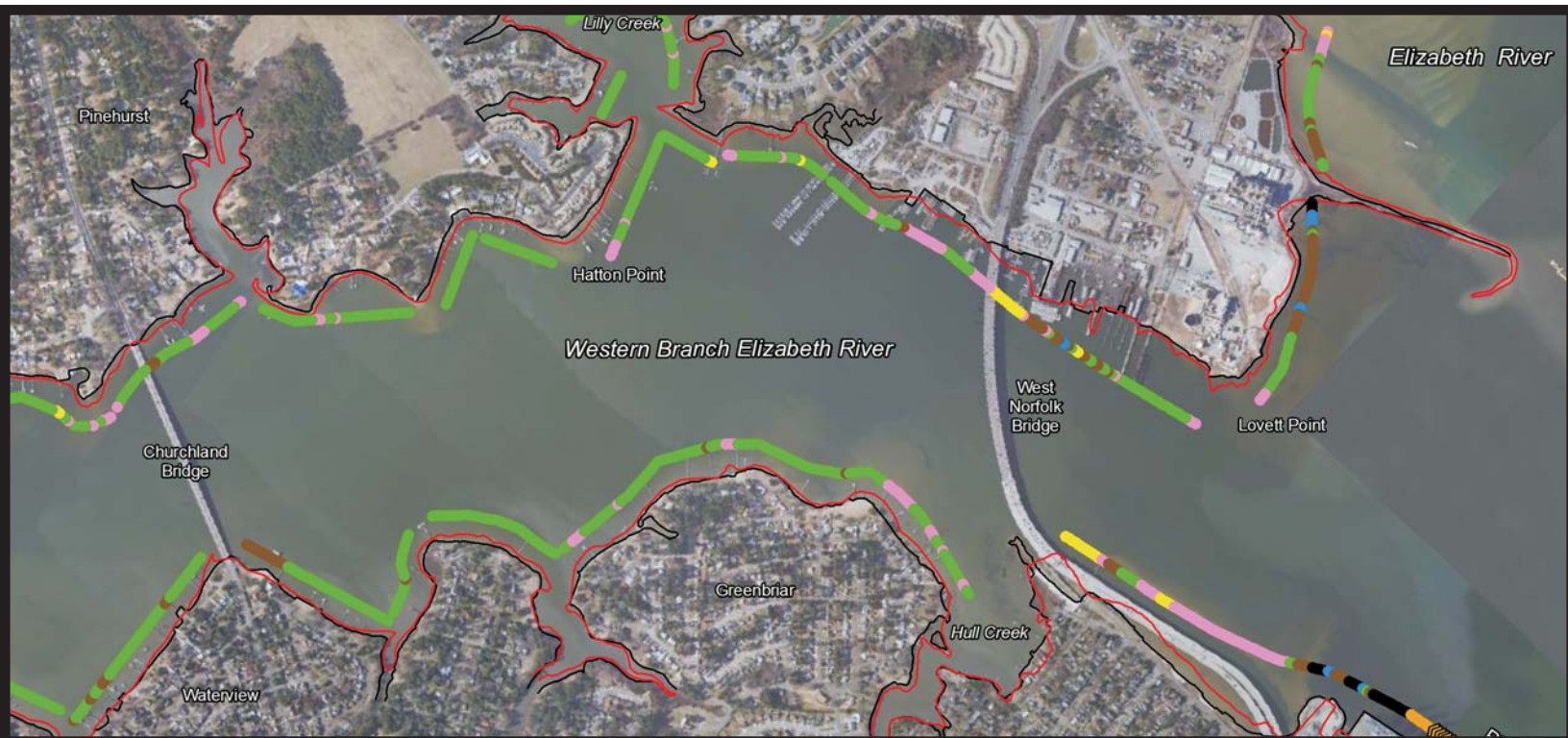


Shoreline Evolution: City of Portsmouth, Virginia Hampton Roads and Elizabeth River Shorelines



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Data Report

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Table of Contents

Table of Contents	i
List of Figures	ii
List of Tables	ii
1 Introduction	1
2 Shore Settings	1
2.1 Physical Setting	1
2.2 Hydrodynamic Setting	4
3 Methods	7
3.1 Photo Rectification and Shoreline Digitizing	7
3.2 Rate of Change Analysis	8
4 Results and Discussion	9
5 Summary	11
6 References	11
Appendix A. End Point Rate of Shoreline Change Maps	
Appendix B. Historical Shoreline Photo Maps	

List of Figures

Figure 1. Location of City of Portsmouth within the Chesapeake Bay Estuarine System	2
Figure 2. Geologic map of the City of Portsmouth (from Mixon <i>et al.</i> , 1989)	3
Figure 3. Index of shoreline plates.	5
Figure 4. Craney Island through time. Note: Tanner Creek was renamed Lafayette River.. . .	10

List of Tables

Table 1. Summary wind conditions at Norfolk International Airport from 1960-1990	6
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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 Portsmouth ([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 City of Portsmouth 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 Portsmouth is located on Virginia's Southside and has about 89 miles of tidal shoreline on several bodies water including the James River/Hampton Roads and Elizabeth River (CCRM, 2008). When all creeks and rivers that drain into these bodies of water are included, these areas have about 8 miles and 81 miles, respectively.

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 Portsmouth is a result of these changes in shoreline. The majority of the City consists of the Lynnhaven Member of Tabb Formation which was deposited during the last high stand of sea level 135,000-80,000 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. As sea level began to rise and the coastal plain watersheds began to flood, shorelines began to recede.

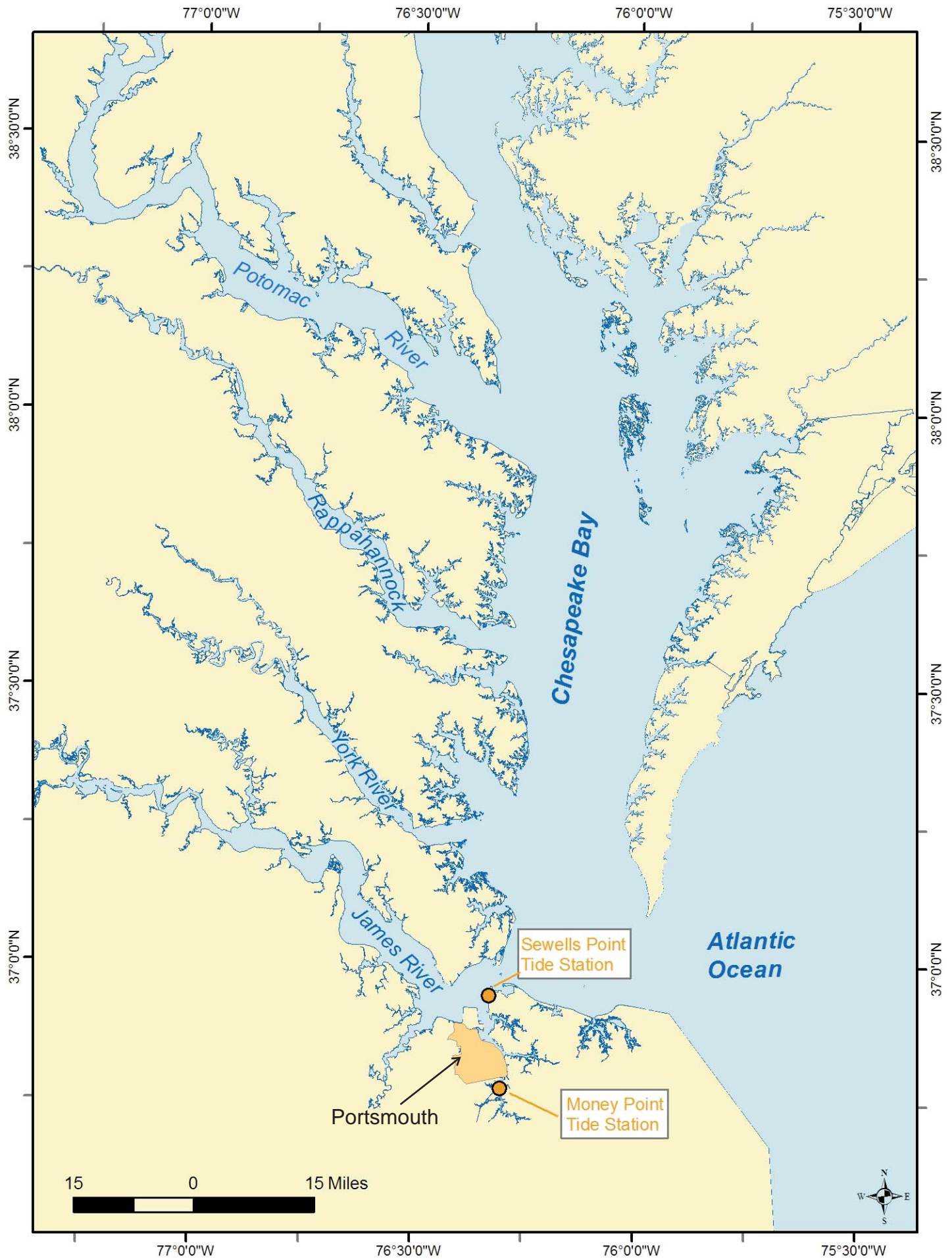
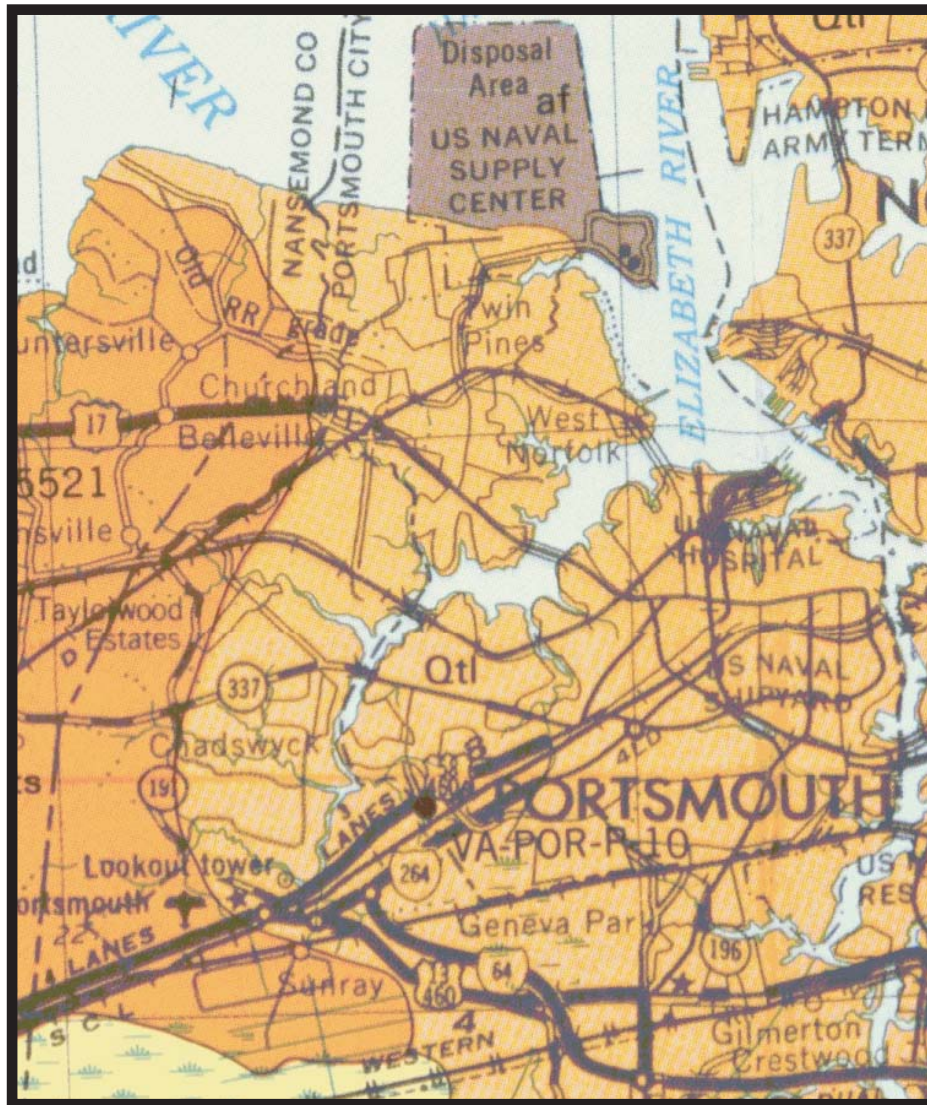


Figure 1. Location of City of Portsmouth within the Chesapeake Bay Estuarine System



1 Mile

1 km

Qtl

Lynnhaven Member of Tabb Formation - Pebbly and cobbly, fine to coarse gray sand grading upward into clayey and silty fine sand and sandy silt; locally, at base of unit, medium to coarse crossbedded sand and clayey silt containing abundant plant material fill channels cut into underlying stratigraphic units. Thickness is 0-20 ft.

Qts

Sedgefield Member of Tabb Formation - Pebbly to bouldery, clayey sand and fine to medium, shelly sand gradin 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.

Figure 2. Geologic map of City of Portsmouth (from Mixon *et al.*, 1989).

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 (Figure 1) 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 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.

The mouths of the James and Elizabeth Rivers also are known as Hampton Roads, one of the world’s biggest natural harbors. As a result, humans have greatly impacted the coast in this area. In addition to numerous piers and seawalls, Craney Island was built here. The Craney Island Disposal Area (Figure 3) is a large, man-made landmass that was created as a long-term disposal area for locally-dredged material (USACE website, 2010). The project was started in the 1946 under the River and Harbor Act of 1946, and when finished in 1957, it was 2,500 acres which expanded into the Hampton Roads and Elizabeth River. Currently, the Eastern Expansion is being built, which will extended the life of the disposal area.

2.2 Hydrodynamic Setting

Tide range varies from 2.4 to 2.9 ft in Portsmouth. At the Sewells Point tide station (Figure 1) near the mouth of the Elizabeth River, the mean is tidal range 2.4 ft (2.8 ft spring range). The US Navy Shipyard in the Portsmouth the tide range is 2.8 ft (3.3 ft spring range). The mean tide range at Money Point on the Elizabeth River is 2.9 ft (3.5 ft spring range).

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. Hampton Roads and the Elizabeth River generally have very different fetch conditions. Due to its proximity to Chesapeake Bay and a larger fetch, the Hampton Roads reach generally has larger wind waves than those that occur in the Elizabeth River. Winds from the north, northwest, and northeast are the biggest threat to Portsmouth’s shoreline on both bodies of water. The Elizabeth River has three branches, the Eastern, Western, and Southern, each of them with different length fetches, ranging from 0.25 to 1.5 miles. Each branch is vulnerable from waves coming from the north and Chesapeake Bay.

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 ⁺	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
Total		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 +Percent

Hurricanes, depending on their proximity and path also can have an impact to the City of Portsmouth'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 (Beven and Cobb, 2004), and having water levels 7.9 ft above mean lower low water (MLLW). (NOAA, 2010). Hurricane Isabel was not the only recent tropical event to pass through the city; 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, 2010) and water levels 5.5 ft above MLLW at the Sewells Point tide station (NOAA, 2010). The City of Portsmouth also was hit by The Veteran's Day Storm on November 11, 2009 which resulted in 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, 2010).

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 Portsmouth Shoreline from 1937, 1954, 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, 1954, 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 date for each year are: 1937 - May 20 and September 4; 1954 - October 11 and October 16; 1963 - February 18. We could not ascertain some of the dates, the 1994 images were flown but the 2002, 2007, and 2009 were all flown in February of their respective years.

The 1937, 1954, 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. The 1994 photos are used rather than higher quality, later photos because of the difficulty in finding control points that match the earliest 1937 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 city were particularly difficult to rectify due to the lack of development when compared to the reference images. Some areas of the original photos were “whited-out” due to the sensitive nature of certain installations at that time.

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. To get vertical control the USGS 30m DEM data was used. 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, 1954, and 1963) have an estimated total maximum shoreline position error of 20.0 ft, while the total maximum 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 Portsmouth and the digitized shorelines for 1937, 1954, 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 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 Portsmouth, this method represented about 28 miles of shoreline along 4,593 transects.

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 charge even when intervening dates exist. Average rates were calculated along selected areas of the shore.

4 Results and Discussion

The change in the Portsmouth shoreline through time is depicted in ten map plates in [Appendix A and B](#). These plates show the individual photos and shorelines for each date analyzed. In addition, end point rates (1937-2009) were plotted where available.

The location labels on the plates were checked; however, they 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.

The City of Portsmouth's shoreline overall is stable due to man-made structures that protect the shoreline and will continue to in the future, such as the Craney Island Disposal Area, U.S. Coast Guard Base Portsmouth, and various piers in the City. Plate 1 varies from a low level of erosion, -1 to -2 ft/yr, to a medium level of erosion, -2 to -5 ft/yr, at the City boundary line to the start of the Craney Island Disposal Area. The rate of shoreline change on the east and west sides of Craney Island, Plates 1 and 3, were calculated between 1963 and 2009 and show accretion. The area where the Craney Island U.S. Naval Supply Center sat has changed dramatically over the years. In the early 1900s, an island existed east of Craney Creek at the mouth of the Elizabeth River ([Figure 4](#)). In the late 1920s, that island was converted to a naval facility as shown in the 1934 map ([Figure 4](#)). This facility has been erased from the 1937 aerial imagery ([Appendix B](#)). By 1961, the facility was connected to the shoreline and the disposal area was noted on the map ([Figure 4](#)). The shoreline along this section has been stabilized with a bulkhead along most of its shore and as such, is stable.

On Plate 4, sections of Craney Island Creek are eroding rapidly from -1 to -10 ft/yr on the north shore. The south shore is the U.S. Coast Guard Base Portsmouth, which has a rate of 0 to -5 ft/yr at some parts but it is now fortified with bulkheads and other erosion prevention structures. The western shore of the of the Elizabeth River on Plate 4 is protected by the bulkhead at APM terminal that was constructed along almost 4,000 ft of shoreline between 2002 and 2007. Plate 5 features the mouth of the western branch of the Elizabeth River, which has lower levels of wave energy and the shore change rate on an average stays around -1 to +1 ft/yr. Also on Plate 5 is the man-made structure at Pinner Point which was filled in artificially creating an accretion rate.

Plates 6-8 show the rest of the Western Branch of the Elizabeth River in which mostly very low erosion, 0 to -1 ft/yr, is occurring. Plates 9 and 10 depict the Southern Branch of the Elizabeth River in which much of the shoreline has been filled and protected by bulkheads and piers accounting for the many accretion areas. The shores of the Portsmouth Naval Medical Center, Old Towne Portsmouth and Norfolk Naval Shipyard are now relatively stable.

5 Summary

Shoreline change rates vary around the City of Portsmouth. Generally, the subreaches with smaller fetches had smaller rates of change, while the large bodies of water had larger erosion rates. Much of Portsmouth's shoreline has been altered by man, thereby altering the shoreline change rates. These bulkheaded areas show large accretion rates in the long-term EPR rate, but more recently, they are relatively stable.

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