumulation of sediment on a beach, deposited by natural processes.

Beach Nourishment: The introduction of sediment along a shoreline to increase or protect the size of a beach (includes dune and berm construction and nearshore disposal of sediment for the purpose of shoreline stabilization).

Breakwater: Shore-parallel structures that reduce the amount of wave energy reaching a harbor or stretch of shoreline located behind the structure. Breakwaters are similar to natural bars, reefs or nearshore islands and are designed to dissipate wave energy. The reduction in wave energy results in gradients in littoral drift, causing sediment deposition in the sheltered area behind the breakwater. Some longshore sediment transport may continue along the coast behind the breakwater. Structures can be detached, attached or utilized as a headland control feature depending on design and functionality characteristics.

Bulkhead: Vertical structures or partitions, usually running parallel to the shoreline, for the purpose of retaining upland soils while providing protection from wave action and erosion. Bulkheads are either cantilevered or anchored sheet piles or gravity structures such as rock-filled timber cribs and gabions, concrete blocks or armorstone units.

Dike: Earthen structures (dams) that keep elevated water levels from flooding interior lowlands. The protected area is often below sea level. In open coast areas, dikes that separate low-lying areas from open water are often constructed with a revetment or similar armor layer on the open waterside to protect the dike from wave action and erosion.

Dredging: The mechanical removal of sediment, often used to increase or maintain the depth of a navigable waterway.

Erosion: The wearing away of land and the removal of beach or dune sediments by wind and wave action, tidal currents, wave currents, or drainage.

Groin: Structures that extend perpendicular or at nearly right angles from the shore and are relatively short when compared to navigation jetties at tidal inlets. Often constructed in groups called groin fields, their primary purpose is to trap and retain sand. Groins can be constructed from a wide range of materials including armorstone, pre-cast concrete units or blocks, rock-filled timber cribs and gabions, steel sheet pile, timber sheet pile, or grout filled bags and tubes.

Headland Control: The concept of systematically placing structures (typically breakwaters) to create artificial headlands in an effort to promote equilibrium beach formation. Bays are formed between these headlands, such that diffraction and refraction cause waves to develop perpendicular to the coast. This is intended to result in a stable shoreline even if sediment is still passing through a system of headlands. This concept is often employed as a regional approach to shore protection.

Jetty: Structures that extend perpendicular or at nearly right angles from the shore commonly used to limit the volume of sediment deposited in inlet channels and prevent inlet migration.

Levee: Flood protection structure that holds back water during flood stage, typically built along a river to protect against flooding.

Pier: A platform extending over water from a shore that is supported by piles or pillars, used to secure, protect, and provide access to ships or boats.

Revetment: A cover or facing of material placed directly on an existing slope, embankment or dike to protect the area from waves and strong currents. Revetments are designed to armor and protect the land behind them and are commonly constructed using armorstone (high wave energy environments) or riprap stone (lower wave energy environments) in combination with smaller stone and geotextile fabrics. Other construction materials include gabions, poured concrete (usually in stepped fashion), pre-cast concrete blocks, and grout filled bags. Structures can be partially detached from the shore (spur) depending on design considerations.

Seawall: Vertical structures used to protect backshore areas from heavy wave action, and in lower wave energy environments, to separate land from water. They can be constructed using a range of materials including poured concrete, steel sheet pile, concrete blocks, gabions, sandbags, or timber cribs.

Sill: Combination of elements from offshore breakwaters and rock revetments, typically built relatively close to shore, continuous and low-lying. Sills are generally built in lower wave energy regimes with the intent of reducing the wave climate and establishing marsh ecosystems or beaches.

Appendix B. Coastal Structure Data

ID	Location	Structure	Material	Year Built	Year Maintained	Length (m)	¹ Source
1	Jamestown-Scotland Ferry	Pier	Concrete	1950s		453	1
2	Jamestown Settlement	Revetment	Rock	1994		63	2
3	Jamestown Settlement	Breakwater	Rock	1994		237	2
4	Jamestown Settlement	Pier	Wood	1994		104	2
5	Jamestown Settlement	Revetment	Rock	1994		63	2
6	Jamestown Settlement	Pier	Wood	1992		34	2
7	Jamestown Settlement	Breakwater	Rock	1994		125	2
8	Jamestown Glass House	Revetment	Rock	1956		120	3
9	Jamestown Glass House	Revetment	Rock	1956		105	3
10	Jamestown Isthmus	Revetment	Rock	1956	1996	529	3
11	Jamestown Isthmus	Revetment	Rock	1996		42	4
12	Jamestown Isthmus	Revetment	Rock	before 1978		391	5
13	Jamestown Historic Site	Seawall	Concrete	1901–1905	1969, 1982	731	6,3
14	Jamestown Historic Site	Revetment	Rock	1935–1936		966	3
15	Jamestown Island	Breakwater	Rock	2002		23	4
16	Jamestown Island	Revetment	Rock		end spurs - 2002	149	4
17	Jamestown Island	Breakwater	Rock	2002		28	4
18	Jamestown Island	Revetment	Rock		end spurs - 2002	161	4
19	Jamestown Island	Breakwater	Rock	2002		75	4
20	Jamestown Island	Breakwater	Rock	2002		74	4
21	Jamestown Island	Breakwater	Rock	2002		74	4
22	Jamestown Island	Breakwater	Rock	2002		74	4
23	Jamestown Island	Breakwater	Rock	2002		74	4
24	Jamestown Island	Breakwater	Rock	2002		73	4
25	Jamestown Island	Breakwater	Rock	2002		57	4
26	Jamestown Island	Breakwater	Rock	2002		57	4
27	Jamestown Island	Breakwater	Rock	2002		58	4
28	Jamestown Island	Breakwater	Rock	2002		56	4
29	Jamestown Island	Breakwater	Rock	2002		58	4
30	Jamestown Island	Breakwater	Rock	2002		58	4
31	Jamestown Island	Breakwater	Rock	2002		58	4
32	Jamestown Island	Breakwater	Rock	2002		59	4
33	Jamestown Island	Revetment	Rock	before 1957	end spurs - 2002	353	3,4
34	Jamestown Island	Breakwater	Rock	2002		42	4

ID	Location	Structure	Material	Year Built	Year Maintained	Length (m)	Source
35	Jamestown Island	Breakwater	Rock	2002		58	4
36	Jamestown Island	Breakwater	Rock	2002		24	4
37	Jamestown Island	Breakwater	Rock	2002		20	4
38	Jamestown Island	Breakwater	Rock	2002		17	4
39	Jamestown Island	Breakwater	Rock	2002		26	4
40	Jamestown Island	Breakwater	Rock	2002		14	4
41	Jamestown Island	Breakwater	Rock	2002		16	4
42	Jamestown Island	Breakwater	Rock	2002		28	4
43	Jamestown Island	Breakwater	Rock	2002		24	4
44	Jamestown Island	Breakwater	Rock	2002		29	4
45	Jamestown Island	Sill	Rock	2002		44	4
46	Jamestown Island	Breakwater	Rock	2002		27	4
47	Jamestown Island	Breakwater	Rock	2002		27	4
48	Jamestown Island	Breakwater	Rock	2002		22	4
49	Jamestown Island	Breakwater	Rock	2002		19	4
50	Jamestown Island	Sill	Rock	2002		26	4
51	Jamestown Island	Breakwater	Rock	2002		57	4
52	Jamestown Island	Sill	Rock	2002		38	4
53	Jamestown Island	Sill	Rock	2002		52	4
54	Jamestown Island	Sill	Rock	2002		132	4
55	Jamestown Island	Sill	Rock	2002		50	4
56	Jamestown Island	Sill	Rock	2002		110	4
57	Jamestown Island	Sill	Rock	2002		46	4
58	Jamestown Island	Sill	Rock	2002		103	4
59	Jamestown Island	Sill	Rock	2002		116	4
60	Jamestown Island	Sill	Rock	2002		69	4
61	Jamestown Isthmus	Bulkhead	Wood	before 1990		205	7
62	Jamestown Isthmus	Bulkhead	Wood	before 1990		502	7
63	Powhatan Creek	Sill	Rock	2002		119	4
64	Mill Creek	Revetment	Rock	before 1989		78	7
65	Mill Creek	Bulkhead	Wood	1947–1948		47	8
66	Mill Creek	Revetment	Rock	before 1984		58	8
67	Mill Creek	Bulkhead	Wood	1947–1948		43	8
68	Mill Creek	Revetment	Rock	before 1984		217	8
69	Northern James River Shore	Revetment	Rock	before 2004		98	7
70	Northern James River Shore	Bulkhead	Wood	before 2004		48	7

ID	Location	Structure	Material	Year Built	Year Maintained	Length (m)	Source
71	Northern James River Shore	Revetment	Rock	before 2004		239	7
72	Northern James River Shore	Revetment	Rock	before 2004		192	7
73	College Creek	Bulkhead	Wood	1947–1948		48	8
74	College Creek	Revetment	Rock	before 2007	West end - 2010	42	5
75	College Creek	Bulkhead	Steel	2011		23	5
76	College Creek	Revetment	Rock	2011		25	5
77	College Creek	Bulkhead	Steel	2011		14	5
78	College Creek	Revetment	Rock	2011		16	7
79	College Creek	Revetment	Rock			13	
80	Felgates Creek	Revetment	Rock	before 1979	1979	27	9
81	Felgates Creek	Revetment	Rock	1979		6	9
82	Felgates Creek	Revetment	Rock	1979		16	9
83	Bellfield Straight	Revetment	Rock	Late 1930s		2,409	9
84	Indian Field Creek	Revetment	Rock	before 1994		418	7
85	Down river from Indian Field Crk	Sill	Rock	before 1962		192	5
86	Down river from Indian Field Crk	Sill	Rock	before 1962		153	5
87	Down river from Indian Field Crk	Breakwater	Concrete	May 1985		11	10,11,12
88	Down river from Indian Field Crk	Breakwater	Concrete	May 1985		10	10,11,12
89	Down river from Indian Field Crk	Breakwater	Concrete	May 1985		10	10,11,12
90	Down river from Indian Field Crk	Breakwater	Concrete	May 1985		9	10,11,12
91	Down river from Indian Field Crk	Breakwater	Concrete	May 1985		9	10,11,12
92	Down river from Indian Field Crk	Revetment	Rock	before 1962		329	5
93	Down river from Indian Field Crk	Revetment	Rock	2007		240	4
94	Yorktown Naval Weapons Station	Pier	Concrete	1940s		2,019	13
95	Down river from Yorktown NWS	Revetment	Rock	before 1962		54	5
96	Down river from Yorktown NWS	Revetment	Rock	before 1962		120	5
97	Down river from Yorktown NWS	Revetment	Rock	2007		63	4
98	York River Cliffs & Fusiliers Redoubt	Revetment	Rock	before 1937	East end - 2005	952	4
99	Yorktown waterfront	Breakwater	Rock	2005		44	4
100	Yorktown waterfront	Breakwater	Rock	2005		41	4
101	Yorktown waterfront	Breakwater	Rock	2005		54	4
102	Yorktown waterfront	Breakwater	Rock	2005		48	4
103	Yorktown waterfront	Pier	Wood	2005/2006	2006, 2007	112	4
104	Yorktown waterfront	Breakwater	Rock	2005		53	4
105	Yorktown waterfront	Revetment	Rock	2005		35	4
106	Yorktown waterfront	Revetment	Rock	2000		72	4

ID	Location	Structure	Material	Year Built	Year Maintained	Length (m)	¹ Source
107	Yorktown waterfront	Breakwater	Rock	2000		30	4
108	Yorktown waterfront	Pier	Wood	2005		148	4
109	Yorktown waterfront	Revetment	Rock	June 2000		155	14
110	Yorktown waterfront	Breakwater	Rock	June 2000		29	14
111	Yorktown waterfront	Pier	Wood	2005		284	4
112	Yorktown waterfront	Breakwater	Rock	June 2000		25	14
113	Yorktown waterfront	Breakwater	Rock	June 2000	Extended 2005	16	14
114	Yorktown waterfront	Revetment	Rock	June 2000		33	14
115	Yorktown waterfront	Breakwater	Rock	Sept 1994		52	10,15
116	Yorktown waterfront	Breakwater	Rock	Sept 1994		44	10,15
117	Yorktown waterfront	Breakwater	Rock	1998		38	
118	Yorktown waterfront	Breakwater	Rock	1998		46	
119	Yorktown waterfront	Pier	Wood	early 1980s	2005	103	8,13
120	Yorktown waterfront	Breakwater	Rock	2005		44	4
121	Yorktown Picnic Area	Revetment	Rock	1978		467	14
122	Point of Rocks	Revetment	Rock	early 1960s	1979	67	10
123	Point of Rocks	Revetment	Rock	early 1960s	1979	76	10
124	Yorktown Battlefield	Revetment	Rock	before 1937	1979, 2007, 2009	1,612	4
125	Moore House	Pier	Wood	before 2004, after 1994		23	7
126	Moore House	Pier	Wood	before 2004, after 1994		50	7
127	Moore House	Pier	Wood	before 2004, after 1994		62	7
128	Moore House	Pier	Wood	before 2004, after 1994		48	7
129	Moore House	Pier	Wood	before 2004, after 1994		20	7
130	Moore House	Pier	Wood	before 2004, after 1994		51	7
131	Moore House	Revetment	Rock	before 1937		254	4
132	Moore House	Pier	Wood	before 1996, after 1994		30	7,13
133	U.S. Coast Guard Training Center	Seawall	Concrete	before 1994		63	7
134	U.S. Coast Guard Training Center	Pier	Concrete	before 1943		1,530	13

¹ Source: 1: Pers. Comm. Wes Ripley (Ferry Facility Manager), 2: Pers. Comm. Michael Shuflat (JT-YT Foundation), 3: John Milner Associates et al. (2006), 4: VHB (2004), 5: Pers. Comm. Dorothy Geyer (NPS), 6: USACE (2002), 7: Google Earth, 8: NPS (1941), 9: NPS (1979), 10: NPS (2011), 11: Hardaway et al. (1991), 12: Hardaway et al. (2006), 13: NOAA (2012), 14: Hardaway et al. (2005), 15: Milligan et al. (1996).

Appendix C. Fill Project Data

Location	Year	¹ Volume (m ³)	² Area (m ²)	³ Source
Felgates Creek	1931		44,964	1,2
W. Indian Field Creek	1931		27,315	1,2
E. Indian Field Creek	1931		39,400	1,2
N. Jamestown Isthmus	1955		24,630	1,3
S. Jamestown Isthmus	1955		59,990	1,3
W. Mill Creek	1947–1948	266,702	71,390	4
E. Mill Creek	1947–1948		5,022	4
Between Mill and College Creek	1947–1948	43,676	47,412	4
Between Mill and College Creek	1947–1948	43,676	6,126	4
Between Mill and College Creek	1947–1948	27,077	6,154	4
Between Mill and College Creek	1947–1948	65,915	3,399	4
Between Mill and College Creek	1947–1948	20,268	2,863	4
S. College Creek	1947–1948	512,747	137,041	4
S. College Creek bridge	1950s		923	1
N. College Creek bridge	1950s		409	1
TOTAL			477,039	

¹ Volumes are proposed volumes from NPS (1941) planning report.

² Area is very approximate.

³ Source: 1: Hardaway et al. (1999), 2: NPS (2011), 3: John Milner Associates et al. (2006), 4: NPS (1941).

Appendix D. Beach Nourishment Project Data

Location	Year	Renourishment Year	Volume (m ³)	¹ Length (m)	² Source
Yorktown Waterfront	1986	1988		113	1
Yorktown Waterfront	1994		5,700	201	1
Yorktown Waterfront	1996		450	110	1
Yorktown Waterfront	1998–1999		7,600	168	2
Yorktown Waterfront	2000			45	2
Yorktown Waterfront	2000			16	2
Jamestown Island	2002		1,610	57	3
Jamestown Island	2002		1,610	60	3
Jamestown Island	2002		1,610	51	3
Jamestown Island	2002		1,610	62	3
Jamestown Island	2002		1,070	61	3
Jamestown Island	2002		505	22	3
Jamestown Island	2002		250	33	3
Jamestown Island	2002		260	19	3
Jamestown Island	2002		250	22	3
Jamestown Island	2002		630	66	3
Jamestown Island	2002		380	48	3
Jamestown Island	2002		300	21	3
Jamestown Island	2002		200	12	3
Jamestown Island	2002		260	18	3
Jamestown Island	2002			6	4
Jamestown Island	2002		460	45	3
Jamestown Island	2002		300	23	3
Jamestown Island	2002		500	43	3
Jamestown Island	2002		510	22	3
Jamestown Island	2002		1,010	14	3
Jamestown Island	2002		1,260	57	3
Jamestown Island	2002		760	63	3
Powhatan Creek	2002		1,010	95	3
Yorktown Waterfront	2003		750	108	2
Yorktown Waterfront	2005			88	5
Yorktown Waterfront	2005			269	5
Yorktown Waterfront	2005			101	5

¹ Length is very approximate.

² Source: 1: Milligan et al. (1996), 2: Hardaway et al. (2005), 3: Hardaway et al. (1999), 4: USACE (2002), 5: VHB (2004).

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