

# Shoreline Evolution: City of Virginia Beach, Virginia Chesapeake Bay, Lynnhaven River, Broad Bay, and Atlantic Ocean Shorelines

## Data Summary Report

Donna A. Milligan  
Christine Wilcox  
C. Scott Hardaway, Jr.  
Mary C. Cox

Shoreline Studies Program  
Department of Physical Sciences  
Virginia Institute of Marine Science  
College of William & Mary  
Gloucester Point, Virginia



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# 1 Introduction

The City of Virginia Beach is situated along both the Atlantic Ocean and Chesapeake Bay (Figure 1). Through time, the City's shoreline has evolved, and determining the rates and patterns of shore change provides the basis to know how a particular coast has changed through time and how it might proceed in the future. Along Chesapeake Bay's estuarine shores, winds, waves, tides and currents shape and modify coastlines by eroding, transporting and depositing sediments.

The purpose of this report is to document how the shore zone of the City of Virginia Beach 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. In addition to documenting historical shorelines, the change in shore positions along the rivers and larger creeks in the City of Virginia Beach 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. In addition to the Atlantic Ocean and Chesapeake Bay shorelines, the Lynnhaven River and Broad Bay shorelines were analyzed for change. Back Bay was not included.

# 2 Methods

## 2.1 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 City of Virginia Beach Shoreline from 1937, 1954, 1970, 1980, 1994, 2002, 2009, and 2011 were used in the analysis. The 1994, 2002, 2009, and 2011 images were available from other sources. The 1994 imagery was orthorectified by the U.S. Geological Survey (USGS) and the 2002, 2009, and 2011 imagery was orthorectified by the Virginia Base Mapping Program (VBMP). The 1937, 1954, 1970, and 1980 photos are part of the VIMS Shoreline Studies Program archives. The historical aerial images acquired to cover the entire shoreline were not always flown on the same day. The dates for each year are:

1937 - April 21, August 15;

1954 - October 11 and 6;

1970 - February 17 and 19;

1980 - March 15

The 2002, 2009, and 2011 were all flown in February and March of their respective years. We could not ascertain the exact dates the 1994 images were flown.

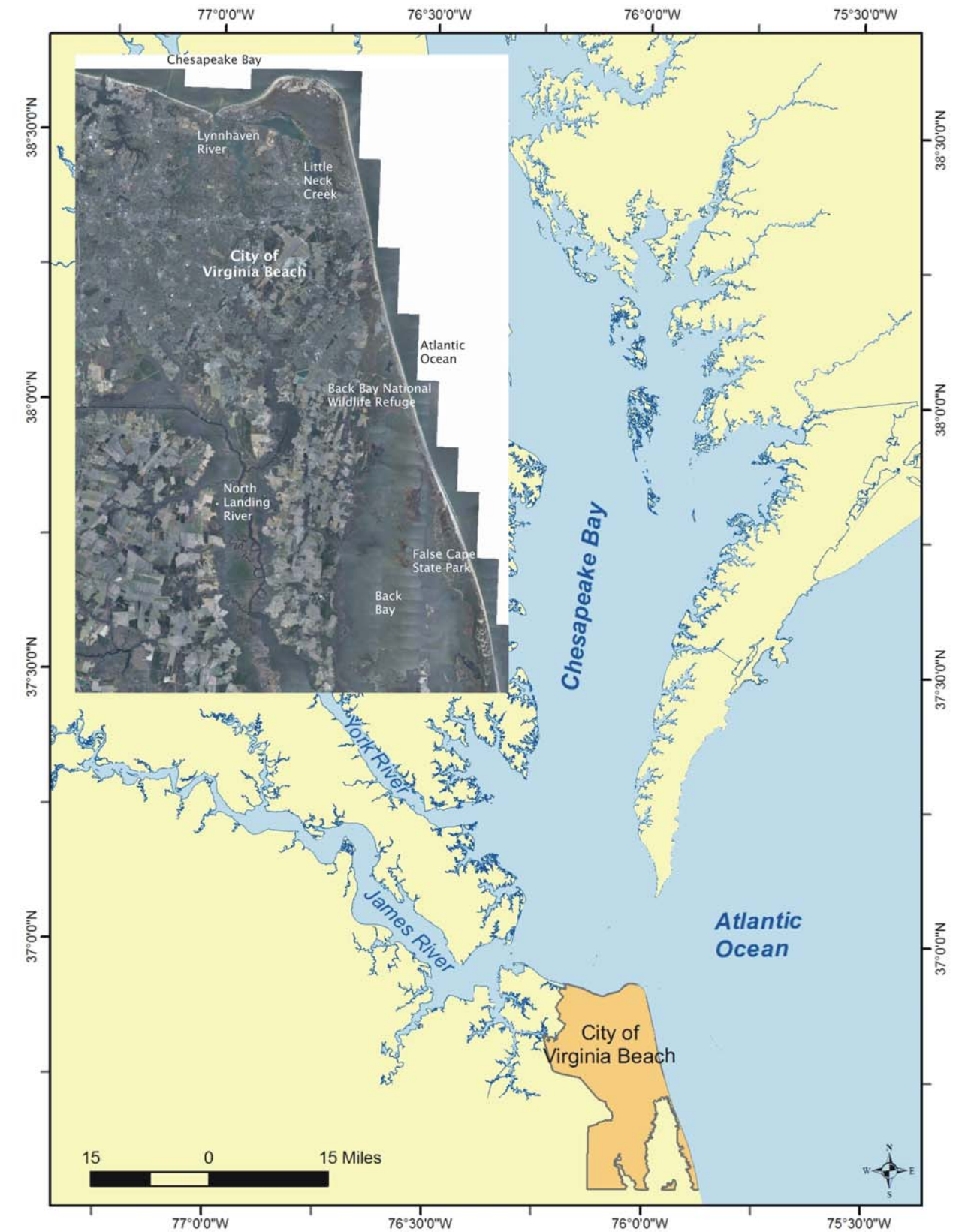


Figure 1. Location of the City of Virginia Beach within the Chesapeake Bay estuarine system.

The 1937, 1954, 1970, and 1980 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, more recent aeriels 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 given the lack of ground features and poor photo quality on the earliest photos. 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 difficult to rectify, either due to the lack of development when compared to the reference images or due to no development in the historical and the reference images. Even areas with development could be problematic in that some areas of the City have changed a great deal over the years with roads being widened and/or moved.

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 along the shorelines of Lynnhaven River and Broad Bay. In these areas, high water limit of runup can be difficult to determine on the shoreline due to narrow or non-existent beaches against upland banks or vegetated cover. Along the sandy Chesapeake Bay and Atlantic Ocean shorelines, the approximate position of high water was mapped since it is much more readily visible on the more recent images. 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. For 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, 2009, and 2011 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.

## 2.2 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 created for the City of Virginia Beach and the digitized shorelines for 1937, 1954, 1970, 1980, 1994, 2002, 2009, and 2011. Baselines were digitized about 200 feet, more 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, which were manually checked and cleaned up. For the City of Virginia Beach, this method represented about 62 miles of shoreline along 9939 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 change even when intermediate dates exist. Average rates between 1937 and 2009 were calculated along selected areas of the shore; segments are labeled in [Appendix A](#) and shown in [Table 1](#). The photo for a small section of shoreline at Cape Henry was whited out in 1937 so the EPR for this area only was calculated between 1954 and 2009.

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, 1970, and 1980) 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  $\pm 0.7$  ft/yr. The

smaller rivers and creeks are more prone to error due to their lack of good control points for photo rectification, narrower shore features, tree and ground cover and overall smaller rates of change. These areas are digitized but due to the higher potential for error, rates of change analysis are not calculated. Several areas of the City of Virginia Beach have shore change rates that fall within the calculated error. Some of the areas that show very low accretion can be due to errors within the method described above.

The City of Virginia Beach shoreline was divided into 23 plates (Figure 2) in order to display that data in Appendices A and B. In Appendix A, the 2009 image is shown with only the 1937 and 2009 shorelines to show the long-term trends along. In Appendix B, one photo date and the associated shoreline is shown on each. These include the photos taken in 1937, 1954, 1970, 1980, 1994, 2002, 2009, and 2011.

### 3 Summary

The rates of change shown in Table 1 are averaged across large sections of shoreline and may not be indicative of rates at specific sites within the reach. Some areas of the City, where the shoreline change rates are categorized as accretion, have structures along the shoreline which results in a positive long-term rate of change due to the structures themselves. Little Creek is an example of this. Many modifications to the shoreline by the military has resulted in a small, positive, long-term rate of change. Some of the areas with very low accretion, particularly in the smaller creeks and rivers, may be the result of errors within photo rectification and digitizing wooded shorelines. Many reaches of shoreline in Virginia Beach have been the recipient of beach nourishment projects. In these areas, the EPR may not adequately reflect the rate of change because data from the projects are not included. The EPR does reflect how well the City has maintained its beaches over time.

Segment B extends along the southern shore of Chesapeake Bay between Little Creek and Lynnhaven Inlet. Generally, the shoreline from Little Creek to the Chesapeake Bay Bridge Tunnel is erosional while the shoreline east of the Bridge Tunnel to Lynnhaven Inlet is accretionary. The City regularly places the sand dredged from the maintenance of the Lynnhaven Inlet on the shoreline just west of the Inlet which creates a positive rate of change for that section of shore.

The shoreline that was analyzed for rates of change in Lynnhaven River, Segment C, show that the shoreline generally has low erosion. This is due not only to the lower energy impacting the shoreline, but also because much of the shoreline has been protected over the years with bulkheads and revetments.

Segment F extends from Lynnhaven Inlet to Fort Story. Since sand transport is generally toward the west along the southern shore of Chesapeake Bay and because of complex ebb shoal dynamics, the section of shoreline just east of Lynnhaven Inlet is naturally highly accretionary. The central section of Segment F around Lynnhaven shores has had limited change through time. However infrastructure was located close to the

shoreline so a beach nourishment project took place recently along this section of coast. Farther east along Cape Henry toward the mouth of Chesapeake Bay is highly and very highly accretionary due to the influx of ocean sand and, more recently, the migration of beach renourishment material from the ocean coast. Segment G, along Virginia Beach's Resort Beach north of Rudee Inlet has been renourished regularly since the 1950s. This has resulted in a positive rate of change. Material has not been regularly placed on the northern-most section of Segment G, but sediment transport is to the north along most of Virginia Beach's ocean coast. As a result, a wide dune and beach system has accreted. South of Rudee Inlet, Segment H has very low erosion increasing to low and medium erosion south along the coast. Sections of Segment H and all of Segment I have been the recipients of beach nourishment projects over time.

Previous research as indicated a change in sediment transport direction just south of Little Island Park (Everts *et al.*, 1983) and higher than average breaking wave heights (Wright *et al.*, 1987) which results in the region having the highest rate of shoreline recession on the southeast Virginia coast (Wikel *et al.*, 2005). These factors result in the southern end of Back Bay National Wildlife Refuge and False Cape State Park, Segment K, have lesser rates of change.

Table 1. Average end point rate of change (ft/yr) between 1937 and 2009 for segments along the City of Virginia Beach's shoreline. Segment locations are shown on maps in Appendix A.

Segment Name	Location	Average Rate of Change (ft/yr)
A	Little Creek	0.4
B	Chesapeake Bay, Little Creek to Lynnhaven Inlet	-0.4
C	Lynnhaven River	-0.1
D	Broad Bay	-0.5
E	Link Horn Bay and Little Neck Creek	-0.1
F	Chesapeake Bay, Lynnhaven Inlet to Fort Story	2.8
G	Atlantic Ocean, Fort Story to Rudee Inlet	3.0
H	Atlantic Ocean, Rudee Inlet to Sandbridge	-1.2
I	Atlantic Ocean, Sandbridge to Back Bay NWR	-1.5
J	Atlantic Ocean, Back Bay NWR to False Cape State Park	-2.8
K	Atlantic Ocean, False Cape State Park to State Line	-0.7

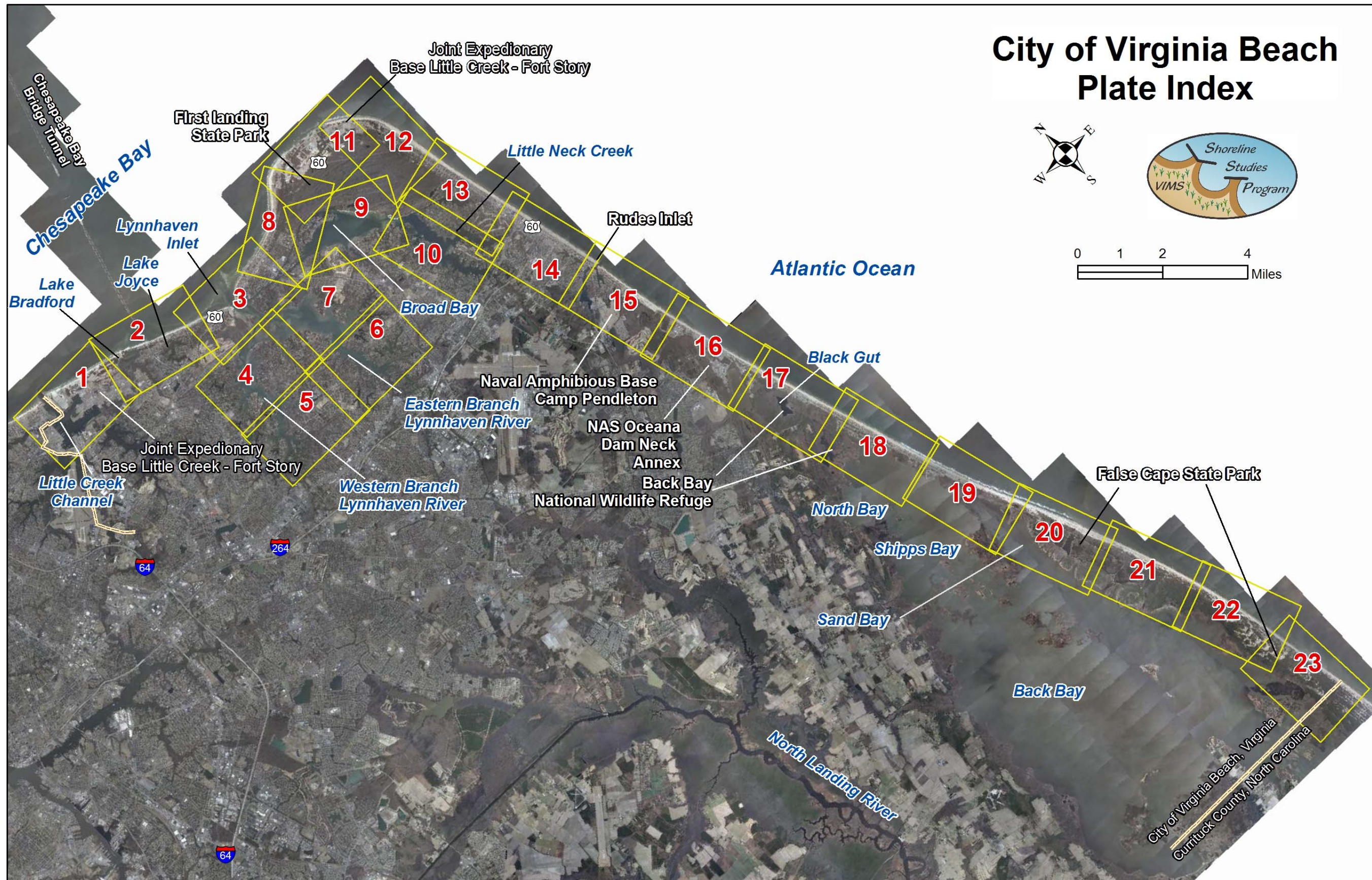


Figure 2. Index of shoreline plates.

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