Shoreline Evolution:
City of Poquoson, Virginia
Poquoson River, Chesapeake Bay, and Back River Shorelines

Data Report

Shoreline Studies Program
Department of Physical Sciences

Virginia Institute of Marine Science
College of William & Mary
Gloucester Point, Virginia
March 2010
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March 2010
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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 Poquoson (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 imagery shows 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 City of Poquoson 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

The City of the Poquoson is located on Virginia’s Peninsula and has about 170 miles of tidal shoreline on several bodies of water including the Poquoson River, Chesapeake Bay, and Back River. When all creeks and rivers that drain into these bodies of water are included, these areas have about 75 miles, 68 miles, and 26 miles, respectively. Historic shore change rates vary from -1.2 ft/yr along the Poquoson River, -0.2 ft/yr along the Chesapeake Bay, and -1.1ft/yr on the Back River (Byrne and Anderson, 1978).

The coastal geomorphology of the City 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 Poquoson is a result of these changes in shoreline. Most of the western, more upland section of the City consists of the Sedgefield Member of the Tabb Formation which was deposited during the last high stand of sea level 135,000-75,000 years before present. The eastern section of the City consists mainly of soft mud that was deposited during the Holocene, or the last 10,000 years, and is the basis for an extensive marsh. Plumtree Island National Wildlife Refuge occurs in this area.
Figure 1. Location of City of Poquoson within the Chesapeake Bay Estuarine System
Holocene Soft Mud - Medium to dark-gray, and peat, grayish brown.

Poquoson Member - Medium to coarse pebbly sand grading upward into clayey fine sand and silt, light-to medium-gray; underlies ridge and swale

Lynnhaven Membe of Tabb Formation - Pebby and cobbly, fine to coarse gray sand grading upward into clayey and silty fine sand and

Sedgefield Member of Tabb Formation - Pebby 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. 20-30 ft). Thickness is 0-50 ft.

Regional stratigraphic column of formations and members.

<table>
<thead>
<tr>
<th>System</th>
<th>Series</th>
<th>Miocene (11 to 65 Ma)</th>
<th>Miocene to Holocene (11,000 years ago)</th>
<th>Holocene (last 10,000 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qm</td>
<td></td>
<td>Yorktown Fm.</td>
<td>Shirley Fm.</td>
<td>Poquoson Mem.</td>
</tr>
<tr>
<td>Qtp</td>
<td></td>
<td>Tabb Fm.</td>
<td>Crooked Fm.</td>
<td>Lynnhaven Mem.</td>
</tr>
<tr>
<td>Qtl</td>
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<td>Pliocene</td>
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<tr>
<td>Qts</td>
<td></td>
<td>Pleistocene</td>
<td>Windsor Fm.</td>
<td></td>
</tr>
</tbody>
</table>

Mya=millions of years ago
ybp=years before present
U=Upper; M=Middle; L=Lower
Fm.=Formation
Mem.=Member

Figure 2. Geologic map of the City of Poquoson (from Mixon et al., 1989).
The last low stand 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. The present estuarine system was a meandering series of rivers working their way to the coast. 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 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 effects 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.

Two shore reaches exist along the coast of City of Poquoson (Figure 3). Reach 1 represents the western section of the City which is the higher upland area. It extends from the Lambs Creek to Bennett Creek on the Poquoson River and from Watts Creek to Brick Kiln Creek on the Back River. Reach 2 consists of the mostly marshy area of the City and extends from Bennett Creek on the Poquoson River to Watts Creek on the Back River and includes the Chesapeake Bay shoreline.

2.2 Hydrodynamic Setting

Tide range is about 2.3 to 2.4 ft in Poquoson. On the Poquoson River, the mean is tidal range 2.4 ft (2.9 ft spring range) at York Point (Figure 3). The mean tide range at Messick Point on the Back River is 2.3 ft (2.8 ft spring range)(Figure 3).

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. Reach 1 and 2 generally have very different fetch conditions. Reach 1 has many smaller creeks on the Poquoson and Back Rivers that are fetch limited, but sections of the Poquoson River have a large fetch to the northeast. Reach 2 is on Chesapeake Bay and is impacted by wind-waves from the north, northeast, east, and southeast. While southeast winds are generally milder, waves from the ocean enter the Bay and can impact Poquoson’s shoreline from the southeast.
Table 1. Summary wind conditions at Norfolk International Airport from 1960-1990.

<table>
<thead>
<tr>
<th>Wind Speed (mph)</th>
<th>Mid Range (mph)</th>
<th>South</th>
<th>South west</th>
<th>West</th>
<th>North west</th>
<th>North</th>
<th>North east</th>
<th>East</th>
<th>South east</th>
<th>Total</th>
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<td></td>
<td>3 5497*</td>
<td>3316</td>
<td>2156</td>
<td>1221</td>
<td>35748</td>
<td>2050</td>
<td>3611</td>
<td>2995</td>
<td>56594</td>
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<tr>
<td></td>
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<td>2.12*</td>
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<td>0.79</td>
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<td>9260</td>
<td>6432</td>
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<td>994</td>
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<td>8.99</td>
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<td>12.77</td>
<td>7.50</td>
<td>6.38</td>
<td>100.00</td>
</tr>
</tbody>
</table>

*Number of occurrences  ^Percent

Hurricanes, depending on their proximity and path also can have an impact to the City of Poquoson’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 city; Tropical Strom Ernesto (September 1, 2006) brought wind speeds of 46 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). The City of Poquoson also was hit by The Veteran’s Day Storm on November 11, 2009 which had water levels of 5.2 ft above MLLW with wind speeds at 29 mph with gusts at 53 mph (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 Poquoson shoreline from 1937, 1953, 1963, 1994, 2002, and 2007 were used in the analysis. The 1994, 2002, and 2007 images were available from other sources. The 1994 imagery was orthorectified by the U.S. Geological Survey (USGS) and the 2002 and 2007 imagery was orthorectified by the Virginia Base Mapping Program (VBMP).

The 1937, 1953, and 1963 images were scanned as tiffs at 600 dpi and converted to ERDAS IMAGINE (.img) format. They were orthorectified to a reference mosaic, the 1994 Digital Orthophoto Quarter Quadrangles (DOQQ) from USGS. The original DOQQs were in MrSid format but were converted into .img format. ERDAS Orthobase image processing software was used to orthographically correct the individual flight lines using a bundle block solution. Camera lens calibration data were matched to the image location of fiducial points to define the interior camera model. Control points from 1994 USGS DOQQ images provide the exterior control, which is enhanced by a large number of image-matching tie points produced automatically by the software. A minimum of four ground control points was used per image, allowing two points per overlap area. The exterior and interior models were combined with a digital elevation model (DEM) from the USGS National Elevation Dataset to produce an orthophoto for each aerial photograph. The orthophotographs that cover each USGS 7.5 minute quadrangle area were adjusted to approximately uniform brightness and contrast and were mosaicked together using the ERDAS Imagine mosaic tool to produce a one-meter resolution mosaic also in .img format. To maintain an accurate match with the reference images, it was necessary to distribute the control points evenly. This can be challenging in areas with little development. Good examples of control points were manmade features such as corners of buildings or road intersections and stable natural landmarks such as easily recognized isolated trees. Some areas of the city were particularly difficult to rectify due to the lack of development that provide good control points.

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 mean low water (MLW). Mean high water (MHW)/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 using USGS DOQQs. Vertical control is the USGS 100 ft (30 m) DEM. The 1994 USGS reference images were developed in accordance with National Map Accuracy Standards.
(NMAS) for Spatial Data Accuracy at the 1:12,000 scale. The 2002 and 2007 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 shoreline error for the three 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 2007. It was decided that digitizing the intervening years would introduce more errors rather than 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 City’s shoreline (Himmelstoss, 2009). All DSAS input data must be managed within a personal geodatabase, which includes all the baselines for Poquoson and the digitized shorelines for 1937, 1953, 1963, 1994, 2002 and 2007. Baselines were created about 200 feet seaward of the 1937 shoreline and encompassed most of the City’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 Poquoson, this method represented about 12 miles of shoreline along 1,873 transects. The extensive marshes were difficult to quantify with shoreline change baselines.

Two types of shoreline change rates are determined by the program. 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 (Figure 4A). 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. However, this method does not use the intervening shorelines so it may not account for changes in accretion or erosion rates that may occur through time.

The Linear Regression Rate (LRR) is determined in DSAS by fitting a least-squares regression line to all shoreline points for given transect. The LRR is the slope of the calculated line (Figure 4B). This method uses all data and is based on accepted statistical concepts. In all areas, a rate can be determined by regression analysis because there is change in the shoreline position. However, mathematically it may not be significant because the line is so flat. In an
Figure 4. Graphics depicting A) sample DSAS baseline, transects and measured shoreline, and B) how the measured shoreline data is analyzed in a linear regression.
estuarine environment, variable rates of change led to concerns that the slope of the calculated regression line may not be significantly different from zero. In order to determine if the shoreline data was amenable to explanation by regression analysis, a two-tailed t-test at 95% significance was run on the data to determine if the rate is statistically significant.

In ArcMap, the rates of change were categorized and plotted at the intersection of individual transects and the baseline. This provided a relatively efficient way to express rates of change along 12 miles of shoreline. For the Linear Regression Rate maps, only those transects that passed the significance test were plotted. The rates calculated along the other transects were not considered statistically significant. In addition, for Poquoson, LRR that used less than six shorelines available for analysis were not plotted.

4 Results and Discussion

The City of Poquoson’s shoreline through time is depicted in 11 map plates in Appendix A & B. These plates show the individual photos and shorelines for each date analyzed. In addition, the Linear Regression Rates and End Point Rates were plotted where available/significant. City-wide and in subreaches, the average End Point and Linear Regression rates of change are nearly identical (Table 2). The maximum and minimum rates did vary slightly, but generally, they were similar. This analysis includes all the regression rates, not just those that are statistically significant. Using only those transects that passed the t-test removes about 23% of the transects from the data. This study showed that the use of the LRR method to report erosion rate does not provide additional information when compared to the EPR particularly in situations where the rate is minimized such that the slope of the regression line is shown not to be significantly different from zero.

Table 2. Comparison of the End Point Rate and the Linear Regression Rate results for Poquoson’s shorelines. The Linear Regression Rate uses all data, not just those that were determined to be statistically significant. Rates are in feet per year.

<table>
<thead>
<tr>
<th>Location</th>
<th>End Point Rate</th>
<th>Linear Regression Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg</td>
<td>Max</td>
</tr>
<tr>
<td>City-Wide</td>
<td>-1.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Lambs Creek to Bennett Creek, Watts Creek to Brick Kiln Creek</td>
<td>-0.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Bennett Creek to Watts Creek</td>
<td>-2.0</td>
<td>2.6</td>
</tr>
</tbody>
</table>
4.1 Reach 1

Reach 1 represents the western half of the city and extends from the Lambs Creek to Bennett Creek on the Poquoson River and from Watts Creek to Brick Kiln Creek on the Back River; the Reach contains Plates 1-3 and 10-11. Reach 1 has an average long-term erosion rate of -0.3 ft/yr (Table 2). Higher rates of change occur between Hunts Point and the mouth of Roberts Creek on Plate 1 with a rate between -1 to -2 ft/yr. The smaller creeks shown on Plate 2 have a very small fetch and therefore little change occurs along this section of shore. On Plate 3, accretion occurred at Griffins Beach with a rate between 1 to 2 ft/yr. In 1937, this section of shore actually was a beach between marsh headlands. Over the next 70 years, a marsh seems to have accreted along this stretch of shore. Between 1963 and 1994, Topping Creek and land adjacent to it on Plate 10 was dug for the construction of a housing development.

4.2 Reach 2

Reach 2 extends from Bennett Creek to Watts Creek; this Reach Contains Plates 4-9. Generally, the largest erosion rates occur on shorelines exposed to the Chesapeake Bay wave climate. The backside and interior creeks of the extensive marsh are not eroding as quickly. Reach 2 has an average long-term erosion rate of -2.0 ft/yr (Table 2); however, higher rates of -2 ft/yr to -10 ft/yr were recorded at Cow Island on Plate 4 and Marsh Point on Plate 6. The highest rate of erosion occurred at Plum Tree Island on Plate 8 with a rate greater than -10 ft/yr. This point is the most exposed section of shore along this Reach.

5 Summary

Shoreline change rates vary around the City of Poquoson. Generally, the subreaches with smaller fetches had smaller rates of change. Along some individual transects, the LRR may provide better information than the EPR; however, City-wide and in individual subreaches, this was not the case. In addition, the LRR along many transects could not reliably be used in all shoreline situations as could the EPR. So, in the City of Poquoson, the EPR is a reliable indicator of shoreline change rates even when intervening dates are available.

6 References


Marine Science. The College of William and Mary, Gloucester Point, VA.


Appendix A
Shoreline Change Rates

Plate 1  Plate 7
Plate 2  Plate 8
Plate 3  Plate 9
Plate 4  Plate 10
Plate 5  Plate 11
Plate 6
Appendix B
Historical Shoreline Photos

Plate 1       Plate 7
Plate 2       Plate 8
Plate 3       Plate 9
Plate 4       Plate 10
Plate 5       Plate 11
Plate 6