Shoreline Evolution:
James City County, Virginia
James, York, and Chickahominy
River Shorelines

Data Report

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1 Introduction

Shoreline evolution is the change in the shore zone through time. Along the shores of Chesapeake Bay, it is a process and response system. The processes at work include winds, waves, tides and currents which shape and modify coastlines by eroding, transporting and depositing sediments. The shore line is commonly plotted and measured to provide a rate of change, but it is as important to understand the geomorphic patterns of change. Shore analysis provides the basis to know how a particular coast has changed through time and how it might proceed in the future.

The purpose of this data report is to document how the shore zone of James City County (Figure 1) has evolved since 1937. Aerial imagery was taken for most of the Bay region beginning that year and can be used to assess the geomorphic nature of shore change. Aerial photos show how the coast has changed, how beaches, dunes, bars, and spits have grown or decayed, how barriers have breached, how inlets have changed course, and how one shore type has displaced another or has not changed at all. Shore change is a natural process but, quite often, the impacts of man through shore hardening or inlet stabilization come to dominate a given shore reach. The change in shore positions along the rivers and larger creeks in the James City County will be quantified in this report. The shorelines of very irregular coasts, small creeks around inlets, and other complicated areas, will be shown but not quantified.

2 Shore Settings

2.1 Physical Setting

James City County has about 152 miles of tidal shoreline on several bodies water including James River, York River, and Chickahominy River. When all creeks and rivers that drain into these bodies of water are included, these areas have about 76 miles, 18 miles, and 58 miles, respectively (CCRM 1975). Historic shore change rate is -0.24 ft/yr along the James River and -1.65 ft/yr along the York River (Byrne and Anderson, 1978).

The coastal geomorphology of the County is a function of the underlying geology and the hydrodynamic forces operating across the land/water interface, the shoreline (Figure 2). The Atlantic Ocean has come and gone numerous times over the Virginia coastal plain over the past million years or so. The effect has been to rework older deposits into beach and lagoonal deposits at the time of the transgressions. The topography of James City is a result of these changes in shoreline. Majority of the County consists of the Lynnhaven Member of Tabb Formation which was deposited during the last high stand of sea level 135,000-75,000 years before present. The last low stand of sea level found the ocean coast about 60 miles to the east when sea level about 400 feet lower than today and the coastal plain was broad and low (Toscano, 1992). This low-stand occurred about 18,000 years ago during the last glacial maximum.
Figure 1. Location James City County within the Chesapeake Bay estuarine system.
Alluvium - Fine to coarse gravelly sand and sandy gravel, silt, and clay, light- to medium- gray and yellowish-gray. Mostly Holocene but, locally, includes low-lying Pleistocene(?). Terrace deposits. As much as 80 ft thick along major streams.

Shirley Formation (middle Pleistocene) - Light-to dark-gray and brown sand, gravel, silt, clay, and peat. Thickness is 0-80 ft.

Chesapeake Group (upper Pliocene to lower Miocene) - Fine to coarse, quartzose sand, silt, and clay; variably shelly and diatomaceous, deposited mainly in shallow, inner- and middle-shelf waters.

Poquoson Member of Tabb Formation - Medium to coarse pebbly sand grading upward into clayey fine sand and silt, light- to medium-gray; underlies ridge and swale topography (altitude ranges from sea level to 11ft) along the margin of Chesapeake Bay and in the lower and middle parts of Coastal Plain rivers. Unit is 0-40 ft thick.

Lynnhaven and Poquoson Members of Tabb Formation, undifferentiated.

Windsor Formation (lower Pleistocene or upper Pliocene) - Gray and yellow to reddish-brown sand, gravel, silt, and clay. Constitutes surficial deposits if extensive plain (alt. 85-95 ft) seaward of Surry scarp and coeval, fluvial-estuarine terrace west of scarp. Unit is 0-40 ft thick.

Bacons Castle Formation of Chesapeake Group (upper Pliocene) - Gray, yellowish-orange, and reddish-Brown

Sedgefield Member of Tabb Formation - Pebbly to bouldery, clayey sand and fine to medium, shelly sand grading upward to sandy and clayey silt. Unit constitutes surficial deposit of river- and coast parallel plains (Alt. 20-30ft) bounded on landward side by Suffolk and Harpersville scarps. Thickness is 0-50 ft.

Chesapeake Group (upper Pliocene to lower Miocene) - Fine to coarse, quartzose sand, silt, and clay; variably shelly and diatomaceous, deposited mainly in shallow, inner- and middle-shelf waters.

Figure 2. Geologic map of James City County (from Mixon et al., 1989)
As sea level began to rise and the coastal plain watersheds began to flood, shorelines began to recede. The slow rise in sea level is one of two primary long-term processes which cause the shoreline to recede; the other is wave action, particularly during storms. As shorelines recede or erode, the coarser bank material provides the sands for the offshore bars, beaches and dunes.

Sea level rise has been well documented in the Tidewater Region. Tide data collected at Sewells Point in Norfolk show that sea level has risen 0.17 inches/yr or 1.45 ft/century (http://www.co-ops.nos.noaa.gov/). This directly affects the reach of storms and their impact on shorelines. Anecdotal evidence of storm surge during Hurricane Isabel, which impacted North Carolina and Virginia on September 18, 2003, put it on par with the storm surge from the "storm of the century" which impacted the lower Chesapeake Bay in August 1933. Boon (2003) showed that even though the tides during the storms were very similar, the difference being only 1.5 inches, the amount of surge was different. The 1933 storm produced a storm surge that was greater than Isabel's by slightly more than a foot. However, analysis of the mean water levels for the months of both August 1933 and September 2003 showed that sea level has risen by 1.35 ft at Hampton Roads in the seventy years between these two storms (Boon, 2003). This is the approximate time span between our earliest aerial imagery (1937) and our most recent (2009) which means the impact of sea level rise to shore change is significant.

The shorelines of James City County are located on 3 different rivers (Figure 3). The majority of the shoreline is on the north shore of the James River and the western shore of the Chickahominy River while the remaining shoreline is on the south shore of the York River.

2.2 Hydrodynamic Setting

Tide range for James City varies (NOAA, 2011). At Kingsmill the mean tide range is 2.3 while the spring tide range is 2.7 ft (Figure 3). Farther up the river at Jamestown Island, the mean range is 2.0 ft and the spring range is 2.4 ft. On the Chickahominy River at Ferry Point, the mean range is 1.9 ft while the spring range is 2.3 ft. The mean tide range farther up the Chickahominy River at Wright Island Landing is 2.2 ft while the spring range is 2.7 ft. On the York River, at Roane Point near the James City County shoreline, the mean tide range is 2.8 ft with a spring range of 3.4 ft.

Wind data from Norfolk International Airport reflect the frequency and speeds of wind occurrences from 1960 to 1990 (Table 1). These data provide a summary of winds possibly available to generate waves. Winds from the north and south have the largest frequency of occurrence, but the north and northeast have the highest occurrence of large winds that will generate large waves. James City County has shorelines on the north and south shores of the Peninsula, thus having slightly different fetch conditions throughout the County. The Chickahominy River has the least amount of wave energy due smaller fetch.
Table 1. Summary wind conditions at Norfolk International Airport from 1960-1990.

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<th>Mid Range (mph)</th>
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</table>

*Number of occurrences "Percent

Hurricanes, depending on their proximity and path also can have an impact to James City’s coast. On September 18, 2003, Hurricane Isabel passed through the Virginia coastal plain. The main damaging winds began from the north and shifted to the east then south. Sewells Point tide station recorded wind gusts at 58 mph, a peak gust at 73 mph with a storm surge 7.9 ft (Beven and Cobb, 2004) and having water levels 7.9 ft above mean lower low water (MLLW). (NOAA, 2009). Hurricane Isabel was not the only recent tropical event to pass though the County; Tropical Storm Ernesto (September 1, 2006) brought wind speeds of 49 mph and a peak gust of 60 mph at the Dominion Terminal Associates station (NOAA, 2009) and water levels 5.5 ft above MLLW at the Sewells Point tide station (NOAA, 2009). James City County also was hit by The Veteran’s Day Storm on November 11, 2009 which had water levels of 7.4 ft above MLLW at Sewells Point with wind speeds at 20 mph with gusts 40 mph at Dominion Terminal Associates station (NOAA, 2009).
3  Methods

3.1  Photo Rectification and Shoreline Digitizing

An analysis of aerial photographs provides the historical data necessary to understand the suite of processes that work to alter a shoreline. Images of the James City Shoreline from 1937, 1953, 1963, 1994, 2002, 2007 and 2009 were used in the analysis. The 1994, 2002, 2007 and 2009 images were available from other sources. The 1994 imagery was orthorectified by the U.S. Geological Survey (USGS) and the 2002, 2007 and 2009 imagery was orthorectified by the Virginia Base Mapping Program (VBMP). The 1937, 1953, and 1963 photos were a part of the VIMS Shoreline Studies Program archives. The entire shoreline generally was not flown in a single day. The dates for each year are: 1937- April 7, 17, 22 and May 20; 1953- October 31, December 3, 8, 16, 17, and January 13, 1954; 1963 - February 22. We could not ascertain the dates the 1994 images were flown, but the 2002, 2007, and 2009 were all flown in February of their respective years.

The 1937, 1953, and 1963 images were scanned as tiffs at 600 dpi and converted to ERDAS IMAGINE (.img) format. These aerial photographs were orthographically corrected to produce a seamless series of aerial mosaics following a set of standard operating procedures. The 1994 Digital Orthophoto Quarter Quadrangles (DOQQ) from USGS were used as the reference images.

ERDAS Orthobase image processing software was used to orthographically correct the individual flight lines using a bundle block solution. Camera lens calibration data were matched to the image location of fiducial points to define the interior camera model. Control points from 1994 USGS DOQQ images provide the exterior control, which is enhanced by a large number of image-matching tie points produced automatically by the software. The exterior and interior models were combined with a digital elevation model (DEM) from the USGS National Elevation Dataset to produce an orthophoto for each aerial photograph. The orthophotographs were adjusted to approximately uniform brightness and contrast and were mosaicked together using the ERDAS Imagine mosaic tool to produce a one-meter resolution mosaic .img format. To maintain an accurate match with the reference images, it is necessary to distribute the control points evenly, when possible. This can be challenging in areas with lack of ground features, poor photo quality and lack of control points. Good examples of control points were manmade features such as road intersections and stable natural landmarks such as ponds and creeks that have not changed much over time. The base of tall features such as buildings, poles, or trees can be used, but the base can be obscured by other features or shadows making these locations difficult to use accurately. Some areas of the County were particularly difficult to rectify due to the lack of development when compared to the reference images.

Once the aerial photos were orthorectified and mosaicked, the shorelines were digitized in ArcMap with the mosaics in the background. The morphologic toe of the beach or edge of marsh was used to approximate low water. High water limit of runup is difficult to determine on much of the shoreline due to narrow or non-existent beaches against upland banks or vegetated cover. In areas where the shoreline was not clearly identifiable on the aerial photography, the
location was estimated based on the experience of the digitizer. The displayed shorelines are in shapefile format. One shapefile was produced for each year that was mosaicked.

Horizontal positional accuracy is based upon orthorectification of scanned aerial photography against the USGS digital orthophoto quadrangles. Vertical control is based on the USGS 30m DEM data. The 1994 USGS reference images were developed in accordance with National Map Accuracy Standards (NMAS) for Spatial Data Accuracy at the 1:12,000 scale. The 2002, 2007 and 2009 Virginia Base Mapping Program's orthophotography were developed in accordance with the National Standard for Spatial Data Accuracy (NSSDA). Horizontal root mean square error (RMSE) for historical mosaics was held to less than 20 ft.

Using methodology reported in Morton et al. (2004) and National Spatial Data Infrastructure (1998), estimates of error in orthorectification, control source, DEM and digitizing were combined to provide an estimate of total maximum shoreline position error. The data sets that were orthorectified (1937, 1953, and 1963) have an estimated total maximum shoreline position error of 20.0 ft, while the total maximum shoreline error for the four existing datasets are estimated at 18.3 ft for USGS and 10.2 ft for VBMP. The maximum annualized error for the shoreline data is +0.7 ft/yr. The smaller rivers and creeks are more prone to error due to their general lack of good control points for photo rectification, narrower shore features, tree and ground cover and overall smaller rates of change. For these reasons, some areas were only digitized in 1937 and 2009. It was decided that digitizing the intervening years would introduces more errors rather then provide additional information.

3.2 Rate of Change Analysis

The Digital Shoreline Analysis System (DSAS) was used to determine the rate of change for the County's shoreline (Himmelstoss, 2009). All DSAS input data must be managed within a personal geodatabase, which includes all the baselines for James City and the digitized shorelines for 1937, 1953, 1963, 1994, 2002, 2007, and 2009. Baselines were created about 200 feet or less, depending on features and space, seaward of the 1937 shoreline and encompassed most of the County's main shorelines but generally did not include the smaller creeks. It also did not include areas that have unique shoreline morphology such as creek mouths and spits. DSAS generated transects perpendicular to the baseline about 33 ft apart. For James City, this method represented about 48 miles of shoreline along 7,804 transects. Some of the marshes and small creeks in the Chickahominy watershed were difficult to quantify with shoreline change baselines. However, detailed shoreline measurements can be made for specific sites using the scale on the maps.

The End Point Rate (EPR) is calculated by determining the distance between the oldest and most recent shoreline in the data and dividing it by the number of years between them. This method provides an accurate net rate of change over the long term and is relatively easy to apply to most shorelines since it only requires two dates. This method does not use the intervening shorelines so it may not account for changes in accretion or erosion rates that may occur through time. However, Milligan et al. (2010a, 2010b, 2010c, 2010d) found that in several localities within the bay, EPR is a reliable indicator of shore change even when intervening dates exist. Average rates were calculated along selected areas of the shore; Segments are labeled in Appendix A.
4 Results and Discussion

James City County's shoreline through time is depicted in 24 map plates in Appendix A & B. The maps in Appendix A show all the digitized shorelines as well as the EPR (1937-2009) where available. The top plate also shows how the shoreline was segmented in order to summarize the individual rates of change. For each Segment, all the rates of change along the shore section were averaged over different time periods as shown in Table 2. The maps in Appendix B show the individual photos for each date and its digitized shoreline.

The location labels on the plates come from U.S. Geological Survey topographic maps, Google Earth, and other map sources and may not be accurate for the historical or even more recent images. They are for reference only.

4.1 Chickahominy River

Plates 1-8 are located within the Chickahominy River watershed. Plates 1 through 4 generally show very low erosion with a few areas of low to medium erosion and Segment 1 has an overall average erosion rate of -0.7 ft/yr (Table 2). However, at the end the Segment on Plate 4, a large portion of Yarmouth Island is eroding at a rate of -2 to -5 ft/yr. Segment 2 is shown on Plates 5 and 6 and has an average rate of change of -0.8 ft/yr, but the rate can vary from very low erosion to high erosion. The high erosion (-5 to -10 ft/yr) only occurs in one small area near an unnamed tidal creek on Plate 5. Segment 3 starts near the Barrett's Ferry Bridge and continues to the mouth of the Chickahominy River. The segment has an overall average rate of change of -0.8 ft/yr. Like other shoreline on the Chickahominy, sections of the shoreline can be eroding at rates up to -5 ft/yr. Plate 8 shows Gordon Creek where no rates of change were calculated.

4.2 James River

Plates 9-20 are located on the James River. Segment 4 on the extends for about 2.5 miles east of the confluence of the James and Chickahominy Rivers. Sections of this shoreline are eroding at rates up to -5 ft/yr, but the overall average rate of change is -1 ft/year (Table 2). Development near the start of Segment 4 on Plate 9 has some accretionary rates due to the construction of structures along the shoreline. Segment 5 starts on Plate 10 where the shore orientation changes from facing approximately south to facing southwest. This change in orientation protects the shoreline and results in an overall lower average rate of change, -0.4 ft/yr.

Plate 12 has a few unique features that have changed the shoreline. Man-made structures such as piers and a causeway for the Colonial Parkway were constructed making the man-made change rate of up to +10 ft/yr. The area behind the bridge in Sandy Bay shows an erosion rate of up to -10 ft/yr between 1937 and 2009. However, most of the erosion occurred prior to the installation of the causeway. Some shore change occurred in Sandy Bay after 1994 but it has been minor. Segment 7 starts near Church Point and continues the southwest-facing coast of Jamestown Island to Lower Point. It has an overall average erosion rate of -0.2 ft/yr.
Table 2. James City County shore segments and their average rate of change for various time periods. Rates are in ft/yr.

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</tr>
<tr>
<td>13</td>
<td>James R.</td>
<td>17-18</td>
<td>-0.6</td>
<td>-2.5</td>
<td>-0.5</td>
<td>2.2</td>
<td>-0.1</td>
<td>-1.4</td>
<td>-0.5</td>
<td>-0.9</td>
</tr>
<tr>
<td>14</td>
<td>James R.</td>
<td>18-19</td>
<td>-0.3</td>
<td>-2.2</td>
<td>0.1</td>
<td>0.1</td>
<td>1.2</td>
<td>-1.0</td>
<td>-0.3</td>
<td>-0.5</td>
</tr>
<tr>
<td>15</td>
<td>James R.</td>
<td>19-20</td>
<td>1.5</td>
<td>-2.7</td>
<td>-1.3</td>
<td>-1.1</td>
<td>1.1</td>
<td>-3.3</td>
<td>-0.7</td>
<td>-0.7</td>
</tr>
<tr>
<td>16</td>
<td>Skiffes Cr.</td>
<td>20</td>
<td>-6.4</td>
<td>-3.0</td>
<td>-7.6</td>
<td>-3.9</td>
<td>-2.6</td>
<td>-6.2</td>
<td>-5.9</td>
<td>-6.5</td>
</tr>
<tr>
<td>17</td>
<td>York R.</td>
<td>21</td>
<td>0.6</td>
<td>-3.2</td>
<td>-0.7</td>
<td>-1.8</td>
<td>-0.5</td>
<td>-0.3</td>
<td>-0.8</td>
<td>-0.8</td>
</tr>
<tr>
<td>18</td>
<td>York R.</td>
<td>22</td>
<td>-1.6</td>
<td>-2.9</td>
<td>-1.3</td>
<td>-2.2</td>
<td>-1.1</td>
<td>-0.5</td>
<td>-1.7</td>
<td>-1.7</td>
</tr>
<tr>
<td>19</td>
<td>York R.</td>
<td>23-24</td>
<td>-1.3</td>
<td>-2.7</td>
<td>-1.8</td>
<td>-3.6</td>
<td>-0.6</td>
<td>-3.5</td>
<td>-2.0</td>
<td>-1.8</td>
</tr>
<tr>
<td>20</td>
<td>York R.</td>
<td>24</td>
<td>-0.8</td>
<td>-0.5</td>
<td>-1.1</td>
<td>-2.8</td>
<td>-0.3</td>
<td>-1.1</td>
<td>-0.9</td>
<td>-0.7</td>
</tr>
</tbody>
</table>

Average: -0.7, 0.9, -1.2, -0.8, -0.5, -1.8, -0.7, -0.7, -0.9
shoreline near Church Point, the slight accretion rate is due to the construction of a seawall to protect the historical sites. Farther along the shoreline, more recent structures were built to hold the headlands. Segment 8, on Plates 13 and 14, extends from Lower Point to Black Point. The change in shoreline orientation allows more wave energy from the long easterly fetch to impact the shore thereby increasing the average overall erosion rate to -1.0 ft/yr (Table 2).

Segment 9 on Plate 14 is the northern shore of Jamestown Island on The Thorofare. It has an overall average erosion rate of -0.9 ft/yr (Table 2). Shore change along Back River, Segment 10, has been very low to low erosion with an overall average erosion rate of -0.8 ft/yr. Segment 11 is the northern shoreline of The Thorofare. Sections of this shoreline has been filled to create causeways for the Colonial Parkway. These man-made structures significantly affect the rate of change. Most of Segment 12 on the James River (Plate 16) shows very low accretion and erosion for the long-term rates. This is somewhat misleading in that the 1963 shoreline indicates that this whole stretch of shoreline was filled during construction of the Colonial Parkway (Table 2 and Appendix B). Between 1963 and 1994, Segment 12 eroded at -1.3 ft/yr and between 1994 and 2009 it eroded at an average overall rate of -1.2 ft/yr (Table 2).

Segment 13 starts at College Creek and extends downriver to the breakwaters at Kingsmill. The overall average long-term rate of change for this shoreline is -0.5 ft/yr (Table 2) although some areas are eroding at rates up to -5 ft/yr. The structures on Plate 18 show a man-made accretion rate. Segment 14 on Plates 18 and 19 starts at the structures at Kingsmill and extends downriver past Carter's Grove Plantation. Its shoreline overall is eroding at -0.3 ft/yr, but individual areas could be eroding up to -2 ft/yr. Segment 15 on Plates 19 and 20 faces southwest and has more areas of higher erosion, particularly near Skiffes Creek. The section of shoreline that shows accretion at the mouth of Skiffes Creek is likely due to dredge material placement between 1937 and 1953. Overall the average erosion rate for Segment 15 is -0.7 ft/yr, but that includes the man-made accretion. Segment 16 along Skiffes Creek has a very high erosion rate of -5.9 ft/yr between 1937 and 2009. This is partly due to dredging at the Creek mouth that widened the channel between 1937 and 1953. It seems likely that a large section of shoreline was removed. This widening, along with increased boat traffic, allowed more wave energy into the Creek eroding the marsh islands.

4.3 York River

Plates 21 - 24 are located on the south shore York River. The shoreline is very similar with areas of low erosion interspersed with areas of higher erosion. Generally, the areas with the highest erosion rates, up to -5 ft/yr, either are marshes or had marshes. When the banks erode, they place sand into the system and mitigate the erosion rate. Segment 17 and 20 have similar average overall erosion rates of -0.8 ft/yr and -0.9 ft/yr, respectively (Table 2). Segments 18 and 19 also have similar overall rates of -1.7 ft/yr and -2.0 ft/yr.
5 Summary

Shoreline change rates vary around the James City County. Generally, the subreaches with smaller fetches such as those up the Chickahominy River had smaller rates of change. Fetch is greater than on the James River than the York River and have greater rates of erosion. Man-made accretion has impacted many areas of shoreline due to the creation of the Colonial Parkway. Other accretion occurs around mannmade structures such as breakwater systems.

6 References


Appendix A

End Point Rate of Shoreline Change Maps

Shoreline change rate segments are shown on the top map. The calculated rates of change for each transect within the segment were averaged to determine an average rate of change for different time periods as shown in Table 2 of the report.

Note: The location labels on the plates come from U.S. Geological Survey topographic maps, Google Earth, and other map sources and may not be accurate for the historical or even more recent images. They are for reference only.

Plate 1  Plate 7  Plate 13  Plate 19
Plate 2  Plate 8  Plate 14  Plate 20
Plate 3  Plate 9  Plate 15  Plate 21
Plate 4  Plate 10  Plate 16  Plate 22
Plate 5  Plate 11  Plate 17  Plate 23
Plate 6  Plate 12  Plate 18  Plate 24
Appendix B

Historical Shoreline Photo Maps

Note: The location labels on the plates come from U.S. Geological Survey topographic maps, Google Earth, and other map sources and may not be accurate for the historical or even more recent images. They are for reference only.

Plate 1       Plate 7       Plate 13       Plate 19
Plate 2       Plate 8       Plate 14       Plate 20
Plate 3       Plate 9       Plate 15       Plate 21
Plate 4       Plate 10      Plate 16       Plate 22
Plate 5       Plate 11      Plate 17       Plate 23
Plate 6       Plate 12      Plate 18       Plate 24