

Shoreline Evolution:  
Gloucester County, Virginia  
York River, Mobjack Bay, and Piankatank  
River Shorelines  
Data Report

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Gloucester Point, Virginia  
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# Shoreline Evolution: Gloucester County, Virginia York River, Mobjack Bay, and Piankatank 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 Gloucester (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 Gloucester 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

Gloucester County is located on Virginia's Middle Peninsula and has about 500 miles of tidal shoreline on several bodies water including the Piankatank River, Mobjack Bay, and York River (CCRM, 2008). When all creeks and rivers drain into these bodies of water are included these areas have 14 miles, 263 miles, and 222 miles respectively. Historic shore change rates vary from 0.7 ft/yr along the Piankatank River, 1.8 ft/yr along the Mobjack Bay, and 0.3 ft/yr along the York river for both shore recession and shore advance along the coast (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. The Atlantic Ocean has come and gone numerous times over the Virginia coastal plain over the past million years. The effect has been to rework older deposits into beach and lagoonal deposits at the time of the transgressions. The result of these transgressions has been a series of plateaus separated by scarps. Along the York and Piankatank rivers, the sediments of the Shirley Formation was deposited during an interglacial, high stand of sea level approximately 200,000 - 250,000 years ago (Figure 2). The lower elevations of the Tabb Formation (Mobjack Bay and lower York

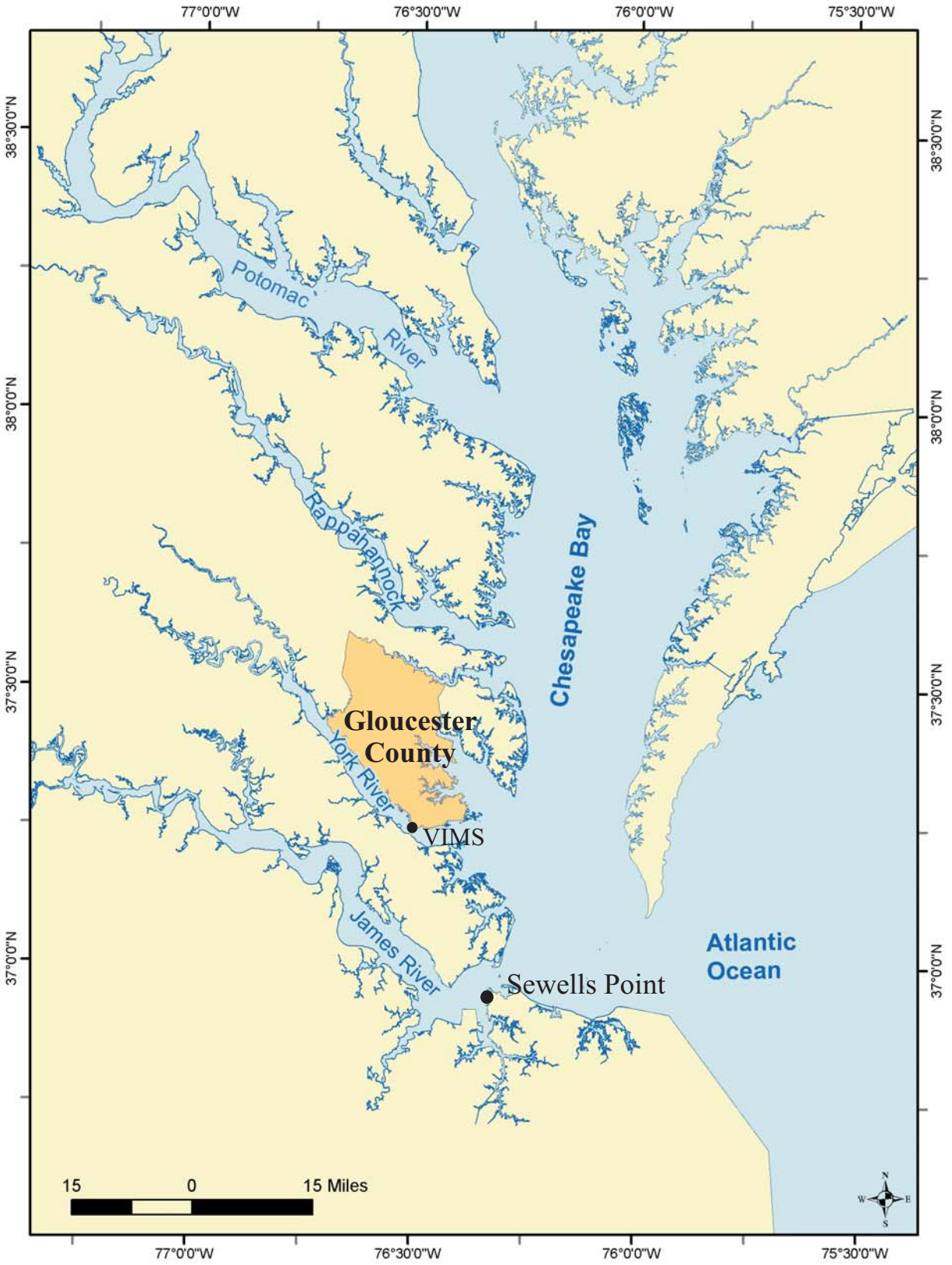
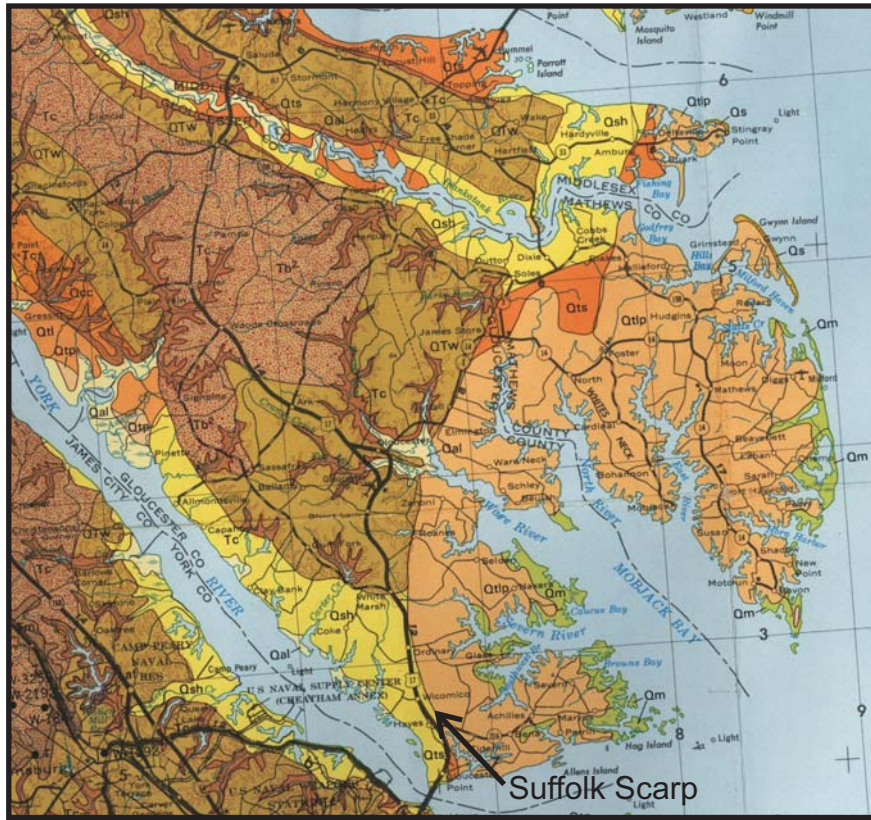


Figure 1. Location of Gloucester County within the Chesapeake Bay Estuarine System





1 Mi

1 km

- |                                      |                                                                                                                                                                                                                                                                                                                                 |
|--------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Qm</b>                            | <b>Holocene Soft Mud</b> - Medium to dark-gray, and peat, grayish brown. Comprises sediment of marshes in coastal areas and Chesapeake Bay. Thickness is 0-10 ft.                                                                                                                                                               |
| <b>Qal</b>                           | <b>Alluvium</b> - 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.                                                                       |
| <b>Qtp</b>                           | <b>Poquoson Member of Tabb Formation</b> - 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.        |
| <b>Qtlp</b>                          | <b>Lynnhaven and Poquoson Members of Tabb Formation, undifferentiated.</b>                                                                                                                                                                                                                                                      |
| <b>Qts</b>                           | <b>Sedgefield Member of Tabb Formation</b> - 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. 20-30 ft) bounded on landward side by Suffolk and Harpersville scarps. Thickness is 0-50 ft. |
| <b>Qsh</b>                           | <b>Shirley Formation (middle Pleistocene)</b> - Light-to dark-gray and brown sand, gravel, silt, clay, and peat. Thickness is 0-80 ft.                                                                                                                                                                                          |
| <b>Qcc</b>                           | <b>Charles City Formation (lower Pleistocene ??)</b> - Light- to medium-gray and light- to dark- yellowish and reddish-brown sand, silt, and clay composing surficial deposits of riverine terrace and coast-parallel plains at altitudes of 70-80 ft. Unit is 0-55ft or more in thickness.                                     |
| <b>QTW</b>                           | <b>Windsor Formation (lower Pleistocene or upper Pliocene)</b> - Gray and yellow to reddish-brown sand, gravel, silt, and clay. Constitutes surficial deposits of extensive plain (alt. 85-95 ft) seaward of Surry scarp and coeval, fluvial-estuarine terrace west of scarp. Unit is 0-40 ft thick.                            |
| <b>Tb<sup>1</sup> Tb<sup>2</sup></b> | <b>Bacons Castle Formation of Chesapeake Group (upper Pliocene)</b> - Gray, yellowish-orange, and reddish-brown sand, gravel, silt, and clay; Unit is 0-70 ft thick.                                                                                                                                                            |
| <b>Tc</b>                            | <b>Chesapeake Group (upper Pliocene to lower Miocene)</b> - 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 Gloucester County (from *Mixon et al.*, 1989).

River) are separated from higher elevations by the Suffolk Scarp (Figure 2). The Tabb Formation was deposited during the last major high stand of sea level that extended from about 135,000 to 70,000 years ago. The differentiation between the three members are likely the result of small-scale variations in the shoreline with peaks at 80,000, 105,000, and 125,000 years ago (Toscano, 1992). The broad area of marshes along the Mobjack Bay were developed on Holocene muds.

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 Gloucester Point show that sea level has risen 0.15 inches/yr or 1.25 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 1993. 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.

Three reaches exist along the coast of Gloucester County (Figure 3). Reach 1 is located on the north bank of the York River starting at county line boundary at the Poropotank River and ends at the Coleman Bridge at Gloucester Point/Virginia Institute of Marine Science (VIMS). Reach 2 starts at the Gloucester Point and heads east toward the Guinea Marsh and the mouth of the Mobjack Bay then it curves around while heading north along Gloucester County’s east border to include all of Gloucester’s tributaries to Mobjack Bay. Reach 3 starts slightly west of Holland Point on the Piankatank River and heads up river the Gloucester County Line on the Piankatank River’s headwaters.

## **2.2 Hydrodynamic Setting**

Tide range varies along its variable coast from 1.3 to 2.8 ft in Gloucester. The three reaches have different tidal and hydrodynamic conditions. Along Reach 1 on the York River, the mean is tidal range 2.8 ft (3.4 ft spring range) at the Roane Point tide station (Figure 3) and 2.4 ft (2.9 ft spring range) at Gloucester Point. The main river shorelines are relatively protected from



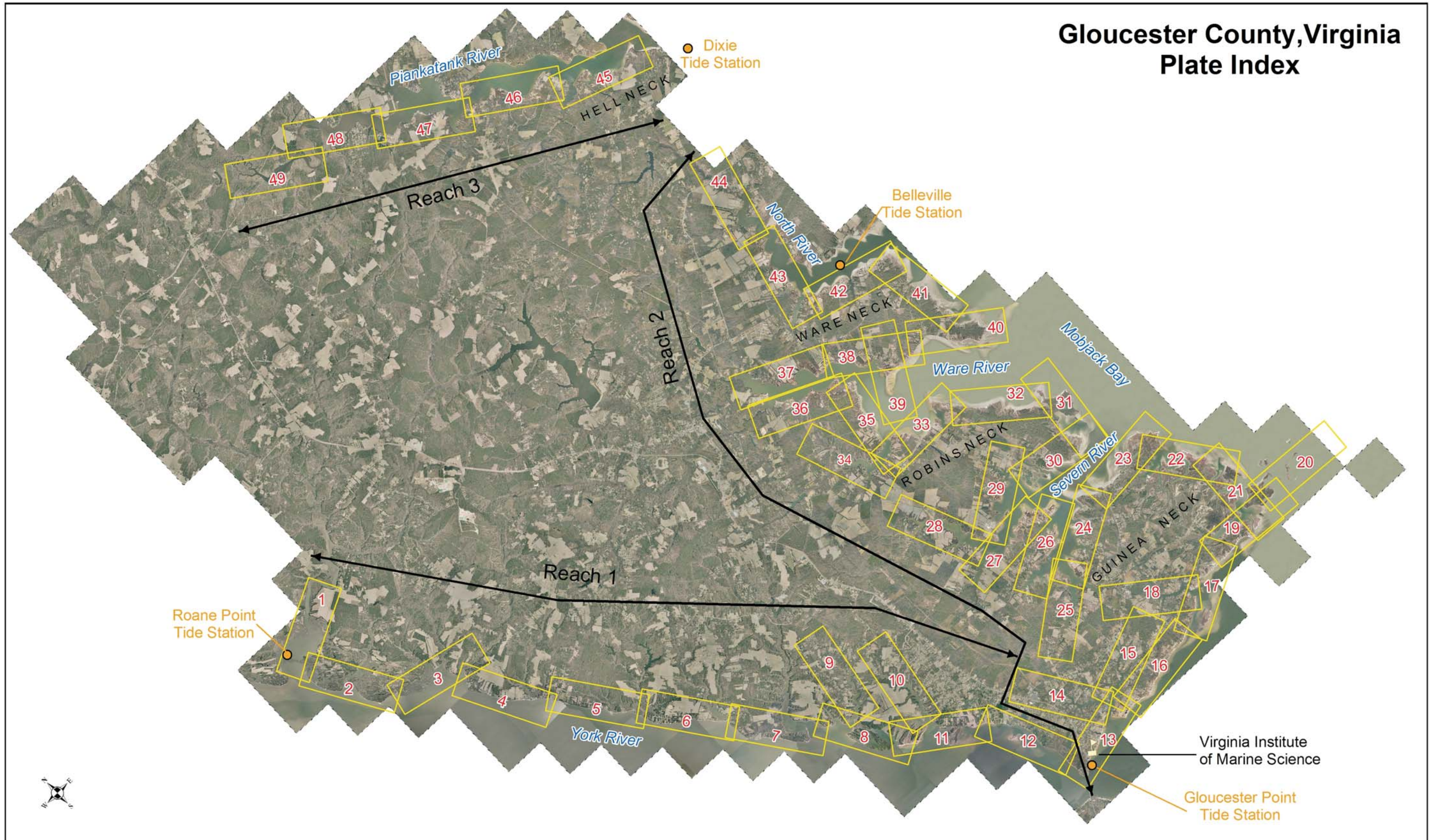


Figure 3. Index of shoreline plates.



northeast winds. However, during northeast storms, winds frequently shift from the northeast to the northwest. This reach is vulnerable to wind waves from the northwest. The mean tide range of Reach 2 varies from 2.4 ft (2.9 ft spring range) at Gloucester Point to 2.5 ft (3.0 ft spring range) at Belleville on the North River (Figure 3). This Reach is relatively protected from both northeast and northwest winds, but winds from the east and southeast generate significant waves. In addition, Boon *et al.* (1991) found that long-period waves (most likely from the ocean) were recorded at a site just north of this Reach in Chesapeake Bay indicating that these waves may influence the overall wave climate. Reach 3 is along the Piankatank River and has a mean tide range of 1.3 ft (1.6 ft spring range) at Dixie tide station (Figure 3). This Reach in general has limited fetch for the development of a large wind-wave climate.

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 occur more and can cause the largest waves.

Table 1. Summary wind conditions at Norfolk International Airport from 1960-1990.

Wind Speed (mph)	Mid Range (mph)	WIND DIRECTION								Total
		South	South west	West	North west	North	North east	East	South east	
< 5	3	5497*	3316	2156	1221	35748	2050	3611	2995	56594
		2.12 <sup>+</sup>	1.28	0.83	0.47	13.78	0.79	1.39	1.15	21.81
5-11	8	21083	15229	9260	6432	11019	13139	9957	9195	95314
		8.13	5.87	3.57	2.48	4.25	5.06	3.84	3.54	36.74
11-21	16	14790	17834	10966	8404	21816	16736	5720	4306	100572
		5.70	6.87	4.23	3.24	8.41	6.45	2.20	1.66	38.77
21-31	26	594	994	896	751	1941	1103	148	60	6487
		0.23	0.38	0.35	0.29	0.75	0.43	0.06	0.02	2.5
31-41	36	25	73	46	25	162	101	10	8	450
		0.01	0.03	0.02	0.01	0.06	0.04	0.00	0.00	0.17
41-51	46	0	0	0	1	4	4	1	0	10
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<b>Total</b>		41989	37446	23324	16834	70690	33133	19447	16564	259427
		16.19	14.43	8.99	6.49	27.25	12.77	7.50	6.38	100.00

\*Number of occurrences

<sup>+</sup>Percent

Hurricanes, depending on their proximity and path also can have an impact on the Gloucester County'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. Gloucester Point recorded wind gusts at 69 mph, a peak gust at 91 mph with a storm surge 8.3 ft (Beven and Cobb, 2004) and having water levels 8.2 ft above mean lower low water (MLLW) and rising when the Gloucester Point station was destroyed during the storm (NOAA, 2009). Hurricane Isabel was not the only recent tropical event to pass through the County; Tropical Storm Ernesto (September 1, 2006) brought wind speeds of 20 mph and a peak gust of 27 mph with water levels rising above 6.0 ft above MLLW at the Yorktown USCG Training Center tide station (NOAA, 2009). Gloucester County also was hit by the Veteran's Day Storm on November 11, 2009 which had water levels of 6.9 ft above MLLW with wind speeds at 48 mph with gusts at 58 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 Gloucester County's shoreline from 1937, 1953, 1968, 1978, 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, 1968, and 1978 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 flightlines 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 county 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, 1968 and 1978) 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  $\pm 0.7$  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 County's shoreline (Himmelstoss, 2009). All DSAS input data must be managed within a personal geodatabase, which includes all the baselines for Gloucester and the digitized shorelines for 1937, 1953, 1968, 1978, 1994, 2002 and 2007. Baselines were created about 200 feet 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 Gloucester County, this method represented about 75 miles of shoreline along 11,094 transects.

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

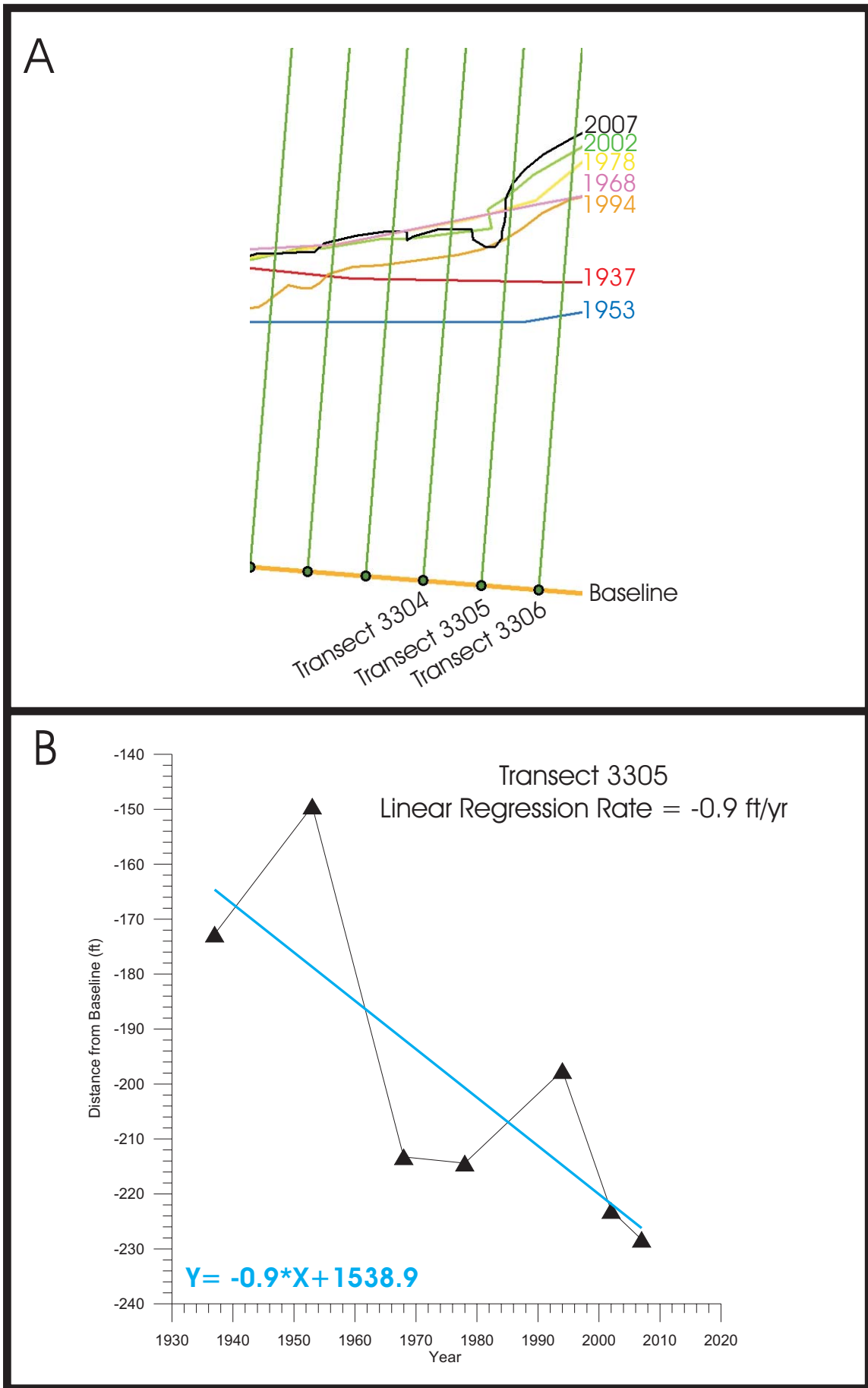


Figure 4. Graphics depicting A) sample DSAS baseline, transects and measured shoreline, and B) how the measured shoreline data is analyzed in a linear regression.

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 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 75 miles of shoreline. For the Linear Regression Rate maps, only those transects that passed the significance test were plotted. The other rates calculated along the transects were not considered statistically significant. In addition, for Gloucester, LRR that used less than six shorelines available for analysis were not plotted.

## 4 Results and Discussion

Gloucester County's shoreline through time is depicted in 49 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. County-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 40% 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 Gloucester’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.

Location	End Point Rate			Linear Regression Rate		
	Avg	Max	Min	Avg	Max	Min
<b>County-Wide</b>	<b>-0.8</b>	<b>3.0</b>	<b>-6.1</b>	<b>-0.7</b>	<b>2.6</b>	<b>-7.4</b>
York River North of Gloucester Point	-1.1	3.0	-5.6	-1.0	2.6	-5.2
York River East of Gloucester Point	-0.8	1.7	-5.7	-0.8	1.8	-5.8
Mobjack Bay and Tributaries	-0.8	2.7	-6.1	-0.7	2.6	-7.4
Piankatank River	-0.5	1.6	-3.8	-0.4	1.5	-4.1

#### 4.1 Reach 1

Reach 1 extends from the Poropotank River, the border between King and Queen and Gloucester Counties, and heads along the north shore of the York River to Gloucester Point. The Reach includes plates 1-12. Reach 1 has an average long-term erosion rate of -1.1 ft/yr (Table 2) with higher rates recorded at Jones Creek on Plate 5 and Catlett Islands on Plate 8. Both have erosion rates from -2 to -5 ft/yr. Breakwaters were installed at Fox Creek on Plate 4 producing a long-term change of +1 to +5 ft/yr. Along the shore of Plate 12, breakwaters and piers caused man-made accretion with the rate of +2 to +5 ft/yr.

#### 4.2 Reach 2

Reach 2 extends from Gloucester Point to the North River along Mobjack Bay and is shown on Plates 13-44; the Reach has an average long-term erosion rate of -0.8 ft/yr (Table 2). However a moderate number of sites along the York River and Mobjack Bay were eroding at a much faster rate, anywhere from -2 to -8 ft/yr. Those sites include Sandy Point and Hog Point on Plate 19, Bush and Rock Point on Plate 23, and the south bank of Bryant Bay on Plate 29. Accretion had occurred along this Reach at sites where man-made structures were installed such as at the VIMS boat basin and along the Gloucester Banks on Plate 13, along the south bank of the Ware River on Plate 33, 35, and 38. The average long-term change rate at the man-made structures sites vary from +1 to +5 ft/yr.

#### 4.3 Reach 3

Reach 3 extends along the south bank of the Piankatank River from west of Holland Point to the River’s headwaters; the Reach includes Plates 45 - 49 and has an average long-term erosion rate of -0.5 ft/yr (Table 2). Reach 3 is relatively fetch-limited and overall had smaller average rates of change than Reaches 1&2. Two sites of accretionary sites occur in Reach 3; the first was man-made on Plate 48 and the other occurred naturally on Plate 49. The accretion on Plate 49

could be the result of marsh growth or it could be an error in the data. This particular area had little development that could be used in the photo rectification process.

## **5 Summary**

Shoreline change rates vary around Gloucester County. Generally, the subreaches with smaller fetches such as along the Piankatank River and tributaries to the larger rivers and bays had smaller rates of change. Along some individual transects, the LRR may provide better information than the EPR; however, County-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 Gloucester County, the EPR is a reliable indicator of shoreline change rates even when intervening dates are available.

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